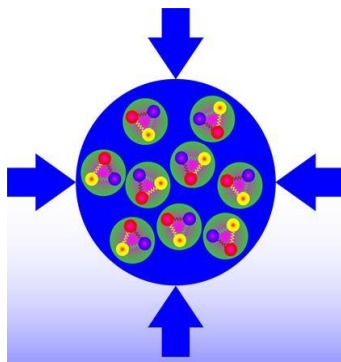
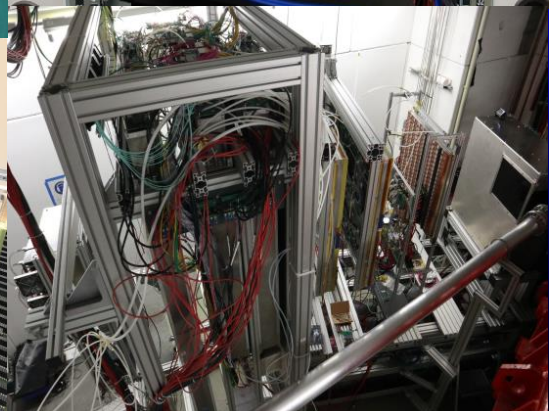
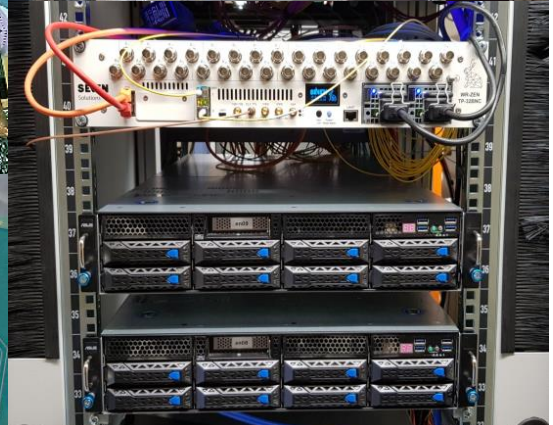
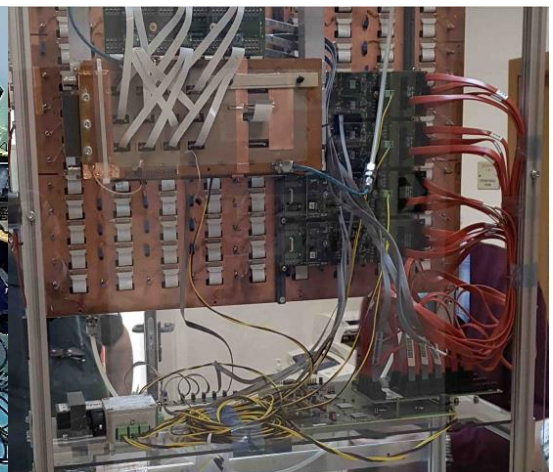
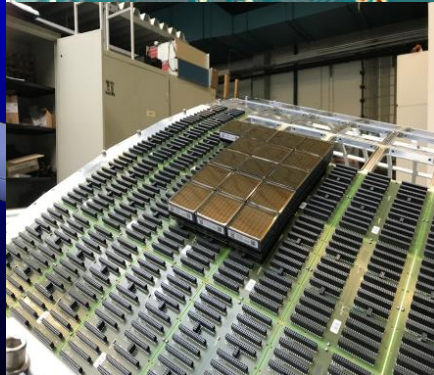
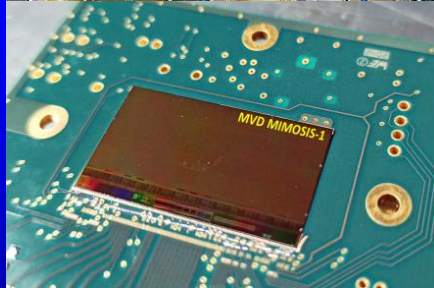
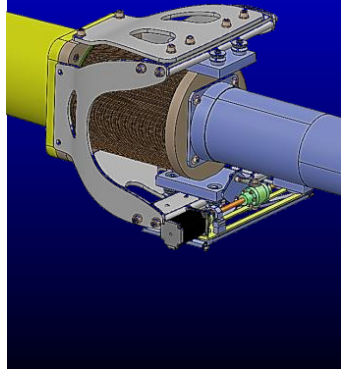




CBM

Compressed
Baryonic
Matter
experiment
at FAIR



PROGRESS REPORT 2021

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Preface

2021 was again a year under pandemic conditions, with restrictions hindering our daily work in the laboratories and in the offices. Nevertheless, we reached important milestones towards the realization of the CBM experiment: The Technical Design Report for the MVD was approved by FAIR in December 2021. The STS team successfully carried out several production readiness and engineering design reviews. The RICH project has entered the production phase, including a full size prototype photo-camera with readout electronics. The MuCh team tested successfully full size GEM chambers and a real size single gap RPC detector at VECC and CERN. Several TRD and TOF modules, both for the outer and inner high-rate regions of the detectors, successfully participated in the mCBM data taking campaigns. A technical design of the target mechanism, the beam pipe and the beam monitors have been developed. The major DAQ achievement was the implementation of the CRI-based readout system in mCBM, which then was successfully used for data taking. A stable timing of the front-end electronics of all detector subsystems could be observed within the expected time resolution for O+Ni collisions at 2.0 A GeV kinetic beam energy at collision rates of about 1 MHz. Progress in data processing and event building contributed substantially to the success of the mCBM runs. The development of the cave infrastructure continued, and the concrete shell of the cave including the ceiling has been completed. Last but not least, the physics performance studies have been advanced, and increasingly realistic simulations of various important observables have been performed. In this respect it is worthwhile to note that recent developments in theory have substantially strengthened the CBM physics case and its discovery potential, by locating the critical endpoint of the anticipated first-order chiral phase transition in the beam energy range of SIS100/CBM.

The Russian war on Ukraine, started in February 2022, leaves us scientists shocked. In CBM, Russian and Ukrainian groups have been working together professionally and amicably for many years and delivered substantial contributions to the project. The CBM collaboration condemns the blatant break of international law and the violation of human rights by the Russian government and expresses their full support to our Ukrainian colleagues and the people of Ukraine. Following the governmental sanctions against Russia, the membership of the Russian institutes in the CBM collaboration and any cooperative activities were suspended. We would like to make clear that this measure is no judgement against our Russian colleagues, whom we continue to see as colleagues and friends.

The suspension of cooperation with Russian institutes has obviously strong impacts on CBM as well as on the FAIR project in general, to both of which Russian groups had strong commitments. For CBM, this concerns in-kind contributions to the CBM dipole magnet, the Projectile Spectator Detector, and mechanical parts for RICH and MUCH. Similarly, many immaterial contributions to software development and physics performance studies will not continue. The participation of German groups to the BM@N experiment at NICA as part of the FAIR Phase-0 activities, funded through the former EU program CREMLINplus (now EURIZON) and the former Russian-German Roadmap of the German Ministry for Education and Research, was stopped as well. We have started measures to compensate for the now missing Russian contributions in order to launch the CBM experimental program as soon as the beams from SIS100 will be available.

Darmstadt, July 2022

Peter Senger

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Several of the contributions to this volume also appear in the GSI Scientific Report 2021.

Executive Summary: Status of the CBM Experiment

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CBM continues to strive for the construction of an unique experiment to explore the QCD phase diagram in the region of high baryon densities with high precision due to an unprecedented rate capability of the experiment.

This effort has received a strong push due to the absence of any signal of a phase transition in the region of lower baryon densities that is under investigation at SPS, RHIC and LHC. Theoretically there are indications that the Critical End Point (CEP) of a first order phase transition sits at a value that can be reached by the SIS100 synchrotron at FAIR. The current status of these theoretical investigations together with the experimentally determined freeze-out points is shown in Fig. 1.

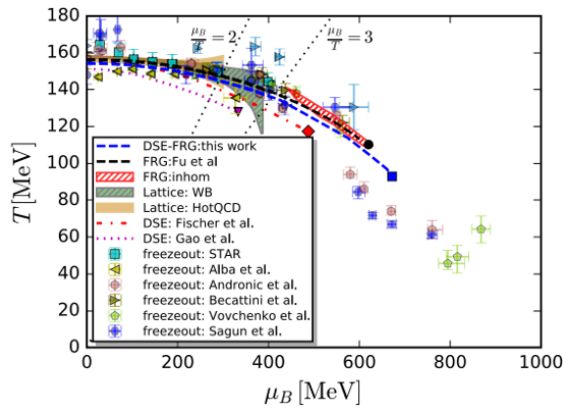


Figure 1: Location of the chiral cross over points analyzed with different theoretical methods in comparison to freeze-out points obtained by thermal model fits to experimental data as summarized in [1]

In 2021, despite the difficult working conditions imposed by the pandemic, the FAIR project progressed tremendously and CBM collaboration successfully continued the developments aiming at readiness for first beam in 2025. However, with the begin of the Russian invasion of Ukraine in February 24, 2022, the collaboration with Russian institutes was suspended and all planning will have to be revised. Hence, in this progress report we restrict ourselves to work that was finished before the war started and acknowledge explicitly the contributions of our Ukrainian and Russian colleagues.

The main focus of the work was to prepare for series production of the various detector systems and to evaluate and optimize system performance. Furthermore, an important step towards the realization of the CBM experiment are the

ongoing FAIR Phase-0 activities:

- operation of mCBM,
- participation in the HADES experiment with the RICH photo detectors,
- participation in STAR with hardware (eTOF) and software (KFPARTICLE),
- participation in BM@N with PSD and STS modules.

FAIR Phase-0 highlights for which details are contained in this report are:

mCBM: For the beam campaign 2021 major effort was put on the upgrade of the DAQ/data transport system to the final CBM configuration integrating the new Common Readout Interface (CRI). Hence, the FPGA firmware for each detector subsystem has been newly developed as well as a Timing and Fast Control system (TFC). The new hardware and software versions were successfully tested during the ^{16}O beam block in July 2021. A first commissioning run for the planned benchmark campaign in 2022 could be taken in O+Ni collisions at 2.0A GeV kinetic bombarding energy accumulating approx. $6 \cdot 10^9$ collisions. Furthermore, detailed high-rate tests could be performed in nucleus-nucleus collisions for various detector subsystems, benefiting substantially from high beam intensities available at the SIS18 of GSI/FAIR. On the base of the 2021 data next development steps towards a CBM data analysis chain could be carried out, the results are presented in various contributions.

HADES: The HADES RICH detector in which already half of the CBM MAPMTs are installed did participate successfully in the recent HADES beam time delivering a wealth of data.

STAR: Data taking with eTOF continued in 2021 with fixed target energies of $\sqrt{s_{NN}} = 13.7, 11.5, 9.2$ and 3.0A GeV successfully completing the BES-II program demonstrating stable operation of the eTOF-system over a period of 6 month. The KF Particle Finder (KFPF) package together with the reconstructed primary vertex has been used to analyze the charged particle tracks reconstructed from STAR Time Projection Chamber (TPC) data in Fixed-Target mode at a collision energy of $\sqrt{s_{NN}} = 3.0$ GeV. Strange (Λ) and multi-strange (Ξ^-) hyperons were successfully identified online by their decay into charged hadrons with an excellent signal-to-background ratio using the KFPF selection technique developed for CBM.

BM@N: The preproduction of the STS ladders has started, and the concept for the integration of the free

streaming STS readout into the triggered data acquisition system of BM@N has been developed. The conceptual design of the mainframe and the cooling system progressed. The PSD (FHCAL) has been completely assembled and installed.¹

Common Systems

Cave and infrastructure In 2021 civil construction continued and the CBM cave was covered by the roof. With this step, the CBM underground facilities like the beam transfer tunnel, the cave, the beam dump, and the underground service rooms are now finished, and only the two surface levels remain to be constructed in order to finalize the CBM building. Preparatory works for technical building installations and the common infrastructure have been started. The design of the upstream platform was modified taking into account exact load data. The concept of the rail system has been modified to save costs, with consequences for the support structures of the downstream detector subsystems. The beam pipe concept for the CBM experiment has been worked out, comprising the upstream part (in front of the target through HADES), the target holder and chamber, the conical segments for STS and RICH/MUCH, and the straight cylindrical pipe segment up to beam dump. The cylindrical pipe is connected to the conical segment via a bending mechanism, in order to follow the beam which is deflected in the magnetic dipole field. Simulations and physics performance studies have started to optimize the geometry and the material budget of the beam pipe.

Magnet In 2021, the FDRs of the magnet yoke and its support, and of the power supply and the energy extraction system have been submitted. The yoke has been assembled, painted, and surveyed by laser tracker measurements. The construction of the power supply, the energy extraction system and the dump resistors has progressed. The construction of a mockup coil has been started, and the layout of the cryogenic system, i.e. the branch box, the transfer line and the cryostat is almost finalized.²

DAQ/FLES The major effort was put on the upgrade of the DAQ system to the final CBM configuration by merging two FPGA layers into a Common Readout Interface (CRI). The present CRI version (v1"BNL-712 v2") has been developed by the Brookhaven National Laboratory (BNL) and is based on the XILINX Kintex UltraScale FPGA. The required, new FPGA firmware has been developed until Q2.2021 for each detector subsystem as well as for the TFC system. Merging of two FPGA layers into a single FPGA CRI board required the development of a new First Level Event Selector interface module. Furthermore, a scalable Experiment Control System (ECS) has been embedded in the upgraded DAQ and data transport system.

¹After the Russian army invaded Ukraine, the Czech, German and Polish CBM groups left the BM@N collaboration.

²Due to the sanctions imposed on Russia after its invasion of Ukraine the cooperation with BINP in Novosibirsk was frozen.

Detector Systems

BMON The beam detector system for the CBM experiment consists of two detector stations, one used for beam monitoring and the second for the T0-measurement. Two prototype sensors based on pcCVD diamond technology have been prepared for tests at the mCBM experiment. The TOF read-out has been successfully adapted to the needs of the BMON detector. Moreover, it has been started to integrate the T0 detector into the mCBM read-out infrastructure. The group also worked on the research and development of a new detector technology based on Low Gain Avalanche Detectors (LGAD). First beam tests showed promising results to use this technology for beam detectors. A first evaluation of this technology, in order to use it in the CBM experiment, has been performed with beam tests at FZ Jülich (Germany), MedAustron (Austria) and the mCBM experiment at GSI.

MVD The MVD Technical Design Report has been approved by FAIR in December 2021. The reporting period was dominated by close-meshed irradiation and test beam campaigns with the first full-scale prototype sensor MIMOSIS-1, accompanied by systematic sensor characterization in the laboratory. The analyses of the data is ongoing in parallel and has already provided valuable input for the design and submission of MIMOSIS-2. Sensor integration studies with the module prototype PRESTO have been continued to address modifications of the current baseline concept regarding increasing the production yield. Finally, the coolant NOVEC-649 was validated as the baseline mono-phase coolant.

STS The STS project team made essential steps towards production and application readiness of major system components, approaching the start of series construction. Several reviews were passed successfully, including the ones on production readiness of read-out ASIC and micro-cables, and on engineering-design of powering systems and detector mechanics. The two stations of mSTS, put together in the past years from prototype components, were shown to operate with high performance in the realistic beam environment of mCBM at SIS18.³

TRD Preparations for a series production of TRD modules were pushed forward. All required materials for construction of outer modules of type-5 are delivered or were ordered. A new detector laboratory is being established at the University of Münster, while the one in Frankfurt has been refurbished. An improved version of the SPADIC readout chip has been submitted and is now being evaluated with respect to its noise behavior. An addendum to the technical design report of the TRD, describing the inner modules of the type TRD-2D suggested by the

³As a consequence of the war of aggression of Russia on Ukraine, and the sanctions imposed, the STS teams lose JINR as project partner and assembly site.

Bucharest group, has been prepared and submitted to the FAIR-ECE. The TRD has successfully taken data with four modules in mCBM, clear correlations have been observed with respect to other detector subsystems (TOF, RICH).

MuCh The MuCh R&D activities concentrated on the development of the GEM chambers for the first two stations and the high-rate RPCs for the 3rd and 4th station. The GEM chambers were equipped with a modified layout of the HV distribution, which allowed successful operation of the chambers under high rate conditions at GIF++ at CERN. A large GEM chamber suitable for the 2nd station has been built using the joining PCB technique, and has been tested with cosmic muons resulting in an efficiency of 95%. Moreover, a RPC has been built with a smaller gas-gap and thinner electrodes for handling high particle rates. One real-size RPC suitable for the 3rd station has been tested with beams in presence of a photon flux at GIF++. At GIF++ the detector has been found to work up to the design rate at relatively high operating voltage with an efficiency of above 95%.

RICH The RICH project has transitioned from the design- into the construction phase, with significant progress in many aspects over the last year. First electronic components for the readout, namely all 230 backplanes, have been produced and tested. Half of them are being installed in a full size prototype of one (of the two) photodetector planes. This prototype will be used for cooling tests, investigation of the mechanical stability and in order to practice camera handling procedures. The firmware for the free-streaming readout based on the CRI was developed and successfully tested with the mRICH detector in mCBM. The software did undergo quite some restructuring and machine learning routine for noise suppression or ring finding were developed and tested.

TOF The TOF project was mainly focused on the development of sealed and gas guides MRPC counters in order to minimize the gas aging effects observed under high rate operation conditions. During the last year for the entire MRPC family (MRPC1-MRPC4) new prototypes were developed, build and installed in mCBM. Successfully recorded data from several high rate runs are being analyzed and first preliminary results are presented in this report.

PSD All modules for the CBM PSD have been constructed and tested with cosmic rays. The readout chain of the PSD was commissioned successfully in the mCBM setup. The PSD project is ready for the Production Readiness Review. The Hamamatsu MPPCs have been already ordered for all PSD modules. The methods of signal processing and energy calibration have been developed and tested.⁴

⁴The collaboration with INR Moscow was frozen due to the sanctions imposed on Russia after its invasion of Ukraine.

Computing

On the computing and software side, the tools for studying the detector performance by more realistic, time-based simulations and reconstruction have been further developed aiming at large scale production studies by the Physics Working Groups. One essential ingredient for such simulations is a realistic description of the experiment geometry, including passive elements like target region and beam pipe. Significant progress was achieved in 2021 in close co-operation with the technical design groups and the project engineers, such that the prerequisites to study beam-related background are now at hand.

The focus of software development has shifted to the online data processing, to which the mCBM data taking campaigns offer an ideal testbed. The transformation of the reconstruction and analysis, developed so far for offline application, into an online-capable software stack entails a major revision or re-implementation of algorithms and data structures. These activities were started with the STS detector as a pilot. Local STS reconstruction (cluster and hit finding) were implemented to be executable on both CPU and GPU, outlining the development path also for other parts of the reconstruction code. Experiences with multiprocessing using FairMQ as communication layer were gathered with mCBM and will pave the path to establishing the full online data inspection and selection in the future.

Physics Performance Studies

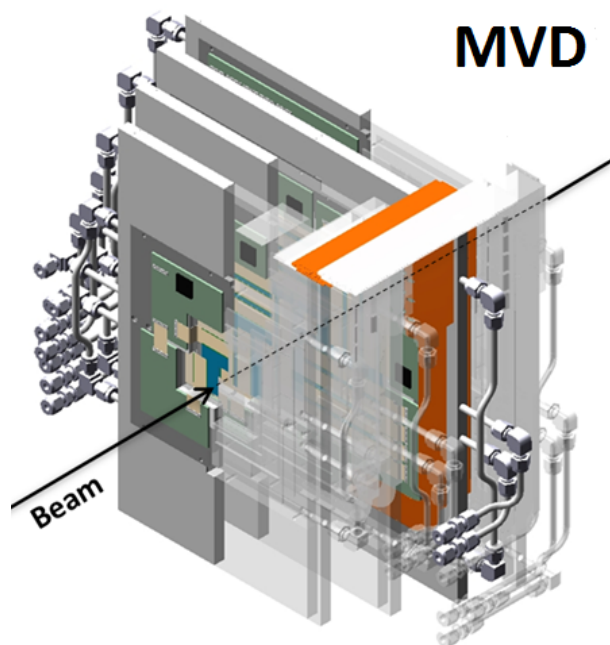
Highlights from the activities of the CBM physics working group presented in this report are:

- Simulation of Drell-Yan processes and development of techniques for combinatorial background determination in di-muon and low mass vector meson measurements,
- Reconstruction of low mass dimuon cocktail at different collision energies,
- Feasibility of femtoscopic measurements and performance for baryon-baryon correlations,
- Optimization of the efficiency and signal to background ratio for strange hadrons yield measurements using Machine Learning techniques,
- Extension of the particle identification framework with Machine Learning methods,
- Data-driven analysis of directed flow of strange hyperons,
- Comparison of the predictions for collision energy dependence of hyperon production and ϕ -mesons using UrQMD, HSD and PHSD models.

References

- [1] F. Gao, J.M. Pawlowski, Phys.Rev. D 102 (2020) 3

Micro-Vertex Detector



Micro Vertex Detector - Summary*

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Abstract: The **MVD Technical Design Report** has been approved by FAIR in December 2021. The reporting period was dominated by close-meshed irradiation and test beam campaigns with the first full-scale prototype sensor MIMOSIS-1, accompanied by systematic sensor characterization in the laboratory. Test beam activities did not conclude by the end of the year, but are being pursued in 2022. The analyses of the data is ongoing in parallel, with promising outcome, and has already provided valuable input for the submission of MIMOSIS-2 by the end of 2021. Having full-size sensors in hand, the development of tools for sensor QA has started, with a focus on probe testing and stand-alone sensor operation. Sensor integration studies with the MVD module prototype PRESTO have been continued to address modifications of the current baseline concept (double-sided sensor integration on a single TPG carrier) regarding increasing the production yield. Finally, the coolant NOVEC-649 has been characterized with PRESTO together with a dedicated cooling circuit, operated in vacuum, and it was validated as the baseline mono-phase MVD coolant.

Sensor: Fully characterizing MIMOSIS-1 w.r.t. detection efficiency, cluster size and spatial precision, noise immunity and radiation hardness is of utmost importance on the way to the final CBM sensor (MIMOSIS-3). This first full-size demonstrator features various options of in-pixel circuitry and sensitive volume doping profile, as well as the final sensor digital readout with three-stage data buffering and radiation tolerant electronic design. Various irradiation (Ljubjana/TRIGA, Karlsruhe/KIT) and test beam (two at GSI/mCBM and DESY, respectively, and CERN-SPS) campaigns have been conducted to assess the sensor's response, before and after irradiation (both ionizing and/or non-ionizing), to charged particles. Single event effects caused by beam halo ions have been quantified with ion beams at mCBM (SIS18/GSI). It was concluded that already MIMOSIS-1 would provide sufficient immunity to SEE expected in future CBM runs. At DESY and CERN a 6-station MIMOSIS-1-only telescope was employed, which allowed to apply, after proper alignment, high-precision tracking to extract e.g. detection efficiency and spatial precision. The preliminary results gained so far do not reveal any show stopper, featuring >99 % detection efficiency and <6 μm spatial precision of irradiated chips within the anticipated range of operation (threshold <150

e⁻). Differences seen w.r.t. in-pixel variants and doping profiles do allow for finally designing MIMOSIS-2, which was pre-submitted in December 2021, evaluated in a production readiness review and finally expected to be submitted (tape-out) in spring 2022.

Sensor integration and QA: The current baseline sensor integration concept relies on sequential front and backside mounting of sensors on a single carrier made of highly heat-conducting TPG. This was demonstrated with module prototyping (PRESTO). Module geometry "c" houses 16 (front) and 12 (backside) sensors. We have started to evaluate concepts to separate front and backside integration, employing two TPG (PGS/RVC) carriers while maintaining the material budget and cooling efficiency. This requires studies on handling and integrating thin sheets of highly heat-conductive graphite and graphite foam, and developing a robust procedure to finally join the corresponding two sub-modules without adding an additional (significant) reduction in yield.

Towards sensor QA we started to develop multi-purpose laboratory read-out electronics for MIMOSIS sensor family to enable probe-testing of sensors, characterization of flex cables and operating small-scale MIMOSIS-based stand-alone test systems.

Detector cooling: NOVEC-649 coolant features very low viscosity in the temperature operation range < -10 °C (hottest sensor) of MVD, enabling moderate pressure drops and efficient heat transport. However, the compatibility of the cooling system components and chiller had to be revisited, with an emphasis on leak tightness, interaction with materials and selection of proper sensors. Having set up the modified cooling system, supplying two PRESTO prototypes, the system was successfully benchmarked both for the absolute temperatures of sensor operation and the temperature gradients between the hottest region and the coolant. The sensitivity of the monitoring even allowed to assess the impact of (environmental) radiative effects on the system. The modified baseline concept of MVD cooling was successfully validated for the projected sensor temperature operation range, with a safety margin of about two.

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Characterization of MIMOSIS-1 with high-energy particle beams*

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The Micro Vertex Detector (MVD) of the CBM heavy ion experiment at FAIR/GSI will be exposed to high-rate non-homogeneous irradiation, while providing a spatial resolution of $\approx 5\mu\text{m}$ and a suppressed material budget complying with a demanding vertexing and tracking capability. A specific CMOS Monolithic Active Pixel Sensor (MAPS), called MIMOSIS, is under development, which takes advantage from the front-end circuitry of the ALPIDE sensor developed for the ALICE-ITS [1]. Based on the outcome of the first development step, achieved with a small scale prototype [2], a full size demonstrator - called MIMOSIS-1 - was fabricated in 2020 and tested on particle beams in 2021. This report summarises its performance studies achieved up to now. Most results are still preliminary.

MIMOSIS-1 is a 504×1024 pixel prototype integrating nearly the complete circuitry of the final sensor. It allows to investigate at full scale various options of in-pixel circuitry and sensitive volume (epitaxy) doping profile, as well as the final sensor digital readout with three-stage data buffering and radiation tolerant electronic design. A picture of MIMOSIS-1 is shown on Fig. 1, exhibiting 4 sub-arrays differing by their in-pixel circuitry, each incorporating a pre-amplification, shaping and discrimination chain (see Fig. 2). The pixel variants are motivated by the quest of optimum radiation tolerance. Two pixel arrays feature ALPIDE-like pixels (DC pixels), where the sensing diode is directly connected to the pre-amplifier (PA).

The two other sub-arrays host so-called AC pixels, where the sensing diode is biased with a high-voltage source (up to $\gtrsim 30\text{ V}$), translating into enhanced depletion capability of the sensitive volume; the consecutive perturbation of the PA is suppressed by a decoupling capacitor inserted in front of the input transistor. DC and AC pixels appear with two different dimensions of the PA input transistor in order to investigate potential radiation tolerance improvements. Some major characteristics of MIMOSIS-1 are recalled in Tab. 1; more details may be found in [3].

The development is intended to ensure a high sensor performance after high-density, non-homogeneous, particle irradiation. To search for an optimal sensor design, MIMOSIS-1 was manufactured with 6 different, $25\mu\text{m}$

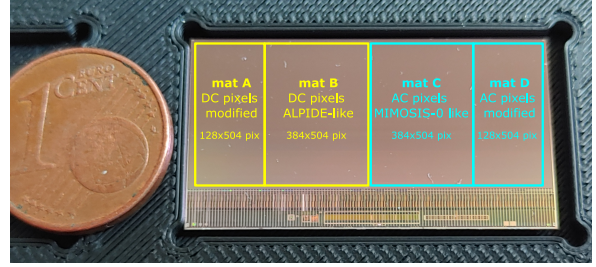


Figure 1: Picture of MIMOSIS-1 indicating its 4 different sub-arrays. Sub-arrays A and B (resp. C and D) host DC (resp. AC) pixels differing by their PA input transistor parameters. The pixelated area amounts to $\sim 4.2\text{ cm}^2$.

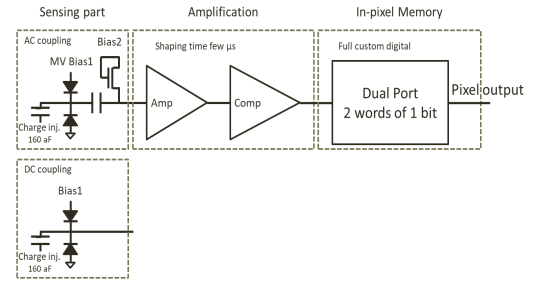


Figure 2: Design of the two alternative in-pixel analog circuits: the DC pixel reproduces the design of the ALPIDE pixel. The AC variant allows to bias the sensing node and thus to extend the depletion field penetration in the epitaxy.

thick, epitaxy doping profiles [4]. Presently, 3 of them were studied, including the unmodified (i.e. standard) one, used in ALPIDE. The 2 modified profile sensors are labelled "n-gap" and "p-stop" hereafter. The profile modifications extend laterally the depletion volume underneath the sensing nodes to reinforce the charge collection efficiency after irradiation. Fig.3 reproduces schematic views of the two modified epitaxial layers published in [4].

The studies performed up to now privileged the modified epitaxial layers and the AC-coupled pixels, which are expected to provide enhanced radiation tolerance as compared to the standard epitaxy and the DC-coupled pixels. The results summarised in this report are shown for representative voltage values applied for back biasing (-3 V or

* Project funded by BMBF (05P19RFFC1), GSI and HIC for FAIR

+ Post-doctoral position funded by the EU project CREMLIN+.

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Parameter	Value
Technology	TowerJazz CIS 180 nm
Epitaxial layer	$\sim 25 \mu\text{m}$ thick, $> 1 k\Omega\cdot\text{cm}$
Sensor thickness	300 μm or 60 μm
Pixel size	26.9 $\mu\text{m} \times 30.2 \mu\text{m}$
Pixel array	1024 $\times$ 504 pixels
Array readout time	$\approx 5 \mu\text{s}$
Power consumption	$< 100 \text{ mW}/\text{cm}^2$

Table 1: Prominent MIMOSIS-1 characteristics.

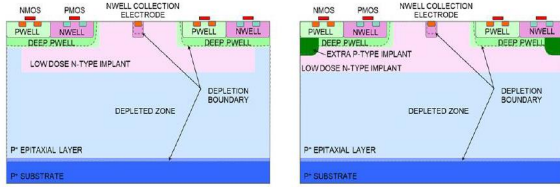


Figure 3: Cross-section of pixels with modified epitaxy, using a low dose n-type implant on top of the p- epitaxy. In case of the "n-gap" variant (left), the n-type layer is interrupted at the pixel edge; in case of the "p-stop" variant (right), extra p-type implants are inserted at the pixel edge.

–1 V) and top biasing (10 V). As no significant difference was observed up to now between the "n-gap" and the "p-stop" epitaxy variants, most of the results shown hereafter tend to concentrate on the "p-stop" epitaxy.

For each split, several sensors were first characterised in the laboratory to determine their domain of nominal signal discrimination and noise performance. These investigations took place with non-irradiated and irradiated chips.

The effect of ionising particles was investigated with sensors exposed to X-Rays to obtain Total Integrated Doses (TID) of 1 MRad and 5 MRad. The impact of non-ionising radiation was studied on sensors exposed to neutron doses corresponding to fluences of $3 \cdot 10^{13}$, $1 \cdot 10^{14}$ and $3 \cdot 10^{14} \text{ n}_{\text{eq}}/\text{cm}^2$. This latter value, which corresponds to 3 times the MVD requirement, is intended to allow investigating which sensor flavour is best suited to unexpected non-ionising radiation loads or, alternatively, could withstand the fluence expected over several years of operation. The irradiation impact was also evaluated for sensors exposed to both, neutrons and X-Rays, to reproduce a combined irradiation of $1 \cdot 10^{14} \text{ n}_{\text{eq}}/\text{cm}^2$ and 5 MRad.

The impact of the different radiation loads on the pixel noise, dominated by the Thermal Noise (TN), and on the Fixed Pattern Noise (FPN), which reflects the pixel-to-pixel dispersion, is illustrated on Fig. 4 for the "p-stop" epitaxy. The evolution of the noise is shown as a function of the in-pixel discriminator threshold value.

Overall, the pixel noise stays in the range 2-3 e^- ENC before irradiation while the FPN values vary typically from 5 to 10 e^- ENC, depending on the discriminator threshold. These results are representative of the different pixel and epitaxy flavours. The increase consecutive to the ra-

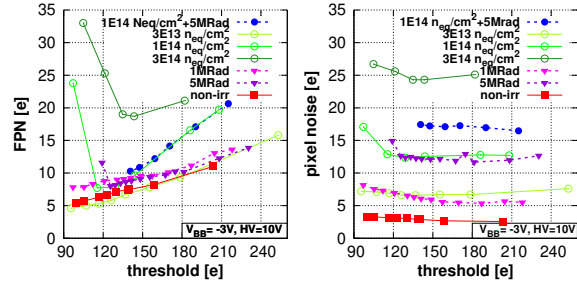


Figure 4: FPN and TN versus discriminator threshold for AC-pixels at room temperature for various radiation loads, in case of the "p-stop" epitaxy. The threshold values are preliminary, being subject to calibration uncertainties under evaluation. Noise measurements performed after ionising irradiation are yet limited to one third of each sub-array.

diation loads expressing the MVD requirements is significant but well affordable. For instance, the combined load ($1 \cdot 10^{14} \text{ n}_{\text{eq}}/\text{cm}^2$ and 5 MRad) leads to a pixel noise slightly above 15 e^- ENC and a FPN ranging from about 10 to 20 e^- ENC. Such values allow to operate the sensors at relatively low threshold settings, where the detection efficiency is at its top value (as shown later in this report).

When rising the fluence to 3 times the nominal requirement, the FPN and TN reach relatively high values, i.e. at least 20 or 25 e^- ENC, respectively. The sensors nevertheless provide satisfactory detection performances, as will be shown in the forthcoming part of the report.

In 2021, three test beam campaigns were realised, two at DESY with ~ 3 -5 GeV electrons, one at the CERN-SPS with O(100) GeV pions. 14 chips were tested in total. The setup was made of 6 MIMOSIS-1 sensor planes mostly separated by 1.5 cm, configured to form a beam telescope. The two upstream and two downstream sensors were standing as reference for the reconstruction of the beam particle trajectories, extrapolated next to the two planes located in the telescope center hosting the Devices Under Test (DUT).

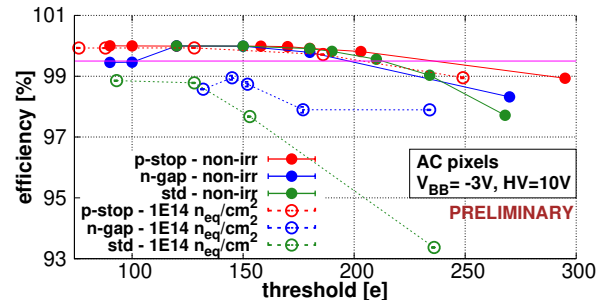


Figure 5: Detection efficiency versus discrimination threshold for the three epitaxy variants, before (full lines) and after (dotted lines) exposure to $1 \cdot 10^{14} \text{ n}_{\text{eq}}/\text{cm}^2$.

Fig. 5 summarises the evolution of the detection efficiency observed for the three epitaxy variants as a function

of the in-pixel discriminator threshold value. The measurements are displayed before and after a radiation load of $1 \cdot 10^{14} \text{ n}_{\text{eq}}/\text{cm}^2$. While all epitaxy variants exhibit similar performances before irradiation, the efficiency being $\approx 100\%$, the radiation damage induced by neutrons is most visible for the standard epitaxy. The sensor maintaining its top efficiency for the highest threshold values is based on the "p-stop" epitaxy. In how far the results shown here reflect sensor to sensor variations or structural features needs still to be established with larger statistical samples. Meanwhile, the "p-stop" epitaxy will be considered as most adapted to the MVD running conditions and the remaining results reported here will privilege this variant.

The impact of a 3 times higher fluence on the detection efficiency may be appreciated on Fig. 6, together with the fake rate due to noisy pixels. Pixels with a fake rate in excess of 10^{-3} per frame were withdrawn; they represent at most 0.01 % of the pixels composing each sub-array.

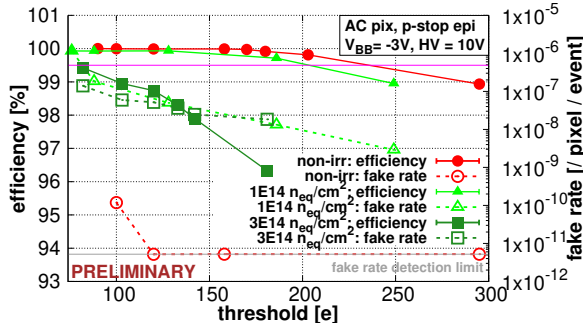


Figure 6: Detection efficiency (full lines) and fake rate (dotted lines) as a function of discriminator threshold observed with AC pixels in case of the "p-stop" epitaxial layer, before irradiation and after neutron irradiations corresponding to $1 \cdot 10^{14} \text{ n}_{\text{eq}}/\text{cm}^2$ and $3 \cdot 10^{14} \text{ n}_{\text{eq}}/\text{cm}^2$.

A fluence as high as $3 \cdot 10^{14} \text{ n}_{\text{eq}}/\text{cm}^2$ affects significantly the detection efficiency but threshold values $\lesssim 140 \text{ e}^-$ still provide efficiencies of $\gtrsim 98\%$. Given the modest fake rate, the sensors may indeed be operated at these low threshold values, which also benefit to the spatial resolution.

The sensitivity of the sensor to ionising radiation was next addressed with the TIDs of 1 and 5 MRad. Fig. 7 displays the detection efficiency and the fake rate observed. The efficiency does not appear to be degraded, showing values exceeding 99.5 % over a wide range of threshold values. The fake rate increases, but remains marginal, in the order of 10^{-6} . The irradiated sensors seem to exhibit a slightly better efficiency at high threshold, and the fake rate is below expectations from the noise estimates. These observations are still under study.

Fig. 8 displays the spatial resolution and cluster size as a function of threshold for various radiation loads. The resolution was derived from the residues assuming a resolution on the extrapolated hit position of $2.5 \pm 0.5 \mu\text{m}$. In case of the DESY data taking, a multiple scattering term of

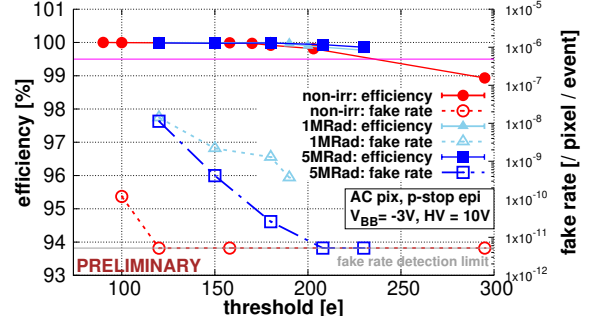


Figure 7: Detection efficiency (full lines) and fake rate (dotted lines) versus discriminator threshold observed with AC pixels in case of the "p-stop" epitaxial layer before and irradiation with X-Rays to TID of 1 and 5 MRad.

($1.5 \pm 0.15 \mu\text{m}$) was accounting for. The results are shown for the shortest pixel edge ($26.9 \mu\text{m}$). The spatial resolution ranges from $4.7 \mu\text{m}$ to $6.2 \mu\text{m}$, complying well with the MVD requirement for threshold values $\lesssim 150 \text{ e}^-$. In the other direction, the resolution is $\approx 0.5 \mu\text{m} - 1 \mu\text{m}$ larger. It is anticipated that thicker epitaxial layers may still improve the resolution.

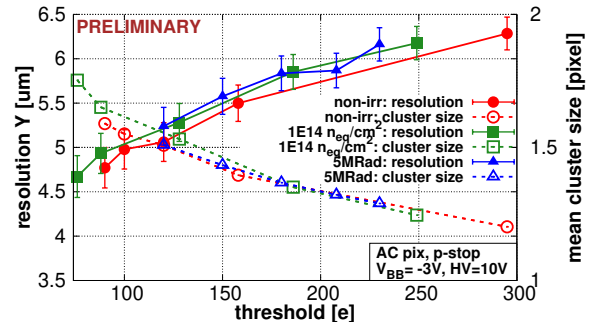


Figure 8: Spatial resolution and average cluster size versus discriminator threshold for AC pixels and "p-stop" epitaxy, before and after X-Ray and neutron irradiation.

In summary, MIMOSIS-1, the first full scale prototype of the CMOS sensor foreseen to equip the CBM-MVD, has undergone quite extensive studies, which addressed in particular the detection efficiency and the spatial resolution after irradiation. The observed detection performances comply with the requirements at a degree allowing to proceed toward the final prototype (MIMOSIS-2) fabrication, planned for Spring 2022. Meanwhile, beam tests will continue, which will complete the study summarised here.

References

- [1] M. Suljic et al., JINST 11.11 (2016): C11025
- [2] M. Deveau et al., NIM-A Vol.958 (2020) 162653
- [3] CBM Progress Report 2020, CBM Collaboration, Nr. 2021-00421 (2021) GSI Darmstadt
- [4] W. Snoeys et al., NIM-A Vol.871 (2017) 90–96.

The Final MVD Sensor Prototype MIMOSIS-2*

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The development of MIMOSIS, the CMOS pixel sensor intended to equip the CBM-MVD, has passed a crucial milestone with the validation of the full scale prototype MIMOSIS-1 [1]. Its characterisation has shown that several of its design variants comply with the radiation tolerance and spatial resolution required for the MVD and has produced the necessary ingredients to progress toward the last prototyping step, namely the fabrication of MIMOSIS-2. The design of the latter will integrate the final, complete, chip steering and data processing circuitry, accounting for a few shortcomings observed on MIMOSIS-1. It will be manufactured with newly available epitaxy variants to allow for further optimisation opportunities of the sensor detection performances. These variants also allow pursuing the exploration of designs best adapted to specific spin-off applications.

Several aspects of the MIMOSIS design require to be validated and fine tuned at full scale, i.e. accounting for features specific to the large assembly of pixels distributed over a sensitive area of several centimeters squared, read out with a multi-stage peripheral signal processing circuitry adapted to large beam current fluctuations and sizeable radiation loads. The development of the MIMOSIS sensor was foreseen to rely on two consecutive full scale prototypes, the manufacturing of the second one serving possibly as pre-production.

MIMOSIS-1, the first of the two full scale prototypes, has undergone a rather complete set of tests addressing prominent aspects of the MVD requirements. With its pixel read-out architecture derived from the design of the ALPIDE sensor [2], combined with a specific in-pixel and peripheral data processing circuitry developed to withstand much higher hit densities and radiation loads, MIMOSIS-1 has met all expectations addressed so far. This applies both to the epitaxy doping profile variants called "n-gap" and "p-stop", as well as to the so-called AC-pixel front-end micro-circuit (see [1] for details).

The tests of MIMOSIS-1 revealed in particular an excellent noise performance of both AC-pixels variants composing the sensitive area and that the depletion field it intro-

duces enhances significantly the tolerance to non-ionising radiation. The latter was observed to be further improved when using a modified epitaxy, with a still tolerable loss in spatial resolution. Overall, the requirements in terms of radiation tolerance and spatial resolution are fulfilled. Moreover, the data processing circuitry implemented in the sensor periphery to handle the high hit density foreseen, as well as their large fluctuations consecutive to beam current variations, was shown to be fully operational.

Following these observations, the design of MIMOSIS-2 is essentially based on the AC-coupled pixels composing the largest sub-array of MIMOSIS-1, made of 384 columns of 504 pixels. In MIMOSIS-2, they compose 896 columns, resulting in an homogeneous sensitive area of 27 x 14 mm². For the sake of further studies, the remaining sensitive area, i.e. 128 out of the 1024 columns, is still composed of those DC-coupled pixels tested with MIMOSIS-1 which are similar to those implemented in the ALPIDE sensor.

In order to further explore the trade-offs between spatial resolution and radiation tolerance as a function of epitaxy depletion, MIMOSIS-2 is manufactured with thicker epitaxial layers than MIMOSIS-1 (i.e. 30 and 50 μm), in addition to the 25 μm thick high-resistivity epitaxy with which MIMOSIS-1 was fabricated. It is expected that a thicker epitaxy may provide enhanced radiation tolerance while preserving more effectively the spatial resolution against the degradation due to the epitaxy depletion. The epitaxy doping profile will be declined in three variants, namely those called "standard", "n-gap" and "p-stop" among the set of starting materials used to manufacture MIMOSIS-1.

Several, rather minor, shortcomings were observed on MIMOSIS-1. Most of them are located at the chip periphery. They concern a rather diverse panel of components; typical examples are the pixel analog outputs used for test purposes, the DACs generating the pulses used to steer the pixel array, the clock tree and the phase-lock loop (PLL) which generates the precisely timed clock pulses in the sensor's digital logic circuits. All observations made during the tests of MIMOSIS-1 hinting to non-nominal operation have been corrected in the design of MIMOSIS-2. Moreover, some electronic performances have been improved by fine tuning the layout.

An emblematic example is the in-pixel discriminator threshold shift across the pixel array, which reflects the voltage drop along the power lines irrigating the array. It

* Project funded by BMBF (05P19RFFC1), GSI and HIC for FAIR

+ Post-doctoral position funded by EU project CREMLIN+.

† Now at IJCLab, Orsay.

is a major source of the sensor fixed pattern noise (FPN) before irradiation. Simulations were achieved, which provided the necessary guidelines to suppress this source of threshold spread. This is illustrated in Fig. 1, which displays the simulated voltage drop occurring in MIMOSIS-1 and the one anticipated after layout optimisation, i.e. in MIMOSIS-2. The reduction of the voltage drop introduced by the layout corrections appears to be about one order of magnitude.

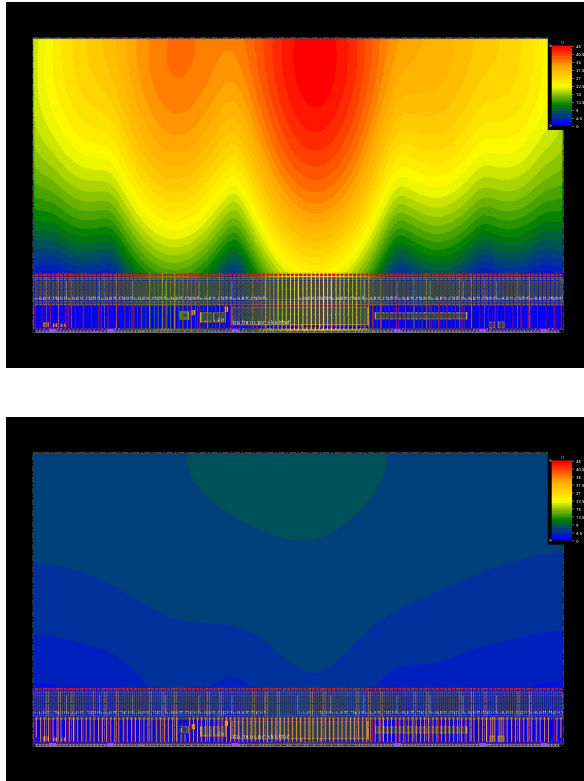


Figure 1: Simulated voltage drop across the pixel array of MIMOSIS-1 (top) and MIMOSIS-2 (bottom), i.e. after optimisation of the power grid. Units are millivolts. The colours express threshold variations ranging from 0 (dark blue) up to 45 mV (red) w.r.t. to the injected reference voltage.

Finally, MIMOSIS-2 will incorporate the remaining part of the data processing peripheral circuitry which was not integrated in MIMOSIS-1 because of the delay it would have introduced in its submission timeline. It did for instance not incorporate the full cluster finding logic. Moreover, the triple-vote logic implemented in the sensor periphery to protect the circuitry against single-event effects (SEE) was still incomplete. All these components have been completed to their nominal design set-up. At this stage, MIMOSIS-2 may therefore come out to be a pre-production test vessel, allowing to move toward final

production at the expense of minor modifications only, if any.

MIMOSIS-2 will be fabricated during Spring-Summer 2022. Its goal will be to assess the performance of the complete sensor circuitry, before and after irradiation. It will also allow investigating potential SEE at some specific, possibly vulnerable, spots of the circuitry. Its tests are supposed to address the question of the fabrication yield and to allow converging on the most appropriate epitaxy thickness and doping profile. This evaluation program will incorporate studies which go beyond the requirements of the MVD and open up spin-off applications which may for instance be of interest for the newly created EURIZON EC project.

References

- [1] B. Arnoldi-Meadows et al., "Characterization of MIMOSIS-1 with high-energy particle beams", this progress report
- [2] M. Suljic et al., JINST 11.11 (2016): C11025

MIMOSIS-1: Studies on Single Event Effects*

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MIMOSIS-1 is the first full-sized prototype for the CMOS Monolithic Active Pixel Sensor (MAPS) developed for the CBM Micro Vertex Detector (MVD). Within an intense test campaign, its cross sections for Single Event Effects (SEE) caused by relativistic beam heavy ions was measured within the mCBM experiment.

To perform the tests, a MIMOSIS-1 was placed near the beam dump of mCBM and directly exposed to the ion beam delivered by the SIS18 accelerator at GSI. Some beam parameters and the related linear energy deposit (LET) of the ions are listed in Table 1. The ion beam was used to simulate the beam halo of the future SIS100 beam and to estimate its impact on the operation of the MVD.

We expected the ions to provoke single event *latch-ups* (LUs). LUs occur once the charge created by an ion switches parasitic thyristors in CMOS devices into their conductive state. This meta-stable short circuit may thermally destroy the device unless it is extinguished in time by means of power cycling. Bitflips occur once ions introduce a charge manipulating a bit stored in a RAM, e.g., the steering registers of MIMOSIS-1. We initially did not expect related observations as these registers were designed to be protected and automatically correct bitflips based on a Hamming code protection.

To detect LUs, we measured the sensor's current consumption and initiated an automatic power cycle once a significant overcurrent, a signature of a latch-up, was detected. During the beam time with Pb ions, we counted the number of automatic power cycles and considered each a latch-up. However, the experiment revealed a bug in the implementation of the related circuits: We found bitflips by reading back the content of the slow control registers and comparing it with the previously programmed value. Some of the misconfigurations indeed caused overcurrents as well and thus triggered a power cycle. Therefore, we monitored the currents manually during the second beam time and rated the event as bit-flip in case a re-programming of the registers recovered the currents to the initial value. This became possible as the sensors were found to tolerate LUs for $\gtrsim 10$ s without suffering permanent damage.

Dosimetry was carried out based on the beam instrumentation, which provided us two-dimensional projections of the beam spot on the sensor. An additional dosimetry film

Ion	kin. Energy	LET in Si	max. Beam Rate
Pb	1.05 A GeV	12 MeV $\frac{\text{cm}^2}{\text{mg}}$	~ 7 MHz
Xe	1.3 A GeV	5 MeV $\frac{\text{cm}^2}{\text{mg}}$	~ 70 MHz

Table 1: Projectile ion, kinetic beam energy and resulting LET of the projectiles in Silicon, as well as the maximum beam rate used in a continuous beam mode used.

indicated a round shape of the beam spot but no quantitative numbers could be extracted due to saturation. This turned into substantial relative uncertainties of $\sim 30\%$ (for Pb) and $\sim 130\%$ (for Xe). Due to this, only upper limits for the SEE cross-sections can be provided at this stage. They amount to $\sim 8 \times 10^{-9} \text{ cm}^2$ for 5 MeV cm^2/mg Xe ions and $\sim 7 \times 10^{-8} \text{ cm}^2$ for 12 MeV cm^2/mg Pb ions and were defined as a mean plus once the experimental uncertainty. The given numbers are considered as preliminary and may be subject to change. The bitflip cross section exceed the LU cross section substantially. The reworked Hamming code protection in the upcoming MIMOSIS-2 prototype will likely reduce the SEE cross section.

So far, the beam test was to simulate the beam halo present in the MVD, where a flux of up to 10 Hz/mm² Au ions is currently considered as acceptable. Assuming this as a uniform flux over the full sensor surface, we anticipate that the 16 most exposed sensors might fact ~ 1 SEE per 4 hours of operation, which is considered as acceptable. No statement is made on the impact of slow target fragments, which may feature LETs of up to 35 MeV cm^2/mg according to GEANT simulations, and of recoil ions created by hadrons in the sensor material. The two latter points will be subject of additional beam tests and simulations studies starting from May 2022.

To simulate the scenario of a direct beam impact into the MVD, the sensor under test was also exposed several spills of 600 kHz/cm Xe-ions with no apparent damage observed. This was the maximum ions flux available and represents 20% of a focused primary beam as expected in the future experiment according to [1].

The results confirm design choices used in MIMOSIS-1 and helped improving the Hamming encoding in MIMOSIS.

References

- [1] M. Deveaux *et al.*, editors. *Technical Design Report for the CBM Micro Vertex Detector (MVD)*, <https://edms.cern.ch/document/2589361/3>, 2021.

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Prototyping the CBM-MVD cooling loop with NOVEC-649™*

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A small-scale prototype of the MVD cooling loop based on NOVEC-649™ from 3M® [1] has been built. Different components for piping and monitoring the coolant have been validated for routine-operation with NOVEC-649 and vacuum compatibility. The thermal performance of the latest generation of heat sinks equipped with 380 µm TPG sheets (current baseline carrier design) has been evaluated. It has been found that the cooling requirements can be achieved with a substantial safety margin using the current MVD baseline design together with NOVEC-649.

Technical details of the setup

The experiments were conducted at the UFO test stand (see figure 1). The cooling loop employs a JULABO PRESTO A40™ [2] cooling unit and is based on 12 mm (6 mm) Swagelok® [3] pipes and compression fittings outside (inside) the vacuum chamber. Threaded connections are sealed with LOCTITE 511™ from Henkel® [4]. Insulated hoses by Huber [5] connect the cooling unit with the cooling loop. Corrugated hoses by Witzenmann® [6] connect the heat sinks with the 6 mm piping inside the UFO. The vacuum feedthrough employs 12 mm Swagelok fittings and is custom made by Pfeiffer Vacuum® [7] to be thermally insulated. Six model S pressure transducers by Swagelok measure the coolant's pressure, three Pt100s by Electronic Sensor® [8] measure the temperature. The coolant flow has been measured to be around 3.6 l/min in an older version of the cooling loop with a flow meter that turned out to be incompatible with NOVEC. There were issues with the tightness and a short in the readout electronics. Two new flow metres have been ordered from Eletta Flow AB [9]. One belongs to M3 series and can be connected with Swagelok 1/2" RS straight fittings (copper or Viton gaskets) to the system. The other is an ultrasonic flow meter. Testing both devices we will identify the best option for the MVD. Leaks are detected by a leak detector optimized for dedicated coolants by Testo® [10]. The cooling loop has been found to be leak tight over the whole targeted temperature range, that is from +25 °C and -40 °C. Aging effects, such as failing rubbers or hairline cracks, have not occurred over hundreds of temperature cycles between +25 °C and -25 °C.

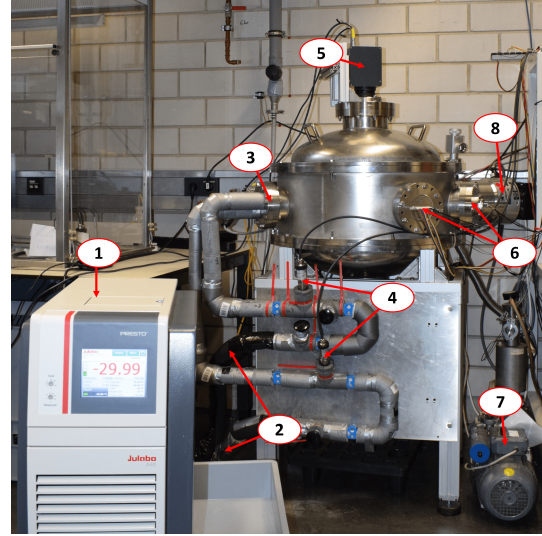


Figure 1: UFO test stand. 1: Cooling unit. 2: Insulated hoses. 3: Fluid feedthrough. 4: Pressure sensors. 5: IR camera. 6: Electrical feedthroughs. 7: Prevacuum pump. 8: Turbo pump.

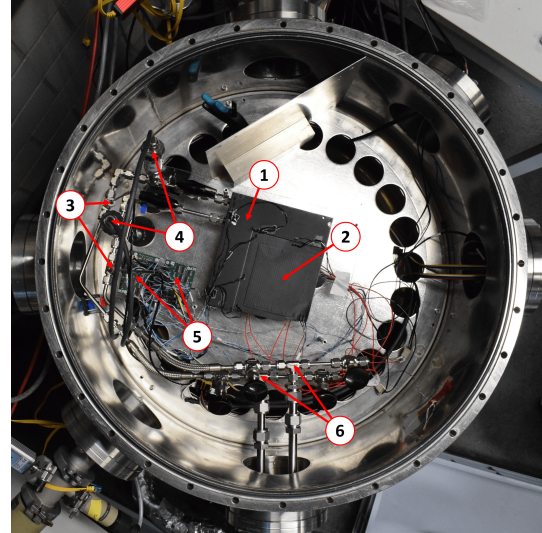


Figure 2: Setup inside the UFO with blackened prototype. 1: Heat sink. 2: TPG carrier. 3: Temperature sensors (in pipe). 4: Pressure sensors. 5: Temperature readout boards. 6: Manifold.

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The aluminium heat sink is connected to the cooling loop with a threaded adapter and is sealed with LOCTITE 511. The properties of this sealant are unknown after irradiation, therefore, alternative ways of sealing were addressed. In collaboration with STS, we tested Swagelok straight fittings (SS-400-1-4 by Swagelok) where the copper gaskets are used for sealing. With about 220 temperature cycles stimulating the aging and thermal stress, it was proven that this connection is tight and in addition compatible with NOVEC in terms of materials. However, to profit from this component, we will need to slightly re-design the MVD baseline heat sinks to mechanically reinforce the thread junction, and consequently, be able to apply the torque needed for making the connection tight.

Results on the thermal performance

The thermal performance of the quadrant is evaluated by measuring the temperature on different points on the carrier and on the heat sink. The heat dissipation of the sensors is mimicked with KAPTON™ heating foils by OMEGA® [11] on both sides on the carrier. Temperatures are measured with Pt100s and an IR camera placed on top of the UFO. To guarantee a uniform and known emissivity of the MVD module, the quadrant is spray-painted in matte black and corresponding corrections are applied in the IR camera readout software.

Among others, the two main parameters to evaluate the thermal performance are the temperature difference between the inlet of the heat sink and the hottest point of the carrier, and the temperature of the hottest point on the carrier (see figure 3). These can be studied as a function of the heater's power for different coolant temperatures on a TPG carrier of size $124.9 \times 143.9 \text{ mm}^2$ (as will be used for MVD module geometry c). The temperature difference seen in figure 3 increase linearly with the power as one would expect from Fourier's law. There is an increasing offset at lower coolant temperatures. The slopes decrease a little bit at lower coolant temperatures. As the measurements were done in vacuum ($p \approx 10^{-6} \text{ mbar}$) conductive or convective heat exchange with the environment is expected to be negligible. It has been shown that the offset can be fully explained with thermal radiation of the UFO wall, as the heat entry due to radiation amounts to $\approx 10 \text{ mW/cm}^2$ compared to 45 mW/cm^2 from the sensors [12]. There is a one-to-one correlation between the temperature on the carrier and the temperature in the laboratory. This correlation explains the offset also quantitatively. The effect decreases at higher power entries as the carrier is heating up. Three issues are driving the heat entry due to radiation: the temperature difference between the UFO wall and the carrier ($>50 \text{ K}$ for MVD operation temperatures), the emissivity of the carrier (>0.9 due to the black paint required for IR camera measurements), and the geometry of the UFO (round shape focused on the carrier). While this effect is rather large in this setup, it will most likely not play a significant role for the final MVD, for two

reasons: the actual MVD stations will not be black and will not be placed inside a focal point of the vacuum chamber; both are driving the radiative heat entry in the UFO setup. Even with this effect and a safety factor of 2 regarding the sensor's power consumption, the hottest sensor will be cooled to below -15°C and the temperature difference across the carrier be around 10 K . Without the safety factor of 2, the hottest sensor is expected to be at -20°C and the temperature difference between this sensor and the coolant at the inlet will be below 9 K . The MVD cooling requirements can very well be met with the current baseline concept. In all these studies the heat entry from the front end electronics, that will be placed on the heat sinks, is ignored. Their influence on the temperature gradient inside the acceptance can however be neglected as it amounts to only an additional 0.2 W per MVD module (quadrant) directly on the heat sink resulting in less than 0.5 K , additionally.

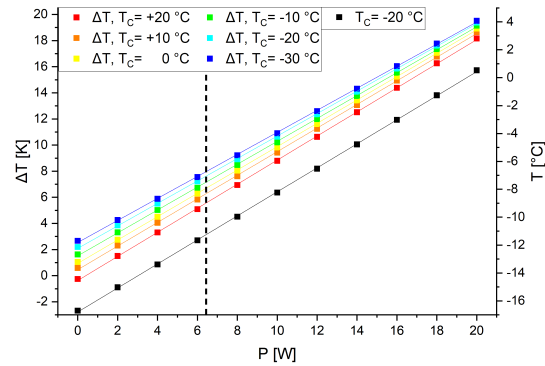


Figure 3: Left axis: Temperature difference between the hottest point of the carrier (MVD module geometry c) and the coolant at the inlet, for different heat entries and coolant temperatures (colored). Right axis: Absolute temperature of the hottest point on the carrier for a coolant temperature of -20°C (black line). The dashed line indicates the expected total power entry by the sensors.

References

- [1] <https://www.3m.com/>
- [2] <https://www.julabo.com/de>
- [3] <https://www.swagelok.com/de>
- [4] <https://www.henkel.de>
- [5] <https://www.huber-online.com/de/>
- [6] <https://www.witzenmann.de/>
- [7] <https://www.pfeiffer-vacuum.com/de/>
- [8] <https://www.electronic-sensor.de>
- [9] <https://www.eletta.se/de/>
- [10] <https://www.testo.com/de-DE/>
- [11] <https://www.omega.de/>
- [12] F. Matejcek. "Systematic Studies on Employing Novec-649 as the Coolant for the CBM Micro Vertex Detector". BA thesis, 2022.

Studies on improving the CBM-MVD module production yield*

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We report on studies to improve the integration yield of the MVD module (representing a quadrant of a station) production. Two conceptual options are being pursued, aiming at separating front/back sensor integration while maintaining requirements regarding vacuum compatibility, thermal performance and material budget.

The current baseline concept outlined in the TDR [1] requires the population of a given 380 μm carrier of Thermal Pyrolytic Graphite (TPG) with sensors on both sides (front/back), to achieve full active coverage inside the geometrical acceptance despite of the sensor's inactive area. The production yield of such a module is driven by successful integration of sensors on one side while the other side is already equipped with sensors bonded to flex read-out cables. The feasibility of such an approach has been demonstrated with the PRESTO prototype [2]. However, the mass production of such modules calls for a firm assessment and further improvement of procedures and the yield, respectively.

Separating front and back side integration calls for the introduction of two sub-modules, which have to be merged as a final, and compared to the baseline concept, additional integration step. This would allow for independent testing of these sub-modules before final assembly. Trading the sensor integration yield for individual sub-modules against the yield of merging two of them is supposed to improve the overall production yield. At the moment, two options are followed up, which have in common issues to be studied, regarding the handling of thin material layers, their thermal performance, and vacuum-compatible gluing:

Option 1: Employing two O(150-200 μm) TPG sheets.

Option 2: Employing two foils of O(25-50 μm) Pyrolytic Graphite Sheets (PGS). Thin foils of PGS feature comparable outstanding thermal conductivity as TPG, but offers no mechanical support. This calls for a low material budget support structure (e.g. Reticulated Vitreous Carbon, RVC). This poses additional challenges in merging PGS to RVC, RVC to RVC as well as establishing a proper heat contact to the heat sink. For both options the cooling efficiency has to be demonstrated for the MVD sensor specifications due to the reduced cross-sectional area of the cooling channel. Table 1 summarizes the key specifications of the high-performance materials under evaluation. Figure 1 compares the options for the compound carriers w.r.t. the ma-

Material	Heat conductivity (W/m/K)	x/X_0 (%) for 100 μm
TPG	1500 (x/y), 20 (z)	0.05
PGS	1300*) (x/y), 20 (z)	0.05
RVC	0.04	0.0016

Table 1: Comparison of different material properties of TPG (Thermal Pyrolytic Graphite), PGS (Pyrolytic Graphite Sheet, *) for 50 μm thickness) and RVC (Reticulated Vitreous Carbon).

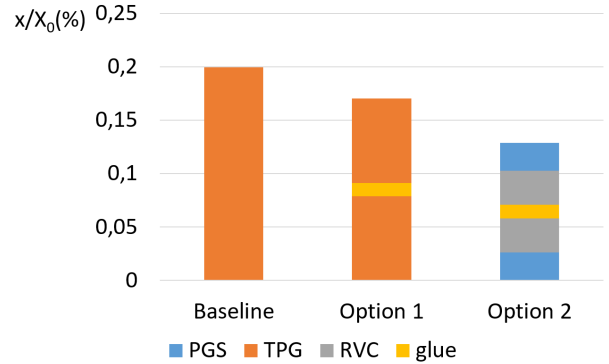


Figure 1: Comparing the material budget x/X_0 of the proposed carrier (only) options 1 and 2 to the current baseline.

terial budget and demonstrates, that separating back and front side sensor integration does not necessarily translate in a significant increase of the material budget.

This activity is work in progress - presently, different samples of the dedicated materials are being characterized and evaluated regarding handling, gluing and thermal properties, preparing integration tests and merging of the sub-modules. The UFO vacuum test stand, equipped with NOVEC-649 cooling infrastructure, PT100 temperature sensors and IR camera allows to deduce quantitative and realistic parameters relevant for the MVD operation. The results will be made available in [4].

References

- [1] CBM-MVD Technical Design Report, Dec. 2021
- [2] M. Koziel et al., NIM-A Vol. 845 (2017), <https://doi.org/10.1016/j.nima.2016.05.093>
- [3] Panasonic PGS product overview, <https://industrial.panasonic.com/ww/products/pt/pgs>
- [4] F. Hebermehl, MA-thesis in preparation, Goethe-University (IKF), 2022.

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Multi-purpose laboratory read-out electronics for MIMOSIS sensor family*

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The MIMOSIS sensor [1] for CBM-MVD is currently being developed and characterized. Three versions of this sensor are foreseen till 2024, two full-size R&D chips and the final sensor. All MIMOSIS family members are compatible w.r.t. bonding pads location and the sensor form-factor. This allows already now to develop probe-card and multi-purpose read-out electronics to learn more about the sensor and prepare sensor QA procedures, as well as, characterize close-to-final MVD modules. This report will summarize the status of the test system development.

The goal: The first version of MIMOSIS has been tested with a focus on its native performance, that is mainly fake-hit rate, charged particle detection efficiency and spatial resolution before and after irradiation, with limiting the influence of environmental conditions (e.g., pick-up noise) to minimum. This was realized by locating the sensor onto its development board packed with efficient passive filters located in the vicinity of the sensor. The main goal now is to separate the sensor from the development board by the means of a dedicated Flex-Print Circuit cable (FPC), and this way mimic more realistic conditions, expected in the experiment. In addition, the setup is ready to operate with a probe-card (in preparation) to test the MIMOSIS sensors prior to integration into any prototype, and finally prior to integration onto the CBM-MVD carriers.

The setup: Figure 1 depicts the setup. The sensor (1) is mounted directly onto a small PCB (2), wire-bonded and connected, by the means of FPCs (4), to the a small adapter board (5) that is next directly linked with the development board (6). The FPCs are composed of two segments, 5 and 10 cm long, respectively. Together with the presence of the extension boards (3), this allows us to assess the impact of FPC length on the sensor performance. An additional connector on the bottom (invisible in Fig. 1), allows to connect the sensor development board to the probe card. The sensor development board features current monitoring and over-current protection. Adapter (5), extension (3) and sensor (2) PCBs can be easily re-designed, to develop and test variants of the final FPC cable.

Outlook: In 2022 we expect to routinely probe-test the MIMOSIS sensors as well as to address questions regarding the maximum FPC length tolerated by the MIMOSIS chip, necessity of a double-layer FPC design, existence of passive filters in a vicinity of the sensor, direct powering from the FEAST DC/DC converters, as well as, implementation of an over-current protection and current monitoring.

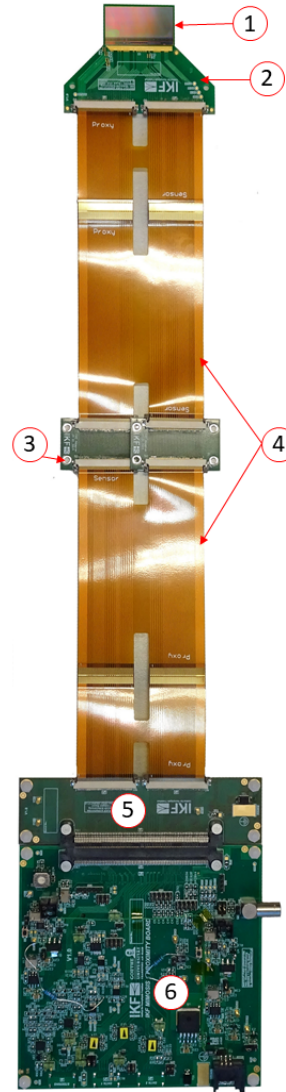


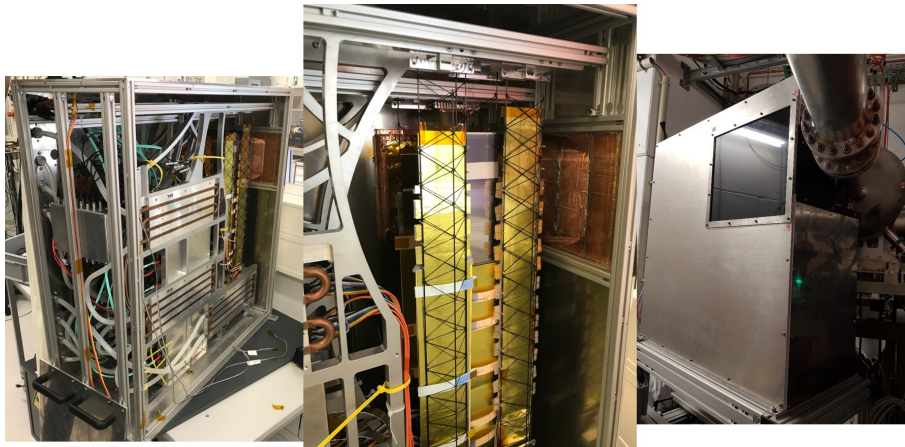
Figure 1: Multi-purpose test electronics for MIMOSIS sensors: (1) MIMOSIS chip, (2) sensor PCB, (3) FPC extension PCB, (4) dedicated FPCs, (5) adapter PCB, (6) sensor development board.

References

- [1] M. Deveau et al., NIM-A Vol. 958 (2020) 162653, <https://doi.org/10.1016/j.nima.2019.162653>

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Silicon Tracking System



Silicon Tracking System – Summary

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In the reporting year 2021, the STS project team [1] made essential steps towards production and application readiness of major system components. The reports in this chapter give account and further insight into the work carried out. The progress was achieved despite pandemic-imposed limitations on in-person work at laboratories and offices, and despite significant delays experienced from industrial suppliers. We managed to carry out several production readiness and engineering design reviews [2, 3, 4, 5], involving external experts. This went along with progress on outfitting the assembly laboratories at GSI, installing a “baby” cooling facility and related infrastructure in the STS integration laboratory, as well as upgrading the module assembly capabilities in the Detector Laboratory’s clean room. The system engineering reached high level of detailing in the STS detector (see Fig. 1), including the unit design, routing of cables and cooling pipes, and further blocks attaching to it like the vacuum box comprising the target and the MVD detector, and the beam pipe section in STS. A mechanical demonstrator has been set up in the STS integration laboratory – on the final detector assembly stand. In Summer 2021, the system demonstrator mSTS was successfully completed (see photos on the cover page of this chapter) and operated in the 2021 beam campaign together with the further mCBM sub-systems.

As a consequence of the war of aggression that Russia imposed on Ukraine, any further cooperation with partners at institutes in Russia became impossible. Our Ukrainian collaborators at KINR, Kyiv, and industrial partners for micro-cables at LTU, Kharkiv, are at severe risk to life and under impossible work conditions. The STS project team loses the JINR group as a long-standing cooperator, and its facilities as a module assembly site. The STS detector of the BM@N experiment at Nuclotron is no longer a partner project. We expected to learn about integration aspects of the quite similar detector system, and about its performance in the beam environment at Nuclotron; we even hoped to achieve physics results, before the STS in CBM is operational. A European project [6], supporting us for this common work, terminated cooperation with Russia and is being re-organized [7]. We had just achieved the mid-term milestone and deliverable [8, 9]. Two progress reports from JINR based on work carried out before the war began are still part of this chapter.

The next steps of the STS project will focus on achieving production readiness of module and ladder assembly in the remaining assembly teams at GSI and KIT, as well as on performance studies with demonstrator systems in the laboratory and mCBM.

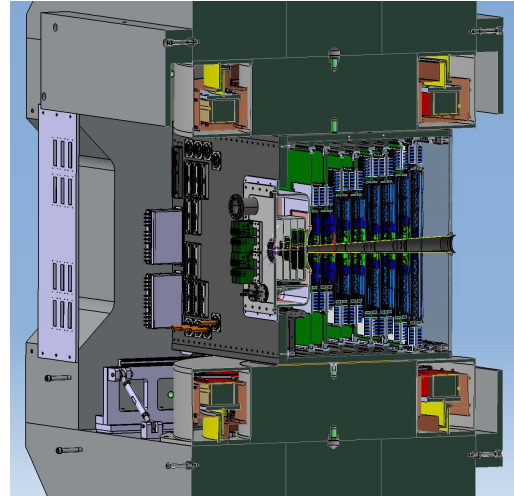


Figure 1: Emerging engineering design: cut-through view of the STS detector system in the superconducting dipole magnet with target box, MVD detector and beam pipe, as well as patch panels on the magnet yoke for detailed planning of cabling and installation procedure.

References

- [1] CBM STS Project, <https://www.cbm.gsi.de/detectors/sts>
- [2] Production Readiness Review of STS Microcables, 30 March 2021, <https://indico.gsi.de/event/12360/>, CBM Technical Note CBM-TN-21002
- [3] Production Readiness Review of the STS-XYTERv2.2 ASIC, 31 March 2021, <https://indico.gsi.de/event/12343/>, CBM Technical Note CBM-TN-21003
- [4] Engineering Design Review of the STS powering scheme and power supplies, 9 June 2021, <https://indico.gsi.de/event/12680/>
- [5] Engineering Design Review of CBM-STS Mechanics, 5 November 2021, <https://indico.gsi.de/event/13250/>, CBM Technical Note CBM-TN-22001
- [6] EU-H2020 project CREMLINplus under grant agreement no. 871072, <https://cordis.europa.eu/project/id/871072>, <https://www.cremlinplus.eu/>
- [7] EU-H2020 project EURIZON, amendment under preparation
- [8] Y. Murin et al., *First STS detector ladder for BM@N*, CREMLINplus milestone report MS6, 15 July 2021
- [9] J. M. Heuser et al., *STS components assembled for the CBM experiment at FAIR*, CREMLINplus deliverable report D2.1, 24 January 2022

Results of the electrical inspection of strips of STS silicon sensors

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Introduction

About 1200 microstrip sensors were manufactured by Hamamatsu Photonics for the Silicon Tracking System of the CBM experiment. They are double-sided silicon detectors with the 2nd metal layer on the P side. Every sensor has 1024 strips per side placed with $58\ \mu\text{m}$ pitch. Sensors of four sizes – $6.2 \times 2.2\ \text{cm}^2$, $6.2 \times 4.2\ \text{cm}^2$, $6.2 \times 6.2\ \text{cm}^2$, $6.2 \times 12.4\ \text{cm}^2$ – will be used to build detector modules.

All sensors were delivered in monthly batches to GSI during the year 2020. Extensive optical [1] and basic electrical [2] inspections have been carried out for all sensors. Optical inspection revealed more defects than reported by the vendor. Therefore, the electrical inspection of the strips was performed for a subset of sensors. The goal was to cross-check optical results, assess the electrical integrity of strips, and ensure compliance of the electrical parameters of strips with the CBM specifications [3].

The sensors for the electrical inspection were selected according to the optical inspection results. In addition, at least one sensor per production batch was included in the subset. The total number of inspected sensors is 80:

- 37 sensors – $6.2 \times 2.2\ \text{cm}^2$,
- 10 sensors – $6.2 \times 4.2\ \text{cm}^2$,
- 13 sensors – $6.2 \times 6.2\ \text{cm}^2$,
- 20 sensors – $6.2 \times 12.4\ \text{cm}^2$,

35 of which have not been inspected by the vendor.

Electrical inspection of the sensors was performed on the dedicated custom-built probe station located in the clean-room environment. It was developed at the University of Tübingen and was transported to the GSI Detector Laboratory in 2020 [4].

Map of defective strips

Electrical inspection of strips at the CBM consists of a set of integrity tests. Three parameters are measured: di-electric current, series capacitance, and equivalent series resistance. They are used for defect analysis and, at the same time, provide essential information about coupling capacitance and polysilicon resistance. There are three important defect classes to distinguish: pinholes, strip breaks and shorts. Both the implant and the metal strip may be defective.

Figure 1 shows a combined map of the defective strips for the N and P sides of all inspected sensors. It has to be noted that only half of the short interconnected strips

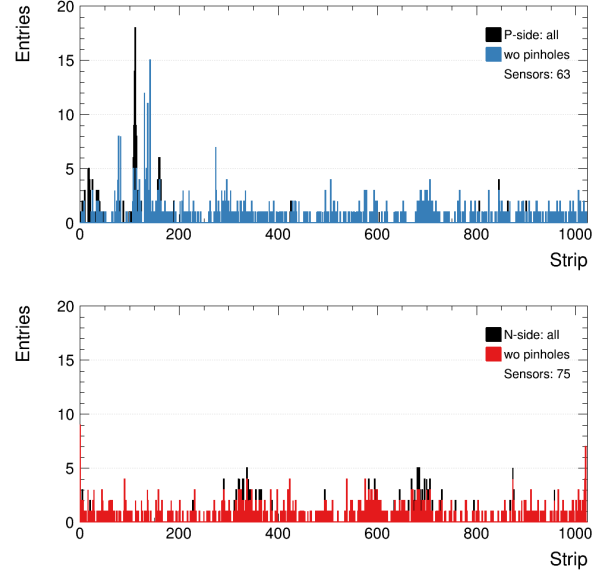


Figure 1: Map of accumulated defective strips for both N and P sides of the CBM microstrip sensors. Data for all sensor variants is combined here. Different number of sensors for N and P sides is due to identified contact loss for some of the sensors.

were analyzed due to the design features of the CBM sensor. Some of the sensors were excluded from the analysis due to apparent loss of contact, which affected the measured parameters. These histograms reveal several tendencies. On the N side, it was found that most of the identified pinholes are located around strip numbers 350 and 700. On the P side, there is an increase in the number of defects for specific strip numbers, which are interconnected by the 2nd metal layer. Optical inspection revealed a circular pattern for defects on both sides of the sensors [1]. Identified regions in Fig. 1 with an increased number of defects correlate with this pattern. It was attributed to the damage caused by a vacuum pick-up tool that is used to handle the sensors during production at the manufacturing site. $6.2 \times 2.2\ \text{cm}^2$ sensors are not affected because they are located on the periphery of the silicon wafer.

Figure 2 shows the breakdown of defective strips by category, except for defects of the 2nd metal layer. Most of the identified defects are implant breaks. On the N side, implant shorts are related to the breaks in the P-stop structures. Both are of the same nature and appear during the manufacturing process. This explains the relatively high

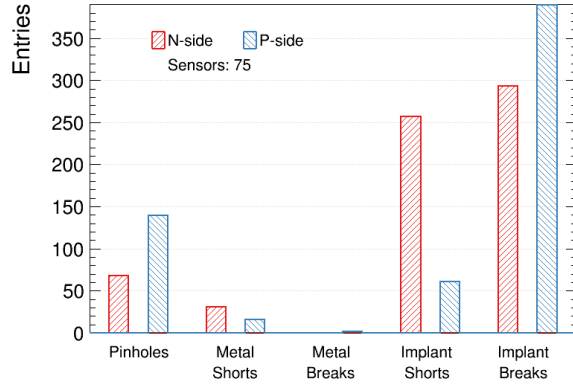


Figure 2: Breakdown of defective strips.

level of implant shorts on the N side. Because of similar signatures, implant shorts on the P side may indicate low interstrip resistance or polysilicon resistor problem. Pinholes make up a significant fraction of defects, averaging three pinholes per sensor. It was found that most of the $6.2 \times 2.2 \text{ cm}^2$ do not have defects of this type. Pinholes in the coupling dielectric layer compromise AC readout and are the only defect type that is potentially dangerous for the readout ASIC. The exact effect depends on the level of leakage current flowing in or out of the readout ASIC [5]. Strip breaks and shorts only affect signal readout. As an example, false multi-strip hits can be observed in the case of a short of two or more neighboring metal strips.

Comparison of results

The obtained results were compared with the data provided by the vendor and with the results of the optical inspection. Hamamatsu carried out the detection of pinholes and metal layer defects. Delivered sensors comply with the requirement for the number of defective strips to be below 1.5%. The vendor does not detect other types of defects.

Optical inspection revealed all surface defects that can be identified visually. A significant number of implantation layer defects were detected, which are not reported by the vendor. In addition, defects of the 2nd metal layer were detected.

Electrical inspection of strips verified the pinhole data provided by the vendor. Some of the metal shorts have not been verified. Correlation with visible defects identified in optical inspection has been established.

Figure 3 shows a comparison between the three inspections for the sensor with the largest number of defects. It can be seen that this sensor easily passes the quality control of the vendor and fails at the CBM. Large clusters of P-stop and strip implant breaks were detected optically and confirmed electrically. One can see small discrepancies between optical and electrical inspection results. On the P side, defects such as low interstrip or polysilicon resistance can only be detected by the electrical inspection. Discrepan-

ancies in identified implant breaks are related to two effects. On the N side with the P-stop technique, broken strip implants are effectively intact due to the presence of an electron accumulation layer. However, one has to keep in mind that the break is a high-impedance channel with resistance, which depends on the bias condition of the sensor. On the P and N sides, some of the implant breaks are not detected electrically due to the location of the defect: when the defect is close to the end of the strip, it is in most cases not detected, because its parameters are within the standard deviation.

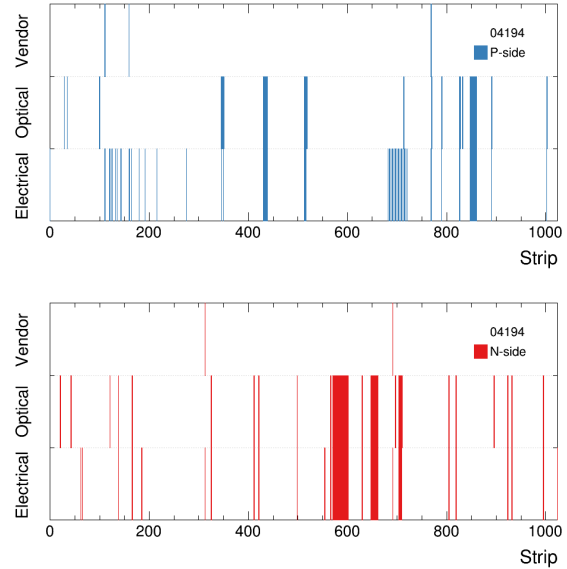


Figure 3: Comparison of the results from three inspections. Defect map of the sensor 04194 with large number of defects is shown as an example. Defective strips are marked with a respective color.

Electrical parameters of strips

The coupling capacitance and polysilicon resistance were extracted from the measurement data for all inspected sensors. Figure 4 and Fig. 5 show corresponding distributions for both P and N sides. The values of the coupling capacitance are normalized to the length of the strip. The obtained values satisfy the CBM specifications for microstrip sensors:

- coupling capacitance: $C_c \geq 10 \text{ pF/cm}$,
- polysilicon resistance: $0.5 \text{ M}\Omega < R_{poly} < 2 \text{ M}\Omega$.

Insulation between adjacent strips is crucial for the operation of the microstrip sensor. It was verified by the measurement of the interstrip resistance for a small subset of the sensors. Figure 6 shows measured interstrip resistance as a function of the bias voltage. On the N side, strips are

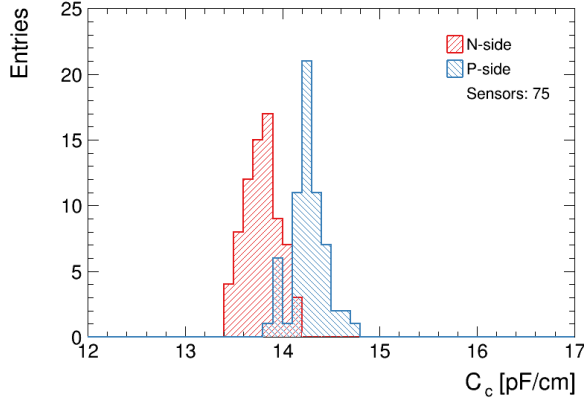


Figure 4: Distribution of the coupling capacitance.

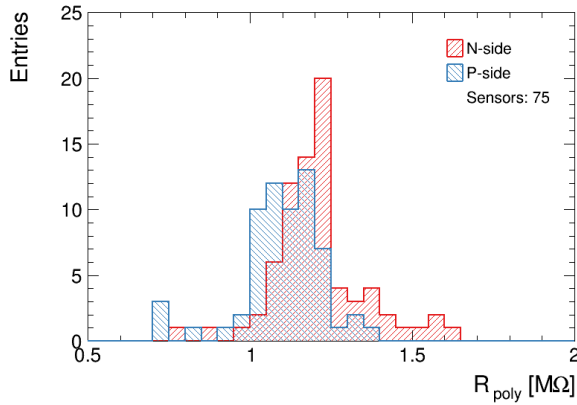


Figure 5: Distribution of the polysilicon resistance.

getting insulated after the full depletion of the sensor. At the operating point of 150 V, interstrip resistance exceeds 100 GΩ on both sides of the sensor. The measured values of other sensors from the subset were always greater than 10 GΩ.

Summary

Electrical inspection of strips for 80 microstrip sensors was carried out at the GSI Detector laboratory using a dedicated custom-built probe station. The fraction of defective coupling capacitors is below 0.5% and is consistent with vendor data. The fraction of the metal layer defects reported by the vendor was not confirmed. Most of the detected defects are defects of the implantation layer. Defects detected by the optical inspection were verified. The observed discrepancies between optical and electrical data are well understood. $6.2 \times 2.2 \text{ cm}^2$ sensors have a very low defect rate. They are not affected by the damage from the pick-up tool due to their location on the silicon wafer. Strip coupling capacitance and polysilicon bias resistance meet the required specifications. Interstrip resistance is high enough to provide sufficient insulation between strips.

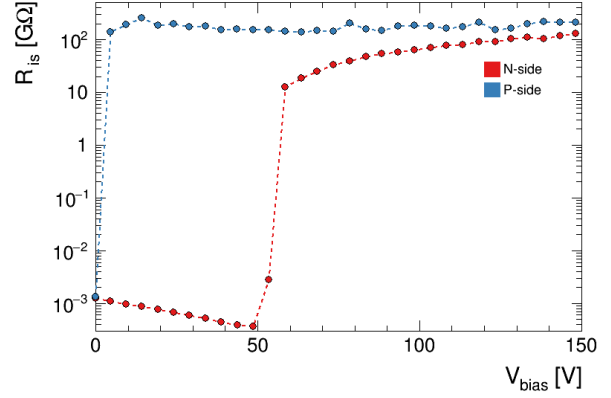


Figure 6: Interstrip resistance as a function of the applied bias voltage.

References

- [1] E. Lavrik et al., *Results of the series optical inspection of STS silicon micro-strips sensors*, CBM Progress Report 2020, 22-24
- [2] O. Bertini et al., *Basic electrical inspection of silicon microstrip sensors for the STS*, CBM Progress Report 2020, 16-18
- [3] J. M. Heuser et al., *Description of the STS microstrip sensors for series production*, CBM-TN-19005 (2019)
- [4] I. Panasenko et al., *A Custom Probe Station for Testing of CBM Silicon Strip Detectors*, CBM Progress Report 2019, 20
- [5] H.R. Schmidt et al., *STS Module and Ladder Assembly*, CBM-TN-20004 (2020), 67

Quality grading and position mapping of the STS silicon sensors

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More than 1200 silicon microstrip sensors have been delivered to GSI during the years 2020-2021. All received sensors were qualified optically [1] and electrically [2]. The goal of the quality control is not only the verification of the basic functionality of the sensors, but their appropriate distribution within the STS layout according to their properties and expected performance requirements. After both, optical and electrical, inspections the sensors were classified into 4 different grades. The amount of sensors per quality grade for each size is summarized in Table 1 for optical inspection and in Table 2 for electrical inspection. For the optical inspection the total number of defective strips per sensor was used for the quality grade determination. For the electrical inspection the possible maximum operational voltage was used to define the quality grade of the sensor.

Table 1: Optical grades summary.

Sensor size	Grade A	Grade B	Grade C	Grade D
22 mm	93	13	2	0
42 mm	296	50	3	0
62 mm	185	144	19	5
124 mm	125	125	107	35
N of defects	≤ 5	≤ 10	≤ 15	> 15

Table 2: Electrical grades summary.

Sensor size	Grade A	Grade B	Grade C	Grade D
22 mm	99	3	4	0
42 mm	267	20	50	0
62 mm	256	28	44	21
124 mm	222	37	84	47
U_{op}	≥ 350 V	≤ 350 V	≤ 250 V	≤ 200 V

From the expected fluence simulated with FLUKA [3] and the geometrical positions of the sensors, as shown in Fig. 1, the required electrical quality of the sensor can be obtained; they are shown in Table 3. Taking into account that the smaller the amount of defective strips is close to the beam pipe the better will be the track reconstruction efficiency, both quality grades, optical and electrical, can be combined and result in the layout proposal shown in Fig. 2.

Since the assembly procedure for modules and ladders is essentially not reworkable, an important point is the number of available sensors in addition to the bare required ones. The amount of spare sensors was calculated according to the layout presented in the current report. Moreover,

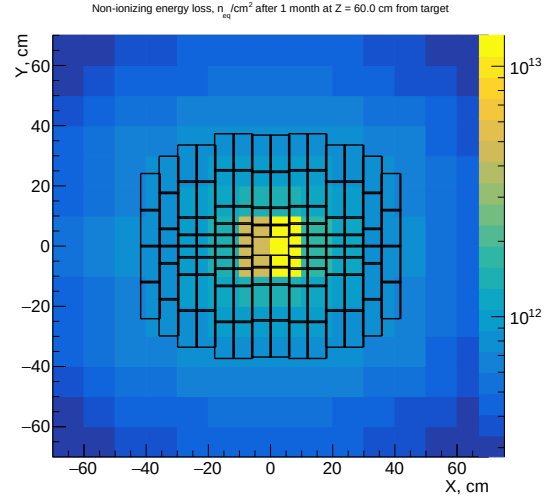


Figure 1: NIEL [$n_{eq} 1 MeV/cm^2$] distribution at 60 cm downstream of the target overlaid with STS station layout.

Table 3: Required number of sensors for STS construction.

Sensor size	Grade A	Grade B	Grade C	Grade D
22 mm	76	4	0	0
42 mm	184	56	32	0
62 mm	72	68	64	0
124 mm	20	84	148	68

sensors already used-up for a test propose were taken into account as well. Thus 24 sensors of 22 mm, 57 sensors of 42 mm, 130 sensors of 62 mm and 52 sensors of 124 mm remain available as spares, a part of which can be used for carrying out a pre-series module assembly exercise.

References

- [1] E. Lavrik et al., *Optical inspection of the silicon micro-strip sensors for the CBM experiment employing artificial intelligence*, NIM A 1021 (2022), 165932
- [2] O. Bertini et al., *Basic electrical inspection of silicon microstrip sensors for the STS*, CBM Progress Report 2020
- [3] A. Senger, *Web and ROOT interfaces to FLUKA calculation results for the CBM cave*, CBM Technical Note CBM-TN-18013 (2018)

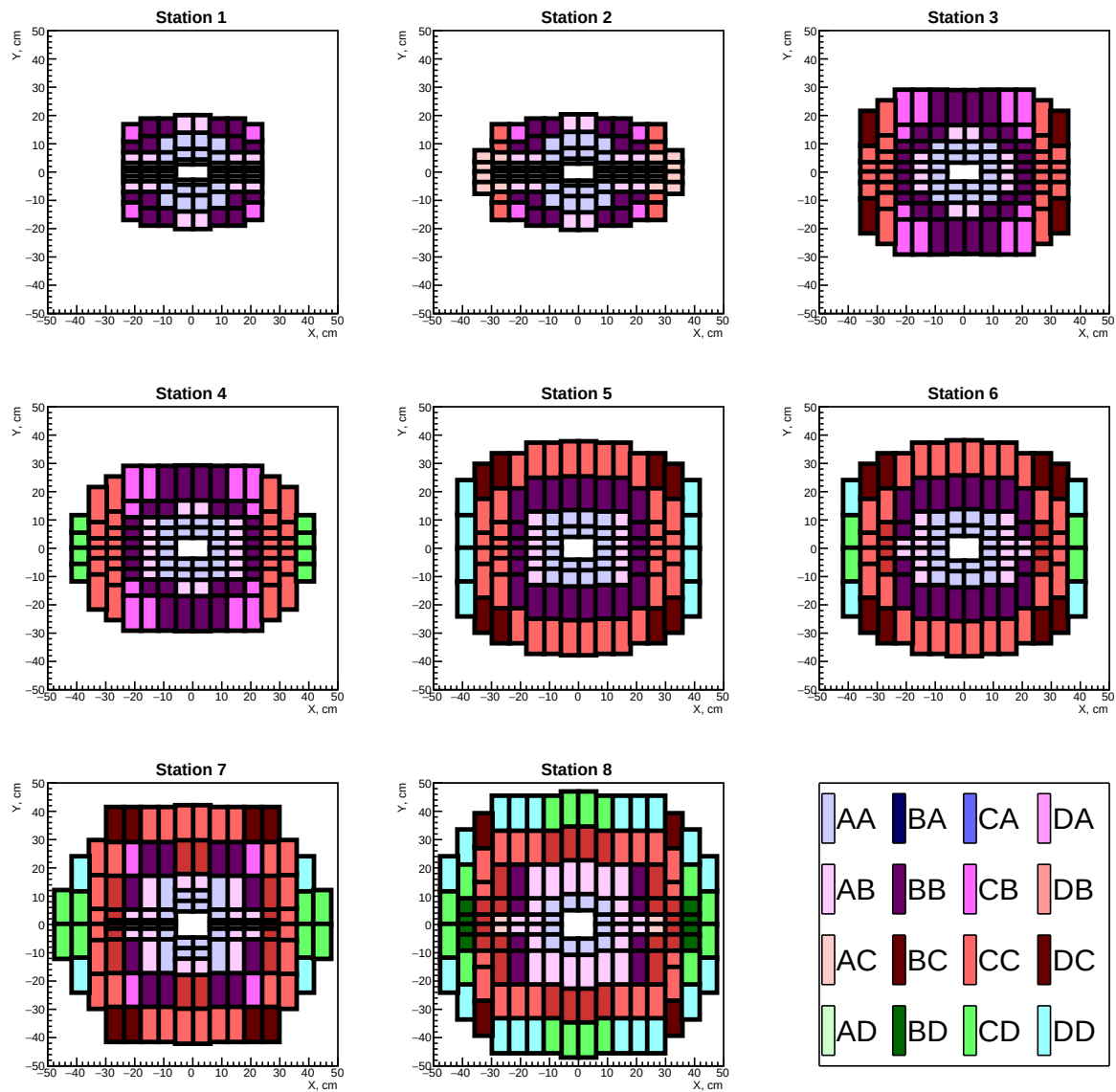


Figure 2: Proposal of the STS layout according to the requested sensors quality, electrical (first letter) and optical (second letter) grades combined.

Operational studies with the STS-XYTERv2.2 ASIC

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Introduction

With the pilot-production delivery of version 2.2 of the STS frontend ASIC STS-XYTER [1] and the availability of more complex setups, various additional ASIC tests and performance studies were done, both in view of the ASIC Production Readiness Review and to gain a more detailed insight into optimal operation of the devices. Part of these studies is reported elsewhere in this progress report [2], several investigations are briefly summarized in this report.

Latchup tests

One potential failure mechanism of CMOS electronics under irradiation are latchup transition (LUT), which lead to potentially damaging increases in current consumption, but can be mitigated by power cycling the affected circuitry.

In March 2021, the LUT sensitivity of the STS-XYTERv2.2 could be tested in the mCBM cave by direct exposure of the entire ASIC area to a 1 AGeV lead beam at different beam intensities. A monitoring circuit provided by the CBM MVD group was used for fast automatic power off in case of a large and sudden current increase.

No LUTs were observed below 10^7 Pb ion per second on the ASIC. LUT related current increases start at 1.4×10^7 ions/s/cm². At 4.1×10^7 ions/s/cm², approx. 2 LUT/min were observed (see Fig. 1), at higher beam intensities LUTs become frequent. This translates into a LUT probability of approx. 6×10^{-10} per Pb ion. After power cycling, the ASIC always returned to the original current.

With the ASICs outside of the detector acceptance and not exposed to beam particles or heavy reaction products in the real STS setup, LUTs therefore should not create problems for STS operation, neither in terms of LUT occurrence nor of damaging effects if recognized quickly.

Double hit performance

The response of the ASIC to double or multiple hits in the same channel with small separation in time was studied for the regular ASIC reset mechanism which will be employed in STS operation. This includes both the effect on a second hit close in time, meaning if a single pileup hit is created, the second hit is lost due to channel dead time or is modified in amplitude due to ongoing baseline restoration, as well as the stability of the measured signal amplitude for longer sequences of hits.

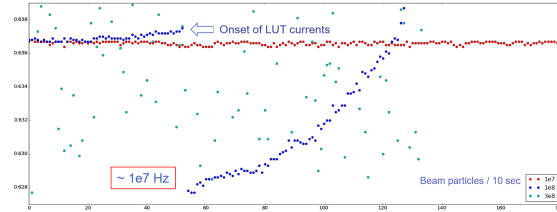


Figure 1: ASIC supply current over time for different Pb ion fluences. After stable currents (red), the onset of LUT related currents (blue) and frequent LUTs (green) at high intensity are visible. The green curve shows arbitrary current values due to frequent LV switching triggered by the monitoring circuit.

In a lab setup, pairs of 2 hits were generated with systematically varied amplitudes of first and second hit as well as separation in time ranging from 100 ns to 10 μ s; measured hits were readout and particularly the properties of the second hit were analyzed.

Up to approximately 250 ns (depending on first hit amplitude) of separation, the second pulse either creates pileup or is lost due to channel deadtime. At larger separation, the amplitude of the second pulse is reduced (see Fig. 2), consistent with the known restoration of the baseline from an undershoot after a previous pulse. At around 800 ns separation, the largest reduction of the second amplitude is present, amounting to up to 2.5 ADC units for the extreme case of largest values of first and second amplitude. After 4-5 μ s, the correct second amplitudes is measured again.

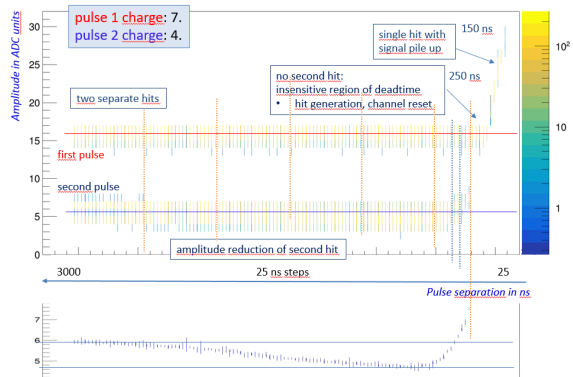


Figure 2: Measured amplitude of a fixed signal second pulse for various time separations from first pulse.

This result is confirmed for longer sequences of up to 20 identical pulses. For separations larger than $4 \mu\text{s}$, the pulse amplitude for MIP signals remains unchanged over the full pulse train. A good operating point for double pulse performance was determined for the feedback current setting with $I_{\text{fed}} = 20$.

Replica hits

STS-XYTER hits contain ADC and timing information coming from different internal processing branches, the slow(ADC) and fast(timing) discriminators. Since hit generation is triggered by an ADC value ≥ 1 , discriminator thresholds have to be set properly to ensure an updated fast discriminator value for each hit ; otherwise so-called replica hits are generated with a non-updated timestamp value identical to a previous hit in the same channel (see Fig. 3).

A significant contribution of replica hits was observed in 2021 mSTS data and thus intensively studied in a dedicated lab setup. The hit response of the STS-XYTER to a mixture of fixed signal pulses together with a noise contribution varying in amplitude and frequency was investigated. Replica hits could be reproduced not only at low signal amplitudes, which can be attributed to bad fast threshold settings, but also at high signal amplitudes. Replica generation increases with noise amplitude, but most significantly depends on the noise frequency, being present especially in the range of 1 MHz to approx. 6 MHz. This behavior is consistent with the ASIC design, where the bandwidth difference between the slow and fast shaper is located in precisely this frequency range.

The mechanism of replica generation is thus probably significant noise in the MHz range which keeps the fast discriminator below its trigger threshold even in case of a signal, while the insensitive slow shaper generates a hit. Replica reduction can thus be achieved by two means: (1) using a fast threshold as low as possible without affecting time resolution and (2) taking special care to avoid and reduce noise contributions in the sensitive frequency range for the full STS system.

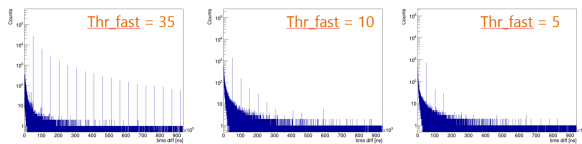


Figure 3: Reduction of replica hits for decreasing values of the fast discriminator threshold Thr_{fast} , as seen in the the same-channel time difference plot. Replica hits appear as spikes due to an artifact in the online time sorting of these hits.

ASIC status

In May 2021, the Production Readiness Review of the STS-XYTER ASIC was approved [3]. Full ASIC production is scheduled for 2022.

References

- [1] K. Kasinski et al., *Characterization of the STS/MUCH-XYTER2, a 128-Channel Time and Amplitude Measurement IC for Gas and Silicon Microstrip Sensors*, Nuclear Inst. and Methods A 908, 225
- [2] A. R.Rodriguez et al., *Comparative study of the noise levels of the STS-XYTERv2.2 ASIC*, CBM Progress Report 2021
- [3] J.M. Heuser et al., *STS-XYTER v2.2 PRR: Questions and Answers*, CBM-TN-21003, <https://indico.gsi.de/event/12339/contributions/53704/>

Test of more than 550 STS-XYTERv2.2 ASICs from pilot production

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Test system

The test stand for the STS-XYTER read-out ASIC is based on a read-out board, a pogopin holder to receive the bare diced ASIC, power supplies, and a PC for control and readout. Within the activity reported here, recent upgrades to the setup have been successfully demonstrated. More than 550 ASICs version 2.2 have been quality controlled. The new aspects of the test procedure are discussed; more extensive monitoring of the different parameters is planned further.

Software improvement

Until now, the PC's operating system was based on Ubuntu 16.04 LTS and the old IPbus library 2.6. The upgraded system is currently running on Kubuntu 20.04 LTS and the latest IPbus [1] version 2.8 library. Its further upgrade to the upcoming newer 22.04 LTS system will be no challenge. Furthermore, all code is based/rewritten on python3 standard, and the newer PyQt5 [2] library was upgraded from PyQt4 for the graphical user interface.

Hardware improvement

On the hardware side, the new pogopin holder has been 3D printed for more reliable and ESD-safe handling (see Fig. 1). The power supply was changed from passive to computer-controlled four-channel devices capable of precisely measuring voltage and current [3]. The read-out system is entirely based on the EMU board with the newest firmware. In parallel to the old STS-XYTER test procedure, we are measuring current before the chip configuration, after configuration, and at the end of the test. Also, internal chip temperature, auxiliary input, and the key performance settings V_{ddm} (1.2 V analog), and $CsaBias$ (bias current for charge sensitive amplifier) are measured and saved after every test.

Summary of results

In total, we have tested 600 STS-XYTERv2.2 ASICs from the pilot production, out of which 550 chips were graded A, the highest quality. Including a new criterion (currently under consideration) limiting the total current after configuration within $\pm\sigma$ from the mean value (min. 0.427, max. 0.478), another three are failing (see gray insert in Fig.2). We can assume that about 5% of STS-XYTERv2.2 chips were failing – a rough estimate. Most of the failures happen already on the level of addressing the chip. In many cases, the test pins are not appropriately

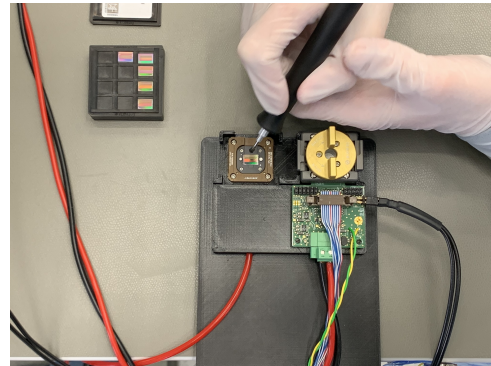


Figure 1: The top view of the new ASIC test box, a 3D-printed ESD holder on an ESD mat.

aligned, and new adjustment is needed simply by removing the pogo pin plug and gently touching the chip before re-connecting the pins. In two cases, the ID fusing procedure failed in the middle. So, the ASIC got an incomplete ID which is not suitable for STS assembly but would be allow using it for any other purpose.

Next steps

The continuous improvement of the software and the current measurement allowed us to save extended report files for about 343 STS-XYTER chips. We can learn more about the ASIC characteristics by analyzing the data. Two of such plots are shown in Figs. 2 and 3. In Fig. 2, we can see a relatively wide distribution of initial current consumption in the undefined state after ASIC power-up, whereas the distribution is relatively narrow after configuration. This shows no correlation between initial and final current consumption. In contrast, the apparent correlation between ASIC temperature and the V_{ddm} voltage is found in Fig. 3. We also propose to improve the measurement procedure by separating all STS-XYTER input currents (1.8 V digital, 1.8 V analog, 1.2 V analog) and stabilizing the voltages by sens wires, which is easily possible using R&S power supplies. In addition, we can also use sens wires to stabilize voltage on-chip and compensate voltage drop on supply wires. We also envision temperature monitoring using an infrared temperature sensor underneath the ASIC, which can also deliver calibration parameters for each individual chip and could be stored in the database alongside ID. The schematic diagram of the improved testing system is shown in Fig. 4, where an almost complete diagram is shown.

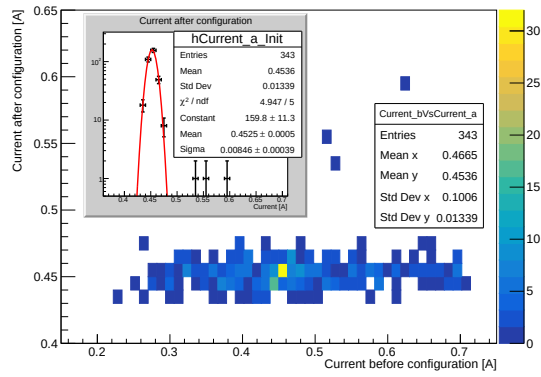


Figure 2: Current consumption after ASIC configuration as a function of initial current dissipation. The gray insert shows the current distribution with Gaussian fit.

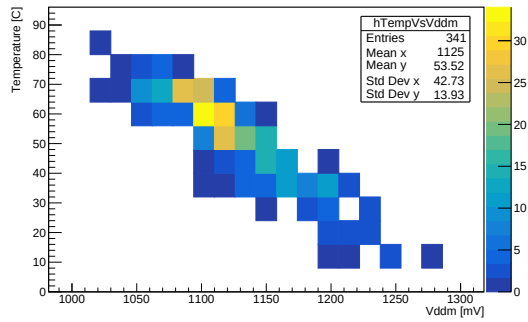


Figure 3: Temperature dependence on the V_{ddm} voltage, measured right before the end of the test.

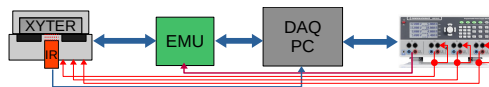


Figure 4: The new, improved STS-XYTER test system is fully computer-controlled.

References

- [1] IPbus, <https://ipbus.web.cern.ch/>
- [2] PyQt5, <https://pypi.org/project/PyQt5/>
- [3] RODE & SCHWARZ (R&S) HMP4040 384W

Comparative study of the noise levels of the STS-XYTERv2.2 ASIC: from FEB-C to STS module

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The latest and final version of the STS-XYTER ASIC, submitted and produced in 2020 Q4 [1], has been thoroughly tested and characterized in the GSI detector laboratory. The ASIC has been also used in the assembly of multiple FEBs-C and modules, which are under operation in the STS laboratory or as part of mSTS detector in the mCBM project [2, 3].

This report summarizes the results of multiple tests, oriented to measure the noise levels in the STS-XYTERv2.2, and to scan a group of user-controlled settings (current on the CSA and shapers, magnitude of the feedback resistor and shaping time), that could influence its overall performance. The studies were carried out in two devices, a FEB-C and a module, labelled 01Tr_3, and consequently in two different setups [4]. The first and simplest setup consists of an ASIC bonded onto a FEB-C, directly connected to a Data Processing Board, implementing the readout protocol. This system allows to measure the characteristics of the analog front-end and to assess the noise levels in a more controlled environment. The second setup is dedicated to the characterization of fully-assembled STS modules [5].

The noise levels are determined on each channel of the ASIC by means of a *s-curves* scan. Although ideally the discriminator response would follow a step function, in reality the distribution is smeared by the electronic noise. The width of the signal distribution is an effective measurement of the overall noise. For an ASIC bonded onto a FEB-C, the measured noise levels are approximately 500 ± 40 e⁻ENC for both polarities. This result is in agreement with the measured values in the version 2.1 of the ASIC [4]. In module 01Tr_3, the noise is reported as the average among all channels to be around 1090 ± 100 e⁻ENC. This result exclude the double-metal interconnected channels of *p-side*, where the noise rises to approximately 1500 ± 80 e⁻ENC.

Figure 1 shows the dependence of the noise in the STS-XYTERv2.2 with the input capacitance. A first order polynomial is used to fit the data, resulting in an average slope of 24.8 e⁻/pF. This simple ENC parametrization allows to estimate the expected noise level in module 01Tr_3 with a relative discrepancy to the measured value of approximately 9%.

Scan of the ASIC parameters

The scan of several parameters in the ASIC intends to check and optimize the operation settings. Figure 2 illustrates the dependence of the overall ENC with the CSA

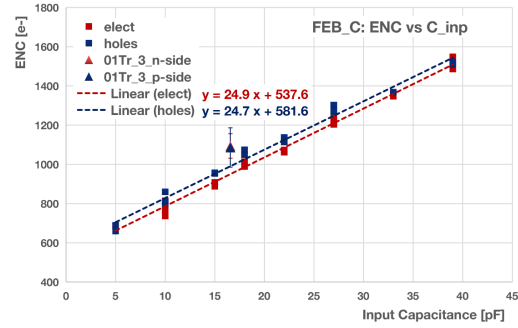


Figure 1: ENC levels in the STS-XYTERv2.2 as a function of the input load capacitance.

and shaper's currents. These two different settings are controlled by independent DACs, but connected to the VDDM potential in the ASIC. A similar behavior in both systems, with no significant variations across the entire scanning range was observed. The overall current consumption of the 1.2 V power line is also indicated.

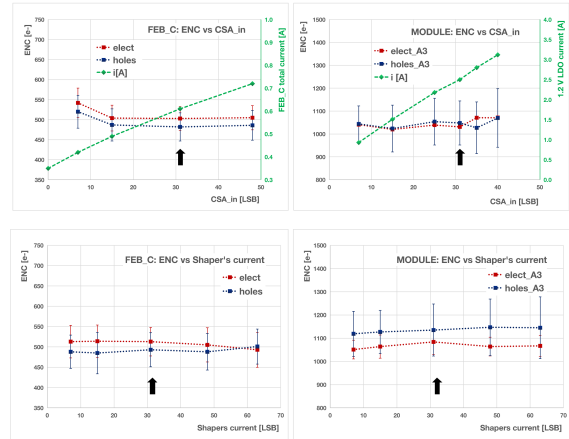


Figure 2: ENC levels as a function of the current on the CSA and the shapers. The black arrow indicates the default operation values.

The feedback resistance determines the time required for the CSA baseline to be restored after a signal is amplified. Therefore, it is a key feature for operating the ASIC in a high rate environment. In an ideal system, the signal amplitude in the CSA should remain constant while the signal is

being processed in the shapers, however, this implies a very large feedback resistance, and hence a large pile up effect. As an alternative, the chip could be operated using a reset circuit that discharges the CSA quickly to the baseline. The last option is also implemented in the STS-XYTER ASIC, but several issues were found during the characterization of the v2.2, that prohibit the use of the fast reset circuit. Nevertheless, the ASIC operation in a high rate scenario is still possible without this functionality, simply by reducing the discharge time constant of the CSA. Consequently, it is important to consider the influence of this parameter in the system noise. Theoretical estimations of the noise contribution suggest that lower feedback resistance ($< 20 M\Omega$) can be responsible for more than 15% of the parallel current noise in the ASIC [6] for non-irradiated sensors.

Figure 3 shows the dependence of the noise as a function of the feedback resistance in the ASIC. Higher register values correspond to a higher feedback resistance, and the typical operating point is marked with a black arrow. It corresponds to a time discharge constant of $1.22 \mu s$ and $2.26 \mu s$ for electrons and holes, respectively. For electrons polarity (n -side), both systems have shown that noise levels are slightly larger at lower feedback resistance (IFED = 7) in comparison to the typical one.

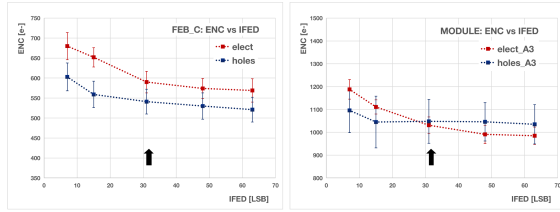


Figure 3: ENC levels for different values of the CSA feedback resistor.

Another design feature of the STS-XYTER ASIC is the user-controlled selection of the shaping times in the amplitude measuring path [7]. This is an important parameter as it dominates the noise bandwidth, and it must accommodate the ASIC response time and the hit rate. Figure 4 illustrates the noise levels measured in both systems. The results show a clear discrepancy between electrons and holes polarity in the FEB-C. In module 01Tr_3, the noise levels show the dominance of the voltage noise component at smaller shaping times ($\tau \approx 90$ ns). To reduce the dead time and pile-up effects, the STS-XYTER ASIC will be operated at the smallest shaping times. This implies, as illustrated in Fig. 4, a slightly larger system noise during the first years of operation of the STS detector. This situation will be reversed as the parallel current noise will dominate the noise distribution, due to larger sensor leakage current after irradiation (shot noise).

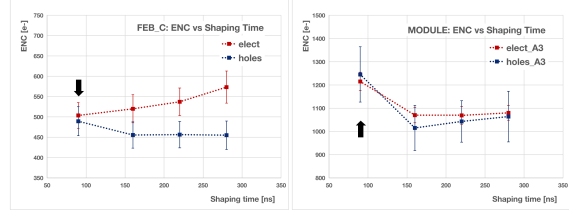


Figure 4: ENC levels in the ASIC for different values of shaping times.

Summary

The test and characterization of the STS-XYTERv2.2 ASIC was an important task carried out during the year 2021. The ASIC was assembled in FEBs-C and modules, that were carefully tested in the GSI detector lab. A large effort was devoted to assess the noise levels of the new chip and to verify its performance as a function of multiple parameters settings. The v2.2 ASIC have shown a similar performance to its predecessor and a stable dependence of the noise with multiple settings. The scans of the CSA and shaper's current have exposed a large and stable plateau, in which the ASIC can be operated without deteriorating the system noise. The selection of the feedback resistance and the shaping time is subjected to several requirements, such as the dead time of the ASIC, pile-up effects, and absolute noise levels. Some of the results described in this study contributed to the approval of the STS-XYTERv2.2 as the final candidate for reading out the double-sided silicon sensors in the STS detector.

References

- [1] C. J. Schmidt, J. Lehnert and K. Kasinski, *New and final ASIC STS-XYTER Version 2.2*, CBM Progress Report 2020, 28
- [2] U. Frankenfeld et. al, *Integration of mSTS Unit 3 and evaluation of ladder operation performance*, CBM Progress Report 2020, 42-43
- [3] A. Toia et al., *Performance studies of prototype STS modules*, CBM Progress Report 2020, 44-47
- [4] O. Maragoto Rodriguez et al., *Test of the STS-XYTERv2.1 ASIC*, CBM Progress Report 2019, 21
- [5] O. Maragoto Rodriguez et al., *Test and characterization of fully assembled STS modules*, CBM Progress Report 2020, 36
- [6] W. Zubrzycka and K. Kasinski, *Noise considerations for the STS/MUCH readout ASIC*, CBM Progress Report 2017, 32
- [7] K. Kasinski et. al, *SMX2 and SMX2.0, 2.1, 2.2 Manual* (2021)

Power cycle test of STS front-end electronics boards FEB8

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Description

We have tested extensively power cycling of two fully equipped STS front-end electronics boards, one of each type FEB8-LNRP (“FEB-A”) and FEB8-LPRN (“FEB-B”), see Fig. 1. The boards were without microcables, i.e. bare STS-XYTER ASICs installed in it, and passively air-cooled with a fan down to room temperature.

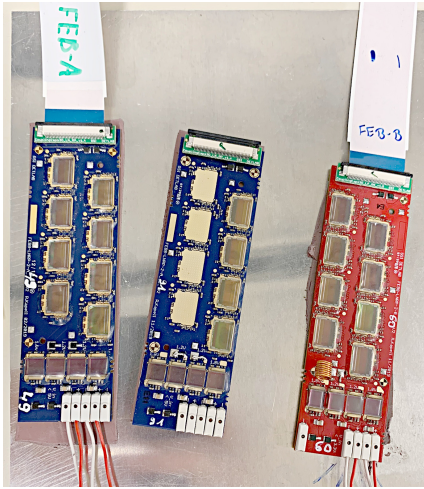


Figure 1: FEB8-LNRP (FEB-A, blue) and FEB8-LPRN (FEB-B, red) thermally coupled to the aluminum heat sink.

Figure 2 top shows temperatures monitored during the cycles. Figure 4 top shows the temperature stability over one month period, and Fig.5 left shows the distribution of temperature. The FEB8 boards were powered up for 2 minutes and powered down for 1 minute. To switch on and off the FEB8 boards, the ROHDE & SCHWARZ HMP4040 [1] four-channel programmable power supply has been used. During the power cycling test, the powering of electronics has been done by switching relay. The first current measurement was done right after switching on, the second measurement right after the STS-XYTER chips were initialized, and the third before switching off, at the end of the cycle. The typical current behavior is shown in Fig. 3. The power supply stabilized the voltage, so it is not changing within 0.1 Volt. The current was varied by about 0.2 A from cycle to cycle for both power supply lines. Unfortunately, because a common supply powered all 8 STS-XYTER chips, it is not possible to find how it depended on the chip’s internal parameters. Thus, it may be valuable to repeat this test with a FEB-C (single-STX-XYTER test board) for a more profound understanding.

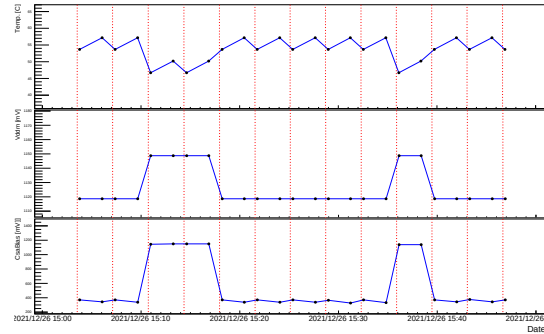


Figure 2: Zoomed graphs of the temperature (top), V_{ddm} (1.2 V analog, middle), and $CsaBias$ (amplifier bias, bottom). Twelve cycles are shown of FEB8-LPRN (FEB-B) with STS-XYTERv2.2 chips. The red dashed lines show the beginning of each cycle. The first measurement after cycle start is done right after chip initialization, and the second within the cycle is always done before powering off.

Summary

From December 23, 2021, to January 27, 2022, we carried out 15 000 cycles and analyzed 13 946. In general, we can conclude that all the current consumption for both FEBs and all parameters gathered from STS-XYTER chips were very stable. Figure 4 shows temperature, V_{ddm} , and $CsaBias$ graphs over one month period. One should mention here that most of the chips had two or three discrete values of $CsaBias$ after powering up and initialization. This is seen in Fig. 5, too. A similar type of test needs to be done for cold environments, too, where we can power-cycle FEBs in the climate chamber, available in the STS integration laboratory, at temperatures as low as -40°C . This program is upcoming.

References

- [1] RODE & SCHWARZ (R&S) HMP4040 384W
- [2] IPbus, <https://ipbus.web.cern.ch>

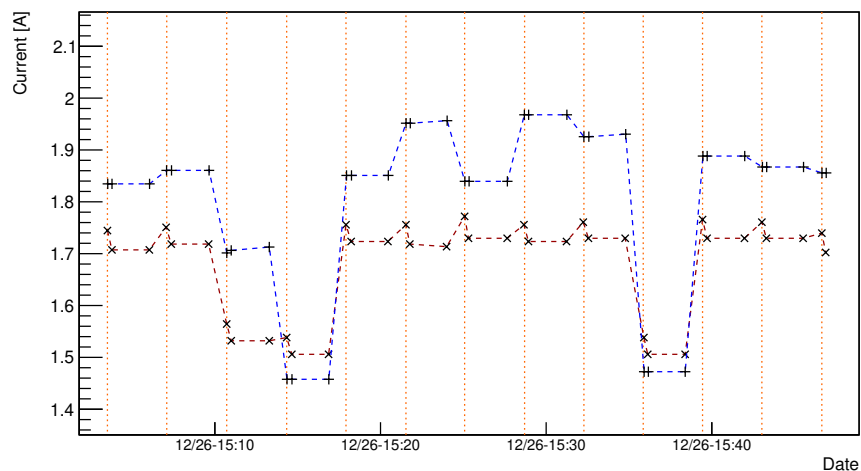


Figure 3: Twelve cycles of the powering on/off are shown for FEB8-LPRN (FEB-B) with 8 STS-XYTERv2.2 chips. The first measurement is right after powering on, while second is after initialization and third before powering off.

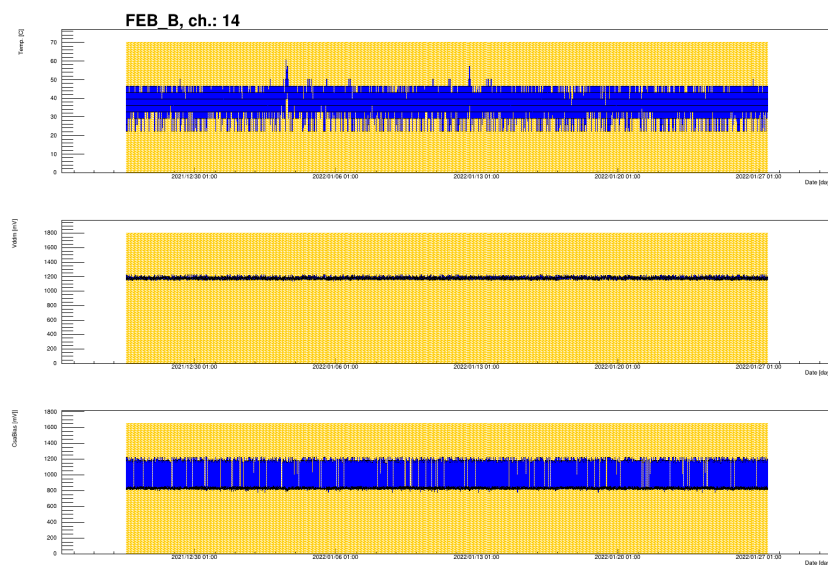


Figure 4: The graphs of temperature (top), $Vddm$ (middle), and $CsaBias$ (bottom) are shown over one month period. The general trend shows relatively stable behavior and sustained parameters over 15 000 cycles.

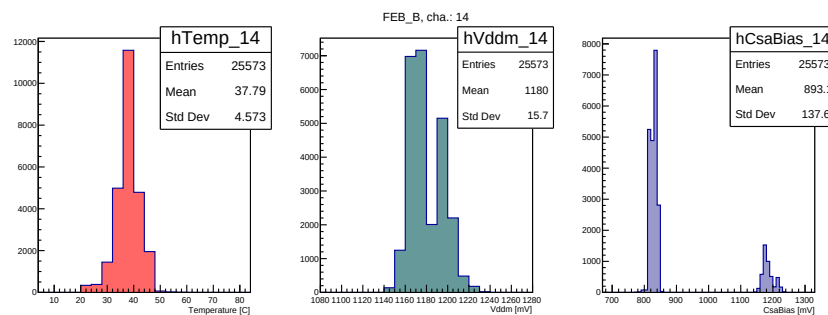


Figure 5: Distributions of temperature (left), $Vddm$ (middle), and $CsaBias$ (right) measured twice for each powering cycle.

Production capability upgrade for STS module assembly at GSI

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Infrastructure upgrades

The GSI Detector Laboratory has upgraded its infrastructure for STS-module-assembly in recent time. A impression of the clean room section is seen in the photograph of Fig. 1. Mainly two additional wire bonders were acquired and put in place. All in all there are now four machines that can be used for wire and TAB bonding. They are shown in the photographs of Figs. 2 - 4. Three microscope tables can be used during die bonding of ASICs, removing of microcable test fans, for different glueing and soldering works and process controls (Fig. 5). One table is prepared for heat and UV curing of glue applied (Fig. 6). Circuit boards for the front-end electronics are surface cleaned at a dedicated place (Fig. 7). A further table is equipped for the QA measurements (Fig. 8); a second setup is in preparation. For the storage of the completed modules a nitrogen cabinet and two ESD system trolleys are available (Fig. 9).

Production throughput

The production throughput was assessed in 2020 in a project team retreat focussed on STS module assembly and has been documented in [1]. Scaling up from prototype assembly, the throughput could be up to 8 modules per month managed by a single team and machine set, and reaching up to 28 modules per month if more machines and a second team would be engaged. The additional machines are available by now. At present a team of three well-trained persons is ready to carry out the assembly task. A second team is being established.

References

- [1] The STS Workgroup *STS Module and Ladder Assembly*, Technical Note CBM-TN-20004 (2020)



Figure 1: Module assembly section in the clean room of the Detector Laboratory.



Figure 2: F&K Delvotec M17L and M17S.



Figure 3: F&K Delvotec G5 TAB bonder.



Figure 4: F&K Delvotec G5 wire bonder.



Figure 5: Microscope table.

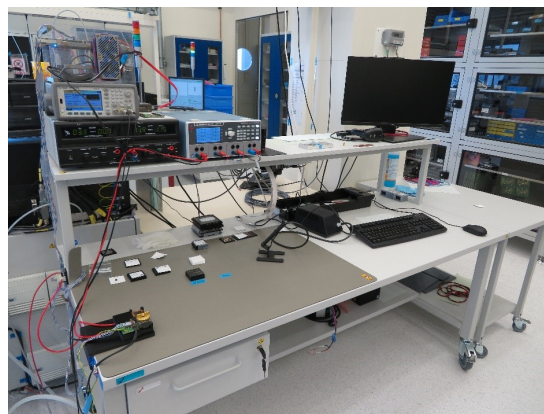


Figure 8: QA measurement.

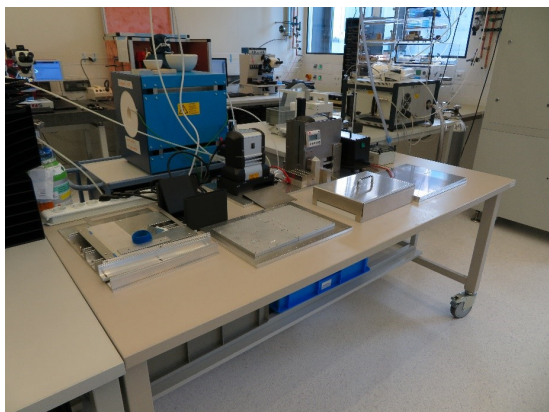


Figure 6: UV and heat curing.



Figure 7: FEB cleaning.



Figure 9: Module storage.

Towards STS module production readiness at KIT

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The Karlsruhe Institute of Technology (KIT) is one of the production centers for the STS detector modules for the CBM experiment. KIT's task will be the assembly of about one-third of the modules for the detector, summing up to 500 modules comprising 500 sensors, 1000 front-end read-out boards, 4000 STS-XYTER read-out chips, and 8000 aluminum micro-cables. The production order has been changed in close agreement with the production scheme implemented at the GSI's detector lab. First, the STS-XYTER ASICs are tab-bonded to the micro-cables and electrically tested. The test results are transferred to the ELOG-database system that logs the QA information for each module and its components like the chip cable ID, the module ID, and others. The cleaning process, which is done in parallel to the production of the chip cable wires has been optimized. After cleaning the FEBs in a Vigon US solution two water rinsing steps follow. The first rinsing step is done in clean water followed by a second step in de-ionized (DI) water. Measurement equipment to check the ion contents in the clean- and DI water baths have been installed and successfully applied. Additionally, the cleaning room has been set up for FEB-cleaning during the production. Next to the tab-bonding machine, a second ultrasound bonder was installed to reduce the production time to complete the modules. This wire bonder is used for wire bonding of the LDO and STS-XYTER chips.

Automated LDO attachment and glue application

After cleaning the FEBs, the LDOs will be mounted automatically with high precision onto the FEB using an automated die-bonder. The FEBs will be attached to the PCB by a silver-epoxy glue curing at low temperatures of about 80°C. However, the glue application process is difficult to automate as the glue's viscosity quickly changes during the gluing process. We evaluated various dispensing technologies: automated glue dispensing utilizing pressurized air and vacuum as well as nanoliter dispensing with a stepper motor system. The results of both processes were not convincing. Therefore, to mitigate the effects of the changing viscosity we designed a step-stencil to apply the glue by a classical stencil print process. Figure 1 shows the step stencil for the FEB 8-2 version 2 and a zoomed-in area of the stencil (marked in red). Before printing the glue the stencil will be rotated by 80°. The glue is pressed through the "star opening" and forms homogeneously and repeatable layer thickness and therefore, a well-defined amount of glue. The step stencil allows us to print the glue directly

onto the STS-XYTER pads although the passive components like the 0402 and 0201 capacitors are already assembled on the FEB.



Figure 1: Step stencil and zoomed-in section.

Module test setup at KIT

The test setup for the quality control has been partially installed at KIT. Currently, we can perform the FEB-test with attached STS-XYTER chip cables. Additionally, the electronics and cooling devices for the module test are available. As the new module test box is not fully completed yet, we currently cannot run the module test. However, we produced two sets of module carriers (see Fig. 2) that will be integrated into the module test box.



Figure 2: Two module carriers prepared to be equipped with signal distribution boards.

Overview of quality assurance and control during STS module assembly

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Test stands for components and compounds

The list of electrical tests, to be performed during module assembly, is related to the prior steps of module assembly. Therefore also the sequence of module assembly steps has to be taken into account. The parameters of the individual components or compounds to be measured during Quality Assurance / Quality Control (QA/QC) is discussed between the Quality Management and the experts in charge, with direct influence on the output file contents as well as on the corresponding database schemes.

The following components or compounds will be tested with final QC or QA decision to be taken after data taking:

- *STS-XYTER ASIC*: Compared to the QC of the STS-XYTER ASICs performed at AGH on the wafer level [1], the QC of the ASICs performed at GSI is a staggered process over several test stands and measurements until the whole data set of one STS-XYTER ASIC is completed. The first measurement of this chain will be performed by using the same pogopin test socket as to be used for testing of the chipcables.
- The cleaned *FEB8-PCBs assembled with LDOs* will be electrically tested in the FEB8 test box. Depending on the test results of this *FEB8 test*, the FEB8 will be used for further production steps of module assembly or will be rejected.
- Two microcables are bonded to one STS-XYTER ASIC to create the first compound of the production process: The *Chipcable*. This compound could be tested in two different ways:
 - (1) The basic electrical test of bond connections between the microcables and the STS-XYTER ASIC via the test fan of the microcables (*Chipcable Connectivity Test via Testfan*; acronym: *CCTvT*). The eFused ID of the chip is not read out during this test. The test setup uses a special test socket and a microcontroller readout. Each chipcable will be measured twice to check the bond connection of each microcable assembled. The measurements will be performed before any kind of gloptop is applied, to enable possibly necessary rework of problematic bond connections.
 - (2) The electrical test of some further STS-XYTER ASIC parameters and testing of the bond connections between the microcables and the STS-XYTER ASIC. The setup of the STS-XYTER ASIC test setup including a pogopin test socket is used. With this test, the eFused ID of the STS-XYTER ASIC as part of the chipcable is read out the first

time. The test will only be performed once after both microcables are assembled, the test fans have been cut away and the gloptop was applied already. The naming of this test has been chosen similarly to the CCTvT naming. It is called: *Chipcable Connectivity Test via PogoPin* (acronym: *CCTvPP*).

- To ensure proper data separation between both setups possibly used for testing the same chipcable, both acronyms are used in the corresponding QA class of the chipcable database scheme.
- The QC passed chipcables will be bonded to the already QC passed FEB8 PCBs. This process creates the second compound of the module assembly production process: The *Chipcable-FEB8 compound* (acronym: *CCFEB*). The bond connections will be tested during the *CCFEB test* subsequently on each of the two rows of chipcables to be assembled. At that testing stage the correlation between chipcable-ID and hardware address of the corresponding STS-XYTER ASICs on the FEB8 takes place the first time.
- The electrical test of the sensor tab bonding to CCFEBs. To perform this test the software of the “Fast connectivity test of modules” [2] will be used. The hardware setup is currently under development/adoption. The taken data from this measurement are the first data of a nearly completed module (shielding and cooling T-shelf excluded) and will be stored in the module related database scheme.

Summary

All test stands received their naming based on discussions with the related component/compound experts. It figured out, that communication between the assembly sites could be streamlined and precised by usage of this common convention. The list of test stands and their namings was distributed first in May 2021 and updated in December 2021 [3].

References

- [1] K. Kasinski et al., *Wafer-Level Testing Plan V.0.1*, <https://redmine.cbm.gsi.de/projects/sts-xyter/documents> (2019)
- [2] B. Schmitt, A. Wilms, and C. J. Schmidt, *Fast connectivity test of modules*, this report (2022)
- [3] A. Wilms, *QA/QC test setups for electronics in the clean-room*, <https://redmine.cbm.gsi.de/projects/module-assembly-qa-test-setups/documents> (2021)

Fast connectivity test during STS module assembly

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The fast module connectivity test is a software used to ensure the quality of compound connections build at different steps of the module assembly. The sensor specific implementation as well as a more elaborate analysis algorithm were developed as part of a bachelor thesis written at the GSI detector laboratory in late summer of 2021 [1]. The main reason for its development is to detect possibly defective tab bond connections between readout cable and silicon sensor assembled in the last steps of the module assembly as early as possible. The software is based on the already existing module test software.

Test setup

The test setup contains a common desktop PC as main control unit with the developed software installed and a GBTxEmulator board. The communication is done via an already existing software installed on the desktop PC utilizing the GBTxEmulator board as a communication interface for the (partially assembled) module under test. Further a shielding box was used. The shielding box is necessary to shield the module under test from electromagnetic interference of the environment. Additionally a sheet of ESD paper between the module and the box is used. An image of the module part of the test setup is shown in Fig. 1.

Test procedure

The whole test can be split up into three main parts. The data generation using the module under test, the data processing and final data analysis on the PC.

Data generation

The data generation uses the discriminators located behind the slow shaper part of the STS-XYTER read-out chip¹ [2]. Over multiple iterations these discriminators count the number of threshold crossings for their respective threshold (further called *counts*). After each iteration the GBTx board reads the data from all STS-XYTER and sends it to the PC where it is added and stored for further analysis. These data are provided to the GBTx board and added to one sum per discriminator. After the generation is finished the data are sent to the PC and persistently stored for further analysis.

¹further information under <https://redmine.cbm.gsi.de/documents/106>

Data processing

Noise measurements are influenced by a variety of different factors both internal (e.g. position of channel under test on the microcable or length of microcable) and external (e.g. running lab equipment) changing even within a test procedure. Therefore the use of pre-defined fixed thresholds as intended for the data analysis is not directly possible. The data processing step is therefore mandatory to refine the data for subsequent analysis. The main reference value of each channel is determined as an average over multiple of its neighbouring channel counts and the count of the channel under investigation itself. Single defective channels - and their low noise count - would have huge impact to the reference value and could mask out possibly defective channels. Therefore counts deviating too much from the previous count or count values smaller than a calculated threshold are excluded from further reference value calculation and replaced by the average value of the previous and next accepted channel count.

Data analysis

With the reference values calculated as an input, the main data analysis can be performed. First a rolling average over a maximum of 9 channels (the reference channel and the next 4 channels below and above) is calculated - if applicable the previously calculated replacement value is used instead of the original count. Afterwards the percentual deviation from the original count to the reference value is calculated for each channel and channels with counts exceeding a certain threshold are marked as defective. Figure 2 shows results for one STS-XYTER chip assembled with two microcables.

Acknowledgements

We would like to thank J. Lehnert and A. Rodriguez Rodriguez (GSI) for their help with the technical specifications and the GBTxEmulator components.

References

- [1] B. Schmitt, *Entwicklung und Aufbau eines Test-Setups für QA-Messungen während des Zusammenbaus von Siliziumstreifen-Sensormodulen des CBM-STs*, Bachelor Thesis, Hochschule Darmstadt (2021)
- [2] K. Kasinski et al., *Characterization of the STS/MUCH-XYTER2, a 128-channel time and amplitude measurement IC for gas and silicon microstrip sensors*, NIM A 908 (2018), 225-235



Figure 1: Part of the setup including the module, the shielding box, a cooling plate and necessary electronics for the read-out.

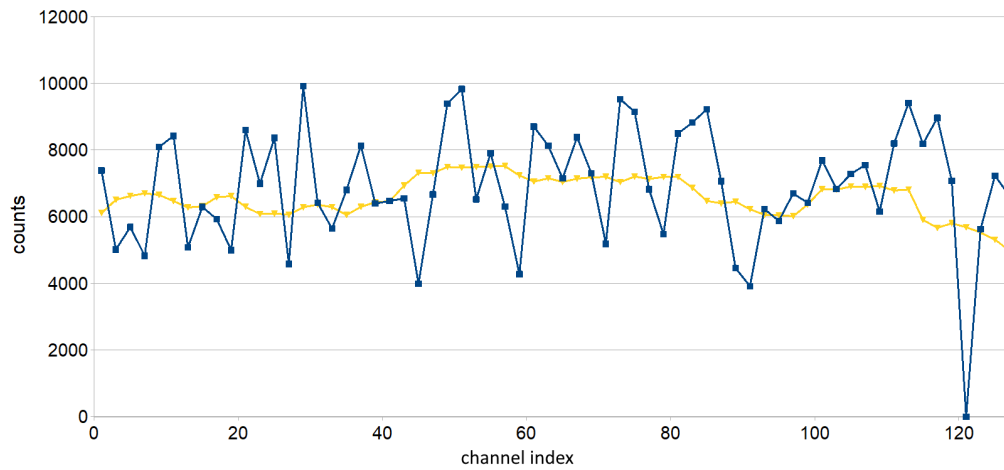


Figure 2: Channel counts (*blue*) and reference values (*yellow*) for each channel of one microcable of the chipcable under investigation, indicating one broken channel at index 120.

Connectivity test of STS chip-cables via test fan

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The chip-cable connectivity test via testfan (CCTvT [1]) is a tool used to test the connectivity between a microcable and one STS-XYTER ASIC after the bonding process. The tool consists of two parts, a hardware and a software part and is used after each bonding process of the two microcables used to assemble one chip-cable. The first version of the tool was introduced in March 2021 and is currently in its third major release-version. The most up-to-date version can be found in the CBM git code repository [2].

Hardware

The hardware part consists of a microcontroller with a multiplexer and a hardware socket connecting to the bondpads located on the microcable testfan. The microcontroller is used to measure the current of every single trace and the resistance between pairs of neighbouring channels.

Software

The software part is installed on a regular PC and connected via a standard USB cable to the microcontroller. It is used to start the test procedure on the microcontroller, receive the test data and perform the analysis on it. Finally the defective channels are displayed to the operator and saved for further use and documentation purposes. Additionally for advanced users a detailed view on the raw data is accessible.

Test procedure

In this section the data generation with the microcontroller and the data analysis on the PC are described in detail.

Data generation

The data generation is started via the PC software and performed by the microcontroller. The data generation is split into two parts, the resistance measurement between neighbouring channels and the per channel current measurement. The first is used to detect possibly existing electric shorts between the channels, the second is used to detect possibly existing broken channels. The measured data are sent via the USB connection back to the PC and analysed by the software subsequently.

Data analysis

The analysis is done similarly for the resistance as well as for current data. The data points are compared with pre-

defined limits and categorized respectively. To find defective channels the respective datapoints (two resistance values to the neighbouring channels and one current value for the trace under test) are checked against a predefined set of rules to locate defective channels.

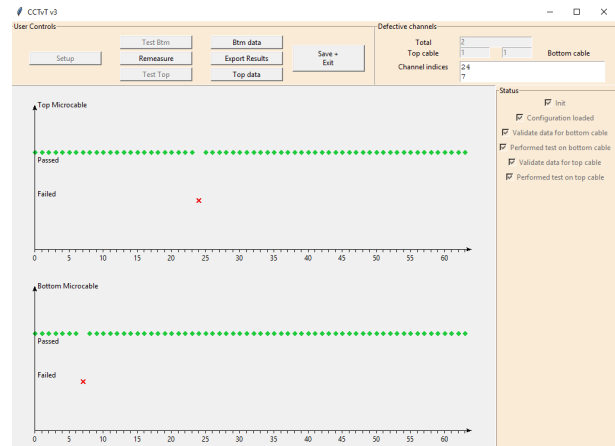


Figure 1: The PC software front-end with dummy test results showing different possible results.

References

- [1] A. Wilms et al., *Overview of quality assurance and control during module assembly*, this report
- [2] <https://git.cbm.gsi.de/sts-qm-software-group/cctvt>

Status report on micro-cable production for the Silicon Tracking System

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Micro-cables

The CBM-STs analogue sensor readout cables are designed and manufactured as documented in reference [1]. The corresponding production readiness review took place in May 2021 [2]. For each module, a micro-cable set is required which comprises 8 different types of cables, 4 of each type. A cable has 64 signal leads each. A set also comprises two layers for ASIC-shielding as well as two layers of general module shielding. One essential ingredient to successful production and further processing of cables, is the employment of high precision masks with a resolution of at least 16 000 DPI, which allow for the reliable production of traces, with width and spacing down to 20 $\mu\text{m}/96 \mu\text{m}$ and free standing Aluminum bond traces of 45 μm width for TAB-bonding.

Production 2019 - 2021

Until now the micro-cables were produced through a frame contract with the Ukrainian company *Research and Production Enterprise “LTU”*. During the process of finalizing the STS design, the nominal lengths of module cable sets could be fixed starting from unit 0 towards unit 8, leaving out the central ladders which have cutouts for the beam pipe. The reason for this particular order of freezing designs are the remaining uncertainties in the final design of the beam pipe and the corresponding ladder designs for the central ladders. Similarly, there are still uncertainties on the detailed design of unit 8 which may still have implications on the lengths of modules in this unit.

During the years 2019, 2020 and 2021, an overall of 520 sets of micro-cables (spar- cable sets excluded) with a total of 147 different nominal lengths between 160.7 mm and 483.7 mm have been produced and delivered to the CBM-STs team at GSI, which amount to nearly 60% of the full amount. For nearly each length, a high precision lithographic mask was designed, printed, and delivered to LTU. The complete CBM-STs will be assembled out of 876 modules and correspondingly, the same number of micro-cable sets. Figure 1 indicates the full spectrum of nominal cable lengths.

Modified shielding layers

During the beam time activities for mCBM at SIS-18 it became apparent that the design of the module shielding layers was still too simple. The shielding layers were cut out of a laminate of polyimide coated Aluminum foil

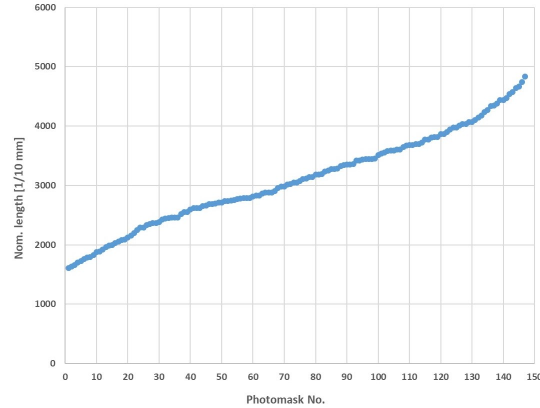


Figure 1: Type of photomask with respect to the micro-cable nominal lengths.

and a 160 μm thick Foamtak-II spacer layer of polystyrene foam. When integrating several modules and their corresponding cable stacks onto a ladder, the bare metal edges of this cut laminate resulted to frequently cause electrical shorts between the shielding potentials of neighbouring modules. To prevent this in forthcoming assembly, the design of the shielding layers was modified. The Aluminum layer is now somewhat recessed with respect to the polyimide edge. After lamination of the shielding layer to the Foamtak-II spacer layer, the aluminum edge then results to be entirely enclosed in the formed sandwich. In addition, the P-side shielding layer is recessed further by 500 μm than the N-side shielding layer. Functionality of this shielding design is yet to be verified in practice.

References

- [1] V. Borshchov et al., CBM Technical Note CBM-TN-20003, *Micro-Cables for the CBM-STs Detector Modules*, v22, 16 December 2021
- [2] J. M. Heuser, C. J. Schmidt, A. Wilms et al., *STS Micro-Cable PRR: Questions and Answers*, CBM Technical Note CBM-TN-21002, 4 May 2021

* corresponding author

Electrical tests performed for STS modules produced at KIT

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The assembly of STS modules is a crucial step towards the realization of the final detector. Multiple efforts, hardware and software oriented, aim to establish a well-defined and reliable procedure for producing and testing modules [1]. The Karlsruhe Institute of Technology (KIT) is one of the production centers for the STS detector modules. KIT is expected to assemble one third of the total number of STS modules, and to perform all checks during the production phase [2].

With the purpose of practicing the assembly steps and to identify possible flaws in the working flow, the KIT team prepared a total of 5 modules during the year 2021. The modules were built using the latest existing version of voltage regulators (LDO), front-end boards (FEB version 2.0) and microcables. Fully functional STS-XYTERv2.1 ASICs and silicon sensors were also used. The fully assembled modules were brought to GSI for checking and later on to be used in the assembly of a demonstrator ladder. This report summarizes some of the most significant electrical tests performed on the modules.

Electrical tests

Initially, the modules were visually inspected, in search for possible damages that could occur during transportation. No issues were found or reported, and therefore, the modules were moved to the next testing phase. Each module was powered on, output voltages and current consumption for each LDO on the FEBs were measured in a dedicated setup. This check allowed to identify assembly issues, electrical shorts and malfunctioning components on the FEBs. Results are shown for each individual module in Table 1. Some of the most crucial issues were related to electrical shorts from the LDOs output to the ground through the silver-conductive glue, and low or almost none current drawn by the regulators. Only the module M03 was graded positively in both FEBs, and therefore, accepted for the next testing steps.

Performance of module M03

The module M03 was further characterized in the test-box, where several parameters including basic chip communication, read/write configurations, ASIC ID read out, VDDM monitoring, and current consumption were assessed [3]. The sensor was biased asymmetrically at 150 V, drawing a leakage current of $9.6 \mu A$. Communication was possible with 12 ASICs out of 16 of the module. The

Table 1: Summary of electrical tests.

LDO status output voltage (Volt) and current consumption (i)						
Module ID	Side	AVDD	VDDM1	VDDM2	VDD	QA
M00	N	Volt, i OK	Short to GND	Not bonded	Not bonded	FAIL
	P	Volt, i OK	OK	OK	OK	PASS
M01	N	Volt, i OK	OK	OK	OK	PASS
	P	Volt, i OK	OK	OK	V = 0, Shut	FAIL
M02	N	Volt OK, i = 0	Volt OK, i = 0	Volt OK, i = 0	Volt OK, i = 0	FAIL
	P	Volt, i OK	Volt NOT OK	Volt NOT OK	Volt = 0	FAIL
M03	N	Volt, i OK	OK	OK	OK	PASS
	P	Volt, i OK	OK	OK	OK	PASS
M04	N	Short to GND	Volt OK, i = 0.24 A (NOT OK)	OK	OK	FAIL
	P	Volt, i OK	OK	OK	OK	PASS

missing chips were all located in a single row of the FEB8-LPRN (B), in charge of reading out the *p-side* of the sensor.

Another essential parameter for good module performance is the overall channel yield. The number of broken channels, extracted from 12 working ASICs, was 48, distributed as 32 out of 1024 for *n-side* and 16 out of 512 for *p-side*, respectively. Two large clusters, composed of 12 channels each, were located at the corners of ASIC 2 and 4 of *n-side*. These could be associated with two important process during the handling of the chipcables: the cutting of the technological zone of the microcables or the wire bonding of the chipcable to the FEB8.

Monitoring of the VDDM potential in M03

Figure 1 illustrates the current drawn by the 1.2 V power domain in the FEBs. Every point was measured after specific CSA current values were set on the ASICs (the accessible ones). The large offset observed for the *p-side* is due to four chips can not be configured properly.

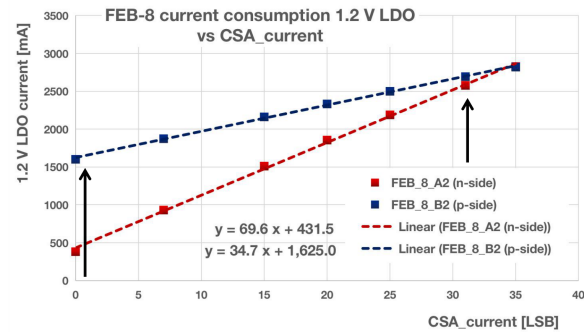


Figure 1: Total current drawn by 1.2 V LDOs on each side of M03.

Figure 2 illustrates the current drawn by the 1.2 V LDOs after a sequential power of the *n-side* ASICs. In the initial state, the CSA current was set to minimum in all ASICs, then sequentially configured at CSA = 31. The overall current shows the expected linear behavior with no difference among the chips. The slope of the linear regression, used to fit the data, is a measure of the current drawn by each ASIC in the 1.2 V power domain. From this result, it is possible to estimate the channels current to a value of 2.14 mA, which is in agreement with the designed parameter (2 mA/ch) of the ASIC [4].

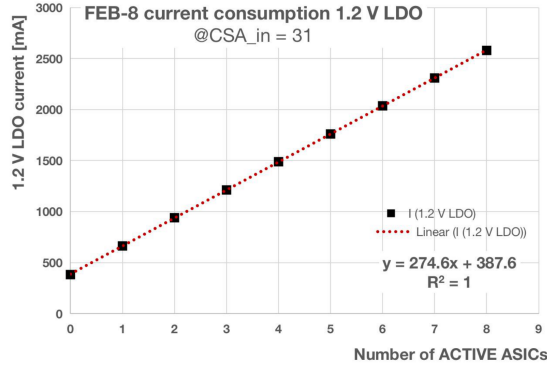


Figure 2: Total current drawn by 1.2 V LDOs of the *n-side* in M03.

Another important test performed in the module M03 was the monitoring of VDDM potential, which determines the proper functioning of the CSA [4]. The proper operating values of this potential are expected to oscillate around 1200 mV. Figure 3 shows the scanned VDDM values as a function of the CSA current in all chips of the module M03 *n-side*. The values are read out via the diagnostic circuit implemented on each ASIC, and they corresponds to a large range of CSA operating currents, being CSA = 31 the typical or reference value. Despite the imminent offset fluctuations among all ASICs, a linear dependence of the potential with the CSA current can be observed.

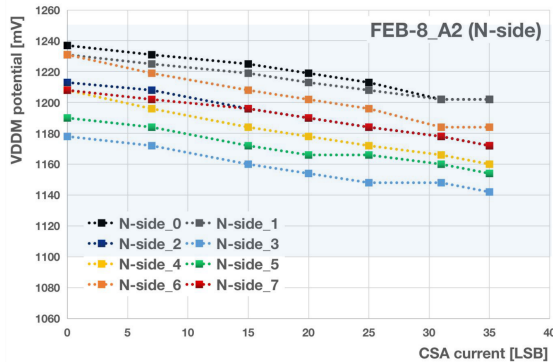


Figure 3: VDDM potential monitored on the *n-side* of M03.

Summary

The production of five new modules, built with close to final components by the KIT assembly team, can be considered as an essential learning step to achieve the expected yield. The testing of these objects has shown important details to improve during the assembly procedure. Module M03 was further characterized in the test box, where 12 out of 16 ASICs proved as functional. ASIC registers configuration and ID readout were initially checked, showing no corrupted bits on the operational ASICs. In addition, M03 was also used to monitor the power consumption in the FEB8 and the dependence of the VDDM potential with the CSA current. These tests allowed to assess the VDDM current drawn by a single channel, resulting in an overall discrepancy of 7% with the design value. This result can be considered in agreement with the expectations.

References

- [1] C. Simons et. al, *Status of STS module assembly at GSI*, CBM Progress Report 2020, 32
- [2] T. Blank et. al, *Setting up STS module production at KIT*, CBM Progress Report 2020, 34
- [3] O. Maragoto Rodriguez et al., *Test and characterization of fully assembled STS modules*, CBM Progress Report 2020, 36
- [4] K. Kasinski et. al, *SMX2 and SMX2.0, 2.1, 2.2 Manual* (2021)

Characterization of the first fully-assembled STS module with Cu micro cables

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During the last years, the KIT IPE laboratory was developing an alternative high-density interconnection technology based on copper microcables, that could be used in the assembly of STS modules. The development of a custom-designed machine and assembly protocol laid the foundations for producing the first full-scale detector module, hereafter called Cu.KIT.202. Figure 1 shows a picture of the module, which was built from a 62 mm × 22 mm CiS sensor, 16 microcables with a length of 20 cm, 16 STS-XYTER2.1 readout ASICs, and two FEBs-8. The FEBs-8 were equipped with the latest version of the SCL LDOs for providing the ASIC operating voltages of 1.2 and 1.8 V.

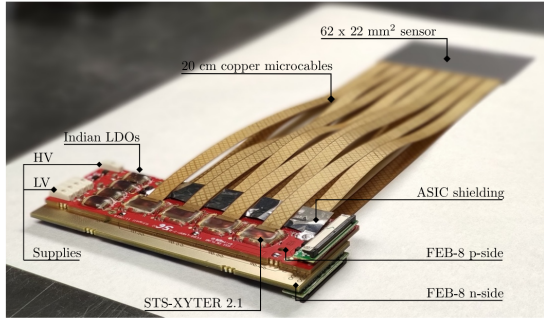


Figure 1: Complete STS detector module in copper technology before application of microcable shielding.

After assembly at KIT, the module was brought to the STS detector laboratory at GSI for testing characterization. The module was installed in the so-called test-box, which provides the cooling, low and high voltage interfaces for operation. Figure 2 shows the measured ENC levels of all channels on the *n*- and *p*-side, measured at a symmetric bias voltage of 150 V. ASICs 1 and 7 of the *p*-side are non-functional due to problems in the wire bonding process. Channels without a proper analog response are set to zero. Neglecting the z-strips on the *p*-side, as well as dead and overly noisy channels, the average ENC levels on the *n*- and *p*-side are 670 e⁻ and 590 e⁻, respectively.

The 62 mm × 22 mm sensor has a total of 42 z-strips on the *p*-side, which are connected via a second metalization layer to form full-length strips. The additional capacitance, introduced by the second metalization layer, almost doubles the noise level of channels 0-41. Also shown in Fig. 2 are the expected ENC levels based on the ASIC load capacitance parametrization. It can be observed that the majority of unconnected channels (48 out of 70) is located on ASICs 4 and 6 on the *p*-side. They are found to be clustered on the

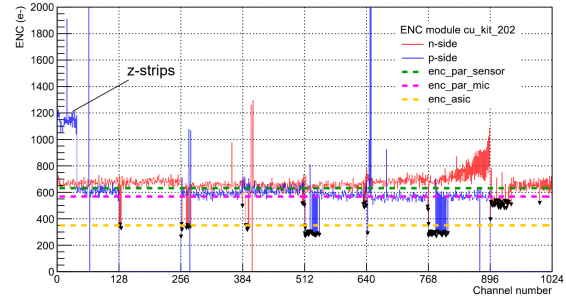


Figure 2: ENC as a function of channel number of the copper module Cu.KIT.202. ASICs 1 and 7 on the *p*-side are non-functional.

lower end of channels, respectively, indicating a slight tilt between microcable and ASIC, or insufficient solder deposition on this end of the cable. The calculated channel yields are 97.4% and 92.1% for the *n*- and *p*-side, respectively, resulting in an overall channel yield of 95.1% for the module.

Figure 3 shows the ADC threshold distribution at calibration. The difference in threshold between the *n*- and *p*-side is less than 1%. The ADC gain distributions reveal a good uniformity with a gain of 0.112 ± 0.002 fC/LSB and 0.112 ± 0.001 fC/LSB for the *n*- and *p*-side, respectively.

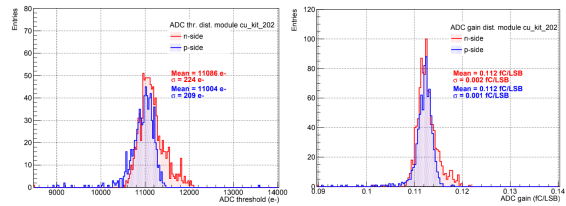


Figure 3: ADC threshold and ADC gain distribution over all channels of the module.

After having assured a good module performance with the help of the ENC measurements, a symmetric bias voltage scan was performed between 40 V to 350 V for ASICs 2 and 3 of the *p*-side and ASICs 4 and 5 of the *n*-side. The ENC-bias voltage curve for all four ASICs is presented in Fig. 4. The data points represent the ENC averaged over all channels of the ASIC while the error bars indicate the channel spread. The sensor depletion is well reconstructed on the *n*-side channels. When increasing the reverse bias voltage starting from 0 V, the depletion zone expands from

the *p-side* towards the *n-side*. At the lowest data point at 40 V, the region surrounding the *p-side* implants is already depleted, hence the ENC values stay completely flat on the *p-side*. Looking at the *n-side* curve, full depletion appears to be reached in between 80 V to 100 V, in agreement with expectations.

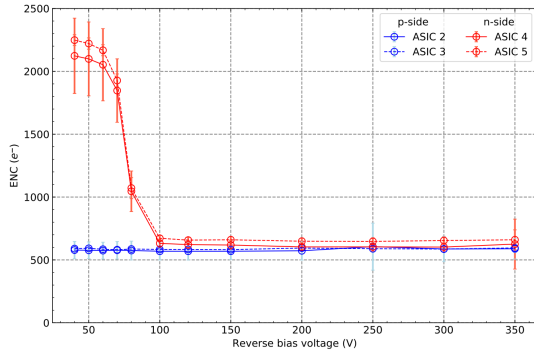


Figure 4: ENC-bias voltage characteristics shown for four selected ASICs of the copper module.

In order to determine the absolute value of the signal size that allows us to calculate the signal-to-noise-ratio of the copper module, measurements with an ^{241}Am radioactive source have been performed. The measurements have been conducted at various ADC threshold levels of $V_{\text{Ref.T}} = 48$ up to $V_{\text{Ref.T}} = 52$, corresponding to 6970, 5600, and 4250 e^- , respectively. The measured energy spectra are shown in Fig. 5 for ASIC 13 (*n-side*), where it can be observed that the 59.5 keV γ -peak is well reconstructed. Since the ADC measures the signal above threshold, the peak position moves to larger values with decreasing threshold. Due to increasing noise pick-up, the peak broadens slightly towards lower threshold values. A Gaussian fit to the measured spectra results in peak positions of 11.50, 13.40, and 15.65 ADC units, respectively. These values can be expressed in electrons using the ADC transfer function, yielding an average signal of the three measurements of 14649 e^- . Finally, the signal-to-noise ratio can be calculated as $\text{SNR} = 14649 e^- / 670 e^- \simeq 22$.

Comparison of aluminium and copper module technologies

A direct, quantitative comparison of noise levels between the copper module Cu_KIT_202 and a module built with aluminium microcables is not possible, because the combination of microcable length and sensor size used in module Cu_KIT_202 does not exist in the final STS detector. However, comparing the measured noise levels with the expected ones for non-irradiated modules in both technologies, respectively, reveals a consistent picture. It can be concluded that with regard to the noise behavior, the slightly increased capacitance of the copper microcable clearly is no show stopper.

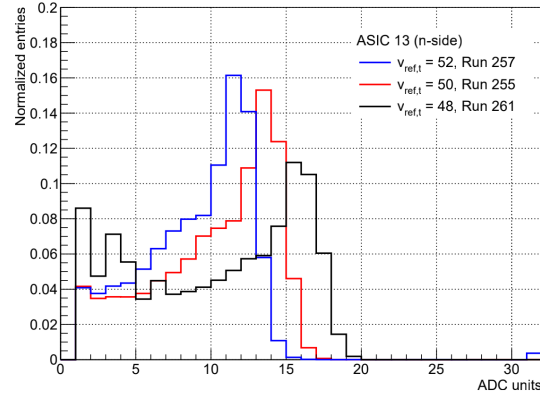


Figure 5: Measured energy spectrum of the ^{241}Am -source as a function of ADC units for ASIC 13 (*n-side*) for threshold values of $V_{\text{Ref.T}} = 52$, 50, and 48, corresponding to 6970, 5600, and 4250 e^- , respectively.

Another essential parameter for good module performance is the overall channel yield. Too many broken channels negatively influence the spatial resolution, and thus momentum resolution of the detector. The aim of the STS production is to have less than 1.5% of broken channels. At this stage, after many years of development, this benchmark is typically achieved by the aluminium modules. Considering the fact that it is the first functional copper module, the yield above 95% for the module Cu_KIT_202 is a great achievement. With more experience, it should be possible to push this metric beyond 98.5%.

It was never intended to build the whole STS with copper modules. It was, however, considered to have a mixed solution of copper and aluminium modules in the case of insufficient throughput of aluminium microcables for series production. In this scenario, the copper modules are best suited as the outermost modules on the ladders. If placed on the periphery, the copper microcables do not cross a single sensor on the ladder. Hence, the slightly higher material budget of the copper microcables does not notably affect the STS performance. Since there are 106 ladders employed in the STS, a total of $212/876 = 24.2\%$ of the modules could be built in the copper technology in this way. Moreover, if placed only on the periphery, the higher thickness and stiffness of the copper microcables should not cause major complications during detector integration.

References

- [1] O. Maragoto Rodriguez et al., *Test of the STS-XYTERv2.1 ASIC*, CBM Report 2019, p. 21
- [2] K. Kasinski et. al, *SMX2 and SMX2.0, 2.1, 2.2 Manual*, 2021

QA tests of the LDOs developed for the assembly of the BM@N STS modules *

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Serial production of the BM@N and the CBM STS modules requires optimization of the assembly and testing processes which, in this case, are genetically connected to each other since mounting of the malfunctioning element destroys the final product of the assembly.

Testing of the low dropout voltage regulators (LDO) is one of the first steps of the assembly of Front-End Board (FEB), therefore mistake on this stage will decrease the production yield of nondefective modules.

The objective of this work was the automation of the testing procedure of the LDOs after their die-bonding onto the FEB. The aim was to reduce the amount of the manual work during LDO testing as a source of errors during the tests. BM@N FEBs are tested with the help of custom-designed fixture after their installation of FEBs onto the cooling plate, a FIN. FIN evacuates the heat produced by the FEB to the liquid cooling system of the STS [1]. The layout of the BM@N STS FEB comprises test pads on the top side of the PCB for testing of the 1.2V and 1.8V LDOs during the assembly process (Fig.1). This procedure includes two tests LDOs operating under the load. The aim

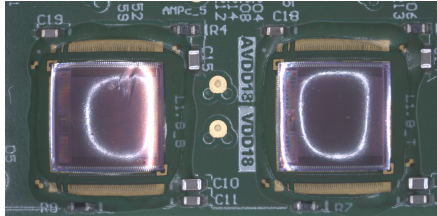


Figure 1: LDO on FEB with test pads AVDD, VDD1.8.

of the first test is the verification of the wire bonding and functionality of the device. If during the first load test any of the LDOs in the FEB did not work properly, FEB is disregarded assembly. The final test under the load is performed to record the response of the regulator to a different load in the range from 0.2 to 2 ohms and to verify the overcurrent protection settings.

The test bench is based on the Keithley programmable DC electronic load Model 2380-500. The block scheme of the test setup is shown at Fig. 2. A special LabView software was developed to automate the load tests. The measurements are relatively simple. After the probe is connected to the output of the LDO under test, the operator presses the button that corresponds to the LDO under test and the rest of testing is done automatically. Once the mea-

surement has started, the program changes the load at fixed intervals and the resistance, voltage and current values are recorded and stored in the PC. The simplicity in realization

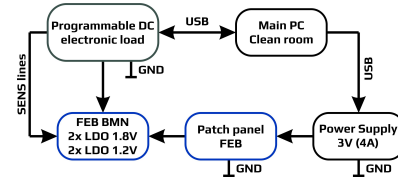


Figure 2: Block scheme of LDO test setup.

of the test due to the automatic change of the load allows the operator to concentrate his attention in the correct connection of the probe to the output of the LDO, while the rest of the test is done automatically by the software, reducing the time and increasing the quality of the measurements.

The results of test of two LDOs are presented in Fig.3. Special tool has been developed for testing two FEBs (p- and n-type) simultaneously. The test time of the LDOs on a FEB was reduced from 30 minutes in manual procedure to 1 minute in automated one.

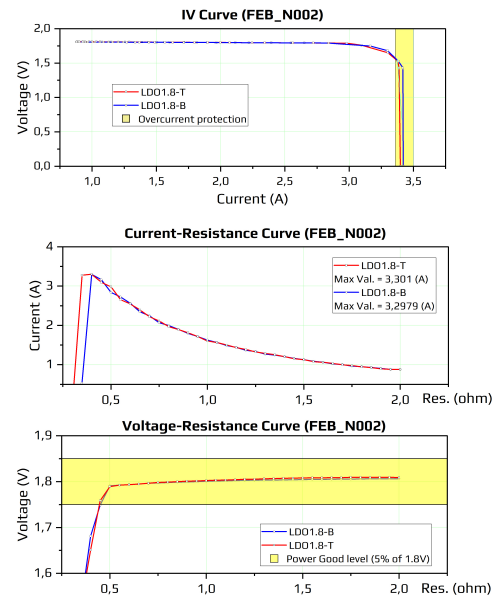


Figure 3: UV, IR curve and VR curve for LDO 1.2V.

References

- [1] D. Dementiev et al., *Front-end Board for the BM@N STS project*, CBM Progress Report 2019, 30

* The results presented in this paper are based on work performed before 24 February 2022.

Study of glue with diamond powder fillers for BM@N STS modules * [†]

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The main sources of heat within the BM@N STS read-out system located within the detector itself are the STS-XYTER and LDO ASICs. Mounted onto Front-End- Board (FEB), they dissipate in total around 13 W per FEB which has to be transferred effectively from FEB to the cooling plate, FIN, to which the two FEBs of the module are glued to. The main requirements to the glues used for this purpose are high thermal conductivity and electrical resistance.

Typically glues with such properties consist of an epoxy (resin and hardener) to which different types of fillers are added to increase thermal conductivity and electrical resistivity of the glue. Unfortunately, changes of the mechanical properties of the adhesive depending on the type and concentration of the filler are inevitable. Several commonly used thermal fillers such as Al_2O_3 , AlN , BN are planned to be compared to a diamond powder. The choice of the last was inspired by the remarkable thermal conductivity and dielectric strength of diamonds.

Two resins of different viscosity were used - HT2 and ED-20 for preparing the samples with different concentration of diamond powder.

The measurement of thermal conductivity requires a laminated glue sample to be of a certain shape and size - cylindric samples of diameter 15 mm and height 5 mm. While making them, we faced the problem of bubble formation during mixing the adhesive. Bubble formation affects the mechanical properties and changes thermal conductivity of the samples, therefore a specialized THINKY ARE-250 centrifuge was used to mix the adhesives. In order to reduce the number of bubbles in the adhesive and before curing glue a degassing in vacuum was undertaken with alcohol pretreated surface molds. The further curing adhesives was performed at room temperature and pressure.

The thermal conductivity of thus prepared cylindric samples of diameter 15 mm and height 5 mm was measured with a help of specialized IT- λ -400 device of the D.I.Mendeleyev Institute for Metrology (VNIIM) in SPb. A typical result of these measurements is showed in Fig. 1.

Table 1 demonstrates numerically the increase of thermal conductivity of samples with the increase of concentration of diamond powder in the sample. The highest thermal conductivity is achieved when the two-component adhesive

has the highest filler concentration (No. 2 HT2). Comparison of samples 1 ED-20 and 3.2 ED-20 shows that the size of the fraction, when mixed in equal proportions, does not greatly affect the thermal conductivity. The comparison of samples 10.1 HT2 and 4.1 HT2 shows that the use of a mixture of diamond powder of two fractions in the filler, within the considered concentration of diamonds in a sample, does not considerably change the thermal conductivity of the glue.

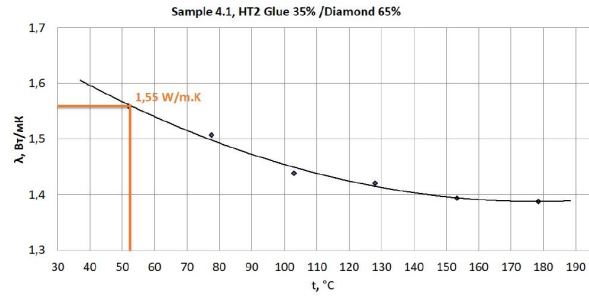


Figure 1: Typical dependence of thermal conductivity of sample vs temperature.

Table 1: Thermal conductivity of samples with different concentration of diamond powder.

Sample ID	Diamond fractions (D), μm	Mass ratio: D1/D2/epoxy resin	λ , $W/(m^{\circ}K)$
No. 2 HT2	D1 – 8.5, D2 – 50	56/21/23	2.3 ± 0.23
No. 10.1 HT2	D1 – 8.5	75/35	1.6 ± 0.16
No. 4.1 HT2	D1 – 8.5, D2 – 50	48/17/35	1.55 ± 0.15
No. 3.2 ED-20	D1 – 8.5, D2 – 50	37/13/50	1.03 ± 0.1
No. 1 ED-20	D1 – 1.5, D – 50	37/13/50	1 ± 0.1
No. 3.2 HT2	D1 – 8.5, D – 50	37/13/50	0.98 ± 0.1
No. 6 HT2	no diamonds	no diamonds	0.48 ± 0.05

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[†] The results presented in this paper are based on work performed before 24 February 2022.

Update on ongoing activities with STS ladder assembly

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The Carbon Fiber ladders designed for STS act as support structures for the sensors. The sensors are glued onto the ladder with the help of glass fiber structures referred to as *L-legs*. For a tracking detector, it becomes very important to place the sensors at the right position. Our main goal is to tune in the assembly procedure in such a way that the sensors should not deviate from their nominal position. We aim to achieve the sensor mounting precision to be within the range of $100\ \mu\text{m}$. In order to achieve the required mounting precision, a well-defined assembly technique has been designed and tested.

Assembly of a full-size mechanical ladder

To test for the functionality and handling of the tools, a ladder has been built with 10 non-functional modules as shown in Fig. 1. This is the first ladder (type 12) built with the maximum number of modules a ladder will have, to get acquainted with the procedure of mounting the modules. In the case of a full ladder, the first two modules are assembled one after the other, since the tools are designed in such a way that both the modules sit on the same positioning block, and that, afterwards, the modules can be assembled in parallel on both the ladder sides as shown in Fig. 2. Each module remains with the tool under vacuum for 24 hours considering the curing time of CAF4 which is used to glue sensors on *L-legs*.

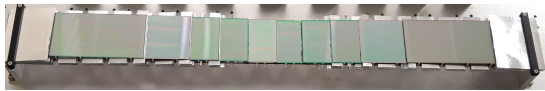


Figure 1: Ladder assembled with 10 dummy modules.

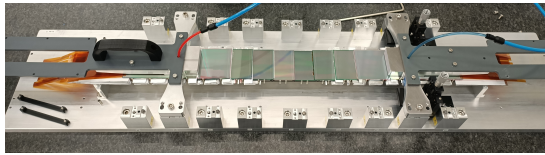


Figure 2: Parallel assembly of modules onto the ladder.

Ladder assembly precision

Once a ladder is fully equipped with modules, the next step is camera-based optical survey [1]. The 3D positions of the sensors are determined from alignment marks on their surface. Between two consecutive sensors on a ladder there is a gap of $1.5\ \text{mm}$ in order to allow for the routing of the modules' micro cables (Fig. 3).

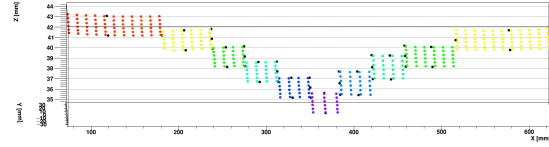


Figure 3: Z positions of sensors measured on ladder.

To see how well the sensors are positioned on the ladder, we check for the deviation from their nominal positions. Figure 4 shows the deviation from the nominal values x , y and z for the markers; in addition, for the z , the surface scan of the sensors was also performed. We established that all sensors are within the required precision range of $100\ \mu\text{m}$. This step is planned to be performed for all the ladders in order to store the information into the component database to be able to track the positions of the sensors in the future.

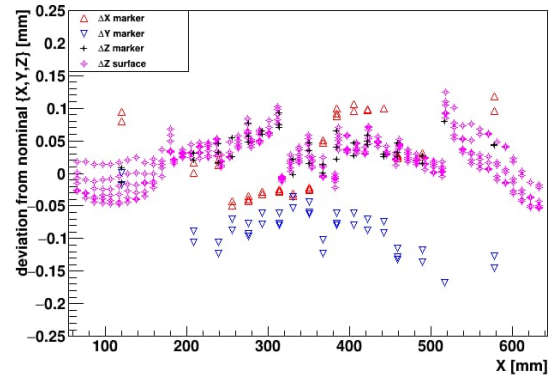


Figure 4: Deviation of sensor positions from the reference.

After having gained experience with the dummy ladder, we assembled a ladder with functional modules. A full-size ladder equipped with sensors only on one half side – referred to as half ladder – has been assembled with three functional modules and two dummy modules using the same technique. This ladder, shown in Fig. 5 was added to the mSTS detector and operated in beam.

Ladder vibration study

The main idea of building a ladder with non-functional modules was to test the ladder under air flow. In order to cool down the sensors, a perforated tube with $2.4\ \text{mm}$ outer and $2.2\ \text{mm}$ inner diameters will be used in the middle of a ladder, blowing cold air directly onto the sensors surface.

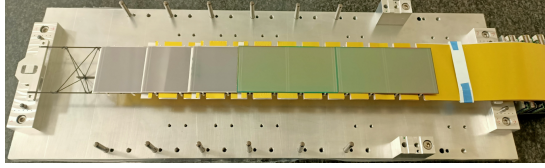


Figure 5: Ladder with functional modules used for mSTS.

This tube is placed approximately 10 mm away from the sensor surface. A gas flow of 20 l/min passing through the tube from the top and bottom could lead to vibrations of the ladder, affecting the tracking performance. To measure the vibrations, a laser doppler vibrometer (LDV) is used [2]. Two identical full-size ladders were assembled in order to measure the sensor vibrations. One ladder was sent to Univ. of Oxford for analysis on a shaker table. From first results it was concluded that the first eigen frequency is around 67 Hz; further work is ongoing [3]. A second, identical ladder we studied at GSI to check for the impact of air flow coming from the perforated tube on the ladder (Fig. 6).



Figure 6: Setup for ladder vibration measurement.

Measurement description

On either side of the perforated tube, several points were measured on each sensor and averaged to see how much the sensor is vibrating near the perforated tube. It was observed that there was no vibration near the 67 Hz mentioned before, and maximum vibrations were coming from low frequencies which could be the effect from the surroundings. The measurements were taken without gas flow and with flow of 20 l/m. Frequency vs. power spectral density is plotted in Fig. 7.

To get a picture for a full ladder, the obtained vibration RMS values are plotted vs. the positions along the ladder. RMS is calculated using the formula shown together with Fig. 8. The measurements with flow and background subtracted is plotted in the graph. A frequency cut of 1 Hz was applied in the RMS calculation to subtract “seismic” con-

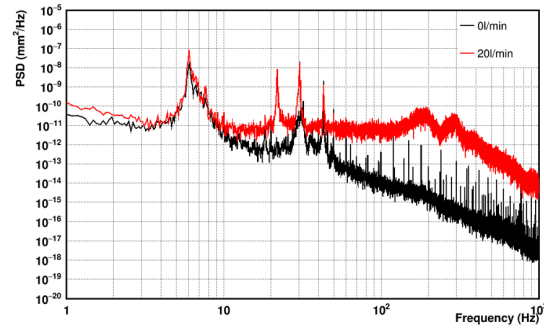


Figure 7: Frequency versus power spectral density spectra.

tributions. As expected, it was observed that the sensors in the center of the ladder vibrate more strongly than the sensors at its ends. However, the elongations are certainly very small when compared to the precision requirement.

$$\text{RMS} = \sqrt{\int_{f_1}^{f_2} \text{PSD}(f) \cdot df}$$

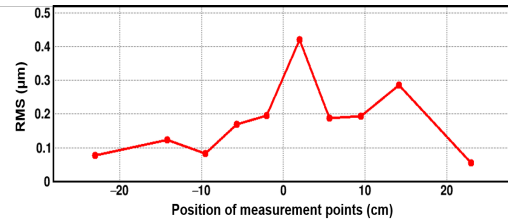


Figure 8: RMS for the vibration produced along the ladder.

Conclusion

To ensure that all the ladders for STS are assembled with the right precision, it is important to verify the precision of the tools. At the same time it is equally important to gain enough practise with the tools to make sure we get familiar with the procedure and the handling. Two full ladders with non-functional modules have been assembled and we verified that it was within 100 µm precision as required. Vibration measurements under the influence of cooling gas flow showed only very small effect. A next step is to prepare two half-ladders with functional modules, to be used in – after electrical evaluation – in the STS mechanical demonstrator.

References

- [1] S. Mehta et al., CBM Progress Report 2018, p. 28
- [2] <https://www.polytec.com/eu/vibrometry/products>
- [3] J. M. Heuser et al., CBM Progress Report 2020, p. 46

Mechanics of STS cooling and progress on the STS thermal demonstrator

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The STS Thermal Demonstrator is tasked to implement the silicon sensor and electronics concept under realistic mechanical boundary conditions. This report summarises the progress made on the thermal demonstrator and the mechanics of the components relevant to STS cooling. These highlights were presented in further detail in the Engineering Design Review of STS Mechanics [1] and dedicated STS Cooling Workgroup Meetings [2].

Sensor cooling

The silicon sensors located near the beam pipe are exposed to cumulative NIEL¹ damage of 10^{14} 1 MeV n_{eq}/cm^2 over its operational lifetime and will dissipate $\sim 6 \text{ mW}/\text{cm}^2$ at -10°C . This marginal power dissipation is conceptualised to be removed by forced convective gas cooling to minimise the additional material budget, and thereby maintain STS's momentum resolution performance.

The cooling elements foreseen for the silicon sensors are perforated carbon-fibre (CF) tubes. The outer diameter and shell thickness of these tubes is 2.4 mm and 200 μm respectively, to reduce the local addition to the material budget by $x/X_0 = 0.14\%$. The tubes were manufactured by ICM Composites² by thinning down thicker CF tubes, which is particularly challenging. Other mechanical R&D activities such as tube bending and its stability under air flow, along with the thermal simulations were reported in [3].

A custom-made leak-tight connector joining the CF-tube to subsequent Swagelok[®] connectors has also been designed and manufactured in-house. A smaller assembly of the CF-tube with the connector is shown in Fig. 1 and the concept has been added to STS's CAD drawings.

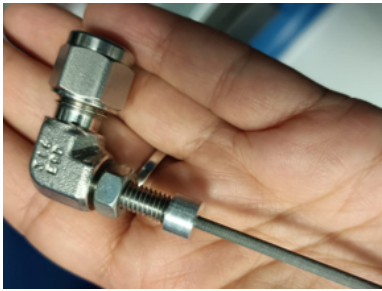


Figure 1: Perforated CF-tube with custom-made connector.

¹Non Ionizing Energy Loss

²ICM-Composites GmbH, Germany, www.icm-composites.de

Electronics cooling

The front-end and readout electronics located outside STS's physics acceptance dissipate substantially more power of $\sim 40 \text{ kW}$ in the detector volume of 3.5 m^3 . They are also targeted to be at -10°C to minimise the heat transfer to the innermost silicon sensors which are located only 20-50 cm away. 3MTMNOVECTM649³ at -40°C will be used as the coolant in liquid state and the corresponding thermal simulations substantiating its usability are in [4].

The crucial selection criteria for all components to be used in the electronics cooling circuit is their compatibility with 3MTMNOVECTM649. All components and their underlying materials (such as gaskets, hoses, sealants, etc.) were chosen based on the prior research and operational experiences [5-7].

FEB cooling plates

The aluminium (AlMg3) heat exchanger plates are manufactured by using a solid state joining process called 'Friction Stir Welding' by Cool Tec⁴. This technology allows to flexibly mill fluid channels to enhance local heat transfer coefficient between the coolant and the cooling plate, thereby increasing the cooling performance. The coolant pressure and spacing between two adjacent STS units limits the maximum cooling plate thickness manufacturable with this technology to 12 mm. The bulging of the sample cooling plate under various pressures was measured with the STS ladder metrology setup [8], and was shown to be $\approx 50 \mu\text{m}$ at nominal pressure of 3 bar(g) (see Fig. 2).

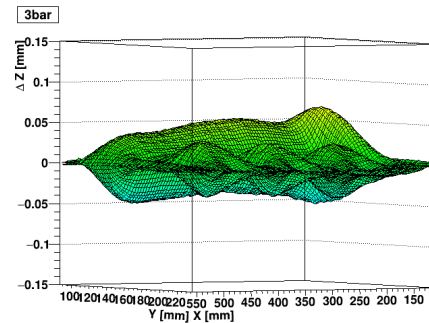


Figure 2: Measured bulging under pressure of the sample FEB cooling plate.

³www.3m.com/3M/en_US/p/d/b5005005025

⁴Cool Tec Electronic GmbH, Germany, www.cooltec.de

The respective connectors on the cooling plates are also important to make sure that no leakages are observed during the lifetime of the experiment, especially when STS is mounted and operational in its sealed thermal enclosure. Due to the limited options on the threaded connections provided by manufacturer on the cooling plate, metal-to-metal sealing ensured by Swagelok® RS-Fittings⁵ are the baseline option. The leak tightness of these stainless steel fittings with copper gasket has been successfully tested with compressed air up to 7 bar(g). Feedback to add more aluminium thickness near the connector region of the cooling plate for better sealing contact has been provided to the manufacturer and will be implemented in future versions.

Distribution manifold

The distribution manifold located inside the STS thermal enclosure is designed to passively distribute the desired flowrate from the cooling plant to a given set of cooling plates on the C-Frame. It comprises of the main tube and individual branches along with their respective valves. Individual branches are made from 1/4 inch stainless steel flexible hoses, and can also help dampen the vibrations carried by the coolant from the cooling system's components. Swagelok® FJ-series metal hose⁶ is the chosen option because of its high pressure rating, Swagelok® VCR end-connection availability, low bending radius (2.54 cm) and low weight (0.16 kg/m). The fine flow regulation is provided by the Swagelok® NR-series needle valve⁷, where components are rated down to -53°C and availability in Novec compatible materials (UHMWPE, PEEK, Grafoil). A sample manifold was produced by Swagelok⁸ and is shown in Fig. 3. Please note that the temperature and pressure sensors in the sample manifold will not be included in the final STS's manifolds because of their unsuitability in radiation and magnetic environment.

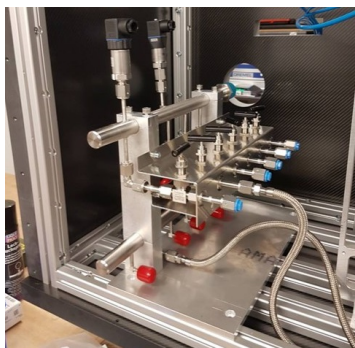


Figure 3: Sample distribution manifold with valves, flexible hoses and pressure-temperature sensors.

⁵www.swagelok.com/downloads/webcatalogs/en/MS-01-140.pdf

⁶www.swagelok.com/downloads/webcatalogs/en/MS-01-180.pdf

⁷www.swagelok.com/downloads/webcatalogs/en/MS-01-168.pdf

⁸Swagelok Stuttgart - B.E.S.T. Fluidsysteme GmbH, Germany, www.stuttgart.swagelok.solutions

Vacuum insulated feedthroughs and hoses

Based on the positive experiences of LHC based trackers [9], vacuum insulated transfer lines are the baseline option to transport the coolant into the STS. They substantially reduce the space taken on the front wall of the STS thermal enclosure and are less prone to breakages when compared to traditional insulation methods such as foam.

The novel aspect of this established concept are the vacuum insulated feedthroughs which would help to easily integrate and disintegrate the STS from the cooling plant, and allows to reliably maintain the vacuum insulation from the transfer lines into the STS thermal enclosure. Sample hoses and feedthroughs have been manufactured by Demaco⁹ (see Fig. 4) and will be used to transfer the coolant into the thermal demonstrator and other setups connected to the cooling distribution system in the STS lab [10].

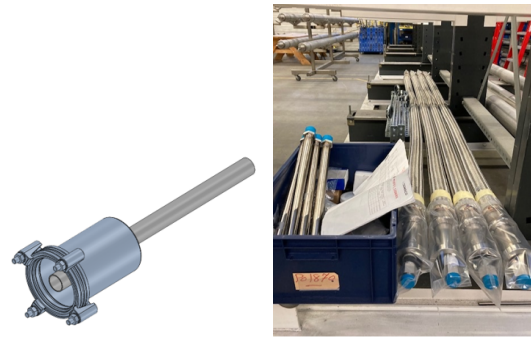


Figure 4: Left: CAD rendering of vacuum insulated feedthrough; Right: Samples of vacuum insulated hoses.

Thermal enclosure

Elementarily, the insulation panel comprises of CF-foam sandwich which is further sandwiched in aluminised polyimide foils for electromagnetic and thermal shielding. Additionally, the inner side of the enclosure's side panel includes thin cooling plates tasked to act as the coldest spot in the enclosure to safely host any condensation outside the electronics area and provide additional cooling of the STS environment. Calculations suggest that additional kapton heaters on the outer surface of the panels will not be needed. Nevertheless, they can be added if the contrary is observed experimentally. The simplified idea of thermal enclosure's insulation panels has been reported in [11] and the respective task force meetings [12].

CF-foam sandwich insulation panel

The sandwich panels are manufactured by CarbonVision¹⁰ by using 37 mm AIREX R82.60 foam sandwiched

⁹Demaco Holland bv, Netherlands, www.demaco-cryogenics.com

¹⁰CarbonVision GmbH, Germany, www.carbonvision.de

between 1.5 mm CFRP skin. The back panel is thinner with foam thickness of 17 mm to reduce the material budget in STS's physics acceptance. HELICOIL® threaded inserts were used to integrate and seal the panels together onto the ITEM mainframe. Polyamide rims are created along the edges of the panels and cutouts for better stability and thermal insulation (see Fig. 5 (left)). Please note that this R&D doesn't address the structural rigidity of bottom panel and precision of positioning inserts, and this is focused as a separate activity. Furthermore, aluminised polyimide sheets ($25\ \mu\text{m} + 25\ \mu\text{m}$) from CGS Tape¹¹ will be vacuum bagged onto these sandwich panels. The proof-of-principle of the in-house vacuum bagging process with aluminium foils on smaller panels was shown and results were deemed satisfactory (see Fig. 5 (right)).



Figure 5: Left: CF-Foam sandwich panels mounted on the mainframe; Right: Vacuum bagging of aluminium foils on CF-foam panels.

Side-wall cooling plate

These aluminium cooling plates are manufactured by Rubanox¹² by using Roll-Bond technology, which allows to minimise the thickness down to 2 mm. Two such samples have been delivered and are integrated to the thermal demonstrator. Please note that no dedicated simulations were done to optimise the channel geometry for these samples since they are foreseen as an initial proof-of-concept. Subsequent versions will be based on thermal demonstrator's experience and detailed thermal modelling.

Thermal dummy ladders and C-frames

The primary test objects in the thermal demonstrator are the thermal dummy modules, described in [11]. The thermally 'active' layer comprises of 50 such modules which are distributed amongst 6 ladders to form a half-station mimicing the first station of the STS. All thermal dummy modules and ladders have been produced with their integration tests done on a C-Frame to check and correct any potential issues. The active layer is sandwiched between

two 'passive' half-stations for imposing realistic boundary conditions on the air flow between individual half-stations. The components for assembling these three half-stations are now available and subsequent integration tests are ongoing (see Fig. 6). The powering and readout scheme is currently being figured out.



Figure 6: Top: 'Active' C-Frame with thermal dummy ladders; Bottom: 'Passive' C-Frame on the mainframe.

References

- [1] <https://indico.gsi.de/event/13250/>
- [2] <https://indico.gsi.de/category/582/>
- [3] K. Agarwal, S. Mehta et al., Forum on Tracking Detector Mechanics (2021)
- [4] K. Agarwal, 37th CBM Collaboration Meeting (2021)
- [5] Private communication: O. C. Lopez, M. Doubek (CERN)
- [6] Private communication: T. Rannersberger (3M Germany)
- [7] A. L. Kelly, M. Sc. Thesis, Auburn University (2014)
- [8] E. Lavrik et al., Nucl. Instrum. Meth. Phys. A 935 (2019) 167-172
- [9] P. Petagna, Engineering Forum: Experiences from Cooling Systems for LHC Detectors (2008)
- [10] I. Elizarov et al., CBM Progress Report 2021 (2022)
- [11] K. Agarwal et al., CBM Progress Report 2019 (2020)
- [12] <https://indico.gsi.de/category/596/>

¹¹Creative Global Services (CGS), Canada, www.cgstape.com

¹²Rubanox Italia srl, Italy, www.rubanox.com

A system for distribution of cooling liquid to STS test and assembly stands

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Motivation

At least three STS systems require intensive cooling in the laboratory: the thermal demonstrator, the C-frame test box, and the full detector during its integration and commissioning without beam. While STS assembly is the main focus of the project team, the thermal demonstrator is a prototype to verify cooling design concepts, and the C-frame test box serves to test STS components at the nominal, sub-zero operational temperatures before their integration into the detector main frame. The cooling supply of all the above mentioned devices will be provided by the cooling plant, which uses 3M™ NOVEC 649™ liquid as a coolant. Due to the foreseen operation and testing sequence the stands will be partly operated in parallel. In addition, the expensive cooling liquid needs to be collected from a detached device for its reutilization, and the flow conditions have to be measured. The distribution system is designed to address these operation scenarios, and is a test rig by itself.

Description

The cooling and distribution system will be a new part of the STS laboratory infrastructure. It will comprise on its left and right hemispheres identical parts, which are as-

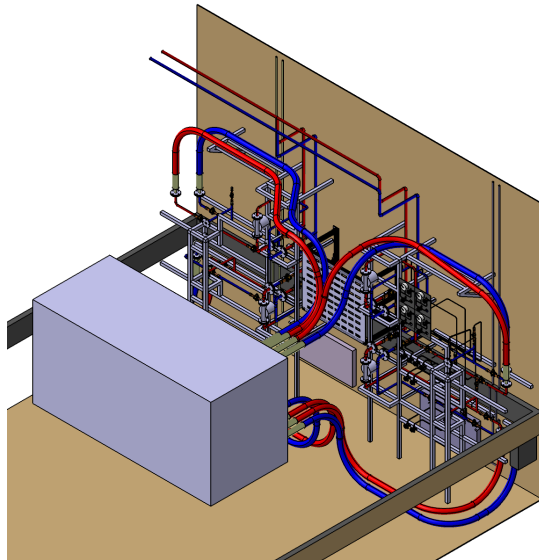


Figure 1: Isometric view of STS connected via eight flexible cooling lines to the distribution system.

sembled next to the wall, for connecting to different test stations through DN25 flanges (see Fig. 1). By moving the STS insulated box either to the right or left in the room, there will be enough space to access the C-frames through the side panels. This is possible due to the use of flexible vacuum-isolated pipes. The distribution system has separate in- and outlets for the thermal demonstrator (see Fig. 2).

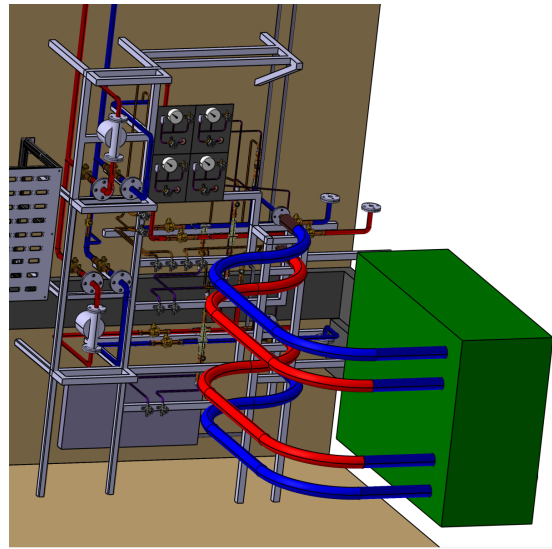


Figure 2: Isometric view of the thermal demonstrator attached to the cooling distribution system.

The ports for the thermal demonstrator and STS are shown in Fig. 3: TD11R, TD12R, TD22R, and TD21R are for the thermal demonstrator, while the ports STS11R, STS12R, STS21R are designated for the STS insulated box. Up to eight STS dedicated ports can be occupied for the cooling system of the detector: four from each side.

An important part of the installation are threaded valves 3/8" for connecting a drainage system for collecting NOVEC 649™ liquid from the devices that are no longer require the cooling supply. Gas pressure is applied through the top group of the valves (V1 – V4) to drain the liquid out of the system through the bottom valves (V5 – V8). For filling the system with the coolant, the procedure is the opposite: first the gas is evacuated through the top valves (V1 – V4), and then liquid is pushed through the bottom group of the valves (V5 – V8). Note that, the shut valves stay closed during the draining and filling sequence to minimize involved volume of the liquid.

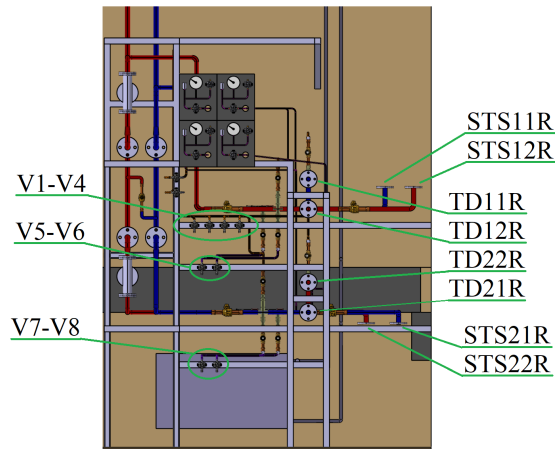


Figure 3: Cooling distribution system, right hand side.

After the thermal demonstrator is no longer in use, top bottom ports are used for connecting the C-frame test box through an adapter as it is shown in Fig. 4. Blind flanges are then screwed on the remaining ports to seal them. As an alternative, they can be used for connecting additional devices, which may appear in the future. The pipelines layout is optimized to take as little space as possible, and to assure access to the control valves. The distribution system is equipped with flow meters, pressure and temperature sensors to measure the flow conditions.

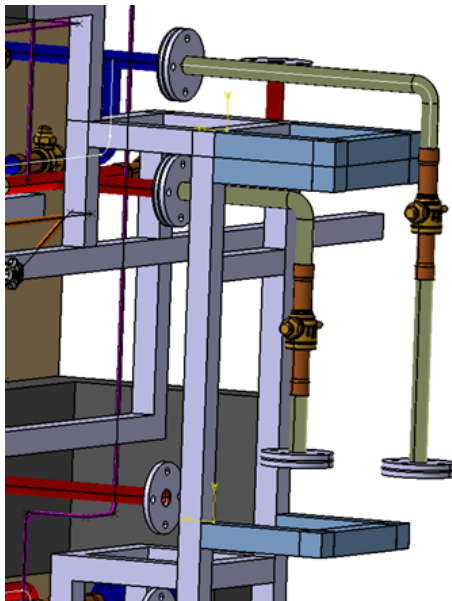


Figure 4: A detachable pipe adapter for connecting the C-frame test box to the cooling distribution system.

Conclusion

The design of the cooling distribution system allows for the supply of the STS test stations with NOVEC 649™ liquid providing cooling to -40°C for the devices assembled by the STS group. A drainage system can be attached to the distribution system to charge and discharge the devices under test with the coolant. Finally the volumetric flow rate, temperature, and pressure can be measured to verify proper flow conditions in the cooling systems.

Progress with the design of production-ready C-frame assemblies

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The design of the C-frame assemblies for all STS units is currently in its final stage. The following sub-assemblies are being finalized in terms of the upcoming production readiness:

- service harness routing – data and power cables;
- cable trays;
- peripheral read-out and power electronics stacks.

For each sub-assembly, two sets of requirements are being considered: general requirements on the C-Frame level, and specific ones for the actual parts. The first ones include compatibility with the C-frame assembly sequence, mounting possibility, and least possible amount of similar designs. The latter ones are discussed briefly in the corresponding sections. Figure 1 depicts the current design state of Unit 07R with the included sub-assemblies.

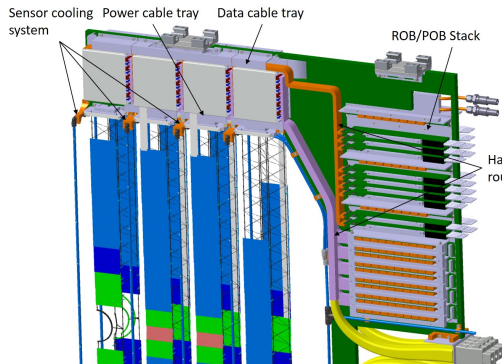


Figure 1: STS unit 07R with sub-assemblies.

Service harness routing and cable trays

For optimal usage of the available C-frame space it was decided to route the read-out cables on top of each ladder and the power cable underneath in the gap between the FEB box and the ladder bearing. The power harness splits up at the end and is routed to low and high voltage connectors, respectively.

The assembly sequence of the C-frame is defined by the harness topology. The ladders are mounted sequentially from the inside of the C-Frame. This requires a modular cable tray design, that allows a fixation of individual single ladder harness bundles and subsequent insertion of the next bundle. The concepts are illustrated in Fig. 2.

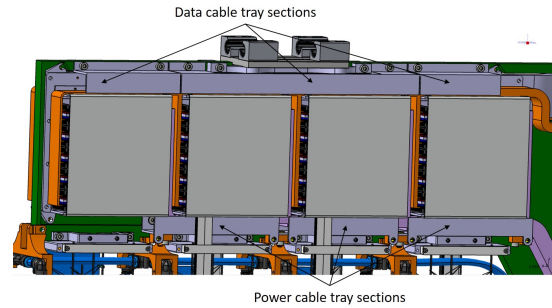


Figure 2: Modular cable trays on unit 07R.

Peripheral read-out and power stacks

The mechanical design of stacks with peripheral read-out and powering equipment has been implemented into the STS model according to the latest development state of the electronics and read-out chain. The stack configuration is individual per half-unit and includes realistic placeholders for mounting, fixation, and cooling parts. The read-out boards have several critical components, e.g. FPGA chips that require cooling. Heat removal is accomplished by attaching a board to a cooling block with contact areas on the chip positions. The need for cooling also occurs for the DCDC converters on the power boards. Based on the experience with mSTS operation, a bracket part was designed that presses single-rows of DCDC modules onto the cooling fin. Figure 3 shows an exemplary stack.

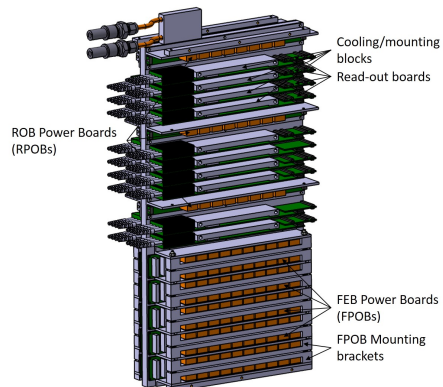


Figure 3: Top stack of unit 07R.

STS assembly sequence and impact on module and ladder production

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The CBM-STS will consist comprise 9 main mechanical assemblies, called *units* 0 – 8, each of which is divided into two half-units, denoted left and right. In total 876 modules have to be assembled, distributed among 106 carbon fiber ladders. The ladders, and thus also the modules employed, are specific for their placement on the individual units. Ladder variants are shown in Fig. 1 [1]. An overview of the amount of modules and ladders to be assembled for each unit is provided in Table 1.

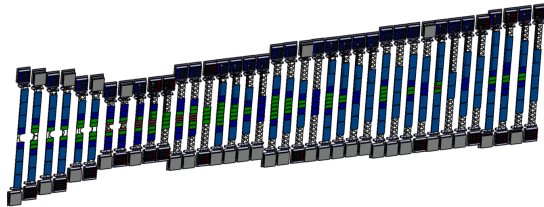


Figure 1: Visualization of STS ladder variants.

Table 1: Number of modules and ladders in each STS-unit.

unit	0	1	2	3	4	5	6	7	8
modules	38	90	104	108	110	108	116	132	70
ladders	4	10	12	13	14	14	15	16	8

Unit assembly sequence

Each half-unit will be assembled in the same way, starting with the innermost ladder (lowest absolute x-position value) towards the outermost one (highest absolute x-position value). The envisaged steps of the detector assembly sequence of each unit could be listed as follows:

- ① Left-side half-unit
 - (i) downstream part
 - (ii) upstream part
- ② Right-side half-unit
 - (i) downstream part
 - (ii) upstream part
- ③ Units 0 – 8
 - (i) The detector assembly sequence will start at Unit 0 and will be consecutively continued up to Unit 8.

- (ii) This third step of the detector assembly sequence is schematically depicted in Fig. 2, as well as the previously completed assembly steps mentioned above.

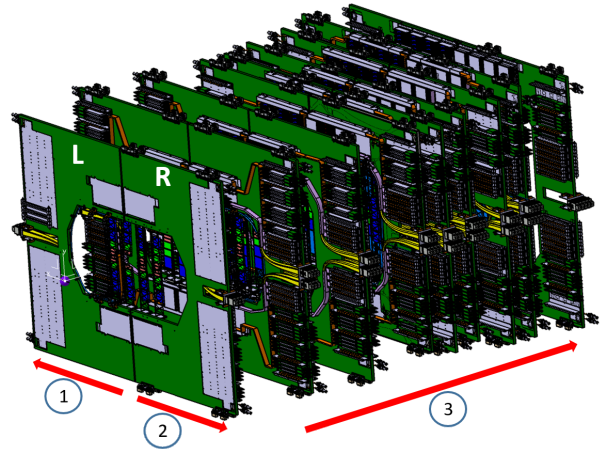


Figure 2: Overview on STS-units including indications of the envisaged main steps of the detector assembly sequence.

Impact on module and ladder production

Based on the layout of the different ladder types, ladders to be assembled on the downstream part of a half-unit have to be assembled starting with the midmost module of the bottom part of the ladder (bottom half-ladder). In case an upstream ladder has to be assembled, the first module to be mounted onto the ladder will be the midmost one of the top part of the ladder (top half-ladder).

All of these boundary conditions and different aspects of assembly processes to be performed prior to the final detector assembly, are reflected in the overall STS module and ladder production sequence that is being worked out. The final work structure and work sharing among the assembly centers could differ from the detector assembly sequence described in this report, depending, e.g., on the detailed boundary conditions around the components to be employed, and logistics.

References

- [1] O. Vasylyev, *Overview of STS mechanical design and components*, Engineering Design Review of CBM-STS Mechanics, 5 November 2021, <https://indico.gsi.de/event/13250/>

STS beam pipe section: Concept and development status

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Requirements to the beam pipe

A central challenge of the CBM experiment with its stationary target and related forward geometry is to separate the beam ions not interacting at the target from those that do interact and emit the reaction products into the canonical aperture which has been defined as the polar angular range from 2.5 to 25 degrees. The non-interacting beam is further guided downstream in an evacuated pipe to the beam dump at the rear end of the CBM underground hall, whereas the reaction products leave the vacuum of the target chamber and pass through a “window” into the tracking volume of the STS and subsequently the other CBM instrumentation where the detector components are operated at ambient air pressure. The beam pipe in the STS requires a minimized material budget in both of its main parts: (1) The window, attaching to the target box, must be lightweight and thin to not deteriorate STS pointing resolution to the evacuated vertex/target region. (2) The guiding volume through STS (“pipe”) must have a low wall thickness to minimize interactions of the remaining beam “halo” there. Additionally, its entrance and exit radii must be large enough to contain the vast part of the non-interacting beam, but without compromising the physics aperture of the STS detector. Beyond the STS-internal requirements, the beam pipe section must be compatible with joining it to the target region upstream and the further CBM detector systems located downstream of the STS. As the pipe must also allow handling for detector assembly, installation, reconfiguration and maintenance, it becomes an integral part of the STS design. Utmost importance must be placed on the robustness of the beam pipe against damage from external pressure and miscellaneous forces, e.g. arising from the coupling to the downstream beam pipe sections through the RICH/MUCH detectors.

Tentative concept and first prototype

A tentative concept for the STS beam pipe was already presented years back in [1], comprising of a “trumpet like” shape for window and pipe matching the geometrical situation at SIS300 and upper SIS100 beam energies and profiles. Different technological options were considered in particular with respect to radiation hardness, which were best met with Be and Al materials, and thus omitting carbon fiber composites. However, since we have had no explicit collaboration group to take over such project, in particular for a Be solution also in terms of funding, we later sought at GSI for a different solution based on composite material. A solution based on Al would not be favored

in terms of background induced to the experiment if such structure would be stiffened e.g., by vault-structuring. An early prototype¹ manufactured around the years 2017/2018 was made from two 250 μm thick prepreg layers separated by a foil, built-up and fused on a hub, yielding a cylindrical and a conical section, plus a 500 μm thin window part. A single vacuum test carried out in 2018 failed, resulting in a structural rupture, however, could not be further investigated in detail.

Relaunched approach

After some pause on this activity, in 2019, the status was presented and discussed at [2], which resulted in a follow-up study kindly offered and prepared by colleagues from Purdue University². It preliminarily suggested that carbon fiber wall build-up at acceptable thickness of around 1 mm was promising w.r.t. forces and vacuum tightness, and had an initial look at different stress situations including those at the window membrane. Soonafter, in the course of the year 2020, the CBM collaboration started a topical workgroup activity on the experiment’s beam pipe and target region, and the relaunched STS beam pipe activity merged with it benefitting from the exchange on the many interconnectivity aspects to agree upon and solve across sub-systems. Most importantly, a new shape of the STS beam pipe section was established, taking into account, the meanwhile, changed STS geometry (with slightly enlarged inter-unit spacing required due to by now detailed knowledge of component sizes and mechanical tolerances) and the requirements for larger initial and external pipe diameter due to CBM physics studies now to be carried out down to SIS100 beam energies as low as 2 GeV/nucleon, allowing for an energy overlap with the complementary BM@N experiment’s program at Nuclotron.

Current concept and its evaluation

Figure 1 shows the about 1 m long beam pipe section of the STS in the detector and how it integrates with the other beam pipe sections to form the CBM vacuum beam transfer line from the entrance to the target region to the beam dump. The proposed new shape of the STS beam pipe is outlined in Fig. 2. The wall thickness is 1 mm, the beam window on the left is 0.5 mm thick, all made from carbon fiber composite. It realizes larger initial diameter of 40 mm (a variant with 50 mm is also considered - bottom draw-

¹W. Niebur et al., GSI, cooperation with Connova Deutschland GmbH

²A. Jung and S. Karmarkar, Purdue University, Composites Manufacturing & Simulation Center, www.purdue.edu/cmcs

ing) and exit diameter of 104 mm. The shape follows an all conical layout that is still compatible with the intended physics aperture and also satisfies the wider beam profile at the lowest end of the SIS100 beam energy range. The window part is attached fix to the rear opening of the target chamber (Fig. 4 (top)), whereas the downstream end of the conical section is held in a sliding and sealing mount (Fig. 4 (bottom)), integrated in the back wall of the STS system, which shall decouple it from axial forces of other beam pipe sectors further downstream.

Radiation study and physics performance

The radiation aspect has been studied with FLUKA simulations (Fig. 3) result in acceptable background interactions in the detector and uncritical radiation load on the carbon fiber composite material [3]. Updated GEANT geometry coding (v21a-d) of STS with active and passive components, including its beam pipe section, have been prepared for CBM's simulation software to enable the Collaboration checking the intended STS construction towards fulfilling the experiment's physics performance, which is an ongoing effort.

Engineering study and prototyping

In order to assess the proposed carbon fiber structure w.r.t. stability and manufacturability, an engineering study was carried out in late 2001 at ICM-Composites GmbH³. The engineering company was entrusted as it also produced the carbon fiber support structures of the STS detector ladders, and carried out a matching study of stiffening those ladder variants with cut-outs for their placement on the detector units close to the region intersected by the beam pipe. The following points were addressed:

1. Preliminary pipe design, comparing two geometries:
 - layer structure and its effect on possible denting under atmospheric pressure;
 - layer parameter analysis under variation of fiber variant, layer structure, laminate thickness;
 - FEM analysis of best variant.
2. Construction trial:
 - carbon fiber winding on a conical core;
 - surface treatment;
 - test of vacuum tightness.
3. FEM analysis of the two variants:
 - with the selected layering;
 - for different load cases (atmospheric pressure, axial and shear forces).

³ICM-Composites GmbH, Weiterstadt, Germany; <https://icm-composites.de/>

Simulations of the structure and experimental verification of aspects of its manufacturing (see Figs. 5 and 6) [4] show doability of the conical part with respect to the targeted wall thickness of 1 mm, yielding rigidity to bulging if a certain laminate layer build-up of 6 fiber orientations and high-modulus carbon fiber is used. Winding studies proved that particular carbon fiber roving is suited to be laid down tightly on a conical hub. Prototype segments produced passed a preliminary evacuation test, realizing exposure to 1 bar external pressure. Also a first confirmation of vacuum tightness could be made. The most sensitive part to be manufactured is the window. Attached to the conical part it is particularly subject to forces in the region of the joint. The long lever arm of the pipe structure in combination with already small movements, e.g. due to handling during integration or bending of the detector mainframe when installed in it, results quickly in shear forces to cause critical damage way before the conical part would fail. As the STS back wall will have to be lightweight (both thermally insulating and “transparent” for particles in the CBM physics aperture), particular care has to be put on the beam pipe sectors connecting to the detectors downstream to minimize/avert impact on STS and the rear pipe mount.

Next steps

The beam pipe is required to be available in its final structure for the start of STS detector integration in the assembly laboratory, scheduled for spring 2023. The aim is thus to have a full prototype engineered and manufactured in 2022 that will be subjected to thorough testing. Stability under vacuum is a crucial requirement to be achieved. The window must be engineered to become more sturdy. The upstream and downstream mounts will be engineered and verified on prototype assemblies as well as the STS mechanical demonstrator. In the workgroup, the external load from the downstream connections must be assessed and minimized by development of suitable support components. A dedicated test stand will be set up in the STS laboratory to validate the full-size prototype beam pipe for vacuum tightness, pressure cycling, load cases and long-term stability with sufficient safety margins.

References

- [1] CBM Collaboration, *Technical Design Report for the CBM Silicon Tracking System*, GSI-Report 2013-4, 95-96 and Appendix F, <http://repository.gsi.de/record/54798>
- [2] J. M. Heuser et al., *System Integration Issues with the Silicon Tracker of the CBM Experiment at FAIR*, Forum on Tracking Detector Mechanics, Cornell University, Ithaca, New York (2019), <https://indico.cern.ch/event/775863/>
- [3] O. Vasylyev et al., *Engineering Design Review of CBM-STs Mechanics: Questions & Answers*, Technical Note CBM-TN-22001 (2022), sect. 4
- [4] C. Möller (ICM-Composites GmbH), STS Construction Meeting, 2 February 2022, <https://indico.gsi.de/event/14209/>

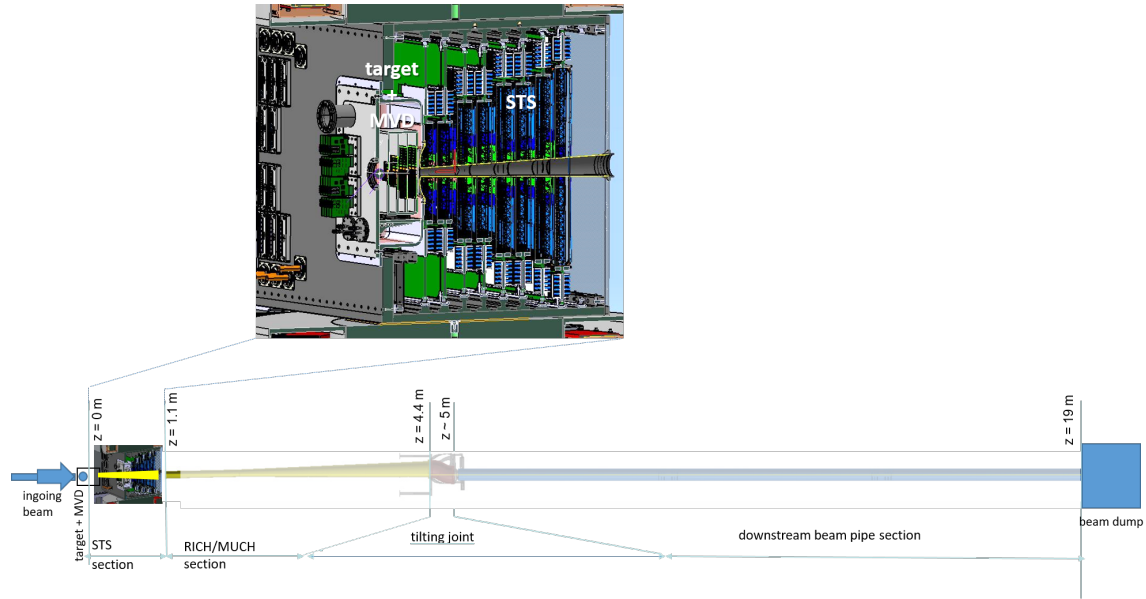


Figure 1: Concept of the STS beam pipe section, and sketch of the full CBM beam line discussed in the work group.

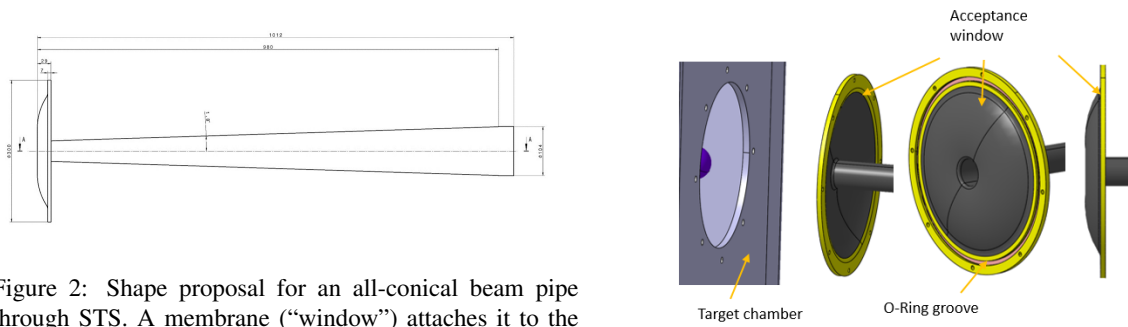


Figure 2: Shape proposal for an all-conical beam pipe through STS. A membrane (“window”) attaches it to the target box (left)

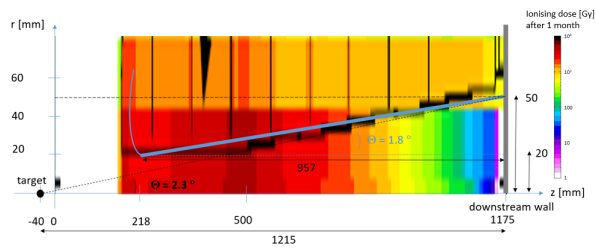


Figure 3: Pipe shape assessment with FLUKA simulations, showing the ionizing dose cross profile from beam interactions with the simulated carbon fiber structure of the pipe. A sketch overlaying it served to extract geometrical dimensions.

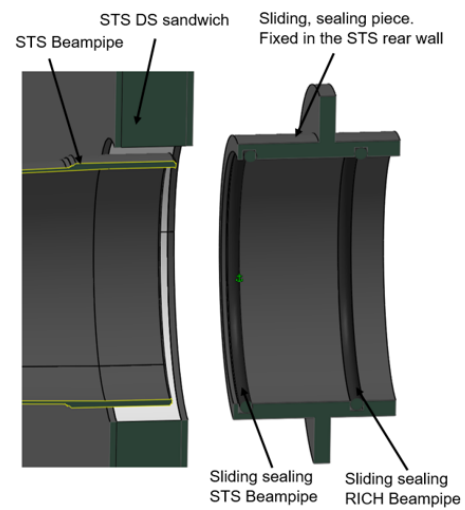


Figure 4: Conceptual views of the mount to the target chamber (top) and interface at the rear STS wall (bottom).

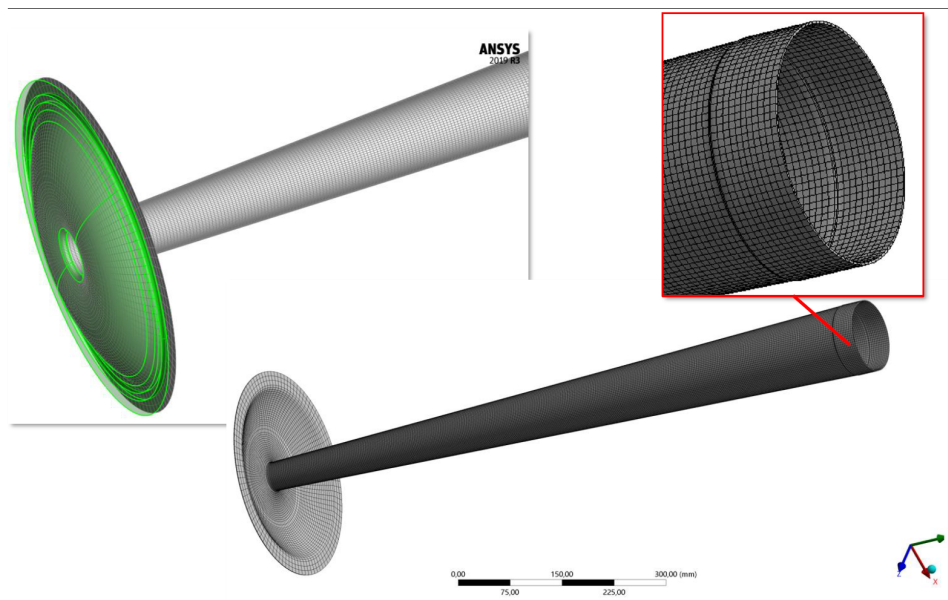


Figure 5: Implementation of the pipe for FEM calculations.

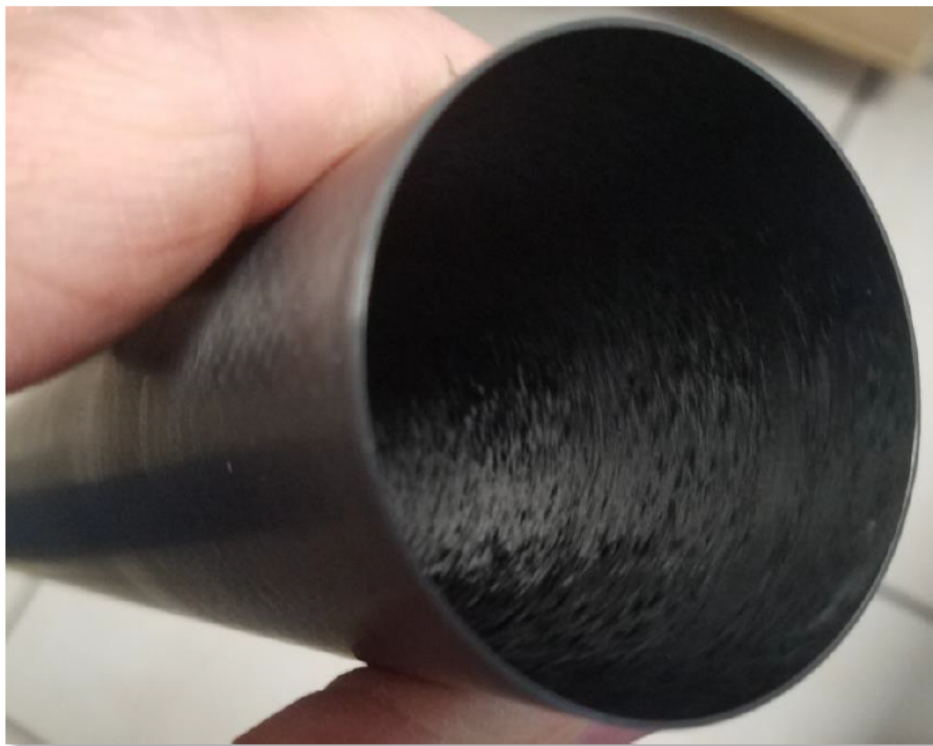


Figure 6: Prototype of the beam pipe's conical section.

Update on the simulation geometry for the Silicon Tracking System

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Introduction

The Silicon Tracking system (STS) [1] is a key detector of the CBM experiment placed inside the 1 Tm dipole magnet. It uses double-sided microstrip silicon sensors of four different sizes, $6.2 \times 2.2 \text{ cm}^2$, $6.2 \times 4.2 \text{ cm}^2$, $6.2 \times 6.2 \text{ cm}^2$, and $6.2 \times 12.4 \text{ cm}^2$ which at 8 tracking stations along the beam axis, cover the area from close to the beam axis outwards. The sensors are produced with a thickness of $320 \pm 15 \text{ }\mu\text{m}$. Each sensor has 1024 microstrips on both p and n-sides, positioned with a pitch width $58 \text{ }\mu\text{m}$. A detector module consists of a silicon sensor connected via Aluminium (Al) polyimide micro-cables to the Front-End Boards (FEBs), placed outside the detector active area, in order to minimize the material budget. It is mounted on ladder space frames made from carbon fibre to minimize multiple scattering of particles. These ladders are assembled on C-frame structures made from Al, as shown in Fig. 1.

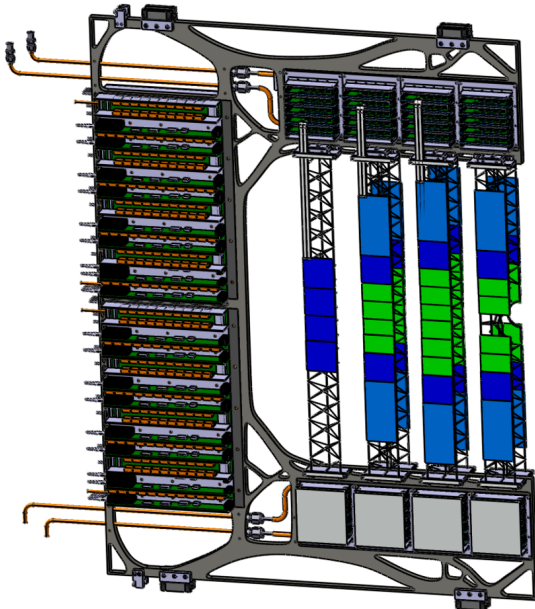


Figure 1: Design of a C-frame along with detector ladders, FEB boxes, POBs, ROBs and cooling interfaces [2].

Updates in STS geometry

Significant developments have been made in the past on the design of different detector components which play crucial role in the physics performance of the detector. Therefore it is important to implement all the design hardware updates in the ROOT-based description of the STS geometry. The most significant changes in the STS geometry are:

- Passive wall material
- Pitch between the stations
- Carbon fibre ladder length
- Sensor thickness
- Micro-cable material
- Beam pipe

Passive walls

The passive thermally and electromagnetically shielding wall around the STS is made from carbon fibers and Airex foam of density 1.5 g cm^{-3} and 0.065 g cm^{-3} respectively. The foam is sandwiched between two carbon fibers sheets of 2 mm thickness.

Pitch between STS stations

The spacing between the STS stations (Pitch) in CAD and ROOT-based geometry was 100 mm. However, new development in the detector design have put stringent limit on the spacing between different electronic components and therefore it was decided to increase the pitch by nearly 5 mm, keeping the last station at the same position [3, 4]. The recent CAD and ROOT-based design of STS detector now have a 105 mm pitch between stations. At the time when this design was made, it was decided that the target should be moved upstream by 40 mm to make space for the elongated STS and its box.

Silicon sensors

To achieve adequate signal to noise ratio, radiation hardness etc, $320 \pm 15 \text{ }\mu\text{m}$ thick silicon sensors from Hamamatsu were chosen. In the prototyping phase, $285 \pm 15 \text{ }\mu\text{m}$ thick sensors from CiS were explored as well [5, 6].

Micro-cables

The micro-cables connected to the sensors for signal read-out are made from aluminium coated with polyimide and have a thickness of 15 μm (metal) and 10 μm (polyimide), respectively.

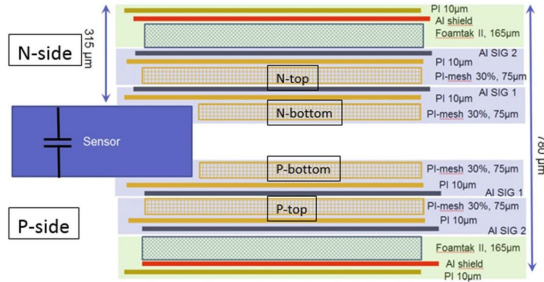


Figure 2: Schematic diagram of the micro-cable stackup of a module [7].

Figure 2 shows a schematic cross-section of the micro-cable. The total thickness of the micro-cables is 774 μm (including both p and n-side) and total radiation length was found to be 0.124%. The material budget per cable was re-calculated using the information of the different layer thickness and fill factor. In the ROOT geometry the micro-cable is implemented as a single volume with the same thickness as the silicon sensors (320 μm .) By solving the implicit function, as given in Equation 1, it is concluded that the material in the micro-cable of thickness 320 μm could be approximated by Manganese with density of 0.5656 g cm^{-3} [8].

$$X_0 Z(Z+1) \log \left(\frac{287}{\sqrt{Z}} \right) = 716.4 \frac{g}{\text{cm}^{-2}} A \quad (1)$$

The material budget for 8 STS stations, recalculated after the modification of the silicon sensors thickness, micro-cable material, and carbon fibre ladder lengths, is shown to exhibit X/X_0 smaller than 1.4% in the active area of the STS detector (Fig. 3).

Beampipe

The ROOT-based STS geometry includes a conical shaped beampipe (Fig. 4) made from carbon fiber reinforced plastic. Two possible configurations are considered for further studies, with the same conical shape, thickness (1 mm) and diameter (104 mm) on the downstream side, but two different diameters on the upstream side: 40 and 55 mm, respectively, for further studying effects at beam energies as low as 2 GeV/nucleon.

In addition, the back side wall has also been adapted to the beampipe flange. Moreover, the vacuum chamber which host the MVD detector has also been modified as shown in Fig. 5.

Discussion

Different versions of the STS geometries, which include recent technical design modifications, allow the study of impact on the acceptance, tracking efficiency, and momentum resolution. Table 1 shows a summary of the STS geometries, the main developments included, the beampipe and the target position. As can be seen from Fig. 3, the material budget amounts to 0.34% for the silicon sensors of thickness 320 μm , 0.12% for the Aluminium-polyimide micro-cables, while fully assembled ladders with modules amounts to material budget from 0.3% to 1%.

References

- [1] CBM Collaboration, *Technical Design Report for the CBM Silicon Tracking System*, GSI Report 2013-4
- [2] O. Vasylyev, *Overview of STS mechanical design and components*, Engineering Design Review of CBM-STs Mechanics, 5 November 2021
- [3] H. R. Schmidt, J. M. Heuser and O. Vasylyev, *Change Request: Modification of the STS Layout*, CBM Technical Board, 25 February 2020
- [4] J. M. Heuser, *STS Integration*, CBM Technical Board, 3 March 2020.
- [5] J. M. Heuser et al., *Production Readiness Review for the Silicon Sensors of the CBM Silicon Tracking System*, CBM-TN-18010 (13 May 2019)
- [6] J. M. Heuser et al., *Description of the STS microstrip sensors for series production*, CBM Technical Note CBM-TN-19005 v1.1 (24 April 2020)
- [7] V. Borshchov et al., *Micro-cables for the CBM-STs detector modules*, CBM-TN-20003, v2.2, 2021
- [8] E. Clerkin, *Materials for the STS cables*, internal communication, November 2021

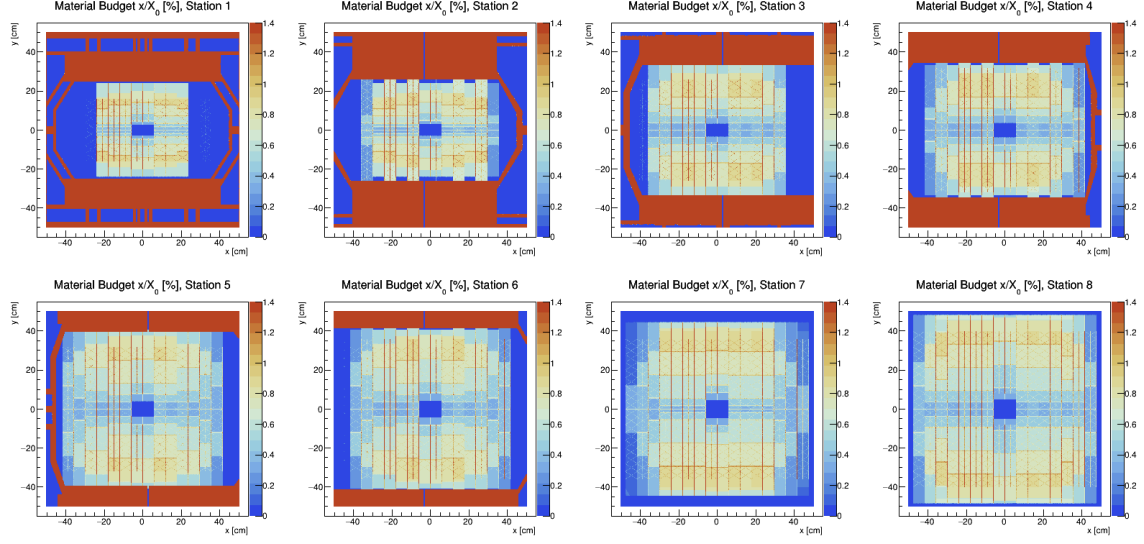


Figure 3: Material budget diagram for all eight STS stations.

Table 1: Summary of various STS geometries, beampipe variants and target positions in CBM coordinate system.

STS geom.	Detail, modification	Beam pipe up- and downstream radii (cm)	Target pos. z (cm)
v21a	pitch, front/back wall solid, ladders/half ladders	old: cyl. $r_u = 2.10$, con. $r_d = 4.00$	-4
v21b	21a + adjusted central ladder	new: conical, $r_u = 2.00$, $r_d = 5.20$	-4
v21c	21b + only beampipe changed, ladder position	new: conical, $r_u = 2.75$, $r_d = 5.20$	-4
v21d	21b + honeycomb foam in backside wall	new: conical, $r_u = 2.00$, $r_d = 5.20$	-4
v21e	21b + STS local origin + global origin from center of magnet	new: conical, $r_u = 2.00$, $r_d = 5.20$	-44
v21f	21b + beampipe flange attached to backside wall	new: conical, $r_u = 2.00$, $r_d = 5.20$	-4
v21g	21e + beampipe flange attached to backside wall	new: conical, $r_u = 2.00$, $r_d = 5.20$	-44
v21h	v21f + sensor thickness ($320 \mu\text{m}$)	new: conical, $r_u = 2.00$, $r_d = 5.20$	-4
v21i	no beampipe flange attached to backside wall + sensor thickness + micro-cable thickness	new: conical, $r_u = 2.00$, $r_d = 5.20$	-44

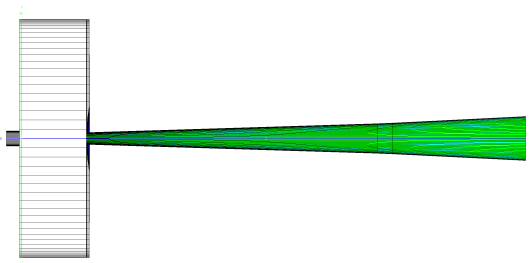


Figure 4: Conical shaped beampipe (v21b) with 40 mm diameter in upstream side for the STS along with a placeholder representation of the target box which also comprises MVD.

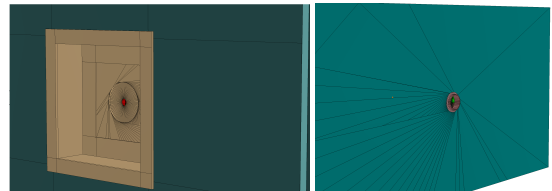


Figure 5: Updated vacuum chamber in the STS box where the MVD detector will be placed (left); beampipe flange to interface STS and RICH beam pipe sections (right).

Assembly, testing and commissioning of the mSTS detector

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Motivation and system layout

The mSTS is a core detector of the mCBM test setup arranged at SIS18 cyclotron as a part of the FAIR Phase 0 project. The layout of the mSTS tracker is downscaled from the STS design. It involves two tracking layers of $12 \times 12 \text{ cm}^2$ and $18 \times 18 \text{ cm}^2$ arranged in four physical units mounted on the aluminum support structures (half-c-frames). The main goal for these studies is to have the ultimate test of the detector performance in the fully integrated system in close-to-final running conditions and fully integrated latest version of components. The development and commissioning of the assembly and testing procedures is planned to be used for the STS. Finally, one can evaluate the hit and track reconstruction performance with the ion beam from SIS18.

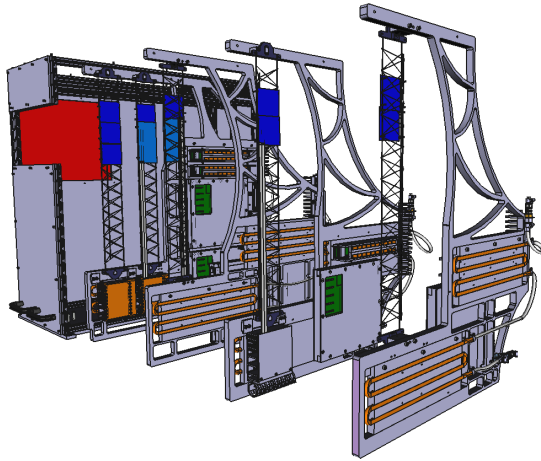


Figure 1: CAD drawing of the mSTS detector. Four units are shifted outside the enclosure for illustration.

The mSTS at the current stage includes 11 modules: two with $62 \times 124 \text{ mm}^2$, 9 with $62 \times 62 \text{ mm}^2$ DSDM silicon sensors; 22 read-out FEBs with 8 SMXs each plus two service FEBs for pulser signal injection. The back-end and powering electronics includes 5 common read-out boards, 5 power boards for FEB to provide supply voltages for the FEBs.

Unit assembly and installation

At the end of 2020 there was only one functioning module at the Unit 1 in the mSTS enclosure. Two modules of the Unit 0 failed because of improper thermal properties of

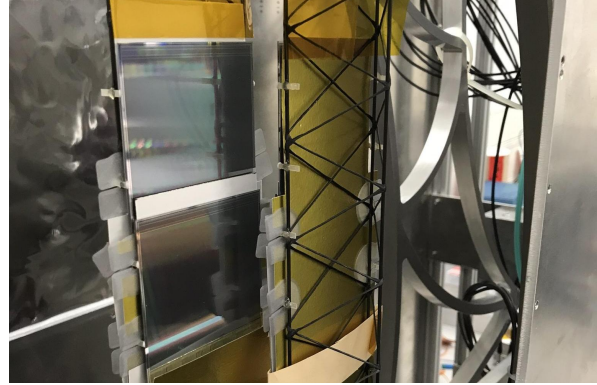


Figure 2: Ladders of Unit 0 (right) and Unit 1 (left) installed inside the mSTS enclosure.

the protection glue at the front-end boards. Thus failed ladder of the Unit 0 was replaced with a new one; the issue with the brittle glob top was addressed. Also, the new version of SMX 2.2, latest LDOs (both 1.8 V and 1.2 V nominal V_{out}) were used for the upgrade.

Modules of the Unit 0 demonstrated good performance before and after installation, showing mild improvement because of proper micro-cable stretching on the ladder support structure (see Fig. 3). However, few ASICs failed after the installation of the ladder to the c-frame support structure. Possible explanation is the residual tension at the FEB connectors of the flat data cables.

The performance of the Unit 1 was affected by multiple electrical shortage in its modules. Particularly, we found out a leak through the bottom edge of the module shield touching the carbon-fibre ladder support structure. Also, one could detect multiple occasional break downs between side edges of the module shields. These issues were addressed with additional Kapton foils and special 3d-printed thin ($120 \mu\text{m}$) insulation pads. All these observations have later led to the improvement of the design of the module analogue lines protection.

The Unit 2 for the given version of the detector was assembled from scratch using the latest versions of the components and taking into account all lessons learnt during the assembly of the previous modules. The process of the mechanical integration is shown in Fig. 4. Few minor mechanical reassessments were made during its assembly; in particular, mechanical support and cooling interface were adjusted for the common read-out boards.

The assembly procedure of Unit 3 was particularly challenging due to the extremely constrained arrangement of

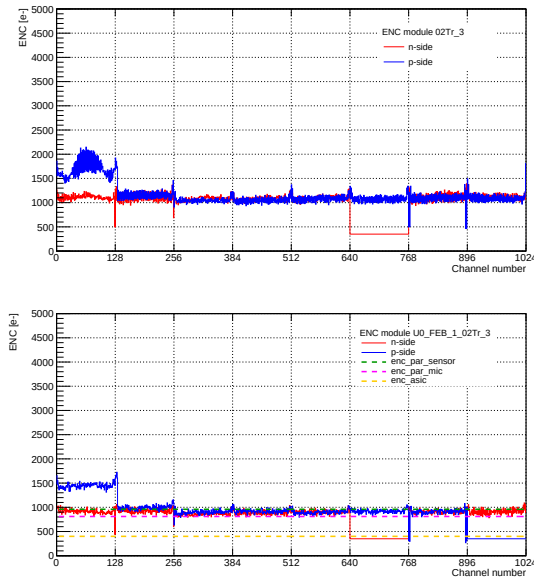


Figure 3: Baseline width of the 02Tr.3 module in the test box before installation (top) and after installation in the Unit 0 (bottom). Mind that ASIC 7 is missing on the p-side.

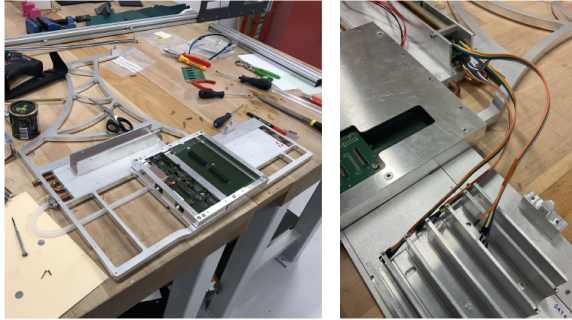


Figure 4: Assembly of the Unit 2 components in the STS laboratory.

its components. Also, the unit frame was used as a test bench for the comparison of the performance if the wide-shielded and narrow-shielded ladders featuring the same topology of three $6 \times 6 \text{ cm}^2$ sensor modules (see Fig. 5, right photograph: all three sensors are exposed at the bottom). Comparative studies showed no significant performance difference. At the end, the narrow-shielded technology was adopted as simpler straight-forward solution.

The last unit of the mSTS suffered from the highest fraction of failed ASICs after the installation. One FEB out of 10 was inaccessible at the end, while three others showed troubled communication with one or two chips each. These issues are believed to be mainly because of the malfunctioning digital communication lines and never experienced with newer integration routines.

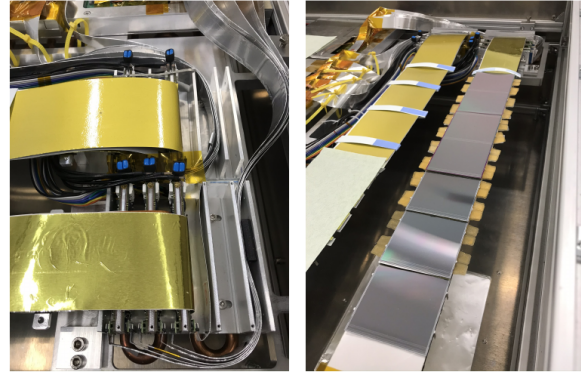


Figure 5: Narrow-shielded ladders installed in the Unit 3.

Also, during the installation of the high-voltage and low-voltage lines for the mSTS modules, we experienced frequent powering failures. Those were addressed with the introduction of new low-voltage lines with more flexible while more robust endings; examples are given in Fig. 6.

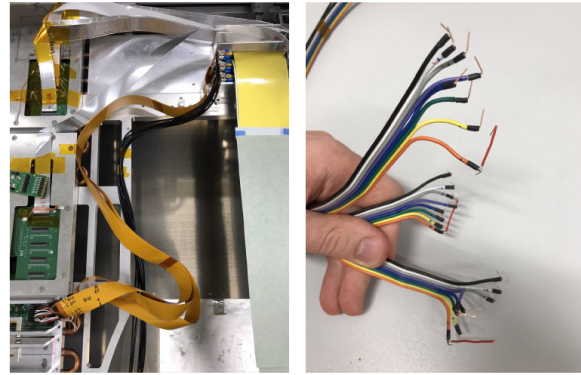


Figure 6: Old (left) and new (right) low-voltage lines for mSTS.

System integration

The units of the mSTS detector were installed in the aluminium enclosure upon their completion. Each module of the given unit was extensively tested before being assembled on the ladder, after ladder installation on the unit and after unit installation into the mSTS enclosure (see Fig. 7).

The mSTS units were provided with necessary services inside the enclosure: low and high voltage according to the STS powering scheme [1], optical lines for DAQ and cooling lines to deal with the heat dissipation in the red-out electronics. The patch panel for the detector services was installed on the front wall of the mSTS enclosure; it is shown in Fig. 9.

The powering and high-voltage bias of the mSTS detector modules required special wire harnesses (shown in Fig. 8) to be manually arranged each time for a specific

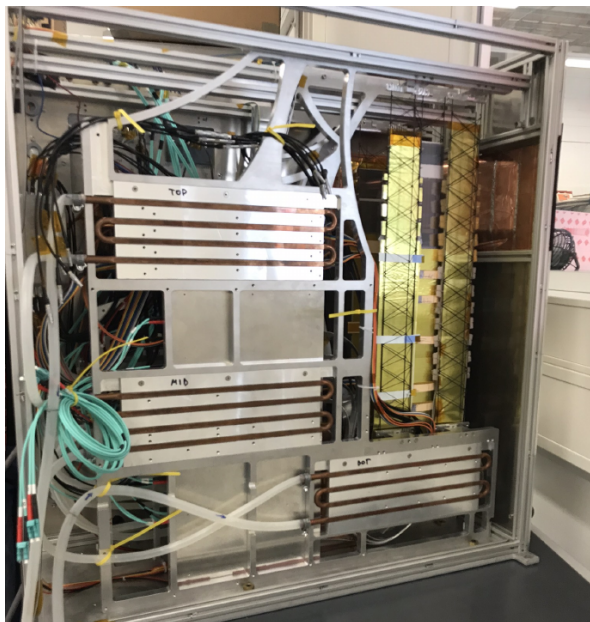


Figure 7: All units installed in mSTS.

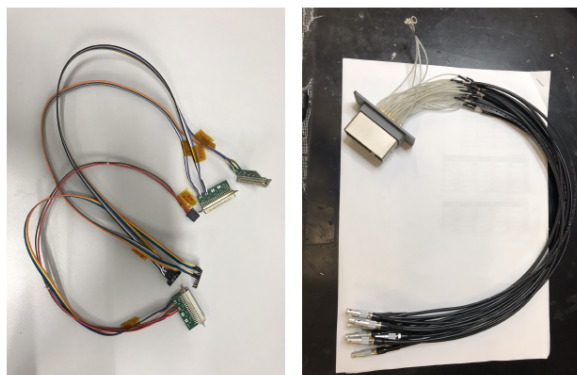


Figure 8: LV (left) and HV (right) wire assemblies for the mSTS detector. The LV line features particularly complicated topology to respect the nominal mapping of the detector powering scheme.

unit to respect the electronics mapping at the cable and power crate levels. Also, a combined high-voltage filter was specifically prepared to provide mSTS sensors with the clean and stable high voltage source.

After installation of the units and integration of the services the assembled detector was fully commissioned and tested in the STS laboratory; no performance deterioration was observed comparing to the individual unit tests.

Transportation to the cave and operation

The mSTS detector was transported to the mCBM cave at once with its enclosure sealed. The basic functionality tests and electrical tests followed the transportation: no im-

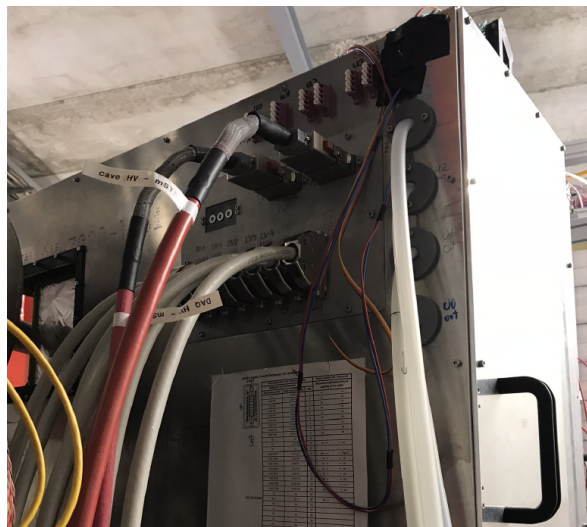


Figure 9: The mSTS detector installed in a cave.

mediate issue was observed at the time. Later, during the first days of the detector operation we observed the need in the additional cooling power for the long-term machine run. Two water cooling units of 300 W and 500 W cooling power at operation temperature of about 15 °C were installed to provide cooling of Units 0–2 and Unit 3, respectively.

The powering of the detector electronics was provided by the MPod power crate installed next to the mCBM cave. The high voltage for first two units was sourced by the same crate. Two other units received bias voltage from the HV unit installed in the counting room.

The calibration files necessary for the proper detector operation were uploaded to the DAQ machines for the first three units. The Unit 3 received those later which lead to its belated introduction to the full system operation. Apart from that, all four mSTS units were proved to be mainly functional after the installation and transportation procedures.

The details of the detector operation are given in the separate chapter of the present report.

Conclusions

The assembly of the mSTS detector served as a perfect playground for the development of the integration procedures of the future STS machine. Many design features were tested and some of those readdressed based on the installation or operation experience.

References

- [1] P. Koczon, C. J. Schmidt, U. Frankenfeld, R. Kapell, J. Lehnert, A. Lymanets, O. Maragoto Rodriguez, A. R. Rodriguez and K. Kasinski, PoS **370** (2020), 063 doi:10.22323/1.370.0063

EPICS based test setups on the way to the Silicon Tracking System's Detector Control System

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Data acquisition, parameters monitoring as well as storage are very important tasks for every experimental setup. Furthermore, the previously mentioned tasks become even more crucial in an environment of heavy ionizing irradiation. In order to ease the use and implementation time of different software instances, a fairly novel approach was used. It is primarily based on a containerization of different EPICS-related applications used to monitor and control experimental setups [1]. This contribution contains an overview of activities which partially or fully build upon the containerized applications.

The mSTS as a pathfinder

Harsh environment, radiation or magnetic field could cause a temporary limitation to access a given setup. Therefore, in many cases certain applications need to be deployed in order to ensure efficient monitoring and control of a setup. For this purpose, a complete Detector Control System (DCS) for the mSTS was deployed. This system features the solutions listed in [1], it ensures operational safety and enables an operator to:

- monitor process variables and check their history;
- control services used by the mSTS;
- take actions in case of alarm states.

The mSTS consists of 11 detector modules, what corresponds to 22 Front End Boards (FEBs). Each FEB is powered by a low voltage line, and it also provides bias voltage for the silicon sensor. In total 51 channels are used to power the mSTS. Moreover, two Lauda chiller are used to efficiently cool down the Front End Electronics (FEE). To monitor the performance of the mSTS several temperature and humidity sensors were placed inside the enclosure. Their values provide a valuable insight into the detector operation, indicating i.e. coolant setpoint. Figure 1 shows the latest scheme of control nodes and services. One of the crucial elements of the system is the Finite State Machine (FSM). It is deployed on one of the nodes which is responsible for the operational safety of the system. If there is any problem with the cooling (device failure, not enough coolant etc.) or the temperature rises too much, then the FSM automatically powers down the FEE. The described detector control system of the mSTS has been operational for more than 8 months without any major problems, neither operational nor hardware.

^{*}https://www.gsi.de/work/forschung/cbm/qm/cbm/activities/sts/group_members

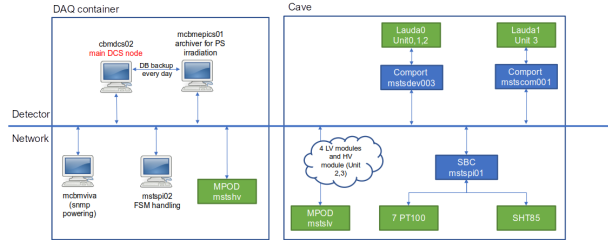


Figure 1: Schematic view of the DCS structure.

Power dissipation of the mSTS

The mSTS modules can be distinguished not only by their units, but also by the components from which they are built. Figure 2 shows how the power dissipation of different units differ depending on the used components. The power dissipation depicted in the plot is the sum of all the contributions from voltage drop in the lines, connectors, DC/DC converters and FEBs.

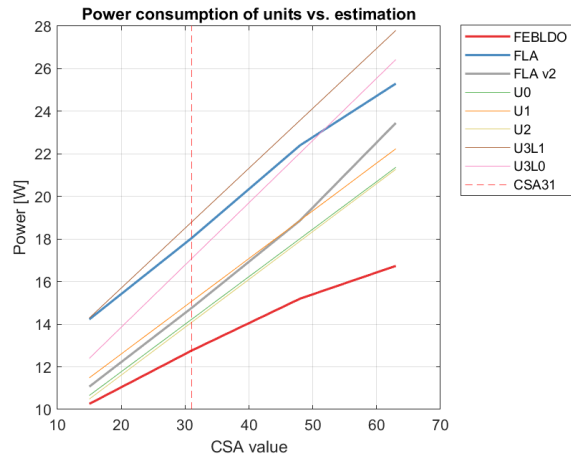


Figure 2: Comparison of a power consumption of different mSTS modules based on average unit current and estimations based on FEB currents measurements (Charge Sensitive Amplifier nominal value marked with dashed red line).

The modules of units 1 and 3 were previously used for other tests, and they are built out of older parts, thus their power dissipation is much higher than for units 0 and 2. Power dissipation of modules from units 0 and 2 matches the calculations depicted as FLAv2 based on measurements

aimed to estimate currents drawn by a FEB and theoretical calculations of voltage drop in the other components of the mSTS. Furthermore, Figure 2 shows the successful efforts made to enhance the electrical performance of the modules.

Irradiation of a MPOD crate

The control system based experimental setups provide important insights into the operation of devices in radiation environments. MPOD crates with low voltage modules will be used for powering of the Front End Electronics (FEE) during the CBM experiment. In order to evaluate the effect of the radiation on the power supplies, a CC24 controller, a low voltage module and a high voltage module were irradiated during the mCBM experiment.

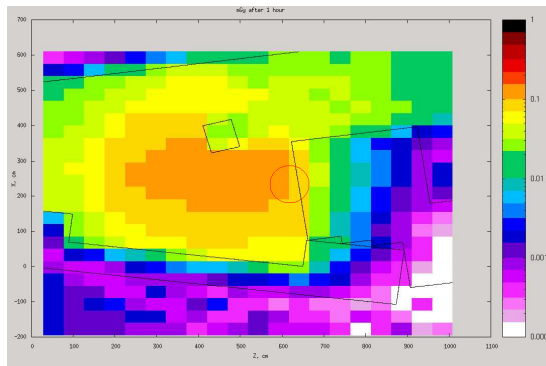


Figure 3: Expected ionization dose distribution in the miniCBM cave at O+Ni 2GeV 10^7 ions/s on 4 mm Ni target; (the red circle indicates the crate position). FLUKA simulation by A.Senger.

The crate was located (Figure 3) in such place to ensure a similar dose that those crates will experience during the CBM experiment.



Figure 4: MPOD mini crate and TLD dosimeters

Figure 4 shows the experimental setup. Control and monitoring were implemented to ensure that a Single Event Upset (SEU) can be detected and associated with a corresponding part of the crate. After two months of irradiation, the total dose reached 67.5 mGy. Based on this number and calculations, we could expect about 1.5 SEU per controller per month during the CBM experiment. Nevertheless, the low SEU statistics resulted in another irradiation campaign at the septum of SIS18 accelerator.

Thermal cycling of FEBs

Another important activity aiming to evaluate the FEE in the operation conditions of the STS is also partially based on the control system developments. There are several possible operation scenarios:

- normal operation as depicted in Fig. 5. It corresponds to the temperatures between -12°C and -17°C . In this scenario, FEBs need to survive temperature changes around 25°C during active cycling and about 20°C during passive cycling;

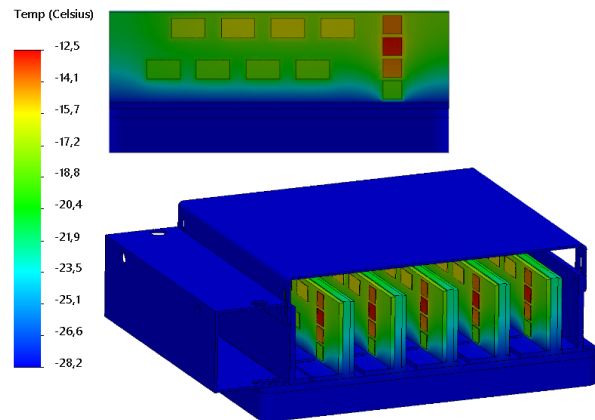


Figure 5: Temperature map of the FEB and a FEB box during the nominal operation.

- reboot scenario - in this case, any FEB is switched off for a given fin, that would mean that the FEB temperature is around -27°C and the non-powered FEB is even colder. In this case, the temperature change would be around 10°C for the active FEB and around 20°C for the passive FEB;
- switch-off scenario - due to the failure of a power board or a power supply, FEB(s) will switch off and their temperature will drop down to -38°C . That would correspond to the temperature change of about 30°C for the passive FEBs. This scenario results also in the need to power up the FEBs at very low temperatures.

To summarize, a FEB needs to survive temperatures changes of:

1. passively* non-powered FEBs) - 30°C
2. actively - 25°C
3. startup at - 38°C

The setup prepared for those tests is depicted in the Figure 6. The components used for completing the setup including interfaces between the FEB and the fin, as well as between the fin and the cooling plate, were different from those planned for the STS. An example of a few cyclings can be seen in the Figure 7.

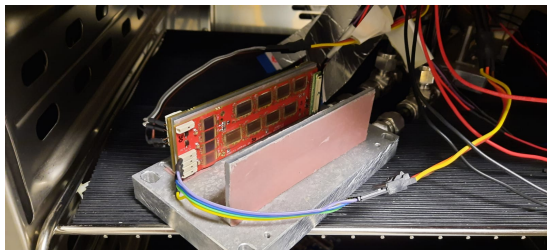


Figure 6: Two FEBs attached to one fin residing on a cooling plate and connected to the low voltage cables and read-out inside a climatic chamber

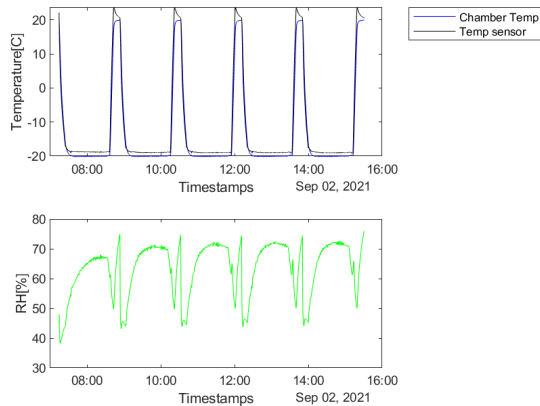


Figure 7: Passive cycling of FEBs, temperatures of the Lauda chiller and Binder depicted in the first plot (40°C change) and relative humidity values in the plot below

Initial round of thermal cycling involved 4 FEBs, and it aimed to evaluate the performance as per the plan which was described above. In order to do that, FEBs underwent frequent optical and performance inspections. The first round of cycling activities leads to the following conclusions:

- during passive cycling no issues were observed regardless of the temperature difference set during the cycling (down to -40°C);

- during the active part of cycling some issues with LDO were observed. Therefore, a second round of cycling experiments has already begun to increase the statistics and also adjust some parameters (LDOs voltage drop, currents) to have a more realistic approach as per the operation in the STS and using the components that are planned to be used for the final detector.

Fiber optic sensors for the STS

In order to ensure safe operation of the detector at low temperatures (ambient temperature about -10°C and cooling plate temperature around -40°C) the information about the relative humidity or frost point is of the uttermost importance. Ionizing radiation and magnetic field also play a role in choosing proper humidity sensors. Furthermore, it has to be relatively easy to implement such sensors in a hardware interlock.

The STS will most likely have 3 different technologies and types of humidity and temperature sensors:

- capacitive sensors - one of the commercially available sensors
- Sniffing system
- FBG based Fiber Optic Sensors

Each of the sensors is supposed to play a different role in the operation of the STS. The capacitive sensors will be used during the commissioning and for the reference at the early stages of operation. Sniffing system which will suck the air from the inside of the STS provides very accurate measurements of the water content. Furthermore, the read-out can be easily integrated with a PLC-based interlock. The Fiber Bragg Grating-based Fiber Optic Sensors (FBG FOS) will provide information about the temperature and humidity throughout the experiment. Their features ensure accurate operation in magnetic field and also after irradiation. A first approach to calibrate and characterize such sensors is summarized in [2]. That contribution contains also the working principles of FBG FOS.

FOS can be used either as an array of sensors or as a single sensor. In both cases, to measure relative humidity it's necessary to precisely measure temperature. The temperature measurement point should be as close as possible to the humidity measurement point.

Tested sensors are depicted in Figures 8 and 9.



Figure 8: Temperature and humidity FBG-based FOS.



Figure 9: Humidity FBG-based FOS in an array.

The thickness of the polyimide coating over the Fiber Bragg Grating is $20\ \mu\text{m}$. The main difference between the active part of the sensors lays in the technique of applying the hydroscopic coating. In case of the array the polyimide was applied in layers of $5\ \mu\text{m}$ and in case of single sensor it was just one layer of $20\ \mu\text{m}$.

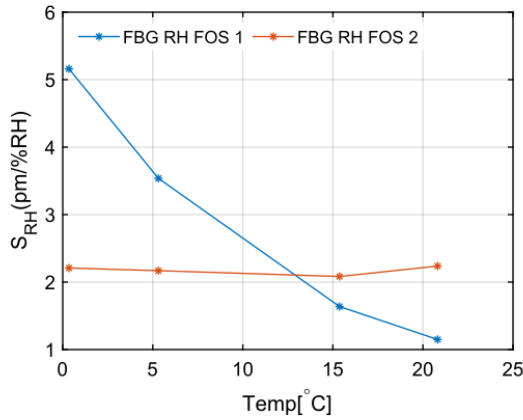


Figure 10: Relative Humidity sensitivity at different temperatures.

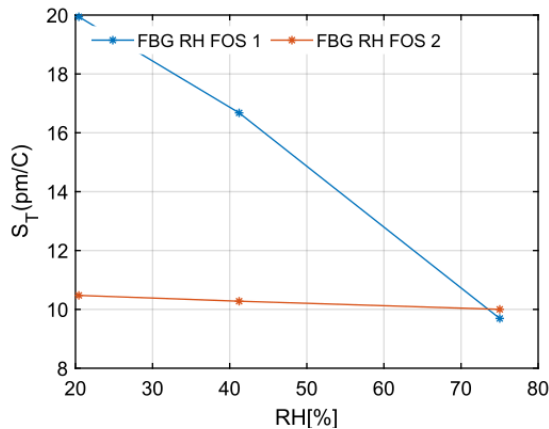


Figure 11: Temperature sensitivity at different relative humidity values.

$$\frac{\Delta\lambda_B}{\lambda_B} = S_{RH}\Delta T + S_T\Delta RH \quad (1)$$

According to equation 1, a Bragg wavelength change is sensitive to both temperature and relative humidity changes. Therefore, both factors need to be experimentally determined in order to measure the RH. The readout of the interrogator, sensors and storage were all implemented with use of EPICS based containerized system.

Calibration curves of two humidity sensors are illustrated in the Figure 10 and 11. The sensor FOS 1 doesn't have a linear response, what is probably related to damage during the assembly. The second sensor has $S_{RH} = 2,17\ \text{pm}/\%\text{RH}$ and $S_T = 10,25\ \text{pm}/^\circ\text{C}$ what is consistent with the results reported in [2]. The time constant of the sensor equals to 180 s, which is a much higher value in comparison to the capacitive sensor data sheets (e.g. 8 s for the SHT85). Nevertheless, a fast response time is not a crucial parameter for the STS.

The performance of these sensors will be compared with the array of sensors in terms of sensitivity factors, time-response and hysteresis. The final design for the STS will be chosen based on the previously mentioned factors and mechanical constraints of the detector.

Conclusions

The containerized EPICS-based applications have proven to be extremely useful regardless of the setup size. EPICS based input output controller, graphical user interfaces, archivers, databases, alarm servers, alarm loggers can be easily deployed and monitored. The described cases summarize the efforts towards the building blocks of the DCS for the STS and presumably other subsystems of the CBM experiment.

References

- [1] M. Bajdel et al., *The Containerized Detector Control System for mSTS in mCBM*, CBM Progress Report 2020, 153-154
- [2] M. Bajdel et al., *Towards humidity and temperature monitoring of the STS*, CBM Progress Report 2020, 49-50

Performance of the mSTS detector during the mCBM beam campaign 2021

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In the mCBM 2021 beam campaign at SIS18 (GSI), O+Ni collisions at 2 AGeV were measured with beam intensity of up to 10^{10} ions per spill (cycle of about 10 s, extraction during ca. 7.5 - 8 s) and approximately 500 kHz interaction rate.

The mini-STs (mSTS) setup consisted of 2 tracking stations covering a total area of $12 \times 12 \text{ cm}^2$ and $18 \times 18 \text{ cm}^2$ respectively, arranged in 4 units with a total of 11 modules: two modules with $62 \times 124 \text{ mm}^2$ and 9 with $62 \times 62 \text{ mm}^2$ double-sided double-metal silicon microstrip sensors, equipped with 2 Front-End Boards (FEBs), each comprising 8 SMX (STS/MUCH-XYTER) ASICs each for the readout, plus two service FEBs for pulser signal injection, 5 C-ROB boards for readout, and 5 POB boards providing low voltage for FEBs and C-ROBs [2].

Commissioning and operation

Prior to the installation in the mCBM cave, an energy calibration was performed to adjust the dynamic range of the ADC using a calibrated internal pulse generator and dedicated counters in the chip to record the S-curves. The estimated baseline noise level corresponds to ENC below the targeted system noise of $1000 e^-$.

During the few hours of main data taking time, the first tracking station was fully operational, except for a few scattered channels and two entire read-out ASICs missing, and was operated with significantly different thresholds (between 2500 and 12000 e^-) in order to allow systematics performance studies. Parts of the last unit in the second tracking station could not be brought into stable operating conditions; therefore, it was kept off.

The mSTS data rates were up to 280 MB/s, which corresponds to an average of 70 Mhits/s.

Hit reconstruction

Reconstruction chain

The data from the detectors are recorded in a set of time slices written into a Time Slice Archive (TSA-file). These time slices contain the full amount of data recorded by the DAQ in a defined time frame (5.12 μs in this case). The TSA-files are first unpacked and written in a CbmRoot tree, which contains *digis*. CbmStsDigis are raw data that contain the address (channel and module) of the fired strip, and time and charge information of the signal. *Clusters* are reconstructed by correlating signals from neighbouring fired strips. *Hits* are finally derived from the correlation of clusters on the p- and n-sides. *Events* are defined using a seed detector (mTOF in this case) and including all digis within

a symmetric time window: $(-50, +50)$ ns. A trigger condition of 3 mTOF digis was set in order to accept the event.

Time calibration

The hit reconstruction algorithm looks for pairs of clusters: front and back side of the sensor, within a specific time window. In order to avoid the reconstruction of hits from non-correlated clusters is necessary to adjust the global mSTS and the individual ASICs' offset to ensure synchronization. A fine time tuning requires a precise time measurement reference, which is the main reason for selecting the detector with the best time resolution available during the campaign: mTOF. The time correlations between mSTS-mTOF have been built for a time slice, from where the global time offset between the two subsystems is extracted after fitting the correlation peak.

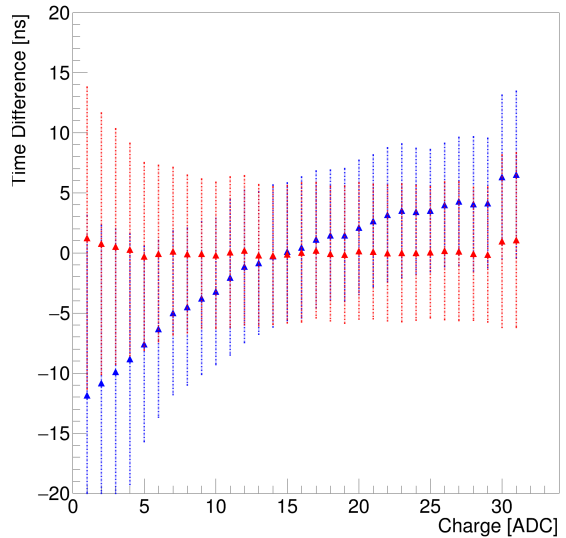


Figure 1: Time walk correction as a function of the signal charge (in ADC units): (blue) time difference between mSTS-mTOF digis; (red) time difference after time walk correction.

It is also crucial to check the charge dependence of the signal timing: time walk effect [1]. The relevance of such a test arises from the fact that the time delay due to time walking is considerable, reaching values of up to 20 ns, which prevents the cluster search algorithm from working optimally with the smallest possible time window. Incorrect digi's time could lead to the wrong formation of clusters either by grouping digis with the incorrect time or

excluding them, making a wrong local hit reconstruction due to truncated clusters. Figure 1 shows a comparison before-after the time-walk correction implemented for an ASIC, where the error bars represent the *r.m.s.* for the given charge intervals. This charge-dependent time-shifting is applied at the digi-level.

Once the proper time calibration has been done, the time resolution of the mSTS can be extracted. Figure 2 shows a time difference plot between mSTS-mTOF digis. Fitting the peak, the value of $\sigma = 6.449(9)$ ns was obtained for a mean value $\mu = -5.536(9)$ ns.

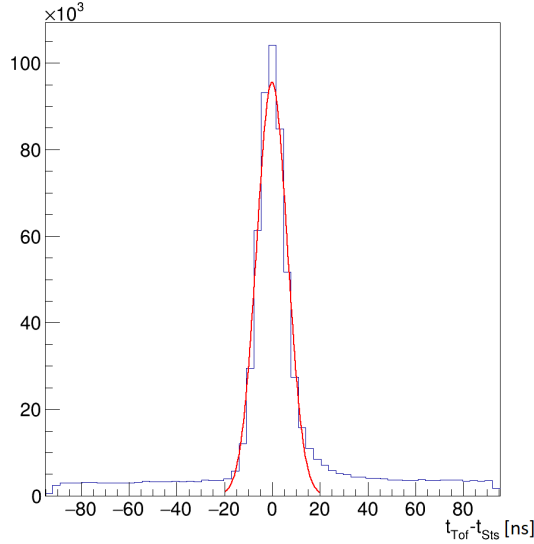


Figure 2: Fitted time difference, mSTS-mTOF digis.

Charge calibration

Charge calibration must be applied before proceeding to the reconstruction step. Figure 3 shows the charge distribution of all clusters as a function of the cluster size. Figure 4 shows the charge distribution of 1-strip-cluster signals that are correlated on the p- and n-sides for unit 0 and unit 2, where different thresholds and calibration were used. Although the lower threshold of the units are not the same, nor the overflow bins lay at the same charge value, the overall distributions are quite similar, with a clear peak around 24 000 e^- corresponding to the MIPs, clearly separated from the noise contribution, especially visible in unit 0 where the hardware threshold was set to 2 580 e^- .

Hit reconstruction

In the reconstruction, clusters are obtained by neighboring strips fired close in time (± 20 ns). Hits are built from the correlation of clusters on the p- and n-sides within a time window of 20 ns. Figure 5 shows the reconstructed hits projected on the XY plane. From the top picture, the impact of the missing ASICs on the reconstruction can be seen, leaving a relevant empty area.

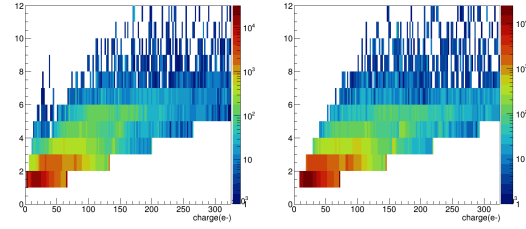


Figure 3: Cluster size vs charge distribution: (left) unit 0, (right) unit 2.

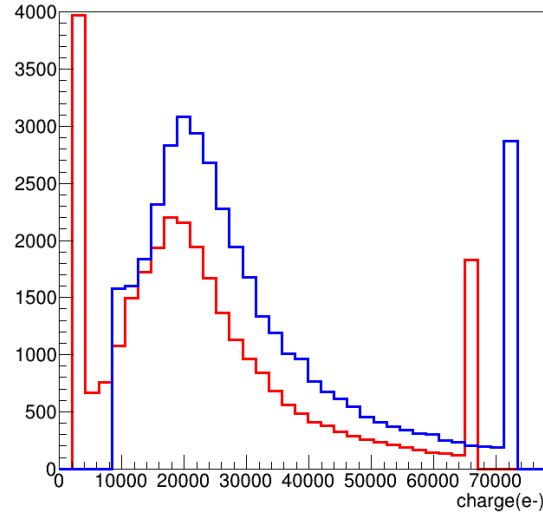


Figure 4: Charge distribution comparison: (red) unit 0, (blue) unit 2.

Space correlations

STS tracklets

The correlations between hits of the different stations allow to extract information on the space resolution achieved with the mSTS system. At first, all hits of station one are combined with all hits of station two inside a time window of $(-50, +50)$ ns (Fig. 6 (top)). Then only the pairs that are closest in time, are kept. For those, X and Y correlation are shown in Fig. 6 (bottom). Picking the pairs closest in time significantly reduces the influence of non-correlated hits and improves the spatial resolution. The correlation is better in X than in Y direction since the sensor pitch follows the X coordinate, while in Y is tilted and the resolution is therefore reduced by $1/\tan(7.5^\circ)$.

Moreover the YY correlation was built by merging the contribution of the different units in the first station, which are located at different z-positions. The effect has been verified in simulations. Figure 7 shows the same correlation, separately for the hits that come from the two different units. Clearly, the two diagonal structures have differ-

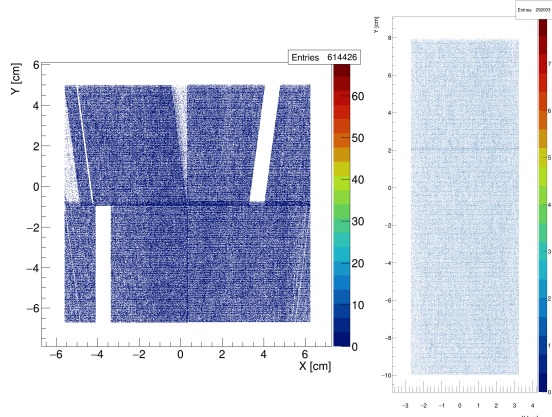


Figure 5: Hits map projection on XY plane: (top) station 1, (bottom) station 2.

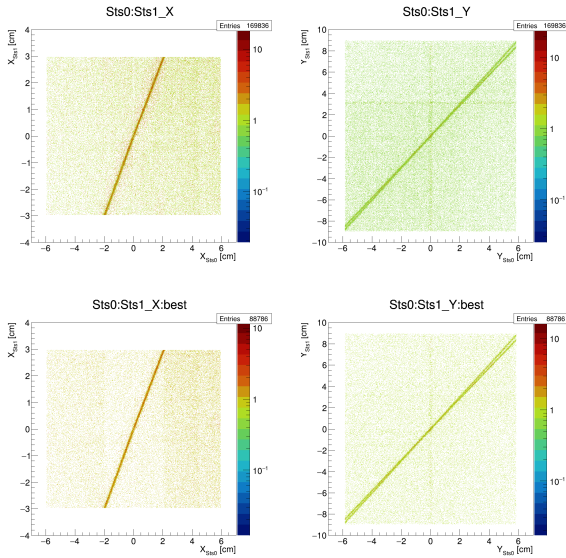


Figure 6: Hits correlation between mSTS stations: (left column) X correlation, (right column) Y correlation; (top) correlations inside $(-50, +50)$ ns time window, (bottom) correlations for best time match.

ent angles, producing two different correlations. Although the difference between the angles is relatively small, it produces significant smearing of the peak obtained when projecting along the diagonal. Then, it is essential to split them when estimating the resolution.

The resolution determination is obtained by fitting the peak after projecting along the diagonal of the corresponding correlation. Figure 8 shows these projections as well as the comparison versus simulation (top: XX correlations; bottom: YY correlations for unit 0).

The standard deviations obtained from the fit reported in Table 1 are highly consistent with the expectations from simulation.

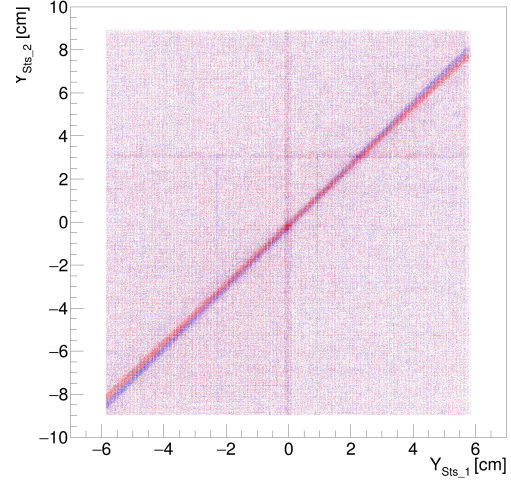


Figure 7: Hits correlation for YY from simulated data: (red) unit 0 contribution; (blue) unit 1 contribution.

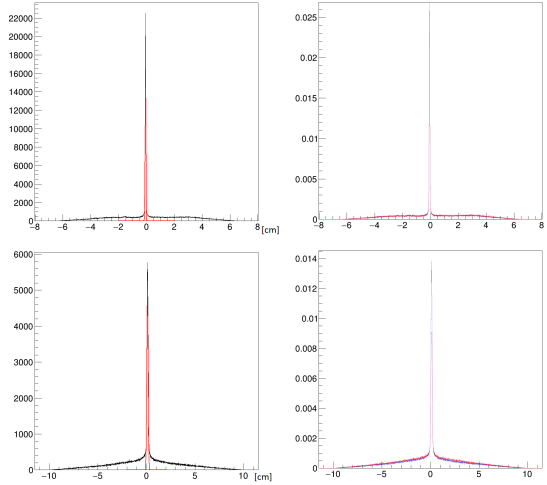


Figure 8: Left column: fitted peak (red) of the diagonal projections (black). Right column: comparison between simulation (red) and data of the normalized projections for the correlation (blue).

Table 1: Standard deviations for the fitted peaks.

[cm]	σ_{XX}	$\sigma_{YY(0)}$	$\sigma_{YY(1)}$
Simulation	0.0280(2)	0.0603(6)	0.1063(13)
Data(run 1588)	0.0280(3)	0.0655(7)	0.1099(16)

Vertex reconstruction

The best mSTS hit combinations are used to extrapolate to the expected vertex position in the target plane. Using a residual minimization procedure, the optimal position of the detector with respect to the target has been determined. Figure 9 shows the XY distribution of reconstructed vertices. The target is a rectangular Ni plate of 15×35 mm².

Our vertex reconstruction is consistent with the target dimensions and a plausible beam spread of about half a centimeter.

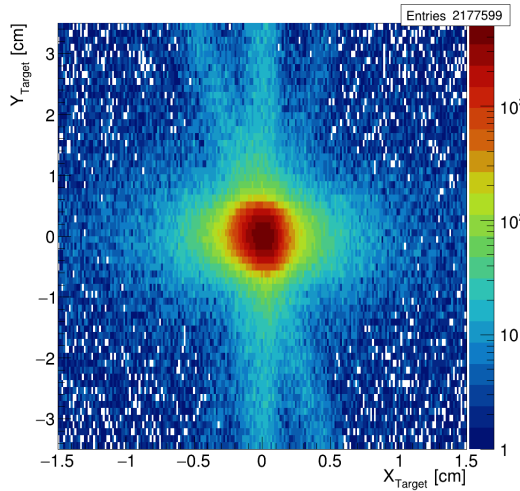


Figure 9: XY distribution of reconstructed vertices.

STS-TOF correlations

STS hits are also correlated with hits reconstructed in the mTOF detector, after a residual minimization procedure [3] has been applied to determine the optimal position of the two detectors relative to each other and to the target. Figure 10 shows mSTS-mTOF correlations in X and Y: the width is mainly determined by the worst space resolution of the mTOF detector, and the large distance between the two systems.

Hit reconstruction efficiency

Using an additional external detector allows one to check the performance of each mSTS station individually, as it is possible to build tracklets from the correlation of any two hits and check the hit reconstruction efficiency of the third station. Specifically, hits in the first mSTS station are correlated with hits in mTOF, the tracklet is extrapolated to the plane of the second mSTS station and the expected space point is calculated. Figure 11 shows the XY distribution of tracklets extrapolated to the first and the second mSTS station, respectively.

Finally the expected, extrapolated space point is correlated to the hits effectively reconstructed on the second mSTS station. This can be studied for both mSTS stations. Figure 12 shows the X and Y correlations between the extrapolated hits and the reconstructed hits, for both cases.

However, to make a quantitative assessment of the hit reconstruction efficiency, as reference candidates should be considered only those space points arising from extrapolation of tracklets that correspond to a real particle, and do

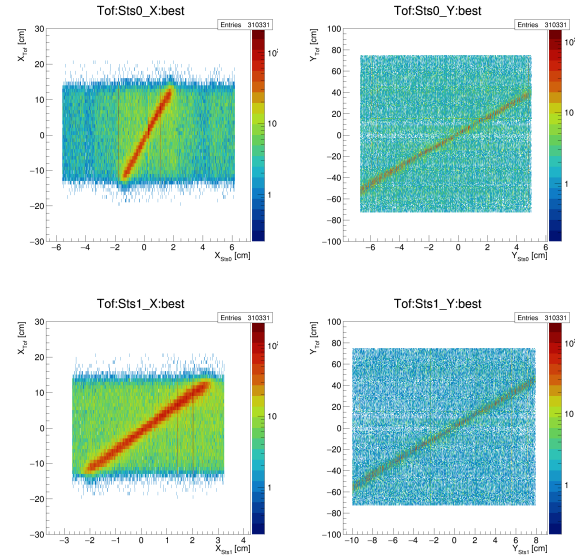


Figure 10: Hits correlation: (left column) X correlation, right column) Y correlation; (top) mTOF vs mSTS station one, (bottom) mTOF vs mSTS station two.

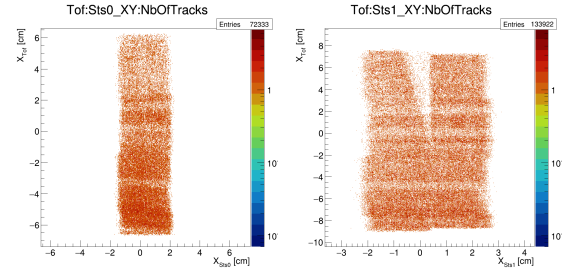


Figure 11: Extrapolations from mSTS-mTOF tracklets: (left) on the first, (right) on the second mSTS station.

not fall into inactive areas of the detector. Therefore the algorithm has been studied with simulations. In simulations it is possible to check whether the correlated detector hits are generated from the same track. Figure 13 shows the difference of the X position of the extrapolated expected hit to the locally reconstructed one, Δx , for all possible combinations (black), only for those where the hit in the reference mSTS station and in the mTOF (blue) or when all three hits in the two mSTS stations and in the mTOF have contribution from the same track (green). Clearly the cases corresponding to the same track traversing all the three stations are concentrated in a narrow peak around zero, on top of a combinatorial background arising from random hit combinations.

In the data, we cannot check whether a pair of hits is generated from the same track. However, the sample of real correlations can be enhanced imposing that all pairs used to build the extrapolations come from the target. For this, the mSTS0(1)-mTOF tracklets were extrapolated to the target plane (similar to what shown in Fig. 9 for the mSTS0-STs1

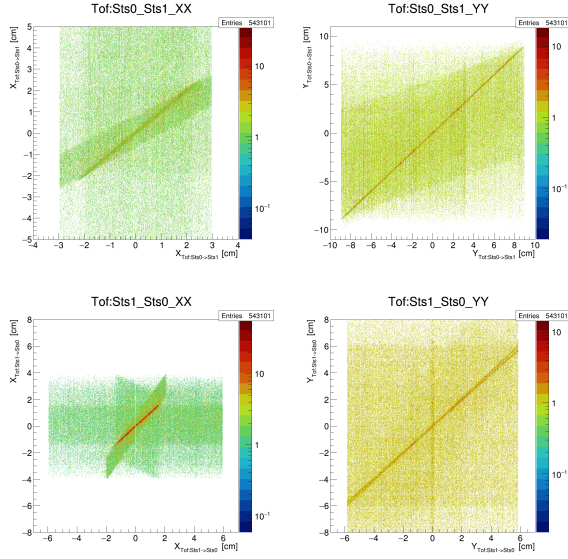


Figure 12: Hits correlation: (left column) X correlation, (right column) Y correlation; (top) extrapolated hits using mTOF and mSTS station 1, (bottom) extrapolated hits using mTOF and mSTS station 2.

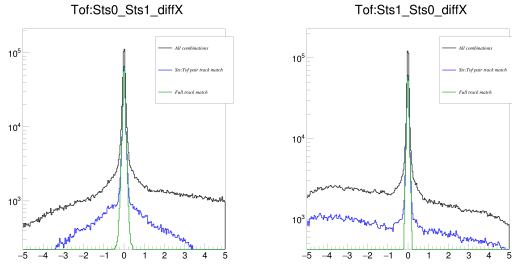


Figure 13: $\Delta x = X_{extrapolated} - X_{locally\ reconstructed}$: (black) all possible extrapolations; (blue) only hits pairs, mSTS:mTOF having contributions from the same track; (green) only when the triad extrapolated (pair mSTS:mTOF), locally reconstructed, have contributions from the same track.

tracklets) and only those pairs coming from the small intense region were used to build the reference space points. Figure 14 shows the difference in X between those reference points (from mSTS0(1)-mTOF tracklets) and the locally reconstructed (STS1(0)) points. The correlation peak is slightly more narrow and centered for simulations, because of the uncertainties of the alignment procedure applied in data, but otherwise the agreement is remarkable.

Based on this, we can derive a condition for the efficiency: the extrapolated hit is considered found (i.e. matched by a local reconstructed hit) if the XY-distance between them $\Delta\rho \leq 0.2$ cm and if they are all inside a time window: $\in [-50, +50]$ ns.

In order to avoid issues with inactive areas of the detector, the comparison between expected extrapolated and

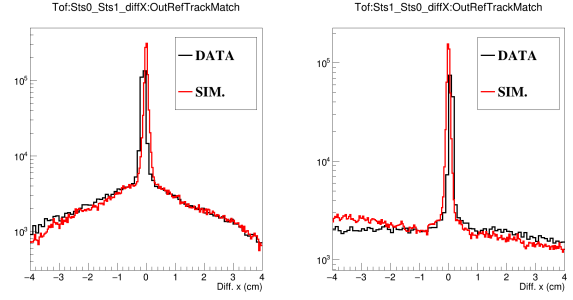


Figure 14: $\Delta x = X_{extrapolated} - X_{locally\ reconstructed}$ of (red) simulations: hits pairs, mSTS:mTOF having contributions from the same track; (red) hit pairs mSTS:mTOF originating from the target.

locally reconstructed hits has been made in a small limited area $x \in [-1.5, 1.5] \cap y \in [-5, -2]$, where the detector is fully operational. This lead to an approximate value of efficiency: 97.6% for station 1 and 97.4% for station 2.

Summary and outlook

For the first time in the beamtime of July 2021 a mSTS setup comprising of two tracking stations and a large number of modules was built with the most up-to-date components, assembled and operated. The targeted STS system noise of around 1 000 e^- was achieved, in agreement with theoretical expectations. Reliable long-term operation in heavy-ion test-beam was achieved. Besides a few unconnected channels (typically less than 1%), and two broken ASICs, three detector units were operational. An excellent space and time resolution, in line with expectations, was demonstrated. The charge distributions of reconstructed hits show a clear separation between noise and mip position. Using the correlations of mSTS hits, the vertex reconstruction is achieved successfully. Using the mTOF as additional external reference, we assess a satisfactory sizable hit reconstruction efficiency of 97.5%, compatible with the expectation from simulations. Further differential studies can bring insights in the dependence on thresholds and further settings of the detector.

References

- [1] A. R. Rodriguez, *The CBM Silicon Tracking System front-end electronics: from bare ASIC to detector characterization, commissioning and performance*, PhD thesis, Goethe Universität Frankfurt (2020), urn:nbn:de:hebis:30:3-549047
- [2] M. Teklishyn and A. Lymanets, *Assembly, testing and comissioning of the mSTS detector*, this report
- [3] A. Weber et al., this report

Beam test of a STS prototype for the J-PARC E16 experiment*

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Introduction

J-PARC E16 [1,2] aims to measure dielectron in pA collisions at 30 GeV. It started its commissioning in 2020, and the first physics data taking is expected in 2023. We will adopt STS as the most inner tracking system for the spectrometer. We expect it to have a position resolution of approx. $30\ \mu\text{m}$, a time resolution of approx. $6\ \text{ns}$ and an efficiency of approx. 95%.

We have performed a beam test using the positron beam at ELPH, Tohoku University [3] in December 2021. The purpose was to establish STS operation by ourselves and to measure the time resolution and the efficiency of the prototype 02TI_6. The size of the Si sensor is $62 \times 62\ \text{mm}^2$. The FEB8 boards are connected by 45 cm-long micro-cables and are equipped with prototype SMX's v2.1 [4].

Experimental setup, DAQ and STS box

The test experiment was performed at ELPH on December 20-23, 2021. Positron beam with a momentum of $600\ \text{MeV}/c$ was used. The beam repetition cycle was 17 sec, out of which the beam was extracted continuously for 10 sec. Fig. 1 depicts the experimental setup. Five scin-

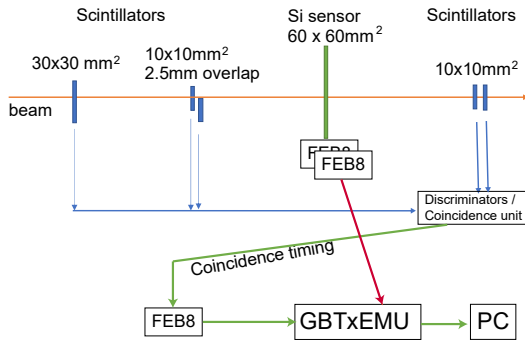


Figure 1: Experimental setup

tillators were used to define the beam spot to be 2.5 mm horizontally and 10 mm vertically. The coincidence rate of the scintillators were about 30 Hz when the beam was extracted. In between the scintillators, the STS prototype was placed. Data taking was performed using a GBTxEMU board connected to a PC through a switching hub. The two

FEB8 boards of the sensor were connected to the GBTx-EMU board through flat cables. We prepared a separate FEB8 board whose calibration port accepted the scintillator coincidence signal. The FEB8 was also connected to the same GBTxEMU. The e-link clock was 160 MHz and the TDC is counted in DDR, which resulted in $3.125\ \text{nsLSB}$.

A special firmware of the GBTxEMU was prepared for the test experiment, based on Smx-tester [5]. Smx-tester has data FIFO for each e-link and records 64-bit 40-MHz system-clock together with the SMX data frames. While TDC of an STS hit is only 14bit (the full range is $51\ \mu\text{sec}$), 64-bit system-clock enabled us to reconstruct higher TDC bits. Slow control and FIFO readout can be done using IPBus which was very slow for data taking ($\sim 1\ \text{sec}$ per e-link). Therefore, SiTCP [6] was implemented which enables fast TCP data transfer up to 1 Gbps. A data frame was 96 bits in total and was received by the PC.

Figure 2 shows a photo of the STS box. The sensor is glued using CAF4 on to the sensor support (black in the photo) which is made of ABS. Then the support is mounted on the aluminum back plate. The FEB8 boards of the sensor are attached to a 1 cm thick aluminum plate using heat-conducting sticky sheets. This plate is attached to the back plate which is cooled on the outside by a fan.

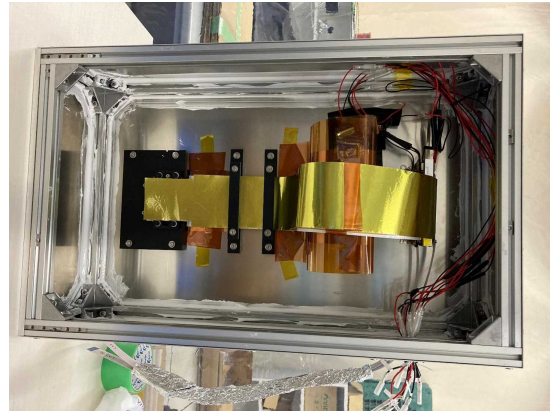


Figure 2: Photo of the STS box, taken after the beam test. The Kapton sheets were not there at the time of experiment, which may have caused the electrical contact problem.

The bias voltage applied to the sensor was only $\pm 35\ \text{V}$ as there was a current leak when more bias was applied. (The nominal value for the bias is $\pm 75\ \text{V}$.) We suspect the cause of the leak is due to an electrical contact between the micro-cables and the STS box. The applied bias voltage

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was close to the value required for full sensor depletion, but did not reach over-bias. Therefore, the collection field is very weak near the strip and could worsen the collection efficiency.

The noise level was quite high and vary time to time, possibly due to grounding, not-enough bias voltage, and loose micro-cables moving around inside the box.

Results and discussions

For a very short period of time the noise level was low enough to take data. The data presented here was taken during that period. Three SMX's from the n-side were only readout and used without ADC calibration (trim adjustment).

Figure 3 shows the time difference of the sensor hit and the scintillator coincidence. We observed two peaks. Peak 1 comes from an SMX and peak 2 comes from the other two SMX's. The figure illustrates a problem in the synchronization which needed to be solved. According to Peak 1, the time resolution was 5.6 ns which is good enough for the J-PARC experiment. Note that time walk correction was not done. Figure 4 shows the beam profile. Here, peak 1 (blue line) corresponds to the Peak 1 in Fig. 3. The efficiency was only approx. 25%.

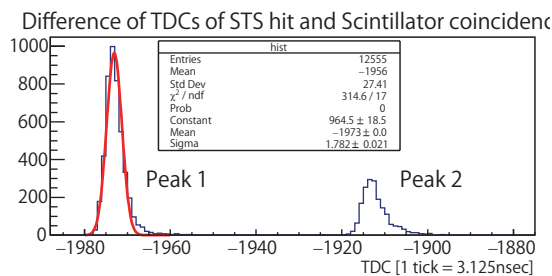


Figure 3: TDC difference between an STS hit and a scintillator coincidence.

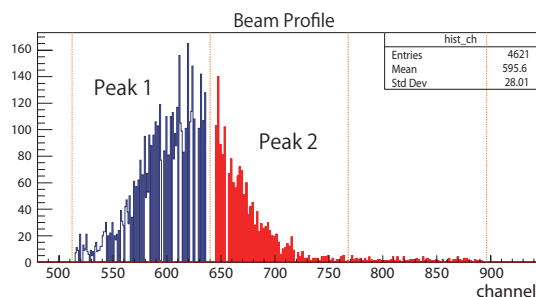


Figure 4: Beam profile. Only three SMX's for n side were read out and shown. The vertical dotted lines indicate the jurisdictions of three SMX chips.

So far identified reasons for the low efficiency are A) half of the channels (even-numbered strips) were effectively masked, which accounts for 50%, and B) the thresh-

olds were too high which accounts for 70%. The root cause of A) and B) were high noise level of ~ 0.8 fC.

A) Due to high noise, mainly even-numbered strips were hot. We effectively masked these strips by raising the corresponding ADC ch.1 threshold very high (trim was set to 1). About half of the strips were masked by the procedure, which resulted in 50% loss.

B) Figure 5 describes the threshold distribution for unmasked channels of the SMX which corresponds to Peak 1, in terms of test pulse height (amp_cal) of SMX [3]. The average threshold was 3.5 fC (corresponds to 44 in amp_cal). Energy loss distribution of incident particles was calculated using Garfield++/Heed and compared with the threshold. The average threshold makes the efficiency to be 70%.

Summary and outlook

A beam test was performed using an STS prototype at ELPH in Japan. The prototype was successfully operated. Time resolution was good (5.6 ns) but the efficiency was low (25%). Main reasons for the low efficiency were identified. Study continues at our lab to improve the STS operation and performance according to the findings.

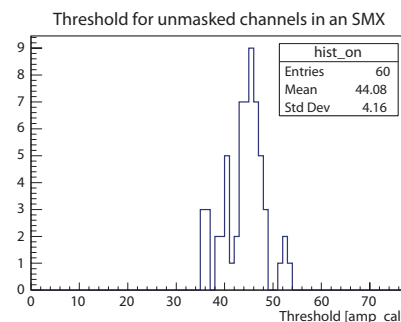


Figure 5: Threshold distribution for unmasked channels in the SMX which accepts most of the beam hits.

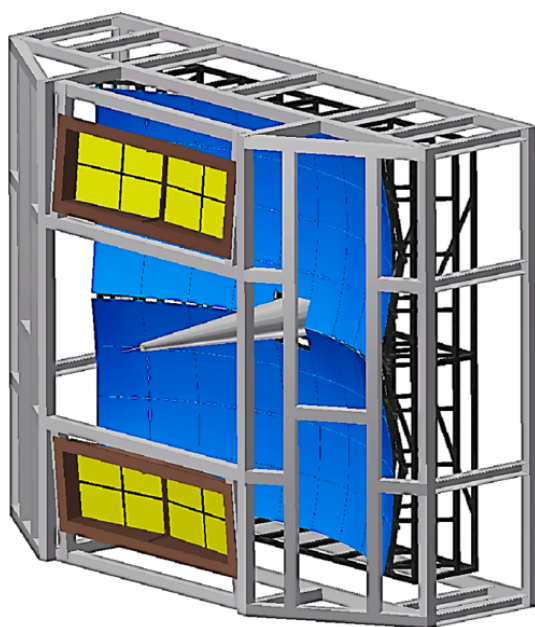
Acknowledgement

We would like to thank the STS team for their kind support.

References

- [1] S. Yokkaichi et al., J-PARC E16 proposal <https://ribf.riken.jp/yokkaich/E16/pub/proposal.pdf>
- [2] S. Ashikaga et al. (J-PARC E16 Collaboration) JPS Conf. Proc. 26, 024005 (2019)
- [3] <https://www.lns.tohoku.ac.jp/en/>
- [4] K. Kasinski et al., *SMX2.0, SMX2.1, SMX2.2 Manual v4.00* (2021)
- [5] W. Zabolotny et al.
- [6] T. Uchida, *Hardware-Based TCP Processor for Gigabit Ethernet*, IEEE TNS. vol. 55, no. 3, 2008.6, 1631-1637, <https://www.bbtech.co.jp/sitcp/>

Ring-Imaging Cherenkov Detector



RICH summary*

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The CBM RICH project has made substantial progress in various fields in 2021 despite the difficulties which we all encountered during the continuation of the Corona pandemic. In this Progress Report we will present our achievements.

The RICH project has transitioned from the design- into the construction phase, with significant progress in many aspects over the last year. Following the clear mandate from the mechanics CDR and photon detector EDR end of 2020, we have started the construction of a full-size camera demonstrator. This prototype of one full camera (the RICH has two of those in total) will allow for a complete test of the mechanical design to qualify it in terms of mechanical stability, practice camera handling procedures, and confirm the functionality of the closed-loop air-cooling system. The latter is already under construction and will allow to derive all necessary experience for the design of the full system for CBM. The whole camera demonstrator including the cooling advanced considerably in 2021 and will be completed and tested in 2022.

The development of the photocamera prototype is closely connected to the overall design of the RICH camera mechanics, in particular also the shielding box. After the successful completion of the RICH mechanics CDR in 2020, the EDR was being prepared and was close to finalization before Feb. 24, 2022. A first version of the gas system FDR has been handed in Jan. 2022.

Progress has also been achieved in the production of first readout components for the electronic readout chain of the CBM RICH. All 230 backplanes for the RICH detector have been produced and did undergo a QA testing. Thus, a "first of series test" for the RICH electronics has successfully been achieved in 2021. In total, a production yield of around 90% is reached which is comparable to the experience in HADES. A fraction (98) of these backplanes will now be installed in the photocamera prototype which is under construction.

The mRICH detector readout firmware was successfully changed to the new CRI platform which will be the final platform for RICH in CBM. The CRI took over the functionality of the previously used DPB and FLIB and showed a remarkable performance in all beamtimes starting summer 2021. A new unpacker that was necessary to

adopt to the data format from CRI was successfully implemented. In addition, a first functional bridge between the CBM DCA and the TrbNet Slow Control was developed and tested.

The slow control system for the RICH detector includes also monitoring of additional sensors regarding e.g. the temperature and magnetic field in the RICH detector. Small sensor boards that can be inserted inside the gas volume below the MAPMTs have been developed and tested. Signals from those sensors can also be included into a hardware interlock system for MAPMT protection for which a concept has been proposed.

The RICH detector, ring reconstruction and low-mass vector meson analysis in cbmroot has seen considerable changes and updates in 2021. The RICH geometry used so far in CBM simulations was established with conversion macros from CAD drawings directly. However, this conversion needs expert knowledge and was not further usable, thus we re-implemented the full RICH geometry based on ROOT. This is a sustainable solution for easier maintenance. Ring finding in mCBM has always been more difficult and less performant than in CBM due to special features of the aerogel setup. New NN based noise reduction algorithms have been developed to improve this situation. In addition, CNN ring recognition has been developed and is investigated as alternative to the well established Hough Transform. The dilepton analysis framework had been growing since more than 10 years and thus developed a structure which was not any more efficient and easy to overlook. Therefore, the whole framework has been restructured providing nowadays also routines for background compilation.

Last but not least it is worthwhile to report at least on this RICH summary level, that the HADES RICH detector is now operated with 428 of the CBMs H12700 MAPMTs including same the DiRICH readout chain as is planned for CBM, has participated very successfully in a 4-weeks HADES beamtime with p+p collisions at SIS18.

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Prototype of the CBM RICH photon detector*

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Introduction

As a result of the construction design review (CDR) of the RICH mechanics conducted in October 2020, it was recommended to start immediately with the assembly of a full-size prototype ("demonstrator") of the first RICH photon detector camera in order to qualify the design in terms of mechanical stability, to practice camera handling procedures, and in particular to confirm the unique closed-loop air cooling concept. Transferring the theoretical 3D model into a full engineering design involved the investigation of manufacturing possibilities and iterative adjustments to the design of the camera parts, which was done in close cooperation with the manufacturing companies and experienced colleagues of the RICH working group. Based on the most recent CATIA CAD model of the detector, the camera front was manufactured in our workshop at the University of Wuppertal. Those parts of the camera box which were too large to be handled by our local workshop were manufactured by an external CNC-milling company after intensive market review. All mechanical main components for the first camera prototype became available end of 2021.

Camera rack

For assembly of the prototype camera, a specially designed camera rack was built from stable aluminum construction profiles. Fixed to this camera rack is a camera mounting flange identical to the later mounting flanges on the RICH vessel. This mounting flange will later be the only contact surface between camera and RICH vessel with its shielding boxes. Using ball bearings, the heavy camera prototype (total weight ~ 600 kg) can be rotated to any position around the x -axis, which aids assembly work. Later, this rotating stand will also be used to practice the installation routine of a fully equipped camera module into both upper and lower mounting position in the detector. Moreover, it will serve as a maintenance rack inside the CBM cave. A photograph of the full-size demonstrator of the photon detection camera including the supporting camera rack is shown in Figure 1.

Construction of the demonstrator

The photon detector camera consists of two mechanical main units, the camera front and the supporting camera box. The camera front consists of 14 individual CNC-milled aluminum columns (material: EN AW-5083), ar-

ranged in a circular shaped pattern following the optimal focal plane of the RICH mirror. The individual elements are screwed - and additionally glued - together, serving as support structure for the MAPMT read-out modules, such that the resulting area of the MAPMTs' entrance windows closely matches to the Monte Carlo optimized photon detection plane of 2226×741 mm², see [1].

The camera box consists of three individual CNC-milled parts (material: EN AW-6082): two identical D-shaped top and bottom plates and a rectangular flange, which are screwed - and additionally glued - together. The D-shaped plates serve as support for the camera front to maintain the specific radius of $R = 1699$ mm of the photon detection plane, resulting in a radius of $R = 1650$ mm at the inner inside of the camera front. The total weight of these parts amounts to ~ 120 kg, and outer dimensions to $2235 \times 990 \times 410$ mm³. All openings in the camera front will be closed by MAPMT readout module backplane PCBs. A gas-tight seal is ensured by means of a rubber O-ring situated in a fine groove in the aluminum elements, sealing against the gold-plated PCB backside, as shown in Fig. 2. Each camera will be inserted from outside into its own shielding box, which in turn is an integral part of the RICH radiator vessel and is fixed solely via its flange against the mounting flange of the shielding box. This design ensures mechanical decoupling of the fragile

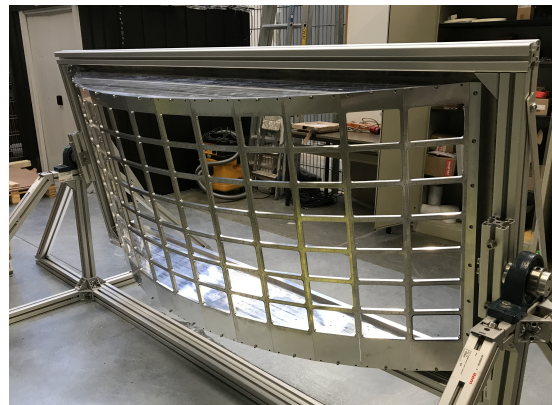


Figure 1: Photograph of the full-size demonstrator of the photon camera unit, showing the camera front consisting of 14 individual support frames, as well as the mechanical frame structure consisting of three individual components. The demonstrator is mounted to the rack for assembly work.

* Work supported by BMBF (05P19PXFCA, 05P21PXFCE) and GSI

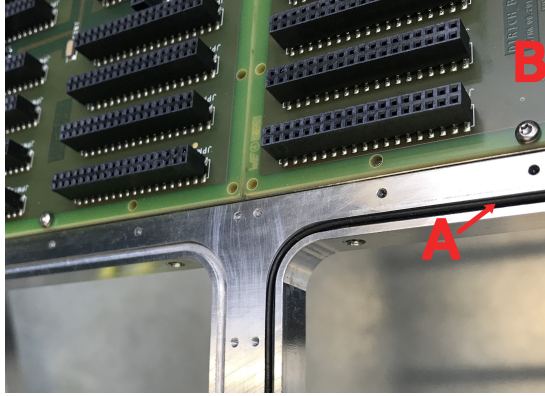


Figure 2: Section of the camera front, showing the rubber O-ring ($d = 1.5$ mm) lying inside a groove in the aluminum column (marked with A) and two green MAPMT readout module backplanes (marked with B).

MAPMTs and camera against the heavy steel parts of the shielding box.

Top and bottom plates of the camera box are identically D-shaped, CNC-milled aluminum parts (material: EN AW-6082) with dimensions of $2038 \times 380 \times 15$ mm³. The flange of the camera box (used for fixation and handling of the camera) is a solid, rectangular CNC-milled aluminum part (material: EN AW-6082) with dimensions of $2235 \times 990 \times 20$ mm³.

The 14 frame elements of the camera front are individually CNC-milled (material: EN AW-5083) with dimensions of $900 \times 157 \times 10$ mm³ each. A similar mounting concept for the readout modules was already applied for the HADES RICH detector, and has proven to provide sufficient strength, gas- and light-tightness.

Due to the slight curvature of the photon detection plane and due to manufacturing tolerances the, gap between neighboring MAPMT entrance windows between two columns is now in the order of $d' \sim 3$ mm, where the gap between MAPMT windows on the same frame element is in the order of $d = 1.5$ mm. This minimum gap is needed in order to still be able to remove individual MAPMTs by a special tool and to provide sufficient safety margin for MAPMT tolerances.

FEM stress simulation

The structural stability and stiffness of the mechanical parts of the camera unit has been simulated by applying a Finite Element simulation (FEM) on a simplified model of the aluminum camera unit. The following parameters of the simulation were chosen: Young modulus $E = 7.0 \times 10^{10}$ N/m², density $\rho = 2.7$ g/cm³ for the camera material and the weight of the camera structure itself, and an additional load of 250 kg acting in vertical direction representing the weight of the MAPMTs and read-out electronics, with a tilt angle of the camera of 22° from vertical

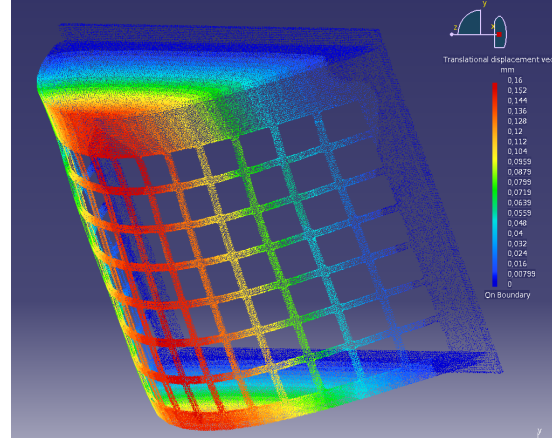


Figure 3: FEM simulation result of structural stability and stiffness of a simplified aluminum camera unit based on CATIA.

around the x -axis. The plates have a thickness of 15 mm and the flange has a thickness of 20 mm, the simulated material consists of a high-strength aluminum alloy (EN AW-6082) to find a good balance between stability and weight.

According to the simulation results depicted in Fig. 3 (obtained with CATIA and independently confirmed with CALCULUS), a maximum deformation of 0.16 mm is to be expected, with maximum von-Mises stress values reaching ~ 10 MPa.

Final design parameters

This preliminary engineering design is based on the following geometrical parameters: A mirror tilt angle of 12° with respect to the horizontal beam line, and the according positions and tilt angles of the cylindrical shaped photon detection plane (dimension 2226×741 mm²) which were the result of detailed Monte Carlo based optimizations (see [3]):

Upper camera unit: center of sensitive plane at $Z = 2402$ mm, $Y = 1655$ mm, tilt angle 22° from vertical around the x -axis; Lower camera unit: center of sensitive plane at $Z = -2402$ mm, $Y = -1655$ mm, tilt angle -22° .

References

- [1] I. Kres et al., RICH geometry optimization, CBM Progress Report 2016, Darmstadt 2017, p.64
- [2] D. Pfeifer et al., Update on the magnetic shielding box design and simulations, CBM Progress Report 2020, p.58
- [3] S. Lebedev et al., RICH geometry optimization, CBM Progress Report 2019, p.55

Prototype of the CBM RICH cooling system*

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A central issue in the development of the CBM RICH photon detectors is the cooling of the frontend readout electronics. Both photon cameras together will comprise around 2500 individual electronic modules, producing a total of around $2 \times 3 = 6$ kW heat dissipation during operation. Within each camera, the electronics are located in a fairly small, closed volume, enclosed by the camera module- and shielding box walls. Direct water cooling of the dissipated heat is almost impossible due to the large number of individual readout cards, and the inherent danger of water leaks right inside the sensitive electronics.

This has been the motivation for the development of a closed-loop air-cooling concept, where cold air ($T \leq 18^\circ \text{C}$) is injected into each camera module and guided via a large number of individual cooling channels right in between the electronic modules, pushing the warm air out between the modules, away from the backplane and PMTs which are particularly sensitive to heat (The sensor temperature must stay below 30°C at all time). The heated air ($\sim 45^\circ \text{C}$) is then extracted again from the camera volumes, and re-circulated via a large blower through a water-air heat exchanger, following the requirement that the detector heat dissipation shall not be released into the cave directly. This concept has been tested on smaller prototypes already, giving first estimates on the required air volume [1, 2, 3]. Based on these measurements, we estimate the cooling air requirement to be in the order of $5 \text{ m}^3/\text{min}$ per camera, or $600 \text{ m}^3/\text{h}$ for the full RICH. The pressure drop inside the camera should stay well below 100 mbar, more in the order of 20-40 mbar according to current estimates. Pressure drop in the heat exchanger+separator is ~ 20 mbar at maximum expected air flow. The new prototype cooling system, which in the current version should be sufficient to cool one full camera module, will allow to derive exact numbers on the requirements, and help to determine the final blower (probably a rotating piston blower for efficiency reasons) to be obtained. It will further allow to get first experience with the cooling system and to develop all necessary control- monitoring- and safety interlock systems. The cooling prototype (see Fig. 1) is build around the large air-water heat exchanger (Parker WFN090) with additional centrifugal water separator (Parker SFH089N) to reliably remove any condensing water from the output airstream. The heat exchanger represents the coldest point in the closed loop, ensuring a relative humidity of the output air less than 100 % everywhere else in the loop to avoid condensation. The heat exchanger is already dimensioned



Figure 1: Picture of the prototype cooling system setup in the lab, consisting of a large water-air heat exchanger with water separator, fed by a small sidechannel blower to be used for the first tests (left).

for the full CBM RICH detector, and will later be moved into the CBM cave as part of the final system. A small blower at the input side provides the necessary airflow and differential pressure (max. 2.2 kW, $400 \text{ m}^3/\text{h}$ @ 100 mbar). For first measurements the system will be operated open-loop, with air inlet via a large filter, but also closed-loop operation is possible. Airflow and pressure are controlled by a variable 3-phase frequency converter in the electronic control cabinet (Fig. 2), including also a Raspberry-Pi for slow-control and monitoring of the blower and all attached sensors. Cooling water is controlled via a solenoid valve, allowing temperature control (for the purpose of test measurements) of the air flow by using a PID control loop.



Figure 2: Control cabinet for the blower control, including a Raspberry-Pi for control of the blower and sensor readout via EPICS.

References

- [1] C. Pauly et al., Conceptual design of the CBM RICH photon detector, CBM Progress Report 2020, p. 61
- [2] D. Pfeifer et al., Camera Cooling prototype - first measurements, CBM Progress Report 2020, p. 64
- [3] D. Pfeifer et al., Magnetic field simulation, construction and cooling of the CBM RICH camera, CBM Progress Report 2019, p.51

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Testing of new DIRICH power modules for their noise bandwidth*

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Introduction

The CBM RICH detector signal digitization and read-out is based on the DIRICH readout chain [1], providing a quasi free-streaming FPGA-TDC readout with leading- and trailing edge time measurement. The sensors and read-out electronic is organized in readout modules of $3 \times 2 = 6$ Multianode PMTs each, digitized by twelve DIRICH FrontEnd modules (FEBs) (32+1 readout channels each). All readout cards per module are supplied via a common DIRICH power module on the same backplane, offering four different Low Voltage (LV) supply channels (1.1 V, 1.2 V, 2.5 V, 3.3 V) as well as high voltage distribution (up to -1500 V) for all six MAPMTs per module. For the CBM RICH, we intend to use DC-DC converters on-board the DIRICH-power module in order to supply all LV needs from a single ~ 36 V DC input line. This drastically reduces the cabling effort and problems due to voltage drops on long supply cables as compared to a powering scheme using external LV power supplies. Experience from the HADES RICH detector, using the same readout chain, however showed significant additional noise induced by the large number of DC-DC converters close to the sensitive analog electronics despite already comprehensive filtering efforts. In the end, in HADES an alternative powering scheme had to be implemented, where LV is supplied by external power supplies, and only a linear fine-regulation onboard the power modules is accomplished. Noise performance of this external supply scheme can be regarded as reference for all future DC-DC-based efforts.

For the CBM RICH detector, a new iteration of the DIRICH power module has been developed, using new generation "silent switcher" DC-DC converters (Linear Technologies LT8648), combined with additional state-of-the-art filtering measures and optimized PCB design, in order to reduce the noise induced by the converters. Further shielding can be achieved using a special metal shielding cage and an additional EMV absorber foil close to the converters.

Different variants of this new power module were tested in the lab, and the noise performance quantitatively compared to the old power module, both using the onboard DC-DC as well as the external powering scheme with only linear regulation of the old module (which is considered as the reference).

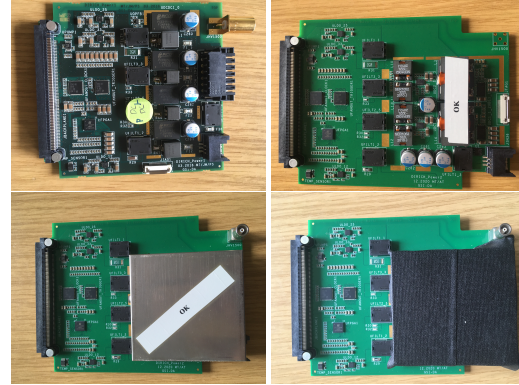


Figure 1: Old power module with on-board DC-DC converter, both single voltage input (SVI) and external LV input (upper left); New power module with SVI port only (DC-DC converter) (upper right); with additional metal shielding box (lower left); and with shielding box plus EMV foil (lower right).

Laboratory Measurement of induced noise

In order to compare the noise performance of the different power modules and configurations, the "average noise bandwidth" of the DIRICH input channels is taken as the measurement observable. To determine this noise bandwidth, the threshold for each channel of a DIRICH is varied in small steps from negative to positive thresholds measuring the scaler rate (the scaler is a simple edge counter after the discrimination stage) at each step. A steep in-/decrease in the measured scaler rate as function of threshold marks the noise edges. The difference between positive and negative noise edge is considered the noise bandwidth, their mean value defines the individual channel baseline. A fully equipped backplane with twelve DIRICH-FEBs, a power module and combiner was set up in the lab in order to compare the different power module versions with respect to the induced noise.

Comparison of the induced noise from different power module variants was achieved according to the following scheme:

- The backplane was fully equipped with all modules in order to achieve a realistic power load situation.
- The noise bandwidth was always determined for the same DIRICH module to ensure equal noise performance of the DIRICH itself.

* Work supported by BMBF (05P19PXFCA, 05P21PXF1), and GSI.

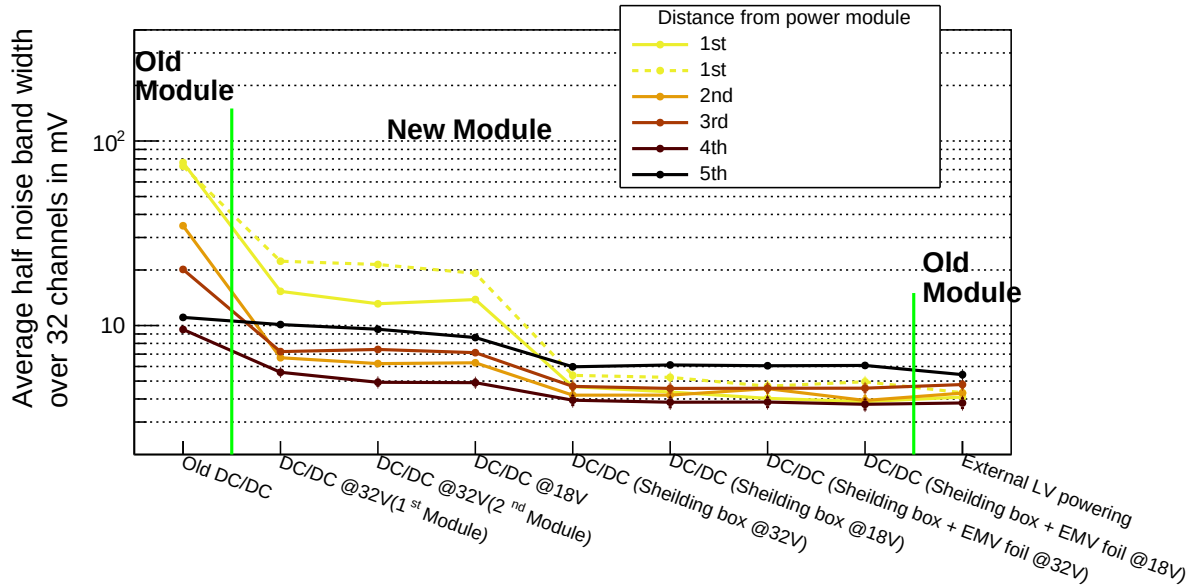


Figure 2: Average half noise bandwidth over 32 channels for the different power modules with different configurations.

- The DIRICH under test was positioned in different backplane slots varying its distance to the power module allowing to measure the distance dependence of the DC-DC-induced noise on the DIRICH.
- Average half noise bandwidth over all 32 channels of the DIRICH under test was measured.
- These measurements were repeated using both old and new DIRICH-Power Module, where both the internal, DC-DC-based as well as the external powering scheme were applied for the old module.
- The measurements of the new power module were repeated with- and without shielding box and EMV foil.
- Also the influence of the DC-DC input supply voltage (18 V to 32 V) on the noise performance was studied.

Measurement results and discussion

Results of the induced noise measurement for all the tested configurations is summarized in Fig. 2. Given is the measured half noise bandwidth (from baseline to end-of-noise) for different positions of the DIRICH module on the backplane with respect to the power module (color code), and for the different configurations (x -axis). The value of half noise bandwidth, measured after the DIRICH pre-amplification stage and given in mV, is a good measure of the minimum threshold the DIRICH can be operated at, before the input channels start to pick up noise.

For reference, the HADES RICH detector is usually operated at threshold voltage levels in the order 50–70 mV (after pre-amplification), ensuring good single-photon efficiency and timing precision. With the new power module,

using the DC-DC based powering scheme, the noise level observed in all DIRICH configurations is usually well below this threshold, particularly if the additional shielding plate is used. For the old power module however, if using the on board DC-DC converters, the noise level reaches average values close to 100 mV in close proximity to the power module, with individual channels even larger. In this case, an operation threshold well above 100 mV would be required, sacrificing significantly efficiency and timing. Noise figures achieved with external LV powering are still the lowest, but only slightly better than the performance achieved with the new module and DC-DC powering if the metal shielding cage is mounted. A clear distance dependence can also be observed, with largest noise levels closest to the power module, proving that the EM noise is mainly radiated over air, and not coming in via the supply lines.

With the new iteration of DC-DC converter and using a shielding cage, the overall noise bandwidth is less than 10 mV which is far less than the standard operating threshold of 50–70 mV, and very close to the external LV powering scheme.

Additional tests showed, that using the new power module with DC-DC powering as compared to the old module with external powering also has very little to zero effect on the overall timing precision of the DIRICH. These results could also be confirmed in the mCBM setup, where the new power module was also tested.

References

- [1] J. Michel et al., Electronics for the RICH detectors of the HADES and CBM experiments, *Journal of Instrumentation*, 10.1088/1748-0221/12/01/c01072, C01072–C01072.

QA testing of DIRICH module backplanes for the CBM RICH*

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Introduction

The CBM RICH detector readout electronics is organized in modules of $3 \times 2 = 6$ Multianode Photon sensors each, read out via 12 DIRICH frontend cards, a DIRICH-Concentrator, and DIRICH-Power module. Central element of each such readout module is the DIRICH backplane PCB, interconnecting the 6 photon sensors mounted at the front side, and the 12+2 readout modules mounted on its backside. The backplane PCBs were the first of the CBM RICH readout components to be built in mass production. With the production starting in 2021, a total of 230 backplanes were assembled by the external company "Rossmannith". Once installed, exchanging backplanes is a time-consuming procedure. Thus, we decided to perform a comprehensive QA survey of each single backplane, assuring that all backplanes later installed in the detector are fully functional. This QA test includes semi-automatic tests of every single analog/digital channel, trigger-, power- and clock distribution.

Test procedure

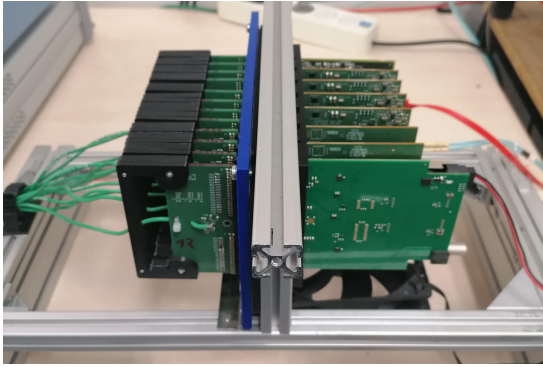


Figure 1: Backplane test setup. The DIRICH readout modules are located on the right, with the input specially designed test PCBs inserted on the left.

Each backplane under test is mounted inside an air cooled rig, shown in Fig. 1, and fully equipped with a reference set of DIRICH readout modules. Using the same DIRICH front-end card at the same position for each tested backplane ensures that any variation observed in comparison to the standard reference backplane data set is caused

solely by the backplane under test. Test pulses of realistic amplitude and shape are injected in parallel into each of the 348 analog input channels using custom made pulse distribution boards replacing the MAPMT's. A single pulse generator is used as common signal source, its output being passively split via resistive dividers, such that the signal amplitude is alternating between two levels in neighboring channels on the backplane. This approach allows to also check for cross talk or short circuits between neighboring backplane channels, and produces a distinct pattern easily comprehensible already on a quick look.

The test procedure itself is based on a software tool for threshold- scan and adjustment which had been developed for control of the HADES RICH (cf. [1]). For automatic evaluation, one fully-functional backplane is defined as reference so that deviations to this reference can easily be detected by a monitoring script. Channel-to-channel variations which can be caused by gain variations in the DIRICH input amplifier stages, are excluded by always using the same DIRICH modules during all measurements.

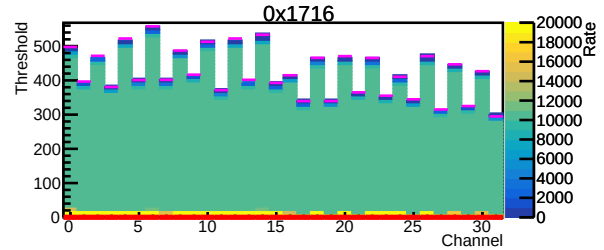


Figure 2: Threshold scan result for 32 out of 384 simultaneously measured channels with the reference backplane measurement marked in pink.

Each DIRICH comprises sensors for supply voltage and temperature, and these values are read out and stored for each start up sequence, providing a first quick check for short circuits on the backplane. A cooling fan mounted beneath the right hand side (see Fig. 1) of the backplane ensures that neither the 12 DIRICH's nor the combiner- or power module exceed at temperature of 35 °C.

The main test measurement consists of a threshold scan on all 384 DIRICH channels, where the discriminator rate, i.e. the rate on the DIRICH input stage, is plotted as function of threshold. If the channel is working correctly, this spectrum must show a clear amplitude-dependent cut-off in rate once the discriminator threshold exceeds the signal ampli-

* Work supported by BMBF (05P19PXFCA, 05P21PXFCE) and GSI

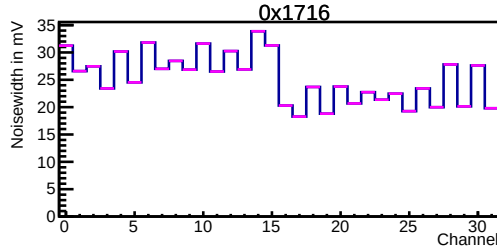


Figure 3: Noise bandwidth scan result for 32 out of 384 simultaneous measured channels with the reference backplane measurement marked in pink.

tude. The pulse generator amplitude is kept constant for all measurements, and chosen such, that this cut-off is visible around 300-500 mV discriminator threshold. An example of such a threshold scan on a single DIRICH (32 channels) is shown in Fig. 2. One can clearly spot the high and low signal amplitude in neighboring channels. The reference measurements marked in pink allow to easily identify major deviations between this measurement and that of the reference backplane.

As a second measurement, the noise bandwidth on all channels is measured. This property is a measure for the noise picked up on the input stage of the DIRICH and as such might be altered by improperly soldered connectors on the backplane, leading to open input channels. Hereby, an either too large or too small noisebandwidth might indicate problems in the individual channel. Figure 3 shows an example of such a noise band measurement for a single DIRICH. The significant asymmetry between channels 1-16 and 17-32 (front / back side of the module) seen here could be caused by proximity to the DIRICH-Power module inducing noise on the directly facing side of the DIRICH module.

Further tests check for the presence of channel 0 trigger reference signals in each DIRICH module, which is crucial for use in the detector. Any conspicuous features in these channels are considered to be a severe issue.

In a final step, all test results are stored within the hardware database at the University of Wuppertal.

Measurement results

After inspecting all 230 backplanes, several defects and features have been found. If a backplane showed defects, the test procedure was repeated multiple times to exclude trivial mistakes. These defects can be summarized as follows (see also Tab. 1): Most of the tested backplanes, 206 pc or 89% of all tested backplanes, showed no significant issues. Hereby, minor deviations within 5% with respect to the reference were tolerated in each channel. These backplanes can directly be installed in the CBM RICH detector where a total of $2 \times 98 = 196$ backplanes is needed to equip both photon cameras. Eleven percent, i.e. 24 out of 230

tested backplanes, showed issues during the tests which require further investigation and maybe SMD rework. Out of these 24 erroneous backplanes, 17 have been found to have only minor issues. These were identified by having at least one major threshold deviation from the reference measurements or were missing at least one complete channel. Since this is a very high standard, erroneous backplanes had to display this feature in multiple test runs. Such defects can probably still be fixed by re-soldering individual connectors on the DIRICH-or the PMT side. A total of seven backplanes showed more severe issues. These can be divided into two major categories. Either the trigger timing signal is missing (i.e. channel 0) in at least one DIRICH channel or the start up sequence could not be completed. While the missing trigger might be fixed by re-soldering the according connector, the latter malfunction indicates a severe short circuit or PCB problem. Backplanes with such severe issues need more detailed investigations to see if they can be fixed. In summary, a total production yield of around 90% is achieved, which is similar to the yield from an earlier backplane mass production for the HADES RICH detector. Albeit having such a high yield, the results still underline the necessity for detailed QA testing prior to installation in the detector.

N	Status
206	without any issues
17	few individual channels missing
7	more severe issues

Table 1: Summary of backplane series production QA results.

A fraction of the tested backplanes will now be installed in the CBM RICH camera demonstrator to evaluate the overall camera design. Later, the whole setup will also be used for realistic tests of the CBM RICH cooling concept.

References

- [1] J. Förtsch et al., Deriving the discrimination threshold in the DIRICH readout chain, CBM progress report 2017, p. 63.

A hardware based interlock system and backplane sensors*

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Introduction

The CBM RICH detector is a gaseous Cherenkov detector with Multi-Anode Photo-Multiplier Tubes (MAPMTs) as photon camera. In order to achieve a long lifetime of the MAPMTs and a low dark rate for the best data quality, it is important to operate at an adequately low temperature. In case of failures, e.g. of the cooling system, an automated shutdown of the low- and high voltage is needed. Additional shutdown scenarios are foreseen and will be included into an interlock system.

The Interlock System

The CBM RICH interlock system will be build from two layers. First of all, a software based interlock system will be in place. Based on e.g. EPICS, the low and high voltage power modules could be switched off if certain control values are out of range. As the experience over the last years in HADES and mCBM showed, software and networks which are essential for communication, are prone to errors. Therefore, a second layer of a hardware based backup interlock has been developed. The hardware interlock is always active, and has threshold values higher than the software based interlock and will react even if the software is not operational.

The hardware interlock system is designed as a modular and scalable system based on logical hardware. It is designed for assembly in an eurorack, defined by the eurocard

standard, with a custom backplane, two master modules as well as up to 6 slave modules (see figure 1).

Specific hardware (e.g. see figure 5) will generate control signals for the interlock unit. For example, a dedicated Trb5sc (or Trb3sc) will read-out temperature values from a temperature sensor chain located between MAPMTs and the DiRICH backplanes. Based on this temperature information the software interlock is fed but also the hardware interlock system is controlled.

Each of the control units is connected to a master channel of the interlock (shown in figure 2). The master module hosts 4 inputs each, which are all separately galvanically decoupled from the rack. A standard Ethernet cable with RJ45 connector is used to connect the origin of the control signals to the interlock system. The connection consists of two LVDS signals, one 5.5 V power line and a ground connection. On the master module, two LVDS receivers per channel are driven by the power connection and convert the LVDS signal into a LVTTTL signal. The LVDS signal from the control unit has to oscillate with a minimum of 0.5 HZ. The oscillation from the control unit is required as a watchdog. In case a control unit has a problem or a complete failure and it stops oscillating, the interlock will directly be activated.

The converted oscillating LVDS signal is further converted into a static signal by the use of an ICM7555. The static signal is galvanically coupled to the common part of the master module.

All static input signals of both master inputs (up to 16 signals) in the power domain of the interlock rack are transported via the backplane towards all 6 connected slave

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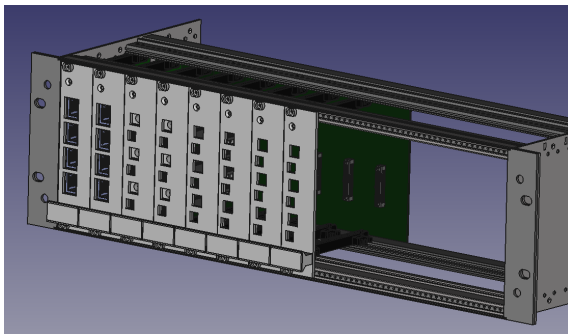


Figure 1: CAD rendering of the interlock system PCBs in the eurorack.

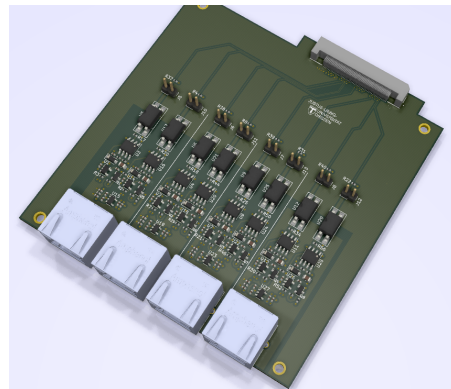


Figure 2: Rendering of the PCB of the master module for the interlock system.

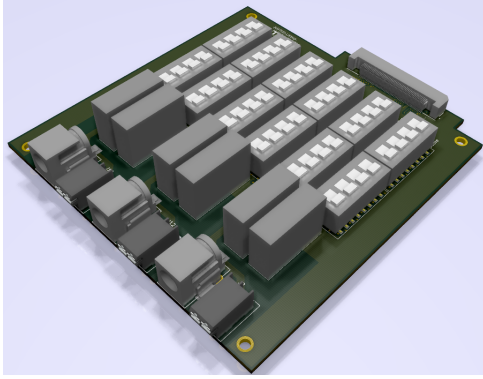


Figure 3: Rendering of the PCB of the slave module for the interlock system.

modules. A slave module has 3 output channels (see figure 3). The channels can be connected to the interlock ports of the commercial low and high voltage power units (e.g. TDK Lambdas, ISEG HV,...) of the RICH detector via standard copper cables.

For each of the up to 18 output channels, a combination of all 16 input channels of the master modules can be selected to control the output channel. The selection of the input channels used for the interlock control, is based on a 16-bit DIP-switch and AND-gates. Finally the AND of all selected input signals control two parallel relays to switch the control lines of the power supply. Two relays are used as a backup in case one has problems and gets stuck.

In case an interlock should not be active, an expert can insert a key, based on a barrel jack connector, to shorten the relays and deactivate the functionality of the output channel of the interlock rack.

The CBM RICH Backplane Sensors

As previously introduced, the CBM RICH detector slow control will monitor the temperatures of the MAPMTs to keep them in a safe temperature domain. Next to the temperature measurement, the RICH will also measure the magnetic field in different positions on the photo camera as magnetic fields have a direct influence on the efficiency of the MAPMTs.

The temperature and magnetic field measurement of the CBM RICH detector is a further development of the existing monitoring system build for the HADES RICH. A network of DS18B20 temperature sensors will be placed in between the MAPMTs and the backplanes where they are mounted on. In addition, MLX90393 3-axis magnetic field sensors will measure the magnetic field on the same PCB. Figure 4, left, shows the first equipped prototype PCB. Each row of the photon camera will be equipped with up to 16 of these PCBs in a chain. The readout of each row is based on 1-wire for the DS18B20 and I²C for the MLX90393 sensor. In order to handle voltage drops, keep the wiring at a minimum and be able to fully activate or de-

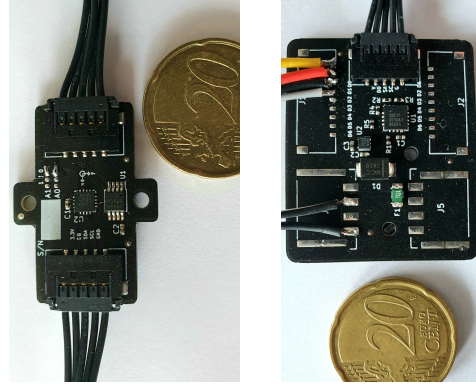


Figure 4: (left) backplane PCB with temperature and magnetic field sensor. (right) Adapter PCB for sensor chains.

activate the sensors, an adapter PCB in front of each chain is required (Figure 4, right).

The adapter boards will be chained to reduce the amount of wires. The boards are connected to a 5.5 V power line. Each board has an own LDO and power protection circuit to generate the operating voltage for the sensors on the connected PCBs and to operate a 1-wire to I²C converter. This converter allows to reduce the amount of wires needed to communicate with one row of sensors to just a single wire.

In order to use the temperature sensors for the hard and software interlock, but also for additional TDC measurements of e.g. laser triggers, a dedicated Trb5sc AddOn board is developed. The board hosts an own Atmega32U4 microcontroller to read out the sensors and to generate the interlock signals. It has a full input protection, spare connections for 1-wire, and is also usable as a general purpose AddOn. In order to cope with long 1-wire connections I²C to 1-Wire drivers are used for the communication with the backplane sensors. In the laboratory, already a first firmware (without the support of the I²C to 1-wire driver) was successfully tested and the temperature as well as the magnetic field sensor boards could be read out.

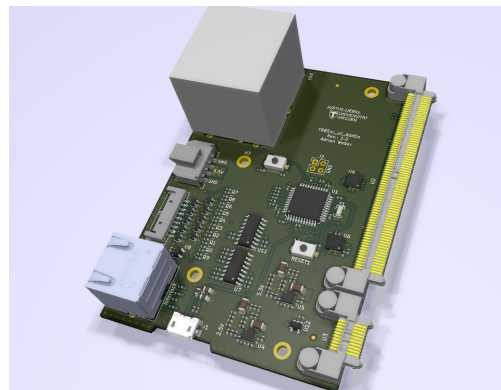


Figure 5: Rendering of the Trb5sc AddOn PCB.

mRICH operation with CRI readout*

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Introduction

The mCBM 2021 beamtime campaign marked the transition from mCBM phase-I to phase-II. From phase-II on, the readout chain utilises the **Common Readout Interface** (CRI-1), merging the functionality of the previously used DPB and FLIB into one single FPGA board. The re-designed readout-chain with the CRI as new key component was operated for the first time in the mCBM 2021 beamtime and showed already a remarkable performance. Here, we report recent developments of the mRICH CRI firmware and first results obtained from the Fe+Ni@1.71 AGeV beamtime in March 2022 will be shown.

The mRICH CRI

The development of the CRI based mRICH readout is based on the ideas and experiences from the previous DPB readout and adds new solutions. The concepts of the CRI based readout system for the mRICH introduced in the CBM progress report 2020 [1] were further improved and the firmware of the CRI was developed. In addition, a first functional bridge between the CBM DCA and the TrbNet SlowControl was developed and tested.

The CRI serves as a data combiner of data links from up to 47 combiner modules with 12 DiRICH boards per combiner each. One additional link of the CRI is reserved for the TFC system. The 47 links to the combiner boards are split up in the CRI into up to 24 links on SLR 0 respectively 23 on SLR 1. The Xilinx XCKU115 FPGA of the CRI utilized the technology of stacked dies. It is build from multiple dies which are interconnected. Each of the dies is a Super Logic Region (SLR) of the FPGA. Both SLRs of the mRICH CRI are handled as individual FPGAs with identical logic, except the TFC connection and the detailed configuration of the logic.

The (m)RICH detector front end electronics (FEE) is based on the TrbNet based DiRICH and combiner boards. The readout of the DiRICH FEE buffers is initiated by trigger signals. Similar to mCBM phase-I, a pseudo trigger is send from the CRI board to the combiners.

On each combiner board, a central trigger system (CTS) is located and translates the pseudo triggers from the CRI into trigger messages of the TrbNet world to readout the

FEE (see Ref. [1]). The trigger distribution via the optoLink board from phase-I is replaced by the usage of special comma characters of SERDES on the optical fiber connection between CRI and combiner, the so called Deterministic Latency Messages (DLM). Based on the duration of a microslice and the 40 MHz clock of the timing and fast control (TFC) system, pseudo triggers are generated on the CRI (see trigger generator in Fig. 1). In order to cope with high data rates an increase in the readout rate, independent of the microslice rate, is needed. Therefore the possibility to generate sub-triggers is introduced. Inside a microslice, several sub-triggers can be produced in the CRI to increase the readout rate of the FEE while the global microslice rate stays constant. The duration of the sub-triggers has to be a multiple of 25 ns as well as an integer fraction of a microslice.

Each SLR of the CRI hosts a control hub. This hub is used to control two data (and slow control) hubs. The control hub is the entry point of the TrbNet slow control into the TrbNet network of a SLR. The hub only handles slow control commands and appears in the TrbNet as an endpoint. The layer of data hubs serves as additional endpoints and can host up to 12 links to combiner boards each (see Fig. 1). A further scaling into more data hubs with less links each is possible.

The layer of data hubs is connected to the combiner boards. The hubs receive the data transmitted by the media interface of the combiners and vice versa. It extracts the slow control as well as the FEE data from the TrbNet data stream. The slow control response from the FEE is transmitted to the control hub and further to the TrbNet-DCA Bridge (or Slow-control Trb3sc). The FEE data from each combiner is extracted from the TrbNet data stream, together with additional control signals from TrbNet.

The extracted data and TrbNet control signals are further processed by the `trb_parser` entity. For each link from a combiner a `trb_parser` entity checks whether the incoming TDC data from the last sub-sub event of the FEE, as well as the CTS packets, are valid or show inconsistencies. In case of format errors or buffer overflows sub-sub-events are fully discarded. Valid data is transferred to an AXI4-Stream interface with configurable data width and a prepended header with meta-info.

The AXI4-stream transfers the validated FEE data to a `ms_filter` entity. The `ms_filter` entity time filters the packages according to their internal trigger time, the timestamp of the CRI as well as the defined microslice window, defined by the `ms_merger` entity.

Data from all `ms_filters` is merged into microslice

* Work supported by BMBF (05P19RGFCA, 05P21RGFC1) and Helmholtz Forschungsakademie Hessen für FAIR (HFHF), GSI Helmholtzzentrum für Schwerionenforschung, Campus Gießen.

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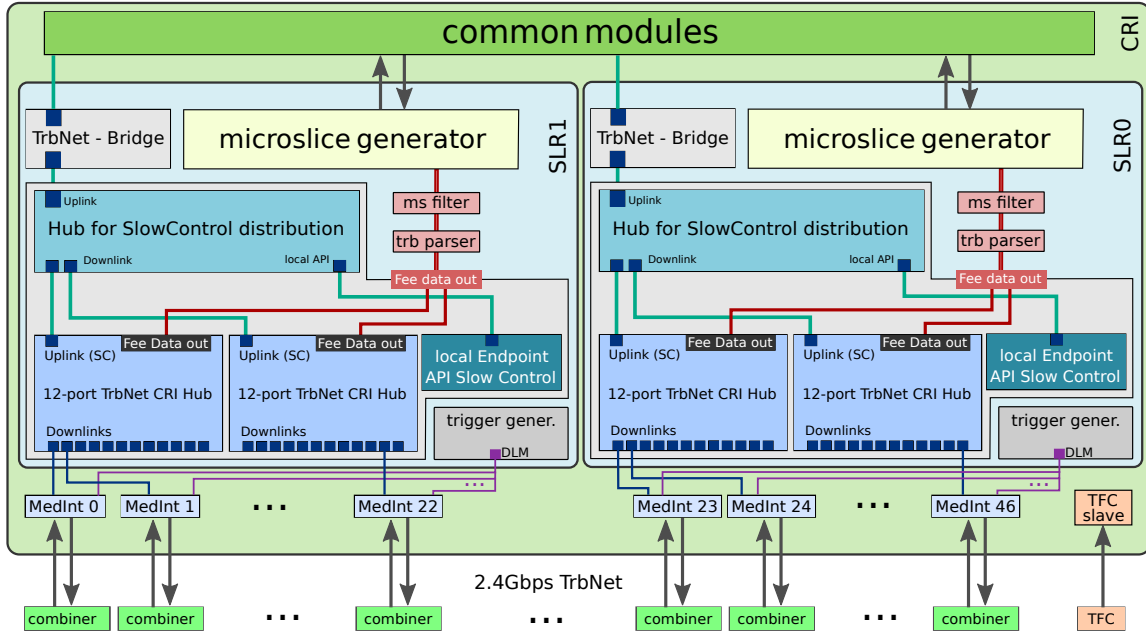


Figure 1: Schematic overview of the mRICH CRI firmware. The firmware is divided into the two SLRs. For each SLR a control hub and two data hubs are instantiated. Each SLR can be connected to up to 23 respectively 24 combiner boards.

packages in the `ms_merger` entity, based on the generated sub-triggers and the microslice duration. The microslice package is further handled by the common CRI infrastructure, including the FLIM interface.

The slow control communication with the CRI is based on the Detector Control Agent (DCA). The slow control of the DiRICH and combiner FEE, as well as parts of the CRI are based on TrbNet and therefore not directly compatible. Next to the possibility of a separate `trb3sc` connected to the CRI as slow control input device, a TrbNet-DCA bridge was developed. The bridge receives TrbNet slow control commands in the TrbNet package format via DCA on the CRI and forwards them into the TrbNet slow control chain. Responses from TrbNet are buffered at the DCA bridge and can be readout via DCA again.

The TrbNet slow control daemon is reused. A dedicated python script accepts the UDP based commands from the daemon, sends them via the DCA to the CRI and handles the response. In order to cope with the different layout of the TrbNet setup with many entry points to a smaller TrbNet network in the CBM experiment, a merging of data from both SLRs is integrated to the python script.

Results from CRI based mRICH readout

The full mRICH readout chain from DiRICH boards via the combiners towards the CRI was tested in several beamtime campaigns. The following results are obtained in March 2022 in the Fe+Ni beamtime at 1.71 AGeV (run 2160). The shown results are produced with an interme-

diate calibration of the mTOF. Further improvements are expected by newer calibrations.

With the introduction of the CRI the synchronisation between the sub-detectors was changed. For the first time the newly developed TFC was used to sync all

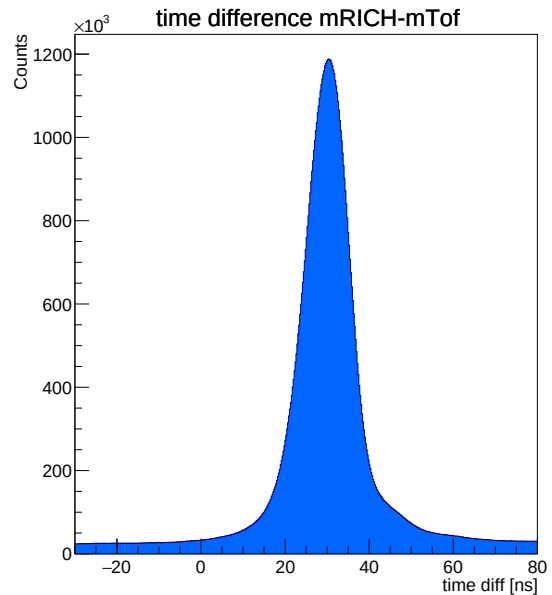


Figure 2: Time correlation between TOF and RICH in run 2160. (Fit of peak: 29.8 ± 5.6 ns)

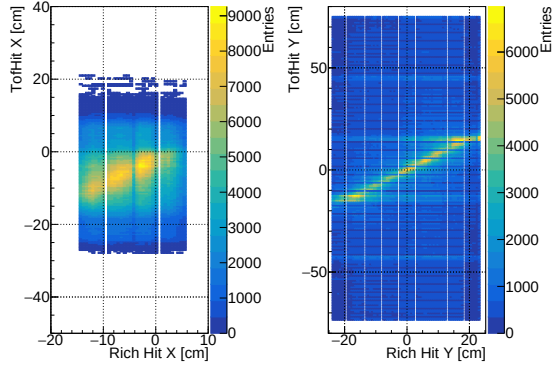


Figure 3: Spatial correlation between mTOF and mRICH hits in run 2160. Only TOF modules in overlap to the mRICH are selected for this histogram.

sub-detectors. Additionally, an important change for the mRICH compared to mCBM phase-I is the encapsulation of the microslices in the RICH. Since phase-II the RICH data format is redefined and all the information for the unpacking of a microslice is contained in a single microslice. This change is especially important for the data distribution for unpacking to different processing nodes.

Figure 2 shows the time difference between digis in the RICH and the TOF detector. The offset between both sub-systems is adjustable by a correction parameter. For now a standard value was used. Further optimization is needed as this has to match the time of flight of the particles. The time correlation obtained by the RICH and TOF detectors is clean and sharp with a standard deviation of 5.6 ns.

In order to prove the correct behavior of the free-streaming readout, not only correlations in time should be observed. Figure 3 shows the spatial correlations in X and Y between TOF and RICH hits for modules located in the overlap region between both detectors with respect to the target. In comparison and as a cross check, figure 4 shows

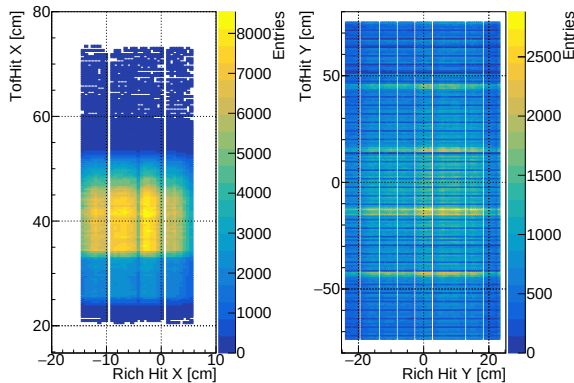


Figure 4: Spatial correlation of hits for non overlapping region of TOF and RICH.

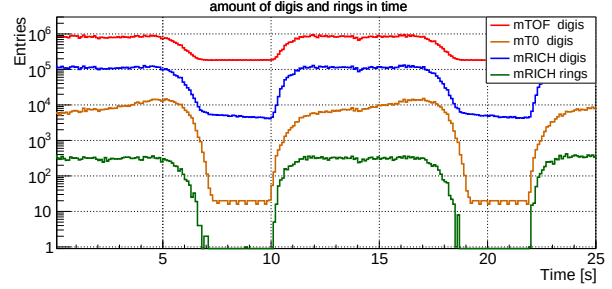


Figure 5: Time distribution of digis from TOF, T0 and RICH, as well as the reconstructed RICH rings. The different detectors reproduce the overall spill shape. Rings in the RICH are only reconstructed in spills.

the spatial correlation for the modules next to the RICH where no spatial overlap to the target is possible. Indeed, figure 4 shows no correlation in X and Y between RICH and TOF. All in all, the correlations in time and space are very clean. They confirm the correctness and synchronicity of the data transport with the new CRI based readout chain of the RICH as well as the TOF detector.

Furthermore, figure 5 shows the amount of digis for different sub-detectors for a certain period of time. It reproduces the spill shape of the beam for the different detectors. In addition it shows, that the RICH rings are only reconstructed during spills, supporting the functionality of the RICH detector and the correctness of the data.

Next to the common analysis between TOF and RICH, also the basic parameters of the RICH detector are in-

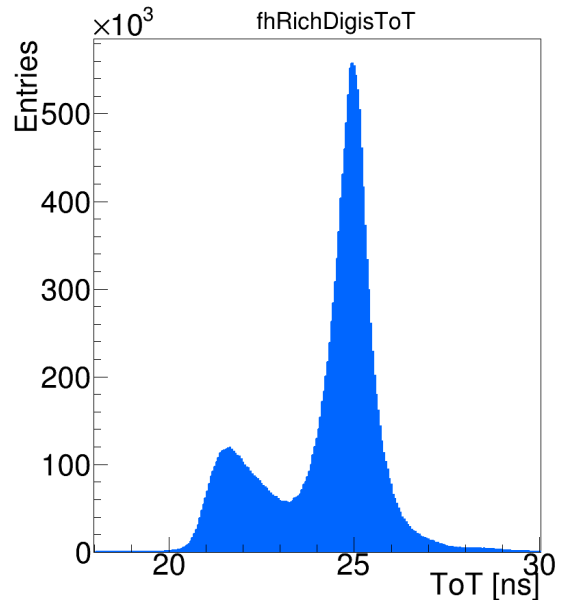


Figure 6: Time over threshold distribution of the RICH in digis in run 2160.

vestigated. Figure 6 shows the time over threshold (ToT) spectra after offset correction. The sharp double peak structure is identical to previous runs in phase-II as well as phase-I. The application of a ToT cut and the event building are needed to produce hits of the RICH detector. Figure 7 shows the hit map of the RICH detector with all FEE boards operational. The right side of the figure shows the centres of the reconstructed rings. The rings cover the full area of the RICH, but still tend to be located in-between MAPMTs.

Summary

The change of the readout scheme of the mRICH detector to the CRI based readout was a success. Next to the stable behavior of the full detector in several beamtimes, major milestones in the firmware development of the RICH detector could be achieved. The synchronicity and validity of the data transport could be shown in two detectors. Next to the time and spatial correlations between sub-detectors also the correctness of the data in the RICH itself could be shown as for example rings could be reconstructed also in between different backplanes, i.e. data from different combiner boards.

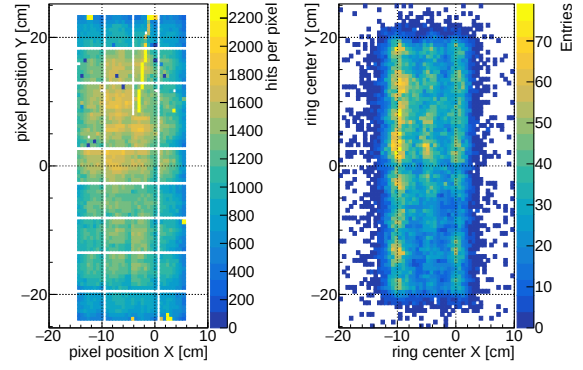


Figure 7: **(Left)** Hit distribution in X and Y of the mRICH for run 2160. Artifacts are visible due to rotation in space and the corresponding binning problems. **(Right)** X and Y position of the centres of reconstructed RICH rings.

References

- [1] T. Geßler et al., “CBM progress report 2020”, Darmstadt 2021, page 148

mRICH pattern recognition using convolutional neural networks*

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In this work a deep learning approach is presented to recognize noise patterns, especially inside ring formations and to ultimately remove them to improve ring finding quality. Specifically for the mRICH detector not only Cherenkov photons from the aerogel are detected but also signals from charged particles passing through the MAPMTs, including potentially additional Cherenkov photons generated in the MAPMT window. This results in a high amount of detected noise hits typically in the center of expected rings, which causes problems for the current ring finder algorithm (via Hough Transformation [1]). This center noise might be used together with parts of the ring hits to calculate a false ring with typically only half the radius (see Fig. 4). These mismatches are way more common in real data than in simulation, because of overall more center noise.

The study is performed on UrQMD simulation data using 1.24 AGeV/c Au+Au minimum bias collisions.

Data labeling

The data labeling is done using information, which is only available in simulations. The core idea is to check if at least one¹ of the photons, which was used to construct a hit, was created inside the radiator (aerogel) volume. If this is the case, the hit is labeled as true hit (value of 1) and noise hit (value of 0) otherwise.

Network architecture

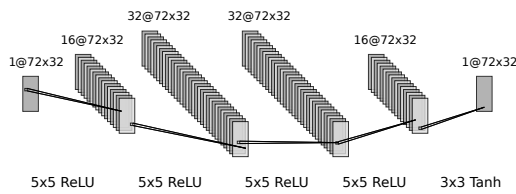


Figure 1: NN architecture stacking 2D convolution layers

Each of the 2304 pixels of the mRICH MAPMT plane provides information to one input of the neural network (Fig. 1). In order to have unique values for each pixel, the hit collection is split into non overlapping time windows with a fixed length. Given some dead time of 30 ns as implemented in simulation, a time length of 25 ns is used. For

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¹The choice of 'at least one' photon created in the aerogel, is motivated by the idea to rather preserve hits than to remove noise.

the input two approaches are compared, the first is to only use the hit location. The second is to also include the corresponding hit time (relative to the start of the time window). The output of this network is then a denoised time window. The training set consists of 357.7k time windows (20% of that as validation data) and the testing set of 357.1k time windows.

Results

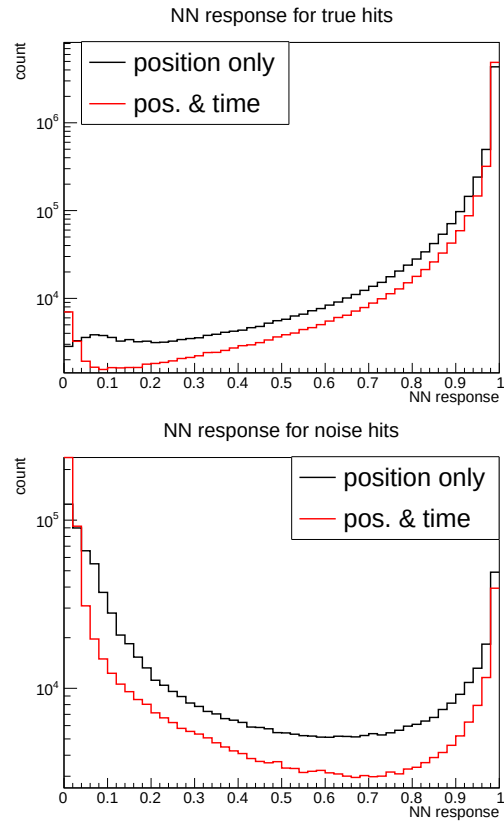


Figure 2: NN response values for true/noise hits respectively, evaluated on the test set.

Evaluating the test set provides metrics in order to evaluate how well the NN is performing. The NN response values are shown in Fig. 2. For true hits, the position and time curve is shifted to the right, with an average value of 0.977 and 0.963 for the position only network. The improvement when including time is a lot more noticeable in

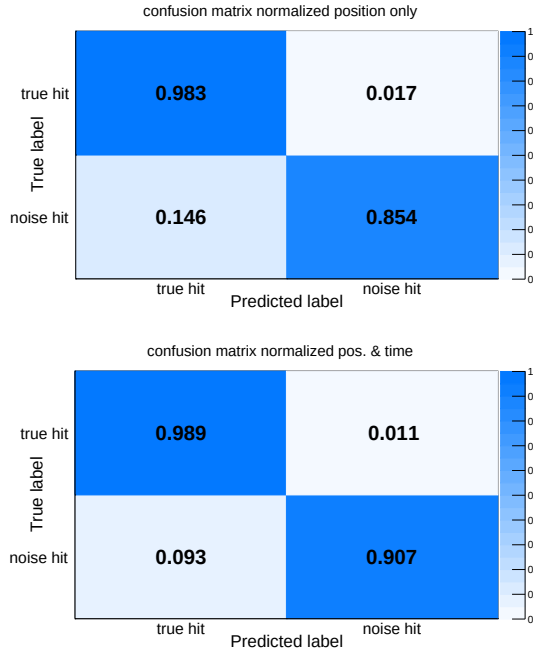


Figure 3: Confusion matrices comparing the two input methods with a threshold of 0.5 applied.

case of noise hits, with an average response value of 0.110 for position and time and 0.307 for position only. When applying a threshold of 0.5 and evaluating the confusion matrices for each method (Fig. 3), a significant improvement can also be seen here for the position and time method compared to only using the hit positions.

In Fig. 4 a simulation event is shown for using only the Hough Transformation ring finder and in Fig. 5 the same event applying the NN before ring finding for noise reduction. In particular the removal of the center noise improved the ring finding.

Outlook

The developed noise reduction neural network has shown good results on simulation data and has now to be tested on real data. The next step to improve the overall performance is to implement a region of interest (ring structures) algorithm, to decrease the input/output size of the NN. Details for the most convenient implementation are under discussion.

References

- [1] Lebedev, S., Hoehne, C., Ososkov, G., & Cbm Collaboration. (2010, April). "Ring recognition and electron identification in the RICH detector of the CBM experiment at FAIR." In *Journal of Physics: Conference Series* (Vol. 219, No. 3, p. 032015). IOP Publishing.

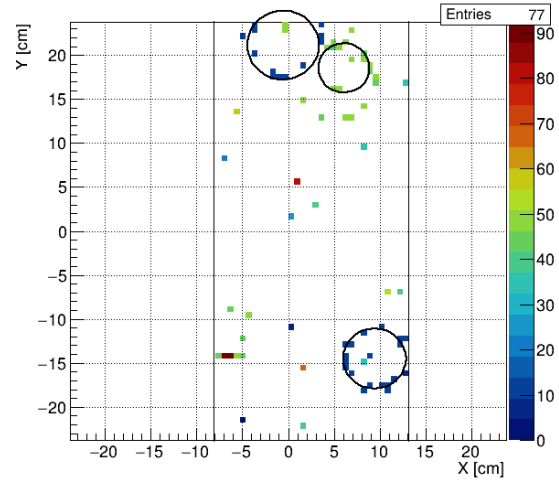


Figure 4: Event display (simulation) of the mRICH (Au+Au collisions at 1.24 AGeV beamenergy) using the Hough Transform ring finder only, color code corresponds to the hit time in ns.

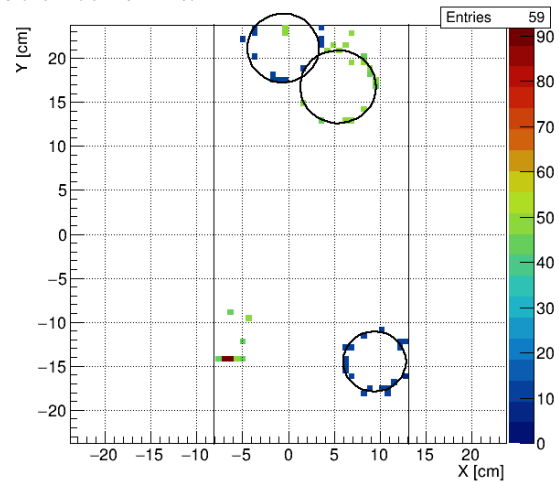


Figure 5: Event display (simulation) of the mRICH (Au+Au collisions at 1.24 AGeV beamenergy) denoising the hits using the NN and running the ring finder afterwards, color code corresponds to the hit time in ns.

Ring reconstruction based on Convolutional Neural Networks for the mCBM RICH detector*

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Convolutional Neural Networks

Convolutional Neural Networks (CNN) are known for showing great performance in image analysis. Therefore, it was proposed to apply it to the ring reconstruction in the mCBM-RICH photodetector plane and to compare it to the currently used Hough Transform Method.

A typical architecture for CNNs is shown in Fig. 1. Convolutional layers use a number of different filters (also called kernels) which are usually square matrices (e.g. 3×3 or 5×5). One filter then slides over the input image and calculates the dot product of the kernel matrix with its currently underlying input matrix. All values generated from one filter produce a so called feature map. These feature maps then form the output of the convolutional layer. After

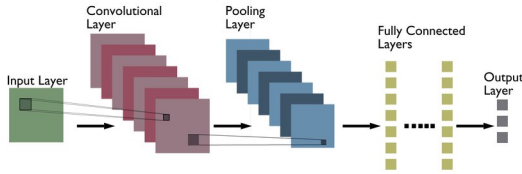


Figure 1: Typical CNN architecture [1]

a convolutional layer often follows a pooling layer which is used to downsample the image in order to keep computational costs low. Depending on the problem, the form of pooling may vary. Similar to the convolutional kernels the pooling kernel also slides over the input image but here returns the maximum/average value of the underlying matrix of the input. The *max pooling* and *average pooling* operations are depicted in Fig. 2. Here, a pooling kernel of size 2×2 is used with a stride of 2 per step, resulting in an output which is half the size of the input. Deep CNNs can consist of multiple blocks which consist of one or more convolutional layers with a pooling layer at the end. The first convolutional layers usually detect simple features like edges and corners while deeper convolutional layers can detect more complex shapes.

For classification and regression problems, the convolutional/pooling layers are typically flattened, followed by fully connected layers and lastly the output layer.

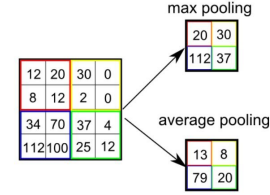


Figure 2: Max and Average Pooling Operation [2]

Applying a CNN on ring reconstruction for the mCBM RICH detector

As Artificial Neural Networks are a type of supervised learning, every input image has to be paired to a corresponding output, which in this case is a flat array with the ring parameters.

To train the CNN, a toy model was constructed, that produces images the size of the mCBM detector ($72 px \times 32 px$) with (at the moment) up to three rings and some random noise (Fig. 3). The ring parameters are then written into the target array. Because the model might be adapted to the CBM RICH detector in the future, where rings often have more elliptical shapes, five ring/ellipse parameters are used: position of the ring center (x, y), semi-major axis, semi-minor axis and angle. Three rings with 5 parameters each results in an output of the size of 15. If there is less than three rings, the relevant array entries will be set to zero. For now, only perfect rings will be used for training, i.e. semi-major equals semi-minor axis and angles will be set to zero.

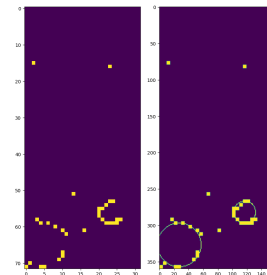


Figure 3: Example of an event display created by the toy model for training the CNN (the right image is scaled in order to draw a thin ring for the fit)

* Work supported by BMBF (05P19RGFCA, 05P21RGFC1).

Model architecture and hyperparameters

The architecture which yielded the best results so far has 4 convolutional blocks, each consisting of two convolutional layers followed by a max pooling layer. In each consecutive block the number of filters in the convolutional layers are double the size of the convolutional layers in the last block, starting with 64 filters in the first block. Each filter is of size 3×3 . The output of the last max pooling layer will be flattened and fed into a dense layer with 64 nodes, followed by the output layer with the 15 nodes that represent the ring parameters. On each convolutional and dense layer the *Rectified Linear Unit* (ReLU) was used as the activation function.

Deep neural networks are prone to overfitting which means the model isn't able to generalize very well and learns the noise in the data rather than its features. There are several regularization techniques that can be used to overcome this problem. Here we apply *batch normalization* after each convolutional and dense layer.

Stochastic Gradient Descent (SGD) (with a momentum of 0.9) was used as the optimizer to reduce the loss (here: *mean squared error*) while training. The model was trained for 24 epochs with a batch size of 256 on a dataset the size of 200000. 80 percent of this dataset was used for training and 20 percent for validation.

The optimal learning rate was determined to be in the range between $1 \cdot 10^{-6}$ and 0.05. This was done by using the "LR range test" proposed by Leslie N. Smith [3]. Cyclical learning rate schedules have shown better results than monotonously decreasing the learning rate (cf. [3]). Therefore, the model was trained by using a triangular cyclical learning rate schedule with the lower bound of the determined range as the initial learning rate and the upper bound as the maximum learning rate as shown in Fig. 4. The schedule is divided in three cycles with each cycle halving the maximum learning rate of the preceding cycle.

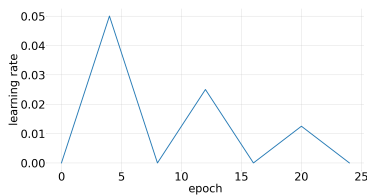


Figure 4: Learning rate schedule used for training the CNN

Results

Accuracy as well as loss for training and validation datasets are depicted in Fig. 5. To also test the model performance on unseen data, a test dataset with 100000 entries was created. Evaluation on this dataset yielded a loss of 0.4455 and an accuracy of 98.18%. For further evaluation a mCBM-simulation dataset was used to visualize the ring fitting which can be seen in Fig. 6. For this dataset, noise reduction as described in [4] was performed as first step.

The model was created with tensorflow/keras in python but is being integrated into ROOT at the moment. Once integrated, a direct comparison between the CNN and the Hough Transform Method will be possible.

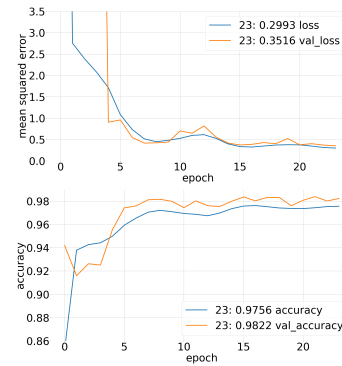


Figure 5: Loss and accuracy charts for training and validation data

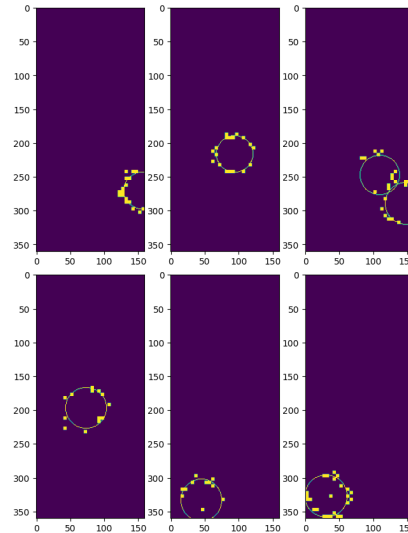


Figure 6: Predictions of the CNN on mCBM-simulation data after noise reduction according to [4].

References

- [1] Deep Neural Networks Meet CSI-Based Authentication - Scientific Figure on ResearchGate. https://www.researchgate.net/figure/Typical-CNN-architecture_fig2_329608053 [accessed 7 Apr, 2022]
- [2] Lung Cancer Detection using Deep Learning - Scientific Figure on ResearchGate. https://www.researchgate.net/figure/Max-and-Average-Pooling-Operation-2_fig13_324728060 [accessed 7 Apr, 2022]
- [3] Leslie N. Smith et al., arXiv:1506.01186v6
- [4] M. Beyer et al., "mRICH pattern recognition", this report.

The new RICH geometry in the ROOT format*

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The current RICH geometry (*v17a*) was designed in 2017. This geometry is realistic with respect to the overall design and the material budget, and shows good electron identification and pion suppression performance. However, the protection of the MAPMTs from the magnetic stray field had been an open issue. A new round of geometry optimization was performed in 2019 and 2020. The main idea was to move the PMT plane out of the magnetic field by rotating the mirror to 12° from its current value of 10° , which allows reduction of material of the shielding box and simplifies the detector installation and maintenance. The results of the optimization can be found in [1].

The release of this geometry was delayed due to several issues. One of them was the procedure of the geometry creation. The geometry was created using the CATIA-GDML Geometry Builder tool [2] which allows creation of a ROOT compatible geometry in the GDML format from the CAD system CATIA5. Then, a GDML file can be converted to the root format using the ROOT *TGDMLParse* class. One of the consequences of using such a tool was that it was hard to make even a small change in the geometry without a CAD expert who should also be familiar with the Geometry Builder tool. Taking into account a long-term support requirement it was agreed to implement all new RICH geometries only using ROOT *TGeoManager* and C++ which are the common development tools in *cbm-root*. The results of this work are presented in this report.

The general geometry volume hierarchy looks very similar to the *v17a* version. Each individual pixel is included into the geometry (see Fig. 1). There are 4 types of pixels: central pixels and 3 types of edge pixels. 8×8 pixels are grouped into the PMT volume which also includes additional passive materials. The basic PMT module consists of 2 by 3 PMTs and passive materials for the DiRICHes, the data combiner and the power boards. On the next level 7 PMT modules are grouped vertically into a PMT column. One half of the full PMT plane is formed by 14 vertical PMT columns. The full mirror consists of 80 mirror tiles of 6 different types (see Fig. 2). The mirror support structure includes belt-shaped aluminum frames which are placed behind each mirror tile. The passive materials also include the RICH aluminum box and the main frame, the entrance and exit panels which are made of kapton, and the mirror aluminum support structures.

The geometry builder allows to adjust many geometry parameters, namely, the rotation angles and positions of the mirrors and the PMT planes etc. It is important to mention that the rotation of mirrors does not change the position

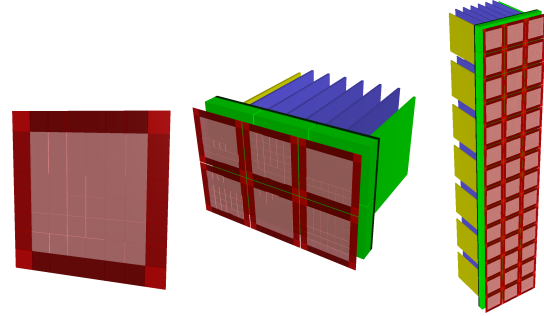


Figure 1: RICH PMT plane components: 8×8 PMT pixels, PMT module, PMT column.

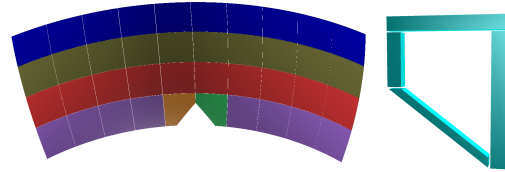


Figure 2: RICH mirror components: half mirror (different colors show different mirror tile types), belt aluminum support for mirror tile.

of the PMT plane as it was in the previous geometry. All single geometry components can be positioned and rotated independently to each other. The full geometry is displayed in Fig 3. The magnetic field shielding box is to be implemented in the next iteration of this development.

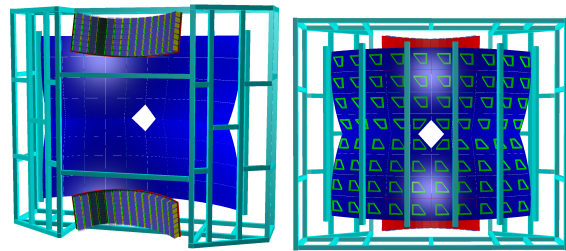


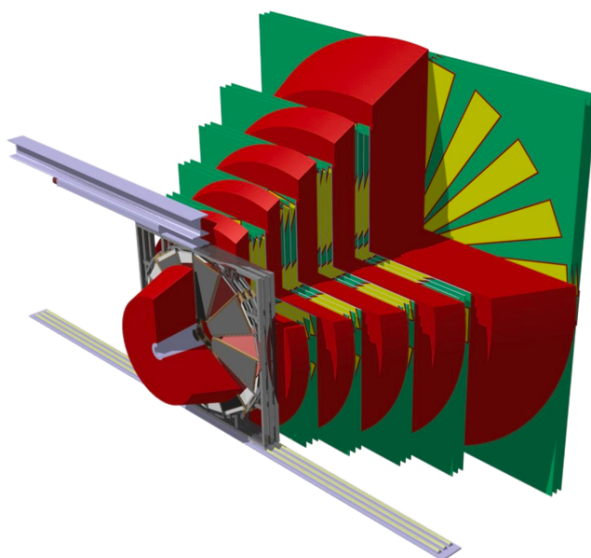
Figure 3: The new RICH geometry in the ROOT format.

References

- [1] S. Lebedev et al. "RICH geometry optimization", CBM Progress Report 2019 (2020) 55
- [2] S. Belogurov et al. 2014 J. Phys.: Conf. Ser. 513 022003

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Muon Detection System



Development of the muon chambers (MuCh) for the CBM experiment: a status report

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The di-muon detection system at CBM consists of segmented absorbers made of the combination of concrete & graphite in the 1st absorber followed by iron plates of varying thickness in the subsequent 5 absorbers. The R&D activities include the development of the GEM chambers for the 1st two stations and the high-rate RPCs for the 3rd and 4th stations. These large size GEM chambers are made of specially-designed readout PCB using 8-layer boards.

Two real-size GEM chambers took data in the miniCBM experiment during 2019-2020 and an issue was observed at high rate and high voltage that resulted in the loss of link connection during data transfer. A detailed investigation was made in the lab to find the issue to be due to the HV distribution that needs some modification in the layout. This has been implemented in a new module as shown in Fig. 1 and two chambers with modified layout have been tested at the GIF++ at CERN and miniCBM at GSI. At both the places, the detectors could run at high voltage and at high hit rate. The chambers were then installed and made ready for taking data with Au beam at miniCBM setup. This is the first time that the GEM chambers are being readout at the miniCBM using CRI boards. A DAQ monitoring system is also developed. The miniCBM data analysis is in progress, however initial results show that the GEM chambers are capable of handling high particle rate. During this period, a detailed analysis was done of the 2019-20 data for obtaining the efficiency of the GEM chambers which goes up to 90%. Some more studies on GEM chamber have been performed.

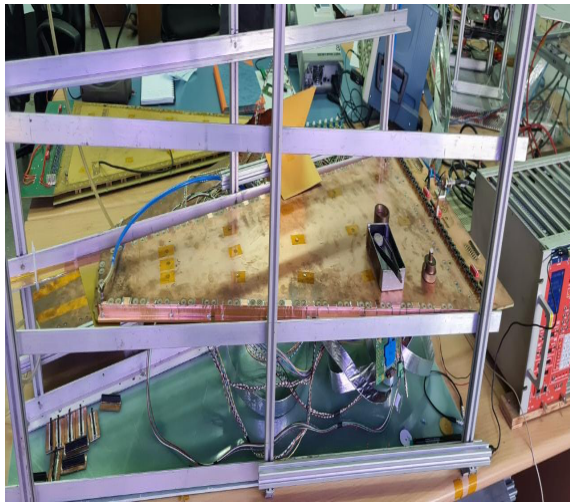


Figure 1: MuCh Station 1 module with modified drift PCB

A large GEM chambers suitable for the 2nd station has also been built using the joining PCB technique and has been tested in the lab using cosmic muons giving $\rightarrow$ 95% efficiency. We have also performed studies on the high-rate RPCs specially built using smaller gas-gap and thinner electrodes for handling high particle rate. One real-size RPC suitable for the 3rd station has been tested with beams in presence of photon flux at GIF++ (Fig. 2) and at the miniCBM setup. In GIF++ it has been found to work up to the desired rate at relatively higher operating voltage giving higher than 95% efficiency. The chamber has also been integrated to the miniCBM DAQ and took data using Au beams.

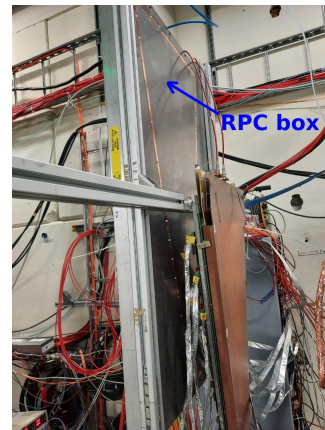


Figure 2: RPC module at GIF++ beam line

On the simulation front, detailed efforts are made to study the performance of the MuCh setup using the proposed beam-pipe and modified beam holes. It was also studied using a setup in which the absorber plates have realistic non-uniformity in the surface thickness. This has resulted in the increase in length of the setup. In the infrastructure front, a major progress has been made on development of a HV system built at VECC. The system based on assembling several HV modules in a crate has been tested at the miniCBM beam and the performance seems satisfactory. During this period, the mechanics went through some modifications mainly to deal with the availability of suitable quality of irons and the design of the new beam-pipe for the low energy beams.

The activities on reviews on GEM, RPC, LV, HV, control system and mechanics are ongoing and scheduled to be mostly completed during 2022-23.

Charging-up effect in single mask triple GEM chamber

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The Gas Electron Multiplier (GEM) detector is being used in many High Energy Physics Experiments as tracking device because of its good rate handling (~ 1 MHz/mm²) capability and high detection efficiency ($>95\%$) [1]. Due to the foreseen high interaction rates (~ 10 MHz), triple GEM chambers will be used as the tracking stations in the first two stations of CBM Muon Chamber (MuCh). The GEM foil, which is the main component of the GEM detector, is made up of 50 μ m thick Kapton with 5 μ m thick Copper cladding on both sides. A large number of holes are pierced into the 60 μ m thick Copper clad Kapton film using photo-lithographic techniques [2]. Depending on the photo-lithographic techniques used, GEM foils are classified as either Double Mask (DM) or Single Mask (SM) foils. Due to the presence of the dielectric medium (Kapton) inside the active volume of the chamber, the behaviour of the chamber changes when exposed to external irradiation. As a result, the gain of the chamber increases initially and then reaches a constant value asymptotically. This phenomenon is known as the charging-up effect [3]. The initial increase in the gain is mainly due to the accumulation of the charges on the surface of the Kapton inside the GEM hole which in effect increases the electric field strength inside the holes and thus the gain of the chamber increases. After some time, when a dynamical equilibrium is achieved, the electric field strength inside the holes do not change further and the gain of the chamber reaches a constant value. The time up to which the gain of the chamber increases, referred as the charging-up time, mainly depends on the charge density inside the GEM holes. In this report, the effect of charging-up time on the gain and irradiation rates of a SM triple GEM prototype of dimension 10 cm $\times$ 10 cm is discussed [4].

The SM triple GEM prototype having a drift gap of 3 mm, transfer gaps of 2 mm each and induction gap of 2 mm is operated in continuous flow mode with Ar/CO₂ gas mixture in 70/30 volume ratio. A Fe⁵⁵ X-ray source of energy 5.9 keV is used to irradiate the chamber and also to measure the X-ray energy spectra. The readout plane consists of 256 X-tracks and 256 Y-tracks. Each of the X and Y-tracks are connected to two 128 pin connectors. For data acquisition, a sum-up board (obtained from CERN) is used for each 128 pin connector and thus a total of four sum-up boards are used in this prototype. The signal from the GEM chamber is fed to a charge sensitive preamplifier (VV50-2) having a gain of 2 mV/fC and shaping time of 300 ns. The output of the preamplifier is fed to a linear Fan-In-Fan-Out (FIFO) module. One analog output signal from FIFO is fed to a Single Channel Analyser (SCA) used in integral mode

and the signals are counted using a NIM scaler. Another output from the FIFO is put to a Multi Channel Analyser (MCA) to obtain the energy spectra. The ambient temperature (T) and pressure (p) are monitored continuously using a data logger.

The gain of the chamber is calculated assuming full energy deposition of 5.9 keV energy deposition in the 3 mm drift gap and knowing the calibration factor of the MCA. To eliminate the effects of temperature and pressure variations, the gain of the chamber is normalised using a parameterisation of the form $Ae^{(BT/p)}$, where A and B are the free parameters. The variation of the normalised gain as a function of time is shown in Fig. 1. The initial decrease

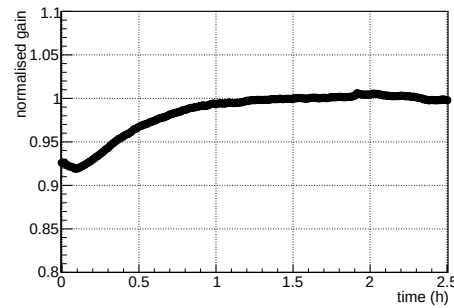


Figure 1: Variation of normalised gain as a function of time (in hour) at a $\Delta V = 409$ V across each GEM foils and with particle flux of ~ 7.78 kHz/mm².

in the gain for the first few minutes is due to the initial polarisation effect of the dielectric. To avoid the initial decrease part, the High Voltage (HV) of the detector is kept on for around one hour before starting the measurement. The measurement is started as soon as the Fe⁵⁵ source is placed on the chamber. In table 1, the details of the applied HV and the corresponding electric field strengths at the different parts of the chamber are summarised.

HV (V)	ΔV (V)	Gain	Drift field (kV/cm)	Transfer field (kV/cm)	Induction field (kV/cm)
- 5085	409	~ 12950	~ 2.4	~ 3.6	~ 3.6
- 5100	410	~ 13600	~ 2.4	~ 3.7	~ 3.7
- 5115	411	~ 14300	~ 2.4	~ 3.7	~ 3.7

Table 1: Potential difference across each GEM foil, average gain and fields on the various gaps of the triple GEM chamber for different HV settings [4].

The studies are performed with different irradiation rates at different ΔV 's across the GEM foils. Taking analogy

from the charging-up mechanism in RC network, the normalised gain is fitted with an exponential function of the form $p_0 (1 - p_1 e^{-t/p_2})$, where p_0 , p_1 and p_2 are the free parameters and t is measured time. The details of the charging-up time for different irradiation rates and different gain of the chambers are summarised in table 2 [4].

ΔV (V)	rate (kHz/mm ²)	Saturated gain	Charging-up time (h)
409	~ 0.04	~ 13000	$0.268 (\pm 0.003)$
	~ 0.14	~ 11800	$0.297 (\pm 0.001)$
	~ 0.42	~ 12600	$0.280 (\pm 0.002)$
	~ 7.78	~ 12200	$0.228 (\pm 0.001)$
410	~ 0.04	~ 13800	$0.285 (\pm 0.005)$
	~ 0.14	~ 13700	$0.351 (\pm 0.003)$
	~ 0.42	~ 13500	$0.407 (\pm 0.002)$
	~ 7.78	~ 13400	$0.335 (\pm 0.002)$
411	~ 0.14	~ 14500	$0.190 (\pm 0.002)$
	~ 0.42	~ 14700	$0.436 (\pm 0.002)$
	~ 7.78	~ 14000	$0.186 (\pm 0.001)$

Table 2: Saturated gain and charging-up time for different irradiation rates [4].

The charging-up time as a function of irradiation rates is shown in Fig. 2 for different ΔV 's across the chamber. No

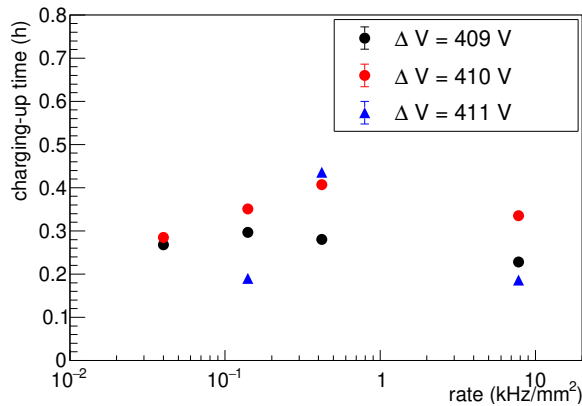


Figure 2: Charging-up time as a function of rate for different voltage settings [4].

clear dependency is observed on the charging-up time of the chamber with different irradiation rates and with different gain of the chamber. This might be due to the fact that we are observing an overall effect due to the three GEM foils and it is very difficult to disentangle the effect of individual foils on the observed charging-up time. The charging-up time is found to be 10-30 minutes for a gain of $\sim 10^4$.

Acknowledgements

We would like to thank the RD51 collaboration for the support in building and initial testing of the chamber in the RD51 laboratory at CERN. This work is partially supported by the research grant SR/MF/PS-01/2014-BI from DST, Govt. of India, and the research grant of CBM-MuCh project from BI-IFCC, DST, Govt. of India.

References

- [1] F. Sauli, Nucl. Instrum. Methods Phys. Res. A 386 (1997) 531.
- [2] Oliveira *et al.*, United States Patent, Patent No.: US 8,597,490 B2.
- [3] P. Hauer *et al.*, Nucl. Instrum. Methods Phys. Res. A 976 (2020) 164205.
- [4] S. Chatterjee *et al.*, Nucl. Instrum. Methods Phys. Res. A 1014 (2021) 165749

Performance test of a real size Resistive Plate Chamber for MuCh

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Introduction

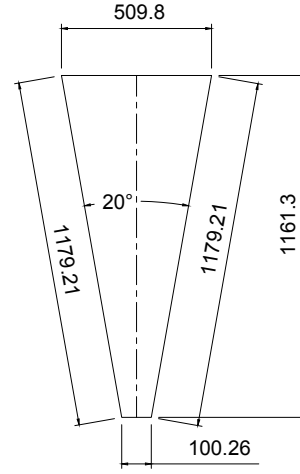
The Compressed Baryonic Matter (CBM)[1] is an upcoming experiment in the future Facility for Anti-proton and Ion Research (FAIR) in Darmstadt, Germany. The CBM experiment will have various detector systems like Silicon Tracking System (STS), Ring Imaging Cherenkov detector (RICH), Muon Chambers (MuCh) among others. The muon detection system of the CBM experiment - Muon Chamber (MuCh) will have a unique feature that its total absorber will be sliced with muon-detectors placed in between them in order to facilitate momentum dependent track identification, hence improving the efficiency of detection of low momentum muons. MuCh will have 4 different stations to house detectors for muon detection and each station will house three detector layers. Gas Electron Multiplier (GEM) based gaseous chambers will be used as active detector elements in the first 2 stations. As for the 3rd and 4th stations, RPC is being considered as a cost-effective technology option[2]. In this report, we have presented the test results of a real size RPC for MuCh tested at GIF++, CERN, Switzerland.

Test results at GIF++

A real size bakelite RPC for the 3rd stations of MuCh has been tested at GIF++ facility at CERN, Switzerland. The dimensions of the detector have been shown in Figure 1. The test set up has been shown in Figure 2. The RPC along with the readout electronics were housed inside an aluminium box. A wet gas mixture of R134a : iC4H10 : SF6 :: 95.2% : 4.5% : 0.3% (with 40 % humidity) was flown through the detector with a flow rate maintained at 5.0 l/hr. Self-triggered ASIC, MuCh-XYTER, was used to read out the signals from the RPC with the help of pick-up panel containing (45 × 10) pads[3].

GIF++ houses Cs-137 gamma source having activity ~14 TBq with a provision to use different attenuation filters to vary the photon flux. The incident photon fluxes at our detector position with different attenuation factors have been tabulated in Table 1. The 2D pad hit distribution from the detector is shown in Figure 3. One can clearly see the beam spot. The pad dimension in this region of the beam spot is ~ 23 mm × 23 mm.

Figure 4 shows the variation of current in the RPC as a function of the applied voltage for different photon fluxes incident on it. It can be observed that the current increases with the increase in photon flux as well as applied voltage. This behavior in current is as expected. The maximum cur-



All Dimensions are in mm.

Figure 1: Dimensions of the real size RPC tested at GIF++.

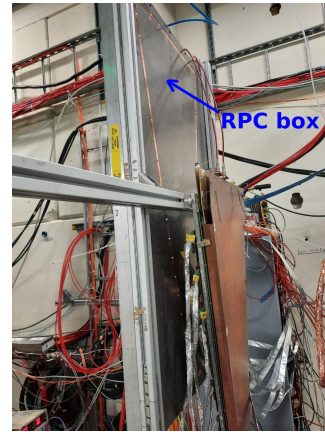


Figure 2: RPC inside the aluminium box ready for test at GIF++.

rent recorded was ~ 160 μA at 9600 V in presence of 2.72 MHz/cm^2 photon flux.

We have measured the muon detection efficiency of the RPC in absence and in presence of photon flux. The photon flux was varied from 0.69 MHz/cm^2 to 2.72 MHz/cm^2 . The variation of the efficiency with high voltage has been shown in Figure 5. A plateau close to ~95% efficiency was obtained in absence of the photon flux from 9400 V.

Attenuation factor	Photon flux (MHz/cm ²)
22	2.72
46	1.36
100	0.69

Table 1: Photon flux incident on RPC at different attenuation factor.

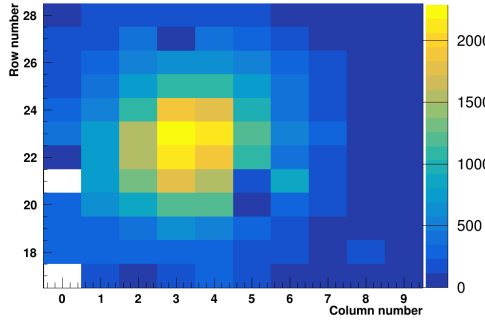


Figure 3: Hit distribution on the pads of the PCB. The RPC was at 9600 V with 2.72 MHz/cm² of photons hitting on it.

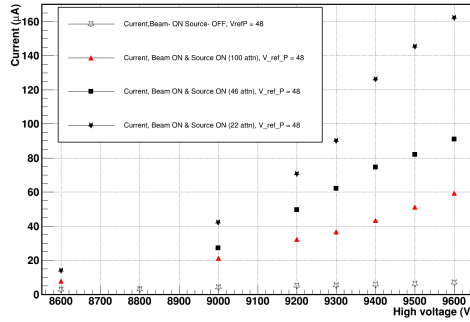


Figure 4: Variation of current as a function of applied high voltage.

The efficiency of the detector reduced in presence of photon background. Higher was the photon flux, higher was the reduction. At the highest voltage studied (9600 V), the reduction is relatively less. This behavior has been shown in Figure 6. However, the RPC has shown muon detection efficiency of $> 90\%$ at applied voltage of 9600 V in presence of $\sim 2.72 \text{ MHz/cm}^2$ photons falling on it, which can be clearly observed in Figure 5 and Figure 6.

Summary

A real size single gap RPC detector has been successfully tested detection efficiency of the incident muons in absence and presence of photon flux at GIF++. The detector has shown efficiency $> 90\%$ in presence of $\sim 2.72 \text{ MHz/cm}^2$ photon flux as background. In the near

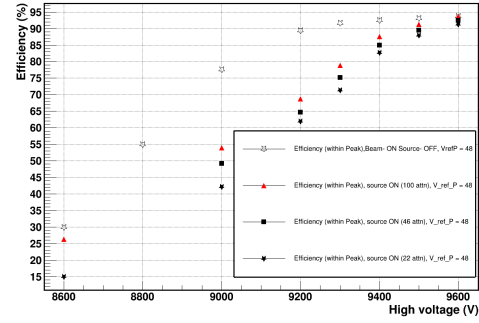


Figure 5: Efficiency of the RPC as a function of applied high voltage at different photon flux.

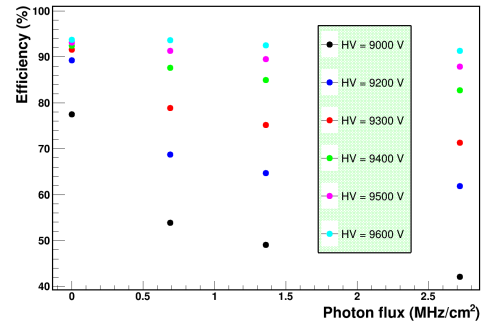


Figure 6: Variation of muon detection efficiency of the RPC as a function of incident photon flux.

future, it has to be tested for high particle rate handling capability as well as its long term performance.

References

- [1] <https://www.cbm.gsi.de/>
- [2] E. Nandy et. al., **Proc. of the DAE Symp. on Nucl. Phys.** **61** (2016).
- [3] Rafal Kleczek, Analog front-end design of the STS/MUCHXYTER2—full size prototype ASIC for the CBM experiment, **JINST** **12** (2017) C01053.
- [4] D. Pfeiffer et. al, The radiation field in the Gamma Irradiation Facility GIF++ at CERN, **Nuclear Inst. and Methods in Physics Research, A** **866** (2017) 91–103.

Efficiency estimation of a GEM chamber and its variation with time, mTOF β and GEM HV from mCBM data 2020

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In this work our focus is to determine efficiency of a GEM detector in the mini-MUCH system and study its variation with time, GEM-high-voltage and, mTOF- β .

We have used the data collected during March-May 2020 in the mCBM experiment at SIS18 in GSI, Germany. Figure 1 shows a photograph of the experimental set-up including all the sub-systems; mSTS, mMUCH, mTRD, mTOF, mRICH and mPSD. All sub-systems are aligned 25° to the beam-axis. For mMUCH, we tested two real-sized GEM modules for the 1st station of MuCh at different values of GEM-HV and thresholds. This analysis however, focusses on two runs that were collected at GEM HV 4700 V and 4800 V in low intensity (2×10^6 /spill) Pb+Au collisions at 1.06 AGeV with thick and thin targets of thicknesses of 2.5 mm and 0.25 mm, respectively.

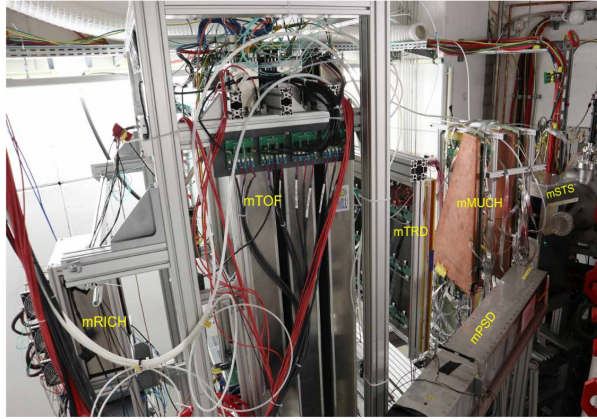


Figure 1: Photograph of the mCBM(2020) setup including all the sub detectors

In this analysis, events are reconstructed from the raw data using a time-based event reconstruction technique following a Fixed Time Window algorithm of 200 ns [2]. In our previous reports [2, 3] we have shown that using mTOF track information we can achieve good spatial and time correlations between GEM1 hits in mMUCH and the projected position of the mTOF tracks on the GEM1 plane. Thus, we further extend our work to determine efficiency of a GEM detector (GEM1) relative to the project mTOF tracks. The GEM1 efficiency is calculated according to the following definition:

$$\text{Eff} = \frac{\text{No. of mTOF tracks with associated GEM1 hits in the projected area}}{\text{No. of projected TOF tracks in common acceptance}}$$

In order to select good quality mTOF tracks and reduce the number of fake tracks, following selection conditions are applied: (a) mTOF tracks with atleast 4 hits (3 hits from mTOF layers and 1 from T0), (b) mTOF tracks within 5 cm radial cut around target origin (0,0,0) and, (c) time correlated mTOF tracks with GEM hits (3σ time window).

Within the common acceptance between mTOF tracks and GEM1 hits (Fig. 2) on the GEM1 plane, we first investigated the variation of x and y residuals of GEM1 hits w.r.to projected mTOF tracks at GEM1 plane for different pad sizes as shown in Fig. 3. These are done after correcting mutual misalignment between GEM1 and mTOF detectors. At first, we have divided a GEM chamber according to the pad dimensions. Pads with the smallest dimension are in $5 < y < 20$ cm, middle size pads are in $-5 < y < 5$ cm and large size pads are in $-20 < y < -5$ cm, as shown in Fig. 2.

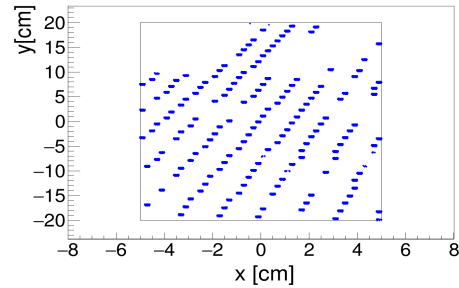


Figure 2: Common acceptance of GEM1 hits & mTOF tracks shown in black boundary, blue points are the fired pads centers.

We see that the widths of the residual distributions are smaller for higher granularity region as compared to that in the lower granularity region which is consistent with pads sizes. This shows our residual calculation for efficiency estimation is reliable. Next we calculated efficiency of GEM1 module within 3σ of the residual mean in x and y according to the definition of efficiency. Then we plotted the efficiency as a function of time which is shown in Fig. 4. This shows uniformity of efficiency with time.

We further studied the mTOF track β dependence of efficiency which is shown in Fig. 5. We calculated the efficiency for four different ranges of mTOF β ; $0.2 < \beta < 0.6$, $0.4 < \beta < 0.8$, $0.8 < \beta < 1.2$ and inclusive β . As can be seen from Fig. 5, at lower β efficiency is higher and vice-versa. This is because the energy deposition in the detector is $\sim 1/\beta$. Thus the observed variation in the efficiency with β is

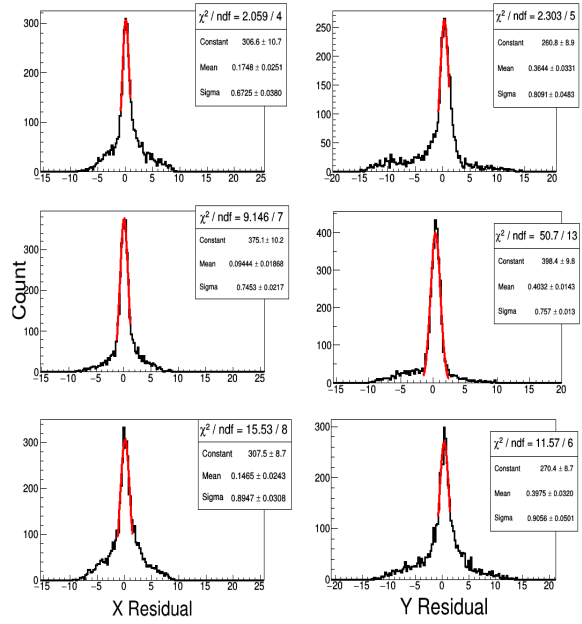


Figure 3: The variation of x and y residuals of GEM1 hits w.r.t projected mTOF tracks at GEM1 plane within the common acceptance of GEM1 and mTOF with different pad sizes : small pads $5 < y < 20$ cm (top), middle pad sizes $-5 < y < 5$ cm (middle) and large pads sizes $-20 < y < -5$ cm (bottom)

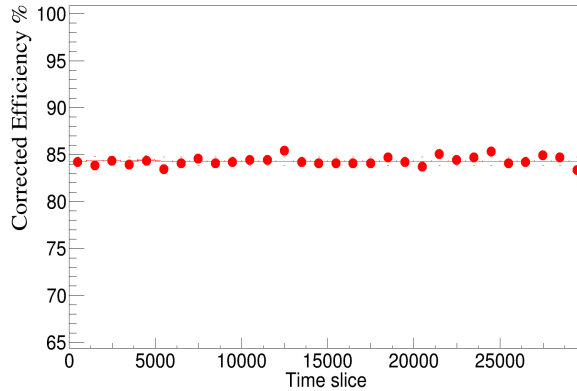


Figure 4: Efficiency variation of GEM1 with time-slice.

consistent with expectation.

Next we studied the dependence of GEM1 efficiency on GEM1 high voltage (HV) for two values of GEM1 HV 4700 V and 4800 V. Figure 6 shows the GEM1 efficiency with GEM1 HV. We notice that the efficiency increases with HV. The increase in GEM1 efficiency is about 8% for an increase of 100 Volts in GEM1 HV, which is consistent with our expectations. Further we will do these exercises with more HVs and detector thresholds data in next mCBM

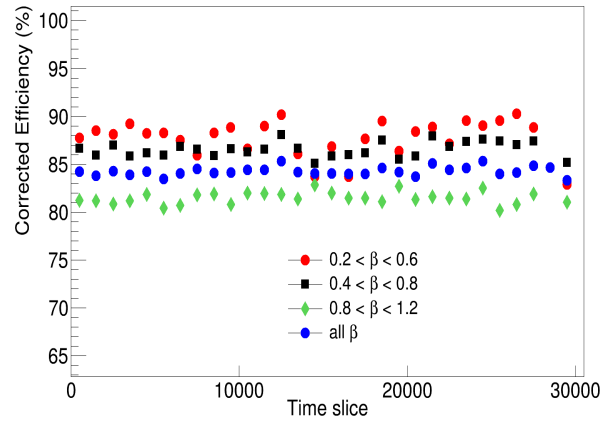


Figure 5: Efficiency variation of GEM1 with TOF β .

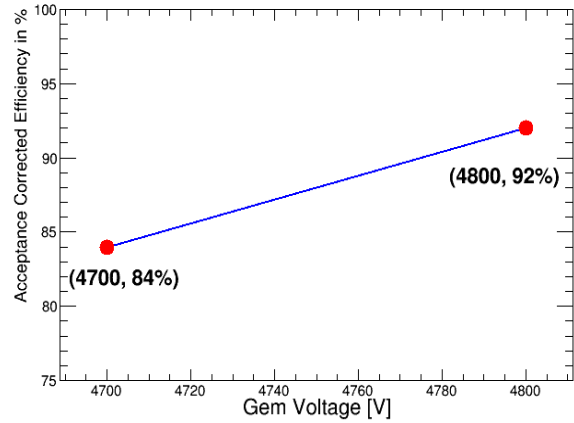


Figure 6: Efficiency variation of GEM1 with GEM1 high voltage (HV).

campaign.

References

- [1] Application for beam time at GSI/FAIR, mCBM@SIS18 2021/22, "A CBM full system test-setup for high-rate nucleus-nucleus collisions at GSI / FAIR".
- [2] CBM Progress Report 2020 "An approach to estimate efficiency of a GEM chamber in the mCBM setup", E. Nandy et. al.
- [3] CBM Progress Report 2019 "Correlation between mMuCh hits and projected mTOF tracks in the miniCBM setup", E. Nandy et. al.

Fabrication and testing of a GEM module for the 2nd station of MuCh in the CBM experiment

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One real prototype of the second station of the muon chamber has been fabricated and tested at VECC. The readout PCB of the module is 100 cm long and it consists of 1824 readout pads. To read out the entire detector, one needs 15 MUCH Front End Boards (FEB). Due to manufacturing constraints of such a large size PCB in India, we went for a joined PCB. The entire PCB gerber layout and mapping was done at VECC and it was fabricated by an Indian industry at Bangalore. Figure 1 shows the gerber layout of readout PCB.

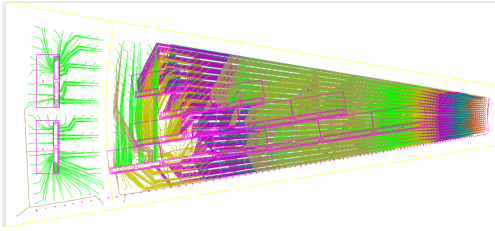


Figure 1: Gerber layout of readout PCB

A second station Muon Chamber consists of a drift PCB and 3 GEM foils placed in a gap configuration of 3-2-2-2 mm and a readout PCB. A mixture of Argon and CO₂ gases at a proportion of 70:30 is used as sensitive medium. High voltage is applied such that summed up GEM voltage across the 3 foils goes upto 1180 Volts. Figure 2 Shows a cluster charge spectra (in ADC) of Fe⁵⁵ source with a clear escape peak and the main peak. Gain of the module has been measured using Fe⁵⁵ at 2 different locations across the active area and it remains consistent with Change of HV as shown in Figure 3.

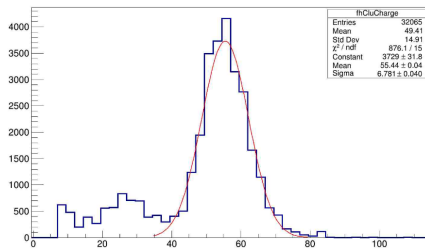


Figure 2: Fe⁵⁵ Spectra (Cluster charge in terms of ADC) at Summed Voltage = 977 Volts

The FEBs used to acquire data were calibrated with a threshold of 6 fC and with a maximum range of 81 fC. Be-

yond 1015 V the Fe⁵⁵ spectra gets saturated at the highest ADC value, i.e 81 fC.

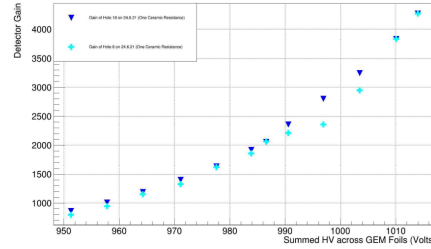


Figure 3: Gain variation at 2 different location on the detector

A 3 fold cosmic coincidence setup was made at VECC with the same module. Detector efficiency, gain etc were measured with cosmic muons. An efficiency upto 98% has been obtained with 18 ns time resolution at Summed GEM HV = 1110 V and detector gain was around 17000. The noise study has been performed across the detector readout plane. As this is a joined PCB so we observed a row of noisy pads across the joining portion of the PCB as shown in the mapping of readout plane in Figure 4. This PCB consists of 19 columns and 96 rows. With proper grounding and shielding this noisy ring has been taken care of.

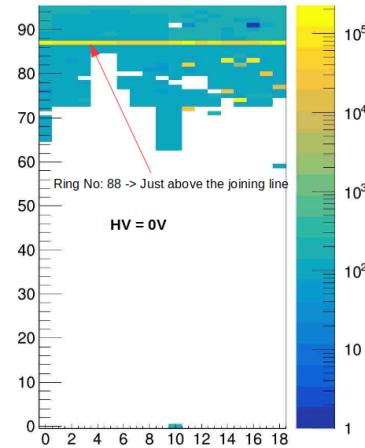


Figure 4: Noise of readout PCB

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Performance studies of bakelite RPC with new technique of linseed oil coating

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Introduction

Keeping in mind the possibility of using bakelite Resistive Plate Chamber (RPC) detectors as future high rate capable tracking devices [1], we have taken up a study to characterise RPC prototypes built using bakelite plates commercially available in local market of India.

The prototype is coated with linseed oil. However, in this work, we have adopted a different technique for the linseed oil treatment. Usually, the linseed oil coating inside the bakelite RPC is done after making the gas gap as reported in Ref. [2] and [3]. In contrast, in the present work, the bakelite plates are coated with linseed oil before making the gas gap. The prototype is tested with cosmic ray using 100% (C₂H₂F₄) gas and conventional NIM electronics.

Fabrication of the detector

Two bakelite plates having a dimension 27 cm × 27 cm and thickness 2 mm are used as the electrodes. The bulk resistivity of the plates is measured to be $\sim 3 \times 10^{10} \Omega \text{ cm}$ at 22°C temperature and 60% relative humidity. The bakelite plates are cleaned using an isopropyl alcohol bath. Commercially available linseed oil is used for the coating. About 2 g of linseed oil is applied over the 27 cm × 27 cm area of each plate. Based on the specific gravity (0.930 at 15.5 °C) of the fluid, the estimated coating thickness would be $\sim 30 \mu\text{m}$. The linseed oil is distributed over the surfaces and both the plates are left for 15 days in a sealed box for curing. Two plates are then cleaned again with dry air. Uniform separation between the electrode plates is ensured by using four edge spacers of dimension 27 cm × 1 cm and thickness 2 mm and one button spacer of diameter 10 mm and thickness 2 mm. All the spacers are made of polycarbonate (resistivity $\sim 10^{15} \Omega \text{ cm}$). Two nozzles also made of polycarbonate for gas inlet and outlet are fixed with the edge spacers. All the spacers are glued on the oil coated side of the plate using Araldite epoxy adhesive. The glued plate is kept for 24 hours for curing and the other plate is glued on it and kept again for curing for 24 hours. After cleaning, a thin layer of graphite is coated on the outer surfaces of the bakelite plates for the distribution of voltage. A gap of 1 cm from the edges of the plate to the graphite layer is maintained to avoid external electrical discharge. The average surface resistivity of the two graphite layers are found to be $\sim 510 \text{ k}\Omega/\square$ and $540 \text{ k}\Omega/\square$ respectively.

Experimental set-up

Two paddle scintillators having dimensions 10 cm × 10 cm (SC1), 20 cm × 20 cm (SC3) and a finger scintillator of dimension 10 cm × 2 cm (SC2) are used to built the cosmic ray test bench. The coincidence signal obtained from the paddles and the finger scintillators are taken as the trigger (3F). RPC is placed in between the finger (SC2) and the paddle scintillator (SC3) as shown in Figure 1. All the scintillators are operated at 1550 V and -15 mV threshold is applied to the leading edge discriminator (LED).

The RPC signal from the pick-up strip is first fed to the 10x fast amplifier, the output of which goes to the LED. From the LED one output goes to the scalar to count the number of the signals from the RPC which is known as the noise count or singles count of the chamber. The other output from LED goes to the dual timer to apply the proper delay to match the signal with the trigger. The output of the dual timer in coincidence with the trigger is defined as the 4-fold.

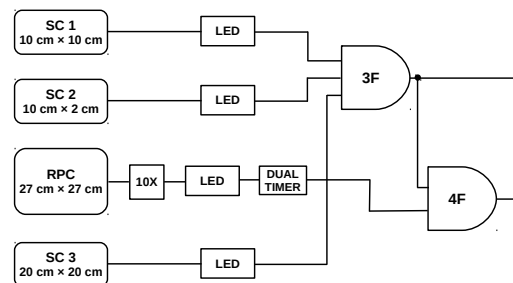


Figure 1: Schematic of the experimental set-up

100% Tetrafluoroethane (C₂H₂F₄) gas is used as the active medium. A typical gas flow rate of 2 ml/min equivalent to 6 gap volume changes per day is maintained by using two needle valves.

The leakage currents from both the sides as measured by the high voltage (HV) modules along with the temperature and the humidity are also recorded at the time of measurement using a data logger, built-in house [4].

Result

After building the chamber, 100% C₂H₂F₄ gas is purged for 24 hours before application of HV. To check the performance of the detector, firstly the leakage current through

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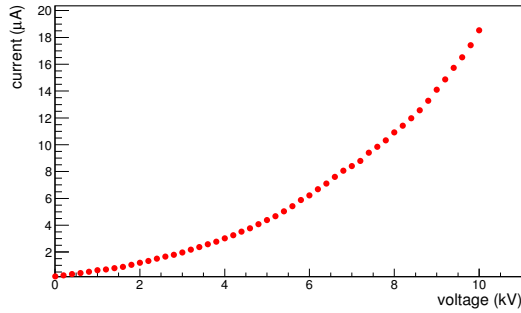


Figure 2: Leakage current as a function of the applied voltage for the RPC module.

the RPC module is measured as a function of the applied voltage and the result is shown in Figure 2. The curve of leakage current vs. voltage as found here is not only very similar to the curve as reported earlier [2] but the magnitude of current is also comparable.

Both the efficiency defined as $4F/3F$ and noise rate are measured for discriminator threshold setting -20 mV for the RPC. The temperature and relative humidity values during these measurements are recorded and the average temperature is found to be about 27 °C and the average relative humidity is found to be 44%. The efficiency and the noise rate as a function of voltage is shown in Figure 3. The efficiency saturates at $\sim 85\%$ from the applied voltage of 10.1 kV onwards [5]. The noise rate increases with applied HV. The noise rate is found to have increased to ~ 170 Hz/cm².

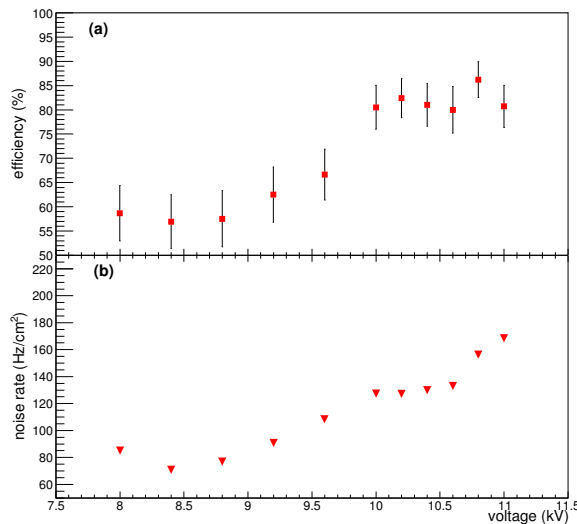


Figure 3: (a) The efficiency and (b) Noise rate as a function of the applied voltage.

Summary and outlook

The detection efficiency of the RPC in the cosmic ray test is comparable with those found with conventional linseed oil coated bakelite RPC [2, 3, 6]. However, the investigation behind the high leakage current and high noise rate is going on. The long-term stability test, measurement of timing properties and the effect of the temperature and relative humidity on the performance are planned to be carried out in future.

Acknowledgement

We would like to thank Mr. Shivshant Chauhan and Mr. Subrata Das for helping in this study. The authors would also like to thank Prof. Sibaji Raha, Prof. Rajarshi Ray and Dr. Sidharth K. Prasad for valuable discussions and suggestions in the course of the study. This work is supported by DST Inspire Fellowship research grant [DST/INSPIRE Fellowship/2018/IF180361] and partially supported by the CBM-MuCh project from BI-IFCC, DST, Govt. of India.

References

- [1] A. Sen *et al.*, JINST **15** (2020) C06055.
- [2] M. Abbrescia *et al.*, Nucl. Instr. and Meth. A **394** (1997) 13.
- [3] B. Hong *et al.*, Journal of the Korean Physical Society, Vol. **48**, No. 4, April 2006, 515.
- [4] S. Sahu, *et al.*, JINST **12** (2017) C05006.
- [5] A. Sen *et al.*, Nucl. Instr. and Meth. A **1024** (2022) 166095.
- [6] R. Santonico and R. Cardarelli, Nucl. Inst. and Meth. A **187** (1981) 377.

Ethernet Control Backend design of HV module Testing for mMUCH at mCBM Experiment

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The mini CBM (mCBM) experiment is considered as FAIR phase-0 experiment and its results are crucial for understanding the complication and performance of the full CBM experiment. This report describes the development of backend control system for the indigenously developed high voltage system which will be used in CBM-MUCH detector system. One of the proto-type is presently installed in mCBM powering one GEM detector. In this article we emphasize on the reliable operations of the raspberry pi based Ethernet control system in backend while UART based communication with microcontroller in its frontend. In order to support dynamics of the experiment, control system hardware, firmware and scripts were designed to have scalable and sustainable control and monitoring system.

First prototype of the two channel HV supply is shown in fig.1. Two modules of Spellman make HV power supply, each has - 5kV, 2mA, 10W isolated output with load and line regulation better than + 0.001 percent are cascaded inside the box.

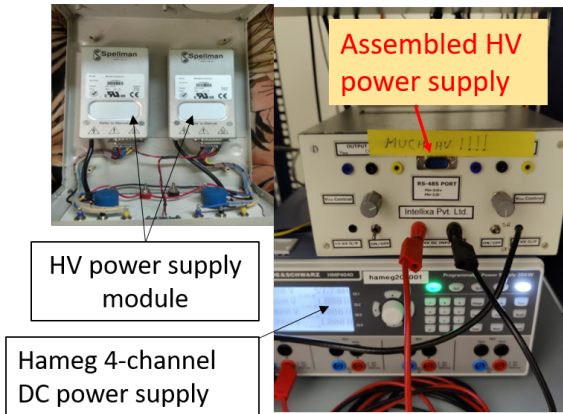


Figure 1: Two Channel HV Supply

This prototype power supply has one slave microcontroller (Arduino Mega) and one master controller board (Raspberry pi board) for control and monitoring of power supply parameters. As shown in fig.2 micro-controller receives and sends commands/monitoring parameters via UART on the front end (HV module side) as well as on the back end (rasberry master side). Rasperry segregates data, wrap it into Ethernet frame and send it to MUCH slow control machine via UDP over Ethernet. Later on, this HV

Supply module was installed in m-CBM cave. One channels of HV supply was used to power GEM detector during the mCBM experiment.

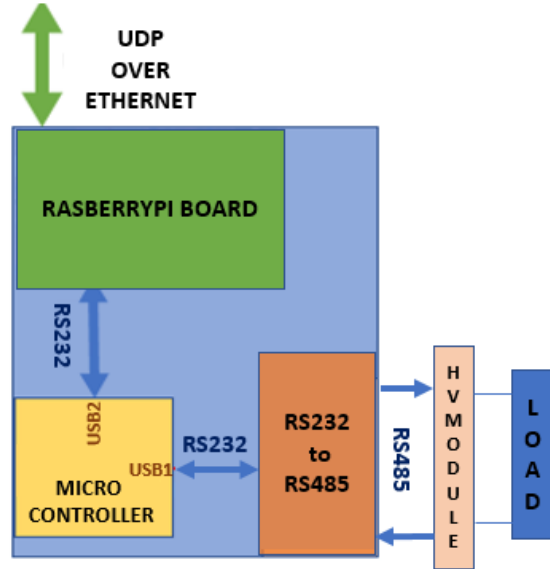


Figure 2: Control circuit for HV Module

As shown in fig.3 rasperryie receive/send data from the ethernet backend via socket program written in its boot memory.

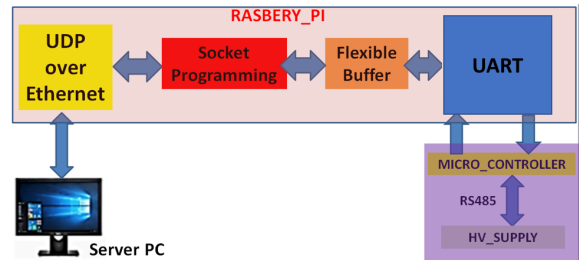


Figure 3: Python scripts in Rasperry

UART and Ethernet communicates via 512KB flexible buffer through hand shaking . Python based UDP socket scripts were written for successful and reliable monitoring, control and data logging of HV Module (HV0) .The system had been validated in the environment of mini CBM experiment for more than 100 hours.

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Design and Development of Readout PCBs for 3rd station at CBM-MuCH

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The Muon Chamber (MuCh) of CBM is a segmented absorber system with detectors placed in between the absorbers. MuCh consists of four detector stations sandwiched between the absorber segments. At the 3rd and 4th stations of MuCh, Resistive Plate Chambers (RPCs) have been conceived for muon tracking. Here we report the design and development of the readout PCBs for the 3rd station of the CBM-MuCH RPC detector.

The segmentation of a real size trapezoidal shaped signal pickup PCB for the 3rd station of the RPC detectors at CBM-MuCH is designed with precise calculations. These detector readout PCBs are of 1181-mm (about 4-ft) in length and 542mm (about 2-ft) wide and 2.4mm thick. Total 18 no. of modules accommodate the full azimuth coverage with coverage of 20 deg for each detector module. Each PCB is designed using trapezoidal pads layout in the 48 no. of concentric circles with progressively increasing radius. The size of the smallest trapezoid pad is 1.01cm and that of the largest pad in the farthest most radius is 5.0 cm as shown in Figure 1. The exact parameter values are crucial for the integration of the designed PCBs with the MuCH front end electronics (FEE) and with the other detector systems at the experimental site. The calculations include the rotation angles, replication steps, vertical and horizontal tolerances to avoid any shorts during the production.

Total 04 no. of connectors with 1.27 mm pitch are placed for insertion of FEE boards at approximately equal distance, leaving space from the zeroth coordinate so that the board could be placed in the test beam system also. The signal tracking of T8 size is chosen and routing is done with minimum 8 mil (1 mil = 0.0254mm) track to track distance. Tracks are broom shaped at the far end so as to avoid cross talk between the nearby signal tracks. The PCB is outlined with the thorough holes for connecting the screws at the board edge to attach the pickup panels to the detector firmly for efficient charge collection. The boards are fabricated with FR4 material, ENIG finish and Glass Transition Temp (T_g) 170 for production quality tests and to decide for the further production lot.

2 no.s of PCBs are produced for the first test with the RPC detectors. The initial testing of the PCBs have been carried out in VECC. The overall performance of the detector along with PCB has been tested successfully in GIF++ facility at CERN Geneva. As of today the RPC detector along with the designed PCB is under test at mini-CBM GSI, Darmstadt Germany.

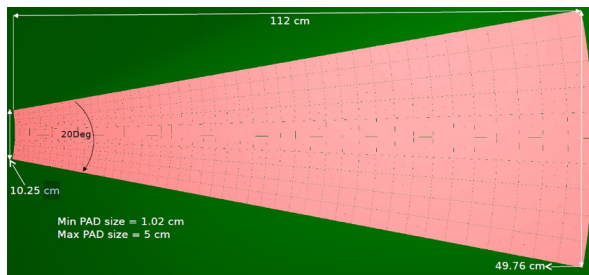


Figure 1: Design of readout PCB for 3rd station at CBM-MuCH

The tolerance between the two pads both horizontally and vertically is 0.2 mm to avoid any shorts and kept such so that it could be produced in the production foundries with optimum charges. Provision is also kept for the injection of the external test pulse charge through capacitor coupling to the FEE boards.

Drift PCB modification of station-1 MuCh module for readout electronics link stability

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Two GEM detectors are installed in mCBM cave as a part of mini-MuCh detector system. In April 2020 beam-time, it was observed that with high voltage of GEM detector, some spikes are generated within the detector system and creating e-link losses in the MUCH/STS-XYTER electronics. The other symptoms which were observed in the data collected with the setup were, timing offsets during the run and unstable DAQ in start of a new run. The basic schematic of the setup used during this period was as shown in figure.1.

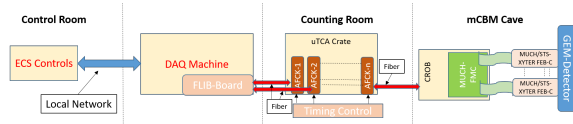


Figure 1: Schematic of the AFCK based setup in mCBM

In this figure.1 in “mCBM cave” section, it was observed that CROB to FEB-C board connection which are known as e-links were getting disconnected with the spikes in the detector and CROB to FEB-C board communication was no more possible. However, the data generated at the FEB boards is still continued to be received at CROB. The data now received after these link breaks have timing offsets. This was further investigated at VECC starting bare PCB. After the detailed investigations, it was observed that the spikes are generated in the HV segmentation introduced for GEM segment isolation.

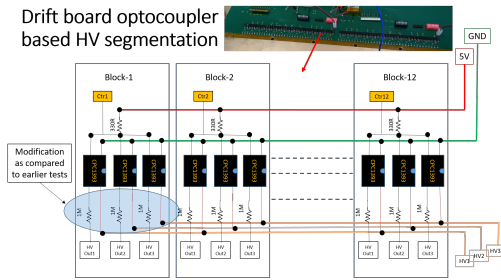


Figure 2: Optocoupler HV segmentation

In figure.2 it can be seen that earlier after the resistive chain, the HV was directly fed to opto-couplers. Due to this a small spike in any segment is seen by all the segments of the GEM foil and the spike gets amplified which in turn was generating e-link loss. This issue was resolved in the

Modification done in drift board after which link break was resolved

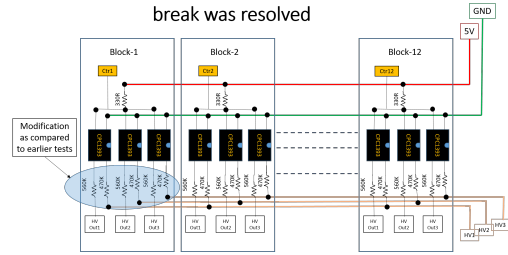


Figure 3: Optocoupler HV segmentation after modification

later design as shown in figure.3 and now 1M resistance which was used only in the output line is now divided in 560K and 470K and thus isolating each optocoupler from one another. After this modifications, the GEM detector was tested in high rate environment in Gif++ experiment in CERN. There it was found that no more link losses were observed. The same detector was then installed in mCBM cave.

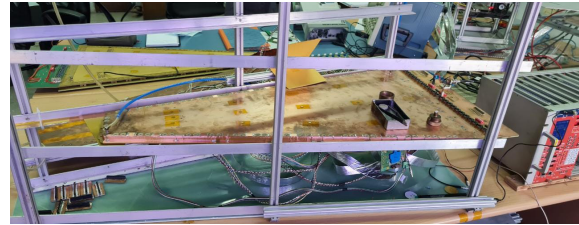


Figure 4: MuCh Station 1 module with modified drift PCB

Apart from this a new drift PCB was designed according to the above modification. Using this PCB along with readout PCB, GEM foils and other components a new module has been built at VECC, as shown in figure.4. The same has been tested at lab with high voltage and no link loss is observed for a continuous operation of 48 hours and more. The cosmic muon detection efficiency has been measured in lab using this prototype and found out to be around 96% efficient corresponding to summed voltage of 1125 Volts. This module was installed in mCBM cave. In March, 2022 it was tested at high intensity Uranium beam. The preliminary high rate results show that detectors and electronics are showing stable behaviour. No such timing offset jump is observed. Further data analysis is in process.

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In house development of high voltage power supply to be used with GEM detectors of CBM-MuCh detector system

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GEM detector stations of the Muon Chambers needs High Voltage Power Supply (HVPS). VECC, Kolkata is engaged in developing these HVPS system along with its necessary control architecture. The system comprises a crate that can accommodate 10-12 numbers of HVPS along with its support components. As a prototype a MPS series high voltage module of rating -5kV, 2mA is control and monitored using a single dedicated microcontroller. Some necessarily specification of HVPS is described in Table 1. Initially an Arduino mega microcontroller is attached to HVPS as shown in Fig. 1 as a slave. This microcontroller is master control by Raspberry pi. In the final scheme these modules will be controlled by Texas instruments based microcontroller (MSP430FG4619). High Voltage setting i.e. ramp up and down rate, set voltage and over current is mainly controlled by microcontroller. Single line python code sent by the user set the desired setting of the HVPS.

Sr. No	Parameter	Value
1	Voltage regulation	better than $\pm 0.001\%$ (load & line)
2	Voltage stability	0.02% (200 ppm) for 8 hrs after 1 hr warm up.
3	Output Ripple	Less than 30mV p-p (very low ripple & noise)
4	Measurement resolution	current $<1\mu\text{A}$, voltage $<1\text{V}$ (14 bit ADC $\sim 0.13\mu\text{A}$, 0.7V)
5	Standards	Compliant to EEC EMC directive, UL, CE marked, RoHS compliant, EN61010-1, UL61010-1

Table 1: HVPS specification of MPS05N10/24/DCC2, Spellman, USA

As the micro controller should remain active in any condition a hardware watchdog timer is also attached with the microcontroller, that reboot the microcontroller in every 7s if no response is receive from it. After restart of the microcontroller the microcontroller set the HVPS to its initial default setting. The user has to re issue the new setting in order to set HVPS.

The Figure 2 shows the state machine flow chart of the micro-controller used to control and monitor the HV power supply module. The microcontroller initaillizes the necessarily parameters of the HVPS and then monitored the present status of the current and voltage. If at any time user want to set the new parameter to the HVPS then an serial

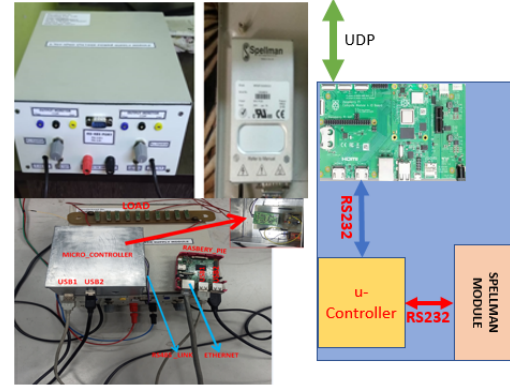


Figure 1: Two Channel HV Supply and its components

interrupt will occur. The microcontroller then load the new parameter of the HVPS setting and then check whether the HVPS reached the desired set point or not. During the operation if at any time the overcurrent is reached the microcontroller will then rampdown the power supply to 0 volt and raise the flag. The user can sent the new setting only after resetting the flag.

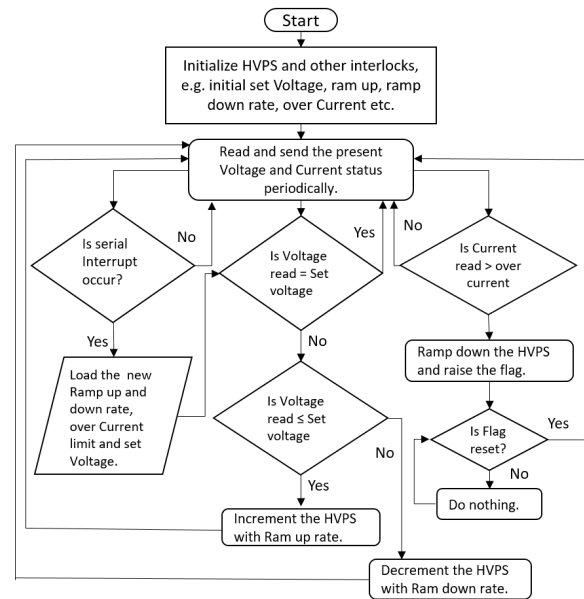
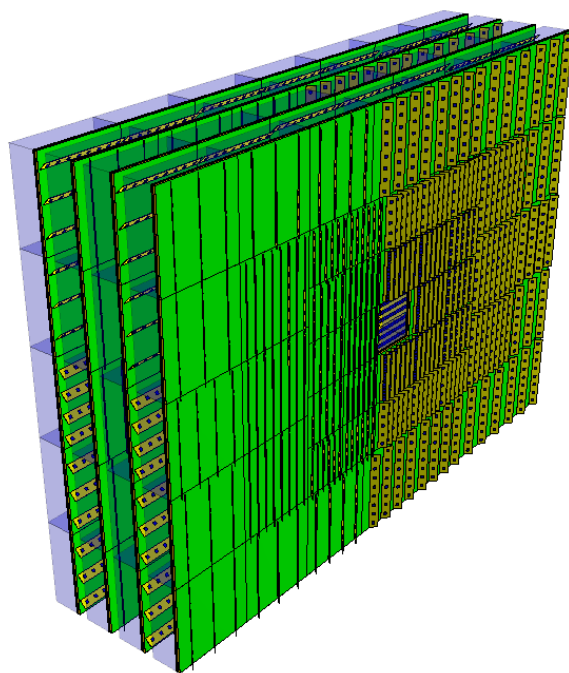


Figure 2: Flow chart for the HVPS micro-controller

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Transition Radiation Detector



Summary on the TRD project

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Introduction

The main task of the Transition Radiation Detector (TRD) is to identify electrons above momenta of 1 GeV/c and thus to extend the electron identification capabilities of the CBM experiment into momentum regions above $p \sim 5$ GeV/c. For high momenta the TRD should provide a pion suppression factor in the range of 10 – 20 at an electron efficiency of 90 %, in order to allow for a high quality measurement of dielectrons in the mass range from below the ρ and ω masses to beyond the J/ψ mass. Due to its capability to identify charged particles via their specific energy loss, the TRD in addition will provide valuable information for the measurement of fragments and thus be also decisive for the hypernuclei program of CBM.

These requirements can be fulfilled with a Xe/CO₂ based Multi-Wire Proportional Counter (MWPC) detector in combination with an adequate radiator. The default MWPC design is composed of a symmetric amplification area of $3.5 + 3.5$ mm thickness, complemented by a 5 mm drift region to enhance the TR-photon absorption probability in the active gas volume. This geometry provides also efficient and fast signal creation, as well as readout, with timescales below 250 ns per charged particle track. The performance of the detector is maximized by reducing the material budget between radiator and gas volume to a minimum.

The baseline design for the TRD at SIS100 will consist of one station, composed of four detector layers. It will be positioned between the Ring Imaging CHerenkov (RICH) and the Time-Of-Flight (TOF) detector and thus will help to reduce the background in the TOF resulting from track mismatches by providing additional position information between RICH and TOF. The TRD will also be used as tracking station behind the last absorber of the MUCH detector in the muon configuration of CBM.

Module development and pre-production

The most important step within the TRD project during the recent year was a first move towards a series production of the outer TRD modules. To prepare this, firstly a pre-production of five type-5 modules will be done [1]. These modules will then be thoroughly tested and a production readiness review (PRR) will be held. If this results in a positive evaluation, the full production of the outer modules will follow. This pre-production is being done in the laboratories in Frankfurt and Münster. A completely new laboratory for the production of wire chambers is there-

fore being constructed in Münster, while the existing one in Frankfurt has been refurbished and cleaned. All required materials (e.g. frames, back panels, pad planes, wires) have been ordered or are already delivered.

In order to validate the design of the outer chambers, final tests have been performed. One addresses the deformation of the entrance window, which in the case of the outer chamber consists of a foil supported by a carbon grid. In the case of a pressure difference of the detector gas relative to the ambient pressure, it will exhibit a slight bulge which can affect the gas gain. A detailed measurement was performed [2] with the result that the maximally tolerable pressure difference is 0.7 mbar. Another study was done for the entrance window of the innermost chambers of the TRD-2D type. Here it is foreseen to use a composite structure of Rohacell, Kapton and honeycomb. Several versions have been investigated [3], with a special emphasis on their absorption of x-ray photons. Based on this measurements an optimized version of the entrance window was designed.

Infrastructure

In preparation of the engineering design review (EDR) of the LV- and HV-system, the requirements on the LV-supply-system have been evaluated in detail. Based on these final numbers a re-design of the system has been done [4]. The overall power demand of the whole TRD was estimated to be 15.8 kW.

Furthermore, work on the design of the TRD support structure and on the gas system has been continued in Münster. For the latter, all components needed to set-up a one-line test system have been purchased.

Front-end electronics and readout

The SPADIC chip, developed at the ZITI in Heidelberg, will be used for the readout of the outer TRD modules. While this ASIC did generally provide the required functionality, it turned out that this version, on one side, exhibited problems in the analogue part in many channels, and on the other side was suffering from a relatively high noise level. As these issues would make the application of the ASIC in the final experiment quite cumbersome, it was decided to rather introduce an intermediate development version 2.3. This version provides, in addition to modifications supposed to solve the above mentioned problems, also several minor bug fixes (e.g. configurable number of pre-samples and proper read-back of the analogue shift register) and other new features (e.g. charge injection on all

channels). Two versions of these test ASIC (2.3a and 2.3b) were produced and extensive tests have started in Heidelberg. It turned out that the problems on the digital side seem to be solved with the new versions, while the investigation of the noise level is on-going.

Further progress has been made in the development of the firmware for the SPADIC based readout. It has been rewritten for the usage with the CRI-based readout which was used during the data taking with mCBM in the recent year. Additionally, the firmware development was moved to a High-Level-Synthesis (HLS) framework, allowing for a much more flexible implementation, bug fixing and optimization.

For the innermost modules the readout is supposed to use the Fast Analog Signal Processor (FASP) chip, developed for high data rates at the IFIN-HH in Bucharest. This readout has been prepared for its operation in the mCBM DAQ chain at GSI and successfully operated during the data taking campaign in 2021 [5].

mCBM participation

The TRD participated also in mCBM data taking in 2021. In addition to the two large modules of the design foreseen for the outer regions of the TRD, read-out by the SPADIC based system, also two modules of the TRD-2D version, planned for the innermost region of the detector and read-out by the FASP/GETS FEE-and DAQ-system, were operated in the setup [5]. Both systems were able to successfully take data with the mCBM-common CRI-based readout scheme. The analysis of this data was one of the main activities during the recent year. Clear correlations between the hits seen by the TRD modules and the TOF detector have been established as a first step towards a complete tracking and physics analysis with mCBM [?].

Software and reconstruction

In the course of the recent year the development of a general unpacker framework has been finalized. This software is also used for the analysis of the TRD data collected in the mCBM setup [7].

The analysis of the test beam data taken at DESY allowed the preparation of updated response functions for electrons, to be used for the simulation and analysis of the particle identification with the TRD. It will now be used in updated physics performance studies.

The impact of different arrangements of the radiator, implying also a different spacing of the TRD layers, on the physics performance was investigated in details. However, no clear conclusion could be drawn so that the final decision on the configuration will rather be based on more technical aspects.

An important prerequisite for more detailed physics performance studies with the TRD-2D, as required for the approval of the TDR addendum, is the inclusion of the TRD in the global tracking scheme. A first implementation has

been done and is now being evaluated and used for further studies.

TDR addendum

The addendum to the technical design report (TDR) of the TRD, describing the proposed TRD-2D design, has been prepared. After an internal review within the CBM collaboration it was submitted to the FAIR-ECE and is currently under review by the committee. A first feedback indicated the need for more detailed performance studies to underline the physics case. These studies are currently under way.

References

- [1] P. Kähler, “Start of TRD module production”, this report.
- [2] L. Faber and F. Fidorra, “Measurements of the entrance window bulge of TRD chambers”, this report.
- [3] D. Dorobantu et al., “Entrance windows for the TRD-2D chambers for the CBM-TRD”, this report.
- [4] P. Kähler and F. Roether, “Design of the LV supply system for the TRD”, this report.
- [5] A. Bercuci et al., “Steps towards integration of the TRD-2D detection system with the CBM experiment”, this report.
- [6] A. Bercuci et al., “Global space-time correlation of the local TRD reconstruction within the mCBM environment”, this report.
- [7] P. Raisig, “(TRD) raw data unpacking from mCBM 2021 onwards”, presentation at the 38th CBM collaboration meeting, Sept. 2021.

Start of TRD module production*

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Introduction

As a major step in the realisation of the TRD in the CBM experiment, the series production of detector chambers is currently starting. Despite of delays, mainly due to shifts and adaptations in the procurement of products, the chamber production chain in the institutes in Frankfurt and Münster is commissioned to a large extent, which is summarised in this report. The first production goal is to complete 35 chambers of “type-5”, which is one of the two large TRD chamber variants foreseen for the outer regions of the detector. 32 modules based on these chambers (*module* consisting of MWPC and radiator) will be installed in CBM, i.e. 26% of the TRD active area, while three will serve as spare/maintenance buffer.

Production process

The production process of MWPCs for the CBM-TRD is divided into the following steps:

1. Backpanel carrier
2. Backpanel complete (read-out cathode)
3. Entrance window frame
4. Entrance window complete (drift cathode)
5. Wire electrode layers
6. Chamber closing

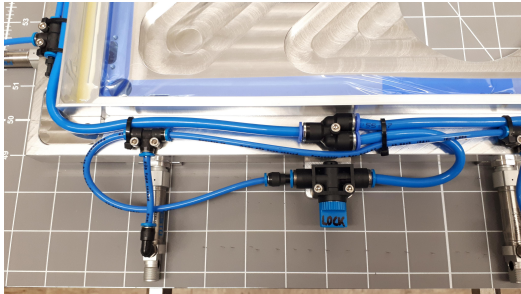


Figure 1: Pneumatically driven alignment frame for the TRD module backpanel frame (step “1”, above).

Production places

Production places for the aforementioned steps have been commissioned, corresponding to the specific requirements in cleanliness, tooling and storage. QA procedures of the production processes have been performed along the up-running of production, i.a. flatness scans of the read-out cathode pad plane (glueing process) and a pressure-dependent characterisation of the pre-stretched foil entrance windows. A part of the cathode pad plane on its corresponding vacuum table can be seen in Fig. 2. The workflow of pre-products has been defined. We start the production in *split-mode* between Münster and Frankfurt, thus requiring a transfer of pre-products, while a transition to independent chamber productions in both institutes is expected after operation launch of new cleanrooms (ISO 7, while also ISO 5 available) in the Münster institute.

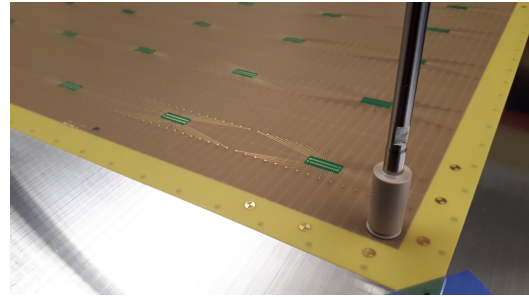


Figure 2: Pad plane for the segmented TRD read-out cathode in 4-layer design with the intrinsically gas-tight connections.

Pre-series and QA

A number of five detector chambers is defined as pre-series, after which those five chambers will be subjected to extensive QA tasks in order to characterise the stability of the production processes. This QA comprises i.a. gas tightness measurements, gain scans on the complete active area and high-voltage checks. The pre-series QA will serve as confirmation of production readiness for the full series.

Summary and outlook

The production process of TRD chambers is commissioned. We expect to finish five pre-series chambers in the 2nd half of 2022 after delivery of delayed upstream products and completion of external works (signal connector soldering).

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Design of the LV supply system for the TRD*

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Introduction

The Low Voltage system for the TRD will supply its front-end electronic with an overall net demand of 16 kW electrical power, transported via a 12 V stage and transformed by DC–DC converters to the lower target voltage levels nearby the supplied electronics. In view of the Engineering Design Review for this LV system calculations of the voltage drop in the full transport layer have been completed, i.e. in the cables and bus bars, as well as on the corresponding power losses, both in dependence on the conductor dimensions. On this basis, decisive design parameters can be pinned down now.

LV transport layout

LV power is distributed to the TRD modules by pairs of bus bars of opposite polarity, which are mounted vertically on the main frame between the detector modules. Those bars will supply the front-end electronics of the TRD, i.e. the read-out electronics and the GBT-based aggregation boards (“ROBs”). The nominal bar voltage is 12 V. As the channel density of the TRD varies for different detector regions, also the power demands are different. The expected power demands are given in Fig. 1. These values include the losses from the subsequent levels, in particular from DC–DC conversion down to the operation voltages of the electronics, but not yet losses within the bars or before. A cross section of 16 mm² per conductor of the bars is foreseen.

The bus bars themselves are fed by cables directly from Wiener PL506 units in the E10-service area. As the TRD can be moved in two dimensions (z for overall positioning, x for TRD-specific maintenance), the corresponding flexibility will be considered for the LV cables and their local paths. Full and safe functionality of the LV system will kept for the TRD maintenance positions, as full system checks relying on a working LV supply are part of the test routines after module exchange.

Conversion to 2.5 V (and also 1.5 V for the ROBs) is realised with the radiation-hard CERN FEAST modules. The input power of these converters is, to first order, by principle constant irrespective of the input voltage (neglecting a minor efficiency dependence), which is used within the voltage drop calculations until the DC–DC stage. Particular for the TRD electronics is the independence of its power demands with respect to the detector’s counting rates. Furthermore to be respected is a strict maximum input voltage

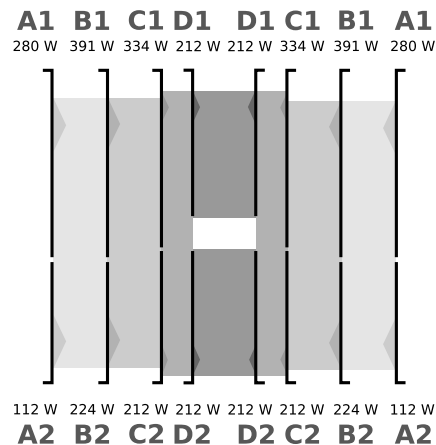


Figure 1: One of the four identical TRD layers and its LV power bus bars, 12 V level. Left and right side are mirrored with respect to each other. The numbers below each bus bar designator indicate the power delivered by this bar, i.e. before losses in the bars itself and cables towards the detector.

of the FEAST voltages of 14 V.

The voltage drop and corresponding power losses in the TRD bus bars and feeding cables are a function of the input voltage (supply clamps), which can be parametrised by a polynomial depending on conductor cross sections and lengths. For realistic conductor geometries, we calculate total power losses of up to 3.1 kW, which is compatible with the thermal design. The FEAST input voltage range is strictly ensured both by active sensing and by complying with the range even on supply side.

Summary and outlook

For an overall TRD net power demand of 15.8 kW, we calculate an additional power loss of 3.1 kW in the assumed transport layer. Voltage limits of the FEAST DC–DC converters are strictly fulfilled by system design. Mechanical and connection details of the bus bar structure are being developed.

* Work supported by BMBF grants 05P19PMFC1 and 05P19RFFC1.

Measurements of the entrance window bulge of TRD chambers

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An overpressure of the detector gas in the TRD will result in deformations of the flexible entrance window, i.e. a bulge. A deformation of the foil changes the electric field, which results in a change in gas gain. The tolerable deformation limit during detector operation is derived from the tolerable electrical field deformation and was determined to be $-0/+1$ mm [1].

The foil is divided into segments by a carbon lattice which is glued to the foil. With a mechanical setup which is shown in Fig. 1 the bending of the foil segments and of the whole carbon lattice were measured independently. To measure the foil deformation as function of the differential detector gas pressure, the chamber overpressure was regulated and monitored with a corresponding gas setup using a newly produced chamber in the TRD preseries production.

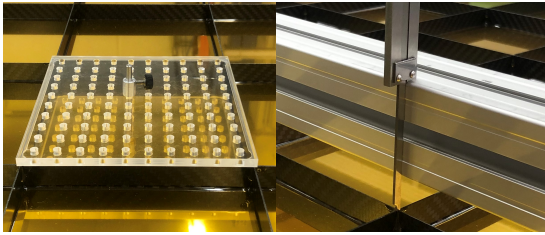


Figure 1: Methods of distance measurements

Using a parabolic fit to describe the bulge along one axis of the structure yields an estimate value of the maximum bulge for the used overpressure. For one measurement along one axis of the carbon lattice the data points and the parabolic fit are shown in Fig. 2.

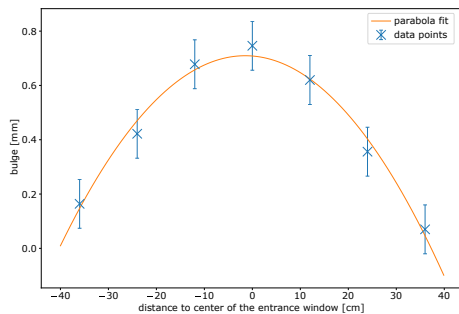


Figure 2: Results of measuring the bulge of the foil for an overpressure of (0.79 ± 0.08) mbar

The maximum bulge was measured along the horizontal, the vertical, and the diagonal axis for two different segments and along the horizontal, and the vertical axis for the carbon lattice. All the measurements were performed over different overpressures ranging from 0 mbar to 1 mbar. Since the two measured bulges are independent, the maximum bulge of the whole entrance window is calculated as the sum of the two. It was possible to confirm a linear dependence of the expansion within this overpressure range [2], as shown in Fig. 3.

The chamber can safely be operated at overpressures up to $p = (0.70 \pm 0.15)$ mbar [2], since the maximum bulge will stay below 1 mm which can be compensated by energy calibration as stated above.

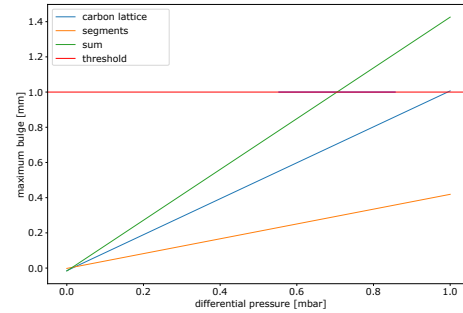


Figure 3: The dependence of the maximum bulge on the overpressure

We obtain a maximum tolerated overpressure of $-0/+0.70$ mbar. This value is to be ensured by the TRD gas system [3] and translates into a maximum allowed gas flow per line. This is an important input value during tuning and commissioning of the first TRD gas line. The measurements can further be used as a reference in simulations of the entrance foil and field deformation, e.g. for start values of the detector gain calibration.

References

- [1] The CBM Collaboration, “Technical Design Report for the CBM Transition-Radiation-Detector (TRD)“, 2018, p.66.
- [2] L. Faber, “Entwicklung und Inbetriebnahme eines Gassystems zur Untersuchung einer CBM-TRD Kammer unter Gasfluss“, Bachelor Thesis, 2021, Münster, chapter 5.2.
- [3] The TRD group, “Conceptual Design Review for the TRD gas system“, 2021.

Entrance windows for the TRD-2D chambers for the CBM-TRD*

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The TRD detector of the CBM experiment will be used as intermediate tracker between the STS and TOF detectors, for electron/pion discriminator and to enhance the PID performance in combination with TOF. In order to fulfil these requirements in the high counting rate environment of high particle multiplicities at low polar angles, which is specific for CBM as a fixed target experiment, the active region of the multi-wire proportional chambers was reduced to 12 mm thickness (4 mm drift and 2×4 mm amplification regions) and the readout cell to $\approx 1 \text{ cm}^2$ pad size. In order to obtain a very good position information in two dimensions, a new pad-plane architecture was developed based on triangularly shaped pads [1].

Another essential component of these chambers is the entrance window, i.e. the mechanical support for the drift electrode which has to have a minimal absorption for the transition radiation (TR) produced in the radiator in front of the chamber and enough mechanical rigidity to minimize the deformation at ≈ 1 mbar pressure difference created by the gas flow in the chamber. A real size prototype with

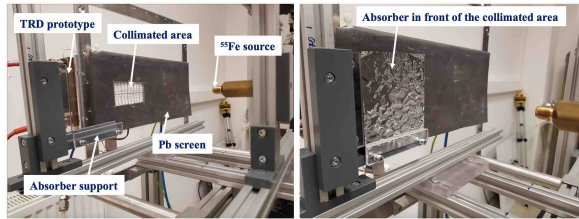


Figure 1: Configuration of the experimental setup used for absorption studies.

outer dimensions of $60 \times 60 \text{ cm}^2$ with an entrance window based on a structure composed of $20 \mu\text{m}$ aluminized Kapton + 3 mm Rohacell + 9 mm honeycomb + 3 mm Rohacell + $20 \mu\text{m}$ Kapton was assembled and extensively tested in-beam, operated with a dedicated FEE [2,3].

Among other performances parameter important for the present studies, it is worth mentioning that for a fibre type radiator, a 2 % pion suppression factor at 90 % electron efficiency has been estimated for a six layer configuration, based on the above mentioned chamber structure. No dependence of the results on the position across the surface of the entrance window was observed. The absorption mea-

* Work supported by the Romanian Ministry for Research, Innovation and Digitisation, NUCLEU Program (contract PN 19060103) and RO-FAIR Program (contract HICORDEFEND 03/16.11.2020).

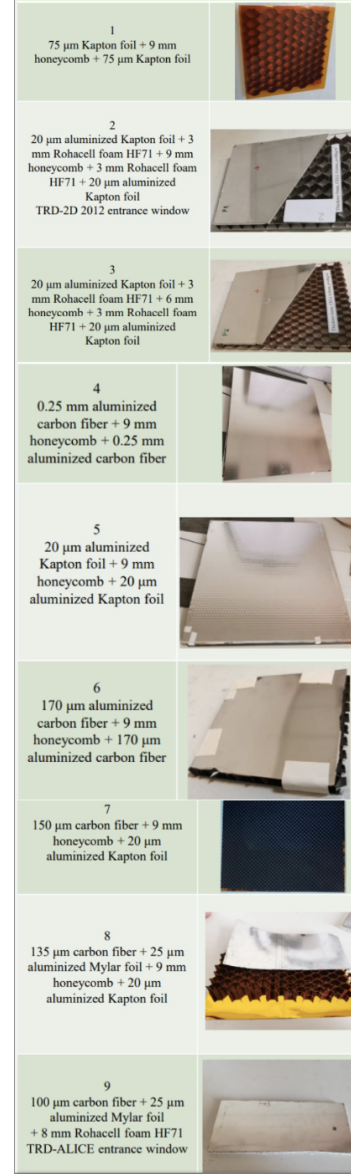


Figure 2: The structure of different samples used in the absorption measurement.

surements for the above described entrance window, using a ^{55}Fe source, showed a 57.7 % x-ray absorption. Before starting the assembling of CBM TRD-2D chambers, we have done some absorption studies of different entrance window configurations in order to decrease as much as pos-

sible the absorption of low energy TR photons, while still limiting the mechanical deformation at ≈ 1 mbar pressure difference to a reasonable level. The setup used for these

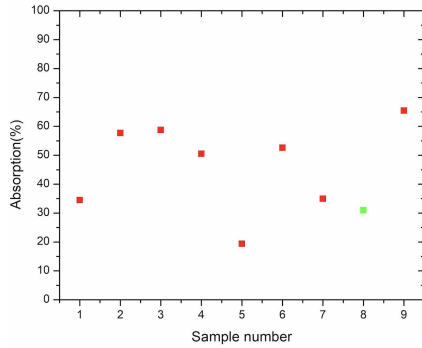


Figure 3: Absorption value for 5.9 keV ^{55}Fe x-rays for the samples presented in Fig.2.

studies is presented in Fig. 1. In front of a smaller sized TRD prototype, of the same configuration as it was presented above, a sheet of lead with a rectangular opening (Fig. 1 left) was mounted. The opening is completely covered by the absorber and the active area of the TRD (Fig. 1 right) is illuminated by the x-rays of a ^{55}Fe source. The signals from the multi-wire anode electrode, processed by a charge sensitive preamplifier, a shaping amplifier and a discriminator, were fed into a scaler.

A few versions of the entrance window of different configuration were assembled and measured. An overview of these versions and their structure is presented in Fig. 2. The results of these measurements are presented in Fig. 3. As

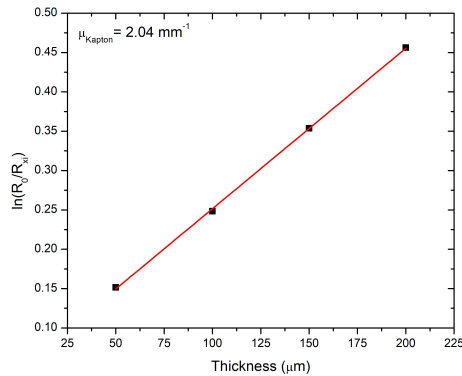


Figure 4: Kapton attenuation coefficient for 5.9 keV ^{55}Fe x-rays.

can be seen, a structure based on 135 μm carbon fiber foil + 25 μm aluminized Mylar + 9 mm honeycomb + 20 μm aluminized kapton foil, has an absorption of 31 %, twice as low than the absorption of sample 2 used as entrance window for the prototypes mentioned above, and more than two times less than the ALICE-TRD entrance window (sample 9). For such a configuration the measured mechanical deformation in the middle of the window of dimensions

60 $\times$ 60 cm^2 , which is the size used for the TRD chambers in the inner zone of the CBM-TRD, is ≈ 1.75 mm at 1 mbar pressure difference. As this deformation will increase the thickness of the drift zone only, minor effects on the gain are expected. The slight increase in the drift time will not have a strong impact on the counting rate performance. However, as it is a global and symmetric deformation, any impact on measured observables could be easily corrected offline.

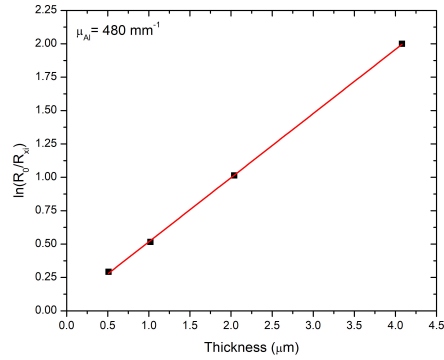


Figure 5: Aluminium attenuation coefficient for 5.9 keV ^{55}Fe x-rays.

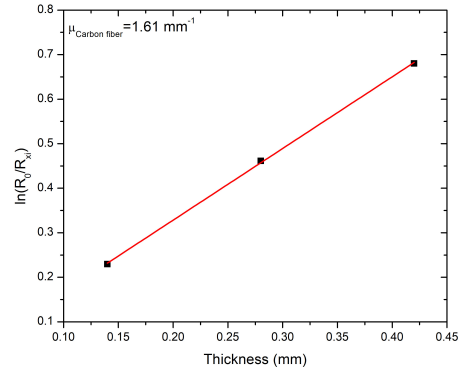


Figure 6: Carbon fiber attenuation coefficient for 5.9 keV ^{55}Fe x-rays.

The measured attenuation coefficients for 5.9 keV ^{55}Fe x-rays in Kapton, aluminium and carbon fiber are presented in Fig. 4, Fig. 5 and Fig. 6, respectively. For the final chambers we foresee to use 100 μm carbon fiber layer, instead of 135 μm . Therefore, the absorption will decrease even further, with direct consequence on the pion rejection performance.

References

- [1] M. Petriș et al., Nucl. Instr. and Meth. **A732** (2021) 375 and references therein.
- [2] M. Târzilă et al., CBM Progress Report 2012, p.60.
- [3] Addendum to the technical design report for the CBM-TRD.

Steps towards integration of the TRD-2D detection system with the CBM experiment*

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A complete new architecture for the inner part of the TRD wall of CBM at FAIR (wrt the TDR [2]) was proposed long ago as an improved tracking device to bridge the gap between STS and ToF systems. During this year we have reached several milestones for system integration: a dedicated physics topic and full system implementation described in the TDR Addendum, experimental and software integration demonstrated in the mCBM setup, Front End Electronics (FEE) and Data Acquisition (DAQ) integration (also in the mCBM setup) and, finally, combined data analysis together with STS, ToF, RICH and PSD systems for the mCBM July 2021 data taking campaign.

TRD TDR Addendum

The advantages of the TRD-2D architecture and its performances in operation with the dedicated FEE are comprehensively described in the Addendum [1] to the TRD-TDR [2]. The Addendum already went through an internal review of the CBM collaboration followed by the FAIR ECE review, in the first part of 2021.

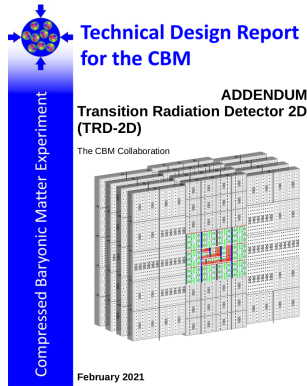


Figure 1: The Addendum for the TRD-2D solution for the inner part of the TRD wall.

The document, of more than 100 pages, describes a design optimized for tracking in two dimensions with amazing resolutions, as demonstrated by detailed simulations. The device is aimed at improving the tracking efficiency in the region of highest particle occupancy of small polar angles, but it also adds to the physics topics the possibility to initialize the detection of low p_T particles by combining high spatial resolution in a magnetic field free re-

gion. Besides, a dedicated FEE is proposed, which support the triangular, signal read-out topology. The FAIR ECE-ECSSG evaluation committee recommendation, to expand the physics case for more realistic simulations is work in progress.

TRD-2D @ mCBM 2021

The final test of the R&D phase of the CBM experiment was the realization of a small scale prototype, the mCBM experiment [3], which integrates all systems foreseen for the final design. The TRD-2D was implemented for the *common data taking* of the July 2021 in-beam test campaign.

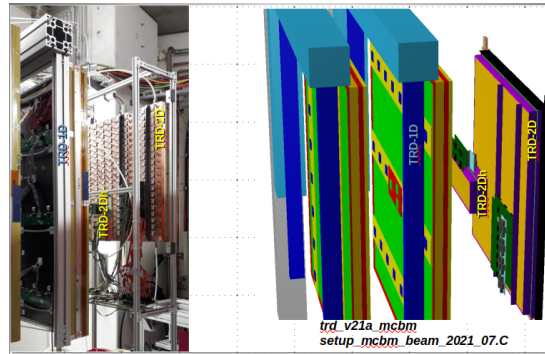


Figure 2: Integration of the TRD-2D detection system with the mCBM '21 for both the experimental setup (left) and its simulated replica (right).

Two modules of the TRD-2D types were installed as shown in Fig. 2 (left), an almost real-size chamber (labeled *TRD-2D* in figure), operated with the native FASP/GETS [4] FEE, and a small sized chamber (labeled *TRD-2Dh* in figure) steered with both FASP and SPADIC FEE (see also Fig. 3 (bottom)). The two modules were supported by the common services of the TRD (gas and LV) and read-out by the common CRI based DAQ of the mCBM.

In parallel with the hardware developments, software a been developed to support the integration in the *CbmRoot*. In Fig. 2 (right) a snapshot from the simulated replica of mCBM is shown, in which the TRD-2D modules are seen installed in front of the large two TRD-1D modules. The unpacking of GETS bit streams into *CbmRoot* data structures was developed from start on the common framework provided by the collaboration.

* Work supported by Romanian Ministry of Research, Innovation and Digitization NUCLEU Project Contract PN 19060103 and RO-FAIR Project FAIR-03/16.11.2020.

TRD-2D FEE/DAQ integration

Concluding a decade long effort for developing a FEE system dedicated to the TRD-2D, the FASP/GETS [4] was finally integrated with the CBM DAQ based on GBTx data serialization and CRI.

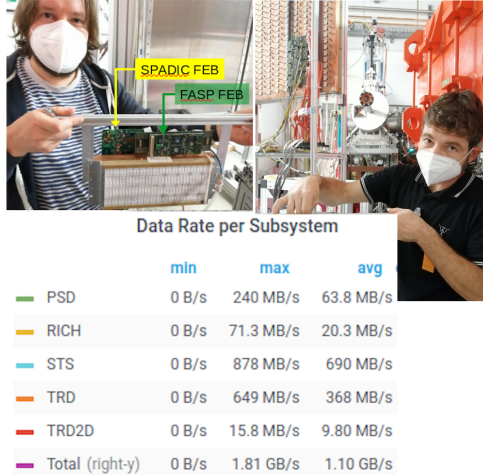


Figure 3: Integration of the SPADIC and FASP ASICs in parallel on the TRD-2Dh chamber for mCBM '21 (top left); Data rate of the TRD-2D as represented in the GRAFANA snapshot taken during July 2021 mCBM data taking campaign (bottom).

The full CBM DAQ, including the FASP/GETS, was finalized shortly before beam start and tested extensively during mCBM data taking. In Fig. 3 (bottom) a snapshot from the DAQ monitoring tool GRAFANA is reproduced in which several statistics of data rate per system are reported. The TRD-2D/FASP is featured in this plot under label *TRD-2D* while the TRD-2Dh/SPADIC (see top left) is integrated with the TRD-1D modules under label *TRD*.

In parallel, a dedicated test was conducted, on the TRD-2Dh module, to compare the two FEE solutions developed in the TRD community, the SPADIC and FASP ASICs. As such, the chamber was hooked to two different data processing chains which were merged in data analysis. The test was successful and its application on TRD-1D chambers was also suggested for further elucidating systematic effects.

TRD-2D first data in the CBM environment

Integrating all developments from the past on all experimental components, the data, shipped by the mCBM infrastructure to disks, represented the true evaluation of the whole effort.

A very successful run (1588), of more than 160 min, was recorded with the following detectors in the downstream direction: *STS*, *TRD-2D*, *TRD*, *ToF*, *RICH* and *PSD*. A very preliminary quality check of the data, besides the obvious DAQ test of time synchronization, was to monitor the beam

profile and compare the data rates for the two beam conditions, on/off.

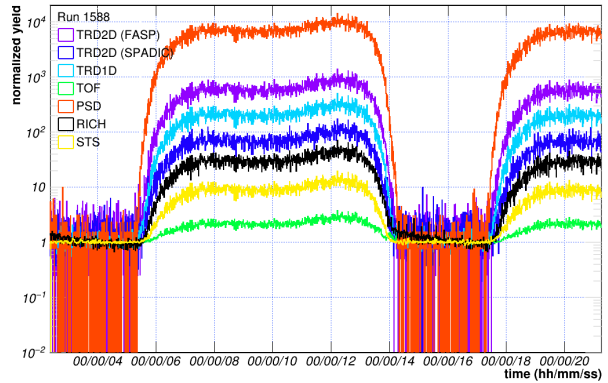


Figure 4: SIS18 beam profile seen in the raw data of all mCBM 2021 detector systems.

In Fig. 4 a time-window of less than 1 min from this run is shown in which four beam spills are registered. As the data rate (number of digis in 10 ms in figure) varies with detector system, a normalization to 1 was been performed on each rate for the beam-off intervals. Using such scaling procedure it would imply to interpret the values measured during beam-on intervals as an estimation of the integrated S/N for each detection system. Such interpretation was supported also by other analysis. For the case of the TRD-2D/FASP the S/N is only surpassed by the Psd system but, as opposed to the later, it is also not limited by the interaction rate.

More details on the spatial-time correlation of the TRD-2D data with the rest of the detection systems, which were installed on the experimental acceptance, are presented on a separate contribution [5].

Conclusions

A very successful year was concluded for the TRD-2D project. Several working connections have been established to the CBM community ranging from the definition a new physics channels for low p_T track reconstruction to the first common data taking with the rest of CBM systems.

References

- [1] A. Bercuci et al., “TRD TDR Addendum”, <https://git.cbm.gsi.de/bucharest/addendum-2d/-/jobs/26503/artifacts/file/main.pdf>, to be published.
- [2] C. Blume et al., “Technical Design Report TRD”, 10.15120/GSI-2018-01091 (2018).
- [3] C. Sturm et al., “mCBM experiment”, this report.
- [4] C. Schiaua et al., “FEE for TRD-2D”, this report.
- [5] A. Bercuci et al., “Global space-time correlation of the local TRD reconstruction within the mCbm environment”, this report.

Global space-time correlation of the local TRD reconstruction within the mCBM environment*

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Four **TRD** modules (see Fig. 1), having geometries and Front End Electronics (FEE) close to those proposed for the CBM experiment [1], were operated in the mCBM test facility at SIS18 at GSI Germany. Their current operation mode in mCBM is without radiators but a second purpose, i.e. as intermediate tracking device, is followed by installing them between the **STS** and **ToF** detectors as in the final experiment.

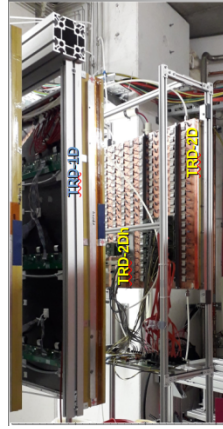


Figure 1: The TRD setup at mCBM 2021 comprising four modules: TRD-2D, TRD-2Dh and two TRD-1D modules.

Three TRD modules were dedicated to tracking, while the TRD-2Dh was mainly used for FEE tests [1]. The current report emphasizes the spatial-temporal correlation of the TRD reconstructed data relative to STS and ToF.

Time correlations, raw-event selection

A close to final common DAQ was tested for the first time during the mCBM 2021 campaign driven by a common clocking scheme (the TFC). A trigger-less data stream imposes challenges also on the data analysis as time-dimension became instrumental in data reconstruction. A hybrid event definition was developed based on a **ToF** data correlation and the time-coincidence with the rest of the detectors within a *time-slice*¹ (TS).

The time correlations are shown in Fig. 2 for all mCBM 2021 systems: STS, TRD-1D, TRD-2D, RICH and PSD.

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¹ A time interval defined by the DAQ of continuous read-out packing.

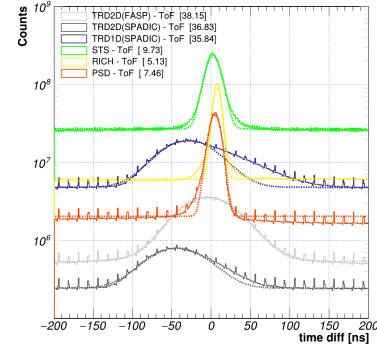


Figure 2: Time differences within a TS between ToF selection and the other mCBM components; the time correlation is emphasized by the Gauss+background fit (dashed-line).

For each system, the distribution has two components: a flat background of uncorrelated data and a Gaussian-like peak of signals correlated to the event. The model is shown in Fig. 2 by a dashed line for each case and its deviations from measurements are to be further investigated. An *event time-resolution* can be also derived for each system (see figure legend) and such value positively compare with realistic simulations of the experimental setup. For the case of TRD-1D the time-resolution is clearly limited by not featuring the time extraction from the SPADIC signals in the unpacker yet but only using the rough ADC sample timing.

The time correlations, as shown in Fig. 2, are used to calibrate and define *time-windows* for *raw-event* reconstruction. They are used to restrict the local cluster/hit reconstruction only to the sub-set within time windows. A further improvement of event definition is based on constructing the spatial correlations between hits in various systems as detailed below. The efficiency and bias of such procedures is under investigation using simulations.

Spatial correlations, local reconstruction

The development of a raw-event selection procedure with data is in progress. From a TRD perspective, a possible test is to extend the time selection to those events with *only* two hits in both the STS and ToF systems. Further constraints are imposed on the hits being measured in different modules of each system. A linear interpolation is performed on the four spatial points, mimicking the particle trajectory, and its intersects with the fiducial volumes of the TRD modules consequently estimated.

In Fig. 3 an example of a linear interpolation between

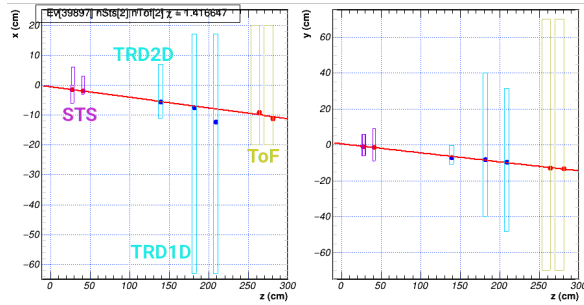


Figure 3: Linear interpolation between STS and ToF hits (red markers) and their spatial correlation with the TRD hits (blue markers); the projection on the horizontal (left) and respectively the vertical (right) plane are shown together with some outline of the read-out volume of each system.

two STS and two ToF points (red markers) is shown for both, horizontal and vertical projections. The TRD local reconstruction generates for this selection the hits displayed as blue markers in the figure. For both projections the linear interpolation is represented by the red line, which enters the active volumes of all three systems, and consequently, its correlation with the TRD hits can be followed. A qualitative outline of the read-out volume of each system is also shown by boxes for a first check on efficiency.

A global view on the performances of the TRD system within the close to final CBM setup, as represented by the mCBM experiment, was obtained by integrating a larger statistics. In Fig. 4 the correlation of TRD hit position with

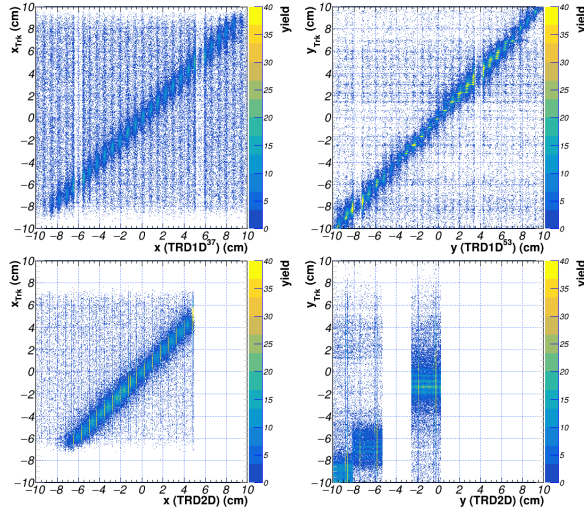


Figure 4: Correlation of TRD hit position with STS-ToF interpolation for the high resolution direction of TRD-1D (top) and TRD-2D (bottom).

STS-ToF interpolation is shown for the data selection introduced before. For the TRD-1D only the high resolution direction is shown which, for the first module (index 37), is

parallel with global x and with global y respectively for the downstream module (index 53). As the TRD-2D delivers position estimators for both coordinates x and y directions are shown. For the global y direction (perpendicular to anodes) the data hints towards wire identification but a more sensitive analysis is in progress.

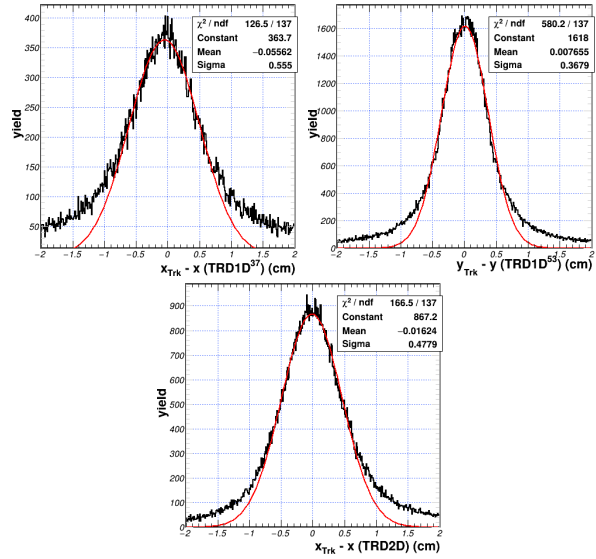


Figure 5: Residual distributions between TRD hits and STS-ToF linear interpolations, along the high resolution direction of each module; the TRD-1D modules (top) and the TRD-2D module (bottom).

A preliminary quantitative estimation of the performances of the TRD system as it is presently implemented is obtained by projecting Fig. 4 along diagonal. In Fig. 5 the residuals for the three tracking TRD modules are reported wrt. the STS-ToF interpolation for the high resolution direction. For all three cases the fit is performed in the range $[-0.7, 0.7]$ c yielding a combined *STS-TRD-ToF* spatial resolutions of $\sigma_x \approx 5$ mm and $\sigma_y < 4$ mm.

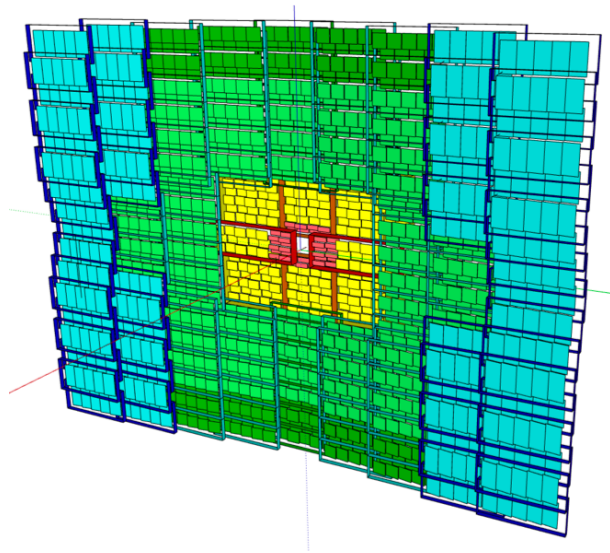
Conclusions

The preliminary results of spatial-temporal correlation of reconstructed TRD measurements with STS-ToF interpolations are as expected. We therefore conclude, that the integration of various detection solution, especially TRD, was successful. Next steps are to refine the performances and prepare for mCBM 2022 Λ reconstruction campaign.

References

- [1] A. Bercuci et al., “Steps towards integration of the TRD-2D detection system with the CBM experiment”, this report.

Time-of-Flight Detector



TOF - Summary

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The main focus of TOF, since the last Progress Report 2020, was on the development of new MRPCs prototypes in order to mitigate the observed gas pollution and aging effects as reported in several meetings and for instance here [1, 2, 3, 4, 5]. The proposed strategy, which was discussed in a dedicated review meeting and supported by the external reviewer, is to develop methods to exchange the counter gas in between the gaps in a much more rapid way compared to gas diffusion. Within the groups different designs have been realized, constructed and partially tested by now [6, 7, 8]. For the MRPC1 prototypes a 100 % gas transmission through the gaps is foreseen which is quite a challenge to realize. These counters have to cope with the highest interaction rates up to 50 kHz/cm² and needs therefore the most efficient way of gas exchange. Figure 1 shows the individual gas supply to each stack of a MRPC1a prototype. For the other MRPC types the situation is more relaxed. Here a sealing around the glass plates using 3D printed frames is intended. However, the gas is not completely forced to flow through the gaps and the gas exchange rate is slightly reduced. Test chambers housing sealed counters of all MRPC types are installed in mCBM and are being tested in the current beam time period. Further more,

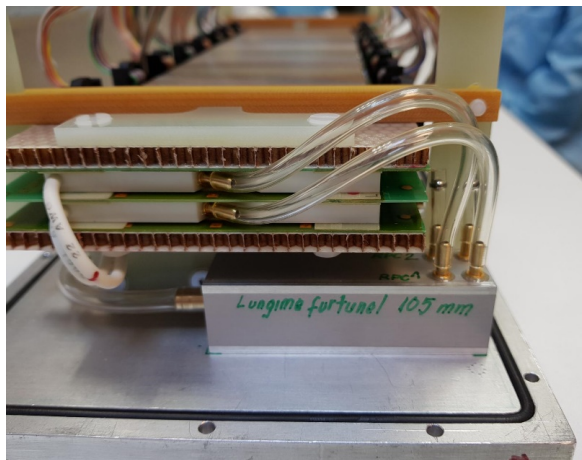


Figure 1: Sealed MRPC1a prototype with 100 % gas transmission. The gas is distributed via pipes to each stack.

X-ray test in the institution labs are being performed. In addition a second aging test with gammas at the IRASM facility (Bucharest) is foreseen. Based on the outcome a production readiness review (PRR) is targeted in Q3 of this year.

The electronics PRR is in preparation as well. Charge

injection tests in the EE department at GSI are being performed and a decision on the final layout including the type of protection diode will be taken soon.

A substantial progress has been achieved in the design of the TOF main frame which permitted the passing of the CDR milestone and entering the engineering phase for most of the frame parts. The engineering design of the outer module chambers is close to final and the integration in the outer TOF module support frame (OTMSF) frame (see Fig. 2) utilizing a light weight construction for minimizing the material budget in front of the active area is being designed. In addition a concept to dismount installed modules for maintenance reasons was developed. Currently a test substructure comprising a half column with 12 modules is under construction at the Physikalisches Institut in Heidelberg. With this frame mock-up test stand the practicability of the mounting procedure, connectivity handling of the infrastructure and cable routing strategies can be exercised.

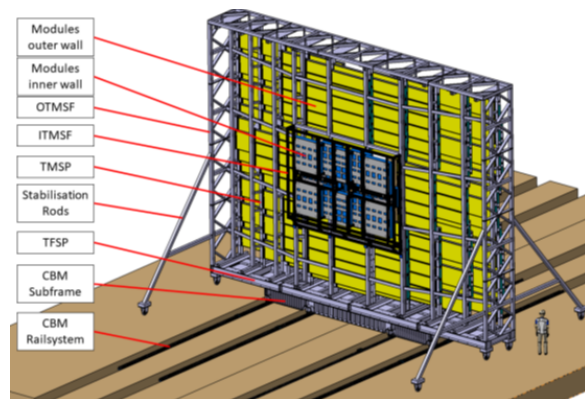


Figure 2: Back view of the CBM TOF wall illustrating the design of the main frame.

References

- [1] I. Deppner et al., CBM Progress Report 2020 (2021)
- [2] M. Petriș et al., CBM Progress Report 2020 (2021)
- [3] M. Petriș et al., CBM Progress Report 2021 (2022)
- [4] B. Wang et al., CBM Progress Report 2021 (2022)
- [5] K. Wang et al., CBM Progress Report 2021 (2022)
- [6] M. Petriș et al., CBM Progress Report 2021 (2022)
- [7] B. Wang et al., CBM Progress Report 2020 (2021)
- [8] K. Wang and Y. Sun, CBM TOF weekly meeting

In-beam test of the MSMGRPC prototypes for the CBM-TOF inner zone in the mCBM experimental setup*

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Two Multi-Strip, Multi-Gap Resistive Plate Counter (MSMGRPC) prototypes with the highest granularity required by the inner zone of the CBM-TOF wall were designed and assembled. They have a double stack configuration with 5 gas gaps per stack of 200 μm gap size. The active area is defined by 32 strips of 9.02 mm pitch and 60 mm length, readout at both ends. The strip architecture for both high voltage and readout electrodes allows to tune the signal transmission line impedance in order to match it to the input impedance of the front-end electronics (FEE) [1]. The resistive electrodes are made of Chinese glass of $\sim 10^{10}$ Ωcm resistivity. They were assembled and mounted together in a gas tight and electromagnetically screened box.



Figure 1: The counters installed in the experimental setup.

The two prototypes were first successfully tested with cosmic rays in the detector laboratory of HPD/IFIN-HH, proving a very good efficiency and time resolution [2].

Later on, these prototypes were installed (Fig. 1) in the mCBM/SIS18 experimental setup and tested in the mCBM

beam-time campaigns of 2021 year. The counters were equipped for the first time with the front-end electronics designed for the inner zone of CBM-TOF, which integrates on the same motherboard the PADI XI front-end electronics (FEE) and the GET4 TDCs. The gas box was flushed in a standard mode, with a gas mixture of 97.5% $\text{C}_2\text{H}_2\text{F}_4$ +2.5% SF_6 . The results presented in this report were obtained us-

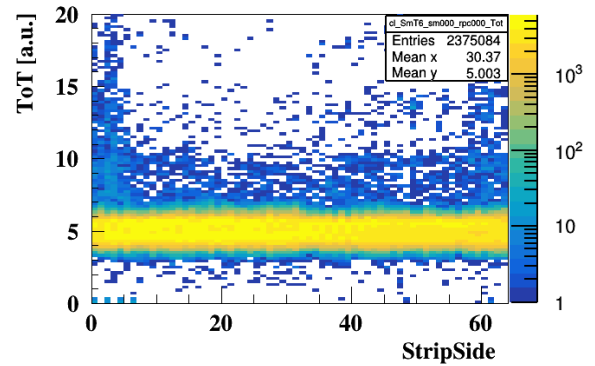


Figure 2: Time over threshold distribution.

ing a 2 A·GeV O^{16} beam on a Au target.

The 2D plot of the Time over Threshold (ToT) distributions for the two ends of the 32 strips of each counter (Fig 2), shows a good matching of the signal transmission line impedance to the input impedance of the front-end electronics.

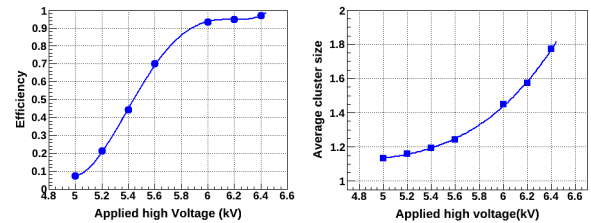


Figure 3: Efficiency and cluster size as a function of one polarity of the applied high voltage.

Fig. 3 shows on the left side the scan of the efficiency with the applied high voltage, reaching a plateau around 96% and on the right side the corresponding cluster size (the multiplicity of the strips with signal in a single hit) for which an average value between 1.5 - 1.7 is obtained in the efficiency plateau, for a 200 mV FEE threshold.

The system time resolution, including the contributions of both detector under study (DUT) and reference counter

* Work supported by Romanian Ministry of Research, Innovation and Digitization, NUCLEU project (contract PN 19060103) and HICORDE-FEND project (contract RO FAIR 03/16.11.2020).

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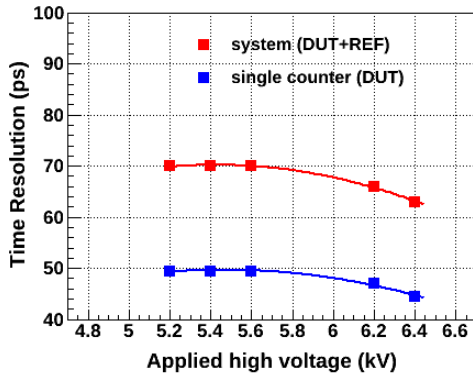


Figure 4: System and single counter time resolution as a function of one polarity of applied high voltage.

(REF), obtained from a Gauss fit of the time difference spectrum, is presented in Fig. 4. A single counter time resolution of the order of 40 ps is obtained if one considers an equal contribution of the two counters.

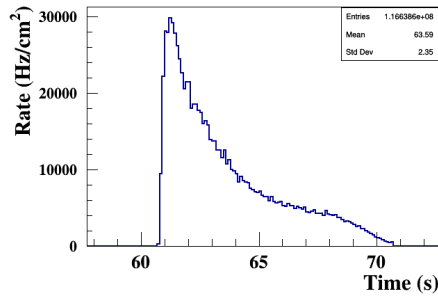


Figure 5: Cluster counting rate as a function of time in spill.

A scan with the beam intensity was converted in the incident particle flux on the chamber.

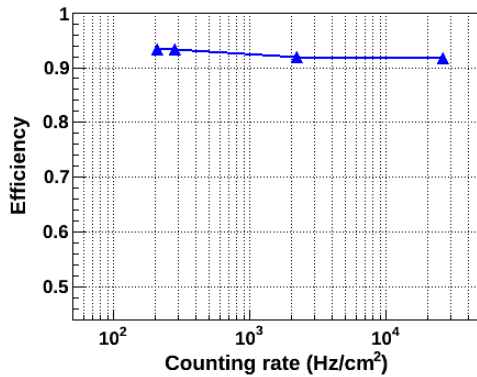


Figure 6: Efficiency as a function of counting rate.

The rate as a function of time in spill reproduces the

beam spill shape as it is shown in Fig. 5, proving qualitatively the counter performance in high counting rate.

As one can be observed in Fig. 5, at the beginning of the spill the counting rate on the counter was about 30 kHz/cm², higher than the expected value for the inner zone of CBM - TOF in the real experiment. Fig. 6 shows

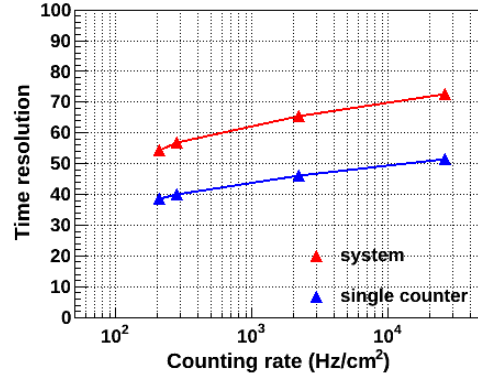


Figure 7: Time resolution as a function of counting rate.

the efficiency as a function of counting rate for a +/-6 kV applied high voltage and 200 mV FEE threshold. As it can be seen, it does not deteriorate significantly with the counting rate. At a counting rate a bit larger than 25 kHz/cm² the measured 70 ps system and 52 ps single counter time resolution, shown in Fig. 7, are still very good. Worth mention-

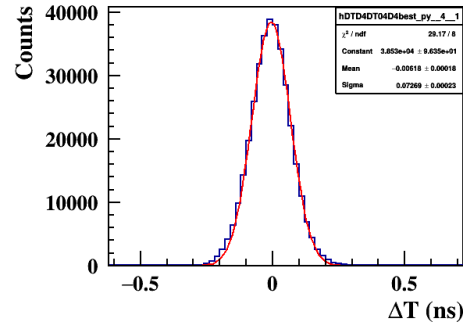


Figure 8: Time difference spectrum at the highest measured counting rate.

ing that the time spectrum still keeps the gaussian shape at the highest measured counting rate, as it could be seen in Fig. 8.

References

- [1] D. Bartoş et al., Romanian Journal of Physics 63, 901 (2018)
- [2] M. Petriş et al., CBM Technical Note (2021), CBM-TN-21004
- [3] M. Petriş et al., 38th CBM Collaboration Meeting, 27.09. - 1.10, 2021, online event.

Ageing effects on MSMGRPC based on low resistivity glass electrodes in high irradiation dose*

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The CBM - ToF sub-detector, based on multi-gap resistive plate counters, will be exposed to charged particles counting rates up to about $3 \cdot 10^4/\text{cm}^2\cdot\text{sec}$ and hit multiplicities up to ~ 1 hit/ cm^2 at the smallest polar angles and 9 meters distance from the target. As CBM experiment is foreseen to run 2 months/year for about 10 years, ageing tests in high irradiation dose are mandatory in order to guarantee that the detector will maintain its performance over the lifetime of the experiment. A schematic archi-

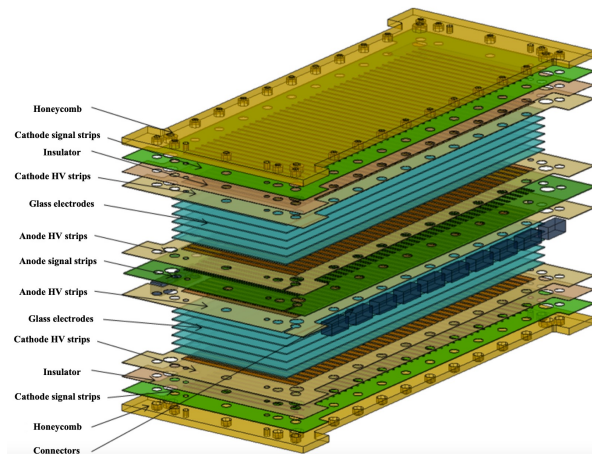


Figure 1: Schematic architecture of the double sided Multi-Strip Multi-Gap Resistive Plate Counter.

ture of the double sided Multi-Strip Multi-Gap Resistive Plate Counters (MSMGRPCs) based on low resistivity glass electrodes, foreseen to be used to equip the region of low polar angles (2.5° to $\sim 11^\circ$) of CBM-TOF sub-detector is presented in Fig.1. Detailed studies on ageing effects of MSMGRPC in high irradiation dose, were performed at the multi-purpose irradiation facility of IFIN-HH based on a high intensity ^{60}Co source.

The MSMGRPC was operated using a standard gas mixture ($90\% \text{C}_2\text{H}_2\text{F}_4 + 5\% \text{C}_4\text{H}_{10} + 5\% \text{SF}_6$), for about

40 hours in a total cumulated dose of 13 kGy. MSMGRPC dark current and dark counting rate, efficiency, cluster size, surface and volume resistivity of the glass electrodes after irradiation were measured and compared with their values before irradiation. After a period of two weeks of recovery under working gas mixture flow, the measured values of these parameters were approaching the same as the ones before irradiation [2, 3].

Nevertheless, after disassembling the irradiated counter, visible layers deposited on both sides of the glass electrodes and ablation type patterns were observed. Photos

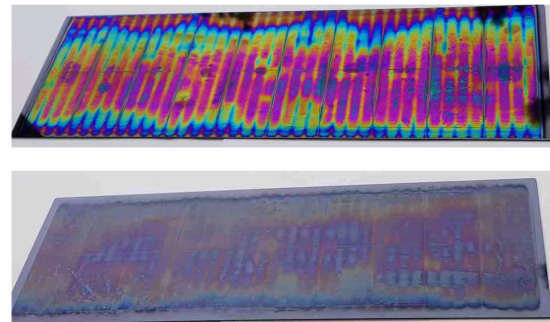


Figure 2: Photos of the two sides of a floating resistive glass electrode.

of the two sides of a floating resistive glass electrode are shown in Fig. 2. The surface facing the cathode electrode is presented in the upper photo and the surface facing the anode electrode in the bottom one.

A comprehensive analysis of the composition and properties of the deposited layers on the glass electrodes, based on different methods, i.e. Scanning Electron Microscope (SEM), X-ray Photoelectron Spectroscopy (XPS), foil Elastic Recoil Detection Analysis (ERDA), Rutherford Backscattering Spectrometry (RBS), Atomic Force Microscopy (AFM) and Terahertz Time Domain Spectroscopy (THz-TDS) were performed.

Some of the results of the EDX investigations on the elemental composition of some samples of surfaces for the anode and cathode sides of a glass electrode after irradiation of the MSMGRPC are presented in Fig.3. The fluorine con-

* Work supported by Romanian Ministry of Research, Innovation and Digitization, NUCLEU project (contract PN 19060103) and HICORDE-FEND project (contract RO FAIR 03/16.11.2020).

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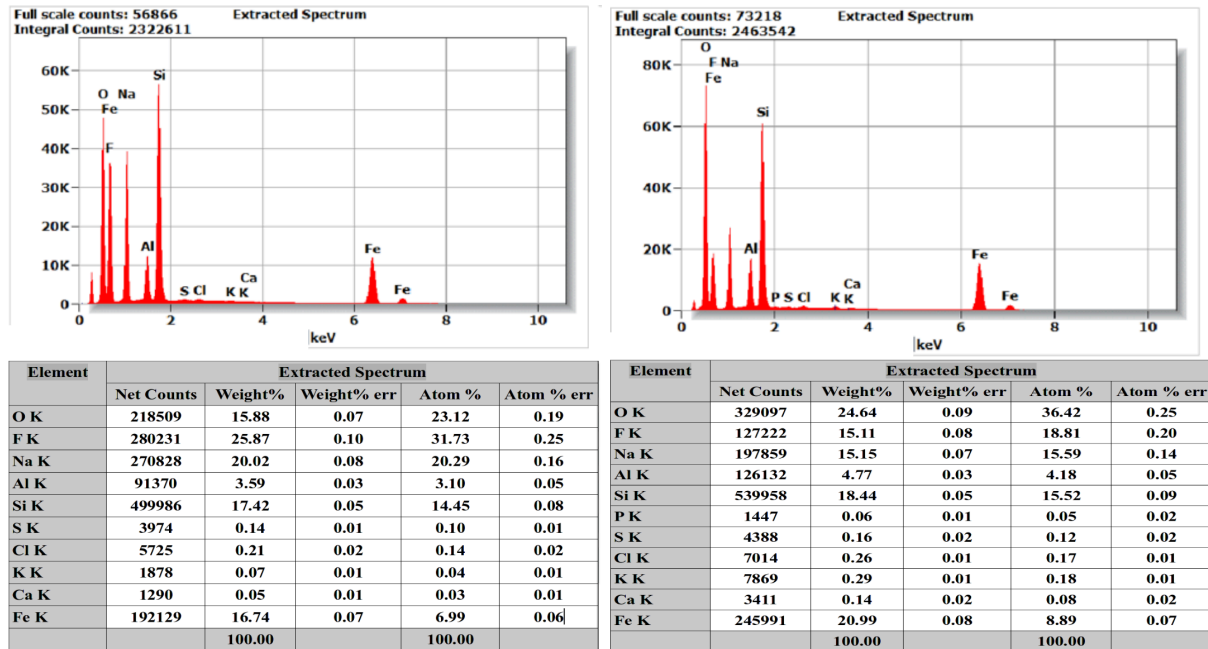


Figure 3: Results of the EDX investigations on the elemental composition of some samples of surfaces for the anode and cathode sides of a glass electrode after irradiation of the MSMGRPC.

tent of the two sides of the irradiated glass electrodes of the MSMGRPC operated in high irradiation dose is significant and different for the two surfaces. The anode side contains $31.73 \pm 0.3\%$ fluorine relative to $18.81 \pm 0.2\%$ found on the cathode surface. One should mention that it is not present in the composition of the non-irradiated glass. As far as concerns the oxygen, relative to $46.10 \pm 0.3\%$ corresponding to not irradiated glass plate, the values obtained for the irradiated glass plate are $23.12 \pm 0.2\%$ and $36.42 \pm 0.3\%$ for the two surfaces, respectively. These findings were confirmed by the other types of analysis mentioned above.

The surfaces scanning using AFM evidenced an increased surface roughness with larger peak to valley structures on the surfaces of irradiated glass electrodes relative to the non-irradiated ones. THz-TDS analysis evidenced negligible changes in the dielectric constants of irradiated floating electrodes, the estimated impact on the transmission line impedance being of the order of a few percent. Therefore, no major impact on the impedance matching to the one of the front-end electronics is expected.

The measured surface and volume resistivity of the floating glass electrodes as well as of the glass electrodes in direct contact with the high voltage electrodes of the irradiated counter were found to be the same as for the non-irradiated glass plates.

The reported measurements were performed using a housing box flashed with the working gas mixture. Therefore, the gas exchange in the $140 \mu\text{m}$ 10 gas gaps of the counter is via diffusion process. It is well known that the polymerization phenomena is inversely proportional with

the gas flow rate. Therefore, a directed gas flow through the gas gaps is expected to decrease the observed ageing effects.

A first prototype, with an architecture designed for a directed gas flow through the gaps between the resistive electrodes, was already assembled and tested in beam in July 2021 (see [4]). However, because this tested prototype has a ratio of the gas transmission of only 70%, another one which aims to have 100% percent gas transmission is in progress to be realized.

Based on the produced charge in the counter by a photon, during the operation in the high irradiation dose, and the charge produced by a charged particle in an in-beam test, we estimated an equivalent of more than $3 \cdot 10^5$ avalanches/ $\text{cm}^2 \cdot \text{sec}$, which is 10 times higher than the counting rate expected at CBM for the most forward region, i.e. low polar angles. Besides an increase of the gas flow through the gas gaps, using a directed flow MSMGRPC architecture, ageing studies in an exposure to a lower dose rate and longer time, conclusive for the operating conditions in the CBM experiment, will be performed.

References

- [1] <https://www.nipne.ro/IRASM.php>
- [2] M. Petriș et al., CBM Progress Report 2020, p.xx, 2021
- [3] D. Bartoș et al., Nuclear Inst. and Meth. in Phys. Res. A 1024 (2022) 166122
- [4] V.Aprodu et al., this CBM Progress Report

First MSMGRPC prototype with a directed gas flow tested in the mCBM experimental setup*

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Before starting the construction phase, ageing tests in high irradiation dose of the MSMGRPCs (multi-gap, multi-strip resistive plate counters) developed for the inner zone of the CBM-TOF are mandatory in order to guarantee that such a detector will maintain its performance over the whole lifetime of the experiment. A detailed study of the ageing effects on the performance of MSMGRPC in a very high gamma irradiation dose and short time exposure is reported in [1]. The tested MSMGRPC was placed in a housing box flushed with the working gas mixture. Therefore, the gas exchange in the gaps of the counter took place via diffusion process. It is well known that a faster gas exchange in the gas gaps via directed gas flow is expected to decrease the observed ageing phenomena, decreasing the polymerisation processes and the chemical radical deposition on the glass plates. Based on these, a new detector architecture was developed for the mitigation of the ageing effects.

The prototype has the spacers positioned outside of the electric field, shorter strips (5.6 cm instead of 6.0 cm, as those reported in [2] have) and forced gas flow through the gaps. The inner geometry (gas gap size, number of gaps per stack) was kept identical to those reported in [2].

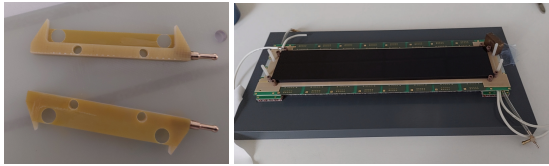


Figure 1: Left - gas guider components. Right - the counter during assembling, with two gas guiders mounted to the ends of the stack.

The gas guiders which assures the gas flow directly through the gas gaps are presented in Fig. 1 - left side. They are mounted at both ends of each stack, one for gas in and the other one for gas out. Fig. 1 - right side shows the counter during assembling having two such gas distribution boxes mounted to the ends of the first stack of the counter.

The prototype was conditioned and tested in the DetLab in Bucharest and transported to GSI for in-beam tests in the July 2021 mCBM beam time. Fig. 2 shows the ob-

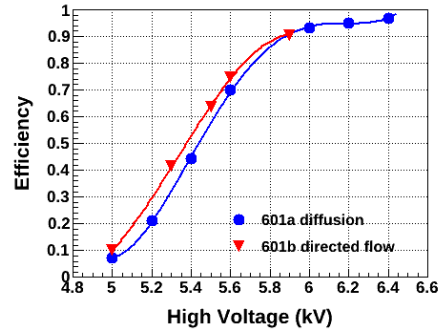


Figure 2: Efficiency of the directed flow MSMGRPC.

tained efficiency (red markers) as a function of applied high voltage, with a similar behaviour with the one obtained for the identical prototypes with gas exchange via diffusion (blue markers). The measured system time reso-

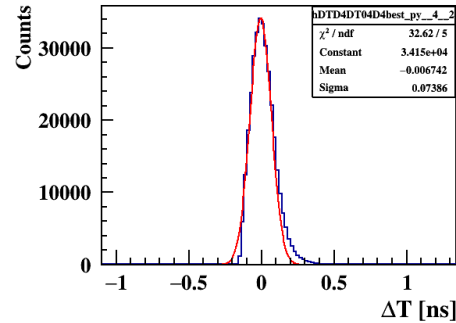


Figure 3: Time difference spectrum.

lution is of 74 ps and a single counter time resolution of 51 ps is estimated, supposing equal contributions of the detector under study and the reference counter. However, we would like to mention that the tested counter has a gas transmission through the gas gaps around 70%. The assembling of a prototype with a 100% gas transmission through the gaps is in progress.

References

- [1] D. Bartoş et al., Nuclear Inst. and Meth. in Phys. Res. A 1024 (2022) 166122
- [2] M. Petriş et al., this progress report.

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Inspections of the low-resistive glass plates from aging MRPC2 using a Scanning Electron Microscope.*

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The unprecedented flux condition of the CBM-TOF wall is fulfilled with the application of the $10^{10} \Omega/\text{cm}^2$ resistivity glass as MRPC electrodes. Thanks to the resistivity decrease of two orders of magnitude, the real-size prototypes of MRPC1 and MRPC2 for TOF show the rate capabilities over $20 \text{ kHz}/\text{cm}^2$ in beam tests [1]. The role of the low-resistive glass makes it the crucial part of the detector.

The operations of MRPC2 in FAIR Phase-0 programs not only yield excellent results, but also help in application issues like aging effect [2]. From mCBM runs, the rise of dark current and noise rate reflected the gas pollution effect of ionization product accumulation. The effect is found to behave in two scales: one is the temporal effect within irradiation periods, the other is the aging effect with run operations. The effects described above has been confirmed in different laboratory tests, and solutions have been discussed and practiced for more stable future operations of CBM-TOF.

Besides the aging tests which has detailed former studies [3], examination on the material of the post-run counters is also a distinctive way to study the aging effect because it provides opportunity to understand the principle and to recognise the position of the interaction. Our colleagues in Bucharest have been using an extensive set of equipment for the analysis of irradiated low-resistive glass [4].

2 MRPC2 real prototypes were sent back from Heidelberg which showed high dark current in operation. We disassembled the counters and find that for one counter the current problem is from a cracked glass plate which has slag and spark signs on the surface. For the other, complicated patterns were observed on most of the glass plates, indicating that the high dark current is an overall effect. Figure 1 has shown one of the surfaces, where a large burnt area can be seen. Within the area distributes some white, powder-like patterns, with most of them along the fish-lines. These visible changes of surface condition can not be formed without long period of discharge.

With most of the electrodes showing similar changes, we are able to collect samples with some typical patterns for SEM inspections and related analysis. The polarities of the samples were recorded as the glass polarity: A the positive, and B the negative. And it is easy to learn that under the view of the gas gap the polarities are just opposite. Samples of both sides from another MRPC2 has been collected as

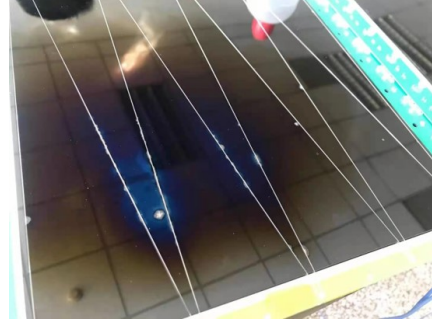


Figure 1: A naked-eye inspection of the returned MRPC2.

comparison. The counter has been working for over 5,000 hours under cosmic rays in our laboratory. Table 1 lists the description of the samples, and Figure 2 summarizes the elemental analysis results. As sample 2 and 3 shows, the long term operation with proper dark current control will not cause significant aging effect.

index	Description	Surface
1	brand new glass	-
2	cosmic	A
3	cosmic	B
4	irradiated, fishline pattern	A
5	irradiated, fishline pattern	B
6	irradiated, spot pattern	A
7	irradiated, spot pattern	B

Table 1: Descriptions of the collected samples.

Figure 3 shows the microscopic view of a brand new sample. The field of vision is neat only with some light colored spots. The glass has shown the components as a type of the doped silicate in Figure 2, and the spots area has a similar fraction, but has additional Mg and K. So the spot structure might be the result of crystallization.

Under SEM, the irradiation structures can be clearly seen as Figure 4 on both sides of the surface. Along with the change of color, cracks and deposition stains invisible to naked-eyes are found in most structures. They could be the source of the dark current and rate. The structures are likely to form by the mutual interactions of discharge, deposition and chemistry. For fishline structures, it is easy to find characteristic distances around $30 \mu\text{m}$, indicating that the contact section of glass and fishline is only tens of μm in width. The unique pattern of fishline region is possibly

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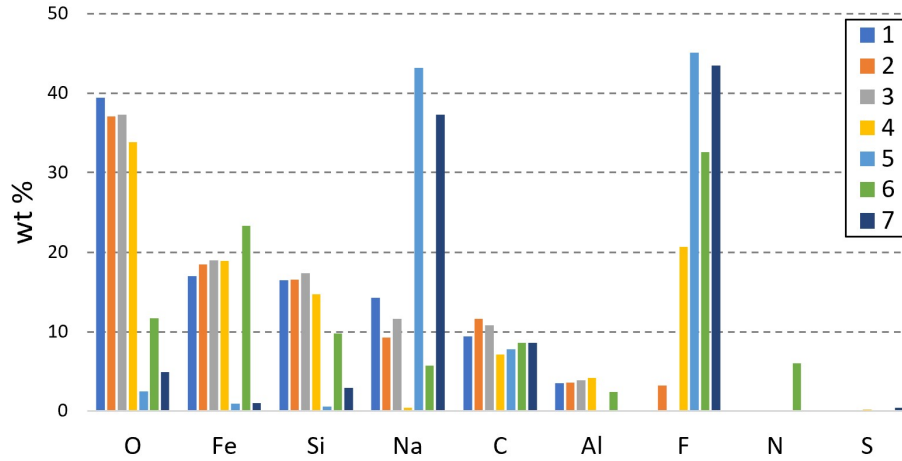


Figure 2: Summary of the element analysis.

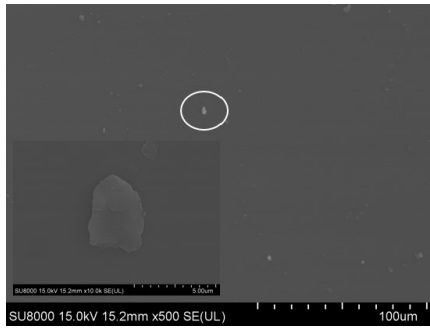


Figure 3: View of the brand new glass, with the zoomed view of a light colored spot.

related to the different electric field compared with the gap region. The element fraction is different on opposite polarities. The negative surface has higher weight percentage of Sodium, while for the positive, the majority is Iron. A reasonable explanation would be that Na^+ is more movable than other ions like Fe^{n+} and Al^{3+} so it drift in electric field towards the negative surface. F^- deposits on both side of the surface and more fraction on the negative side. Sample 5 shows an unusual pattern of a spot which is visible as well without scope. It is possibly attributed to an intense streamer, because the circle pattern has the same level of size as a typical avalanche. In addition, the less deposition in the circle can be explained by the space charge effect.

This work has provides the evidences that lead to a better understanding of the glass aging effect, including the deposition of Fluorine, the patterns around fishline, and the marks of intense streamers. They can well explain the increase of the dark current and noise rate for the aging counters. Based on the results, it is necessary to improve the gas exchange in gas gaps, which leads to the development into the sealed MRPC [5]; and to avoid abnormal discharges, which requires an advanced slow control in terms of tem-

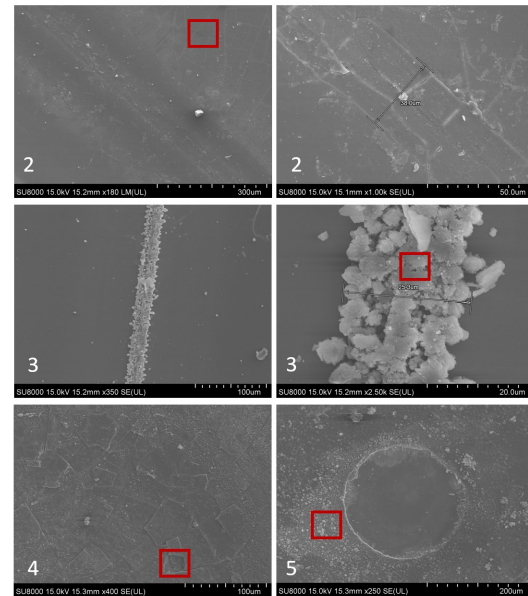


Figure 4: Typical pictures of the surface patterns on irradiated glass plates. Red squares mark the region for element analysis with results shown in 2.

perature, working high voltage, etc. Proper improvement on the fishline, if practical, will also benefit the glass in operations.

References

- [1] J. Wang, et al. NIMA. 713 (2013) 40-51.
- [2] I. Deppner. Talk given at 38th CBM Collaboration Meeting, 2021.
- [3] Y. Wang, et al. JINST. 7.11 (2012) P11017.
- [4] D. Bartos, et al. (2021) arXiv:2105.12214.
- [5] B. Wang, et al. Appl. Sci. 11.11 (2021) 4722

New potential MRPC prototypes to reduce gas aging effect for CBM TOF

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The aging effects of MRPC detectors have been studied over the past few years. The structures of MRPCs need to be specially optimized to maintain its performance over the whole lifetime of the experiment, since CBM-TOF is foreseen to run 2 months/year for about 10 years in high luminosity environment.

Here we report the SEM analysis results of the aging effects of CBM/STAR eTOF MRPC3b operated at STAR, including the surface characteristics and elemental analysis of glass electrodes and fish line spacers. Semi-sealed CBM-TOF MRPC3/4 prototypes, which may weaken the aging effects, have been tested under cosmic-ray, and some preliminary results were showed here. Prototypes built with cuboid spacers have been proposed which may reduce the gas pollution around the former fish line spacers.

SEM analysis

Through visual inspection of MRPC3b from STAR that were operated at high luminosity for a long time, obvious traces of depositions could be found on the surface where fish lines lie against glass electrodes. A scanning of the deposition both on the electrodes and fish lines has been done with Scanning Electron Microscope (SEM) to get a better resolution. Figure 1 shows the images of electrode samples (Figure 1(a) 1(b)) and fish line samples (Figure 1(c) 1(d)).

For Figure 1(a) 1(b), the deposition traces could be found in the region of about 30 microns around the contact surface between fish lines and electrodes. More compositions were found on the cathode surface. The fish line (Figure 1(c) 1(d)) irradiated for a long time at high luminosity also shows obvious marks compared with the new fish line.

Further chemical elemental analysis results with SEM proved that under the strong electric fields, the elements of the glass electrodes have a directional movement inside the glass and fish line (including sodium and silicon, etc.), especially in the deposition areas. The fluorine in the working gas also appears along the deposition of the cathode glass. These results illustrate that some gas molecules may be ionized due to the high electric field and avalanche effect, and for the vicinity of fish line, the ionizations may be more severe. These gas pollution may lead to aging effects.

Semi-sealed CBM-TOF MRPC3/4

Semi-sealed CBM-TOF MRPC3/4 with 3D printed gas guider and gas blockers are designed to speed up the working gas exchange in the gas gaps and may reduce gas aging effects in MRPCs. The structures of semi-sealed MRPC3/4

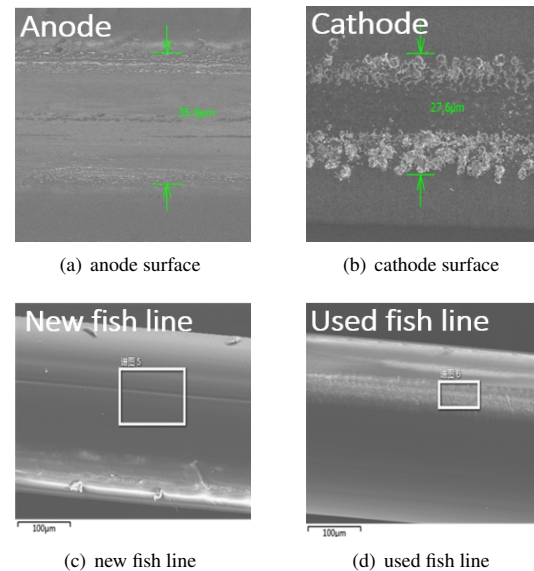


Figure 1: Samples of SEM images: (a) the anode surface of electrode (b) the cathode surface of electrode. (c) the new fish line. (d) the used fish line in MRPC3b.

are basically same with normal MRPC3/4: double-stacks and ten gaps MRPC with ultra-thin float glass electrodes. The sealed design is showed in Figure 2. Gas blockers are placed along both sides of each stack and a specially designed gas guider is placed on the side perpendicular to the direction of the fish line to ensure a uniform flow of gas in each stack.

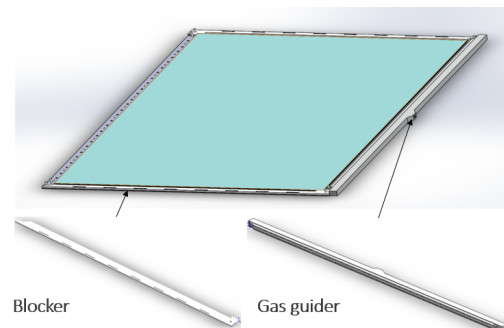


Figure 2: structures of Semi-sealed MRPC3/4

Semi-sealed MRPC4 prototypes have been assembled and tested under cosmic rays along with two normal MRPC4. The working gas mixture is composed of 90% Freon, 5% iso-C₄H₁₀ and 5% SF₆. The dark currents for

sealed counters are very stable and low, less than 10 nA at 6000 V. A single counter time resolution of 65 ps and an efficiency of 94% were obtained in the test. These results are consistent with normal counters. Further test is expected in the upcoming mini-CBM high rate environment.

Novel design of MRPC spacers

More compositions are found by SEM in the vicinity of fish line, which may hint the gas pollution is more severe in this area due to the gas exchanges are less adequate and the electric field is stronger. Simulations of the electric field show (Figure 3(a)) that, using the normal fish line as the support spacers between two electrodes, the electric field intensity in the region of 20 microns around the spacer-electrode contact surface is more than 4 times larger than the parallel gas gaps. But if the normal fish lines are replaced by cuboid spacers, electric field distribution will obviously be fairly uniform (Figure 3(b)).

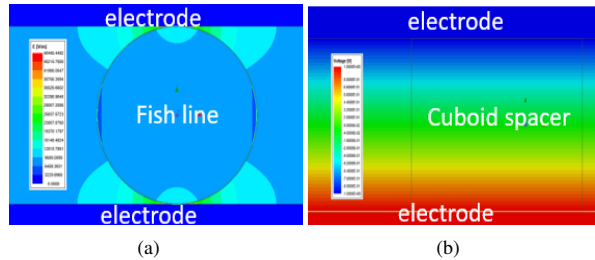
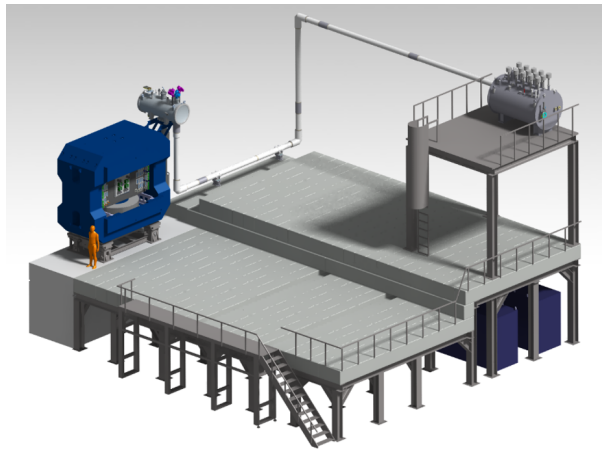


Figure 3: Simulations of electric field in gas gap: (a) fish line spacer (b) cuboid spacer

Based on above considerations, a novel MRPC with cuboid spacer has been proposed. 400 mm long, 208 μm thick, 2 mm wide teflon tapes will be used to replace fish lines. The assembling and test of this new detector are still ongoing.

In conclusion, the SEM analysis results for ultra-thin float glass CBM/STAR MRPC3b have been reported. Detailed studies show the aging could be more severe around fish line. Two potential MRPC prototypes (semi-sealed MRPC3/4 and MRPC with cuboid spacers) have been proposed to reduce the aging effect. More studies and tests in terms of performance, aging and material stabilities are still underway.

Magnet



The superconducting dipole magnet of the CBM experiment

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End of 2020 we decided to perform separate Final Design Reviews (FDR) for the various components of the magnet in order to advance with the construction of the major parts, and, hence, to reduce the delays caused by the pandemic restrictions at BINP in Novosibirsk. End of January and beginning February 2021, the FDRs of the magnet yoke and its support, and of the power supply and the energy extraction system have been submitted. Meanwhile, the yoke blocks, each consisting of five steel layers, are welded and machined. Finally, the yoke has been assembled and painted (see figure 1). Laser tracker measurements of the precise yoke geometry are ongoing. Also the construction of the power supply, the energy extraction system and the dump resistors including the ordering of commercially available components is progressing according to schedule.



Figure 1: Assembled yoke of the CBM magnet

One of the important tasks, which suffered from the restrictions, was the construction of a realistic mock-up coil including the impregnation. Meanwhile, the coil vessel consisting of an U-shaped circular mandrel and a cover plate has been manufactured from stainless steel (see figure 2). Also, the winding tools have been built. The wire layers will be isolated by a 0.3 mm thick G-10 foil with holes. The coils will be impregnated at a temperature of about 50 – 60 °C in order to reduce the viscosity of the compound. Moreover, the coil will be impregnated inside the vessel at a pressure of 2-3 bar. The winding and impreg-

nation tests with the mock-up coils are planned for early 2022.

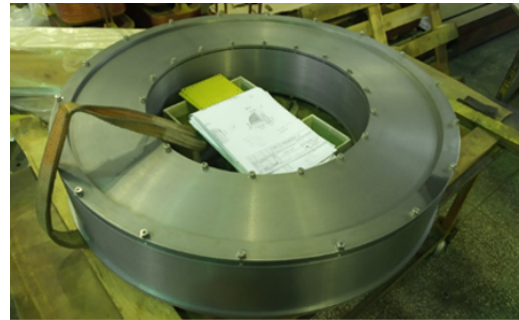


Figure 2: Photo of the mock-up coil vessel consisting of a circular U-shaped mandrel with a cover plate.

A crucial part of the coil construction are the support struts of the coil, which have to compensate the magnetic forces corresponding to 300 tons. On the other hand, the struts should be thermally isolating, because they have to resist the pressure between the coils at a temperature of 4 K and the vacuum vessel at room temperature (see figure 3). The idea is to use for each coil two large single rings made of Glass-Fiber Reinforced Plastic (GFRP), which are connected by a stainless steel ring, as illustrated in figure 3.

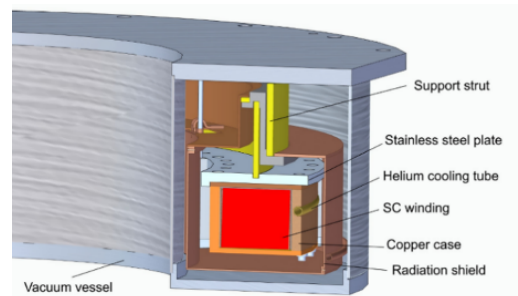


Figure 3: Cross section of the upper coil with the SC winding inside the copper case and the Helium cooling tube, the stainless steel plate the support struts, the radiation shield and the vacuum vessel.

In order to determine the mechanical stability of the GFRP rings, a pressure test and ANSYS calculations have been performed. For the pressure test, a GFRP ring with a diameter of 1640 mm, a thickness of 12 mm and a height of 180 mm was used. A photo of the test setup is shown in figure 7. The ring was stable up to a pressure equivalent

to 740 tons, although the pressure could be not applied exactly uniformly over the ring circumference because of the large ring diameter. Nevertheless, this result creates some confidence, that the struts will withstand safely 300 tons uniformly distributed over the ring. In addition, as result of the ANSYS calculations, the thickness of the outer strut, which experiences the large temperature gradient, will be increased to 14 mm, and its shape will be modified, in order to achieve a safety factor of 5 against buckling. Once the final struts will be available, the pressure tests will be repeated on shorter samples under well defined conditions.

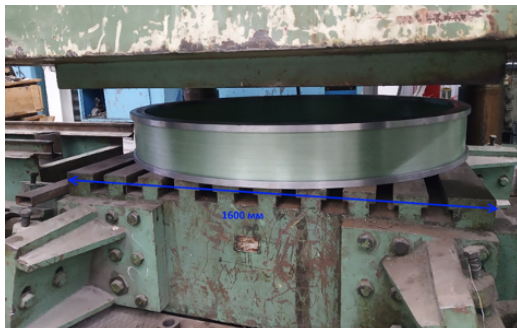


Figure 4: Photo of the test setup with a strut ring of 1640 mm diameter, and a 1000 ton press with a table size of 1600 mm.

The layout of the cryogenic system, i.e. the branch box, the transfer line and the cryostat is progressing. The branch box distributes the liquid Helium coming from a cryogenic plant to the CBM magnet, and to the feed box for the HADES magnet (see figure 5).

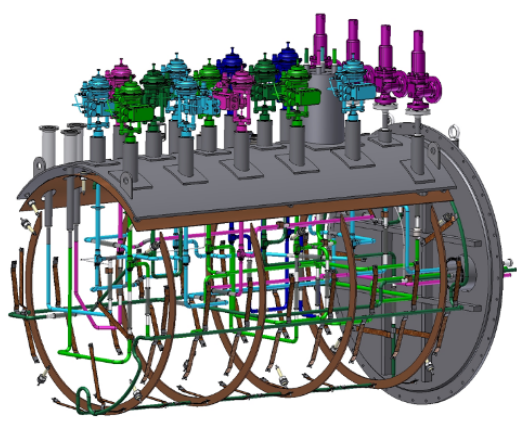


Figure 5: Piping inside the branch box for distribution of the liquid Helium to the cryostats of CBM and HADES.

The final specifications for the control valves, the pipe sizing, and the safety valves in branch box and cryostat are still under development, and will be documented in great detail for the examination by a notified body (TÜV). The cryostat provides the liquid Helium to cool the coils, which are connected in series (see figure 6). The Helium flow is

driven by the thermosyphon effect, i.e. by convection, and is supported by an additional heater. A concept for multiple mounting of the T and L junctions is under discussion. The implementation of such a concept is crucial to guarantee the correct reassembly and operation of the cryostat after the Factory Acceptance Test and the Site Acceptance Test at FAIR.

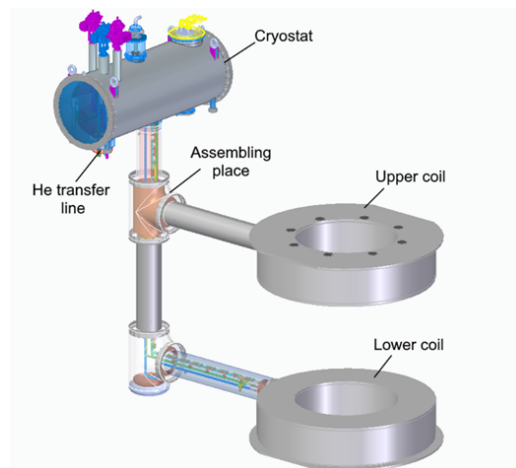


Figure 6: The cryostat with the connection to the coils.

The branch box is connected to the cryostat via a transfer line of more than 30 m length. The details of the piping inside the transfer line have been specified. The routing of the transfer line has been adapted to the modified platform geometry. The branch box is sitting on a balcony at the wall of the cave as shown in figure 7.

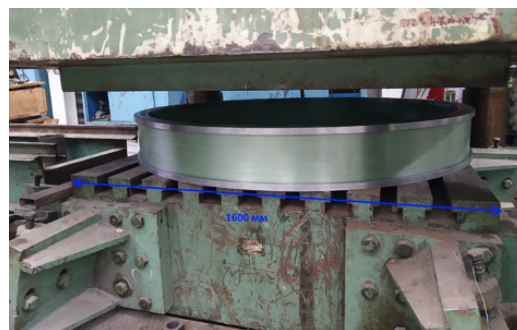
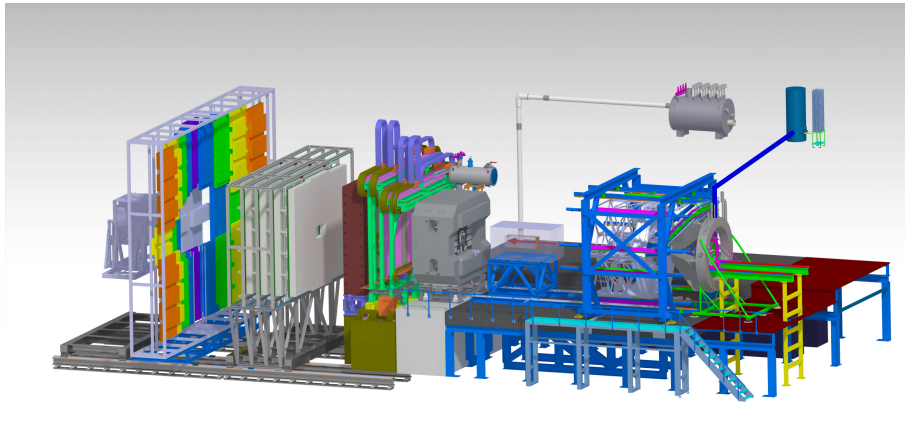


Figure 7: The cryostat with the connection to the coils.

Postscript: Due to the sanctions imposed on Russia after the Russian attack on Ukraine, the cooperation between GSI/FAIR and BINP in Novosibirsk has been indefinitely suspended. Therefore, the development and fabrication of the magnet has been ceased, and even the delivery of the produced parts like the yoke is not possible. We have contacted Western companies, which would be able and willing to produce the magnet, but before publishing a call for tenders, we have to clarify the funding situation, as the magnet ought to be a Russian in-kind contribution.

Infrastructure



Status of Upstream Platform Development *

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Introduction

The purpose of the platform is to provide required support for the HADES detector, ECAL and their equipment. Overview of the platform with detector and equipment is in the Fig. 1. The platform has two levels. The HADES detector, ECAL, HADES magnet and the beam dump are located on the lower level of the platform. The cryoplat-form and area designed as parking position for the RICH detector are located on the higher level of the platform.

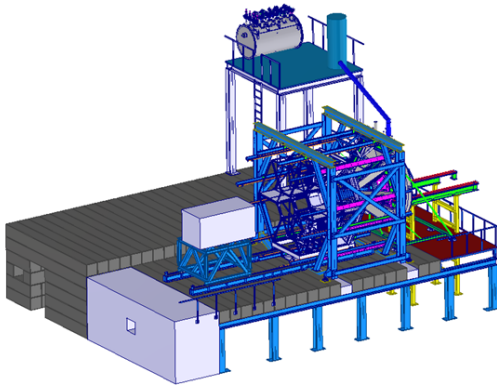


Figure 1: Overview of Conceptual Layout of the Upstream Platform.

Constraints and Requirements

The platform consists of concrete beams with the dimensions of $0.6 \times 0.6 \times 6.7m$ on the upper section and $0.6 \times 0.6 \times 7.8m$ on the lower section and supporting steel construction. The area underneath the platform provides space for placement of several racks and must contain an emergency escape corridor of minimal dimensions of $1.2 \times 2m$ without any obstacles.

The dimensions of any single component and sub-assembly must not exceed $6 \times 10m$ with weight up to $30t$. These limits are given by the dimensions of the access shaft and by the lifting capacity of the crane in CBM cave.

The fixation of the platform is possible only to the re-inforced concrete floor of the CBM cave and to the CBM magnet foundation. The load applied on the steel construction is presented in the table 1.

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Table 1: Upstream Platform Load

Item	Load	Location
Concrete blocks	200t	Upper and Lower Section
Cryoplat-form	15t	Upper Section
RICH	16t	Upper Section
Hades	25t	Lower Section
Ecal	35t	Lower Section
Hades Magnet	5t	Lower Section
Beam Dump	35t	Lower Section
Additional Load	1t/m ²	Upper and Lower Section

Design Description

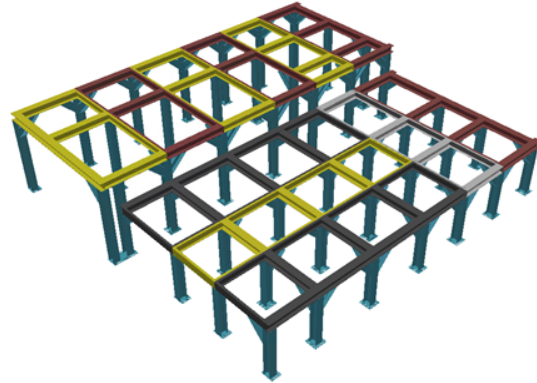


Figure 2: Upstream Platform Design Overview.

The upstream platform is designed as a simple steel beam frame with concrete beams lying on the top of it. The concrete beams themselves form a straight floor intended for placing the detectors and other equipment. The steel frame provides required support for the concrete beams.

The total weight of the steel platform is 34 tons. The assembly breakdown can be seen in Fig. 2 (see different colors of the frames and pillars). The steel support structure consists of 6+5 individual subframes and 43 pillars. The maximal size of each subframe is $6.2 \times 2.75 \times 0.3m$ for the upper part of the platform and $9.6 \times 3.05 \times 0.3m$ for the lower of the platform. Its maximum weight is $2.4t$. Its dimensions are not limited by the access shaft to the CBM cave but by maximum allowable dimensions for the transportation on a truck.

The platform is designed to be assembled in CBM cave from frames and pillars. All components and subassemblies are bolted together.

FE Analysis

A preliminary finite elements analysis is performed on simplified but reliable beam model. The simplified 3D model is shown in Fig. 3. All profiles (I and C-shaped profiles) are substituted for 1D elements. The simplification has no impact on the platform deformation, but it can influence the local stress behavior.

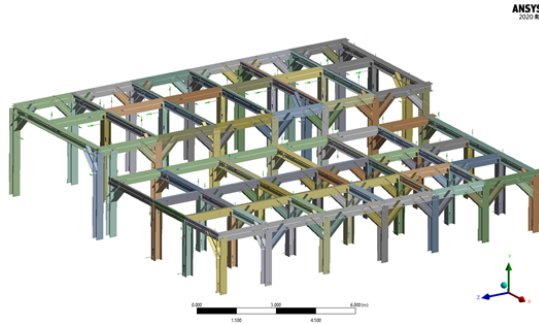


Figure 3: Simplified FEA Model of the Upstream Platform.

The meshed FEA model of the upstream platform with concrete beams on the top of it is shown in the Fig. 4. The figure shows not only the mesh but also the load acting on the surface of the platform (summarized in the table 1). The boundary conditions of the model are set as follows:

- All components of the steel frame (beams) are bonded.
- Frictional contact occurs between the back side of the frame and the rigid wall representing the CBM cave wall. There is no fixation to this wall.
- All pillars are fixed to the ground.
- The first steel beam of the platform lower section is fixed (highlighted in red in Fig. 4). It represents a fixation of the frame to the CBM magnet foundation.
- Frictional contact between the concrete beams and beam frame.
- Frictionless contacts between the concrete beams. The beams are in contact, they can separate and can slide with no friction, but they cannot overlap.

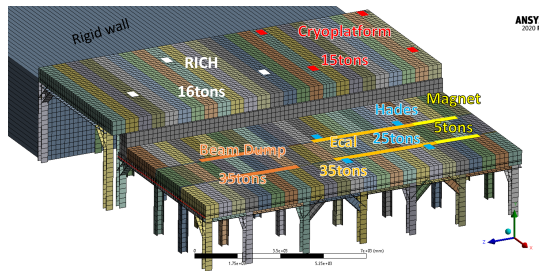


Figure 4: Meshed FEA Model of the Upstream Platform with Load Distribution.

The table 2 lists some material properties used for the analysis. The properties used for the mild steel are commonly used values. The material properties for the con-

crete beams have not been known yet. The young modulus of the beam is a value for pure concrete only. The density is counted with some reinforcement (50% of steel). These values are used for calculation of the weight as well as preliminary deformation of the beams.

Table 2: Material Properties

Material	Young Modulus	Density
Steel	$2e + 11Pa$	$7850kg/m^3$
Concrete	$3e + 10Pa$	$5000kg/m^3$

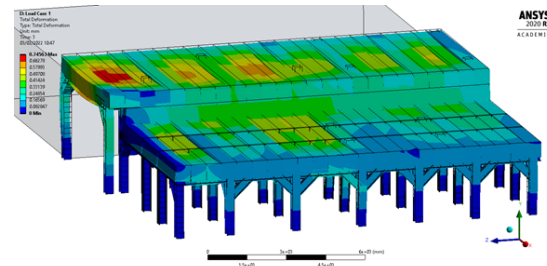


Figure 5: Total Deformation of the Platform for Load Case 1 and Step 3.

Fig. 5 shows the deformed model of the platform (gravity sag + equipment mass + additional load). The highest deformation (up to 0.75mm) of the platform can be seen on the upper section. Due to the higher number of pillars underneath the lower section of the platform, where a higher load is expected, the maximum deformation of the lower part of the platform is about 0.5mm.

Conclusion

The designed steel construction of the upstream platform provides a support for the number of concrete beams which form a flat surface where HADES, ECAL, HADES magnet, beam dump, RICH and Cryoplatform are placed. The platform has two parts. The upper section with the height of 4.2m and the lower section with the height of 3m. The design allows to use the area underneath the platform for placement of several racks.

The steel support structure of the platform is designed as an assembly of 11 welded frames and 43 pillars. The final assembly will take place in the CBM cave. The maximum size of components is limited by the allowable dimensions for the transportation on truck. The biggest component is the subframe of the lower section with the dimensions of 7.8x2.6x0.3m with the weight of 1.6t.

The finite elements analysis has been performed to calculate deformation and stress of the platform loaded by its own weight (steel support structure and concrete blocks), weight of the equipment on the platform and additional load of $1t/m^2$.

Beam following assembly*

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Introduction and Requirements

During the last year, the design of the CBM beampipe with its driven deflection mechanism has been developed. The following contribution is dedicated to a brief overview of the CBM beampipe geometry with the focus on the RICH/MuCH section that has been committed to its first Finite Element Method analysis. Its main focus is towards the design of the tilting joint including the flexible component for downstream beampipe deflection and its stability simulations. Some preliminary design concepts of the bellow assembly holding frame for the both configurations of the experiment either with RICH or MuCH detector are introduced as well.

The CBM beam pipe will serve for maintaining of vacuum about 10^{-4} mbar along the primary beam path in order to avoid unwanted secondary interactions of the beam with the atmosphere. It is needed to design the CBM infrastructure with a low material budget to prevent degradation of the experiment performance caused by the secondary collisions with the surrounding parts. It is the reason, why light materials such as carbon fibre composite materials are preferred and all infrastructure systems close to the ion beam might be designed with respect to the low material budget as well as mechanical stability at the same time. [1]

Design overview of CBM beampipe sections

The beampipe for the CBM experiment is divided into a few sections that are named according to the adjacent detectors. The beampipe is formed by a conical section and a cylindric downstream piping. The cone originates at the STS section and goes through the whole RICH/MuCH section with its basic geometrical deflection of $1,2^\circ$. The downstream section will be connected via a flexible tilting joint, which deflects the cylindrical downstream section of the beampipe. The design of the beam pipe provides a deflection angle in the range between $-2,5^\circ$ and $2,5^\circ$ of the downstream beampipe position from the main longitudinal axis of the experiment.

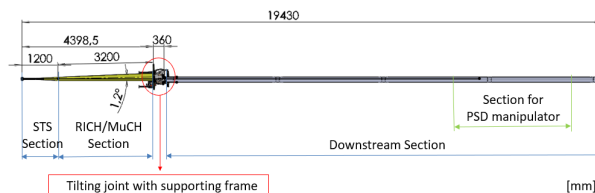


Figure 1: CBM beampipe scheme

RICH/MuCH section

The latest design has been created with the intention to reduce the dimensions of the metal bellow weldment with large material budget from the previous concepts. The reduction has been reached at the expense of the opening of the cone and with $1,2^\circ$ basic geometrical deflection. Therefore, this latest concept can be used just for a single polarity. The polarity change is intended to be performed by rotation of the cone. And so, the beampipe support frame has to accommodate two configurations.

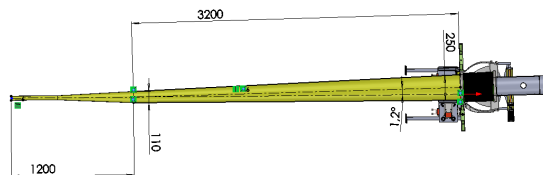


Figure 2: RICH/MuCH beampipe

The upstream part of the RICH/MUCH cone is inserted to the connecting part of the STS section, which is joined to the STS rear wall. The cylindrical mounting of this joint enables sliding movement of the RICH/MUCH beampipe in axial direction through the O-ring sealing, and so provide a degree of freedom for axial shift as well as the rotation around the z axis.

The downstream connection of the RICH/MUCH cone is realised via a carbon fibre flange, which mates with the flange of the bellow weldment. The result of this connection is the fixed position of the RICH/MuCH beampipe in all directions.

Using Ansys or Abaqus software, the preliminary FEA calculations of deformations and stability of the RICH/MuCH cone were performed. The total deformation of the beampipe under vacuum conditions is shown in the

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figure 3. The simulations have been performed for 1 mm wall-thickness of carbon fibre. The load is determined by the pressure difference between the inner vacuum and outer atmospheric pressure. This leads to outer pressure forces acting on the cone normal to its surface.

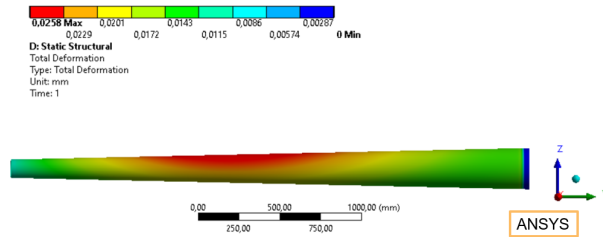


Figure 3: Total deformation of the RICH/MuCH beampipe under vacuum conditions

Tilting joint

The design of the tilting mechanism for the downstream beampipe will be realised as an assembly of a metal bellow and carbon fibre composite plates surrounding the bellow for length fixation purpose. The deflection is performed by a stepper motor *NEMA 34* with the nominal operating torque $9,33\text{ Nm}$. The motion is transformed by the lead-screw with the nominal diameter of 12 mm . The transmission of torque from the motor to the leadscrew is guaranteed by the servo shaft couplings. The leadscrew is connected with the aluminium roller controlling the movement of the bellow downstream flange on the aluminium arc-shaped rail. The centre of the arc curvature is located at the beginning of the beampipe within the target area.

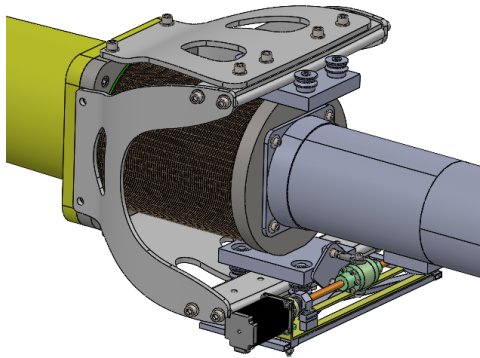


Figure 4: Tilting joint with bellow

A metal bellow represents highly flexible thin-walled mechanical part, which serves for compensation of angular, axial or lateral displacement. There is a wide range of different bellow types based on the way of manufacturing. This application uses an edge-welded stainless steel bellow, which consists of a number of pairs of edge-welded rings. Due to the advantageous mix of its mechanical properties,

such solution meets high demands of the CBM experiment on infrastructure components. Based on the geometrical attributes of mating parts as well as of the given maximal deflection of the downstream section, the edge-welded bellow with inner diameter of 250 mm and outer diameter of 285 mm from the material *DIN 1.4404* has been chosen. The length of the bellow itself with 108 convolutions (i. e. pairs of rings) is 280 mm , which means that the bellow is slightly compressed from the state of its free length all the time. The length of the whole weldment with the bellow and side flanges is 350 mm . The outer face surfaces of these both flanges have got a groove for viton O-ring sealing to preserve vacuum tightness. [2]

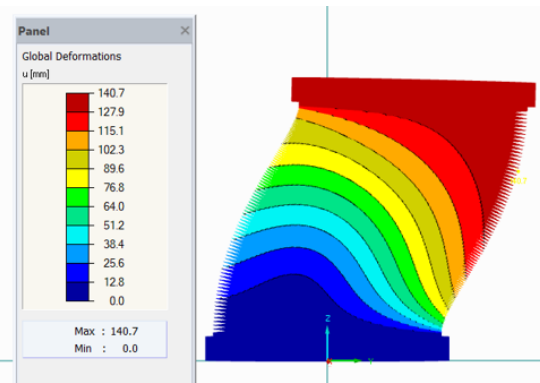


Figure 5: Deformed bellow in its extreme position

Under vacuum conditions, reaction forces are produced within the bellow tending to return the whole part in its undeflected shape and shrink it due to the spring-like behaviour of metal bellows. Therefore, a rigid frame and an assembly with leadscrew are used to maintain a given position of the bellow edge flanges. The bellow can withstand extreme mechanical, chemical and radiation conditions due to stainless steel material.

The bellow itself with its sub frame from carbon fibre composite plates forms a closed system in terms of local forces generated by the flexible bellow in reflection of the outer overpressure of 1 atm . Different designs of the frame have been always tested for 2 positions. In the first one the bellow is undeflected in terms of angular deformation, which means that there are not created any lateral reaction forces. But the compressive tendency of the bellow under vacuum causes an axial load on the carbon fibre composite sub frame (which is supposed to absorb all the deformation energy). Such a sub frame will be exposed to the axial vacuum force of $7\,000\text{ N}$ and to the forces generated by weights of all components including the beampipe. The definition of the boundary conditions is defined by the mounting to the beampipe frame, and so the left flange is clamped.

In comparison to the previous case, the extreme position of the deflected bellow by $1,3^\circ$ adds a lateral reaction of the bellow of $2\,460\text{ N}$, which is captured by the kinematic mechanism with the leadscrew. The vacuum reaction forces of the bellow are positively but non-linearly proportional by its dimensions.

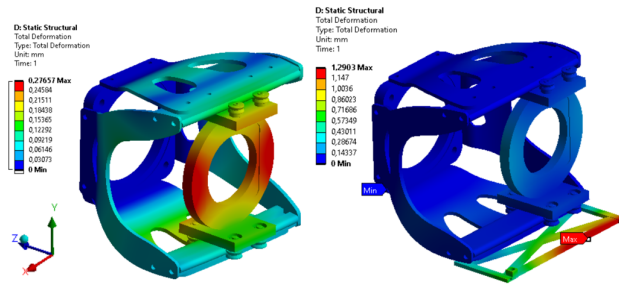


Figure 6: Total deformation of the frame of bellow in un-deflected (left) and extreme (right) position

Mounting of the tilting joint

The frame structure for the tilting joint clamping also serves as a supporting construction for both the RICH/MuCH cone and the downstream section of the CBM beampipe. Based on the spacial demands on the main beampipe frame, 2 versions are needed because of the alternative configurations of the CBM experiment, that could be operated either with RICH or MuCH detector. Both versions are expected to be adapted for both polarities of the magnetic field.

The first frame for RICH version consists of steel HEB profiles fixed to the ground. The central box clamps the bellow flange and enables position compensations in all directions due to the vertical C-shape profiles. The central box is connected to the frame by carbon fibre composite plates in a web-like shape.

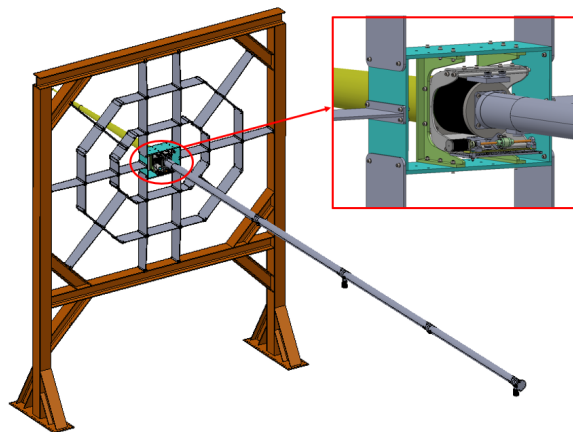


Figure 7: Beampipe frame for RICH configuration

The second configuration of the experiment with the MuCH requires different attitude because of the lack of space between detectors for any frame construction. Therefore, a wedge-shape bended metal sheet will be installed in order to fix the edge flange of the bellow weldment to the front wall of the MUCH station.

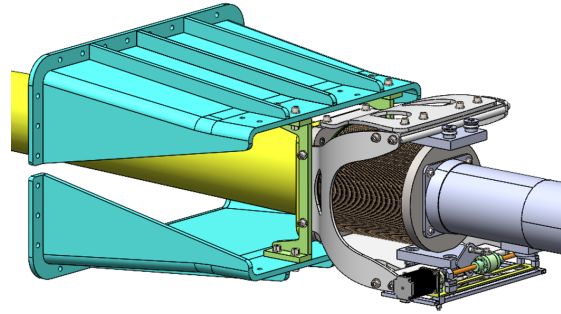


Figure 8: Beampipe frame for MuCH configuration

Conclusion

Beam following system was developed based on the bellow and the drive with leadscrew. The support frames of the beampipe are in development. Their static structural stability as well as their behaviour under dynamic conditions will be evaluated and the design solutions will be optimized in relation to the results of FEM analyses.

References

- [1] B. Friman, C. Hoehne, J. Knoll, S. Leupold, J. Randrup, R. Rapp, P. Senger, and others, *The CBM Physics Book, Compressed Baryonic Matter in Laboratory Experiments*. 27. 1. 2011, Springer Verlag, ISBN 978-3-642-13293-3
- [2] Mewasa AG *Edge welded bellows* [online], 4. 1. 2021 cit. [23. 5. 2021], website of the Mewasa company, available on: <http://www.mewasa.ch/>

Status of PSD Beam Pipe*

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Introduction

The Beam Pipe is a tube which isolates the charged particles coming from the particle accelerator from our experiment. In this specific case, the particles are after a collision with the target material. In order to prevent any undesirable secondary interactions of primary beam with the atmosphere and hence compromise performance of the detectors, strong vacuum ($\approx 10^{-4}$ mbar) must be maintained inside the beam pipe. The positions for pumping and monitoring of the vacuum using the ISO-K flanges and the positions for auxiliary diagnostics using the ISO-KF flanges are a part of the beam pipe. Due to the overall length of the pipe, it was divided into smaller segments to enable production with the required precision and to reduce the risk of damaging the pipe during transport. The pipe was designed as a thin shell, which is also structurally robust, using as few metallic components as possible. The service life of the beam pipe must achieve at least 40 vacuum to atmosphere pressure cycles. Due to the environment in which the pipe will be used, the radiation resistance to the non-ionizing and to the ionizing radiation must be guaranteed. The limit radiation dose, when the beam pipe maintains all of its original properties, are the minimum dose of 100 kGy for ionizing radiation and fluences 1013 neq/cm² (1 MeV neutrons). The proof of reaching the required mechanical and radiation resistances must be based on the testing of provided prototypes. The vacuum tightness test under operating conditions must also be substantiated by tests of the beam pipe prototype.

PSD Beam Pipe

An appreciation of dimensions and the number of connection parts or pipes can be gained from Fig. 1. Tolerances and precision of dimensions and shapes are given by ISO 2768 – mK. As shown, the PSD Beam Pipe consists of 5 straight segments and 5 interconnecting insets. Two interconnecting insets include ISO – K flanges for vacuum inputs and three interconnecting insets include ISO – KF flanges that can be used for auxiliary diagnostics and monitoring.

• Straight part

In total, the Beam Pipe comprises five straight segments with a simple circular cross-section. Three of

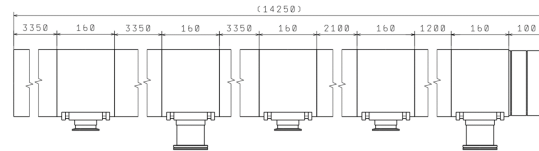


Figure 1: Layout of PSD Beam Pipe.

them have a length of 3350 mm, one segment has a length of 2100 mm and the last one has a length of 1200 mm. The inner diameter of the pipe is 180 mm, with a wall thickness of 3 mm. On both ends of the pipe is a 100 mm long section where interconnecting insets are slid inside.

• Interconnecting inset

Connection parts have three grooves for O-rings to ensure tightness at both ends. The outer diameter of the part with grooves for O-rings is 180 mm. The minimum wall thickness is 3 mm. In the middle section of the inset is a hole for the ISO - K or ISO - KF flange. The diameter of the hole depends on what type of inset is used. For ISO – K, the hole diameter is 76,2 mm and for ISO – KF flange the diameter is 57 mm. There is a support part between the vacuum flange and the inset. This support part is glued to the surface of the inset and the vacuum flange is glued inside. At both ends of this support part are grooves. While manufacturing the inset by means of winding, an extra bundle of carbon fibers fits directly into this groove at each side, hence the bundles are over-winding the support part and help to get a stiff connection. The last configuration of the inset is without a vacuum inlet. The inset with ISO - KF flange is shown in Fig. 2.

Vacuum in Downstream Beam Pipe

The required level of vacuum to be maintained in the downstream Beam Pipe is $\approx 10^{-4}$ mbar. To reach it, multiple vacuum pumps have to be used. Downstream Beam Pipe consists of several straight segments of different lengths and shapes. Placement of vacuum pumps has a leading order impact on the pressure profile. Several cases of pressure profiles for Beam Pipe are shown in Fig. 3. Full beam pipe with marked inlets or pumping positions is shown in Fig. 4. All the calculations are done using MolFlow. For the moment, pumping speed 35 l/s and outgassing rate [1] of 10^{-6} hPa · l · s⁻¹ · cm⁻² are assumed.

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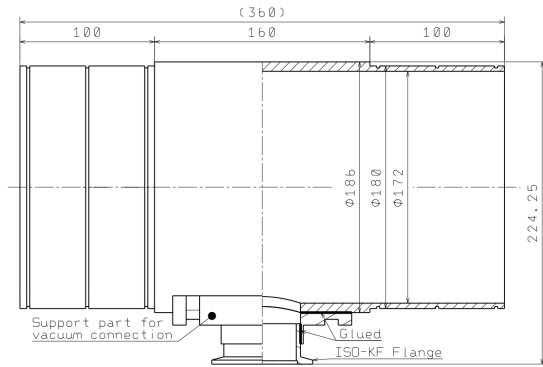


Figure 2: Interconnecting inset - configuration with ISO - KF flange.

There is no better knowledge of leakage of connection or any other specific parts. The most important impact on the final placement of vacuum inlets will be given by available space along the pipe.

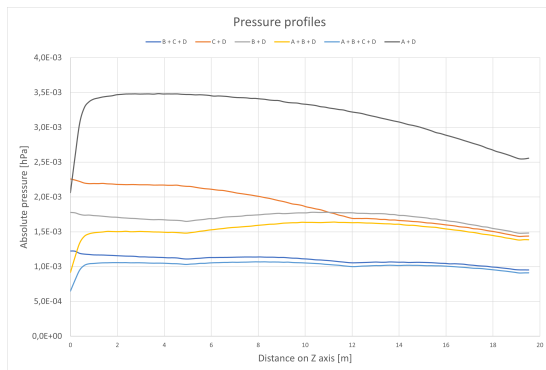


Figure 3: Pressure profiles for different placement of vacuum inlets.

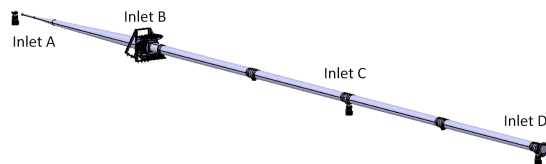


Figure 4: Downstream Beam Pipe with two vacuum inlets.

The required vacuum level is achieved in two steps. First, a vacuum of lower quality is achieved by vacuum stations connected to the outlets of turbomolecular vacuum pumps mounted directly on ISO - K flanges on the interconnecting inset as shown in Fig. 5.

Conclusion

A 14.25 m long tube called PSD Beam Pipe was designed. It is connected to the metal bellow and the end

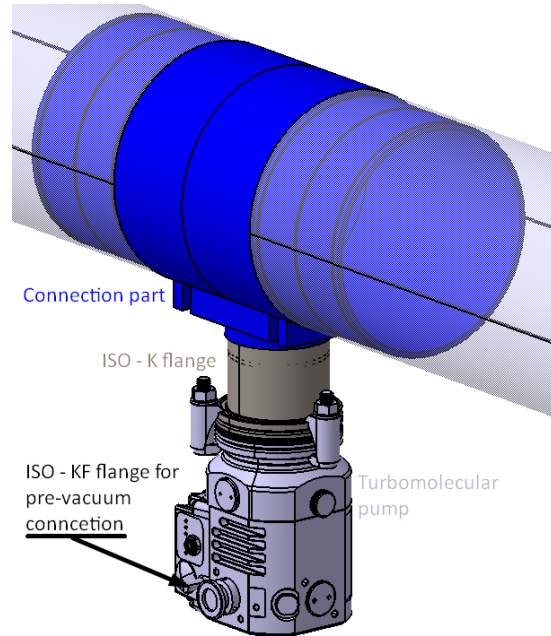


Figure 5: Beam Pipe with turbomolecular vacuum pump assembly.

the pipe is closed by an exit window made of thin metallic foil. It consists of several different parts since manufacturing, transport and installation would be impossible in case of single piece solution. The PSD beam pipe consists of 5 straight segments. Between those are interconnecting insets with negative shapes and with O-Rings to reach vacuum tightness. Wall thickness is 3 mm and the inner diameter of the pipe is 180 mm. The vacuum was calculated for several cases and the results are shown.

References

- [1] MOSHEY, E. A., *A compilation of Outgassing Data on Vacuum Materials*. Princeton, NJ, 1982

The Up-stream Part

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A concept for the vacuum pipe has been created for the beamline to the CBM experiment target. The vacuum pipe runs between the last accelerator quadrupole, at the entrance of the Cave, through the Hades experiment to the target approx. 17m away. The vacuum pipe with all the necessary components is called the up-stream part (see Fig. 3) and consists of

- the part in front of Hades with a beam diagnostic, t0 counter and a pump station which allows to operate the part without the downstream vacuum system,
- a feed-through of the vacuum pipe through the Hades experiment and
- the beam diagnostics with t0 counter and pump station before the CBM target holder.

From the accelerator side, a pressure of 10^{-8} mbar is expected; the pressure at the target should be in the range of 10^{-4} mbar. The required pressure profile is to be achieved by means of differential pumping, which will require smart dimensioning and positioning of the pumping stations in further development. As far as possible, proven vacuum and diagnostic technology will be used to minimize the system's susceptibility to errors. One of the biggest challenges is the passage through the Hades experiment, where a vacuum pipe of about 6 m is needed, which has special requirements on the mountability. The maximum diameter that can be carried out is 170 mm, which limits the diameter of the vacuum pipe. Due to the unsuitable dimensions of the CF-DN160 standard flanges, a smaller size would have had to be selected for the feed-through. To avoid large changes in cross-section, a flange solution was used for the feed-through that has proven itself with GSI quadrupoles (see Fig. 1 and 2).

For further development, the interfaces to the mounting and the pump stations must be specified. Furthermore, a suitable assembly plan must be drawn up, which describes the work steps for switching between the Hades and CBM experiment and, in the best case, the vacuum in the downstream part is kept.

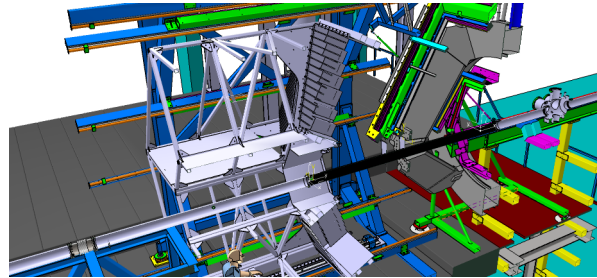


Figure 1: Cross-section of the longitudinal axis at the area of the vacuum feed-through in the Hades experiment.

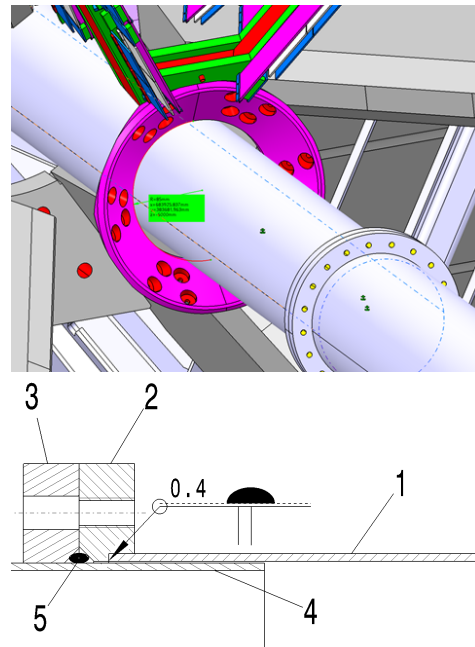


Figure 2: Smallest diameter for the Hades geometry of 170mm (left) and the approach for the vacuum flange for the feedthrough (right). The vacuum pipe from the accelerator side (1) and the welding flange (2) are pre-assembled. The vacuum pipe (4) is fed through and sealed with the loose union flange (3) and the O-ring (5).

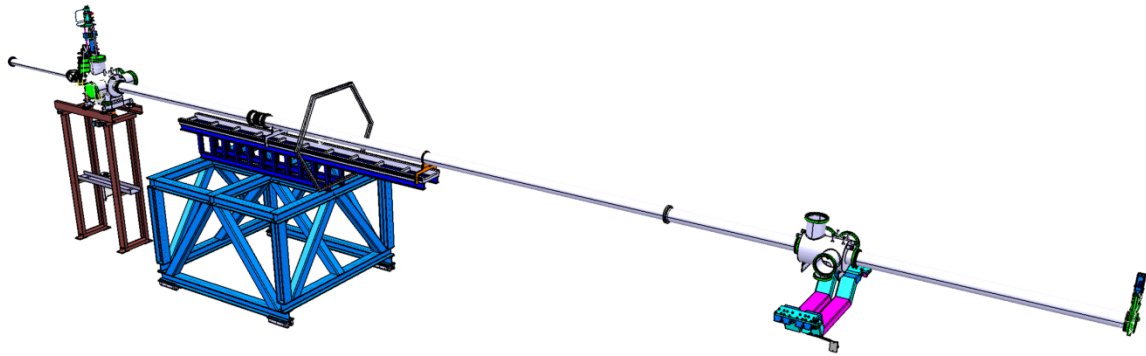
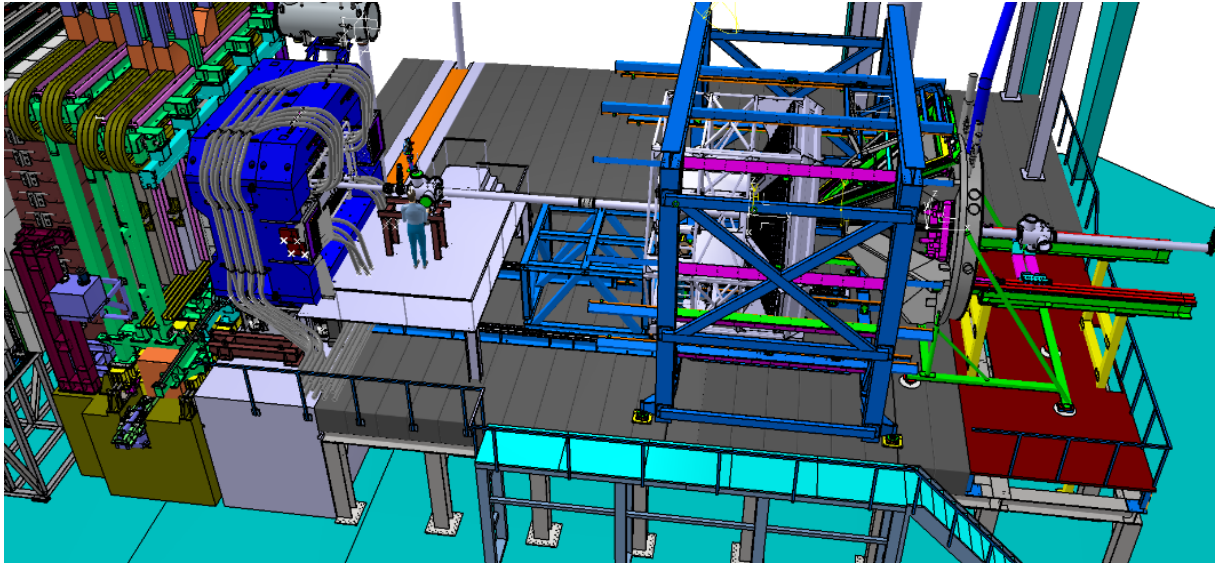


Figure 3: General view of the up-stream vacuum system for the CBM experiment, running from the cave entrance through the Hades experiment to the target holder in front of the dipole magnet with STS and MVD detector (right to left).

Construction of a target exchange device for the CBM experiment at FAIR

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Introduction

Since it was deemed desirable, to rapidly exchange targets between or even within a single run of the CBM experiment, a device for target exchange has to be included in the designs. This device should be mounted to the so called "front flange" of the Multi-Vertex-Detector (MVD), and thus will be located within the magnet and centered around the beamline. Due to its position within the experiment and the requirements this mechanism needs to fulfill, the design is quite challenging. First of all, the space for the installation is limited to a diameter of around 300mm around the beamline due to the cables and connectors of MVD and the Silicon Tracking System (STS). The planned location of T0-Counters and Beam diagnostics, limits the space upstream of the envisioned target to around 500mm. The available space for the mechanism itself is further reduced when one takes into account, that six targets with as large a diameter as possible need to be stored and moved within this space. Furthermore, the entire mechanism needs to be vacuum tight and able, to reliably operate at a pressure of 10^{-4} mbar. The amount of electronics should be minimal, due to the inherently high radiation doses and strong magnetic fields encountered in the center of the experiment. Best case would be, a purely mechanical device. Last but not least, the exchange of target sets should be as easy a procedure as possible, to limit the exposure of personell to activated targets during the required maintenance.

Construction

To incorporate all these requirements, several approaches have been considered. The very first drafts included a simple revolver wheel and a ladder-style arrangement on the inside of MVD's front flange, driven by a radiation hard stepper motor and, in case of the ladder-style arrangement, a ball screw. The development of these two ideas was discontinued rather quickly, because maintenance and target exchange would require removing the MVD from its position along with all connections and, because no shielding of activated targets was reasonably achievable. Instead it became clear, that storage of the targets upstream of the flange and movement along the beam axis would be required.

Since the individual targets need to be moved along the beam axis, to reach the final measurement position, and the use of segmented targets should be possible as well as that

of single slice targets, a shell construction out of carbon fiber tube was devised. These shells, as seen in figure 1 should hold the individual target foils and provide structural support as well as points for the exchange mechanism to hold on to, without touching the delicate foils directly.

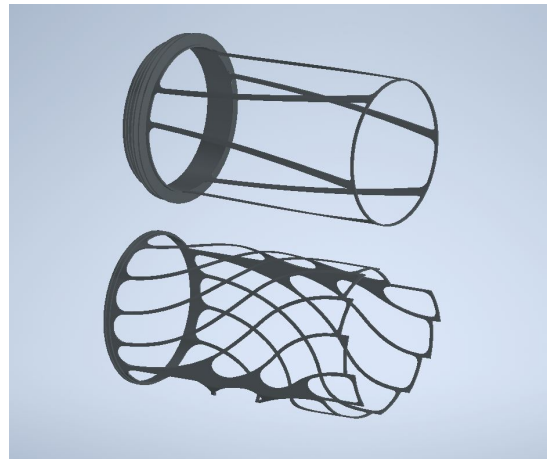


Figure 1: Lightweight carbon fiber shells as holder for target foils.

In order to store a selection of targets (for a run of the experiment, a total of five different material and one empty target should be available) a ladder and drum style magazine were considered. Ultimately the drum style was chosen, because it makes an overall more compact build of the mechanism possible and does not require a separate drive- and control unit.

To move the targets along the beam, a carrier was designed, to hold on to the shells and move along the central axis of the device. To reduce the material budget and increase the overall stiffness along with the rigidity and tolerance to mechanical forces, the axis in the center of the device was designed to be a large diameter and hollow in the center.

In order to increase the life expectancy of the device and reduce the overall complexity, a single acting spring loaded pneumatic cylinder with a lift of 250mm was chosen as drive unit. It controls the movement of the target shells along the beam and also the rotation of the storage magazine. Since the synchronization between the two movements is exclusively mechanical, there are no electronic controls, that could fail in the intense radiation of the environment.

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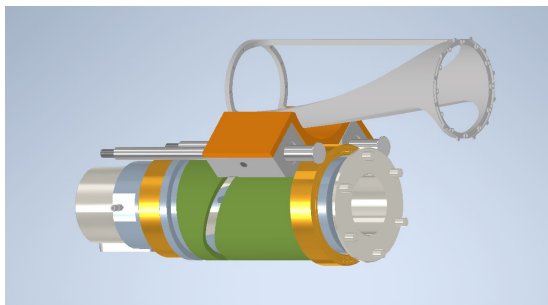


Figure 2: Central axis and movement mechanism with target carrier and bearings.

In order to make maintenance and troubleshooting of the device easy, the vacuum vessel was designed such, that the most critical part (the drive unit) is not inside the vacuum volume. instead it is accessible from the outside at all times. In order to exchange a target set for another however, the vacuum will still need to be broken and the vessel opened. In order for this procedure, to be as easy as possible, the vessel should be designed with a single cover, that can be opened with few screws and a contour fitting o-ring to provide sufficient sealing, for a stable working pressure.

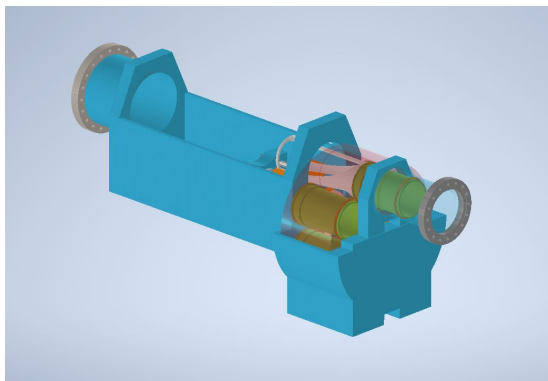


Figure 3: Compact mechanism inside the vacuum vessel, displayed without covers.

Rapid prototyping

In parallel to the CAD design and concepting work, prototyping in terms of additive manufacturing has been going on, as presented in [3]. Most of the individual design choices, such as the use of hollow axis and the holder for targets through compliant mechanisms has been experimentally verified. individual parts were 3D-printed and fitted together, in order to check for tolerances, even though additive manufacturing is currently not (or only to a limited extent) foreseen, to be used for the final manufacturing of the device. For several parts, such as the carrier bolt (the piece that holds the target shells during movement and measurement) Additive manufacturing is still under con-

sideration for the final pieces, because the use of heavily optimised structures provides a significant reduction of material budget while retaining the stiffness of solid parts manufactured with traditional methods such as milling and turning. Since the time needed for further research in this regard however might not align with the timeline of the project, current manufacturing was considered, to achieve a MVP (minimum viable product) as soon as possible.

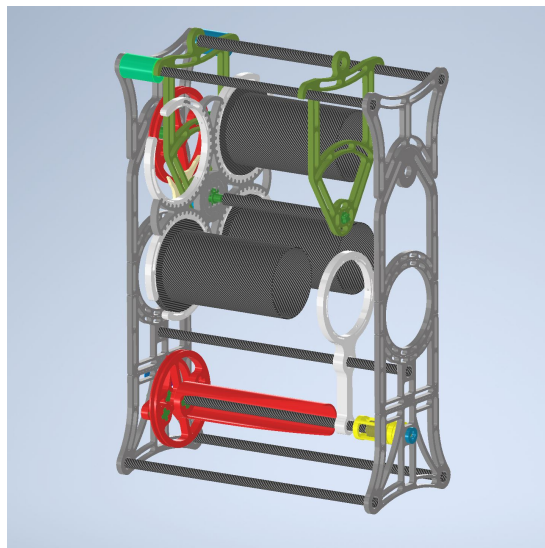


Figure 4: Rapid prototyping of the device

References

- [1] P. Dahm, "CBM Target Concept", Beampipe Brainstorming, 14.04.2021, <https://indico.gsi.de/event/12363/>
- [2] P. Dahm, "CBM Target Region", Beampipe Brainstorming, 09.06.2021, <https://indico.gsi.de/event/12642/>
- [3] P. Dahm, "Update on MVD & target region", Beampipe Brainstorming, 08.09.2021, <https://indico.gsi.de/event/13125/>

Status of PSD Beam Pipe GEANT4 geometry*

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Introduction

The beam pipe engineering development is discussed in separate contributions [1, 2]. Here, the overview of the current status of development of the geometry for simulations is given. Short prospects of a planned future development is included at the end of the contribution.

Main constraints

The main focus in the beam pipe development is to find a balance between the requirements connected with the physics performance of the experiment and the engineering requirements in order to be generally able to build it. The requirements shrink to the material budget as low as possible for achieving the best possible physics performance of the experiment and to keep enough material so the beam pipe is stable. To find this balance it is necessary to perform Monte Carlo simulations to identify problematic concepts or unexpected hot spots in concepts and designs suitable from the engineering point of view.

Basic concepts of the GEANT geometry assembly

The overall view of the engineering design is shown in Figure 1. The corresponding representation of the assembly in the GEANT geometry is shown in Figure 2. For improved clarity, the assembly is divided into three main parts:

- Conical section - RICH/MuCH section
- Bellow assembly
- Cylindrical tube - PSD beam pipe

The conical section and the cylindrical one are in the GEANT assembly represented by simple cone (*TGeoCone*) and straight pipe (*TGeoTube*).

The simplified bellow assembly consists of a carbon fiber bellow holding structure, stainless steel bellow with flanges, aluminum guiding rail with carriages, and stepper motor with a steel lead screw with nut.

- **Bellow holding structure** The opposing pieces of the holding structure are realized by the same symmetric shapes. The left and right pieces have also shapes

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Figure 1: Overview of the beam pipe.

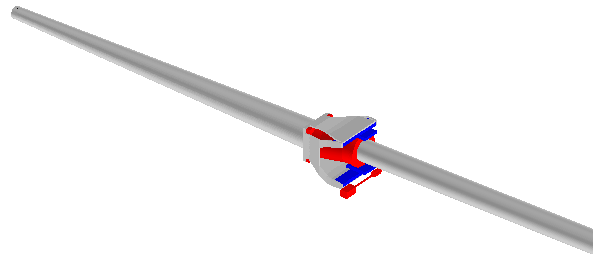


Figure 2: GEANT representation of the beam pipe geometry.

that have to accommodate the movement of the bellow. Both shape types are represented by several arbitrary trapezoids (*TGeoArb8*) in order to reproduce the complex curved shape from the engineering design.

- **Stainless steel bellow** The bellow is represented by a set of five cut tubes (*TGeoCTub*) in order to follow the complex shape of the deformed bellow. To represent the bellow segments as simply as possible the thickness of the wall of the tube segments was chosen to be the same as the thickness of the bellow segments and the density was reduced as there is a vacuum on the inside and air on the outside of the bellow.
- **Guiding rail and carriages** The guiding rail is represented also by a trapezoid (*TGeoArb8*) and the carriage is represented by a simple building box (*TGeoBBox*).
- **Stepper motor and lead screw with nut** The motor is represented by a simple building box (*TGeoBBox*) and the lead screw with nut by an assembly of tubes (*TGeoTube*). In the case of the lead screw, the tube has zero as the value of the inner radius.

The respective assemblies same as the overall assembly are enclosed in *TGeoAssembly* in order to avoid collisions and overlaps between the binding volumes.

Materials

The materials are represented as a composition of elements according to relevant material libraries. The compositions of respective materials are:

- Carbon fibre composite: 89.26% - carbon, 6.11% - oxygen, 2.71% - chlorine, and 1.92% - hydrogen;
- Stainless steel: 67.135% - iron, 17.5% - chromium, 11.5% - nickel, 2.5% - molybdenum, 1% - manganese, 0.25% - silicon, 0.05% - nitrogen, 0.035% - carbon, 0.0225% - phosphorus, and 0.0075% - sulfur.
- Aluminum: 100% - aluminum

Figure 2 is color coded according to materials: **gray** - carbon fibre composite, **red** - stainless steel and **blue** - aluminum.

Currently existing configurations

So far the existing configurations are:

- **Maximum deflection** of 2.55° - v21e;
- **No deflection** - v21f;
- **Phys. case 2** corresponds to Au beam of 3.3 AGeV/c, 50% magnetic field - v21g;
- **Phys. case 1** corresponds to Au beam of 12 AGeV/c, 100% magnetic field - v21h;

Planned development

Currently, the plan is to automatize the geometry modification by means of creating the bellow assembly in a parametric way with the beam deflection angle as the input parameter. The second step is to implement the lamination effect of the bellow by means of variable material density in different bellow sections depending on the deflection angle.

Conclusion

A simplified, but detailed enough initial geometry representation was created for the first simulations. The next steps in development were defined to make the geometry overcome the current need to change the volumes definitions for each beam deflection angle.

References

- [1] J. Kollarczyk et al., *Beam following assembly*. CBM Progress Report 2021, 2022
- [2] M. Smetana et al., *Status of PSD Beam Pipe*. CBM Progress Report 2021, 2022

Candidate SIS100 beampipe geometries for simulation

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Several new beampipe simulation geometries were created during the course of last two years, though they were not widely distributed, in order not to confuse the community with a myriad of technically unfeasible designs. This decision was counter-balanced by a need to rapidly provide a realistic beampipe geometry which could in tandem influence incremental design improvements. Evidently, as the section of the beampipe which transverses a detector, can heavily affect detector's design, construction, maintenance and operation, detector groups rightly have vested self interest and responsibility to ensure the quality and performance of their section of the pipe. Conversely, the beampipe itself is an extensive subsystem which transverses the entire experiment, affects every detector subsystem, introduces crucial mechanical challenges to overcome by physically connecting detector subsystems and thus requires global-experiment-design-considerations at each step. The beampipe is thus an area where coordination and communication in the spirit of the CBM collaboration is vital to ensure that physics performance is prioritised whilst robustness of the technical design is assured.

Reference [1] of this report, indirectly discusses the creation of the many simulation geometries over the last year based upon the previous ("v16a.1e") default. Each corresponds to the creation of slightly varying trial STS geometries. As some of the geometries in Ref. [1] are the current default beampipe simulation geometries distributed with our DEC21 CBMROOT software release, of particular importance is Tab. [1] which shows which beampipe to use with which STS and then the recommended placement for the target along the nominal beam axis. Ref. [2] contains the technical design considerations used for the STS beampipe section, with some advancements, especially in the beampipe window, which at present are not in the default simulation geometries mentioned above. This is at least partially addressed in Sec. [2] of this document. Ref. [1] also contains the STS back-wall flange which is used, and the target box which is used with some modifications, in Sec. 3 of this manuscript.

From the STS back wall, the beampipe is to transverse the RICH/MUCH section, through the TRD, and the TOF, and finally on to the PSD and the beam dump. Information regarding the technical considerations such as vacuum and connector inlets of the cylindrical beampipe from the TRD on, is contained in Ref. [3] of this report. Ref. [4] contains the beampipe simulation geometry for the entire downstream section. Primarily, it comprises of a down-

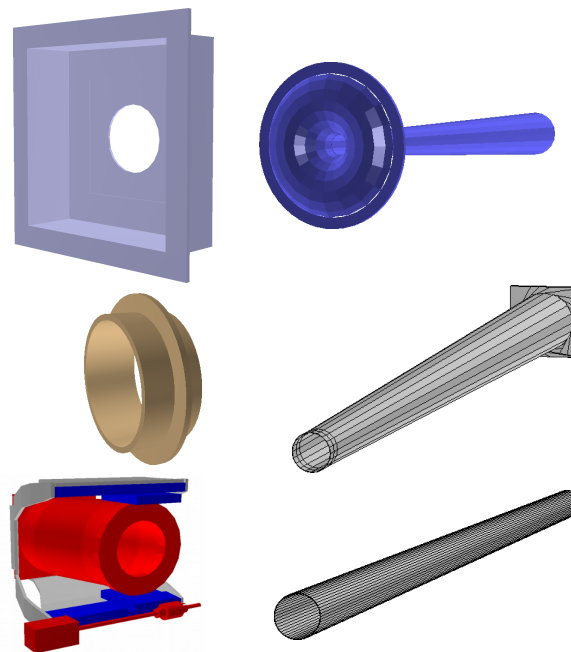


Figure 1: Size of beampipe parts are not to any fixed scale. **Top-left** shows the target box which houses the MVD and target. **Top-right** shows the beampipe window along with a wide conical section. **Middle-left** shows the STS flange which is supported by the back of the STS box. **Middle-right** shows the narrow conical section which transverses through the MUCH/RICH detectors. **Bottom-left** shows the implementation of the bellows. **Bottom-right** shows a simple cylindrical tube used for the downstream section.

stream cylinder, and the narrowed conic-based tube which transverses the RICH/MUCH. Between these two sections, a bellow assembly (see Ref.[5]) is added to allow a deflection angle for the beam between the downstream cylinder and narrowed conical section. Creation of a sophisticated representation of the bellows for simulation is contained in Ref. [4]. The bellow assembly is responsible for a significant percentage of the overall material budget of the beampipe as part of its structure and supports needs, and it was a noteworthy advance to add a small deflection angle of 1.2° between the STS and RICH/MUCH conic sections, so latter conic could have its directrix significantly reduced, reducing its material budget but more importantly the material budget of the entire bellows part. Ref. [6] highlights this case. It is a necessity for simulation geometries, unlike their CAD equivalents, to have an accurately specified

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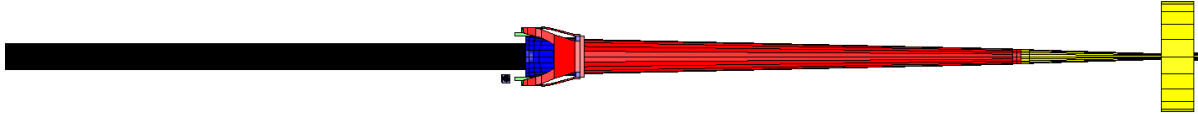


Figure 2: Shows the concatenation of a STS beampipe (v21d) and the undeflected downstream beampipe (v21f) using the method discussed in Sec. 1. The downstream cylindrical part, in black, has been cut short for display purposes.

internal make-up. Composite material and positioning information of parts is contained in Ref. [4] of this report.

The two substantial pseudo-independent efforts of the last two paragraphs are complementary beampipes geometries for simulation which unfortunately create a small confusion for our simulation teams in the CBM collaboration, as highlighted by creation of redmine issues 2424, 2429, and 2431, on how to use these two independently created geometries in conjunction with one another. The next section, Sec. 1, of this document documents a straight forward approach to do this, without the need for code changes to the CBMROOT code base. Later, Sec. 3 provides a single monolith binary which follows the traditional single geometry binary per subsystem approach.

1. Setting-up a simulation

This section documents how to set up our software suite, CBMROOT, to run a basic transport simulation using the two introduced beampipes with correct configuration. Subsequent simulation stages of digitisation and reconstruction follow their normal *modus operandi*. The basic configuration stage for CBMROOT is via setup files which are placed in the “geometry/setup” folder but must follow strict naming conventions. Using one of the default setup files as a starting sample is a good approach, e.g. open “setup_sis100_hadron.C” in a editor and rename it by changing only the “hadron” part of the filename, i.e. “setup_sis100_newpipe.C”. The default beampipe is “v21d” in this sample setup. This is fine to be used for the upstream and STS sections but needs to have the addition of the downstream sections. Here, the user will need to specify the beam energy as different downstream pipe geometries are used for different beam energies. The following lists the downstream beampipes with energy and magnetic field strength pairs such that a full stripped gold ion ($Z = 79+$) beam (cp. Ref.[4]) hits the beam dump.

- **(pipe_v21e)** Maximum deflection angle.
beam dump possibly at (0.7m,0,18.82m)
T = 2 AGeV (P = 2.85 AGeV/c) MF = 50%
T = 3 AGeV (P = 3.89 AGeV/c) MF = 70%
T = 4 AGeV (P = 4.91 AGeV/c) MF = 85%
T = 5 AGeV (P = 5.93 AGeV/c) MF = 100%
- **(pipe_v21h)** maximum kinetic energy for SIS100
beam dump possibly at (0.225m,0,18.845m)
T = 11 AGeV (P = 12 AGeV/c) MF = 100%

For example, choosing a 4 AGeV beam, the pipe_v21e may be used with a magnetic field strength of 85% of the nominal 1 T field. This beampipe may be included by simply listing its tag ‘v21e’ after the upstream beampipe ‘v21a’ separated by a colon. See Fig. 2 for two pipes joined together in this way.

```
TString pipeGeoTag = "v21d:v21e";
CbmSetup* setup = CbmSetup::Instance();
setup->SetModule(ECbmModuleId::kPipe, pipeGeoTag);
```

The magnetic field strength should also be changed to:

```
Double_t fieldScale = 0.85; // field scaling factor
```

This beampipe configuration does not include the STS flange (middle-left of Fig. 1) which separates the STS wide conical and RICH/MUCH narrowed conical sections of the beampipe. This back-wall flange isolates axial and toroidal vibrations which could cause damage to delicate STS instruments even if their magnitude are small (Ref. [7]). In terms of the transport simulations, the STS back-wall flange is an important addition to the material budget. To include it, the STS team (cf. Ref. [1](Tab. [1] and Fig. [5]) has provided the following STS geometry.

```
TString stsGeoTag = "v21g"
setup->SetModule(ECbmModuleId::kSts, stsGeoTag);
```

These changes are sufficient to configure this setup file. To run a transport simulation for 10 events, the following command may be executed from the “macro/run” folder

```
cd macro/run
root -l -q 'run_tra_file.C("inputfile",10,,"",,"sis100_newpipe")'
```

where “inputfile” is generated URQMD data for the 4 AGeV gold on gold collision. This completes a simulation mini-guide for the *official* full beampipe distributed with the CBMROOT DEC21 release.

2. Updated beam window

A near-target simulation beampipe was created in the GDML language which was based, mostly, on the technical drawing TN ED-1159370-D-001-IO for the purpose of getting sufficient convergence between the CAD and GEANT for the beam window, and also in order to simplify the present beampipe geometry script to allow more rapid implementation of changes in the future. It had already been decided in beampipe meetings, although not updated yet in the CAD, that a cylindrical section in the initial part of the STS beampipe section seen in the technical drawing should be removed in favour of an uninterrupted conical beampipe

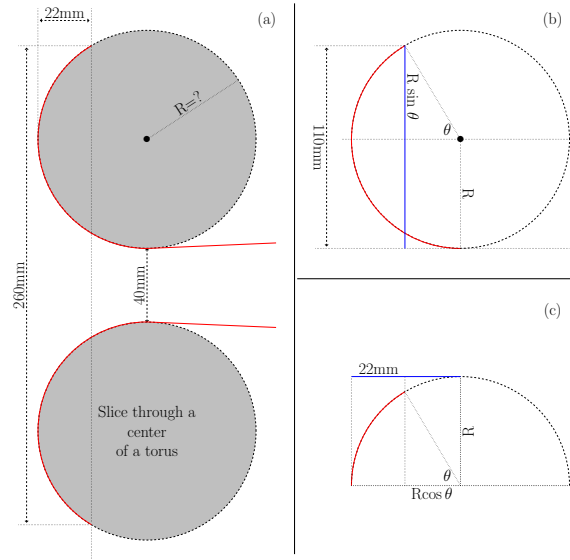


Figure 3: Geometric arguments for fitting a torus shape to approximate the CAD window. The graphic determines the radius of its tube. Details are explained in the text.

section from the window through to the back of the STS box (cf. Ref. [2]). This came about due to FLUKA studies (Ref.[6]) which showed radiation buildup in the kink between the cylindrical and conical regions.

Several challenges are required to be overcome to develop a functioning beampipe which can be used in the vicinity of the target. Unfortunately, CBMROOT expects a certain nodal hierarchy of its volumes, with many fixed nodal names. The MVD detector is to be placed in the “pipevac1” volume of the beampipe. The target is also placed in this structure and its position depends on whether it is generated on the fly in the transport macro or included as a stand-alone subsystem in the setup file.

In order to select a simple shape for the window which approximates the technical drawing’s design, the parameters for a cut torus was calculated by the following short geometric arguments. A torus may be thought of as a filled circle which is made solid by revolving it round a central origin in the 3rd dimension until it meets up with itself again after 360° to form the classical doughnut-shape. As such it is defined by two non-equal radii, the radius of revolution, and the radius of the tube R . Figure 3(a) shows the central 2D slice of a torus orientated vertically, and displays the three numerical values extracted from the technical drawing which will define the size and scope of the window section. Namely the diameter of the window should be 260 mm and bulge forward towards the MVD detector and target by 21.81 mm (22 mm) and the opening for the conical section should have a diameter of 40 mm. The main effort will be to determine R with the radius of revolution following simply via the inclusion of half the gap between the two circles, i.e. $R + 20\text{mm}$. In Fig. 3(a), the part of the

torus which makes up the surface of the window is shown as a red solid line from this perspective.

The symmetry of the top and bottom of Fig. 3(a) allows us to redraw Fig. 3(b) subtracting half the 40 mm gap so we know the distance between the closest and furthest point to the origin on the surface of the window is 110 mm. Writing an equation for the length of the blue line in Fig. 3(b):

$$R \sin \theta + R = 110 \quad (1)$$

A second equation which relates R to the angle θ is sought. Figure 3(c) focuses now on the top semicircle of (b). The numerical value which relates the bulging of the window towards the target, and MVD is included on the diagram. Writing an equation of the length of the blue line in Fig. 3(c):

$$R = 22 + R \cos \theta \quad (2)$$

Combining these two equations and eliminating for θ give the quadratic equation and root.

$$R^2 - 264R + 12584 = 0 \quad (3)$$

$$R = 62.43 \text{ mm} \quad (4)$$

The radius of revolution is half of 40 mm larger, i.e. $R_R = 82.43$ mm. Solving for θ allows the determination of where to place the cut to obtain the full window shape.

The rest of the near-target beampipe is created in a straight forward fashion after extracting other values from the technical note. The conical section should have a diameter of 80mm at its most downstream section and be 1012 mm in total length. The outer flange for the window is set to 300mm diameter using a short cylinder of 7 mm. Finally, the window is placed 240 mm from the target. The surface of a torus of 0.5 mm thick carbon fibre is used. Full human readable details may be seen in GDML script for this beampipe in the geometry repository of CBMROOT. Top right of Fig. 1 shows the window, its flange, and the conical pipe combined together as a combined upstream beampipe geometry.

3. A monolith binary

As a single geometry binary is supplied for all other subsystems in the CBMROOT simulation environment, it may be expected that a single monolithic beampipe geometry binary is supplied in the near future. This must follow the restrictive hierarchical nodal structure expected by CBMROOT in order to function correctly without the need for code changes between switching of versions. As the beampipe has close proximity to many detector subsystems, there needs to be precise placement with little or no keep out volumes which may create unwanted overlaps. These are known to have a detrimental effect on the consistency of our simulations. Lastly, it is vital that we capitalise on the many advancements in design of a simulation beampipe geometry from our diverse but collective efforts.

These aims are accomplished by writing a beampipe macro which creates empty nodes obeying a fixed nodal

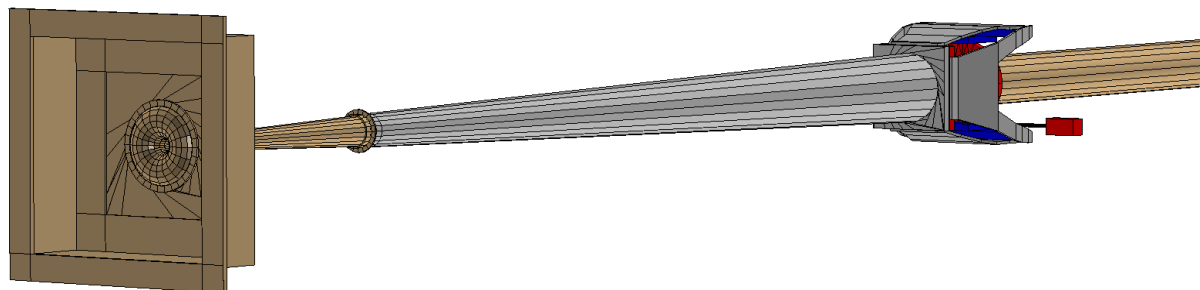


Figure 4: Shows the combined volumes to form beampipe (v22b) consisting of a target box, window, STS section, RICH/MUCH section, bellows, and downstream cylindrical section which has been cropped short for display purposes.

structure. The actual volumes are then cherry-picked from the existing geometry binaries by pointing directly to that binary from the node. Placement information is also extracted and processed with only some small manual effort to specify the change in coordinate systems between the source geometries. The “pipe_v22b” beampipe geometry as shown in Fig. 4 is made up of the independent volumes in Fig. 1. With the exception of the downstream cylinder in the bottom right of the Fig. 1, all other volumes are extracted from existing binaries or GDML scripts. It is a topic of a future decision as to which volumes should belong to the beampipe geometry and which are better incorporated into other detector subsystems. Nevertheless, the target box, cf. Fig.[5] of Ref. [1], is supplied by the STS team with a small edit to cut a circular opening for the window flange. The top right window was already introduced in Sec. 2. The STS flange is extracted from the “sts_v21f” geometry binary whilst the RICH/MUCH narrow conical section is extracted from “pipe_v21f”. The version of the bellows assembly then depends on which closest approximates the angle of the downstream tube from the “pipe_v21f”, “pipe_v21g”, or “pipe_v21h” binary. An extracted bellows

is shown in the bottom right of Fig. 4.

Finally, in order to visualise this beampipe in conjunction with all detector subsystems included, Fig. 5 shows this monolith beampipe from a vertical upstream position. The downstream tube (red) transverses through the PSD (green and magenta), the central openings of the TOF (dark red) and the TRD layers (cyan), and then on to the bellows (blue). The narrowed conic tube transverses the RICH, followed by a wider conic through the STS. Just visible is the beam window (green) at the end of the target box (red). Unlike Sec. [2], the MVD versions ‘v20c’ should be used with ‘pipe_v22b’. Its sensor layers (magenta and green) supported by heat-sinks (red) are followed by the tiny semi-circular disk which is the target (blue). This completes our discussion of the beampipe simulation geometries.

References

- [1] “Update on the simulation geometry for the Silicon Tracking System” M. Shiroya, D. Emschermann, E. Clerkin, V. Friese, A. Toia, O. Vasylyev, and P. Dahm CBM Progress Report 2021 (this journal)
- [2] “STS beampipe section: Concept and development status” J. M. Heuser, O. Vasylyev, M. Faul, and A. Senger CBM Progress Report 2021 (this journal)
- [3] “Status of PSD Beam Pipe” M. Smetana, M. Janda, J. Kollarczyk, P. Chudoba, F. Lopot, and A. Kugler CBM Progress Report 2021 (this journal)
- [4] “Status of PSD Beam Pipe GEANT4 geometry” P. Chudoba, M. Janda, J. Kollarczyk, M. Smetana, A. Kugler, and F. Lopot CBM Progress Report 2021 (this journal)
- [5] “Beam following assembly” J. Kollarczyk, P. Chudoba, M. Janda, M. Smetana, F. Lopot, and A. Kugler CBM Progress Report 2021 (this journal)
- [6] “RICH-MUCH section of the CBM beam pipe.” A. Senger CBM Progress Report 2021 (this journal) (first communicated <https://indico.gsi.de/event/13201>)
- [7] “FEM with Floquet Theory for Non-slender Elastic Columns Subject to Harmonic Applied Axial Force Using 2D and 3D Solid Elements” E. Clerkin, and M. Rieken *Moving Boundary Problems in Mechanics* ISBN 978-3-030-13719-9 (March 29th, 2019) pp 267-282

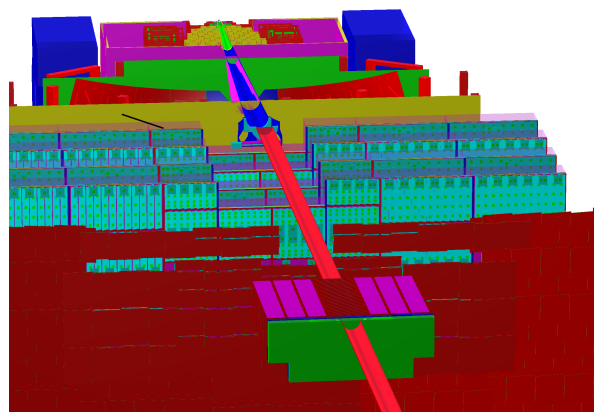


Figure 5: Shows the CBM experiment in its compact electron configuration with the top material ($y > 0$) cut away to reveal the beampipe.

FLUKA calculations for the RICH/MUCH section of the CBM beam pipe.*

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The CBM beam pipe

The CBM beam pipe downstream the target box consists of several sections: the conical pipe inside the Silicon Tracking System [1] is coupled to a conical pipe which guides the beam through the RICH/MUCH detectors. Behind the RICH/MUCH detectors, this conical pipe is connected via a bellow to a straight cylindrical pipe through the TRD, TOF, PSD down to the beam dump. This cylindrical pipe has a total length of about 15 m and consists of several pieces. While the first two conical pipes have a fixed position, independent of beam energy and magnetic field, the long cylindrical pipe will be pivoted around the bellow according to the deflection of the beam.

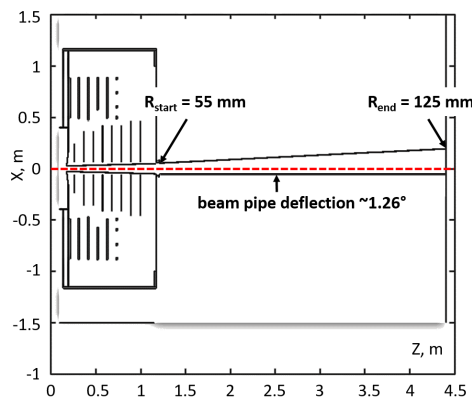


Figure 1: Proposed RICH-MUCH section of the beam pipe. The red dashed line illustrates the beam direction without magnetic field. The beam pipe inside the STS and the beam pipe inside RICH/MUCH are bent by an angle of 1.26° .

Geometry optimization

Originally, the polar angle acceptance of the CBM detectors was defined by an inner polar angle of 2.5° and an outer polar angle of 25° . The angular acceptance of the beam pipe inside the SIS also is close to 2.5° , which allows for a deflection of a gold beam at a kinetic energy of 11A GeV at the nominal magnetic field integral of 1 Tm. At gold beam energies below 5A GeV, the magnetic field has to be reduced. The opening of the STS beam pipe also

allows to switch the polarity of the field. An extrapolation of a conical beam pipe through RICH/MUCH with the same polar opening angle of 2.5° would result in a pipe diameter of almost 40 cm at a distance of about 4.5 m. It turned out, that the bending of a pipe and a bellow with such a large diameter under vacuum conditions would require large forces, and, consequently, very massive beam pipes. In order to relax the forces, it was proposed to reduce the opening angle of the conical beam pipe through RICH/MUCH, so that the final pipe diameter is only 250 mm. In order to accommodate the required bending angle, the RICH/MUCH beam pipe will be connected to the STS beam pipe at an angle of about 1.26° , as illustrated in figure 1. This angle allows both the maximum bending angle and calibration measurements without magnetic field, but no switching of the magnetic field polarity. For this case, the connection between STS and RICH/MUCH has to be rotated by 180° .

FLUKA calculations

Simulations have been performed with the FLUKA package ([2], [3]) in order to study the radiation dose produced in the beam pipe by the beam. The FLAIR interface ([4]) was used for the visualization of the results. The calculations were performed for an Au beam with an energy of 4A GeV, a 1% interaction Au target, and for two magnetic field settings and beam intensities: 85% of the nominal magnetic field value with a beam intensity of 10^9 ions/s for physics experiments (see Fig. 2), and without magnetic field with a reduced beam intensity of 10^7 ions/s, which can be used for detector alignment measurements (see Fig. 3). Fig. 2 illustrates, that the flux of charged particles and the ionizing dose is mainly produced in the beam pipe at the side of the deflected beam, like in a straight conical beam pipe with a larger opening angle. The background produced by the beam in the opposite (non-bending) site of the beam pipe is much lower. In the case of no magnetic field, as illustrated in Fig. 3, the background is more or less symmetric, although the non-deflected beam is closer to the straight side of the beam pipe.

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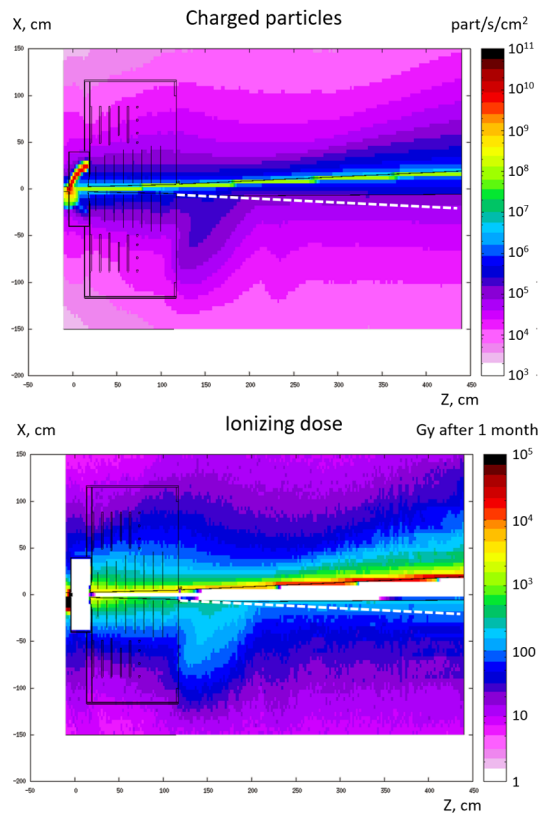


Figure 2: FLUKA results for an Au beam with a kinetic energy of 4A GeV, an intensity of 10^9 ions/s, 85% nominal magnetic field, and a 1% interaction Au target. Top picture: charge particle distribution. Bottom picture: ionizing dose. The white dashed line illustrates the acceptance of a straight beam pipe with a large conical opening angle

Conclusion

The beam pipe of the CBM experiment has to guide the beam from the target through the detector systems down to the beam dump, taking into account the variable deflection of the beam depending on beam energy and magnetic field strength. The beam pipe consists of conical parts inside the STS and the RICH/MUCH detectors, connected via a bellow to a cylindrical part. In order to reduce the force required for the bending of the bellow, the conical opening angle of the beam pipe through RICH/MUCH is decreased, and the beam deflection is taken into account by connecting the RICH/MUCH beam pipe to the STS beam pipe at an angle of about 1.26° . This concept allows the performance of measurements at SIS100 beam energies at the envisaged magnetic field settings, including detector alignment measurements without magnetic field. The FLUKA calculations demonstrate, that the radiation background produced by the interaction of the beam with the inclined conical beam pipe with reduced opening angle is comparable with the radiation produced in a straight conical beam pipe with

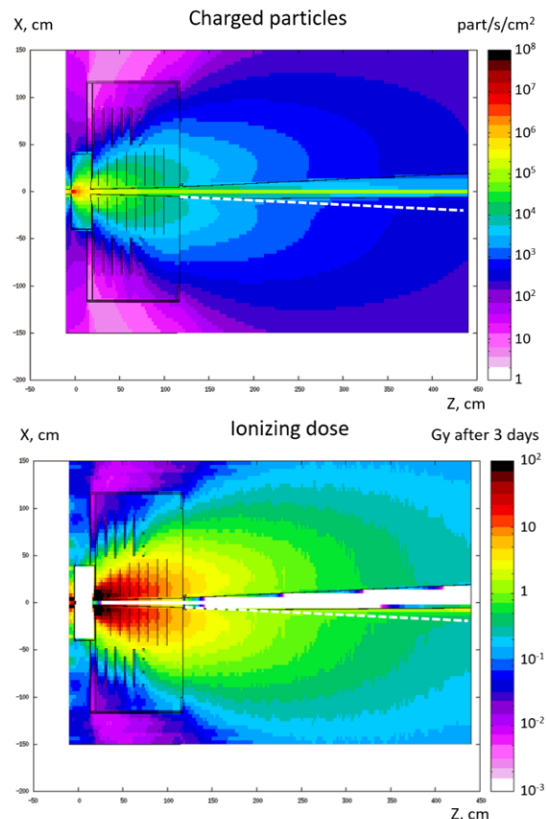


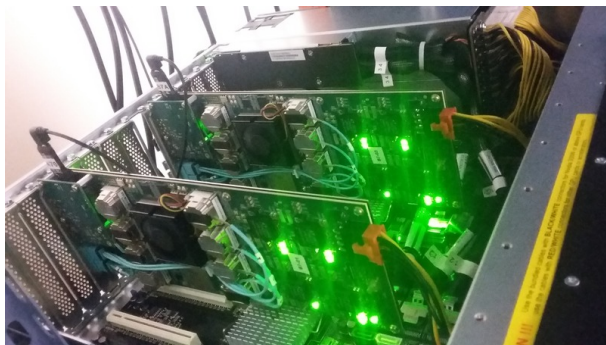
Figure 3: FLUKA results for an Au beam with a kinetic energy of 4A GeV, an intensity of 10^7 ions/s, zero magnetic field, and a 1% interaction Au target. Top picture: charge particle distribution. Bottom picture: ionizing dose. The white dashed line illustrates the acceptance of a straight beam pipe with a large conical opening angle

larger opening angle.

References

- [1] See report "STS beam pipe section: Concept and development status"
- [2] "The FLUKA code: Description and benchmarking" G. Battistoni, S. Muraro, P.R. Sala, F. Cerutti, A. Ferrari, S. Roesler, A. Fasso', J. Ranft, Proceedings of the Hadronic Shower Simulation Workshop 2006, Fermilab 6-8 September 2006, M. Albrow, R. Raja eds., AIP Conference Proceeding 896, 31-49, (2007)
- [3] "FLUKA: a multi-particle transport code" A. Fasso', A. Ferrari, J. Ranft, and P.R. Sala, CERN-2005-10 (2005), INFN/TC_05/11, SLAC-R-773
- [4] "FLAIR: A Powerful But User Friendly Graphical Interface For FLUKA" V.Vlachoudis, Proc. Int. Conf. on Mathematics, Computational Methods & Reactor Physics (M&C 2009), Saratoga Springs, New York, 2009

Data Acquisition and Online Systems



Improvement of time alignment between hardware and software

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Background

Previously, a prototype of the timing system has been integrated into the experimental setup [1]. It has been demonstrated that the problem of relative time drift within TFC system was successfully solved. At the same time, operating systems of computing nodes were already synchronized using Precision Time Protocol (PTP). Running on independent reference clocks, the TFC system and the PTP network have inherent clock drift that led to significant time shifts over extended operating periods, eventually hindering event reconstruction.

Implementation

The BNL-712 board, which serves as a platform board for the TFC system, features a high-performance PLL Si5345. This PLL is used by the TFC core to generate system and auxiliary clocks. In the TFC Endpoint firmware, the clock recovered from the inbound TFC link is forwarded to Si5345 as a reference. A similar scheme can be used in the TFC Master to synchronize local clock with an external reference.

As the computing infrastructure of the experiment is synchronized with the accelerator White Rabbit network, we select the same time reference for the TFC system. Thus, a White Rabbit receiver is needed to receive the reference clock, which must then be forwarded to the FPGA.

The PEXARIA5 card has been chosen as a White Rabbit client. This board can be easily mounted into a FLES Entry Node and provides up to 3 outputs with programmable frequencies yet synchronous with the White Rabbit network. Combined with a White Rabbit Timing Mezzanine Card (TMC) attached to the TFC Master board, PEXARIA5 makes a solid solution for delivering a global White Rabbit clock to the TFC Master.

Evaluation

To evaluate the clock drift performance of the proposed synchronization scheme, an evaluation setup has been built (Fig. 1). At the beginning of the test, both the computing node and the TFC Master design were started synchronously to the same global clock. The absolute value of the initial time offset between the node and the board is irrelevant for the test and is arbitrary.

After approx. 60 min of stable operation the clock output of the PEXARIA5 card was turned off, thus emulating loss of external reference clock for the TFC Master board. As a

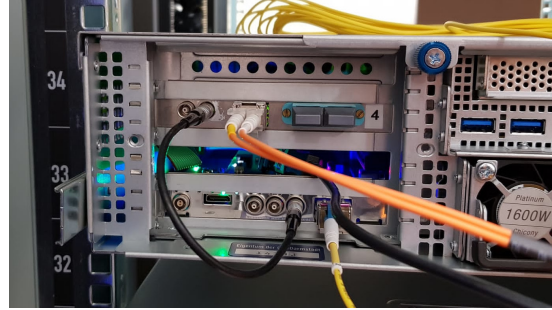


Figure 1: Photo of the evaluation setup (by D. Emschermann). Upper card - BNL-712 with an optical connection (unused) and a LEMO input for the external clock. Lower card - PEXARIA5 with a White Rabbit input and a LEMO clock output. PTP link on the computing node is not shown.

result, Si5345 switched to a free-running mode, which led to TFC clock drift at an increasing rate (Fig. 2). Another ≈ 60 min later, the clock output of PEXARIA5 was re-enabled and the board clock phase stopped drifting relative to the external reference and remained stable until the end of the test.

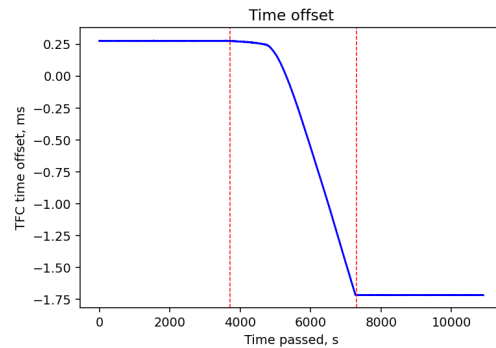


Figure 2: TFC Master clock drift relative to the computing node. Dashed vertical lines mark approximate points of mode switching (to free-running and back).

References

- [1] V. Sidorenko, I. Fröhlich, W.F.J. Müller et al., "Prototype Design of a Timing and Fast Control system in the CBM Experiment", Preprint, 2021, doi:arXiv:2110.12738v2

Prospects of GBT-FPGA as the TFC core interface

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Background

One of the major functions of the Timing and Fast Control system is to ensure common time notion in all of the DAQ electronics. In the tree-like TFC network, a Master node distributes time information to a number of CRI boards (Endpoints) [1]. With this approach, the overall accuracy of CRI time synchronization is sensitive to variations of downstream transmission latency from Master to Endpoints.

Generic, non-deterministic implementation of optical communication between FPGAs involves using FIFOs to handle clock domain crossings (CDC), which are unavoidable due to design of Gigabit transceivers (Fig. 1). Even using shallow buffers and no Submaster layer present in the TFC network, latency uncertainty introduced by these FIFOs exceeds 200 ns, which requires further improvements.

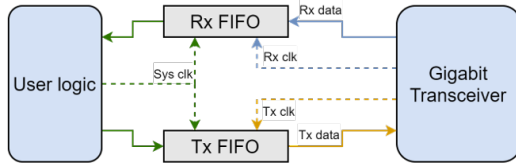


Figure 1: Non-deterministic implementation of optical link access in FPGA.

Latency-optimized GBT-FPGA core

A potential solution to the problem of latency uncertainty is to use the GBT-FPGA core [2]. This IP core handles low-level control of FPGA Gigabit transceivers and provides a versatile data link with optional forward error correction.

The core comes in two versions: standard and latency-optimized. Whereas the standard version uses a FIFO-based interfacing scheme similar to that described above, latency optimization features a bufferless CDC on either the transmitter or the receiver. Although having no buffer in the datapath entails certain system constraints, it potentially removes virtually any latency uncertainty.

So-called *gearbox* modules are responsible for clock domain crossing in the GBT-FPGA datapaths (Fig. 2). Since the core is meant to transfer *data frames* that are made up of multiple *data words*, system-side *frame clock* is slower than the *word clock* by an integer factor. As a latency-optimized gearbox splits up or recomposes a frame, mis-

alignment between frames and words may corrupt latency-deterministic transmission. Therefore, this alignment must be monitored by the user firmware using feedback flags of GBT-FPGA and adjusted if needed.

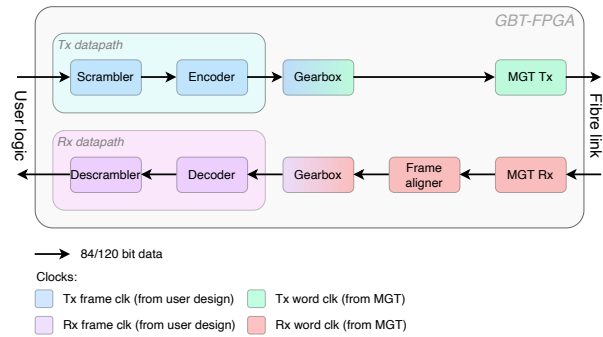


Figure 2: Datapaths in the GBT-FPGA core.

Evaluation setup

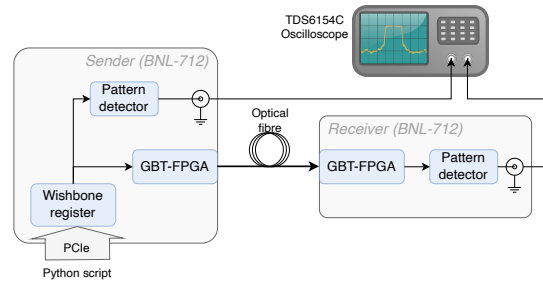


Figure 3: Block diagram of the evaluation setup.

In order to evaluate potential benefits of using GBT-FPGA as the TFC data transfer interface, a basic system has been built with two BNL-712 boards connected with an optical fibre (Fig. 3) to emulate TFC Master and Endpoint. The optical link is served on both ends by GBT-FPGA, with latency-optimized Tx path on the Master side (sender) and Rx path in the Endpoint (receiver).

In the sender, data for transmission is set from a Python script in software. When a predefined test pattern is being sent in a series of frames, a pattern detector in the sender generates a long pulse that is connected to a coaxial connector and can be monitored with an oscilloscope.

Likewise, reception of this series of test frames causes a

pattern detector on the receiver side to generate an equivalent pulse, which is also captured with an oscilloscope.

With this scheme, the delay between rising edges is equal to the transmission latency. This delay is then measured with an oscilloscope connected to the corresponding RF connectors (Fig. 4). In the current setup, a Tektronix TDS6154C oscilloscope is used for the measurements.

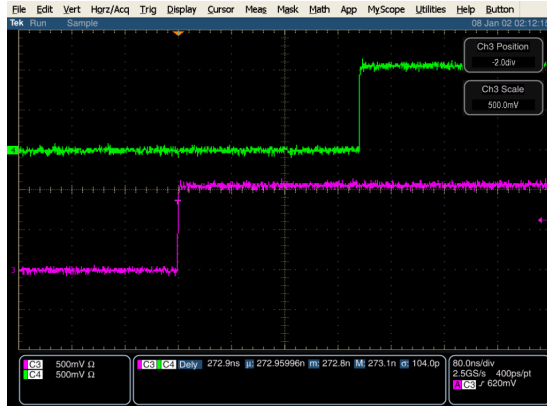


Figure 4: GBT-FPGA latency measurement.

Evaluation

To evaluate link latency and its reset-to-reset determinism, 15 series of measurements were done. Each series (run) contained 1000 latency measurements as described above and depicted in Figure 4. Between runs, the GBT-FPGA on the Receiver side was reset. To handle the number of measurements to be done, the evaluation process was automated with a Python script that controlled the boards and collected oscilloscope readings via VISA interface over Ethernet.

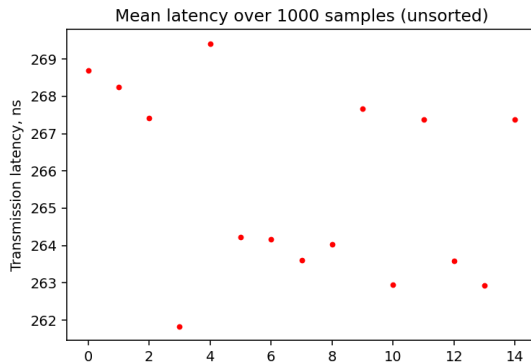


Figure 5: Mean latency values over 15 measurement runs.

As seen in Figure 5, core reset in the receiver makes the mean transmission latency vary from run to run within ~ 10 ns, between approx. 261.6 ns in run 3 and 269.2 ns in

run 4. This suggests correct frame-word alignment in the Receiver GBT-FPGA core on both ends.

On the other hand, the latency stays relatively stable within each run. Figure 6 shows a typical latency distribution and demonstrates that transmission latency does not vary by more than ~ 500 ps.

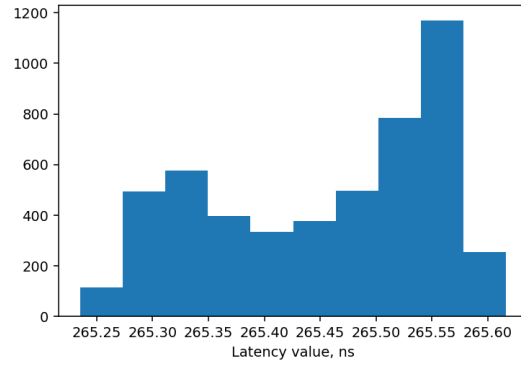


Figure 6: Transmission latency distribution within one run (5000 samples).

Conclusion and future work

Overall, the initial test demonstrates excellent absolute transmission latency values below 270 ns based on GBT-FPGA cores, which makes it feasible to attain hardware response time of the TFC system within a few microseconds. Latency variation within each run is contained within ~ 500 ps range, but there is still a significant reset-to-reset latency uncertainty of ~ 10 ns. The sources of this uncertainty have yet to be investigated in future work.

It is also expected that link latency determinism can be further improved by introducing TLink as a layer below GBT-FPGA [3]. This is a protocol-agnostic FPGA core that has been developed at CERN and is meant to mitigate clock phase variance by controlling at low level.

References

- [1] V. Sidorenko, S. Bähr and J. Becker, “Towards Timing and Fast Control (TFC)”, CBM Progress Report 2019 (2020), p. 156, doi:10.15120/GSI-2020-00904
- [2] M. Barros Marin, S. Baron et al., “The GBT-FPGA core: features and challenges”, JINST 10 C03021 (2015), doi:10.1088/1748-0221/10/03/c03021
- [3] E. Brandao De Souza Mendes, S. Baron and M. Taylor, “TLink: A Timing Compensated High-Speed Optical Link for the HL-LHC experiments”, Proceedings of Topical Workshop on Electronics for Particle Physics 2019 (2020), p. 57, doi:10.22323/1.370.0057

FPGA-related development for CBM DAQ *

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In 2021 the work was mainly concentrated on the continued development and maintenance of fundamental components of the CRI firmware.

Address Generator for Wishbone (AGWB)

The hierarchy of internal registers in the CRI firmware is managed by the AGWB [1], which generates the address map, the HDL implementation of registers and bus infrastructure, and the support (routines and data structures) for the software. In 2021 the problems discovered in the previous year were finally solved. A requirement to combine in a single VHDL code slightly different designs for individual SLRs of a large FPGA has been solved by introducing so-called “variants”. This new functionality has also been included in the final implementation of the AMAP XML format, supporting the C++ code.

The mechanisms checking the coherency of versions between the hardware and software were modified to support “variants”. A set of minor improvements increased the efficiency and legibility of the generated VHDL. The correctness of the XML description of the system is now verified using the RELAX NG schema - for faster detection of mistakes. The generated VHDL code for each block may optionally contain the automatically created test registers. The inserted WB crossbars may include additional pipeline registers for better timing closure in complex bus trees. The generated Python interface has been supplemented with reflection functionalities, significantly improving the quality of the interactive work.

Development of the HCTSP controller

The former DPB firmware used a complex controller for communication with the frontend chips using the Hit & Control Transfer Synchronous Protocol (HCTSP) [2]. Most of its functionalities were implemented in hardware, which resulted in a very high resource consumption and limited flexibility. For CRI with a higher number of connected FEBs and a necessity to support various FEB configurations, that concept of the HCTSP controller had to be redesigned.

The new solution: the HCTSP bridge uses a significantly different paradigm. Functionalities not requiring

real-time operation have been moved to the software. This modification was also facilitated by changing the controlling interface from IPbus to PCIe, which significantly reduced the roundtrip latency. The architecture of the HCTSP bridge has been designed based on the possible scenarios of communication with the frontend ASICs. That approach enabled sharing of certain blocks between multiple FEBs (e.g., command slots, ACK catchers). Only a few blocks had to be separately instantiated for individual uplinks (e.g., the 8b10 decoders and special sequence detectors). Handling command acknowledgments and retransmission in software eliminated the need for a complex switch matrix for command responses.

The Python library controlling the HCTSP bridge has been implemented. The design has been tested in VHDL-Python co-simulation tests.

The CRI firmware with the HCTSP bridge has been successfully used during the beam tests.

Preparation of the tester firmware

The third area of activity was the further development of the SMX tester firmware for QA testing of SMX ASICs and assembled Front End Boards [3]. In 2021 the tester firmware has been modified to use the HCTSP bridge block (for improved flexibility). The introduced changes include the run-time selectable E-Link clock frequency. Additionally, the possibilities of reading the SMX data at higher speeds have been improved by adding a possibility to transmit the received data in UDP packets.

The full speed readout of the SMX ASICs is possible with tester operating in a GBTxEMU mode with the dedicated GERI board.

References

- [1] W.M. Zabolotny et al., “Control and Diagnostics System Generator for Complex FPGA-Based Measurement Systems”, *Sensors*, 2021, no. 21, pages 7378, DOI: 10.3390/s21217378
- [2] K. Kasinski et al., “A Protocol for Hit and Control Synchronous Transfer for the Front-End Electronics at the CBM Experiment”, *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, 2016, vol. 835, pages 66–73. DOI: 10.1016/j.nima.2016.08.005
- [3] W. Zabolotny et al. “SMX and front-end board tester for CBM readout chain”, *Journal of Instrumentation*, 2022, vol. 17, no. 04, pages C04030, DOI: 10.1088/1748-0221/17/04/C04030

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A FLES Interface Module for the CRI*

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Latest FLES hardware developments focused on the transition of the readout chain from the Data Processing Board (DPB) plus FLES Interface Board (FLIB) to the Common Readout Interface (CRI). Figure 1 gives an overview of the architectural change. This revised readout architecture features only a single FPGA-based PCIe card, the CRI. A new FLES interface module (FLIM) was developed to provide a FLES interface for the CRI hardware design. Logically, the CRI FLIM design is a merge of the DPB FLIM and the FLIB design without the components for the optical link. However, all components have been adapted or rewritten to fit the new architecture and the Kintex Ultrascale FPGA.

A schematic overview of the FLIM design and the integration into the overall CRI hardware design is depicted in Figure 2.¹ The FLIM and the subsystem design share the same PCIe interface between FPGA and host. However, the designs have vastly different requirements for communication with the host. While the subsystem logic uses only PIO access, the FLIM implements a high-throughput DMA design. To minimize dependencies between the hardware designs and device drivers, the FLIM and the subsystem design use two separate PCIe physical functions (PFs).² The CRI FLIM uses the same PDA kernel driver architecture as the FLIB in conjunction with an adapted userspace device library. As the FPGAs PCIe-block provides only a single interface shared by both PFs, an arbiter is used to route TLPs to the appropriate destination.

The overall architecture of the FLIM follows the former FLIB design. It provides multiple independent input chan-

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¹The CRI's Kintex Ultrascale FPGA is split into two Super Logic Regions (SLRs). The discussion here focuses on a single SLR. The FLIM and PCIe components are duplicated for both SLR.

²A PCIe PF is a full-featured PCIe function associated with its own configuration space including PCI IDs, bus address, and device driver.

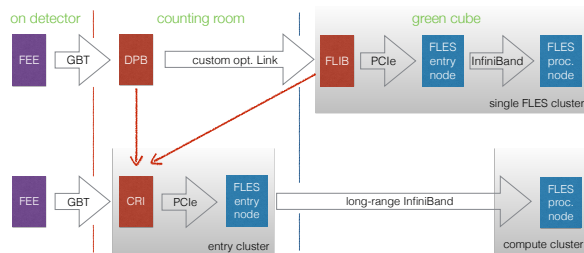


Figure 1: Comparison of the DPB/FLIB and the new CRI readout chain. Tasks of the DPB and the FLIB are merged into a single FPGA card, the CRI.

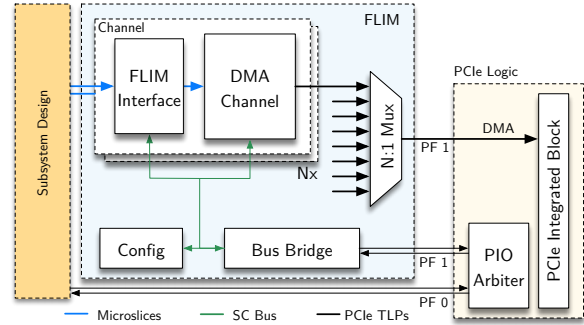


Figure 2: Overview of the new FLIM design for CRI. Each FLIM provides multiple independent channels to the subsystem design. FLIM and subsystem design share a single PCIe interface, but are mapped to different PFs.

nels. Each channel is associated with its own DMA engine and a set of buffers in the host memory. All channels dynamically share the same PCIe interface. For configuration and control of the DMA engines, the FLIM features its own slow control bus and PCIe bus bridge.

Towards the subsystem components, the new CRI readout chain keeps the same microslice-based FLES interface already used in the DPB. The transition between FLIB and CRI designs was split into two steps to ease the transition for the subsystems. In the first step, which is now concluded, the microslice interface towards the subsystem design was kept close to the DPB version. Only the clock frequency was slightly adapted to better fit the overall design. In the second step, the microslice interface will be revised to streamline operations and provide the full performance of the PCIe interface.

While the external interface was kept close to the original design, most internal components have been rewritten to fit the new FPGA architecture. This is especially true for the PCIe-related parts of the design, as the new Ultrascale FPGA core provides a significantly different interface compared to the old FPGA. During the rewrite, care was taken to ensure that most of the internal data path is already capable of exploiting the full performance of the faster PCIe interface and that not many changes are required in the second transition step.

The newly developed FLIM is fully integrated into the CRI hardware design and was successfully used in the mCBM 2021 data taking.

CRI based mMUCH DAQ setup and online monitoring

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For last few years, Common Readout Interface (CRI) development work has been going on. After April 2020, mMUCH was uninstalled for debugging of link loss and other issues. During November 2021, mMUCH was re-installed on the beam table in mCBM cave. The readout chain of mMUCH was updated to CRI based DAQ as compared to AFCK in earlier mMUCH setups. Fig. 1 shows the present mMUCH setup connection to CRI Based readout chain in mCBM. Two real sized GEM detectors and one real sized RPC detector were installed in the cave. mMUCH detector front end boards (FEBs) were readout via Common Readout Board (CROB) having one master GBTx and two slave GBTx. Each CROB is connected to CRI via two LC-MTP12 fan-ins. Each CROB consists of 1x Rx and 3x Tx links. The MTP12 connectors carry 12x Rx and 12x Tx optical fiber links, however, due to firmware and resources limitation, only 3-CROBs could be readout via two MTP12 connectors. So maximum 6 CROBs can be connected to one CRI as per the present configuration. Each CROB may be connected to maximum of 9 Front End Boards (FEBs) via MUCH-FMC however, due to some issue, few of the slots in these CROBs were not stable in communication with FEB boards. This will be further investigated.

CRI card is mounted on PCIe GEN3 16x data bus on motherboard of the DAQ server. Number of CRI connected in a particular DAQ server depends on available PCIe slots. In mMUCH setup two CRIs were used which were installed in en05 entry node placed in the cbm counting room. CRI-0 is connected to GEM-1 detector using 3 CROBs via SLR-0 and RPC detector was connected to

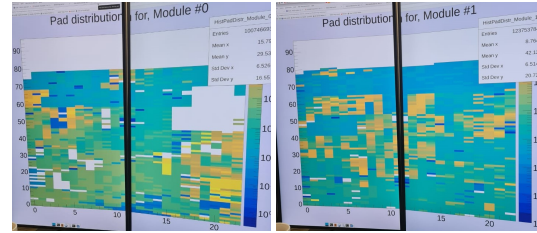


Figure 2: Pictures of online monitoring for GEM1 (left) and GEM2 (right) sector channel map during DAQ running in publisher mode.

1 CROB via SLR-1. GEM-1 was readout via 15 FEBs while RPC was readout via 4 FEBs. CRI-1 is connected to GEM-2 using 3 CROBs via SLR-0.

For performing quality assurance or online monitoring of the raw data, monitoring scheme and parameter files have been updated to accommodate CRI based readout configuration. Relevant classes and macros have been updated for online monitoring.



Figure 3: Picture of Online monitoring canvas for FEB by FEB electronics channel plots. Maximum of 54 FEBs can be connected under 6 CROBs. Blank space shows that particular FEB is not connected.

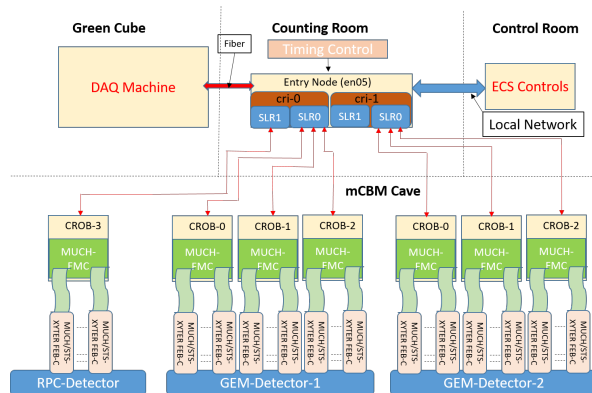


Figure 1: CRI based mMUCH DAQ Setup at mCBM.

To summarize, a CRI based mMUCH DAQ setup has been enabled and all the relevant python codes for DAQ configuration and CbmRoot Online Monitoring classes have been adopted. The same has been used for March 2022 data taking with mCBM and one of the main goals of the beamtime, which is commissioning of CRI based DAQ for mMUCH, has been achieved. Online pictures shown in fig. 2 and fig. 3 shows different canvases for mMUCH (for 2 GEMs and one RPC detector) online monitoring during data acquisition running in the publisher mode.

Computing



Large-Scale Performance of the Data-Flow Scheduler (DFS) and FLESnet

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Abstract

We present measured, sustained timeslice building rates of FLESnet and DFS on large-scale deployments with 96 nodes: 48 entry and 48 processing nodes. The results show an average sustained aggregate data rate of up to ≈ 340 GB/s.

Additionally, we discuss early ideas on handling elasticity and heterogeneous data volumes in FLESnet using DFS, i.e., how to dynamically add and remove nodes during runtime and how to deal with skewed distributions of microslice sizes efficiently for resilient performance.

Introduction

The First-Level Event Selector (FLES) cluster builds timeslices (TSs) for analysis using *FLESnet*¹. *Entry nodes* receive data from sensor links in a single, circular memory buffer and chop the stream into micro slices (MSs) to aggregate them to timeslice components (TCs). *Processing nodes (PN)* receive TCs from all entry nodes to build complete timeslices (TSs) for further analysis.

Our data flow scheduler (DFS) coordinates transfers from all entry nodes to all processing nodes over time as many parallel independent pairwise data transfers in a round-robin manner to avoid the congestion of endpoints. It aims for uniform progress and buffer fill levels [1], which leads to a shorter duration to build TSs.

Elasticity for FLESnet

Currently, FLESnet is designed for a static number of entry and processing nodes. DFS fault-tolerance (DFS-FT) [2] tolerates processing nodes' failures by reassigning the data to the remaining processing nodes. Adding or replacing nodes at run-time is desirable for better system's elasticity.

To complete a timeslice, a predefined number of entry nodes has to be available. When an entry node fails, incomplete timeslices have to be triggered and discarded. DFS already supports that, but FLESnet should allow replacing/adding an entry node while the system is running. When a processing node fails, adding a new processing node would be beneficial to relax the load on other nodes.

Entry nodes should agree to which PN each TC should be sent so that matching contributions arrive at PNs to build complete timeslices. When a new PN_x joins FLESnet, all input nodes have to agree from which point in the data stream PN_x starts receiving TCs. Without an agreement,

the TCs to PNs mapping could become inconsistent, and PNs would miss some TCs to complete their TSs. The timing of the agreement is challenging and crucial as all nodes have to behave consistently. DFS has to decide from which time interval a new node would join the system via a consensus procedure. New entry nodes should join the system as soon as possible to prevent data loss. The joining of a new processing node is not that critical and assigning TCs to it could be delayed to a relaxed following time-interval.

Heterogeneous Data Volumes

DFS load balancing (DFS-LB) [3] dynamically distributes TSs according to processing nodes capabilities in heterogeneous systems. It currently assumes TCs of a common fixed size, which allows straightforward bandwidth prediction. With heterogeneous MSs, the accuracy of prediction decreases and may lead to worse load balancing proposals. DFS should monitor the entry buffers and attempt to predict the fill distribution and react appropriately.

Each of n entry nodes has a limited single buffer with MSs, and each PN has n limited buffers to receive TCs from the entry nodes. Data can be freed from a PN's buffer when a TS is complete (TCs for that TS were received from all entry nodes). Data can be freed from an entry node's buffer when the respective PNs acknowledged them. If a PN's buffer is full, the respective entry node cannot send more data to that processing node. If an entry node cannot get rid of its data, its buffer may fill up, and eventually data would need to be dropped, which should be avoided. Thus, entry and processing nodes strongly depend on each other.

When we assume a skewed distribution of MS sizes over entry nodes (e.g., detector elements far away from the beam produce less data), some processing buffers of a PN could be filled more compared to others. Here, a more dynamic assignment of the buffers in the PNs could help alleviate the risk of overfull buffers.

When we assume a fluctuating distribution of overall TS sizes (e.g., short periods with many events to measure and periods with few events to measure), DFS-LB should take the buffer fill levels into account for the assignment of TS building to avoid full buffers.

DFS Integration into FLESnet and mCBM

We integrated DFS, DFS-FT, and DFS-LB into the main repository of FLESnet and tested them on the mCBM FLES cluster at FAIR/GSI.

¹<https://github.com/cbm-fles/flesnet>

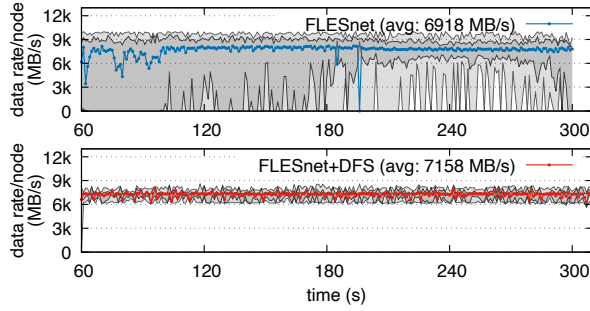


Figure 1: Measured avg. timeslice building rate per entry node on *overload scenario* with 48 entry nodes. Gray areas and lines denote min/max and 10th/90th percentiles.

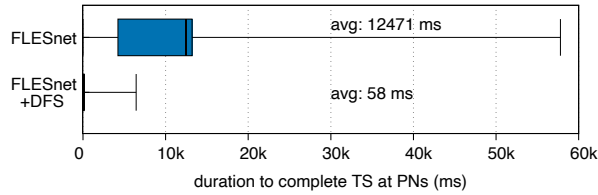


Figure 2: Duration to complete timeslices at PNs on *overload scenario* (min/max, median, 10th/90th percentiles).

Performance on a Large-Scale Deployment

We tested FLESnet and FLESnet+DFS on up to 96 nodes to evaluate their scalability and sustained performance. Two different scenarios are examined: An *overload scenario*, where data is generated faster than the network can distribute, and a *network limit scenario*, where data is generated slightly below the network limit. We use FLESnet as a baseline to evaluate the performance of FLESnet+DFS. The shown results exclude the first 60 seconds of each run to focus on sustainable performance independent of initialization, warm-up, and idealized empty-system phases.

Experimental Setup. We tested the scenarios with Libfabric on OmniPath¹ with 96 nodes: 48 entry nodes and 48 processing nodes. Each node has 2x Intel Cascade Lake Platinum 9242 (CLX-AP) with 48 cores, 384 GB RAM, 1x Intel OmniPath host fabric adapter, 100 Gb/s per 1-to-1 connection. Each micro slice is 10 KB, and each TS component is 1 MB. The circular entry buffer is 128 GB, and the receive buffer for each entry node at each processing node is 2 GB, i.e., 96 GB per PN. Each node embodies either an entry or a processing node.

Overload Scenario. In this scenario, each entry node generates 9 GB/s, resulting in 432 GB/s total data generation rate. Fig. 1 depicts the bandwidth statistics over runtime. FLESnet+DFS reaches a stable aggregate bandwidth of ≈ 340 GB/s. FLESnet+DFS can complete timeslices at processing nodes ≈ 50 x faster than pure FLESnet (Fig. 2).

¹<https://www.hln.de>

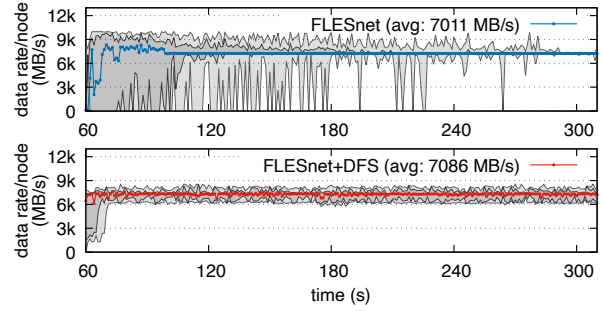


Figure 3: Measured avg. timeslice building rate per entry node on *network limit scenario* with 48 entry nodes. Gray areas and lines denote min/max and 10th/90th percentiles.

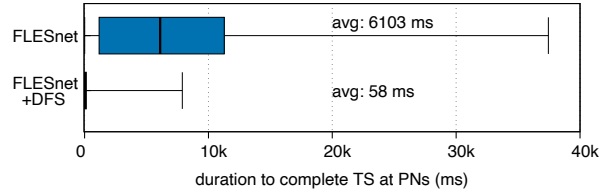


Figure 4: Duration to complete TSs at PNs on *network limit scenario* (min/max, median, 10th/90th percentiles).

Network Limit Scenario. In this scenario, each entry node generated ≈ 7.1 GB/s, resulting in 340 GB/s total data generation rate. Fig. 3 depicts the bandwidth statistics over runtime. FLESnet+DFS reaches a stable aggregate bandwidth of 340 GB/s without data loss and completes timeslices at PNs ≈ 100 x faster than FLESnet alone (Fig. 4).

Conclusion

We discussed early ideas for elasticity and heterogeneous data volumes in FLESnet and its Data-Flow Scheduler. We aim to allow adding nodes during runtime and to fairly distribute heterogeneous TS volumes over processing nodes for overall resilient throughput.

Performance results of FLESnet on a large-scale deployment indicate more stable throughput and shorter durations to complete timeslices with DFS. Aggregate bandwidths of up to ≈ 340 GB/s were reached with 48 entry nodes.

Acknowledgments. The project got funding from BMBF grants 05P19ZAF C1 and 05P21ZAF C A. NHR@ZIB provided computing time on the HLRN-IV system Lise.

References

- [1] F. Salem, F. Schintke, T. Schütt, and A. Reinefeld, “Scheduling data streams for low latency and high throughput on a Cray XC40 using Libfabric”, CCPE 32(20), 2020.
- [2] F. Salem, F. Schintke, and A. Reinefeld, “Handling compute-node failures in FLESnet”, CBM Progress Report 2019, pp. 167–168.
- [3] F. Salem, F. Schintke, “Load balancing mechanism for FLESnet”, CBM Progress Report 2020, pp. 156–157.

A new unified architecture for unpacking, applied to mCBM data

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Motivations

For last few years, ‘unpackers’ for the different subsystems in mCBM had been developed differently by each subsystem. This led to incoherence between the subsystems and restrictions towards running in parallel with different subsystem at the same time. This also made the maintenance complicated when trying to use the same logic in both a FairTask and a FairMQ device.

Stronger integration of the unpackers in a common scheme preparing for usage in different frameworks is therefore very much needed and started to be introduced for the 2021 mCBM campaign with the first subsystems readout using the CRI board.

Differences with previous approaches

The concepts driving this new architecture are 1) a separation between the framework bound part and the pure algorithmic part, 2) in the pure algorithmic part a separation between the processing code (so-called “Algo” class) and the configuration code (so-called “Config” class), 3) the usage of only standard digis classes as output storage, and finally 4) a separation of the monitoring of the raw data and unpacking process into a separate class, optionally called from within the “Algo” part.

The rationale behind separating the framework bound and algorithmic part is that it allows to use the later in both the FairTask and FairMQ worlds. This minimizes the eventual code maintenance and makes sure that the raw data are processed in identical ways irrespective of whether running online or offline, or whether running in a laboratory test-stand or a combined experiment such as mCBM or CBM.

The further separation between the processing code and the configuration code in the algorithmic part allows to switch between different versions of the former depending on the geometry tag of the sub-system. This provides a unified and simplified way to handle eventual raw data format changes, which may still happen as we gain more experience with our completed experimental setup. It is also preparing the stage for a transition from the current parameter classes, based on the FairRoot ones, to the planned online configuration system with a client-server approach.

In previous versions of the unpacking code, *Digi* classes derived from base ones were sometime used to represent intermediate stages or to provide expanded information. This however is not compatible with the existing reconstruction chains, which are already running on simulated data using the standard *Digi* classes (local reconstruction and event builder) It is also leading to many flag controlled

code blocks and code duplication in order to accommodate both possibilities. An additional reason for avoiding derived *Digi* classes is that the base ones are currently under review to minimize their memory footprint, which includes removing inheritances and virtualization. As a consequence, in the new unpacking scheme, only the standard *Digi* classes *CbmXxxxDigi* are used, with “Xxxx” being the given detector sub-system.

Calls to monitoring methods such as filling histogram are often expensive in CPU time, while the monitoring information displayed in the human interface is often expensive in memory. It is therefore often a target for removal when code is optimized for maximum online performance. By moving the monitoring of the raw data and of the unpacking process to a separate class and calling its methods only if an instance of the monitoring class is added to the “Algo”, we can keep the possibility to enable it if necessary without having performance losses when running on data known to be valid. This also allows FairMQ processing patterns where for example multiple branches are processing timeslices in parallel, but only one of those has monitoring enabled. In this example, with *N* the number of branches, the amount of monitored data would be downscaled to 1/*N*, and if fact, because the timeslices are distributed to the first branch ready, even less as the monitoring branch is slowest. However, for the same reason, the global processing throughput would not be much impacted provided *N* is sufficiently large: at worst equivalent to *N*-1 branches.

Outlook

The new architecture was implemented for the mSTS, mTRD and mTRD2D, mTOF, mRICH and mPSD during the transition to the CRI based readout for the Spring-Summer 2021 mCBM beamtime campaign. The two remaining detectors were added for the Spring 2022 mCBM campaign: mBMON (a.k.a. T0) and mMUCH [1].

This represents only the first step toward the final CBM online code, as further optimizations are still needed to allow for parallelization at various levels (processes or threads, GPUs, ...). Various improvements will also be needed to make the monitoring less tightly coupled to the processing code while keeping its functionalities and improving its ease of use by non-expert users.

References

- [1] V. Singhal *et al.*, “MuCh unpacker and converting raw data into *CbmMuchDigi*”, this report

Towards an online-capable software stack

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The CBM software collection `cbmroot` has evolved over many years by now to a considerable size. Quite naturally, the developments were focused on typical offline tasks, such as the realistic simulation of the experiment data, the reconstruction of these simulated data, and their analysis to assess the physics performance of the anticipated experimental setup. The chosen framework was `FairRoot` based on the `ROOT` package as a platform. Typically, emphasis was put on the efficiency of the reconstruction and quality assessment by comparison to the MC truth, while execution speed was, with some exceptions, not a design criterion.

With the advent of real experiment data, first from isolated laboratory or in-beam setups of single detector systems, and lately from the mCBM full-system prototype, the demand for software to be applied in real-time arose and has been ever increasing since. The final aim of the CBM experiment, namely to online inspect the full raw data stream and select physically interesting data based on this online inspection, became more prominent and has now to be addressed in earnest.

Efficient online data processing, however, comes with special requirements for data structures, interfaces, and algorithms, many of which are not met by the current software. Possibly the most prominent lacking feature is to enable concurrency to make cost-efficient use of the available computing capacities. An online execution model is yet to be established. `FairMQ` is a promising model, enabling concurrency on the process level and providing a control system for process deployment and monitoring. First experiences with `FairMQ` were already gathered, but its full-scale application is yet to be demonstrated, and the final choice of the online framework is yet to be done.

In view of this situation, efforts to establish a software stack capable of online application were started in the fall of 2021. The main design considerations are:

- Re-define data structures. Minimize their size, since the memory footprint is decisive for processing speed. Remove, wherever still present, MC-related information. Avoid polymorphism and virtual tables, such that the data structures can also be used on GPU.
- Define proper data interfaces and containers. Data should be provided to a processing step in the required arrangement such as to avoid re-sorting. Use STL containers instead of e.g., `TClonesArrays`.
- Separate the actual algorithms from framework layers, enabling to make use of the algorithms from different execution models (e.g., `FairRoot`, `FairMQ`) without changes to the algorithms.
- Implement granular processing steps operating on the smallest independently treatable data units. This allows to flexibly implement concurrency features (multi-threading, multi-processing) in the calling software layer.
- Separate monitoring and data QA from the algorithms. The algorithms must provide monitoring data to higher-level instances, where their handling is managed (e.g., online display, state transitions).
- Minimize the dependence on external software (e.g., `ROOT`). Use the standard C++ libraries wherever possible.
- Use modern C++ features. The minimal requirement is the C++17 standard.
- Establish maintainable code which can be passed between developers with minimal friction. This means that the code shall be concise, modular, and well-structured. Concise yet complete in-code documentation is imperative.
- Execution speed is to be considered from the beginning.

The implementation strategy is to gradually replace the currently used reconstruction software with minimal disruption. The online software must be applicable also for offline usage, be it with archived experiment data or with simulated data. Thus, the new software is part of the `cbmroot` repository and its build system. For the algorithm layer, a new top-level directory `algo` is used, in which no dependence from `ROOT` is allowed and in which the design criteria outlined above are applied.

As a prototype of an online processing application, a simple chain using STS data only was established (Fig. 1). This chain comprises as processing steps the unpacking of raw data, an event trigger based on the time distribution of the STS digis, and event building providing event-wise digi data (`CbmDigiEvent`). The latter are forwarded to file storage in a `ROOT TTree`.

Figure 2 shows schematically the implementation units for the integration in the `FairRoot` task/run framework. The algorithm layers comprise re-implementations of the STS unpacker [1], the digi-based trigger [2], and the event builder [3]. The unpacker algorithm is formulated to operate on one FLES microslice as the smallest independent data unit. The loop over FLES components and microslices is executed on the task level, which also manages the supply of input data to the algorithms and the handling of their output data (digis, trigger, events) as well as

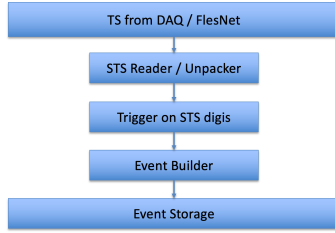


Figure 1: Prototype for online processing, comprising a simple chain with STS data only

the proper configuration of the algorithms with the user-defined parameters. On the task level, a source task interfacing the FLES timeslice input and a simple QA task inspecting the produced events are added. The central steering class `CbmReco` implements the processing graph (chain) by wrapping `FairRunOnline` and instantiating the task in the processing chain. Execution is done with the binary `cbmreco_fairrun`, which is user-configured through a YAML file. Alternatively, a ROOT macro `reco_ts.C` to be executed from the ROOT prompt can be used. The execution time of the process steps and some basic numbers are monitored on the console (Fig. 3). The current simple QA controls the time distribution of the digis relative to the triggered event; a peaked distribution signals that real events were triggered (Fig. 4).

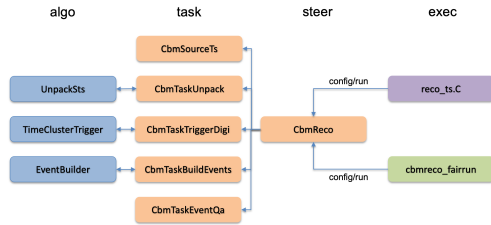


Figure 2: Implementation of the online prototype in the FairRoot task/run scheme

```

[INFO] SourceTs: Reading time slice 19 (index 190) at t = 1626314963871488000 ns
[INFO] Unpack [ 836.8 ms] TS 19 (index 190), components 3 / 11, microslices 3003, in
[INFO] TriggerDigi [ 319.1 ms] TS 19, digis 19258412, triggers 31022
[INFO] BuildEvents [ 45.3 ms] TS 19, triggers 31022, events 31022, frac STS digis 34.0 %
[INFO] DigiEventQa [ 20.8 ms] TS 19, events 31022, digis 6555173, digis per event (211.3

[INFO] SourceTs: Reading time slice 20 (index 200) at t = 1626314966431488000 ns
[INFO] Unpack [ 610.2 ms] TS 20 (index 200), components 3 / 11, microslices 3003, in
[INFO] TriggerDigi [ 223.4 ms] TS 20, digis 15405215, triggers 31854
[INFO] BuildEvents [ 43.4 ms] TS 20, triggers 31854, events 31854, frac STS digis 43.0 %
[INFO] DigiEventQa [ 21.1 ms] TS 20, events 31854, digis 6623533, digis per event (207.9

[INFO] SourceTs: Reading time slice 21 (index 210) at t = 1626314968991488000 ns
[INFO] Unpack [ 634.9 ms] TS 21 (index 210), components 3 / 11, microslices 3003, in
[INFO] TriggerDigi [ 215.0 ms] TS 21, digis 15395240, triggers 31224
[INFO] BuildEvents [ 42.6 ms] TS 21, triggers 31224, events 31224, frac STS digis 42.3 %
[INFO] DigiEventQa [ 20.7 ms] TS 21, events 31224, digis 6537473, digis per event (208.7
  
```

Figure 3: Console log of the process execution in the task/run scheme

Figure 5 illustrates the equivalent implementation in the FairMQ scheme (work in progress). The algorithm layer is identical. Tasks are replaced by device classes with equivalent functionality. For each device, an executable binary is created. The execution is done from a shell script, which

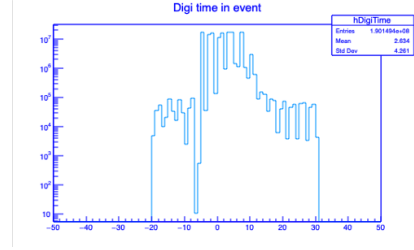


Figure 4: Event building QA: time distribution of STS digis relative to the event

thus also implements the process graph and the user interface.

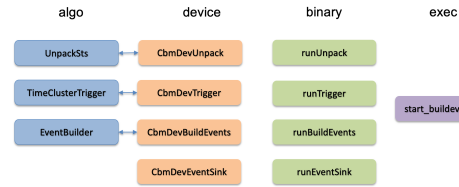


Figure 5: Implementation of the online prototype in the FairMQ scheme

The presented prototype aims to prepare the ground for comparison and further development of the execution frameworks as well as serve as a template for integrating more processing steps. Multi-threading will be introduced on the task/device level for the unpacker in the loop over components or even microslices. In the FairMQ integration, it has to be considered how far multi-processing shall be introduced, e.g., by defining not one device per process step, but, for the unpacker, per FLES component. Alternatively, the entire reconstruction process can be implemented as a single device, thus not making use of the multi-processing capabilities of FairMQ, but profiting from its runtime integration in terms of process deployment and monitoring. In this latter case, the process graph can be decoupled from the framework binding and be implemented in a standalone, ROOT-free fashion.

The next processing steps to be integrated are to add local STS reconstruction (cluster and hit finding), for which an implementation on GPU is underway [4], and to include the unpackers of other detector systems, which will make the online processing already applicable to mCBM.

References

- [1] P.-A. Loizeau *et al.*, “A new unified architecture for unpacking, applied to mCBM data”, this report
- [2] D. Smith *et al.*, “A minimum-bias trigger algorithm based on the digi time distribution”, this report
- [3] D. Smith *et al.*, “Eventbuilding in CBM”, this report
- [4] K. Hunold, A. Redelbach, and F. Weiglhofer, “Optimization of reconstruction in STS for GPUs”, this report

MuCh unpacker and converting raw data into *CbmMuchDigi*

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During the 2021 mCBM campaign, A unified unpacking scheme has been developed [1] by separation between the framework bound part and the pure algorithmic part. It also provides stronger integration of the different subsystem's unpackers. Following this common architecture, a new unpacker is now developed for the MuCh subsystem, as last year due to COVID situation, the MuCh team could not take part in the 2021 mCBM campaign. Three new classes have been added i.e *CbmMuchUnpackAlgo*, *CbmMuchUnpackConfig* and *CbmMuchUnpackMonitor* under the Cbm-Root directory structure *reco/detectors/much/unpack*. This unpacker also provides unified unpacking with respect to mCBM and CBM. It uses the standard output digi container, *CbmMuchDigi* vector, to store digi information. The same digi container is used for simulation then reconstruction and also will be used for the final CBM.

CbmMuchDigi objects contain only 3 basic information: a) time-stamp of the digi, b) unique address of the digi following *CbmMuchAddress* scheme, and c) charge of the digi. Time-stamp of the digi is the relative time to the start time of the particular TimeSlice, instead of the absolute UNIX time as in the previous unpacker. The *CbmMuchBeamTimeDigi* vector branch, used earlier, contained many data acquisition chain related raw information like ROC Id, FEB Id, Channel Id, real-x, real-y etc to generate *CbmMuchAddress* during further reconstruction. Storing all DAQ related information in the raw digi makes it 5 times heavier than *CbmMuchDigi* in terms of memory. Now spatial position information, from CRI based data acquisition readout chain and hit message of Sts-MuCh-Xyter (SMX) chip, is extracted and is packed in a unique 32 bit integer value following *CbmMuchAddress* scheme during the unpacking using this unified unpacker. With this spatial address value, relative hit time and ADC information is packed in the *CbmMuchDigi* container. In the unpacking process, raw DAQ related information is not present in the rootified file, therefore the ascii parameter file *mMuch-Par.par* must be correct with respect to mapping of CRI to MuCh Detector position, Number of GBTx board connected to CRI, Number of FEBs connected to GBTx, FEB to channel mapping etc. This information is used for generating *CbmMuchAddress* for each digi. During 2022 data taking at mCBM, the par file has been modified according to CRI connection information. As in the mMUCH setup, one layer of RPC detector has also been installed during December 2021 at mCBM. For the same RPC row column to FEB number, channel number mapping information has also been incorporated in the MuCh parameter file and corresponding param class is modified. Based on the

active Elink IDs from hit messages, FEB id is generated in the *MuchUnpackConfig* class, which is used for generating spatial address information.

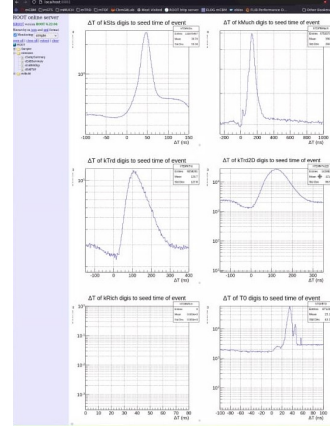


Figure 1: Generated online time-correlation plots between different subsystems in the mCBM setup. Top right plot shows the time-correlation of the mMUCH detectors (both GEM and RPC combined) using this new unpacker.

To summarize, a unified MuCh unpacker has been developed in which the unpacking approach has been revisited and translation of raw data into digis has been performed and the same is used for recent data taking with mCBM during March-April 2022. One of the main goals, a lighter structure which is easier to handle and adjust towards parallel processing/multi-threading, has been achieved by unpacking data in a common process, in particular for MuCh using the standard output digi vector *CbmMuchDigi*, and also the digi vector is stored in root file. Using this unpacker algorithm, an MQ device has been developed which is compatible for online usage and first attempt has been made for performing time correlation between different subsystems via MQ based online event building. Fig. 1 is an online plot during data taking where an event builder device is running directly on the raw data stream using unified unpackers of different subsystems. Note: The "old" scheme/code of unpacker is still valid but needs some tweaking.

References

- [1] P.-A. Loizeau *et al.*, "A new unified architecture for unpacking, applied to mCBM data", this report.

Event building in CBM

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Introduction

The data acquisition concept of CBM has to cope with autonomous, self-triggered front-end electronics, without any hardware trigger. The DAQ will aggregate the measurements from the detectors and deliver a raw data stream partitioned into “timeslices” to the online data processing. The timeslice is a transport container without physical meaning; it typically contains data from several thousands of events. The task of online data processing is to select subsets of these data for storage, suppressing the raw data rate by more than two orders of magnitude.

Our current picture of online processing falls into three steps:

- **Unpacking:** the packed raw data are transformed into context-free data units called “digis”. Context-free here means that the data can be interpreted without knowledge of their position in the data stream. Time calibration is applied in this step, too.
- **Triggering:** from the digi stream, points in time denoting potentially physically interesting events are derived. The software trigger can be very simple (minimum-bias, just identifying events) or very complex (reconstructing and analysing events up to track or secondary vertex level).
- **Event building:** digis belonging to a triggered event are copied from the full data stream and forwarded to storage.

In this report, we describe an implementation of the third step, the event building.

Algorithm

The event building itself is algorithmically close to trivial, since it constitutes but a copy procedure from the time-ordered digi stream into event objects. The prerequisite parameters are time intervals around the trigger time which ensure that all (relevant) digis belonging to the triggered event are comprised in the output event. These intervals have to be determined e.g., by studying the simulated detector response to an event and specified to the event building algorithm. They will differ from detector to detector, depending on their timing response and also from the variation of time-of-flight of the particles to the detector elements.

The algorithm performs a loop over all seed (trigger) times for a given timeslice input. For each seed time, all

digis from each detector which fall within the pre-defined time window around the seed time are collected to form event candidates.

The seed times are taken from the digi data stream of one or several reference detectors to be specified by the user. Each digi from the reference detectors then is taken as a seed. Digis from reference detectors which fall into the time window set for this detector are combined into a single seed (“seed cluster”). Fig. 1 illustrates the method.

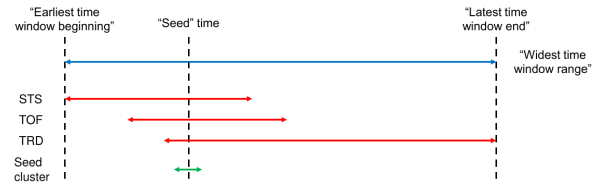


Figure 1: Event building with different time windows per detector.

Alternatively to the built-in trigger, external triggers can be used by the algorithm. In this case, the class `CbmSeedFinderSlidingWindow` is used to create a trigger list from the timeslice data [1].

Valid events are selected by applying a set of predefined cuts, immediately after the construction of each event candidate. These can currently include a minimum and a maximum number of digis for each detector which an event can contain, and are set by calling the `SetTriggerMinNumber()` and `SetTriggerMaxNumber()` functions at the task level.

The event builder supports three distinct modes of operation:

- **NoOverlap:** Digis cannot be shared between events. New seeds found within the “widest window range” of the previous event (see Fig. 1) are discarded. This mode may lead to incomplete or missed events in the case of event pileup and hence should only be used at very low event rates.
- **AllowOverlap:** New seeds are only rejected if they are found within the “seed time window range”, i.e. the time window size of the reference detector of the previous seed. In this mode, the time windows associated with subsequent events may overlap, and individual digis may be assigned to more than one event as a result.

- **MergeOverlap.** New seeds are never rejected. Instead, if a new seed is found within the “widest time window range” of the previous seed, then any digi found within the time windows around it is also added to the last event. This process is recursive, meaning that additional seeds keep getting added as long as their associated time windows overlap with any of the previous ones. This mode is the safest one at high interaction rates, as no valid events will be lost. On the other hand, as multiple events are combined into one in the case of pileup, information from additional reconstruction steps is required to disentangle them.

Implementation

The implementation is split into two classes. `CbmAlgoBuildRawEvents` implements the actual algorithm. It processes a number of `std::vector` of digis (one per detector system) and creates a `std::vector` of `CbmEvent` objects as output. The event objects contain references to the digis belonging to the event (digis with a time stamp within the event time interval). `CbmTaskBuildRawEvents` provides the integration into the `FairRoot` framework; it prepares the input to the algorithm depending on whether it is obtained from simulation or from unpacking of real experiment data. The created event objects are stored in a `TClonesArray` branch of the output ROOT tree.

The task provides the user interface, to which the event window parameters as well as the selection of the operation mode and the choice of using external triggers from `CbmSeedFinderSlidingWindow` are communicated.

Quality Assessment

The implementation includes QA tools, which are provided via the class `CbmBuildEventsQa`, and allow the tuning of the time windows, by comparing reconstructed events to Monte Carlo truth. The matching is done by majority rule, i.e. the matched MC event is the one which contributed the most digis. The diagnostic data currently includes

- the fraction of correctly assigned digis per reconstructed event, with and without detector noise;
- the fraction found digis of the matched MC event;
- the fraction of noise digis per reconstructed event;
- 2D plots which show “correct digis” vs. “found digis”, with and without noise.

Fig. 2 shows QA plots for 100 central Au+Au collisions at 10 AGeV, with STS detector only, in the SIS100 electron setup. Time-based digitisation was done at event rate 10^6 Hz with noise included. `CbmSeedFinderSlidingWindow` was used with the optimal parameters determined in Ref. [1] to create a trigger list. Events were reconstructed in the `AllowOverlap` mode using a time window of $[-100;100]$.

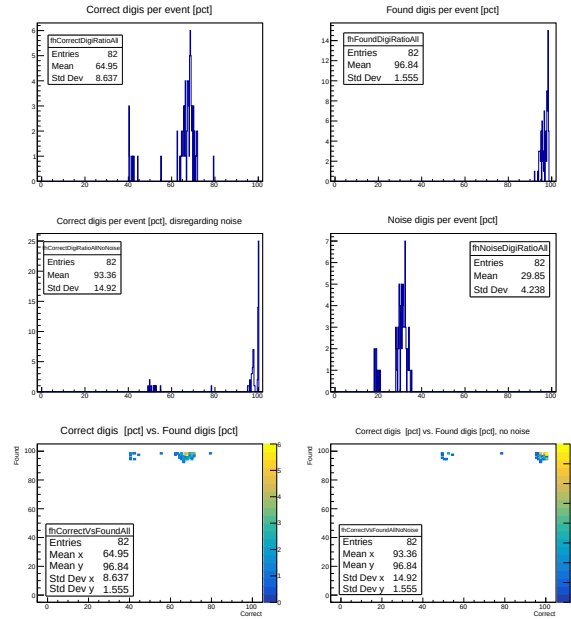


Figure 2: QA plots for the eventbuilder algorithm.

Outlook

The presented implementation of the event building is to be regarded as an intermediate step. The main current limitation arises from the definition of the `CbmEvent` objects, which manage references (indices) to the actual digis in the timeslice data, and not the digi objects themselves. To make use of that, the complete timeslice data have to be stored along with the events, thus not enabling a real data suppression in the output file. Furthermore, the implementation comprises logically different functionalities: triggering (if no external triggers are used), event building, and event filtering.

Further development of the event building software is under way [2]. The aim is to

- implement and use a self-contained event data structure suitable for file storage;
- further separate the algorithm from the framework integration;
- optimize the algorithm for real-time application;
- clearly separate the functionalities of triggering, event building and event filtering.

References

- [1] D. Smith *et al.*, “A minimum-bias trigger algorithm based on the digi time distribution”, this report
- [2] V. Friese and J. de Cuveland, “Towards an online-capable software stack”, this report

A minimum-bias trigger algorithm based on the digi time distribution

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Introduction

The task of online data processing in CBM is to identify, isolate and analyse data from collision events out of a time-ordered data stream as delivered by the data acquisition, with the aim to apply physics selection criteria and forward only interesting events to storage. The result of this online data inspection is a series of trigger times indicating regions of interest containing data from potentially interesting event candidates. Data within these regions of interest will be selected from the data stream and written to storage media.

The conceptually simplest identification of event data analyses the time distribution of data from a trigger detector, where event data will show up with peaks above a quasi-continuous background produced by thermal detector noise and data originating from non-interacting beam particles traversing the target. As an example, Fig. 1 shows the simulated time distribution of digi objects from the Silicon Tracking System (STS). In the real experiment, the digi object stream is the result of the unpacking step, which converts the packed raw data into context-free data units.

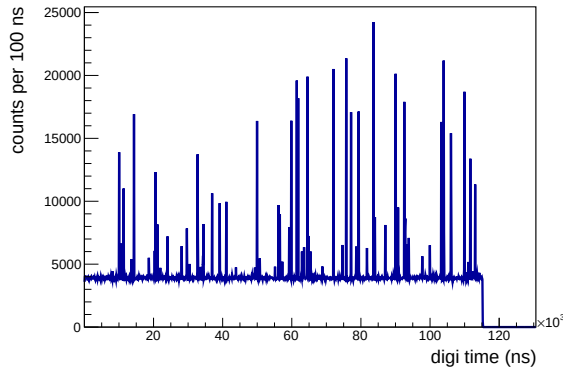


Figure 1: Distribution of digi times from the Silicon Tracking System (STS) as obtained from simulation of minimum-bias Au+Au collisions at $p = 10$ GeV/nucleon. The simulation includes thermal detector noise and data from non-interacting beam particles traversing the target.

In this report, we present the implementation of such a digi-based event trigger. It should be noted that, as no event selection criteria beyond the data rate are applied, it represents a minimum-bias trigger, roughly equivalent to a level-0 trigger in a conventional experiment with hardware triggers.

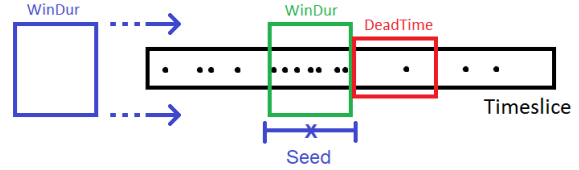


Figure 2: Working principle of the trigger algorithm

Trigger algorithm

The principle of the algorithm is rather simple and illustrated in Fig. 2. Starting from a given digi, a time window is expanded until the number of digis within this trigger window exceeds a given threshold **nMinDigis** or the maximum window size **WinDur** is reached. In the former case, a trigger is issued; in the latter case, the window is moved forward in the digi stream and the search for triggers is continued. The trigger time is defined as the mean of the first and the last digi time in the trigger. It should be noted that this time does not coincide with the true event time; the trigger time bias has to be evaluated by simulations and corrected for when performing event building.

The algorithm thus actually triggers on the local digi rate. To prevent from triggering twice on the same event, the search for a new trigger starts only after a time interval **DeadTime** w.r.t. the last found trigger. The dead time thus constitutes the minimal time between two subsequent triggers. The output of the algorithm, a list of trigger times for the current timeslice, is forwarded to the event builder, which selects data in the region of interest around each trigger time.

The three parameters of the algorithm have to be adjusted to the experiment conditions (collision system, event rate) and the chosen trigger detector. A proper choice of **nMinDigis** will prevent triggering on random noise fluctuations while keeping sensitivity also to low-multiplicity events. **WinDur** should be set such as to comprise the majority of data from one event. It must thus be adjusted to the time distribution of data within an event. Similarly, **DeadTime** depends on the event shape.

The algorithm is implemented in the class `CbmSeedFinderSlidingWindow` and is used from the event building task `CbmTaskBuildRawEvents`, to which it delivers the list of trigger times.

Quality Assessment

For an evaluation of the trigger procedure, the derived triggers have to be compared to the simulated input events (MC truth). The association of a trigger to an event makes use of the Monte-Carlo origin of all digis having contributed to a trigger (all digis within the trigger windows), which is recorded during the creation of the digis in the detector response simulation in the format of `CbmLink` objects.

We define as “found event” an event having an associated trigger, as “true trigger” a trigger with an associated event, and as “fake trigger” a trigger without associated event. The performance figures are then

- Trigger efficiency: the number of found events divided by the number of all events, and
- Trigger purity: the number of true triggers divided by the number of all triggers.

Trigger inefficiencies arise for low-multiplicity events which do not pass the trigger threshold, and for close-by events the temporal separation of which falls into the trigger dead time. Fake triggers can be caused by noise fluctuations accidentally surpassing the trigger threshold.

The association of trigger to events and the calculation and visualisation of the quality figures is performed in the class `CbmSeedFinderQa`. Apart from trigger efficiency and purity, figures like the fraction of found digis per trigger (digis from the matched event which were used for the trigger decision over all digis in the event), the fraction of correct digis per trigger (digis from the matched event which were used for the trigger decision over all digis used for the trigger) and the difference of trigger time to event time are monitored. These quality figures serve to optimise the three parameters of the algorithm (**WinDur**, **nMinDigis** and **DeadTime**) and to assess rate effects arising from close-by events. Figure 3 shows examples of such QA plots.

Application

The presented algorithm constitutes a simple and computationally inexpensive approach to identify events from the data stream. For its successful application, it is required that the number of digis in a typical event exceeds the statistical noise fluctuations, and that the temporal event shape is narrow in comparison to the average event separation. Thus, a detector with low noise level and with fast response should be chosen for triggering. Still, at very high interaction rates the effect of close-by events will become noticeable. The present algorithm and its QA allow to study such rate effects and determine the range of applicability of the simple, digi-based approach.

It should be noted that although in this report, the digi times are used for deriving event triggers, the same algorithm can be applied to any time-stamped data series, e.g., also for higher-level objects like hits or tracks.

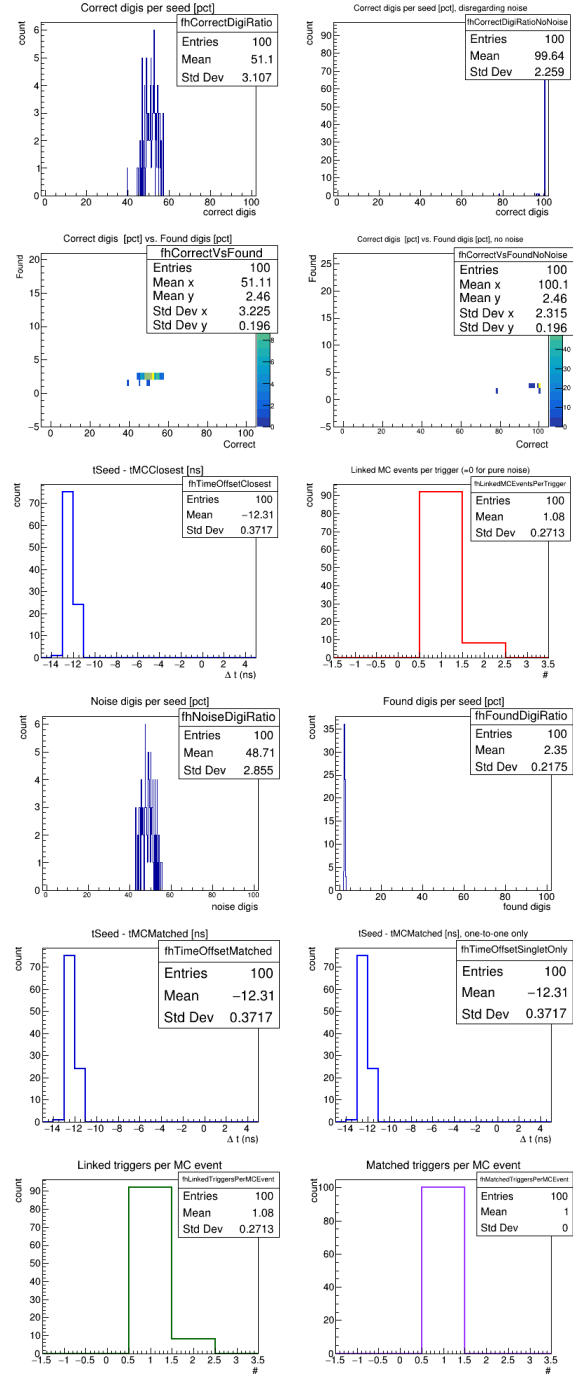


Figure 3: Example of trigger QA plots, obtained for central Au+Au collisions at $p = 10A$ GeV at 10^5 collisions per second with STS digis

Using the STS as a trigger detector for CBM

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The simplest way to identify events in the data stream delivered from the CBM experiment is by the analysis of the time distribution of the data (digis) of a trigger detector [1]. Formally, any detector in the CBM setup can be used as trigger detector. However, a good choice requires the detector to provide a narrow distribution of digi times within an event and a low noise level. The Silicon Tracking System (STS) satisfies these conditions because of its large acceptance, its location close to the target, which minimises the spread in time-of-flight within each event, and its good time resolution of about 5 ns.

In this study, we investigate the application of digi-based triggering to the STS. We used Urqmd input files for Au+Au 10 AGeV with impact parameters 0 fm (central), 2 fm, 4 fm, 6 fm, 8 fm and 11 fm (peripheral). Transport simulations were carried out using the SIS100 electron setup for all files. The time-based digitisation was done at an event rate of 10^5 Hz, 10^6 and 10^7 with noise included in the STS detector response simulation (“digitiser”).

The application of the digi-based trigger to the STS data requires the tuning of the three parameters in the trigger algorithm: the trigger window size **WinDur**, the trigger threshold **nMinDigis** and the **DeadTime** between two triggers.

WinDur should be chosen such that the majority of the digis belonging to single event are comprised. This ensures maximal sensitivity to the events. Figure 1 shows the simulated time distribution of STS digis in central collisions. The simulation was performed in event-by-event mode, where the event start time is set to 1000 ns. The distribution has a width of about 6 ns, the major contribution to which is the time resolution of the sensors (5 ns). The variation in time-of-flight, governed by the distributions in flight path and velocity, is modest in comparison. Based on this time distribution, a trigger window of 10 ns is chosen, which, if applied around the peak, comprises more than half of the total event multiplicity. It should be noted that while the normalisation of the digi time distribution evidently depends on the event centrality, its shape is in good approximation independent from that.

The trigger threshold prevents from triggering on noise digis. Its value must thus be adjusted to the noise data rate and its fluctuations. Figure 2 shows the distribution of the number of STS noise digis in time bins of 10 ns (the trigger window size) as obtained from STS simulations. We find a mean value of 390 per 10 ns with a sigma of 19.8; the distribution is perfectly Poissonian. Thus, a trigger threshold at e.g. 4 sigma (469) would give a probability for a fake (noise) trigger of $3 \cdot 10^{-5}$ in 10 ns, in other words a fake

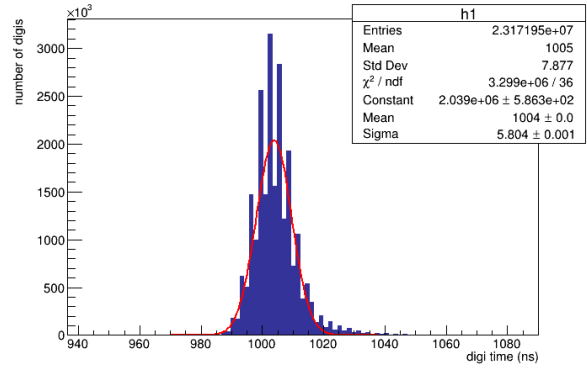


Figure 1: Distribution of the STS digi time with respect to the event time, obtained from the simulation of 1,000 events (central Au+Au at $p = 10$ AGeV). In the event-by-event simulation used here, each event starts at $t = 1000$ ns for technical reasons (to avoid negative digi times).

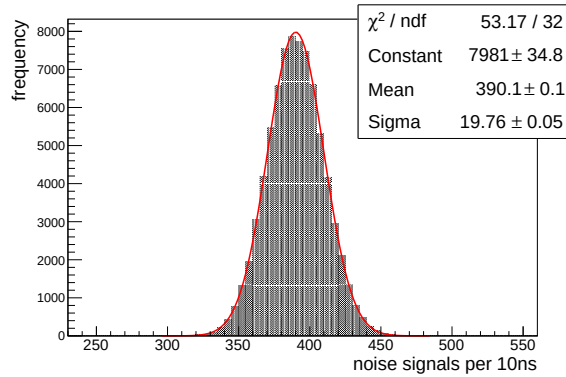


Figure 2: Distribution of the number of STS noise digis in a time window of 10 ns. The distribution is fitted by a Gaussian function shown by the red line.

trigger rate of $3 \cdot 10^3$ /s only. This is to be compared with typical collision rates in CBM, which range from 10^5 /s to 10^7 /s.

To demonstrate that this trigger threshold is still sensitive also to peripheral, low-multiplicity events, we applied the trigger with varying threshold to the result of time-based simulation (collision events plus noise), keeping **WinDur** fixed to 10 ns and **DeadTime** fixed to 50 ns. The trigger threshold was adjusted to yield a trigger efficiency close to

100%. This study was performed for different impact parameters separately. The results are summarized in Table 1. We find that a trigger threshold of 700 accommodates even the most peripheral events investigated ($b = 11$ fm), a value which is even above the threshold of 500 derived from the noise-only simulation.

Centrality	nMinDigis	% correct triggers
0 fm (central)	850	100
2 fm	900	100
4 fm	780	96
6 fm	850	100
11 fm (peripheral)	700	100

Table 1: Optimised trigger threshold (nMinDigis) for different collision centralities of collision at an event rate of 10^5 Hz. The trigger window size is 10 ns, the dead time 50 ns.

The trigger dead time prevents from triggering multiple times on the same event. This can happen for high-multiplicity events where the trigger threshold is already reached at the rising edge of the digi time distribution. The dead time was optimised using the trigger efficiency, i.e., the fraction of triggered events, as criterion. Tables 2 and 3 show the optimised threshold value for different centralities at event rates 10^6 /s and 10^7 /s, respectively. We find that the optimised dead time (averaged over all the centralities) is around 36 ns for a rate of 10^6 /s and 25 ns for a rate of 10^7 .

Centrality (IMP)	mMin Digis	Event rate Dead time(ns)	$= 10^6$ Hz %correct triggers
0 fm	850	45	100
2 fm	900	35	97
4 fm	780	38	96
6 fm	850	40	100
11 fm	700	25	98

Table 2: Optimised trigger dead time for different collision centralities at an event rate of 10^6 /s

Centrality (IMP)	mMin Digis	Event rate Dead time(ns)	$= 10^7$ Hz %correct triggers
0 fm	850	29	84
2 fm	900	29	90
4 fm	780	27	82
6 fm	850	24	87
11 fm	700	18	86

Table 3: Optimised trigger dead time for different collision centralities at an event rate of 10^7 /s

The quality assessment of the trigger [1] allows to compare the derived triggers to the simulated MC events on the base of the association of digis used in the trigger decision

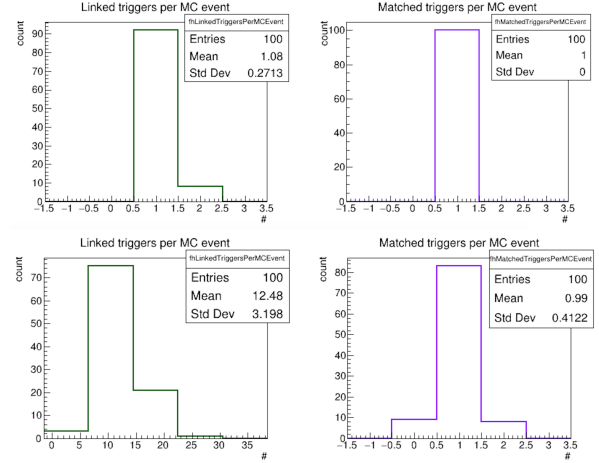


Figure 3: QA plots for the trigger algorithm. The top row shows results for an event rate of 10^5 /s, the bottom row for 10^7 /s.

to their MC origin. Fig. 3 shows examples of such QA information, comparing simulations at 10^5 to 10^7 events per second. For each MC event, a linked trigger has at least one digi from this event included; a matched trigger has the majority of digis originating from this event. While at low event rate (10^5 /s), the association of MC event to trigger is almost one-to-one, and all events have an associated (matched) trigger, the situation at the highest rate is less straightforward. Here, each MC event contributes to ten or more triggers (lower left panel), and only about 80 % of MC events have exactly one matched trigger (lower right panel). Some MC events do not have any associated trigger: they are merged to the trigger of another event. Other MC events have two associated triggers, meaning that the event was triggered twice. Obviously, at such high rates the trigger algorithm is not sufficient to reliably separate close-by events.

In summary, we find the digi-based trigger applicable on STS data for rates up to 10^6 /s. For higher rates, the simple inspection of digi rates is not sufficient to separate events. Under such conditions, it will be necessary to reconstruct the digi data to higher-level objects like hits or tracks, which will yield both a better time resolution and an effective noise suppression.

References

- [1] D. Smith *et al.*, “A minimum-bias trigger algorithm based on the digi time distribution”, this report

Time-based simulation and event building for mCBM

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Mini-CBM or mCBM, a FAIR Phase-0 experiment at the SIS18 facility of GSI, is an experiment for tests of detectors and their trigger-less free-streaming read-out chains [1] and also for the preparation of the CBM data analysis software [2]. Figure 1 shows the mini-CBM geometry setup of the 2021 beamtime. The geometry is implemented in the CBMRoot software.

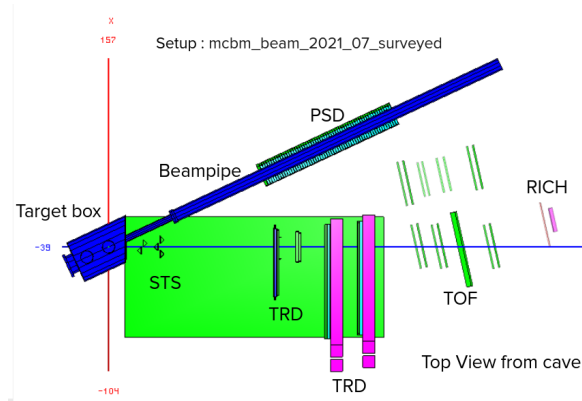


Figure 1: The mini-CBM geometry (setup tag : mcbm_beam_2021_07_surveyed) showing the subsystems STS, TRD, TOF, RICH and PSD.

In this report we investigate the application of the CBM event builder to mCBM simulated data. Currently, the event building scheme is to apply cuts to events which are build around a trigger or a seed, using separate time windows for each detector [3]. The seed can be supplied either from the digi streams of a reference detector, or from the seed finder algorithm implemented in the class `CbmSeedFinderSlidingWindow` [4]. In this work we use the latter technique to generate seed times. In the mCBM 2021 beamtime, the geometrical acceptance for TOF detector was larger than STS, and therefore, TOF was chosen as the seed finding detector.

Application of CBM Event builder to mini-CBM

A transport simulation was carried out for mCBM, using an UrQmd input file for O+Ni at 2 AGeV mbias, with the geometry mcbm_beam_2021_07_surveyed. Digitisation was done in time-based mode at an event rate of 10^5 Hz. Detector noise was switched off in the simulation. The distribution of MC point and digi multiplicities for STS and TOF is shown in Figure 2. Table 1 shows the ratios MC

Subsystem	MC points/evt	Digis/evt	Digis/point
STS	0.9	4.7	5.2
RICH	2	0.08	0.03
TOF	4.9	2.8	0.5
PSD	10	2.4	1.6

Table 1: Average number of MC points/event, digis/event and digis/point for different subsystems in mCBM. 100 MC events were simulated.

Sub-system	Event time window (ns)	% evts	Correct digis (%)	Found digis (%)
TOF	[-10,40]	60	99.86	99.61
STS	[-10,40]	60	99.84	67.74
STS	[-20,30]	88	99.97	95.78
STS	[-30,30]	90	99.96	99.6

Table 2: Results from QA of the event builder for mCBM with STS and TOF, where TOF is the seed detector used in conjunction with the sliding window seed finder. Results were obtained with a selection criterium of a minimum of 4 TOF + 4 STS digis per event. ‘% events’ refers to the fraction of accepted MC events which were found, while the two rightmost columns are quoted ‘per event’.

points/event, digis/event and digis/point for different subsystems in mCBM as per the values obtained after digitisation. According to these results, a typical event will have at least 4 STS digis and 2 TOF digis. The trigger or seed finder has three parameters, the trigger threshold, the trigger window and the deadtime of the trigger [4]. The trigger parameters were set to `nMinDigis=1`, `WinDur=10 ns`, `DeadTime=50 ns` in this study.

The parameters of the event builder, in particular the event time windows, were optimised for best QA results. The results of this optimisation are discussed in next section. The ‘valid event’ selection criterium was set to require at least 4 STS and 4 TOF digis in the event time windows.

Event builder QA

The QA class `CbmBuildEventsQa` uses `CbmMatch` objects to determine a corresponding MC event for each reconstructed event. The matched MC event is the one which contributed the most digis. The class then determines the fraction of digis of the MC event which were found (sensitivity), and the fraction of digis of the reconstructed event

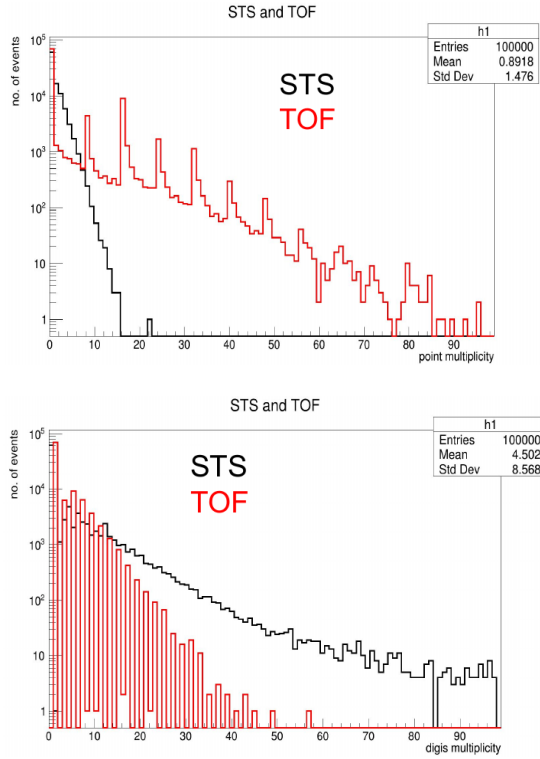


Figure 2: (Top) The Monte Carlo point multiplicity and (bottom) Digi multiplicity, for STS and TOF, obtained with the mcbm_beam_2021.07_surveyed geo setup. The input file is generated using UrQmD for mbias collisions of O+Ni at 2 AGeV.

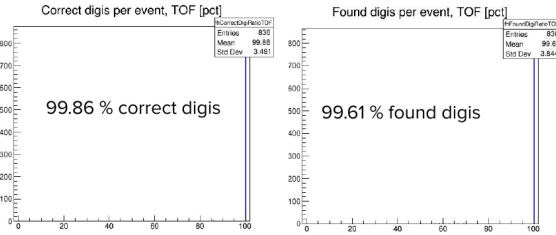


Figure 3: QA plots showing the fraction of correct digis (left) and found digis (right) for TOF with an event time window $[-10, 40]$ ns.

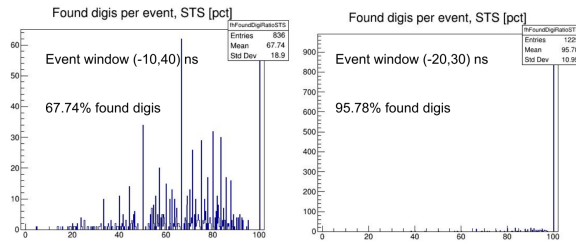


Figure 4: QA plots showing the fraction of found digis for STS with event time window $[-10, 40]$ ns (left) and $[-20, 30]$ ns (right).

which originate from the matched MC event (specificity). This is done separately for each detector subsystem.

The QA results for mCBM event building are shown in Table 2. With an event window of $[-10, 40]$ ns for TOF, the QA results show that percentage of correct digis and found digis in a reconstructed event were 99.86% and 99.61%, respectively (Fig. 3). Keeping the event window for TOF fixed at $[-10, 40]$ ns, the event window for STS was tuned. It was found that when the STS event window is changed from $[-10, 40]$ ns to $[-20, 30]$ ns, the fraction of found digis increases from 67% to 95% as shown in Fig. 4. The reason for the optimized event time window of STS having an offset of -10 ns with respect to the event time window of TOF can be attributed to the time-of-flight of the particles from STS to TOF (distance ~ 240 m, time-of-flight ~ 8 ns).

The geometrical event acceptance of the mCBM setup (2021 surveyed geometry), requiring at least 1 TOF and 1 STS MCPPoint, is 14 %. The event-finding efficiency is calculated as the ratio of the number of events produced by the event builder and the number of geometrically accepted events in the MC file. Its values for different event windows are listed in Table 2. The efficiency depends on the chosen event window through the requirement to have at least 4 STS digis and 4 TOF digis associated with the TOF trigger. The QA result for TOF were constant throughout the optimisation process, since the event building parameters for TOF were not changed. This event reconstruction was done at low event rates (10^5 /s), and the fraction of event losses due to pile-up was found to be less than 0.1%.

Conclusion

In this work, we applied the time-window based event builder in conjunction with the sliding window seed finder to a time-based simulation of the most recent mCBM geometry, with an event rate of 10^5 Hz. We determined a set of parameters for the event builder which lead to events being constructed with high accuracy, and hence demonstrated the feasibility of this approach for mCBM. Future work should e.g., investigate which adjustments must be made if detector noise is accounted for in the simulation.

References

- [1] D. Emschermann and C. Sturm for the CBM collaboration, *Preparation of a free-streaming DAQ system for mCBM@SIS18*, GSI-FAIR Scientific Report 2017, doi:10.15120/GSI-2017-01856
- [2] C. Sturm *et al.*, *Start of mCBM Commissioning*, CBM Progress Report 2018, ISBN 978-3-9815227-6-1
- [3] D. Smith *et al.*, *Event building in CBM*, this report
- [4] D. Smith *et al.*, *A minimum-bias trigger algorithm based on the digi time distribution*, this report

Optimization of reconstruction in STS for GPUs

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In order to operate the CBM experiment at interaction rates up to 10 MHz, real-time data reduction is required. More specifically, since the free-streaming readout data are processed in software, the performance of the reconstruction algorithms is a critical issue. Up to now the algorithms are developed and executed using CPUs, however processing of GPU code should have a high potential for significant acceleration. Focusing on the reconstruction tasks performed within a single detector, an optimization of the reconstruction algorithms for the STS has been performed and the actual speedup has been analyzed in detail.

STS reconstruction of clusters and hits

The basic algorithm used for finding clusters for digital measurements (digis) in the STS is explained in [1]. This STS cluster finder algorithm is linear in the number of underlying measurements and it represents the first step in the chain of reconstruction within the STS. The subsequent process of determining STS hits reflecting the original interaction points of traversing particles has already been optimized as outlined in [1]. As a result, data-level parallelization at the level of STS modules for clusters and hits has been implemented and the combination of clusters at frontside and backside is performed only for the subset of clusters within the relevant time window, see also [2].

Setup, frameworks and new algorithms

As input to the reconstruction algorithms, the Cbmroot framework has been used to simulate 100 to 2000 central collisions of Au-Au in one time slice leading to number of digis in the range of 2 to 30 millions. As an interface between CPU and GPU function and corresponding copies in memory, the XPU framework [3] is utilized, also in order to measure runtimes of specific parts of the algorithms.

As a first logical step, sorting of STS digis with respect to time has been implemented based on the parallel merge sort algorithm on the level of modules. Subsequently, for the process of cluster finding two algorithms have been developed based on sorting digis both in readout channels and also each channel in time. The channel-wise cluster finder approach assigns one STS module to each GPU threadblock and one channel to each thread for parallel processing. The alternative algorithm of digital-wise cluster finding assigns one STS digis to a thread taking advantage of coalesced memory access. Also the calculation of the properties, e. g. widths, of STS cluster has been analyzed for channel-wise or digi-wise thread mapping. Finally, as a

new approach related to STS hit finding, the calculations of cluster widths relevant for determination of hits at module level, have been pre-drawn to the calculation of clusters.

Results

In order to evaluate the effect of aforementioned developments of new algorithms and also in underlying data structures, a set of benchmark tests repeating 50 runtime measurements for each point has been done [4]. As a result, the best performance has been observed as a combination of channel-wise cluster finding and digital-wise cluster calculations including pre-drawn cluster widths. All results for the total runtime required for local STS reconstruction are summarized in Fig. 1. This Figure also contains information on different hardware used for these measurements. Comparing the runtimes on the CPU with parallel execution of 32 threads and the fastest processing on AMD MI100 using 256 threads per threadblock, a speedup factor of approximately 6 has been obtained. It is interesting that these algorithms developed for efficient and data-local clustering directly lead to a speedup factor of 3 as compared to original algorithms for local STS reconstruction.

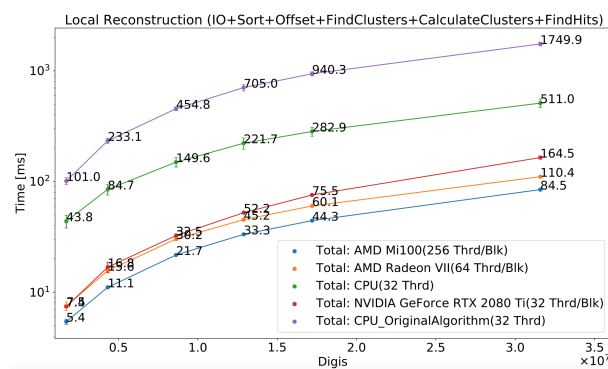


Figure 1: Runtimes needed for local STS reconstruction as a function of input digis on different hardware.

References

- [1] V. Friese, “A cluster-finding algorithm for free-streaming data”, EPJ Web Conf. 2019, 214 01008
- [2] A. Redelbach, “Optimization of performance for reconstruction in STS and MVD”, GSI Prog. Rep. 2019 (2020) 165
- [3] XPU framework, <https://git.cbm.gsi.de/fweig/xpu>
- [4] K. Hunold, Master thesis 2022, Goethe-Universität Frankfurt

Cellular Automaton Tracking

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Time-slice reconstruction with CA Tracker

The core of the track reconstruction in the CBM experiment is the Cellular Automaton (CA) based algorithm used for the Silicon Tracking System (STS). It takes as an input time-slices which contain hit measurements produced using time-based cluster and hit finder algorithms within a given time interval with no a priori defined physical collisions. The size of the time-slice will be adjusted to the hardware architecture of the compute nodes. Typically, a time-slice contains data from a large number of events (1000 or more). This fact introduces a challenge for the data processing chain. Due to the memory limitation and the performance optimisation the data from the large time-slice container needs to be send in portions (so called sub-slices) to the tracker. In this case information from different physical collisions can not only overlap in time for high interaction rates but also a collision (or even track) can be split into two sub-slices in the border region.

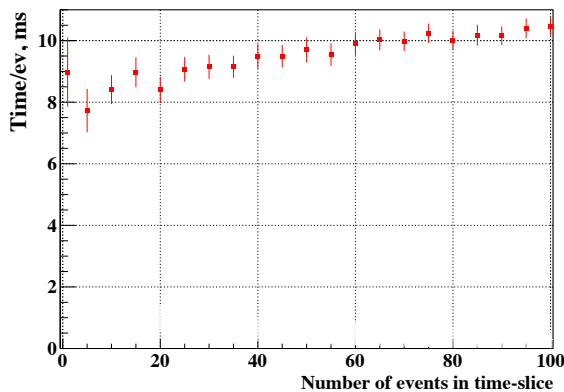


Figure 1: The time the CA track finder takes to reconstruct an event as a function of number of events in the time-slice without sub-slices.

In order to address this time-slice border problem we have introduced a special procedure. Namely, it is a pre-processing stage when we split original time-slice into smaller sub-slices in a safe way with no track-splitting. Time-slice is cut into sub-slices of a fixed time length with a certain small overlap region. The tracker starts with reconstructing the data from first sub-slice. The reconstructed tracks are stored except the ones which touch the overlap area. Those tracks are rejected and the starting time of a next sub-slice is shifted to the earliest hit time of rejected tracks. This way rejected tracks will be reconstructed with the next sub-slice and the whole time-slice

can be processed with this sliding window without track splitting and almost no duplicated work. As for the overlap region length, for the safe processing it should be larger than the time difference between the first and last hit time in a track in order to guarantee no track splitting. It corresponds to about 30 ns and is negligible in comparison with sub-slice length. Also this approach implies that the hits in a time-slice are time sorted, which is currently not fully true. For a time being the hit sorting is done before the actual time-slice splitting.

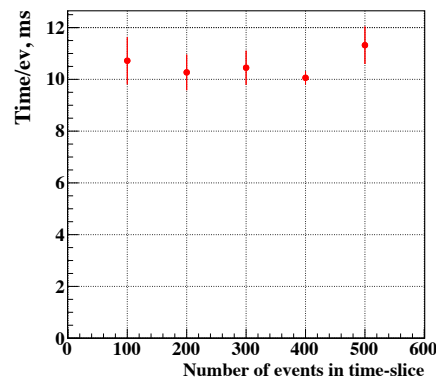


Figure 2: The time the CA track finder takes to reconstruct an event as a function of number of events in the time-slice with sub-slices.

The algorithm speed has been studied as a function of number of events in the time-slice. We compare the situation before the sub-slice algorithm was introduced (Fig. 1, here due to the computing node memory limitation only up to 100 events in a time-slice could be processed) and after (Fig. 2). One can see that with the sub-slice algorithm unlike the situation before it the speed of algorithm does not depend on the number of events in the time-slice and the limitation on the number of events in the time-slice is removed. The results were obtained on Intel Xeon CPU E5-2660 with 1000 minimum bias AuAu events at 10 AGeV simulated at 10 MHz interaction rate.

Track Finder for mCBM

The CA tracker used in STS was modified and adapted for the mCBM case, where it reconstructs straight tracks in the absence of a magnetic field. The modified algorithm consists of the same steps as the original one: it builds triplets through the whole detector system and bins them into tracks. However, the extrapolation is performed with

a straight line track model and binning triplets into tracks is done without momentum cut, but with additional cut on the slope of the triplets instead.

The algorithm reads the geometry automatically now and technically supports all available mCBM setups. A special class has been created that allows save global tracks for further analysis. The tracker requires as input hits with correctly reconstructed parameters and its estimated errors. The work on the input information is still ongoing. Also it was noticed that the extrapolation procedure used in the algorithm which assumes speed of light is not precise enough for the case when high time resolution sub-detectors like mTOF (Time-of-Flight) are used. This is to be changed in the future.

A similar approach of extending the existing CA track finder is used for the global CA-based track reconstruction algorithm, which is currently under development.

Tracker Input Interface

The quality of tracking directly depends on the quality of the input data.

While in the current reconstruction chain the CA tracker depends only on two detectors — MVD and STS, the new global CA tracker depends on six different detectors — MVD, STS, MUCH, TRD, TRD-2D and TOF. Each of these detectors has its own way of accessing parameters. To facilitate the development of a global tracker, it is necessary to standardize the communication with the detectors.

For this purpose, an interface class is created for each detector that controls its interaction with tracking. For example, the `CbmTrdTrackerInterface` class. All detector-specific implementations of the detector's geometry and parameters are hidden behind this interface. For example, in order to find out the number of logical tracking stations, the tracker simply calls the `CbmTrdTrackerInterface::GetNtrackingStations()` method, and does not worry about how exactly this number of stations is stored or calculated in the detector code.

In addition to the interface class, a QA class is created to control the quality of the data from the detector. In this example, the `CbmTrackerInputQaTrd` class. The QA class only verifies the data used by tracking and doesn't debug the detector's internal features. It allows one to catch input data problems before the tracking even starts and ease the debugging. The scheme of communication between tracking and detectors is shown in the (Fig. 3). It also allows to debug the tracker with indeal input – with reconstructed hits corrected using MC information, or with hits generated from MC points, completely bypassing local reconstruction.

Refactoring of the CA tracker code

The CA tracker code has been developed for many years. Since reconstruction in CBM is a challenging task, initially the main goal of the tracker development was to demon-

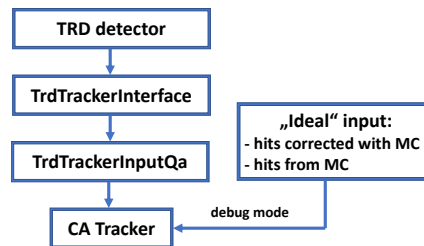


Figure 3: Detector interface to the Global CA Tracker

strate that we are in principle able to process data with the required accuracy and speed. Therefore, historically, the tracker code is a highly optimized test code, to which more and more new functions were added. In parallel to adding new features, periodic attempts were made to reorganize the code. Despite this, in order to reliably use existing code in online data processing, it must be refactored. A lot of work is being done in this direction, in particular, to get rid of hardcoded parameters and collect them in a parameter class. In addition, quality assurance is being moved out of tracking — both input QA and trackers output QA — into separate classes, and detector specific code is being moved into interface classes.

A change of origin and an update to SIS100 simulation geometries

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1. Introduction

For last year's progress report, the two authors had conducted a survey of differences between technical and simulation geometries, and published in Ref. [1], the recommended detector positions of the simulation (GEANT) geometries to best align with the most recent technical computer aided designs (CAD). In that 2020 document, it is strongly stressed that detector placements were likely to change in the course of the coming year, in response to the allowances for support structure and improved technical designs and in the main, this is exactly what occurred.

One such substantive change was the anticipated elongation of the box enclosure of silicon-tracking-system detector (STS), warranted by an internal expansion of the spacing between sensor layers. It had been believed to make space of the box enlargement, the target would need to shift upstream by 4 cm, in order to avoid collisions with other volumes, and would thus affect many detector subsystems by increasing their distance to the target. It had been decided by the technical board in April 2020, that such a change request could be accepted but only once a new STS simulation geometry, which realised these changes in pitch and length was developed and made available to the community. These STS geometries were developed by Mehul Shiroya during the course of the year, and was distributed to the wider collaboration in November 2021 via its inclusion in the official geometry repository available at https://git.cbm.gsi.de/CbmSoft/cbmroot_geometry. Its development is documented in Ref. [2] of this report. It should be perhaps noted that after full implementation of this change, and due to small miscellaneous changes which saved some space, the target shift may not have been needed as the STS still would have a 1.2 cm clearance to neighbouring matter. It is therefore possible that this decision may be revisited in the near future, especially if simulations show detrimental performance of our detectors. Major geometry changes during the year 2021 with a particular focus on changes that occurred across CBM subgroups will be discussed in Sec. 3 of this manuscript which addresses the default experimental setups which coincide with our DEC21 software release.

In addition to these many changes, it was decided to act now on the widely held desire to change the origin of the CBM experiment. Since its inception, the origin had been naturally defined as the target position, which has a conceptually convenient location to imagine the initial beam particle interactions. However, it suffers from a lack of

fixed-position status which is believed to be crucial for direct comparison between the CAD and the GEANT geometries. This was partly emphasised by the STS change which moved the target, meaning that the origin would need to be defined as a distance along the nominal beam axis from another fixed point. Additionally recent requests have been made that the target should be capable of being moved depending on the beam momentum. The design of target exchange device, Ref [3], proposed during the course of the year hasn't this capability yet. The magnet is a massive fixed structure, centred symmetrically around the nominal beam axis. Its centre of the mass, coinciding with a non-physical point in space, under vacuum, inside the beampipe, inside the STS box, is a natural reference point defined by the magnetic field of our experiment. The nominal beam axis and the vertical direction through the centre of the magnet provides sufficient orientation to this point, which, along with standard distance measures, allows us to define a coordinate system which satisfies our technical requirements whilst being non-arbitrarily defined. It is a special point being the centre of the magnetic field. It was thus decided that the *centre of the magnet* should become our new origin. Although such a change would and did erect many challenges for development of our software framework (CBMROOT), it was expressed by senior developers at our software meetings, that changing the origin within the CBMROOT simulation environment, may even help find issues within our code base which may, in the long-run, lead to a more robust software environment. In Sec. [2] of this report, this information is documented for perpetuity and recorded for future reference by the collaboration.

When also considering that the CBMROOT code base changed considerably between the APR21 release and the DEC21 software release with the additions of several new features, coordination of the realisation of the last two paragraphs into our simulation geometries introduces a real dilemma on how to maintain control when making two or more changes to each detector geometry. In order to test and validate a software release with new features, a nominal change in the position of the target, a new defining origin and coordinate system, plus the normal incremental improvements to our subsystem geometries, a two step approach was pursued. In the next section of this report, we updated all default geometries in Ref. [1] from our APR21 software release with the newly defined origin. In the subsequent section, we discuss new geometries introduced for DEC21 with particular emphasis on our new DEC21 geometry defaults.

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2. Coordinate Change (APR21 → APR21+)

Several detectors had their geometries updated which often changed their length as well as their placements. New space provisions needed to be accounted for, in particular, for incorporation of the proposed beam-pipe designs, cf. Refs. [4, 5] of this report. A target shift was planned and a coordinate system which redefined the origin from the target position to the centre of the magnet. A script which switched between the two coordinate systems, and the candidate default geometries was distributed in the macro geometry folder of CBMROOT and was announced at the CBMCM (Ref. [6]) Uptake of this tool by the community was however disappointing, probably due to a lack of manpower across CBM subgroups. Once the feature freeze for the DEC21 software release was announced, a two stage approach to transition from the APR21 default geometries was in the end forced so that consequence of each change on the software could be traced effectively. A new intermediate geometry for each subsystem was created to be identical to the APR21 default geometry but with the new coordinate system. For most geometries, this meant a defacto translation of the geometry upstream by 40 cm to account for the centre of the magnet being 40 cm downstream from the old target position. For geometries such as the STS, RICH, MUCH and PIPE the translation occurred in the near top volumes of the geometries whilst the TRD, TOF, and PSD had their positional matrices directly modified. Their macros were supplied to CBMROOT and corresponding binaries were made available via the geometry repository. Additionally new parameter and material budget files also needed to be created in the parameter repository, available from https://git.cbm.gsi.de/CbmSoft/cbmroot_parameter. The same MVD as in Ref. [7], could be used without incorporation of the coordinate change as it is essentially embedded into a volume, named “pipevac1”, of the beam-pipe which itself moved. However, during the testing process, MVD geometries v20c, v20d were requested by the tracking team for use with the beam-pipe which did not shift the “pipevac1”

volume. One of these beampipe geometries (Ref. [2]) is the current default so these MVD geometries are also used as defaults. Simulation versions of complete technically feasible candidate beampipe, Refs [8, 9], are distributed in the DEC21 release although not as defaults as no testing period could be performed.

These geometries which could be directly compared to the APR21 defaults but defined in new coordinate system of the magnetic field were colloquially called APR21+ setups where the plus symbol referred to the addition of a new origin. For naming of the APR21+ geometries, an increment of the letter index of the tag rather than an update of the number which represents the year was preferred so as to not be confused with geometries with new features. The RICH detector and PLATFORM geometry were exceptions to this loose rule. The APR21+ geometries are listed in Tab. 1 and may be compared with the APR21 geometries in Tab. [1] of Ref. [1]. The testing period for these geometries turned out to be extensive as this change in particular revealed several issues in CBMROOT after the DEC21 code freeze. Namely changes to TOF and RICH tracking needed to be fixed before the final release. It is expected that the APR21+ geometries, not used as DEC21 defaults, will be removed from distribution in the near future.

3. New Defaults (APR21+ → DEC21)

In relation to CAD updates during the past year, many of the systems, that will make up the CBM Experiment moved closer to production. As such, the level of detail in the planning and CAD modelling increased significantly. Major changes include technical geometries for MVD, STS, MUCH, TRD, TOF and PSD, which were all submitted in the time after last years progress report. Apart from detectors, a lot of infrastructure was included in the models, as shown in the collaboration meeting in late 2021. Very recently, the Cryo installation for the magnet and the steel construction for the upstream platform were updated with close to final designs and a concept for the beampipe

SUB	Electron	Hadron	J/ψ	LMVM
MAG	v21a	v21a	v21b	v21b
PIPE	v16e_1e	v16e_1e	v20b_1m	v20b_1m
MVD	v20a_tr	-	-	-
STS	v20a	v20a	v20a	v20a
RICH	v21a	-	-	-
MUCH	-	-	v20c.*jpsi	v20c.*lmvm
TRD	v20c_1e	v20c_1h	v20c_1m	v20c_1m
TOF	v20c_1e	v20c_1h	v20c_1m	v20c_1m
PSD	v20c	v22c	-	-
PLAT	v13a	v13a	v13a	v13a

Table 1: APR21+ geometries. Geometries required in a validation and testing stage for the DEC21 SW release. Simulation of electron, hadron, J/ψ and LMVM experimental setups of the CBM experiment at FAIR. The ‘*’ abbreviates ‘_sis100_1m_’ in the tag name.

SUB	Electron	Hadron	J/ψ	LMVM
MAG	v21a	v21a	v21b	v21b
PIPE	v21d	v21d	v21d	v21d
MVD	v20d_tr	-	-	-
STS	v21e	v21e	v21e	v21e
RICH	v21a	-	-	-
MUCH	-	-	v21c.*jpsi	v21c.*lmvm
TRD	v20b_1e	v20c_1h	v20c_1m	v20c_1m
TOF	v21a_1e	v21a_1h	v21a_1m	v21a_1m
PSD	v22a	v22c	-	-
PLAT	v22b	v22b	v22b	v22b

Table 2: DEC21 geometries. The 2021 geometry versions in the DEC21 software release for simulation of electron, hadron, J/ψ and low mass vector meson (LMVM) experimental setups of the CBM experiment at FAIR. The ‘*’ abbreviates ‘_sis100_1m_’ in the tag name.

was included. Since each of these points is described in more detail in the respective subsystem sections of this report, only a summary of the currently used models and their submission dates is given in the following list. Current used models in CAD were last updated in:

- MVD 07.04.2021
- PSD 08.04.2021
- STS 20.02.2022
- Magnet 25.06.2021
- RICH 04.11.2020
- Cryo 08.12.2021
- MUCH 29.09.2021
- Beampipe 21.02.2022
- TRD 08.10.2021
- Platform 03.02.2022
- TOF 15.02.2022

The rest of this section will address the effect of convergence to new technical redesigns on the simulation geometries. Several geometries with new layouts were introduced in the DEC21 release, and so were not directly comparable to their APR21 counterparts. In many cases, an origin-changed geometry also needed to be created, along with the binaries and parameter in the same fashion as was done in previous section. This occurred due to the geometry being created before the origin change was demanded at the geometry submission stage. For example, the MUCH geometries (Ref. [10]) were already made available before the APR21 software release, but were not included at that time as default geometries due to insufficient testing and validation. New MUCH geometries were created for the release.

It was decision in the SWM in February 17th 2022 that the PSD should be placed away from the beam in its parking position, v22c, for the hadron setup. Tab. 2 contains a list of the current setups and the default geometries to be used for each setup. Since APR21 release (Ref. [1]), many of the geometries were updated, upgraded, and redesigned.

Table 2 contains a list of the geometries in the DEC21 release and Tab. 3 contains the positions of all detector subsystems from the centre of the magnetic origin point. Some additional changes of the distance between the target and detector as compared with Tab. [2] and [3] of Ref. [1]. It is noted that space provision for inclusion of a bellows assembly (Ref. [5]) matched the displacements between the old target position and the centre of the magnet thereby making geometries appear to maintain their positions whilst in fact being 44 cm further from the nominal target position. Also as a consequence, there is now no significant distinction of the possible positioning of downstream detectors between the muon and electron setups.

Unlike in Ref. [1], provision of the beam-fragmentation T0 counter is, at the very minimum, paused due to Russia's invasion of the Ukraine which has lead to Western countries to sanction Russia, which has had huge implementation for international scientific facilities and collaborations such as FAIR and CBM. Changes in technical and simulation geometries, and the experimental setups will likely change dramatically as an indirect consequence.

SUB	width	height	length	position
MAG	4.4	3.7	2.0	-0.2
MAG (clamps)			2.38	-0.39
MVD (TR)	0.8	0.8	0.525	-0.36
MVD (VX)				-0.39
STS	2.38	1.423	1.338	-0.1
RICH	6.0	5.478	2.2	1.388
MUCH (J/ ψ)	5.0	5.0	3.52	0.85
MUCH (LMVM)	3.88	4.03	2.5	0.85
5th Absorber	5.0	5.0	1.0	3.27
TRD	9.9	8.55	2.9	4.4
TOF	13.5	10.78	2.19	6.9
PSD	4.85	10.04	1.96	10.1
lat.				-0.9
vert.				0.7
angle				3°

Table 3: Dimensions of detectors and position distances from the origin defined as the centre of the magnet. All measurements are in meters, width is the left to right view looking at the subsystem (SUB) from the beam perspective, height is vertical, and lengths are along the beam axis. The subsystems are centred on the beam axis.

References

- [1] E. Clerkin and P. Dahm “Recommended SIS100 subsystem positions for simulation of the future CBM experiment at FAIR” CBM Progress Report 2020 pages 170-173
- [2] “Update on the simulation geometry for the Silicon Tracking System” M. Shiroya, D. Emschermann, E. Clerkin, V. Friese, A. Toia, O. Vasylyev, and P. Dahm CBM Progress Report 2021 (this journal)
- [3] “Construction of a target exchange device for the CBM experiment at FAIR” P. Dahms CBM Progress Report 2021 (this report)
- [4] “STS beampipe section: Concept and development status” J. M. Heuser, O. Vasylyev, M. Faul, and A. Senger CBM Progress Report 2021 (this journal)
- [5] “Beam following assembly” J. Kollarczyk, P. Chudoba, M. Janda, M. Smetana, F. Lopot, and A. Kugler CBM Progress Report 2021 (this journal)
- [6] “How realistic are our simulations? - Addendum” E.Clerkin 38th CBM Collaboration Week (September 2021) <https://indico.gsi.de/event/13089>
- [7] P. Klaus, M. Koziel, J. Michel, C. Muntz, J. Stroth “CBM-MVD: Updated MVD simulation geometry” CBM Progress Report 2020 page 174
- [8] “Status of PSD Beam Pipe GEANT4 geometry” P. Chudoba, M. Janda, J. Kollarczyk, M. Smetana, A. Kugler, and F. Lopot CBM Progress Report 2021 (this journal)
- [9] “Candidate SIS100 beampipe geometries for simulation” E. Clerkin CBM Progress Report 2021 (this journal)
- [10] “Implementation and performance simulation of realistic design of the GEM chambers for the first two stations of MuCh” O. Singh, S. Chatterjee, P. P. Bhaduri, and S. Chatopadhyay CBM Progress Report 2020 pages 79,80

Real and simulated CBM data interacting with an ESCAPE datalake

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Introduction

ESCAPE is an on-going EU-funded Horizon 2020 project whose aim is to standardise, store and share data from large scale European astronomical and particle physics infrastructure under the auspicious of open science, sharing data, and possibility of leveraging efforts of citizen scientists worldwide towards astronomy and experimental particle physics research. The FAIR particle accelerator in Darmstadt is a member of this collaborative cluster and the CBM experiment as a pillar of FAIR has been proactive in engaging with testing, and validating the tools for this open science project. In particular, in the case of the CBM experiment, here we document the CBM interacting with the FAIR and CERN datalakes, which are distributed repositories of raw or blobs of semi-structured data used for managing big data, as maintained by other work-packages of the ESCAPE project. For information on ESCAPE, Refs. [1, 2, 3] and the references therein may be consulted.

We wanted to showcase a spectrum of CBM data interacting with ESCAPE data environment in a broad sense. Fig. 1 shows a highly simplified block diagram of possible interaction points of CBM and ESCAPE. The CBM experiment is in its production stage and its software suite CBMROOT is still under active development, but we nevertheless wanted to showcase ESCAPE interacting with both experimental and simulated data. On the simulation side, many of the existing tools may be tuned to interact with the ESCAPE datalakes. In particular we will interact with the datalake as our storage medium for input and output of data for transport and digitisation stages. For real experimental data, CBM has a mini CBM project (mCBM; cp. Ref.[4]) which takes beam from the existing GSI SIS18 accelerator and is used by us in the CBM collaboration to test hardware and software of the full CBM. It will here give us the exciting opportunity to showcase ESCAPE interacting directly with a functioning particle physics experiment under real-time data injection conditions. This was the first-time a showcase of this kind was shown. Lastly, to complete the data demonstration, the final task was to interact at the reconstruction of tracks stage which may be thought of as the basic data analysis step. We had the two options to either interact with simulated data or with the mCBM real experimental data. It was decided to use real data from mCBM July 2020 data processing run as a stronger statement of ESCAPE usability. These three demonstrations were prepared during the course of 2021 and the efforts accumu-

lated and showcased during a single week period for the data acquisition challenge (DAC21) in November 2021. In each of the three sections that follow, we report on the success of each of these challenges. This report was compiled from the DAC21 activities logbook. All times are approximate and in UTC.

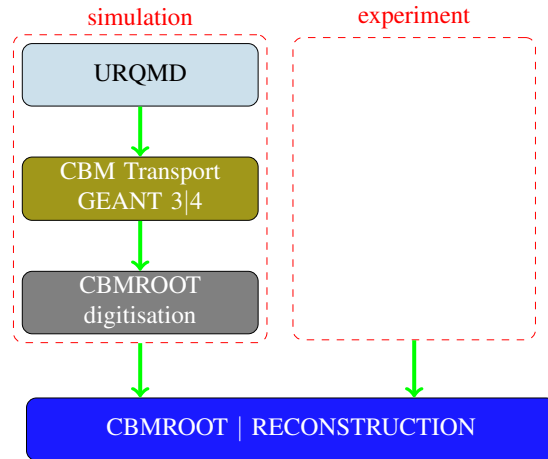


Figure 1: Basic block diagram layout displaying interaction points between the CBM toolkit and external software packages for the CBM experiment at GSI/FAIR.

mCBM data ingestion

In order to showcase the injection of real-time data, it had been hoped that mCBM cosmic-ray data taking which was originally planned for early November would be available. During late November, this had been rescheduled for December. During the DAC, it was instead decided to replay acquisition of data taken by mCBM in July 2021. From the data-lake point of view, this is functionally the same as if we had data coming directly from the detector. Fig. 2 shows a photo of the mCBM experiment at this time, with the detector acronyms overlaid.

The task and our team was split between a replay side and an injection side. The physical transfer of data was not needed in this demonstration. It was noted that the FAIR datalake was hosted on the same lustre filesystem as was replayed to by the replay team, but instead replicas of the data were registered to the datalake providing its functionality.

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Replay Side

- 2021-11-23, 15:00 - preparatory scripts for replay start. Several issues needed to be overcome whereby locked-in commands tried to specific ssh-keys were disabled by IT administrators. Our original plan therefore needed a work around and an alternative approach was pursued. The process was achieved by rsyncing of the experimental data over Infiniband at 150-200 MB/s, with 10 parallel copy jobs run on the GSI Green IT Cube cluster, leading to a 2 GB/s average rate. This rate was chosen to mimic the approximate high rate of mCBM data taking. The job array started at 18:32, most of them (9/10) finished around 18:36. One of the files had a much reduced writing speed of 800 kB/s due to an unknown reason. Writing for the final delayed file closed at 19:56.

Infrastructure used: As a source, two compute nodes of the miniFlies cluster (experiment side cluster of the mCBM), with each 5 HDD (4 TB) holding the original data files of the mCBM 2021 beam campaign. The files were written in parallel so at least one file from each HDD is needed to reconstruct a segment of any mCBM run.

mFLES to Virgo (GSI batch cluster hosted in the Green-Cube building) Infiniband backbone comprises of 10 Virgo logical nodes (SLURM jobs with non-default resources options), with 8 GB RAM each, each executing an rsync process to one of the mFLES HDD for the first 10 files of a typical mCBM run.

Ingestion Side

- 2021-11-23, 15:30 - initial setup
- 2021-11-23, 17:30 - status check shows no replicas or rules having been registered with Rucio in spite of the first batch of files having already appeared in the

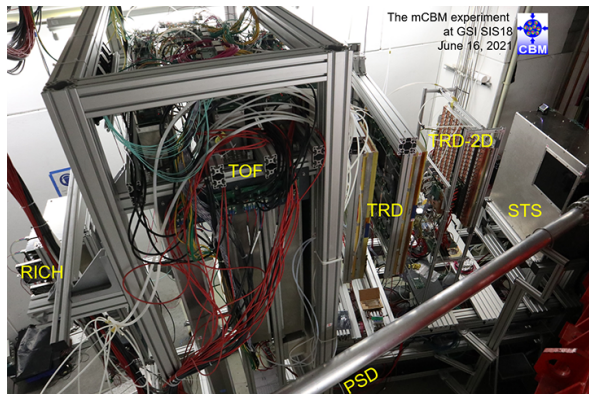


Figure 2: Above image shows the mCBM experimental setup. The beam pipe is visible transversing the lower right quadrant and the target box on the right centre of the photo. Each of the six detectors subsystems are over-labelled.

source directory. Problem tracked down to file-system notifications not functioning as expected, began converting the script to polling mode

- 2021-11-23, 18:00 - tests of converted script repeatedly fail on connections to the CERN Rucio server being refused. Eventually discovered that recent changes to GSI network which allowed direct access to FAIR-ROOT from our compute cluster, now require rucio-clients traffic from FAIR-ROOT to the Rucio server to go through a local HTTPS proxy
- 2021-11-23, 18:30 - refactored script launched successfully, with forced delay of 60 seconds between files to avoid pile-up. Replicas begin to be added to the data lake
- 2021-11-24, 13:00 - status check shows 92 replicas registered successfully but owing to a typo, the script only ran once instead of periodically. Ran the script again to register the remaining 8 files
- 2021-11-24, 13:15 - final status check shows all 100 replicas registered successfully. Conducted a random sampling of associated DIDs, all files accessible

Conclusions

Achieved asynchronous zero-copy injection of mCBM data into the data lake. Registering a replica and a corresponding replication rule took 30-60s per each 4-GB file (having subtracted the aforementioned forced delay), i.e. comparable to the rate at which the data has been replayed

Current bottleneck: calculation of Adler32 checksums (which obviously has to be done at least once, although with a bit of care one can avoid repeating the calculations for unchanged data) on the client side prior to registration of new replicas. This would ideally use checksums calculated by the underlying file system at the time of data being stored (if available and possible to be extracted at file rather than inode level), however Adler32 appears to be supported by rather few modern file systems and may not be available even when supported (e.g. at GSI - Lustre does support Adler32 but our cluster uses CRC-32C for performance reasons)

Possible future development in Rucio: add support for more modern checksum algorithms (e.g. xxhash as fast hash and SHA256/BLAKE2B as strong hash), ideally featuring a transition path from the current Adler32+MD5 schema

CBM simulation

The future CBM experiment at FAIR in its electron configuration with a MVD, STS, RICH, TRD, TOF and PSD detectors was simulated. (See Fig. 3) This constitutes the most detector rich configuration of the full CBM experiment.

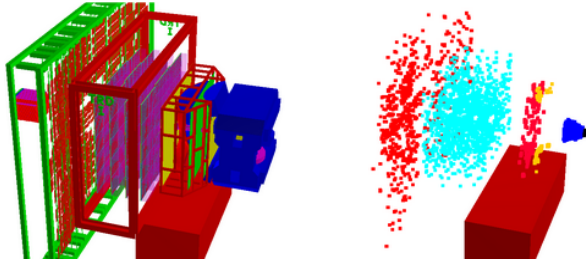


Figure 3: Left shows the CBM simulation geometries for the future CBM experiment at FAIR. It consists of a blue magnet yoke on the right, followed by the RICH detector, the TRD, the TOF and PSD detector on the left. The beam enters from the right. The STS detector is contained inside the magnet. Right shows hits after transport from the demo scripts used during DAC21. Black (Blue) points show hits in the sensors of the MVD (STS) detector.

Task completed during (Thu 2021-11-25) and (Fri 2021-11-26). In the weeks before the challenge, several docker images and demo scripts were prepared. CBMROOT, our simulation software developed at GSI/FAIR for the simulation of the CBM experiments is built upon FairRoot which in turn is built upon FairSoft software packages. Docker images for each of these steps, starting from the most recent stable docker-hub Debian release were produced. Finally a fourth docker image containing the necessary python, gfal, rucio [5], java, voms-client [6] and xrootd [7] was subsequently built on top. This allowed the task to be completed using a standard MacBook connected to a network external to GSI running a docker container.

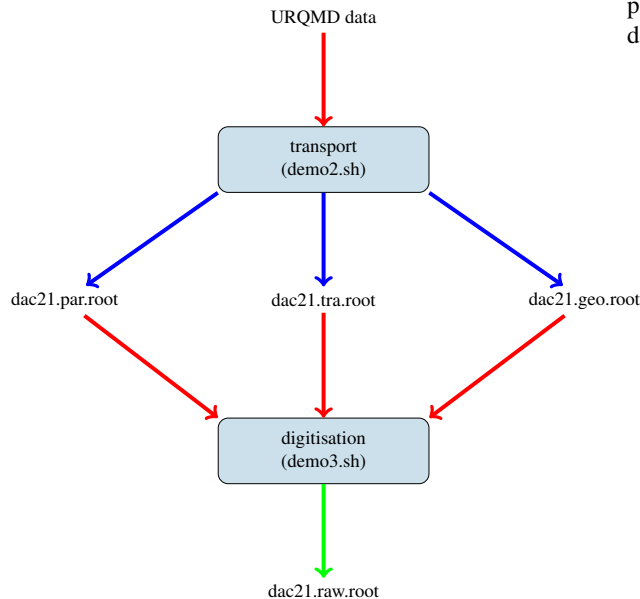


Figure 4: Demos used in simulation challenge. The red arrows show data extracted from data lake, and the blue arrows show data sent to the datalake.

Demo script one (demo1.sh) uploaded initial URQMD data to the data lake using Rucio and followed an extraction from the data lake. The file was consistent with initial interaction of a gold beam of 10AGeV on a gold target. File consistency was verified via md5sum before and after uploads. Subsequent running of script would have returned failure as this data had already been placed on the datalake and therefore would not have been needed to be run during DAC21.

A second demo script (demo2.sh) simulates the transport of particles through the CBM experiment in its electron setup as shown in the left panel of Fig. 3. Three data files are uploaded to the data lake containing parameters, geometry and transport data as symbolically represented by the blue arrows in Fig. 4. It was decided that the demo script would run as a cron job running every 5 minutes which started on Thursday evening and continued through to Friday midnight.

A third script (demo3.sh) extracted some of this transport data and generated digitisation data which was run ad-hoc during the two days. Hits in the sensors of the CBM detector for a typical run is displayed in the right panel of Fig. 3. Demonstration was sporadically successful. It is noted however that interaction with the datalakes gave error messages due to server side issues. Additionally, timeout of voms proxy was also an issue, as some long timelapses between connections occurred. Success and failure statistics are discussed in the proceeding study.

mCBM reconstruction

Goal of this task was to reconstruct recent mCBM (July 2021) data interacting with the data lake. Task was completed inside a docker container run on a Gentoo Linux desktop machine on the internal GSI network.

- 2021-11-22 It was noted that much of our demo environment developed for this task suddenly became obsolete due to changes in the development branch of CBMROOT which required updated versions of FairSoft and FairRoot. To make matters worse, these were major rather than incremental changes which required modification of the installation process. Bleeding-edge CbmRoot was needed for reconstruction of July data as tracking and reconstruction code were being actively developed. The necessary CBMROOT software was not available to complete this task on this day.
- 2021-11-23 Development of new Docker Images built on latest stable Debian, building a FairSoft image, on which a FairRoot image was built followed by a CbmRoot image. Finally an image with Rucio, gfal libraries, xrootd and all necessary additions to CBMROOT necessary to complete this task was built on top of the CbmRoot image.
- 2021-11-24 Although unpacking of mCBM had been working for a week prior to DAC21, unpackers had

made it into CbmRoot the week prior, several developments in the reconstruction data still had not been submitted to the CBMROOT development branch. It is therefore difficult to prepare for this DAC21 task ahead of time. On this day, our CBMROOT software was still not able to reconstruct the 2021 data and we seriously planned to switch to plan B which meant reconstructing 2020 data instead.

- 2021-11-25 New tracking and reconstruction code merged to the development branch of CbmRoot by its tracking team. These new CBMROOT macros allow reconstruction of the real experiment 2021 data from the SIS18 experiment shown in Fig. 2. The simulation geometries shown in Fig. 5 was used during the reconstruction process.
- 2021-11-26 13:00 CbmRoot source code updated and rebuilt within the running Docker container. This was also done so as to not have to rerun the docker image which was being used for the task.
- 2021-11-26 15:00-19:00 Several demonstration scripts tested and completed our task although in an ad-hoc fashion. Decided a systematic approach is warranted.
- 2021-11-26 18:47 Some raw mCBM data from run 1588 taken during July 2021 is uploaded to the data lake using a Rucio-upload command. This forms the basis for later reconstruction.
- 2021-11-26 20:05 Script (demo6.sh) pulls this mCBM data. If pull is successful then continues, otherwise failure 1 is output to the log file. Next the script reconstructs the data using standard mCBM reconstruction macros merged into CBMROOT the day before. Upload reconstructed data to data lake otherwise declare failure 2 to the log files. Only full completion is considered a success.
- 2021-11-26 20:05 In order to get some success/failure statistics, this demonstration was run one hundred times with the script (demo6.sh) in a “for” loop with a 60 second sleep between runs.

Statistics trial started at 21:04:50 and ended at 23:25:50. Of the 100 cases, 0 had “failure 1”, i.e. reading the raw mCBM data from the data lake using a Rucio-get command, 75 had “failure 2”, i.e. writing the reconstructed mCBM data to the data lake using a Rucio-upload command, and 25 were deemed fully successful having no failures reported. The failure rates were high, as one of the protocols failed on the clients side. The target RSE supported both “root://” and “davs://” as protocols. When contacting the RSE via the Rucio upload command, the Rucio client primarily chose “davs://” as the protocol. The “davs://” protocol was not supported in the container due to a minor error in the configured paths. gfal2, using its HTTPS plugin, couldn’t resolve the libdavix dependencies correctly. It

therefore reported that the protocol is not supported. The error message also contained “The requested service is not available at the moment”, which is misleading and lets a user believe that the service was at fault. Despite the high failure rates, overall the challenge was deemed successful as a showcase of reconstruction of mCBM data interacting with the ESCAPE data environment.

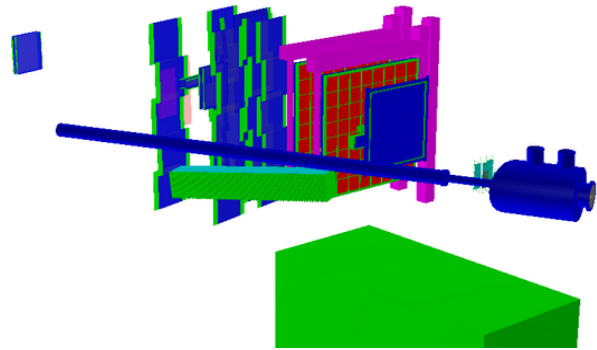


Figure 5: Shows the simulation geometries of the July mCBM setup. The figure is comparable to the photo shown in Fig. 2

References

- [1] R. Bolton, S. Campana, A. Ceccanti, X. Espinal, A. Fkiaras, P. Fuhrmann and Y. Grange “ESCAPE prototypes a data infrastructure for open science” EPJ Web of Conferences 245, 04019 (2020) CHEP 2019
- [2] M. Allen, G. Lamanna, X. Espinal, K. Graf, M. van Haarlem, S. Serjeant, I. Bird I, E. Cuoco, and J. Wagh “ESCAPE-addressing Open Science challenges”
- [3] R. Di Maria, R. Dona “ESCAPE Data Lake” EPJ Web of Conferences 2021 (Vol. 251).
- [4] “mCBMSIS18 – A CBM full system test-setup for high-rate nucleus-nucleus collisions at GSI/FAIR” The CBM Collaboration, Letter of Intent, 19 June 2017
- [5] C. Serfon, M. Barisits, T. Beermann, V. Garonne, and L. Goossens, M. Lassnig, A. Nairz, R. Vigne, Ralph et al. “Rucio, the next-generation Data Management system in ATLAS” Nuclear and particle physics proceedings, 2016, volume 273, pages 969-975
- [6] Alfieri R, Cecchini R, Ciaschini V, Frohner A, Gianoli A, Lorentey K, Spataro F. “VOMS, an authorization system for virtual organizations” European Across Grids Conference 2003 Feb 13 (pp. 33-40)
- [7] Bauerdick LA, Bloom K, Bockelman B, Bradley DC, Dasu S, Dost JM, Sfiligoi I, Tadel A, Tadel M, Wuerthwein F, Yagil A “XRootd, disk-based, caching proxy for optimization of data access, data placement and data replication.” Journal of Physics: Conference Series 2014 Jun 11 (Vol. 513, No. 4, p. 042044)

Infrastructure for the CbmRoot Continuous Integration Pipeline

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During the last year, the existing Continuous Integration (CI) pipelines for the CbmRoot project were extended and improved. Beside the jobs itself, these changes mainly affect the hardware infrastructure on which the jobs of the CI pipeline are executed. In the beginning, for each supported OS, some real hardware with an installation of this OS had to be maintained, while today only one base OS needs to be supported for the real hardware. The actual jobs of the CI pipeline are meanwhile only executed in virtual environments like containers or virtual machines.

Continuous Integration

As described in [1], the CbmRoot software project uses a development workflow based on merge requests. In this workflow the different developers work in their own workspace and request integration of their development in the main repository when they have finished their development. Before this integration can happen, it must be confirmed that the integration is possible from a technical perspective as well as from the software perspective.

These checks happen automatically after a developer has created a so called Merge Request (MR) on our GitLab [2] web interface. A picture of the complete Continuous Integration (CI) pipeline, which currently consist of 4 different stages, most of them with several parallel steps, is shown in Figure 1.

In Figure 1 the processing order is from left to right and any following stage is only executed if all jobs of the previous stage have finished successfully. In contrast to the sequential execution of the different stages, the execution of the jobs inside one stage happens in parallel, at least if the needed resources are available. Since many MRs can happen in parallel there is always the possibility that all available resources are already used. In such a case a job will only start when a needed resource becomes available.

In the first stage (*Checkrepository*) it is checked if the MR can be added to the existing code base without introducing any conflicts, whereas the second stage (*Checkformat*) checks if the code foreseen for integration fulfills some formal requirements like the existence of the proper license header or the correct code format. During the third stage (*Build*) the code foreseen for integration will be compiled and tested on several different supported Operating Systems (OS) and potentially also for different combinations of our dependencies FairSoft and FairRoot. Each job of this stage uses the CMake [3] based build system of CbmRoot and automatically uploads in the end of the job some results to our CDash [4] webpage

(<https://cdash.gsi.de/index.php?project=CbmRoot>) for later usage. If also this third stage succeeds, in the fourth and currently last stage (*Finalise*) the code owners are informed and a code review is requested from them. A code owner is a developer which is responsible for the code touched by the MR. Depending on the affected code several code owners may be informed. The ownership is defined based on the directory level of the CbmRoot project. For example for the code of each of the detector subsystems a developer of this subsystem is responsible to review changes of this code. If the CI pipeline has successfully finished and the code owners have reviewed and accepted the new code, the changes are finally merged into the main code repository.

The different stages of the CI pipeline and the jobs inside each stage are defined in a special file which is part of the CbmRoot repository. The orchestration of all the jobs is done by the GitLab service itself which sends the jobs for executions to registered computers and receives back the log output as well as the result of the jobs. The service takes care that all jobs of the complete pipeline are sent to the proper computers in the correct order.

Infrastructure

The CI pipeline is very flexible such that new stages and jobs can easily be added or removed if necessary. The problem with this flexibility is that the computing resources which are used to execute the jobs must be scaled in the same flexible way. This scaling was one of the major issues when CBM moved to GitLab and the described MR workflow, since our computing environment couldn't cope with the workload enforced by many parallel MRs. The second major issue was that for each supported operating system which should be tested in the build stage a running system of this type is needed. When moving to GitLab and the MR workflow, this meant to install, administrate and maintain a zoo of hardware and operating systems. This maintenance work needs sufficient manpower which we didn't have, such that this shortcoming was the main reason that we could only support a minimal set of OSs for the Build stage and a rather small CI pipeline. A setup with real hardware for each OS would mean to scale the hardware for each of these OSs with required workload, so it became pretty obvious that a solution with several OSs on real hardware was out of question. The direction we went was towards virtualization which means in our case containers and virtual machines [5]. The advantage of virtualization is that one needs not to setup several different op-

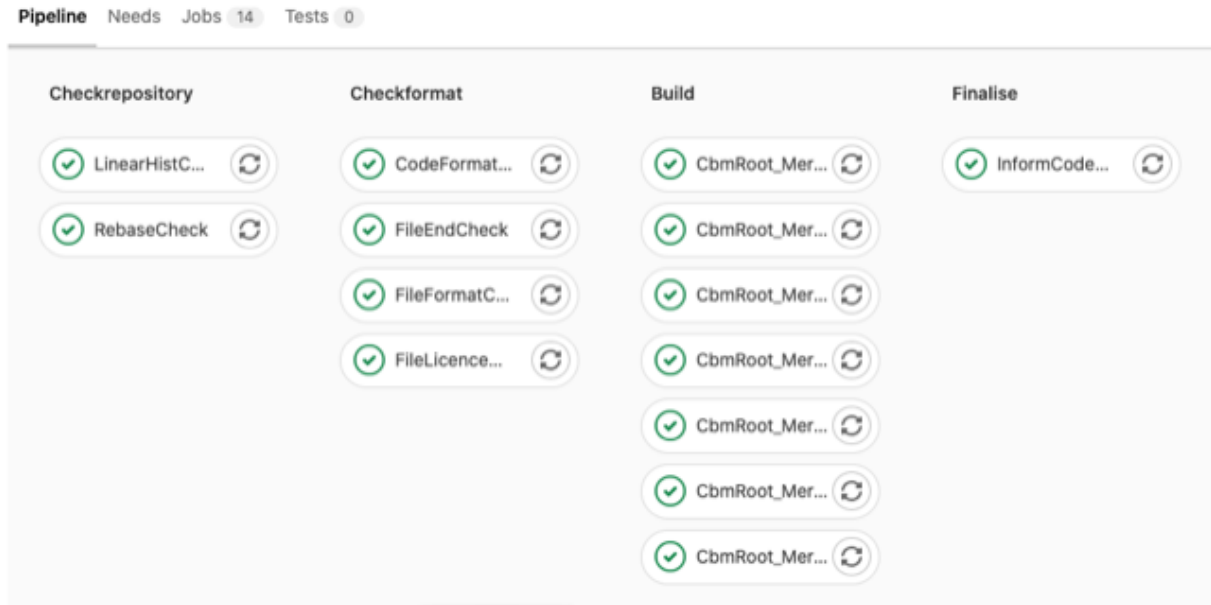


Figure 1: CbmRoot CI pipeline.

erating systems on real hardware but only one type which allows to run any type of other OS in virtual environments.

Since our colleagues from the FIAS institute in Frankfurt already set up a computer which allowed to execute Docker containers [6] as well as the interface between GitLab and Docker (docker runner), we moved all jobs which did not need a full FairSoft/FairRoot installation from real hardware into Docker containers. We started with these type of jobs since they could be executed in a generic container which was already provided by the Docker community. Scaling these jobs is as simple as starting more Docker containers up to the point the real hardware is overloaded and does not allow to start any new jobs till another job has finished. If this resource problem happens too often a new docker runner needs to be installed and connected. Meanwhile we operate 5 docker runners which are not only used by the CbmRoot CI pipeline but also by the CI of several other projects. Setup of a new docker runner needs below one hour.

For the jobs which needs a full FairSoft/FairRoot installation to build CbmRoot on Linux systems we had two possible solutions. Either we use also docker containers which we would need to build ourselves or we use singularity [7], which is the container runtime supported at GSI and used on the Virgo cluster [8, 9]. The advantage to use docker containers is the existing docker executor which allows to easily run the jobs from GitLab. The advantage of singularity is that we can immediately use the containers and the existing FairSoft/FairRoot installations of the GSI infrastructure, but with the drawback that there is no interface between GitLab and singularity which allows GitLab to start the jobs. Since the advantages of using singularity pre-

vailed the disadvantages we developed the needed interface ourselves, which in the end turned out to be more easy than initially expected. Currently we operate 3 of these singularity runners which are exclusively used for the CbmRoot CI pipeline.

Beside Linux we also support macosx as operating system which is used by many developers, we run also build and test jobs on this platform for several versions of macosx. Unfortunately as macosx must run on specific Apple hardware and is also incompatible with the so far used container solutions, we were still left with three real computers with different macosx versions which we had to maintain, after moving all other jobs to containers. Fortunately it is possible to use VirtualBox [10] on macosx which emulates a complete computer in software. This allows to create virtual machines, install different macosx versions and finally run them on the same computer. There is also an interface to use VirtualBox from GitLab, which made it possible to reduce our hardware to only one host which executes virtual machines for each of the supported macosx operating systems.

With this final step all jobs of the CbmRoot CI pipeline can run in some virtual environment. This completely decouples the real hardware running the different virtual environment runtimes (docker, singularity and VirtualBox) from the virtual environments which are used to execute the CI jobs. Since we use standard docker containers and the GSI singularity containers, we only need to provide the macosx images for VirtualBox.

Configuration Management

The installation of the used virtualisation service (docker, singularity, VirtualBox) on real hardware is now a two step process. As first step a basic version of an operating system is installed on the host computer which is the same for all hosts. In a second step the actual service is installed using the IT automation tool Ansible [11]. Unfortunately this is only correct for Linux based systems, for macosx the workflow is different and not described in this contribution.

The installation of our basic operation system Debian 11 is nearly automatic for the CI infrastructure servers. To start the installation one needs to trigger a boot of the machine using the graphical management interface of the server. During the boot procedure the computer fetches an ISO image from a storage device and starts up the installation environment. Currently it is still needed to type the installation command on the command line which is also accessed from the graphical management interface of the server. After this step the installation is fully automatic and according to the configuration which is included in the ISO image. The installation procedure also installs a default user which is later needed during the configuration step. The complete installation takes roughly 15 minutes and in the end the host boots into the newly installed system which is now also reachable from the network.

The installation of additional software and users as well as the configuration of the service is completely described in scripts, such that reinstalling the service or newly installing the service will end up in an identical setup of the host computer. Depending on the service the complete installation and configuration of a service needs another 15-40 minutes, such that it takes something like 30-60 minutes to bring up a new service from scratch.

Recent developments

During the last one or two month sometimes very large runtimes for the complete CI pipeline were seen (3x normal time). Investigations of these runs showed that these runtimes were due to large runtimes of one of the macosx jobs. Debugging showed that from time to time the used virtual machine did not properly start but hanged, was terminated and then restarted, such that the CI jobs could only start with a delay of 30 minutes or even one hour if two restarts happened.

Beside this reliability problem there is also another constant overhead which results in longer runtimes of the macosx jobs. This overhead is due to the usage of VirtualBox: before a CI job could start the VM must be started, which needs a copy of the virtual machine image. Because of the large size of such an image, the copy procedure takes several minutes.

Another open source machine emulator and virtualiser for macosx is available: qemu. Initially developed for Linux, there is meanwhile also an interface to the native macosx virtual machine interface available, which allows

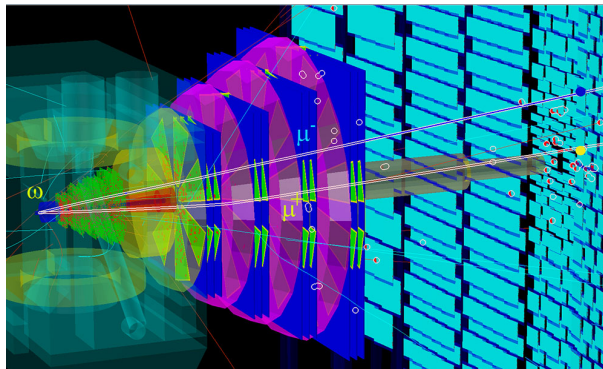
execution with nearly native speed. One of the advantages of qemu is that it can work in snapshot mode which does not touch the base image of the VM at all, but only saves the changes in a new file which will be dropped when switching off the VM. When using this feature there is no need to copy the base image which speeds up the start of the VM enormously. After one to two minutes the VM is running, compared to 10 to 15 minutes with VirtualBox. Also the start of the machine happens reliably. Comparing the execution times of a job between qemu and VirtualBox, the runtime of qemu is smaller by 10 to 15 minutes.

Again there was no interface between GitLab and qemu available, but with the experience of writing the GitLab to singularity interface, implementing such an interface was a matter of some days. Since beginning of May 2022 the new qemu bases macosx CI jobs are in production and so far no problems were found.

References

- [1] F. Uhlig, "The long way from Subversion to GIT", CBM Progress Report 2020 (2020) 178
- [2] GitLab Inc., "The complete DevOps platform", <https://about.gitlab.com/>, accessed at 05.05.2022
- [3] Kitware Inc., "About CMake", <https://cmake.org/overview/>, accessed at 05.05.2022
- [4] Kitware Inc., "Software Testing for Everyone", <https://cdash.org/overview/>, accessed at 05.05.2022
- [5] IBM, "Containers vs. Virtual Machines (VMs): What's the Difference?", <https://www.ibm.com/cloud/blog/containers-vs-vms>, accessed at 05.05.2022
- [6] D. Merkel, "Docker: lightweight linux containers for consistent development and deployment", Linux journal, 2014(239), 2
- [7] Syslab Inc., "SingularityCE", <https://sylabs.io/singularity/>, accessed at 05.05.2022
- [8] M. Al-Turany, "New Virgo Cluster", GSI Jahresbericht 2020 (2020) 89
- [9] GSI IT Department, "Virgo User Manual", <https://hpc.gsi.de/virgo/preface.html>, accessed at 05.05.2022
- [10] Oracle, "About VirtualBox", <https://virtualbox.org/wiki/VirtualBox>, accessed at 05.05.2022
- [11] RedHat Inc., "About Ansible", <https://docs.ansible.com/ansible/latest/index.html>, accessed at 05.05.2022
- [12] "QEMU, a generic and open source machine emulator and virtualizer", <https://qemu.org>, accessed at 05.05.2022

Physics Performance



Identification of Hadrons using PID framework

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The Compressed Baryonic Matter (CBM) experiment at the Facility for Antiproton and Ion Research (FAIR) aims to investigate the QCD phase diagram at high net baryon density, such as those found in neutron stars' cores.

A Muon Chamber (MuCh) detector in CBM experiment, consisting of hadron absorbers and tracking detectors for muon measurements, can be replaced with Ring Imaging Cherenkov (RICH) detector for electron identification. It is critical to measure leptons and hadrons simultaneously in order to obtain a complete picture of the reaction [1]. This could be accomplished with the RICH detector, which has a low material budget and has little influence on hadron trajectories on their way to the Time-of-Flight (TOF) detector.

In this work, Particle Identification (PID) Framework [2] is used to identify hadrons. This framework is based on graphical cuts and fitting parameters to predict a particle track to be of a particular hadron species. For this study, CBMROOT (APR20 version) is used.

One million events of 12A GeV Au-Au minimum biased collision are taken which are generated using DCM-QSM-SMM event generator [3] with transport engine GEANT4. The SIS100 electron setup of the CBM experiment is used for this study.

m^2 vs. $q \times p$ distributions are plotted for pure sample of protons, kaons, and pions and for all particles as well. Here m represents the mass calculated from the Time of Flight (TOF) detector. q and p represents charge and momentum of each track respectively.

Projection of $q \times p$ on m^2 are taken into slices and fitted with proper distribution functions (Gaussian for signal, second-order polynomial for background). Stabilized fitting parameters for each particle are used to calculate the Bayesian probability (purity) by using formula:

$$Purity_i = \frac{P_i}{(\sum P_i + P_{bg})} \quad (1)$$

P_i and P_{bg} are the probabilities of a track being associated with a hadron species and a background particle, respectively. Here:

$$P_i = A_i e^{-\frac{(\mu_i - m^2)^2}{2\sigma_i^2}} \quad (2)$$

and

$$P_{bg} = a(m^2)^2 + bm^2 + c, \quad a \neq 0 \quad (3)$$

A , μ , σ are the fitting parameters for signal and a , b , and c are the fitting parameters for background. This Bayesian probability or purity is further used to identify hadrons (proton, pion, kaon etc.).

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As we are interested in hadrons produced in the early stages, only primary particles are considered here by using their PDG values. Fig. 1(a) shows the hadrons based on their PDG values and Fig. 1(b) shows the particles detected as hadrons using purity greater than or equal to 90%.

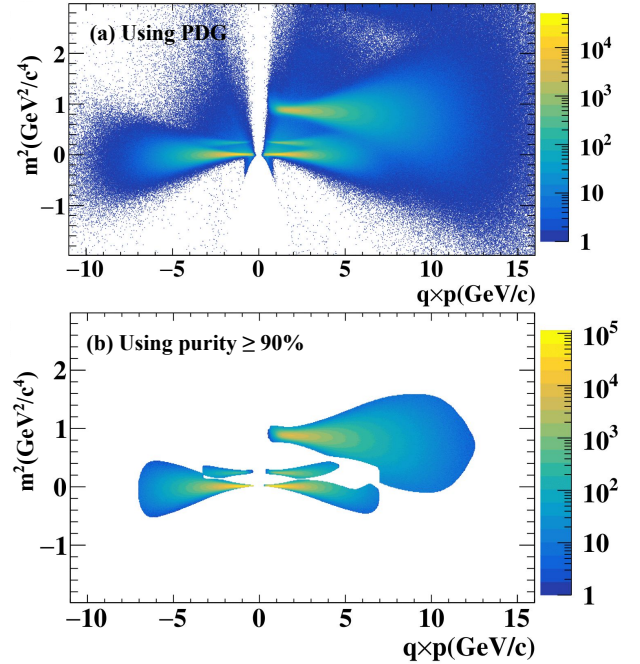


Figure 1: m^2 vs. $q \times p$ distribution for (a) hadrons detected using PDG, (b) particles detected as hadrons using purity $\geq 90\%$.

Recall and precision are calculated for each hadron species as follows:

$$Recall = \frac{\text{True particles using PID}}{\text{Total particles using PDG}} \% \quad (4)$$

$$Precision = \frac{\text{True particles using PID}}{\text{Detected as particle using PID}} \% \quad (5)$$

Further, we use distance of closest approach (DCA) to minimize the false particle detection using cuts $DCA_{proton} \leq 0.36$, $DCA_{\pi^+} \leq 0.58$, $DCA_{\pi^-} \leq 0.52$, $DCA_{K^+} \leq 0.84$, and $DCA_{K^-} \leq 0.75$. Fig. 2 shows comparison of recall and precision for each hadron species before and after using DCA cut. In the case of recall, we are compromising some true particles by employing DCA.

However, there is a large gain in precision for all hadron species.

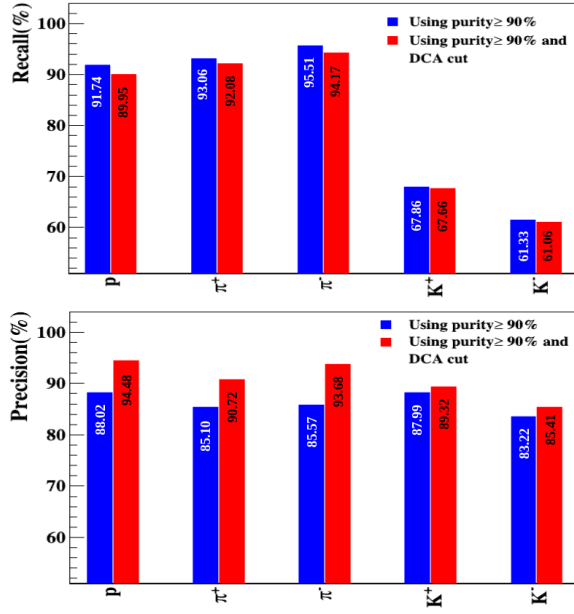


Figure 2: Comparison of recall and precision for each hadron species before and after using DCA cut.

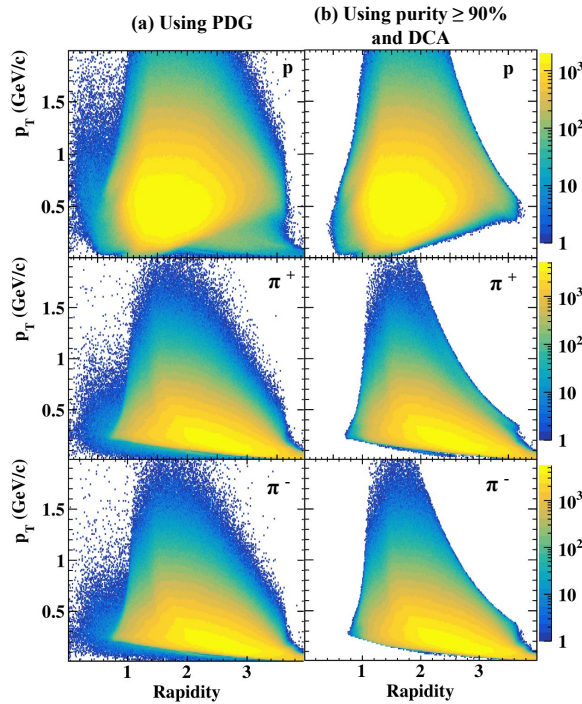


Figure 3: Rapidity vs. p_T distribution for proton, π^+ , and π^- (a) using PDG, and (b) using purity $\geq 90\%$ and DCA.

PID framework is able to predict protons and pions more

accurately compared to kaons. It is because of lower statistics of kaons compared to pions and due to merging of kaons with pions. Fig. 3 compares the rapidity vs. p_T distributions for proton, π^+ , and π^- as identified by PDG and PID framework.

Using the same predicted purity values for ultrarelativistic quantum molecular dynamics (UrQMD) event generator and for different GEANT3 and GEANT4 transport engine setups, we are able to detect hadrons to a similar extent with negligible difference which are compared in Fig. 4.

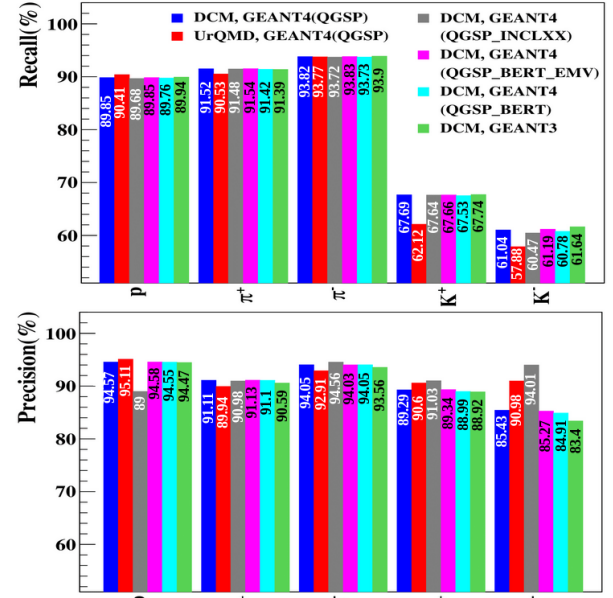


Figure 4: Comparison of recall and precision for each hadron species for different event generators and GEANT transport engine setups using purity $\geq 90\%$ and DCA.

Acknowledgement

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References

- [1] Anna Senger, International Journal of Modern Physics E. Vol. 29, No. 2 (2020) 2030003
- [2] <https://git.cbm.gsi.de/pwg-c2f/analysis/pid/>
- [3] Baznat, M., Botvina, A., Musulmanbekov, G. et al. Monte-Carlo Generator of Heavy Ion Collisions DCM-SMM. Phys. Part. Nuclei Lett. 17, 303–324 (2020)

CBM performance for Λ hadron measurements using Machine Learning

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Theoretical calculations predict the possibility of a first-order phase transition from hadron gas to a deconfined phase of strongly interacting matter and the existence of a critical point in the region of the QCD phase diagram above 450 MeV chemical potential (μ_B) and below 180 MeV temperature [1]. One of the signatures of the new phase of matter is the enhanced production of strange baryons and Λ is the most abundantly produced hyperon at FAIR SIS-100 energies. The CBM performance for the reconstruction of the Λ hyperon via its decay to proton and π^- is presented. The separation between signal and background can be optimised using Machine Learning (ML) boosted decision trees (BDT) algorithms. In this analysis, the XGBoost library (XGB) [2] was used to achieve an efficient selection of the decays and a high signal to background ratio.

Au-Au collisions at 12.4 GeV/c were generated using DCM-QGSM-SMM (Model A) [3] and URQMD (Model B) [4] with collision products transported through the CBM setup using GEANT4. Cellular automaton and Kalman Filter Particle (KFParticle) based PFSimple package [5] are used for track finding, fitting, and decay kinematics reconstruction. PFSimple interfaces the mathematics of the KFParticle package and provides a convenient interface to control the reconstruction parameters. The optimization of selection criteria via ML is performed on five variables associated with the Λ daughter tracks. These variables are the squared distance between the daughter tracks and primary vertex (PV) divided by its error, the distance of the closest approach between the two tracks, the squared distance between daughter tracks divided by its error, and the distance between PV and secondary vertex divided by its error. The signal sample of Λ baryons is taken from Model A. Background candidates are selected from Model B in the invariant mass regions which are outside the expected mass peak. Train and test data sets are created from the signal and background. The XGB algorithm is trained, and it returns its probabilistic predictions on the train and test data sets. Over-fitting is controlled considering the Receiver Operating Characteristic (ROC) and Area Under the Curve (AUC). The BDT model is then applied to events from Models A and B. A selection is performed on the probabilities returned by XGB using the Approximate Median Significance criteria.

The raw yield is extracted multi-differentially in transverse momenta (p_T) and laboratory frame system rapidity (y_{LAB}) using a multi-stage fitting procedure from the model B. Initially, the pure Λ signal from Model A is fitted with a Double-Sided Crystal Ball (DSCB), a Gaussian with

power-law tails. In the second step, the background outside the peak region of Λ candidates from Model B is fitted using a second-order polynomial ($pol2$). Finally, the whole invariant mass of Λ candidates from Model B is fitted with a combination of DSCB and $pol2$, initialized by the parameters from the earlier stages, allowing for the final extraction of the raw yield. A correction factor (acceptance $\times$ efficiency) estimated from Model A is used to correct the extracted raw yield. This corrected yield is shown in Figure 1 for two p_T intervals and it is compared with the simulated one. The corrected yield for primary Λ (produced in the collision) matches the simulated yield for Model B within the errors.

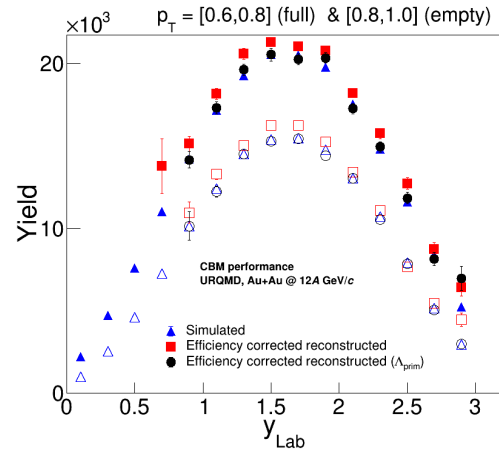


Figure 1: Simulated yield (blue arrows) vs corrected yield (red squares and black circles) of Λ hyperons for Model B in two p_T intervals. The red squares represent the total corrected yield including primary and secondary Λ s while the black circles represent the primary only Λ s.

Removal of the secondary Λ , produced in the decay of other particles, from the primary Λ will be investigated using a BDT multi-classifier approach. Systematic will also be evaluated. An equivalent study is also ongoing for the K_s^0 meson.

References

- [1] <https://doi.org/10.1103/PhysRevD.101.054032>
- [2] <https://doi.org/10.48550/arXiv.1603.02754>
- [3] <https://doi.org/10.1134/S1547477120030024>
- [4] [https://doi.org/10.1016/S0146-6410\(98\)00058-1](https://doi.org/10.1016/S0146-6410(98)00058-1)
- [5] <https://doi.org/10.3390/particles4020025>

Feasibility study of femtoscopic measurements at the CBM experiment at FAIR*

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Introduction

Geometry and dynamics of the source produced in heavy-ion collisions can be studied via the femtoscopy method. Correlations of two particles at small relative momentum are sensitive to Quantum Statistics and the Final State Interactions. They allow one to explore the source's space-time properties, which are of the order of 10^{-15} m and 10^{-23} s, respectively. CBM experiment will cover an essential part of the QCD Phase Diagram with beams of heavy ions. It is a baryon-rich region that can be studied via the femtoscopy method. On the one hand, meson-meson correlations are the most commonly studied, and baryon-baryon systems, together with two-meson and meson-baryon correlations, provide complete information about source parameters. On the other hand, non-identical particle combination measurements complement our knowledge about space-time asymmetries during the emission process. The physics of heavy-ion collisions is successfully deduced based on studies of the properties of the particle-emitting source.

To define a femtoscopic correlation function [1], [2] in the case of identical particle combinations a Longitudinally Co-Moving System (LCMS) is used which is defined as $p_{L,1} + p_{L,2} = 0$. $p_{L,1}$ and $p_{L,2}$ are longitudinal components of momentum for single particles. Using LCMS system the correlation function is defined using variable:

$$q_{\text{inv}} = \sqrt{(p_1 - p_2)^2 - (E_1 - E_2)^2} \quad (1)$$

In the case of non-identical particle combinations, Pair Rest Frame (PRF) reference is used, which defined variable:

$$k^* = p_1 = -p_2 \quad (2)$$

PRF reference can be also used for identical pairs of particles and then $q_{\text{inv}} = 2k^*$.

The definition of the correlation functions is as follows:

$$C(k^*) = \frac{A(k^*)}{B(k^*)} \quad (3)$$

or

$$C(q_{\text{inv}}) = \frac{A(q_{\text{inv}})}{B(q_{\text{inv}})} \quad (4)$$

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Correlated pairs of particles (from the same event enter) enter the numerator $A(k^*)$ or $A(q_{\text{inv}})$ and uncorrelated pairs of particles (from different events) enter the denominator $B(k^*)$ or $B(q_{\text{inv}})$ of the correlation function.

This part of the thesis focuses on the estimation of the required number of $Au - Au$ collisions needed to obtain correlation functions for pions, kaons, and protons, for two ranges of centrality and four values of beam momentum: 12 AGeV/c, 7.95 AGeV/c, 4.4 AGeV/c and 3.3 AGeV/c, for UrQMD data.

The methodology

Table 1: The established number of events (10^6) needed to obtain the statistical error bar of 10%, 5 % and 1 % for $p-p$ correlation function, central collisions (0 – 10%)

	Beam momentum [AGeV/c]			
perc.	12	7.95	4.4	3.3
10 %	3.88	3.02	2.21	1.55
5 %	15.51	12.07	8.84	6.19
1 %	96.94	75.43	55.23	38.66

Table 2: The established number of events (10^6) needed to obtain the statistical error bar of 10%, 5 % and 1 % for $p-p$ correlation function; non-central collisions (> 10%)

	Beam momentum [AGeV/c]			
perc.	12	7.95	4.4	3.3
10 %	1.86	1.43	0.82	0.61
5 %	7.42	5.73	3.27	2.45
1 %	46.37	35.78	20.45	15.32

The method is proposed to estimate the necessary statistics to obtain a one-dimensional correlation function with a systematic uncertainty of a given value of 10%, 5%, and 1%. It is based on the analysis of the value and the uncertainty of the first bin of the correlation function. The whole available statistics (48 million UrQMD $AuAu$ collisions for four beam momentum values) were used for this method. By analysing the first bin of the obtained correlation function one can easily get its value and the uncertainty, and then, to determine the information about desired

Table 3: The established number of events (10^6) needed to obtain the statistical error bar of 10%, 5 % and 1 % for $\Lambda - \Lambda$ correlation function; central collisions (0 – 10%)

	Beam momentum [AGeV/c]			
perc.	12	7.95	4.4	3.3
10 %	17.00	36.02	207.21	657.44
5 %	68.51	143.02	831.42	2629.12
1 %	428.11	896.13	5198.22	16436.10

Table 4: The established number of events (10^6) needed to obtain the statistical error bar of 10%, 5 % and 1 % for $\Lambda - \Lambda$ correlation function; non-central collisions (> 10%)

	Beam momentum [AGeV/c]			
perc.	12	7.95	4.4	3.3
10 %	12.11	19.13	72.31	308.32
5 %	50.34	75.34	287.05	1231.41
1 %	312.33	470.11	1795.12	7696.12

statistics.

$$E_{stat} = \frac{\text{error of the bin}}{\text{value of the bin}} \frac{1}{\sqrt{N}} \quad (5)$$

where E_{stat} is the value of the statistical uncertainty that one desires to obtain (0.1 for 10%, 0.05 for 5%, 0.01 for 1%) and N is the number of expected events. This statistics needed to obtain the proton-proton correlation functions with systematic uncertainty of order of 10%, 5% or 1% for central and non-central $Au - Au$ collisions for 4 different beam momentum are presented in the Tables 1 (up to 10% of central collisions) and 2 (above 10% centrality).

Finally, the estimated number of events needed to obtain the systematic error of the order of 10%, 5% or 1% for pion-kaon, pion-proton, and kaon-proton for central and non-central four beam momentum are presented in the tables 1-4.

Table 3 and 4 presents required statistics to calculate the lambda-lambda correlation function; table 3 shows the most central collisions, and the table collects required statistics for non-central collisions.

Tables 5 and 6 present the required statistics to calculate the kaon-proton correlation function, table 5 shows the most central collisions, and table 6 collects required statistics for non-central collisions.

Table 7 and 8 presents required statistics to calculate the pion-kaon correlation function; table 7 shows the most central collisions, and table 8 collects required statistics for non-central collisions.

Table 5: The established number of events (10^6) needed to obtain the statistical error bar of 10%, 5 % and 1 % for $K^+ - p$ correlation function; central collisions (0 – 10%)

	Beam momentum [AGeV/c]			
perc.	12	7.95	4.4	3.3
10 %	1.18	1.02	0.66	0.44
5 %	4.70	4.08	26.57	17.85
1 %	117.58	102.02	66.43	44.63

Table 6: The established number of events (10^6) needed to obtain the statistical error bar of 10%, 5 % and 1 % for $K^+ - p$ correlation function; non-central collisions (> 10%)

	Beam momentum [AGeV/c]			
perc.	12	7.95	4.4	3.3
10 %	1.52	1.33	0.88	0.59
5 %	6.08	5.33	3.51	2.34
1 %	152.01	133.33	87.76	58.67

Tables 9 and 10 present the required statistics to calculate the pion-proton correlation function; table 9 shows the most central collisions, and table 10 collects the required statistics for non-central collisions.

Summary

We have discussed a number of required events to obtain correlation functions for different particles combinations having the error bar of the first point of a given uncertainty. Three different cases are discussed: uncertainties of the order of 10%, 5%, and 1%. This method assumes the bin width of $k^* 10$ MeV/c. This work proves that CBM will be able to analyze two-particle correlations with high precision.

References

- [1] V.G. Grishin, G.I. Kopylov, M.I. Podgoretskii, Sov. J. Nucl. Phys. **13** (1971) 638
- [2] R. Lednicky, V. L. Lyuboshitz, Sov. Journ. Nucl. Phys. **35** (1982) 770

Table 7: The established number of events (10^6) needed to obtain the statistical error bar of 10%, 5 % and 1 % for $\pi^+ - K^+$ correlation function; central collisions (0 – 10%)

	Beam momentum [AGeV/c]			
perc.	12	7.95	4.4	3.3
10 %	0.92	0.66	0.31	0.16
5 %	3.68	2.67	1.24	0.66
1 %	92.06	66.91	31.00	16.41

Table 8: The established number of events (10^6) needed to obtain the statistical error bar of 10%, 5 % and 1 % for $\pi^+ - K^+$ correlation function; non-central collisions (> 10%)

	Beam momentum [AGeV/c]			
perc.	12	7.95	4.4	3.3
10 %	1.23	0.90	0.42	0.22
5 %	4.93	3.62	1.68	0.87
1 %	123.15	90.44	41.94	21.68

Table 9: The established number of events (10^6) needed to obtain the statistical error bar of 10%, 5 % and 1 % for $\pi^+ - p$ correlation function; central collisions (0 – 10%)

	Beam momentum [AGeV/c]			
perc.	12	7.95	4.4	3.3
10 %	2.60	2.23	1.56	1.20
5 %	10.40	8.98	6.25	4.71
1 %	260.06	224.38	156.16	119.82

Table 10: The established number of events (10^6) needed to obtain the statistical error bar of 10%, 5 % and 1 % for $\pi^+ - p$ correlation function; non-central collisions (> 10%)

	Beam momentum [AGeV/c]			
perc.	12	7.95	4.4	3.3
10 %	3.38	2.95	2.07	1.59
5 %	13.51	11.78	8.29	6.37
1 %	337.81	294.55	207.16	159.37

CBM performance for measurements of baryon-baryon correlations*

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Femtoscopy is a method of extraction the information about the space-time structure of the source that emits particles and it is used to measure the size of a fireball created during a heavy-ion collision. Thus, it is possible to explore the dynamics of a such collision [1].

Femtoscopy uses two-particle correlations for measuring the size of the source. The main tool that femtoscopy use is the correlation function (CF) defined in the case of the experiment by eq. 1, where, q is the difference between the four-momentum of two particles ($q = p_1 - p_2$). The N (the numerator of CF) is a distribution of correlated pairs, whereas D (denominator) is a distribution of uncorrelated pairs. The mixing technique creates the uncorrelated pairs - particles in such pairs belong to different events.

$$C(q) = \frac{N(q)}{D(q)} \quad (1)$$

It is worth stressing that there is also another (theory) definition of the correlation function 2

$$C(q) = \int \rho(\Delta r^*, q) |\psi(\Delta r^*, q)|^2 d\Delta r^* \quad (2)$$

In this definition, r^* is the difference between the emission points of two particles. The shape of the correlation function depends on the size of the source ρ and the type of the particles. The particle's species defines the influence of the quantum statistic and interactions between particles described by $|\psi(\Delta r^*, q)|^2$ term. For proton-proton CF, the interactions are well known (Coulomb repulsion and Strong attraction). Therefore proton-proton femtoscopy is used to measure the space-time structure of the collision. Later results of such measurements might be used as an input for measurements of the interactions between more "exotic" particles - because it is impossible to measure interactions and sizes of sources simultaneously.

After measuring the experimental CF, the data is fitted with theoretical CF C_{theo} . The fit results allow one getting information about the source's size or parameters of interactions between particles.

Proton-proton measurements

In the first part, we focus on proton-proton correlations used for measurements of the size of the source. After obtaining the CF, the ideal case would be to fit the theoretical

CF and get the size of the source from fit. Unfortunately, the experimental CF is disturbed by detector effects. It is mostly due to the following effects:

- limited momentum resolution - this effect makes measured correlation functions "smoother."
- merging effect, this occurs when two particles are reconstructed as a single one, it leads to a decrease in the value of the CF for small q
- splitting effect, this happens when one particle is reconstructed as two tracks, this leads to an increase in the value of the CF, especially $q \approx 0$.
- contamination, this effect happens when we have in our sample pair of particles that are not desired - e.g., meson π in proton-proton CF. The contamination makes the correlation function "flatter".

These effects are usually taken into account in two ways - first, we try to suppress these effects by selecting the pairs with proper "quality", the second is to take into account these effects by modification of theoretical function. For example, instead of fitting data directly with $C_{theo}(q)$ we use formula 3.

$$CF(q) = (C_{theo} - 1)(q)C_{purity}(q) + 1 \quad (3)$$

In the formula above, the $C_{purity}(q)$ is a fraction of desired pairs in data sample (e.g. $\pi^+\pi^+$ pair in $\pi^+\pi^+$ analysis). Such an approach allows us to deal with the misidentification without requiring very high purity (which will inevitably significantly reduce statistics). We assume that the contaminated pairs can be treated as the not correlated ones. The similar approach might be used to take into account the influence of secondary particles, in this case, we use eq. 4 where λ describes the fraction of pairs from primary particles in our sample.

$$CF(q) = (C_{theo} - 1)\lambda(q) + 1 \quad (4)$$

However, formulas 4 and 3 cannot be used for all types of pairs. In the case of baryon-baryon correlations, the products of decays can still be correlated - this is primarily because daughter baryons have momentum similar to the momentum of their mother [2]. For example, in the case of proton-proton correlations, part of protons comes from lambdas. So if we want to consider the influence of lambdas, our fitting function should look like in eq. 5.

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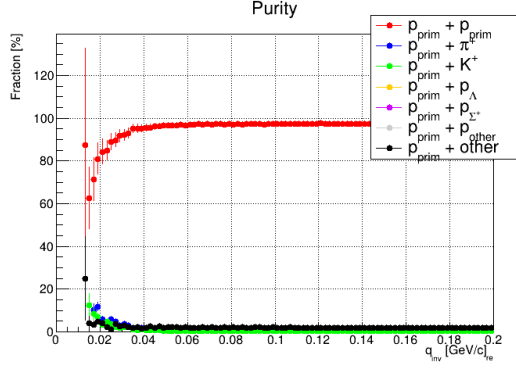


Figure 1: The structure of pairs that contribute to the CF after applying the criteria listed in the table 1 for most central Au-Au collisions at $p_{beam} = 10 \text{ GeV}$.

$$CF(q) = F_{p,p}(q)C_{theo\ p,p}(q) + F_{p,p(\Lambda)}(q)C_{theo\ p,p(\Lambda)}(q) + F_{p(\Lambda),p(\Lambda)}(q)C_{theo\ p(\Lambda),p(\Lambda)}(q) \quad (5)$$

Where $F_{i,j}$ is a fraction of pairs i, j in the data sample. In principle, there might be other sources of protons (like sigmas) and this formula might be longer. It is also worth to stress that $C_{theo\ p,p(\Lambda)}(q)$ is not the same as $C_{theo\ p,\Lambda}(q)$ due to fact that $\vec{p}_\Lambda \neq \vec{p}_{p(\Lambda)}$.

Therefore the first step of the analysis was to estimate the influence of residual correlations. For this purpose, we used the UrQMD model and checked energies of $\sqrt{s_{NN}} \approx 2.7, 3.04, 3.9, 4.9 \text{ GeV}$. The impact parameter selected the most central (0-5%) events. The results are shown in fig. 2. It can be observed that the production of all particles falls when energy decrease, only the number of protons increases. It is an effect related to the stopping of baryons. We can see that for top energies of CBM, approximately 90% of protons are primary particles. This number means that approximately only 80 % of pairs will come from (both) primary protons; however, by applying additional criteria of selection (e.g., DCA - Distance of the Closest Approach), we can suppress the contribution from secondary particles (see fig. 1).

The shape of the source from the UrQMD model was studied. In principle, the quality of the fit does not depend only on the detector's performance; also, the shape of the assumed source plays a significant role. When the assumed shape of the source of theoretical CF does not describe well the real shape of the measured source, the quality of the fit is poor. The simulations show that the shape of the source for proton-proton correlations is quite well described by Gaussian shape; the same happens for K^+K^+ pairs. However, the shape of the pion source is not gaussian (fig. 3). It might be caused by contribution from resonance decays, but further studies are required.

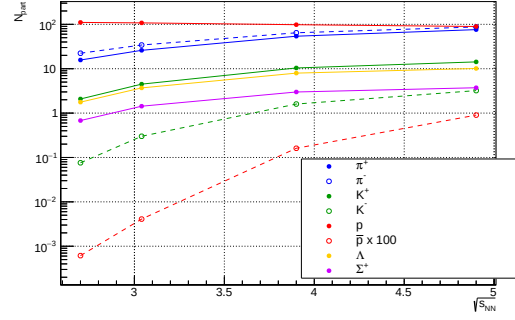


Figure 2: Production of particles from UrQMD model as a function of energy. Only particles with $0.2 < p_T < 3 \text{ GeV}/c$ and $-1.2 < \eta < 1.2$ were taken into account.

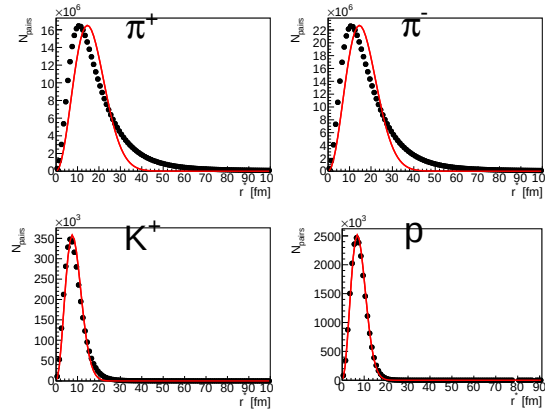


Figure 3: Distribution of femtoscopic radii for most central AuAu collisions at $p_{beam} = 12 \text{ GeV}/c$. The red line corresponds to the Gaussian fit.

The next step of the analysis was focused on the detector performance. For these studies, we take central AuAu collision from UrQMD at $p_{beam} = 10 \text{ AGeV}$. The SIS-100 electron setup was used to simulate the response of the CBM detector. The UrQMD model does not contain the femtoscopic correlations; CF obtained from the pure model should be flat. This effect was used to optimize the data selection criteria - as long as CF was not flat, the anti-splitting and anti-merging cuts required some corrections. The general list of criteria of data selection is listed in table 1.

The two-particle selection criteria based on distances between trajectories of two particles at a given distance were used to suppress merging and splitting. In principle, we calculated the X and Y for a given particle at distances of 20, 30, 40, 50, 60, 70, 80, 90, and 100 cm from the vertex. Then the distances between these two points were calculated and used. After some studies, we used two values to suppress the merging and splitting.

We rejected particles that are closer than 1 cm at 100 cm ($\sqrt{X_{100\text{ cm}}^2 + Y_{100\text{ cm}}^2}$). Such distance roughly corresponds to the last station of the STS; therefore, we called this "an STS exit separation cut", similar criterium was used for suppressing splitting in $\pi^-\pi^-$ analysis [3]. We also required that the maximum separation between two particles in these layers should not be smaller than 0.1 (X-direction) and 0.2 cm [Y-direction].

Cut	Min	Max
Event cuts		
V_{xy} [cm]	0	0.25
V_z [cm]	0	0.12
Track cuts		
p_T [GeV/c]	0.2	10
η [GeV/c]	1	3.5
$N_{hits\ in\ STS}$	5	8
DCA_{xy} [cm]	0	0.5
DCA_z [cm]	0	0.1
<i>charge</i>	1	1
m_{TOF}^2 [GeV^2/c^4]	0.8	2.05
Pair cuts		
STS exit sep. [cm]	1	500
$ \Delta_{max}X \Delta_{max}Y $ [cm]	0.1;0.2	-

Table 1: Criteria of data selection in analysis.

When criteria of data selection were optimized, the correlations were implemented into the analysis. The studies with the pure UrQMD model predict that the radius of the source size should be at the level of $\approx 3.6\text{ fm}$. Therefore this was an assumed size of the source in analysis. We assumed that the source has a spherically symmetrical Gaussian shape (this is a quite good approximation for protons what was shown in fig. 3). It was also assumed that all protons are correlated (this means that $\lambda = 1$). The CF used for fitting takes into account contamination of proton sample. Despite the fact that the effect of limited momentum resolution was not taken into account, the results of fit seem quite well describe the data 4. On the other hand, the parameters obtained from fit don't follow those that were put into the simulation. Obtained radius is approximately 10% smaller than expected. The λ extracted from the function was at the level of 0.7.

The analysis was performed on 1M events. In principle, it seems to be enough to fit the proton-proton CF but not enough for optimization of two-particle criteria of selection and not enough to study all the systematic uncertainties in the fig. 4 we can see that the CF without correlations is not flat - this suggests that two-particle selection criteria should be better optimized.

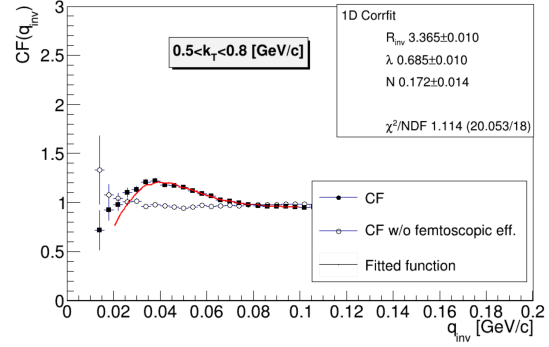


Figure 4: The result of fitting CF for protons. The open markers show the CF without femtoscopic effects that should be flat.

Perspectives on multi-strange baryon measurements

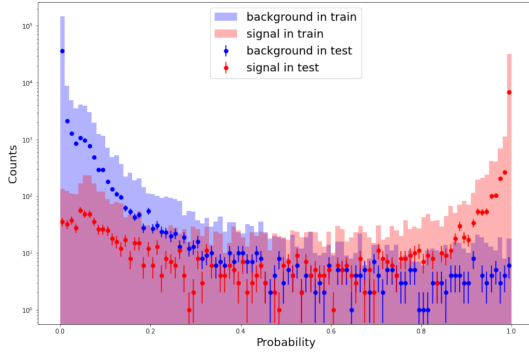
There are also ongoing studies concerning femtoscopy of strange and multi-strange baryon measurements. In this case, the results from proton-proton measurements will be used to estimate the size of the source that emits those baryons. It allows femtoscopic formalism to study interactions between strange and multi-strange baryons.

Like protons or charged kaons, strange and multi-strange particles are not reconstructed "directly" in CBM. The special packages like PFSimple [?] (that base on KFPackage [5]) were created for reconstruction of such particles.

The analysis of the possibility of measurements Ξ^- was performed. This baryon mainly decays into Λ and π^- . Due to the complicated topology of decay, optimizing selection criteria is not an easy task. For femtoscopic measurements, it is required to have a high purity of particles. On the other hand, we would like to have possibly the highest reconstruction efficiency. Therefore we used Machine Learning (ML) algorithms to optimize selection criteria.

For the machine learning algorithm, we used some pre-selected data. The preselection was mainly used to clean up data from corrupted data (e.g., not-a-number values) or candidates that are not a needed particle - for example, for Xi^- that has mass $\approx 1.3\text{ GeV}/c^2$ data sample for learning contained only candidates with $1.254 < m < 1.6\text{ GeV}/c^2$. Two models were used for ML - UrQMD and DCMQGS-SMM to make an algorithm (at least partially) model-independent. A Pearson test rejected variables that strongly depend on invariant mass. The XGBoost model was used for training. This model returns "probability" value from 0 to 1 (see 5. A higher probability value means a cleaner sample of data. The comparison of the ML algorithm and "standard" selection criteria from KFPackage are shown in table 2.

Cut name	Value
KFPackage	
$\chi^2_{prim-\pi^-}$	> 18.42 cm
χ^2_{geo}	< 6.0 cm
χ^2_{topo}	< 5.0 cm
$L/\Delta L$	> 5.0
DCA	< 1.0 cm
Machine learning	
p	> 0.992

Table 2: Criteria of data selection of Ξ^- .Figure 5: The probability distribution used to selection Ξ^- [6].

The ML learning algorithm gives promising results. The selection criteria used for standard analysis (2) allowed to extract of 3924 Ξ^- from the analyzed sample of data. ML algorithms found 4126 Ξ^- , the number of false positives in cases of ML was approximately two times smaller. The ML algorithm improved signal selection by 5 % and suppressed background by the factor by $\approx 50\%$.

Summary and plans

The feasibility studies of strange and multi-strange correlations are in progress. We were focused on algorithms that provided us with an easy way to select these particles. In the future, we plan to integrate the PFSimple with the framework for femtoscopic analysis and study the two-particle effects that might disrupt correlations of strange particles. We would also like to estimate the statistic needed to analyze the correlations between multistrange baryons.

References

- [1] M. A. Lisa et al. “FEMTOSCOPY IN RELATIVISTIC HEAVY ION COLLISIONS: Two Decades of Progress”, Annual Review of Nuclear and Particle Science, Vol. 55:357-402

- [2] H. Zbroszczyk “Proton femtoscopy in STAR”, EPJ Web of Conferences, vol 71, (2014)
- [3] P. Senger, V. Friese, CBM Progress Report 2020, p. 208-209 (2021).
- [4] Lubynets O., Klochkov V., Selyuzhenkov I., Glaessel S., Blume C., CBM-GSI gitlab. https://git.cbm.gsi.de/pwg-c2f/analysis/pf_simple
- [5] M. Zyzak, “Online selection of short-lived particles on many-core computer architectures in the CBM experiment at FAIR”, PhD thesis 2015
- [6] M. Karabowicz “Feasibility study of femtoscopic measurements of strange particles in the CBM experiment at FAIR” engineer thesis 2022

Directed flow of Λ hyperons in Au+Au collisions at 12A GeV/c

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Strange quarks do not exist before the heavy-ion collision and are produced at its early stage, which makes the strange and multi-strange hyperon production an important tool to extract the properties of the created QCD matter. Anisotropic flow of produced particles, in particular with the strange quark content, is sensitive to the equation of state and the degrees of freedom in the early fireball. In CBM the short lived particles (e.g. K_0 and Λ) are reconstructed via their weak decay products. Reconstruction algorithm of the decays is implemented as the Kalman Filter Particle Finder [1]. For the current analysis we used its simplified version, the PF Simple [1], which was optimized for efficient strange hyperons reconstruction and background rejection. Application of the machine learning technique for candidates selection criteria optimization is described in [2].

Anisotropic flow can be characterized by coefficients of a Fourier series of produced particles azimuthal angle distribution. The directed flow $v_1 = \langle \cos(\varphi - \Psi_{RP}) \rangle$ describes particle emission in preferred direction relative to the reaction plane. The scalar product method was used to calculate the directed flow. Reaction plane is estimated using signal registered in the PSD. The resolution is determined using sets of particles separated in kinematic space and therefore assumed to correlate between each other only due to common reaction plane (subevents method) [3]. Non-uniformity of the CBM acceptance and inefficiencies in azimuthal angle φ (sensitive volume, magnetic field, additional material etc.) biases results for directed flow. This non-uniformity was corrected according to the procedure described in [4] and implemented in QnTools and QnAnalysis frameworks [4]. Additionally, the (p_T, y) -dependent reconstruction efficiency correction was applied as weights for individual tracks. Signal's contribution from observed flow was extracted using invariant mass fitting.

A sample of 5M Au+Au collisions at $p_{beam} = 12A$ GeV/c was generated with the DCM-QGSM-SMM model. GEANT4 was used to transport particles through the CBM detector material. These events were reconstructed with the CBMROOT software. In order to check validity of the correction procedure as implemented in the analysis frameworks [4] the results of the data-driven analysis were compared to the known Monte Carlo input. v_1 coefficient was calculated as a function of rapidity. Also results were compared with predictions of the UrQMD model and real data measured at STAR FXT [5]. DCM-QGSM-SMM predicts similar with STAR FXT magnitude of $v_1\{K_S^0/\Lambda\}$. UrQMD demonstrates similar with STAR FXT behaviour of $v_1\{K_S^0\}$ and opposite slope of $v_1\{\Lambda\}$ as

a function of rapidity.

In summary, performance of the CBM experiment for directed flow of strange hyperons was investigated using flow analysis framework. Reconstructed directed flow reproduces the Monte Carlo input within statistical precision. The future plans are to extend analysis on multistrange particles, and perform p_T , y and centrality differential analysis.

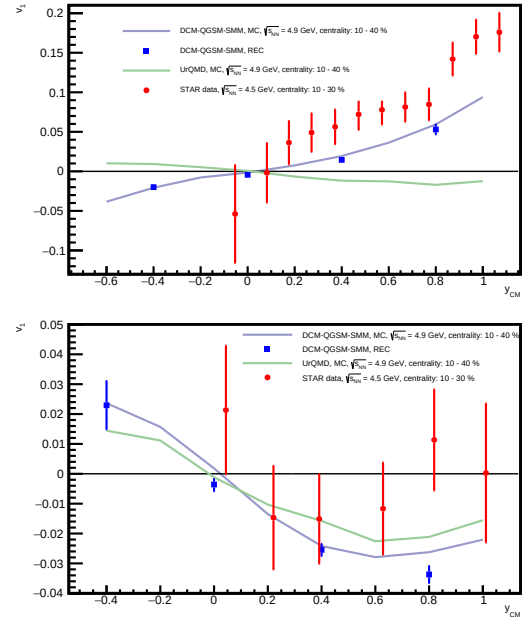


Figure 1: Directed flow of Λ hyperons (top) and K_S^0 (bottom) vs. rapidity.

References

- [1] S. Gorbunov, PhD thesis (2012); M. Zyzak, PhD thesis (2016); <https://git.cbm.gsi.de/m.zyzak/KFParticle> https://git.cbm.gsi.de/pwg-c2f/analysis/pf_simple
- [2] S. Khan et al, CBM progress report “Machine Learning application for Lambda baryon physics analysis”
- [3] O. Golosov et al, CBM progress report “CBM performance for measurement of proton directed flow”
- [4] I. Selyuzhenkov and S. Voloshin, PRC77, 034904 (2008); L. Kreis, I. Selyuzhenkov, V. Klochov <https://github.com/HeavyIonAnalysis/QnTools>; <https://github.com/HeavyIonAnalysis/QnAnalysis>
- [5] <https://arxiv.org/abs/2007.14005>

Feasibility Studies of Combinatorial Background Determination for Low Mass Vector Meson Analysis *

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Di-electron analysis package in CbmRoot

The initial low-mass vector meson (LMVM) analysis code was implemented already many years ago [1]. Since then it was constantly growing and more and more new features were added to the analysis. At some point it became hard to add new functionality and to maintain the existing code. In 2021 the LMVM code was significantly redesigned and rewritten with the aim for a long-term support. As a result, the code has a clear structure, all obsolete code was removed, code readability and debugging improved significantly.

Combinatorial Background

In di-electron spectroscopy as expected for CBM [2], the signal is strongly superimposed by combinatorial background with signal-to-background ratios typically lying in the range of 10^{-1} or less. In this work we will establish routines to calculate the combinatorial background and evaluate the significance for signal extraction, in particular for masses larger than $1 \text{ GeV}/c^2$.

The expression to describe the combinatorial background is $B_C = 2k\sqrt{\langle B^{++} \rangle \langle B^{--} \rangle}$, where $\langle B^{++} \rangle$ is the yield of e^+e^+ pairs from same events (analogue $\langle B^{--} \rangle$). The factor k is a correction factor that considers potential asymmetries in the yield of particles of both charges and should be around 1. It is defined as $k = \frac{\langle b^{+-} \rangle}{2\sqrt{\langle b^{++} \rangle \langle b^{--} \rangle}}$, where the lowercase $\langle b \rangle$ denote the according yields from event mixing techniques.

The di-electron signal spectrum is then calculated by subtracting the combinatorial background from the whole same event unlike-sign pair sample: $S = \langle B^{+-} \rangle - B_C$.

In order to reduce statistical fluctuations in the calculation of the combinatorial background, the data from same event yields is replaced by data from the event mixing techniques for masses above $0.3 \text{ GeV}/c^2$. Therefore, the yields of mixed events are normalized to the yields of same events in the region $0.3 \text{ GeV}/c^2 \leq M_{ee} \leq 1 \text{ GeV}/c^2$.

The UrQMD and PLUTO files that were used for this analysis are taken from /lustre/cbm/prod/gen/.

Results

The yields of mixed event like-sign and unlike-sign pairs $\langle b \rangle$ are shown in Fig. 1 for $2 \cdot 10^6$ central Au+Au collisions

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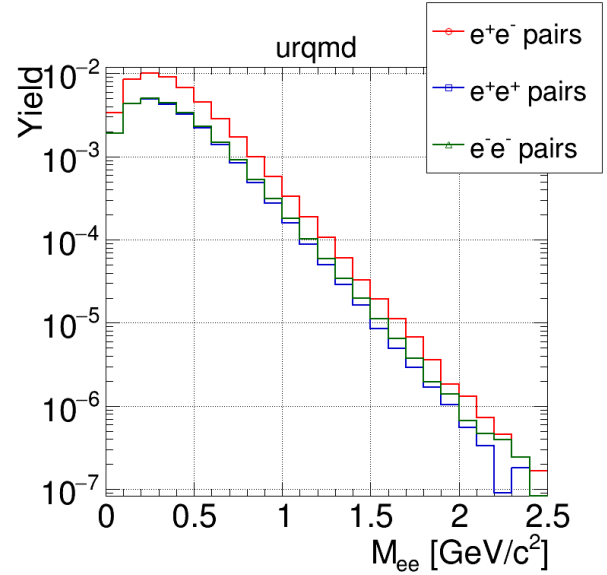


Figure 1: Yields of mixed event unlike-sign and like-sign pairs from UrQMD, $2 \cdot 10^6$ central Au+Au collisions at 8 AGeV beam energy (UrQMD).

sions at 8 AGeV beam energy from UrQMD. As the acceptance for electrons and positrons in CBM is rather symmetric, both like-sign spectra are rather similar. The fact that e^-e^- spectra overshoot e^+e^+ spectra at high masses is most probably connected to misidentification of π^- . In Fig. 2 data from the combinatorial background procedure (B_C and signal) are compared with input data. Here, the full di-electron analysis has been computed including single-track and pair cuts in order to reduce contributions from γ -conversion and π^0 -Dalitz decay. Overall, a rough agreement is seen, however statistics becomes scarce such that no more detailed evaluation can be done even with the large binsize that is chosen already.

The strong reduction of the errors at masses above $0.3 \text{ GeV}/c^2$ in comparison to the errors at smaller masses is due to the fact that, as mentioned before, data from mixed events is used for B_C at masses above $0.3 \text{ GeV}/c^2$.

In Fig. 3, the whole invariant mass spectrum is shown including the cocktail from known di-electron sources¹. Additional correlated di-electrons are calculated from

¹Note: In-medium ρ and QGP radiation show an asymmetric P_x distribution in this simulation. Not seen in the invariant mass spectra, but a known and to be corrected problem.

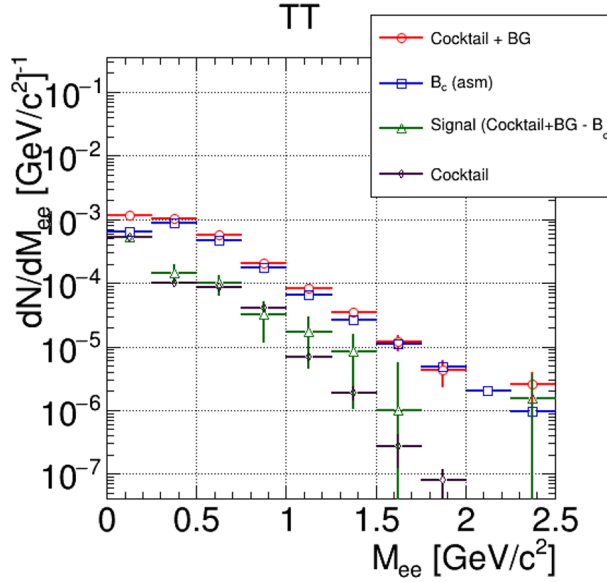


Figure 2: Invariant mass spectrum after all single-track and pair cuts except p_t cut for input data (red and black) and data from the combinatorial background procedure (blue and green). Simulation based on $10 \cdot 10^6$ central Au+Au collisions at 8 AGeV beam energy including correspondingly scaled di-electron sourced from PLUTO.

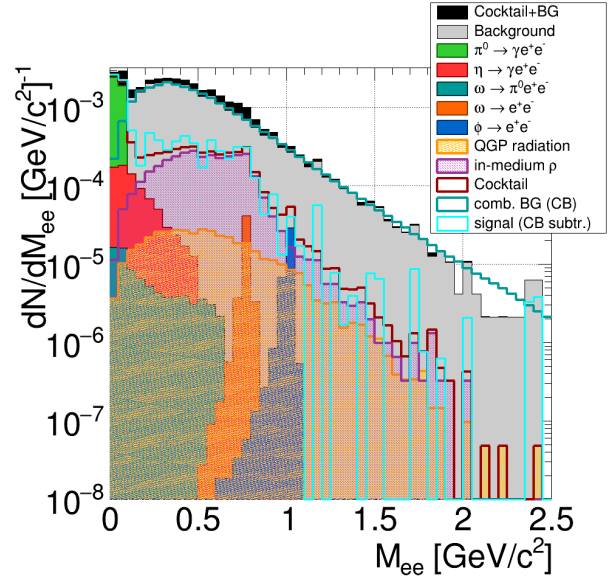


Figure 3: Invariant mass spectrum after all single-track and pair cuts except p_t cut, including the calculated combinatorial background and the final signal spectrum calculated by combinatorial background subtraction. Simulation based on $10 \cdot 10^6$ central Au+Au collisions at 8 AGeV beam energy including correspondingly scaled di-electron sourced from PLUTO.

PLUTO, embedded with one/event into UrQMD and scaled according to table 1. Overlaid is the calculated combinatorial background and the background subtracted signal. Given the available statistics a reasonable description is observed.

Particle	Multiplicity	BR
$\rho_{i.m.}$	0.0305	
ω	2.29	$7.36 \cdot 10^{-5}$
ω_{Dalitz}	2.29	$7.7 \cdot 10^{-4}$
ϕ	0.312	$2.97 \cdot 10^{-4}$
QGP	$4.53 \cdot 10^{-3}$	

Table 1: Scaling factors of the implemented PLUTO particles for 8 AGeV beam energy collisions. The multiplicity values for $\rho_{i.m.}$ and QGP include the corresponding branching ratios.

Summary and Outlook

A procedure to calculate the combinatorial background had been implemented successfully. In order to further study the quality of background subtraction, statistics need to be increased considerably. Fast simulations are planned for that and will then allow to extract the significance of measurements beyond masses of $1 \text{ GeV}/c^2$.

References

- [1] T. Galatyuk, Di-electron spectroscopy in HADES and CBM: from p + p and n + p collisions at GSI to Au + Au collisions at FAIR PhD Thesis 2009, <https://repository.gsi.de/record/186237>.
- [2] C. Feier-Riesen et al., Investigation on impact of higher material budget in STS on LMVM, CBM Progress Report 2020, page 75.

Particle Identification by Machine Learning Methods

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In this report, classification methods are presented that improve the particle identification (PID) by the RICH detector at the CBM experiment. In Dielectron analysis, particle identification is of high importance to ensure a pure electron sample and keep hadronic contributions to the combinatorial background as low as possible. Furthermore, machine learning methods for particle identification by the TRD have been investigated. Currently, machine learning techniques are applied to all particle identification detectors in order to increase the significance of the measurements for the pair analysis.

Machine Learning for RICH PID

For the purpose of PID by the RICH detector, a multi-layer neural network is compared with a Gradient Boosting classifier and the Random Forest. The results show that the Random Forest classifier performs best on the simulated data and outperforms the ANN implemented in cbmroot in distinguishing between pions and electrons. Fig. 1 shows the results based on a ROC (receiver operating characteristic). Furthermore, the figure shows that a newly trained neural network with a similar architecture to the ANN implemented in cbmroot produces similar results.

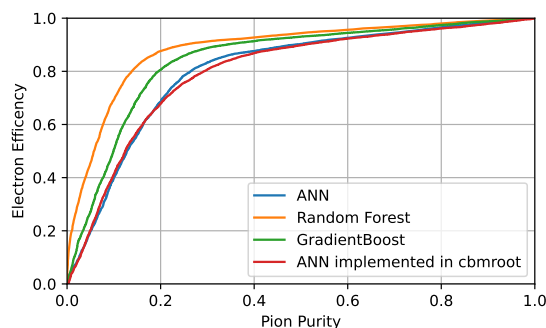


Figure 1: ROC (receiver operating characteristic) for different machine learning methods for PID with the RICH detector. For comparison, the ANN implemented in cbmroot is shown.

A Random Forest is a classification method that consists of multiple uncorrelated decision trees. All decision trees are grown under a certain type of randomization during the learning process. For a classification, each tree in this forest is allowed to make a decision and the class with the most votes decides the final classification. The random forest we use consists of 2000 decision trees. For the opti-

mization of the inputs to the classification method the correlation matrix of the inputs was investigated (see Fig. 2). It is noticed that in the information about the major semi-axis A (Aaxis) of the photon ellipse there is already a lot of information about the minor semiaxis B (Baxis). For strongly correlated data (compare Fig. 3), dimension reductions help to improve the performance of the classification methods. However, a restructuring of the input data such as (Aaxes, Baxes) $\rightarrow$ (Axes, Baxes/Aaxes) could only minimally improve the methods.

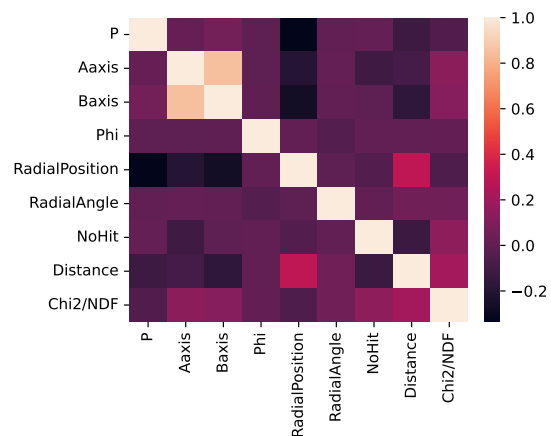


Figure 2: Correlation matrix of the input variables in the classification methods in a color representation. White items represent to a strong correlation, black items to a negative correlation.

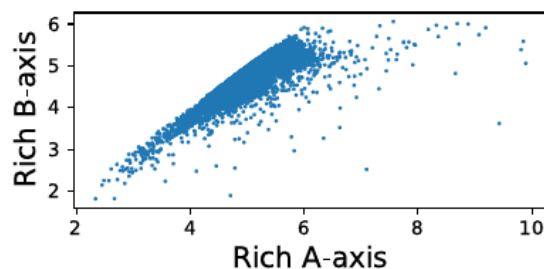


Figure 3: Most correlated input for particle identification classification by RICH

Significance for Pair Analysis

Since we want to refer to the di-electron pair analysis in the further course of the project, it is suitable to define the significance of the measurement in dependence of pion purity p and electron efficiency e . Such a definition helps to compare different classification methods. In the pair analysis, Lorenz vectors of positive charged particles are combined by those of negatively charged particles. Since both the electron and the positron of one signal have to survive the classification at an electron efficiency e , the resulting signal is proportional to the square of the electron efficiency (see Eq. 1). The sum of signal S and background B is obtained by multiplying the positive tracks by the negative ones (see Eq. 2). $N_{e-}, N_{e+}, N_{\pi+}, N_{\pi-}$ are the respective numbers of particles. We use that $N_{e-} \approx N_{e+}$ and $N_{\pi-} \approx N_{\pi+}$.

$$S \propto N_e \cdot e^2 \quad (1)$$

$$B + S = (N_{\pi+} \cdot p + N_{e+} \cdot e) \cdot (N_{\pi-} \cdot p + N_{e-} \cdot e) \quad (2)$$

$$\approx (N_{\pi} \cdot p + N_e \cdot e)^2 \quad (3)$$

$$\text{Significance} = \frac{S}{\sqrt{S+B}} \propto \frac{N_e \cdot e^2}{N_{\pi} \cdot p + N_e \cdot e} = \frac{e^2}{\frac{N_{\pi}}{N_e} \cdot p + e} \quad (4)$$

Machine Learning for TRD PID

Fig. 4 shows the ROCs of the same methods described above for the RICH applied for the TRD variables and therefore in comparison to the likelihood method. The color code is showing the significance calculated from Eq. 4. The Random Forest method does not beat the likelihood method. This is to be expected since a likelihood method is the optimal classifier. However, it must be shown that the probability density of electrons and pions in the 4-dimensional parameter space of the energy deposition in the layers of the TRD can be calculated. The fact that the Random Forest method operates so far at the optimum shows the quality of the method.

Summary and Outlook

Random Forest method shows a very promising performance on PID with single detector information, such as RICH or TRD. Currently, the presented machine learning methods are being tested on all particle identification detectors simultaneously. The results may help to increase the significance of the measurements for the pair analysis. For this purpose, the best machine learning methods are combined and applied to up to 19 input variables. Since the likelihood method in the TRD yields better results than other methods, it may be used as input for the machine learning methods instead of the energy deposition in the TRD layers. Furthermore, it is investigated whether the best cut values obtained by the significance function (Eq.

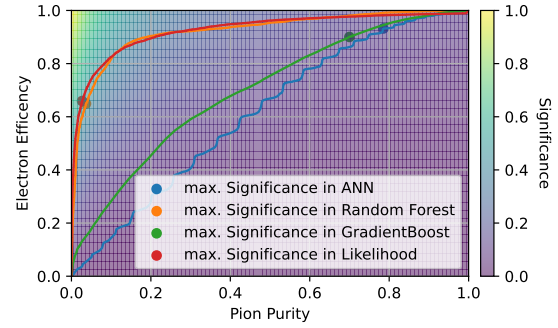


Figure 4: ROC (receiver operating characteristic) for 3 machine learning methods and the likelihood method for PID with the TRD. The color code is showing the significance of the pair analysis after classification (see Eq. 4). Points of maximum significance are shown as full circles.

4) on the output of the methods actually optimizes the pair analysis.

Simulation of Drell-Yan process at FAIR SIS100 energies with PYTHIA*

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Introduction

The Drell Yan (DY) interaction [1] is one of the processes which can also produce a muon pair in the final state. This report presents the study of simulation of DY process at SIS100 energies using PYTHIA8 [2]. The contribution of DY process as a background to the J/Ψ mass production region and to the lower mass region is also reported.

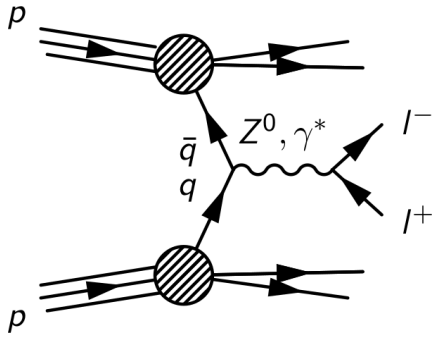


Figure 1: Feynman Diagram representing DY process in pp collision. The DY boson decays to a lepton pair.

In a DY interaction, quark from one hadron can take up a sea anti-quark from colliding hadron and forms a virtual photon state which subsequently decays into a lepton pair.

$$pp \rightarrow \gamma^* X \rightarrow l^+ l^- X$$

In the di-muon channel the virtual boson decays to a muon pair

$$\gamma^* \rightarrow \mu^+ \mu^-.$$

Figure 1 shows the Feynman Diagram representing the DY interaction of two colliding protons.

Simulation of DY process

The simulation of DY events in pp collisions for the CBM detector at the SIS100 energies is done using PYTHIA 8.306 [2] event generator. Four samples of pp events corresponding to the four SIS100 energies are generated in the center of mass frame. During generation one DY is triggered per event and the virtual boson decays only to a muon pair.

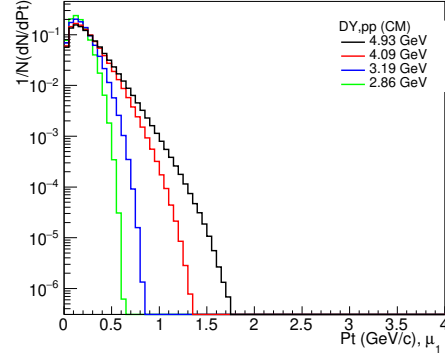


Figure 2: Transverse momentum, P_t distribution of the first muon from DY boson. Different color lines represent different SIS100 CM energies.

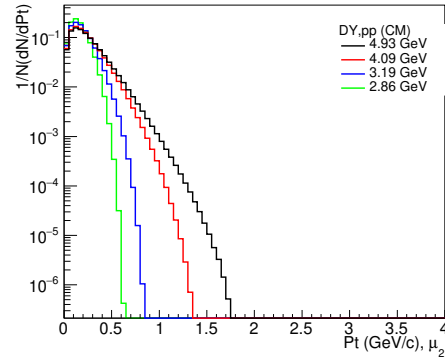


Figure 3: Transverse momentum, P_t distribution of the second muon from DY boson. Different color lines represent different SIS100 CM energies.

The transverse momentum, P_t distribution of the two final state muons¹ is shown in Figures 2 and 3 respectively. A comparison of the P_t distributions at different center of mass (CM) energies is also shown in the given Figures. It is observed that at the highest SIS100 CM energy of 4.93 GeV, the maximum P_t of the individual muons is about 1.7 GeV. The maximum P_t decreases with the decreasing CM energy of collision.

From the di-muon pair the invariant mass of the intermedi-

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¹ Positive muon is called as the first muon and negative muon is called as the second muon.

ating DY boson can be calculated as

$$M_{\gamma^*} = M_{\mu_1\mu_2} = \sqrt{(P_{\mu_1}^2 + P_{\mu_2}^2)}$$

where, P_{μ_1} and P_{μ_2} are the four momenta of the two muons. The invariant mass distributions of the DY virtual photon at different CM energies are shown in Figure 4. Table 1 gives the details of number of DY events generated at different SIS100 CM energies and the number of events reconstructed in different ranges of di-muon invariant mass.

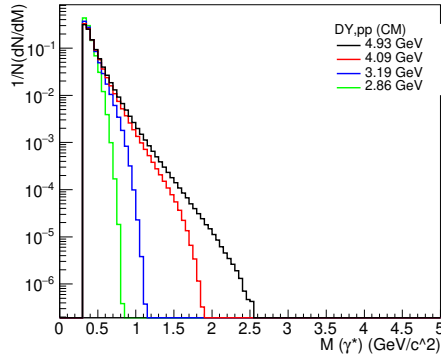


Figure 4: Distribution of di-muon invariant mass for the DY event at different CM energies.

E_{CM}	Events	$M_{\mu_1\mu_2}$ (GeV)			
		0-1	1-2	2-2.9	2.9-4.2
4.93	$9.6 * 10^7$	99.163%	0.833%	0.004%	0
4.09	$9.1 * 10^7$	99.5%	0.5%	0	0
3.19	$7.4 * 10^7$	99.998%	0.002%	0	0
2.86	$5.1 * 10^7$	100%	0	0	0

Table 1: Number of DY events generated for different CM energies (in GeV) and percentage of events in different invariant mass range bins.

Discussion

Following observations can be made from the invariant mass distribution of the DY photon.

- In the mass range 2.9-4.2 GeV, no DY event was reconstructed in the di-muon channel for all SIS100 CM energies.
- This indicates a negligible contribution from DY events to the J/Ψ mass region.
- For the lower di-muon pair invariant mass region, DY events can be used as a source of physical background in addition to the combinatorial background.

PYTHIA 8.306 can also be used to generate the triggered DY events in pp collisions in the lab frame of reference. The Angantyr model from PYTHIA 8.306 can be used to generate the DY sample for heavy ion interactions. PYTHIA is well tested for simulating pp events at the HADES [3] collision energies. A systematic check of the DY background contribution to the low invariant mass signal region can be done using the PYTHIA settings defined in Table 1 of [3].

References

- [1] S. Drell and T. M. Yan, Massive Lepton Pair Production in Hadron-Hadron Collisions at High-Energies Phys.Rev.Lett. 25 (1970) 316–320.
- [2] T. Sjostrand et. al., An introduction to PYTHIA 8.2, Comput. Phys.Commun. 191 (2015) 159.
- [3] The HADES collaboration, Inclusive dielectron spectra in pp collisions at 3.5 GeV kinetic beam energy, Eur. Phys. J. A 48 (2012) 64.

Reconstruction of low mass dimuon cocktail at top SIS100 energy

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In this report, the performance of the Muon Chamber (MuCh) detector system for reconstruction of muon pairs originating from the direct and Dalitz decay of Low Mass Vector Mesons (LMVM) are discussed for central (0-5%) Au+Au collision at beam momenta of 12 A GeV ($\sqrt{s_{NN}} = 4.93$ GeV). The CBMROOT APR21 version is used for this study with GEANT4 transport engine. The

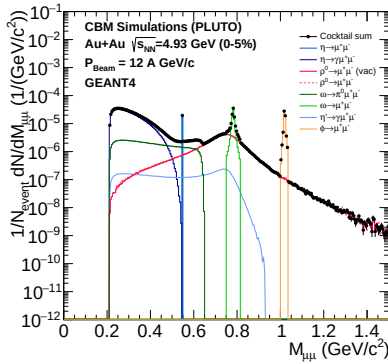


Figure 1: The invariant mass distribution of LMVM cocktail via di-muon channel at $\sqrt{s_{NN}} = 4.93$ GeV from PLUTO event generator.

MuCh LMVM setup is used which consists of four hadron absorbers of thicknesses 58 cm (28 cm Graphite + 30 cm Concrete), 20 cm (Iron), 20 cm (Iron) and 30 cm (Iron) respectively. The detector stations each having three layers

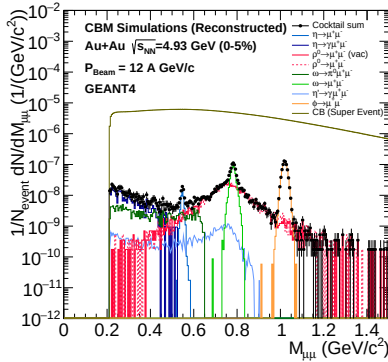


Figure 2: The reconstructed invariant mass distribution of LMVM cocktail via di-muon channel at $\sqrt{s_{NN}} = 4.93$ GeV.

of tracking detectors are placed in between the absorbers. The Gas Electron Multiplier (GEM) like detectors are implemented in the GEANT simulation for the first two stations of MuCh and Resistive Plate Chamber (RPC) like detectors are implemented in the last two stations. The PLUTO event generator is used to model the phase space

decay of vector mesons [1]. The UrQMD event generator is employed to estimate the background contribution. According to the thermal fireball model used in the PLUTO event generator, vector mesons are generated with a thermal transverse mass (m_T) and a Gaussian rapidity spectrum and decay isotropically into dileptons. To generate the input signals, only two input parameters namely beam energy and temperature of the system are provided. For the afore-

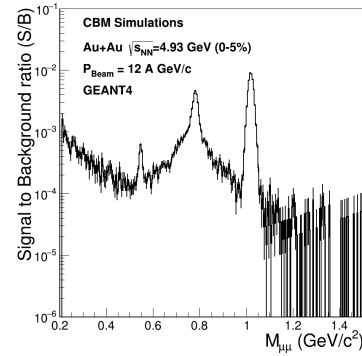


Figure 3: Signal to background ratio as a function of dimuon invariant mass.

mentioned system, the input parameter values are beam energy: 12.04 A GeV and temperature: 130 MeV. The input LMVM cocktail distribution from PLUTO is shown in Fig. 1. For each dimuon source, 1 million events are simulated. A set of track quality cuts are applied to select the muon track candidates. A reconstructed global track having STS hit ≥ 7 , MuCh hit ≥ 11 , TRD hit ≥ 1 , TOF hit ≥ 1 , $\chi^2_{VERTEX} \leq 2.0$, $\chi^2_{STS} \leq 1.8$ and $\chi^2_{MuCh} \leq 4.0$ is considered as a valid muon track candidate. The signal is extracted from the embedded set of events using the Monte Carlo (MC) particle identity. The reconstructed spectra are shown in Fig. 2. The combinatorial background is calculated using Super Event (SE) technique. In Fig. 3, the signal to background ratio is shown as a function of invariant mass. The signal peaks are well below the combinatorial background and therefore a precise estimation of the combinatorial background is essential for the extraction of the signals. For a foreseen nominal interaction rate of 100 kHz, the beam time required to obtain the dimuon spectrum as shown in Fig. 2 (black marker) is ~ 1 minute of the beam on target.

Acknowledgements

The authors would like to thank Prof. Teteyana Galatyuk, Dr. Anna Senger and Dr. Saikat Biswas for their valuable discussion for this study.

References

- [1] S. Chatterjee *et al.*, CBM Progress Report 2020, 193

Reconstruction of di-muons with the low energy setup of MuCh

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Muon Chamber (MuCh) sub-system of the Compressed Baryonic Matter (CBM) experiment at FAIR SIS100, dedicatedly designed for dimuon measurements, consists of several hadron absorbers and a triplet of gas detectors called stations placed in between the absorbers [1]. The

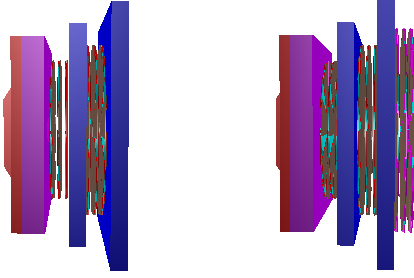


Figure 1: The low energy setup of MuCh; Left: Three absorbers and two detector stations (configuration a), Right: Three absorbers and three detector stations (configuration b).

standard MuCh setup optimized via simulation, is made of four hadron absorbers of thicknesses 58 cm, 20 cm, 20 cm and 30 cm respectively for LMVM detection at SIS100 energies. The first absorber, composite in nature, is made up of Concrete (30 cm) and Graphite (28 cm) while the rest of the absorbers are made up of Iron [2]. An additional 100 cm thick Iron absorber is foreseen for the J/ψ detection setup [3]. The triplet of detector stations are placed in between the absorbers. In the simulation, the first two detector stations are made up of Gas Electron Multiplier (GEM) like detectors and the last two detector stations are made up of Resistive Plate Chamber (RPC) like detectors [4, 5].

Configuration	Cut on detector hits	Cut on χ^2/Ndf
a	STS hits ≥ 7	$\chi_{VERTEX}^2 \leq 1.8$
	MuCh hits ≥ 5	$\chi_{STS}^2 \leq 1.7$
	TRD hits ≥ 1	$\chi_{MuCh}^2 \leq 3.1$
	TOF hits ≥ 1	
b	STS hits ≥ 7	$\chi_{VERTEX}^2 \leq 1.8$
	MuCh hits ≥ 8	$\chi_{STS}^2 \leq 1.7$
	TRD hits ≥ 1	$\chi_{MuCh}^2 \leq 3.1$
	TOF hits ≥ 1	

Table 1: Cuts on detector hits and χ^2/Ndf of the reconstructed global tracks to select the muon track candidates.

The aforesaid LMVM setup is not suitable for the detection of di-muons at low beam momenta ($< 4.0 \text{ A GeV}/c$) due to the possibility of those soft muons completely getting stopped inside the hadron absorbers. In order to reconstruct the muon pairs at low beam momenta, a truncated version of MuCh, which consists of three MuCh absorbers and two detector stations, is proposed [6]. In this report, another variant of the MuCh low energy version is discussed which consist of three MuCh absorbers and three detectors (2 GEM + 1 RPC) layer. The two different configurations

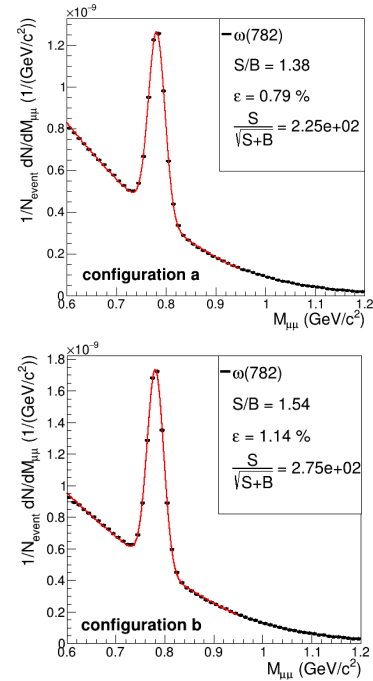


Figure 2: Invariant mass distribution; Top: configuration a and Bottom: configuration b.

are shown in Fig. 1. The reconstruction performance of the di-muon is investigated using the APR20 version of CBM-ROOT for central Au+Au collision at beam momentum of 2 A GeV/c with GEANT3 as the transport engine. The magnetic field is scaled to 50% of its maximum strength to make sure that the beam hits the iron dump. A detailed study regarding the magnetic field scaling as a function of the beam energy is available in Ref. [7]. The signal (ω) is taken from the PLUTO event generator and embedded in the background taken from the UrQMD event generator. One $\omega (\rightarrow \mu^+ \mu^-)$ is embedded per event into the back-

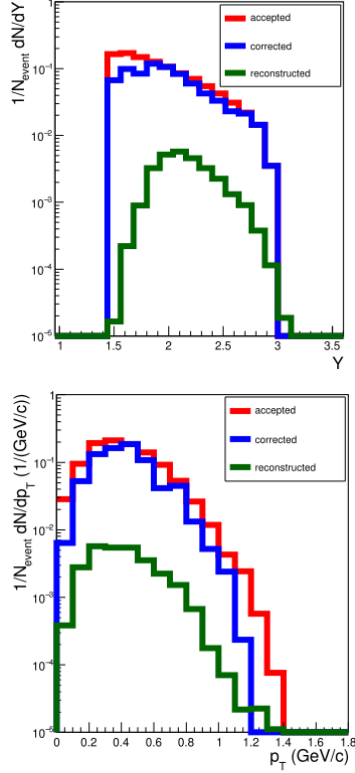


Figure 3: Efficiency×acceptance corrected spectra; Top: rapidity (Y) distribution and Bottom: transverse momentum (p_T) distribution.

ground. The muon track candidate selection criterion are summarised in table 1. Apart from the hit and χ^2/Ndf cuts, an additional 3σ cut on the reconstructed TOF mass is applied to reduce the combinatorial background. The invariant mass distributions of ω with the two different configurations (configuration a & configuration b) are shown in Fig. 2. It is found that with the inclusion of the third detector station both the reconstruction efficiency and signal to background ratio improves. The efficiency×acceptance corrected spectra (Y - p_T) is shown in Fig. 3. After the correction, the corrected spectra matches well with the accepted spectra.

This study will also be repeated with the realistic beam momenta foreseen at SIS100 and also with the GEANT4 transport engine.

Acknowledgements

The authors would like to thank Prof. Tetyana Galatyuk, Dr. Anna Senger and Dr. Saikat Biswas for their useful comments during this study.

References

- [1] The CBM Collaboration, Technical Design Report for the CBM: Muon Chambers. GSI-2015-02580

- [2] O. Singh *et al.*, CBM Progress Report 2019, 95
 [3] S. Chatterjee *et al.*, CBM Progress Report 2019, 99
 [4] O. Singh *et al.*, CBM Progress Report 2018, 161
 [5] E. Nandy *et al.*, CBM Progress Report 2018, 163
 [6] A. Senger, CBM-PH-18001
 [7] A. Senger *et al.*, CBM-PN-2020-001

Di-muon combinatorial background estimation using different techniques

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In this report, different techniques for the di-muon combinatorial background estimation are discussed. Four different methods as available in the literature, namely, super event method, mixed event method, like-sign method and event by event method are employed for this purpose. The goal of this exercise is to precisely model the shape of the combinatorial background for dimuon measurements at SIS100 heavy-ion collisions and estimate the related systematics. Due to the very small branching ratio $\times$ multiplicity values of the different physical sources at FAIR, the signal peaks are well below the di-muon combinatorial background. Therefore a precise understanding of the background distribution is very crucial to extract the signal yields from the measured raw $\mu^+\mu^-$ spectra. The weak decays of pion and kaon are one of the major sources of the combinatorial background. For our present investigation, the combinatorial background is calculated for 0-10% central Au+Au collisions at beam momentum of 12 A GeV/c and with GEANT4 as the transport engine. The APR21 release of CBMROOT software is used for this study. The super event method is the default tech-

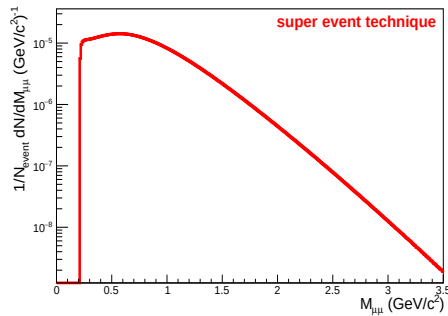


Figure 1: Invariant mass distribution using super event technique.

nique available within CBMROOT software to estimate the combinatorial background for dilepton simulation. In this method, one muon track candidate is combined with all the other oppositely charged muon track candidates of all the events, to calculate the uncorrelated invariant mass distribution as shown in Fig 1. The advantage of using the super event technique is that due to the large combination of the muon pairs, the statistical uncertainties associated with the large mass bins are rather small. However, this method is not realistic because the event information is restored at the time of combining the muon track candidates. Also, the method is suitable for purely central collisions, where all the events have nearly the same track multiplicities.

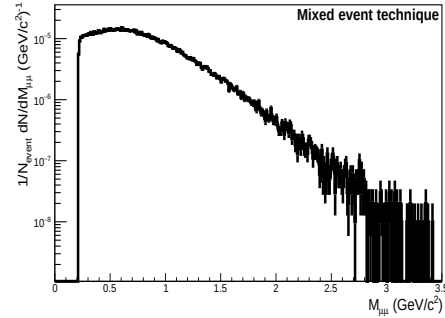


Figure 2: Invariant mass distribution using mixed event technique.

In the mixed event technique, an artificial pool of events are created having similar multiplicities or in other words, the events having similar impact parameters. Since in this current investigation all events are of 0-10% central Au+Au collisions, hence an event pool is created by using some randomly chosen mutually exclusive events. Within the pool, the oppositely charged muon track candidates are combined with each other to calculate the combinatorial background. The mixed event technique is more realistic as compared to that of the super event technique. The combinatorial pair mass spectra calculated using the mixed event technique is shown in Fig. 2. In the event by event

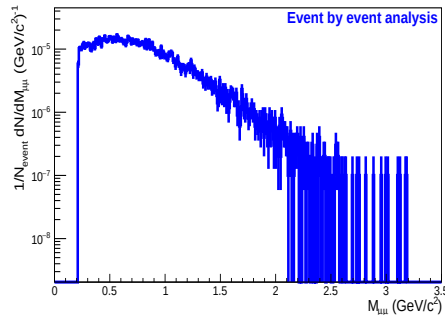


Figure 3: Invariant mass distribution using event by event technique.

analysis, the oppositely charged muon track candidates are combined with each other within the same event. This is the most general and realistic way to calculate the combinatorial background in any raw data analysis. The main disadvantage of this method is that it requires huge statistics as compared to the above-mentioned methods to have comparable statistical uncertainties at the respective mass bins. The invariant mass distribution using the event by

event analysis is shown in Fig. 3.

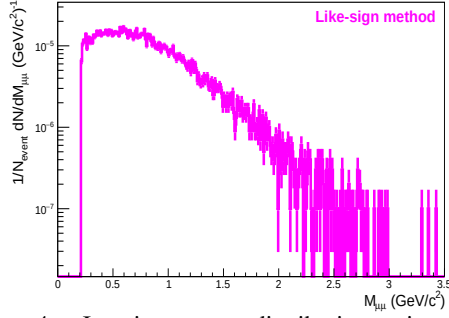


Figure 4: Invariant mass distribution using like-sign method.

The like-sign method had been extensively used in dimuon analysis by the NA50, NA60 experiments [1, 2] at CERN-SPS. In this method, the combinatorial background is calculated by taking the combination of like-sign pairs within the same events. After combining the like-sign pairs, the unlike sign combinatorial background, is expressed as $N^{\mu^+\mu^-}(BG) = 2\sqrt{N^{\mu^+\mu^+}N^{\mu^-\mu^-}}$. The distribution of the combinatorial background calculated using the like-sign method is shown in Fig. 4. For a compar-

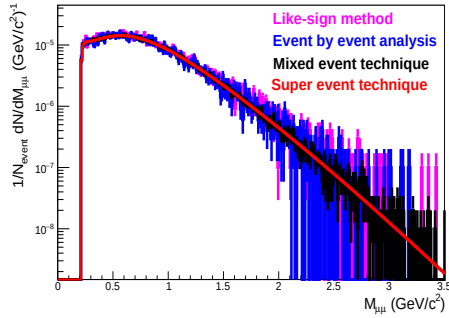


Figure 5: Invariant mass distribution using different techniques.

ative study, the distribution of combinatorial background calculated using different techniques as discussed above is shown in Fig. 5. The investigation related to the different techniques to reduce the combinatorial background and extraction of dimuon signal is ongoing and will be reported in the near future.

Acknowledgements

The authors would like to thank Dr. Anna Senger, Prof. Tetyana Galatyuk and Dr. Saikat Biswas for their valuable discussions in the course of this study.

References

- [1] R. Shahoyan, NA60 Note 2004-3
- [2] P. Crochet *et al.*, *Nucl.Instrum.Meth. A484* (2002) 564-572

Energy dependence of hyperon production in Au-Au collisions at FAIR energies

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Heavy-Ion collisions provide us an experimental tool to investigate the strongly interacting matter at extreme temperatures and densities. Under such extreme conditions the creation of a quark gluon plasma (QGP) is expected. In a QGP phase the quark gluon confinement in hadrons is removed and therefore these quarks and gluons can exist as quasi-free particles in an extended region of space-time. One of the proposed signatures of a phase transition from nuclear matter to a deconfined quark gluon plasma phase is the enhancement of strangeness production in A+A relative to p+p collisions[1]. The yields and distributions of strange hyperons are therefore of great interest as a sign of strange quark production. It is expected that the QGP phase should reflect a high strange (anti)quark density[2]. Multi-strange (anti)baryons, due to their strange quark content are expected to be a more sensitive probe of the QGP phase than single strange hadrons.

The energy dependence of the yields of strange particles and the ratio of yields of strange particles in central Au+Au collisions are investigated at E_{lab} energies from 4-35 GeV/A. The analysis is done using the particles produced in the mid-rapidity region ($\Lambda : |y| < 0.4$, Ξ and $\Omega : |y| < 0.5$) by UrQMD model, HSD and pHSD model. The average multiplicities of Ω^- , Ξ^- and Λ^0 and their anti-particles are plotted as function of beam energy in figure 1 and 2 respectively. Whereas their ratios (anti-baryons $\bar{B}$ / baryons B) in figure 3.

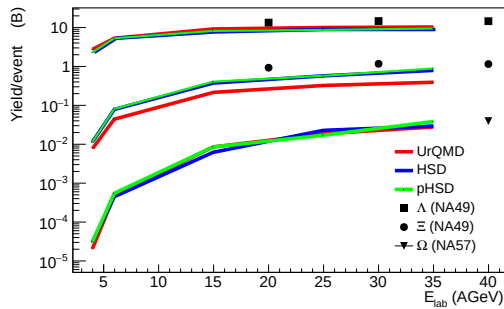


Figure 1: The average yields of Λ^0 , Ξ^- , and Ω^- in central Au+Au collisions as a function of beam energy, obtained from pHSD, HSD, and UrQMD models. The symbols are the data from NA49[3] and NA57[4] experiments.

All models reproduce reasonably well the average yields of Λ^0 hyperons, but underestimate the average yields of multi-strange hyperons. The pHSD model overestimates

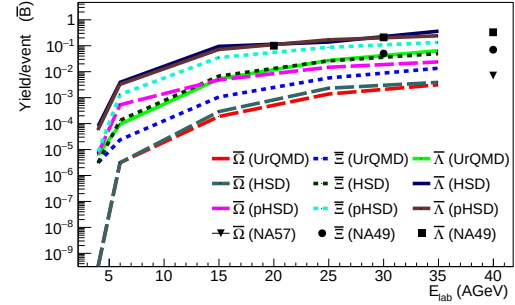


Figure 2: The average yields of $\bar{\Lambda}^0$, $\bar{\Xi}^+$, and $\bar{\Omega}^+$ in central Au+Au collisions as a function of beam energy, obtained from pHSD, HSD, and UrQMD models. The symbols are the data from NA49[3] and NA57[4] experiments.

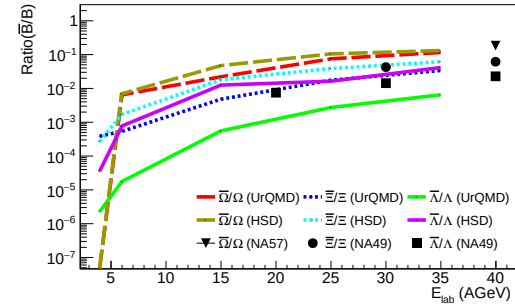


Figure 3: The $\bar{\Lambda}/\Lambda$, $\bar{\Xi}/\Xi$, and $\bar{\Omega}/\Omega$ ratios around mid-rapidity in central Au+Au collisions as a function of beam energy, obtained from pHSD, HSD, and UrQMD models. The symbols are the data from NA49[3] and NA57[4] experiments.

the average yields of $\bar{\Xi}^+$ and $\bar{\Omega}^+$, and describes $\bar{\Lambda}^0$ fairly well. The $\bar{\Lambda}^0$, $\bar{\Xi}^+$, and $\bar{\Omega}^+$ data points and their ratios are reproduced suitably well by HSD model. Whereas UrQMD model significantly underestimates the average yields of anti-hyperons and also their ratios.

References

- [1] J. Rafelski, Phys. Lett. B 97, 297 (1980); P. Koch, B. Müller, and J. Rafelski, Phys. Rep. 142, 168 (1986).
- [2] J. Rafelski, Phys. Lett. B 262, 333 (1991).
- [3] C. Alt et al. (NA49 Collaboration). Phys. Rev. C78, 034918, (2008).
- [4] F. Antinori et al. (NA57 Collaboration). Phys. Lett. B595, 68, (2004).

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Study of ϕ meson using HSD and PHSD model

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The CBM experiment is a future fixed target experiment designed to operate at very high interaction rates up to 10 MHz for selected observables. The high-intensity beams with a high-rate detector system in combination with sufficient beam time provides a unique conditions for a comprehensive study of QCD matter at very high net baryon densities achievable in the laboratory. Strangeness enhancement, one of the observable, is one of the important signatures of the QGP that we have studied through ϕ -meson containing ($s\bar{s}$). ϕ meson can be extracted through di-leptonic channel (branching ratio for $e^+e^- = 2.97 \times 10^{-4}$ and $\mu^+\mu^- = 2.86 \times 10^{-4}$) or di-hadronic channel K^+K^- with a branching ratio of 49.2%. ϕ -meson ($s\bar{s}$) has a very small cross-section of interaction and longer lifetime. Hence, it escapes early without interacting the medium and preserves the information about the conditions in which mesons were produced.

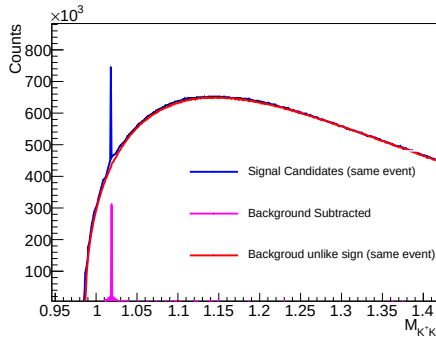


Figure 1: Invariant mass of ϕ meson reconstructed from K^+K^- in central Au + Au collisions by PHSD model at 25 A GeV Lab energy.

We have studied the ϕ meson using both Hadron-String-Dynamics (HSD) and Parton-Hadron-String Dynamics (PHSD) transport models. HSD is a microscopic transport approach which is governed by the off-shell dynamics with incorporated self-energies for the hadronic degrees-of-freedom. It includes the baryon octet and decouplet, the 0^- and 1^- meson nonets as well as higher resonances. While as PHSD incorporates both partonic and hadronic degrees-of-freedom as well as the transition from the hadronic to the partonic phase, the QGP phase in terms of strongly interacting quasiparticles with further dynamical hadronization and final hadronic interactions in the late stage.

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We have simulated 5 million events of central Au + Au collisions from PHSD model at E lab 6 - 40 A GeV. Reconstruction of ϕ mesons has been done from K^+K^- decay channel within the mid-rapidity ($|Y| < 1$). Same-event technique has been used for signal extraction. The combinatorial background formed from uncorrelated K^+K^- kaon pairs has been reconstructed by same-event technique where like sign kaon pairs from each event are combined. Fig. 1 shows unlike sign signal candidates over like sign background after proper normalization, with ϕ meson signal on the top. Then the ϕ meson signal extraction is done by subtracting the combinatorial background and fitted with Breit Wigner function.

ϕ -meson yield have been extracted from the Breit Wigner

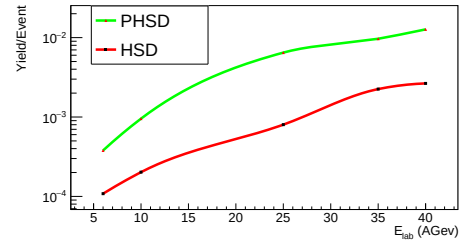


Figure 2: Energy dependance of yield at various FAIR energies within the rapidity cut of $|Y| < 1$ in central Au + Au collisions.

fit from HSD as well as PHSD model and then plotted with different energies and shown in Fig. 2. Increase in the ϕ -meson yield with energy can be seen clearly, as expected. We also studied the effect of Pt on the ϕ meson yield as shown in Fig. 3. Yield of ϕ meson is maximum around 0.5 GeV/c.

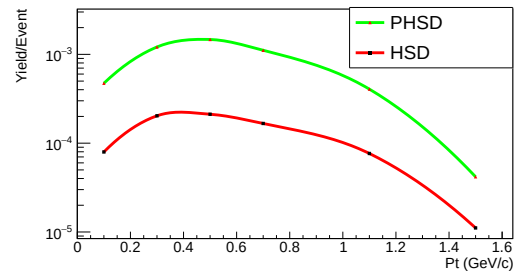


Figure 3: The invariant yield of ϕ mesons as a function of Pt measured within the rapidity cut of $|Y| < 1$ for central Au+Au collisions at 25 A GeV.

FAIR Phase-0 Activities

Achievements of the mCBM beam campaign 2021

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The CBM full-system test-setup named mCBM@SIS18 (short “mCBM”) was set up 2017/2018 at the detector test area HTD of the SIS18 facility of GSI. The primary aim of the mCBM setup is to commission and optimize the complex interplay of the different detector systems with the triggerless-streaming data acquisition and the fast online event reconstruction and selection. In particular, it allows testing of the detector and electronics components developed for the CBM experiment as well as the corresponding online/offline software packages under realistic experiment conditions up to the top CBM interaction rates of 10 MHz.

During the mCBM beam campaign 2021 high-rate tests with nucleus-nucleus collisions for various detector subsystems could be performed, benefiting substantially from high beam intensities available at the SIS18 of GSI/FAIR. Major effort was put on the upgrade of the DAQ/data transport system to the final CBM configuration integrating the new Common Readout Interface (CRI). Hence, the FPGA firmware for each detector subsystem has been newly developed as well as a new Timing and Fast Control system (TFC). A first commissioning run for the planned benchmark campaign in 2022 could be taken in O + Ni collisions at 2.0 AGeV kinetic bombarding energy, running at approx. 1 MHz collision rate.

The Setup

As depicted in Figure 1, the mCBM experiment is positioned downstream a solid target under a polar angle of about 25° with respect to the primary beam towards a beam dump located 7 m downstream at the south end of the experimental area. mCBM does not comprise a magnetic field, and, therefore, measures charged particles produced in nucleus-nucleus collisions traversing the detector stations under straight trajectories. The mCBM setup includes detector stations of all CBM subsystems. For the 2021 campaign the GEM stations for the MUCH system could not be upgraded due to pandemic travel restrictions and hence, the MUCH detector was not mounted. The photograph of Figure 1 shows the 2021 setup, the lower panel of Figure 1 depicts the top view of the corresponding GEANT geometry.

As visible in Figure 1 the mCBM experiment for the 2021 beam campaign comprised of:

- the STS subsystem which was fully equipped with 2 stations, 5 STS ladders, respectively,
- the 2 large TRD stations which were complemented

with 2 detectors for the inner TRD region (TRD-2D),

- the TOF subsystem consisting of 6 modules was grouped into two stacks; the TOF mainframe was moved and rotated closer to the optical beam axis positioning the inner stack at a center polar emission angle of 12.5° and the outer stack at 25.0°; RPC counters under test were placed for high-rate tests in between the TOF modules of the inner stack,
- the RICH subsystem using 2x aerogel radiators was placed directly behind the TOF detector and delivers a second measurement of the particle velocity in a selected acceptance window,
- and a single PSD prototype-module positioned directly under the optical axis of the beam, 5° tilted relative to the beam axis while pointing to the target (not visible at the photograph of Figure 1).

Furthermore, the vacuum system of the mCBM experiment has been completed with an Aluminum beam pipe. The fast and segmented diamond counter for time-zero (T_0) determination positioned 20 cm upstream of the target has been used during the high-rate tests using the former AFCK-based data transport, but could not be included into the new CRI-based data transport (see chapter).

For tests in high-rate nucleus-nucleus collisions the TOF mainframe was moved and rotated towards smaller polar emission angles, significantly enhancing the charged particle rate observed at the inner TOF stack. Hence, RPC counters under test were placed in between the TOF modules of the inner TOF stack. Furthermore, MIMOSIS-I sensors for the MVD, LGAD sensors for the beam monitoring system as well as STS front-end electronics were placed directly on the beam axis, in front of the SEM-grid beam counter, upstream of the mCBM beamdump (not visible in Figure 1).

The DAQ/data transport as well as the detector subsystems were remotely controlled by VNCs while the communication was granted by permanent Zoom rooms. During shifts, the mCBM experiment could thus be operated properly with a small team of 4 to 6 persons on-site and about 20 experts world-wide connected remotely.

DAQ/data transport

The CBM experiment at FAIR will measure relativistic nucleus-nucleus collisions with collision rates up to 10 MHz leading to data rates up to 1 TB per second. To

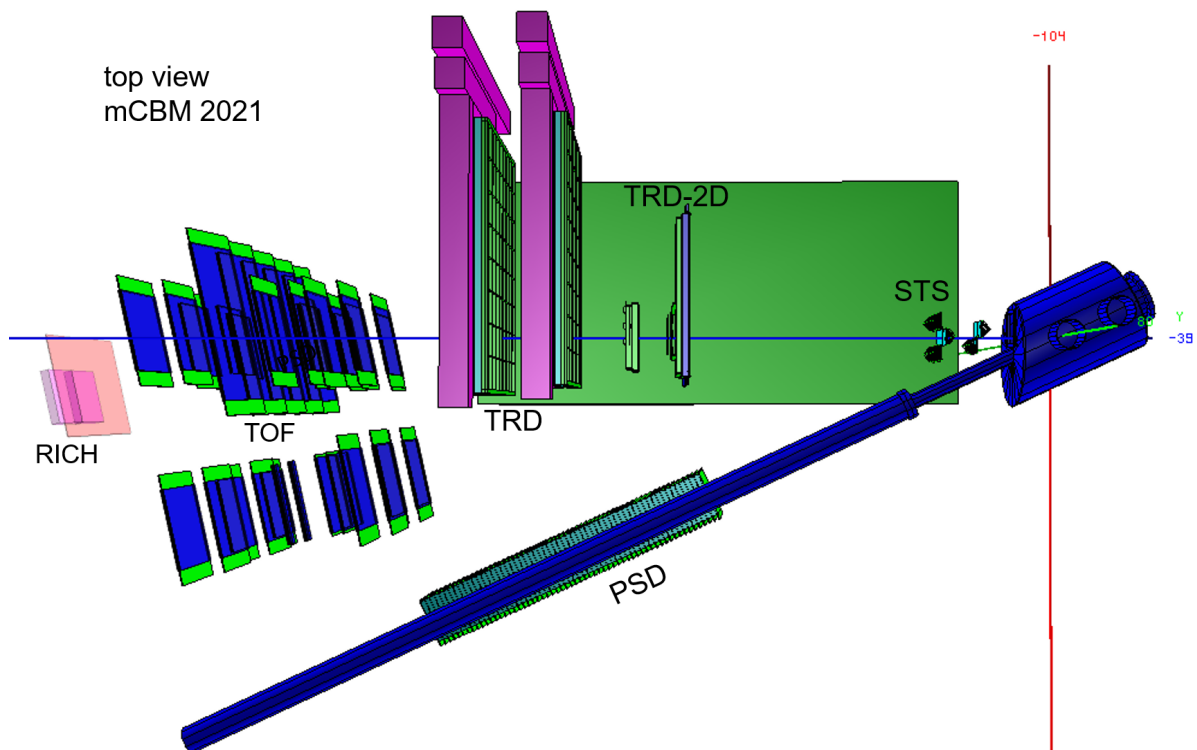
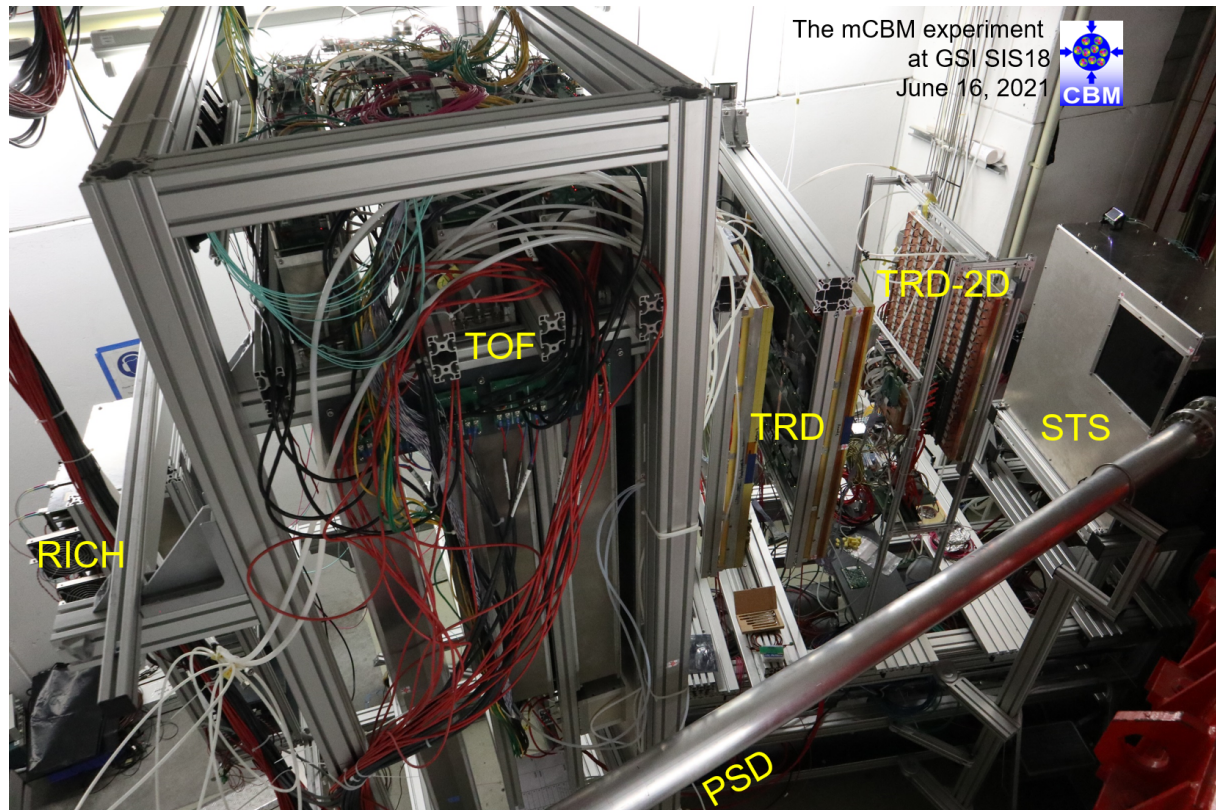


Figure 1: Photograph of the mCBM setup inside the HTD cave and GEANT geometry (lower panel) of the mCBM setup as of June 2021. The beam enters from the right.

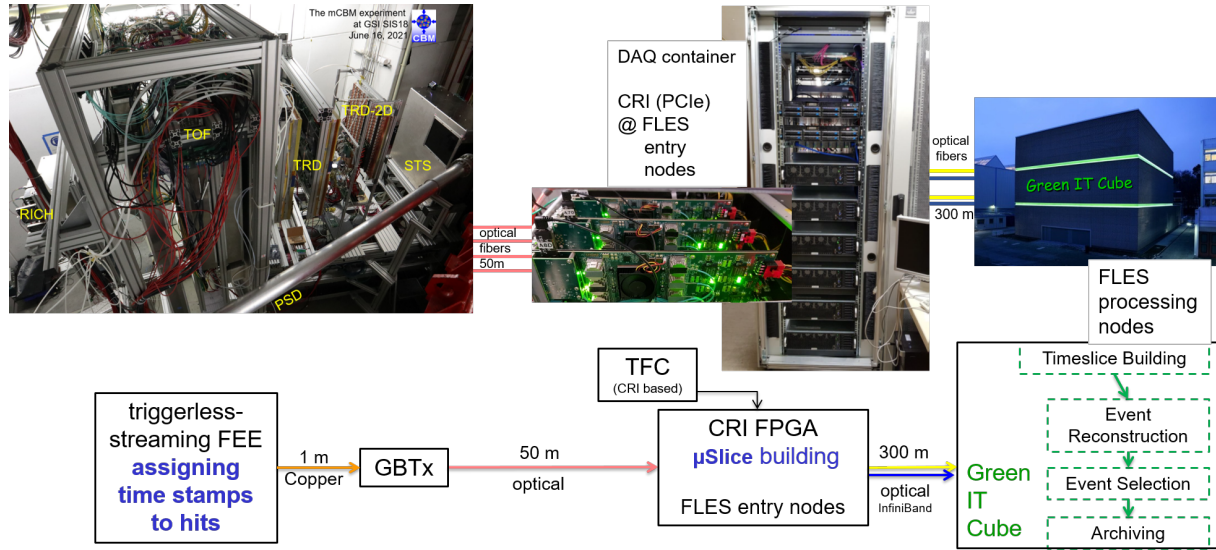


Figure 2: The CBM DAQ and data transport system based on CRIs, applied to the mCBM experiment.

achieve the required performance a triggerless-streaming data acquisition system is being developed. For the mCBM beam campaign 2021 the major effort was put on the upgrade of the DAQ system to the final CBM configuration by merging two FPGA layers (DPB and FLIB) into a Common Readout Interface (CRI). The CBM DAQ and data transport system as it is used in the mCBM setup is depicted in Fig. 2.

It includes ultra-fast and radiation-tolerant ASICs as front-end chips followed by CERN GBTx-based radiation-tolerant data aggregation units. The detector front-end digitizes signals above threshold and assigns a time stamp to the hit. By a Timing and Fast Control (TFC) system the detector front-ends are time-synchronized to the nanosecond level. This data is then forwarded via an electrical connection to the GBTx readout board, where the electrical signals acquired through a large number of e-links are converted and merged into an optical GBT link operating at a link speed of 4.48 Gbit/s. These GBT links interface the detector subsystems with the PCIe-based CRI boards integrated in the FLES input nodes. The present CRI version (v1.0, "BNL-712") has been developed by BNL and is based on the XILINX Kintex UltraScale FPGA. The required, new FPGA firmware [18] has been developed in Q3-2020-Q2-2021 for each detector subsystem as well as for the Timing and Fast Control system (TFC) [21],[20]. Merging of two FPGA layers (DPB and FLIB) into a single FPGA CRI board required the development of a new FLES Interface Module (FLIM) [19]. Furthermore, a scalable Experiment Control System (ECS) has been embedded in the upgraded DAQ and data transport system.

Results

During the mCBM campaign 2021 various beams could be used benefiting substantially from the highest available beam intensities. The used ion species with the corresponding kinetic project energies as well as highest beam intensities are listed in Table 1.

2021	projectile	E_{kin}	max. beam intensity per spill (10s)
March	$^{208}\text{Pb}(67+)$	1.06 AGeV	$2 \cdot 10^9$
May	$^{124}\text{Xe}(46+)$	1.30 AGeV	$3 \cdot 10^9$
June	$^{16}\text{O}(8+)$	2.00 AGeV	$1 \cdot 10^{10}$

Table 1: mCBM high-rate tests in 2021.

High-rate tests

Systematic high-rate tests in nucleus-nucleus collisions with collision rates up to 10 MHz were performed investigating the TOF RPC rate capability and if aging of the RPCs is observed at the highest collision rates, the bit-flip and latch-up probability of the MVD MIMOSIS-I sensor as well as of the front-end ASIC of the STS system (FEE STS-XYTER v2.2). Additionally, first tests on the rate capability of LGAD sensors presumably suited for the CBM beam monitor system could be conducted. The beam tests indicate a remarkable radiation tolerance of all tested components.

Fig. 3 shows the TOF RPC efficiency (left figure) and the time resolution of the RPCs (right figure) as a function of the observed counting rate [16]. The efficiency de-

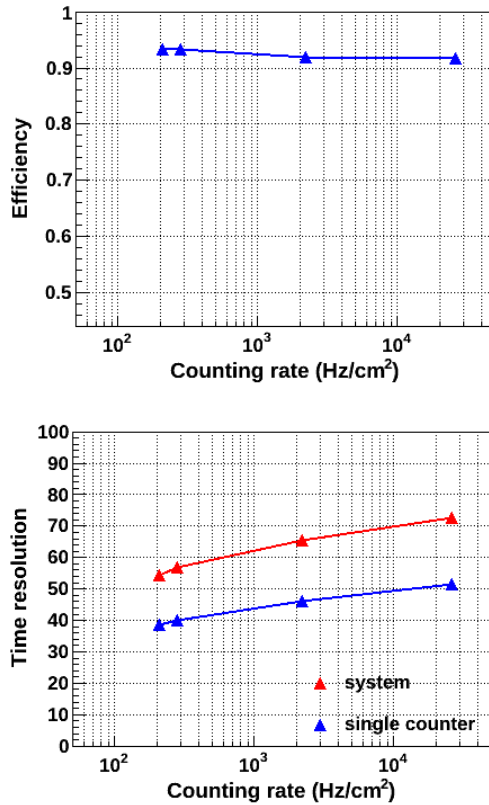


Figure 3: Upper panel: TOF RPC efficiency (HV: ± 6 kV, 200 mV FEE threshold) and time resolution as a function of counting rate (lower figure), see [16].

grades only slightly with the counting rate. The time resolution reduces to the measured 70 ps for the system and 52 ps for single counters at the highest counting rates of about 25 kHz/cm² showing still a sound performance. It is worth mentioning that the time distribution remains Gaussian shape at the highest counting rates.

The first full-sized sensor prototype MIMOSIS-I for the Micro Vertex Detector (MVD) was placed in front of the mCBM beam dump, being directly exposed by the ion beam under various beam intensities. The tests were performed to simulate the beam halo during CBM experiments at the SIS100 [11]. During the beam tests it has been observed that the bit-flip protection did not perform as expected. The so identified design bug will be fixed in the next generation MIMOSIS-II. Furthermore, the observed bit-flip probability exceeds the measured single event latch-up probability substantially, while the sensor under test tolerated latch-ups without being permanently damaged. Additionally, the sensor under test passed without apparent damage the exposure with direct Xe beam at the highest beam intensity simulating direct beam impact events.

Similar to the MVD MIMOSIS-I sensor tests, the front-end ASIC of the STS system STS-XYTERv2.2, mounted on a front-end board, was exposed by direct Pb beam

with different beam intensities while placed in front of the mCBM beam dump [12]. Up to 10⁷ Pb ion per second on the ASIC no Latch-Up Transitions (LUTs) were observed. At higher beam intensities the LUT related current increased, and at the highest beam intensities LUTs became frequent, but without showing severe damages. Power cycling returned the measured current to the original value. With the estimated LUT probability of approx. 6×10^{-10} per Pb ion no remarkable risk is expected for the operation of the CBM STS since the front-end boards with mounted ASICs will be positioned outside the detector acceptance with large distance to the primary beam. Furthermore, permanent damages by LUTs could not be observed and can be circumvented while detected quick enough.

Commissioning run for the benchmark measurements in 2022

The new DAQ hardware and 1st firm- and software versions for the new DAQ system and data transport were successfully tested during the ¹⁶O-beam block in July 2021. O+Ni collisions at 2.0 AGeV kinetic bombarding energy were measured with max. 1 MHz collision rate as a first commissioning run (run 1588) for the planned benchmark campaign on Λ production in 2022. As a key requirement of a triggerless-streaming DAQ system, the CRI branches of all detector subsystems were stably synchronized over the full run period. Hence, a stable timing of the front-end electronics of all detector subsystems could be observed within the expected time resolution as it is visible in Figure 4. Here, all time differences $time\ diff = (t_{subsystem} - t_{TOF})$ are displayed within the given time window measured by the STS, TRD, PSD and RICH detector subsystem with respect to the time of the TOF system. The measured time results from time stamps assigned to the raw hit messages by their front-end ASICs, converted into digis with unit [ns] during the unpacking stage of the data analysis. Individual time offsets of the subsystems are corrected during the unpacking stage, no detailed time calibration procedures were applied. As observed, the subsystem time offsets remain constant during the run as well as between runs.

Supplementary to the correlation in time, correlations of spatial coordinates between detector stations are presented in Fig. 5 [13] and Fig. 6 [15]. Fig. 5 shows spatial correlations between both STS stations STS 0 and STS 1 (left figures), between STS stations and TOF modules (right figures), and Fig. 6 between TOF-STs interpolations with TRD detectors, left: TRD1D and right: TRD2D.

First data-driven alignment studies have been performed correcting the position of the STS stations in respect to the target [13] as well as of TOF in respect to STS and target [17]. Both are based on forming tracklets projecting to the target, either using both STS stations [13] or in a row stacked modules of the TOF wall involving the position of the STS units [17]. While doing so, the reconstruction of the vertex turned out to be a suitable tool, being sensi-

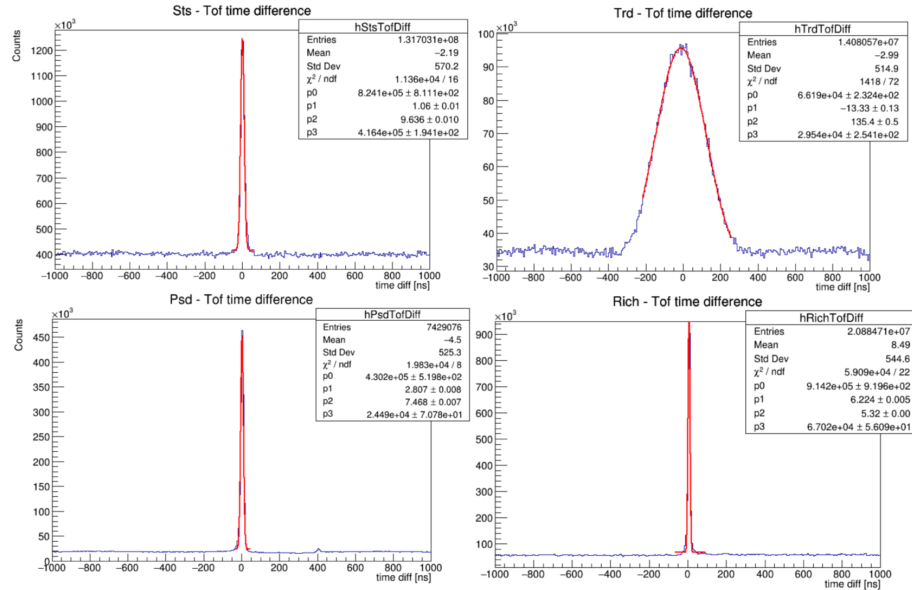


Figure 4: Stable timing: time difference measured by the detector subsystems in respect to the TOF system.

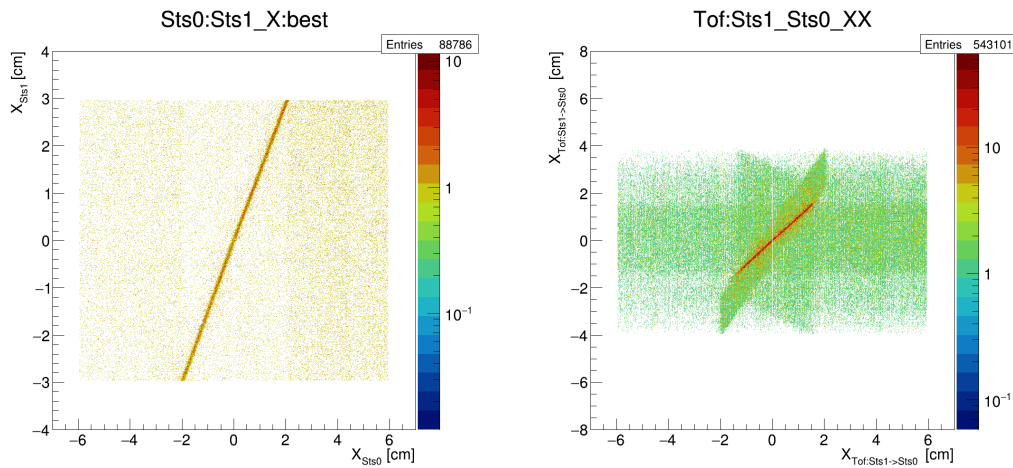


Figure 5: Correlation between spatial coordinates (x) of both STS stations STS 0 and STS 1 (left) and between both STS stations and TOF (right figure) [13].

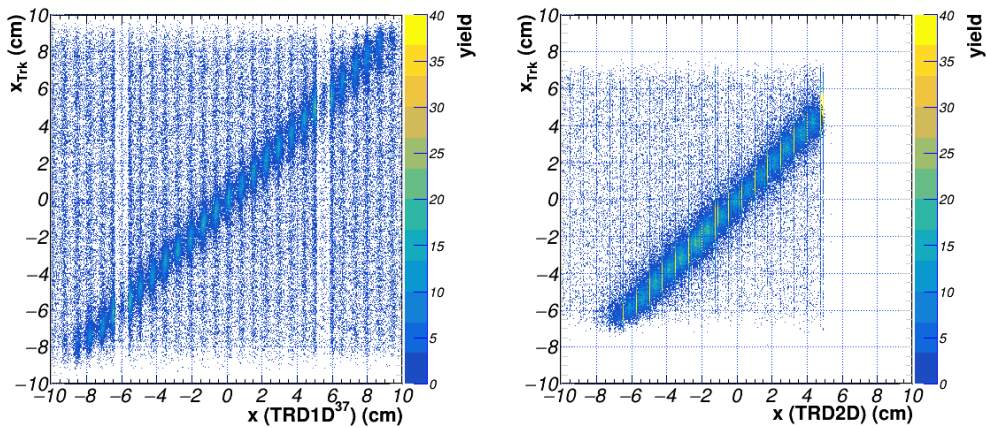


Figure 6: Correlation between spatial coordinates (x) of TOF-STs interpolations and TRD1D (left) or TRD2D (right figure) [15].

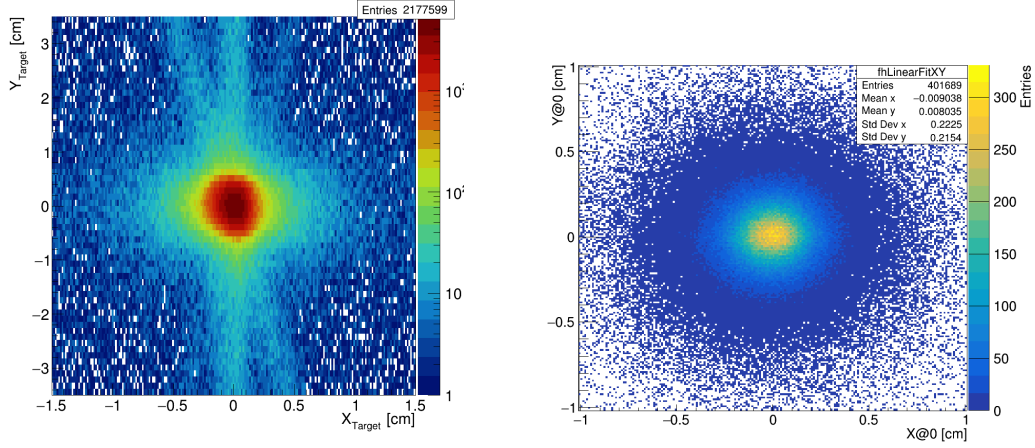


Figure 7: Vertex reconstruction after a first alignment by correcting the position of the STS stations in respect to the target [13] (left) as well as of TOF in respect to STS and target [17] (right figure).

tive to x and y as well as z -shifts of the detector units and stations. The resulting vertex reconstruction is shown in Fig. 7. The dimension of the reconstructed vertex matches reasonably with the beam spot measured on the scintillation target of the beam diagnostics station, upstream in front of the mCBM target chamber.

A first, preliminary CBM data analysis chain is being developed. As a first step, the raw data messages packed and compressed in tsa files are being unpacked by an unified unpacking scheme separating the framework from the algorithmic part [22]. Accordingly, the subsystem-specific unpacking converts the raw data messages into CbmDigiEvents (Digi classes) within this common architecture, applying additionally individual subsystem time-offset corrections as well as involving the detector channel mapping and (partially) first calibration steps of the corresponding detector subsystem.

After data unpacking, a first, simplified event building is performed based on a time-cluster-search within a time window defined by the timing response of a reference detector system [23]. The digi-times of the reference detector are then taken as seeds for setting the time windows of the detector systems by adapting the window width according to the corresponding timing response. Found event candidates are further filtered by digi-based trigger conditions [24], [25] cutting e.g. on digi-multiplicities of selected detector stations or it's combinations. For mCBM data taken during the benchmark commissioning run O+Ni at 2.0 AGeV in July 2021 the trigger condition of the event candidate selection requests $M_{TOF \text{ digi}} \geq 6$.

Subsequently, detector hits are reconstructed by the subsystem specific hit finding algorithms applied to digi events. Reconstructed hits have been used for spatial correlations shown in Fig. 5 and Fig. 6 as well as for the vertex reconstruction displayed in Fig. 7. Furthermore, TOF tracklets are formed based on reconstructed TOF hits using both active layer of the TOF configuration included into the new CRI readout in July 2021. TOF tracklets have

been used e.g. to project onto the STS detector planes towards the target for efficiency studies of the STS [13] or for investigations on the alignment of detector stations [17]. The well-developed and investigated CBM track reconstruction algorithm *Cellular Automaton Tracking* (CA) has been adapted for application on mCBM simulations and experiment data [26]. Moreover, the flexibility of the track reconstruction approach could be expanded significantly by a standardized interface. Hence, the CA tracker can be applied soon to real mCBM data, enhancing the selection power especially for heavy collision systems which are scheduled for the beam campaign 2022.

References

- [1] J. Adamczewski-Musch et al. (HADES collaboration), Sub-threshold production of K^0 s mesons and Lambda hyperons in Au+Au collisions at $\sqrt{s_{NN}} = 2.4$ GeV, Phys.Lett. B793 (2019) 457-463
- [2] M. Merschmeyer et al. (FOPI collaboration), K^0 and Λ production in Ni+Ni collisions near threshold, Phys. Rev. C 76 (2007) 024906
- [3] mCBM@SIS18 - A CBM full system test-setup for high-rate nucleus-nucleus collisions at GSI / FAIR GSI-2019-00977, <https://repository.gsi.de/record/220072>
- [4] Wojciech M. Zabołotny, Grzegorz Kasprówicz, Adrian P. Byszuk, David Emschermann, Marek Gumiński, Krzysztof T. Poźniak and Ryszard Romaniuk, Selection of hardware platform for CBM Common Readout Interface, Proc. SPIE, vol 10445, 2017, ISBN 9781510613546
- [5] J. Heuser, W. F.J. Müller, V. Pugatch, P. Senger, C. J. Schmidt, C. Sturm and U. Frankenfeld, Technical Design Report for the CBM Silicon Tracking System (STS), GSI-2013-05499, <http://repository.gsi.de/record/54798>
- [6] S. Chattopadhyay, Y. P. Viyogi, P. Senger, W. F.J. Müller and C. J. Schmidt,

- Technical Design Report for the CBM Muon Chambers (MuCh),
GSI-2015-02580, <https://repository.gsi.de/record/161297>
- [7] C. Blume, C. Bergmann, D. Emschermann,
Technical Design Report for the CBM Transition Radiation
Detector (TRD),
GSI-2018-01091, <http://repository.gsi.de/record/217478>
- [8] C. Höhne,
Technical Design Report for the CBM Ring Imaging
Cherenkov Detector (RICH),
GSI-2014-00528, <http://repository.gsi.de/record/65526>
- [9] N. Herrmann,
Technical Design Report for the CBM Time-of-Flight Sys-
tem (TOF),
GSI-2015-01999, <https://repository.gsi.de/record/109024>
- [10] F. Guber and I. Selyuzhenkov,
Technical Design Report for the CBM Projectile Spectator
Detector (PSD),
GSI-2015-02020, <https://repository.gsi.de/record/109059>
- [23] D. Smith, S. Roy, P.-A. Loizeau, and V. Friese,
Event building in CBM
- [24] D. Smith, S. Roy, P.-A. Loizeau, and V. Friese,
A minimum-bias trigger algorithm based on the digi time
distribution
- [25] S. Roy, D. Smith, P.-A. Loizeau, V. Friese, D. Emscher-
mann, and C. Sturm,
Time-based simulation and event building for mCBM
- [26] V. Akishina, S. Gorbunov, and S. Zharko,
Cellular Automaton Tracking

Published in (this) CBM Progress Report 2021

- [11] B. Arnoldi-Meadows et al.,
MIMOSIS-1: Studies on Single Event Effects
- [12] J. Lehnert et al.,
Operational studies with the STS-XYTERv2.2 ASIC
- [13] D. Ramirez and A. Toia,
Performance of the mSTS detector during the mCBM beam
campaign 2021
- [14] A. Bercuci et al.,
Steps towards integration of the TRD-2D detection system
with the CBM experiment
- [15] A. Bercuci et al.,
Global space-time correlation of the local TRD reconstruc-
tion within the mCBM environment
- [16] M. Petris et al.,
In-beam test of the MSMGRPC prototypes for the CBM-
TOF inner zone in the mCBM experimental setup
- [17] A. Weber, C. Sturm, and C. Höhne,
First data driven alignment studies of the mCBM setup
- [18] W. Zabolotny et al.,
FPGA-related development for CBM DAQ
- [19] D. Hutter, J. de Cuveland, and V. Lindenstruth,
A FLES Interface Module for the CRI
- [20] V. Sidorenko, D. Emschermann, W.F.J. Müller, and
J. Becker,
Improvement of time alignment between hardware and soft-
ware
- [21] V. Sidorenko, M. Guminski, W. Zabolotny, W.F.J. Müller,
and J. Becker,
Prospects of GBT-FPGA as the TFC core interface
- [22] P.-A. Loizeau, P. Raisig, V. Friese, D. Smith, A. Weber, and
A. Bercuci,
A new unified architecture for unpacking, applied to mCBM
data

First data driven alignment studies of the mCBM setup*

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Introduction

The mCBM 2021 beamtime campaign marked the transition from phase-I to phase-II of the mCBM experiment. The upgraded DAQ with its CRI based readout chain was tested for the first time. Data was taken with O+Ni at 2.0 AGeV. Using the "golden" run 1588, first data driven studies of the alignment of the mCBM system were done. For the first studies, the alignment focusses on the mSTS and mTOF detector to achieve the long term goal of a topology cut based Λ reconstruction.

The Concept

The mSTS detector in run 1588 consists of two stations. Station 0 is build from two units, here referred to as unit 0 and unit 1. The second station consists of one unit, referred to as unit 2. In case of the TOF detector, only 2 modules were available. Each of them consists out of 5 counters in a configuration with slight overlap.

In order to align the mSTS and mTOF, the analysis focusses on the hits from both detectors. The raw data of run 1588 was unpacked with the standard parameters for STS and parameter-set 2 for TOF. The applied reconstruction macro includes event building as well as the hit construction, including a calibration of the TOF hits. The analysis is based on the mCBM geometry setup `mcbm_beam_2021_07_surveyed`.

The alignment is based on an iterative method that for now is executed by hand. An automation is possible, but was not used due to a lack of reliable termination conditions. In STS, residuals from a hit in station 1 and a hit in station 0 are calculated. Due to the lack of a magnetic field, both hits form a linear track. By extrapolating the track and scanning for the minimum width of the 2-dimensional distribution of the extrapolated tracks, the best target spot can be explored. The position of the best target spot is an important reference for the Z-alignment of the STS. Unfortunately, very small uncertainties in the X and Y location of the two units in station 0 have a huge influence on the correctness of the extrapolated Z position of the vertex.

Based on the pre-alignment of the STS units, the TOF can be further aligned. The alignment is based on the calculation of residuals between all counters in the TOF de-

tector and all units in the STS. A hit in a counter of TOF is chosen. A simple linear track is formed by the assumption of a virtual vertex point. The position of the vertex point is given by the best vertex reconstructed by STS only. The TOF hit is extrapolated along this simple linear track to the Z-positions of the three units in STS. In each station, the closest hits from STS to the extrapolated TOF hit are selected and the residuals are calculated (see Fig. 1).

By comparing the 2D residual histograms of the 5 counters in the two TOF modules, different information can be extracted. For example the trend of the residual position in different counters of one TOF module can show the misaligned of this module, but also a rotation of the full TOF detector. The comparison of all 10 TOF counters to the different STS units is helpful. Differences of the residuals between units are used to extract the overall positioning of the TOF in Z but also its rotation around the Y-axis.

Based on the investigation of all combinations of residuals from TOF counters to STS units, corrections on the geometry were extracted. The corrections are translated to correction matrices for the `cbmroot` geometries and applied on the reconstruction stage. This process is then repeated in iterating the corrections a "best set" of correction values is found.

In addition to the residuals, also a pseudo tracking between STS and TOF has been implemented. A pseudo track is defined by the selection of a hit in the most downstream TOF module. In the TOF Module closer to the target, a second hit is required. Furthermore, a hit in both STS stations is required. By a linear fit of the four data points in space, the track parameters are extracted. In order to accept a pseudo track, a cut on a small χ^2 is applied. Based on the accepted tracks, the determination of the best possible vertex position in Z, based on STS and TOF, is possible.

Unfortunately the overall measurements of the detector positions in reality is not very precise and difficult. The

Detector	X	Y	Z	rot. Y
full STS	0.275	-0.89	-0.5	0.
STS unit 0	0.0	0.045	0.0	0.
STS unit 1	-0.04	0.06	0.0	0.
STS unit 2	0.0	-0.11	0.0	0.
full TOF	0.85	-1.05	0.0	0.5

Table 1: Alignment corrections for STS, STS units and the TOF detector in cm. X,Y,Z are translations in space. Rot. Y is a rotation around the Y axis.

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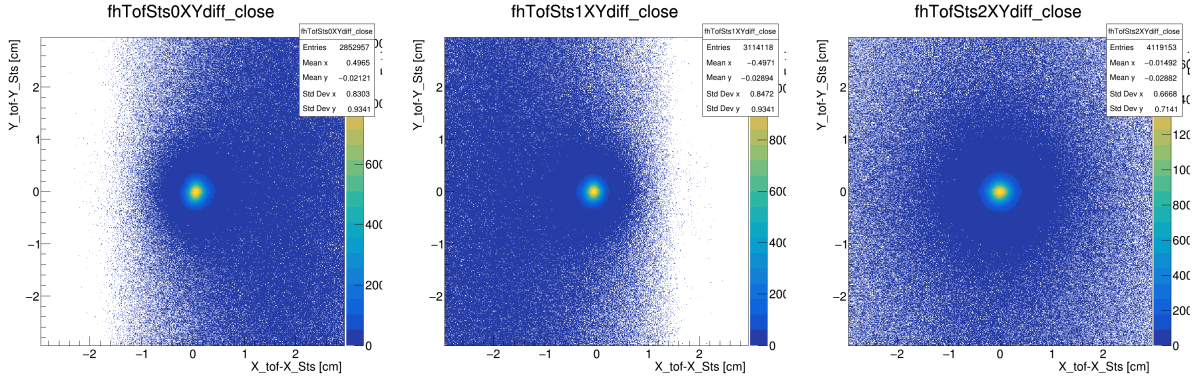


Figure 1: Residuals calculated by hits from all TOF counters to the three different STS units, unit 0 to unit 2 from left to right.

constraints on the movements of the `cbmroot` geometry for the data driven alignment are therefore relaxed. This gives too much freedom for possible alignments and is extremely challenging. An automated procedure would find several minima and the termination of the process finding the best result would not be trivial.

Results

Figure 1 shows the extracted residuals separately for the three units of STS. Furthermore, figure 2 shows the sum of all 3 units with a zoom into the center. Both figures show an undistorted shape of the residual distribution. The applied alignment correction, shown in table 1, leads to reasonably good results in terms of the peak position close to the center as well as the precision. For all units the results are better than 0.7 ± 1.8 mm, in X and Y. A detailed look into the individually extracted residuals between TOF counters and units also supports this result.

The previously introduced pseudo tracks are used to check for the extrapolated vertex position versus the result from STS alone. By the use of the corrections of table 1, the best vertex could be reconstructed at $Z=0$ cm with a center at 0.00 ± 0.15 cm in X and Y (compare figure 3). The positioning of the best vertex at the origin of the geometry validates the applied corrections.

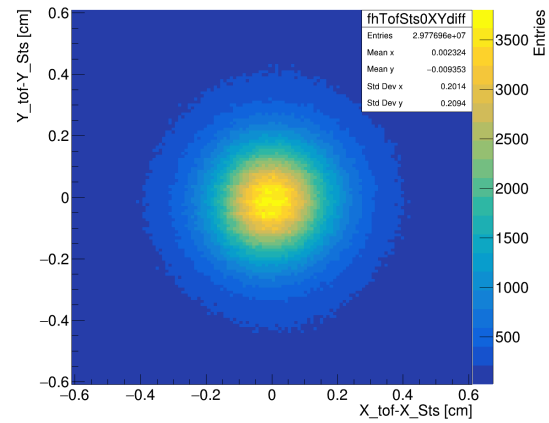


Figure 2: Residuals calculated by hits from all TOF counters and all STS units.

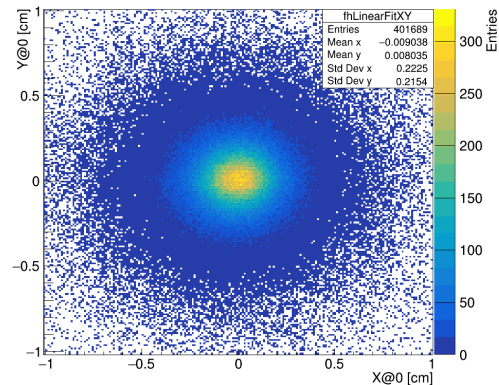


Figure 3: Best extrapolated target position by the use of pseudo tracks, constructed from 2 TOF hits and 2 STS hits. The vertex is determined to be at $Z=0$ cm.

CBM Publications 2021

- O. Golosov for the CBM Collaboration
Data-Driven Methods for Spectator Symmetry Plane Estimation in CBM Experiment at FAIR
 Particles 4 (2021) 354
- F. Guber, M. Golubeva, A. Ivashkin and S. Morozov
Synergy in the Development of Forward Hadron Calorimeters for NA61/SHINE, BM@N, MPD and CBM Experiments
 Act. Phys. Pol. B Proc. Suppl. 14 (2021) 563
- V. Klochov for the CBM Collaboration
The Compressed Baryonic Matter Experiment at FAIR
 Nucl. Phys. A 1005 (2021) 121945
- A. Kumar *et al.*
Commissioning and testing of pre-series triple GEM prototypes for CBM-MuCh in the mCBM experiment at the SIS18 facility of GSI
 JINST 16 (2021) P09002
- M. Kuttan *et al.*
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 JHEP 10 (2021) 184
- M. Kuttan *et al.*
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 Nucl. Phys. A 1005 (2021) 121896
- A. Senger and P. Senger
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 Phys. Scr. 96 (2021) 054002
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- V. Singhal, S. Chatterjee, V. Friese and S.Chattopadhyay
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Sensors 21 (2021) 7378

Doctoral, diploma, master and bachelor theses 2021

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CBM PhD Awards 2020 / 2021

The CBM PhD Award decorates the best doctoral work related to the CBM experiment. With this award, the CBM collaboration especially wants to honour the contributions of students to the CBM project. The award was granted for the first time at the CBM Collaboration Meeting in April 2016 for PhD theses defended in the year 2015. It is given annually and is endowed with a prize money of 500 Euro.

The prize winner for 2020 is

Dr Adrian Rodriguez Rodriguez

Goethe-Universität Frankfurt

for his work on

**The CBM Silicon Tracking System
front-end electronics – from bare
ASIC to detector characterization,
commissioning and performance**



The prize winner for 2021 is

Dr Dirk Hutter

Goethe-Universität Frankfurt

for his work on

**An input interface for the CBM
first-level event selector**



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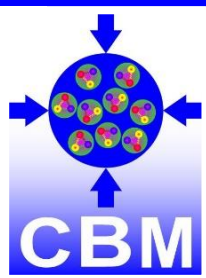
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