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The Compressed Baryonic Matter Experiment at FAIR

The CBM Collaboration, January 2015

Substantial experimental and theoretical efforts worldwide are devoted to explore the phase diagram of strongly interacting matter. At top RHIC and LHC energies, QCD matter is studied at very high temperatures and very low net-baryon densities. For larger net-baryon densities and lower temperatures, it is expected that the QCD phase diagram exhibits a rich structure such as a critical point, a first order phase transition between hadronic and partonic matter, or new phases like quarkyonic matter. The discovery of these landmarks would be a breakthrough in our understanding of the strong interaction, and, therefore, is in the focus of various high-energy heavy-ion research programs. The Compressed Baryonic Matter (CBM) experiment at FAIR will play a unique role in the exploration of the QCD phase diagram in the region of neutron star core densities, because it is designed to run at unprecedented interaction rates. High rate operation is the key prerequisite to measure rare diagnostic probes which are sensitive to the dense phase of the nuclear fireball, such as multi-strange hyperons, lepton pairs, and particles containing charm quarks, with high precision and statistics. Most of these observables will be studied for the first time in the FAIR energy range. The start version of the CBM setup is very well suited to perform an internationally unrivaled nuclear-matter research programme with a substantial discovery potential using beams from SIS100. The experimental exploration of strongly interacting matter at ultra-high baryon densities will be extended towards higher beam energies with the full version of the CBM detector system using high-intensity beams from SIS300.

I. PROBING QCD MATTER WITH HEAVY-ION COLLISIONS

High-energy heavy-ion collision experiments provide the possibility to create and investigate extreme states of strongly-interacting matter in the laboratory. Figure 1 illustrates the conjectured phases of nuclear matter and their boundaries in a diagram of temperature versus baryon chemical potential [1]. In experiments at LHC and top RHIC energies, matter is produced at very high energy densities with equal numbers of particles and antiparticles, i.e. at almost zero baryon chemical potential. After hadronization, the fireball finally freezes out chemically at a temperature of 155 - 165 MeV [2]. This temperature coincides with the critical temperature predicted by Lattice QCD calculations for a chiral phase transition [3, 4] which is found to be a smooth crossover from partonic to hadronic matter [5]. Lattice QCD calculations for finite baryon chemical potential are still in their infancy, and are not yet able to make firm predictions on possible phase transitions at high net-baryon densities. On the other hand, model calculations predict structures in the QCD phase diagram at large baryon chemical potentials, like a critical endpoint followed by a first order phase transition [6]. Moreover, new phases are predicted, such as quarkyonic matter which can be considered as a Fermi gas of free quarks, with all thermal and Fermi surface excitations permanently confined [7]. The experimental discovery of these landmarks and regions in the QCD phase diagram would be a major breakthrough in our understanding of the properties of strongly interacting matter at extreme conditions, with fundamental consequences for our knowledge on the structure of neutron stars, chiral symmetry restoration, and the origin of hadron masses.



FIG. 1. Sketch of the phase diagram for nuclear matter. Taken from [1].

II. EXPERIMENTS EXPLORING HIGH NET-BARYON DENSITIES

Pioneering heavy-ion experiments have been performed at AGS in Brookhaven [8] and at low CERN-SPS beam energies [9] in order to explore the QCD phase diagram at large baryon-chemical potentials. Due to the available detector technologies at that time these measurements were restricted to abundantly produced hadrons. At the CERN-SPS, the NA61/SHINE experiment continues to search for the first-order phase transition using light and medium size beams [10]. This detector setup is limited to reaction rates of about 80 Hz. The STAR collaboration at RHIC plans a second beam energy scan to improve the statistical significance of the data taken in the first series of measurements [11]. However, the reaction rates at RHIC drop down to a few Hz when decreasing the beam energies below $\sqrt{s_{NN}} = 8$ GeV. Neither STAR at RHIC nor NA61 at SPS will be able to run at beam energies of 10 A GeV and less. At the Joint

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Institute for Nuclear Research (JINR) in Dubna, a fixed target experiment is being developed at the Nuclotron to study heavy-ion collisions at gold-beam energies up to about 4 A GeV. Moreover, the collider facility NICA together with a multi-purpose detector is planned at JINR [12]. The luminosity limitations of these existing and future facilities constrain the research programs to the investigation of bulk observables, and prevent high precision measurements of rare diagnostic probes. In contrast, the Compressed Baryonic Matter (CBM) experiment at the Facility for Antiproton and Ion Research (FAIR) is designed to run at extremely high interaction rates (up to 10 MHz). This feature is the key requirement for the measurement of both bulk and rare probes with unprecedented precision. The combination of highintensity beams with a high-rate detector system and sufficient beam time provides worldwide unique conditions for the study of nuclear matter at neutron star core densities. In the FAIR Modularized Start Version only the SIS100 ring will be available. In order to close the gap between SIS100 and low RHIC and SPS energies, SIS300 will be required. In addition, SIS300 will be used as a stretcher ring offering the opportunity to run several experimental programs in parallel.

III. THE CBM PHYSICS PROGRAM AT SIS100

FAIR will provide heavy-ion beam energies from 2 - 11 (14) A GeV for Q = 0.4 A (0.5 A) nuclei with the SIS100 synchrotron, and 11 - 35 (45) A GeV with the SIS300 synchrotron. Already in central Au+Au collisions at top SIS100 energies the nuclear fireball will be compressed according to transport model calculations - to more than 8 times saturation density ρ_0 . Even at moderate SIS100 energies, for example at 5 A GeV, a density above 6 ρ_0 is reached as illustrated in figure 2 [13]. At such densities, the nucleons will start to melt and to dissolve into their constituents. The calculations predict that the dense fireball spends a relatively long time within the phase coexistence region. Those conditions appear to be sufficient to allow for a phase transition. For example, according to a non-local 3-flavor Nambu Jona-Lasinio model calculation, which predicts a deconfinement phase transition in the core of a 2 solar mass neutron star [14], a mixed phase of hadrons and quarks develops at densities between 5 ρ_0 and 8 ρ_0 , above which pure quark matter is formed. In conclusion, the beam energies available at SIS100 appear to be especially well suited for generating signals of the phase transition, and offer the opportunity to address fundamental scientific questions:

• What is the equation of state of nuclear matter at neutron star densities, and what are the relevant degrees of freedom at these densities? Is there a phase transition from hadronic to quark-gluon matter, or a region of phase coexistence? Do exotic QCD phases like quarkyonic matter exist?

- To what extent are the properties of hadrons modified in dense baryonic matter? Are we able to find indications of chiral symmetry restoration?
- How far can we extend the chart of nuclei towards the third (strange) dimension by producing single and double hypernuclei? Does strange matter exist in the form of heavy multi-strange objects?
- What is the production mechanism of charm quarks at threshold beam energies, how does open and hidden charm propagate in cold and in hot nuclear matter?



FIG. 2. Evolution of the central net baryon density $\rho(t)$ as function of elapsed time reached in a central Au+Au collision at 5 A GeV as calculated with different transport models and with a 3-fluid hydrodynamics code. [13].

The experimental challenge is to identify diagnostic probes of the dense phase of the fireball which is transiently formed in the collision. In experiments performed so far at AGS, at low SPS energies, or at very low RHIC energies, mainly such particles have been measured which are created at freeze-out where the density already has dropped below saturation density. The focus of the CBM experiment at FAIR is to study messengers from the dense fireball such as multiple strange hyperons, lepton pairs, and hadrons containing charm quarks in order to find answers to the questions raised above. A survey of the theoretical concepts and the experimental programs devoted to the exploration of the QCD phase diagram with focus on high baryon densities is given in the CBM Physics Book [15]. The CBM research program at SIS100 includes the following observables.

Strangeness

At top SPS energies it was found that the production of hyperons is enhanced in heavy ion collisions, i.e. the multiplicity of hyperons per participating nucleon increases with the mass of the collision system [16]. The enhancement increases with the number of strange quarks in the hyperon. According to transport models, multi-strange (anti-)hyperons are produced in sequential collisions involving kaons and Λ s, and, therefore, are sensitive to the

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density in the fireball. This sensitivity is expected to increase towards lower beam energies close to or even below the production threshold. SIS100 beam energies will be ideally suited to perform such experiments which require a systematic measurement of multi-(anti-)strange hyperons at different energies and for different colliding nuclei. Up to date, only about 300 Ξ^- hyperons have been measured in Au+Au collisions at 6 A GeV [17]. The excitation functions of multi-strange hyperons ($\Xi^-(dss)$ and $\Omega^-(sss)$) and anti-hyperons ($\Xi^+(\bar{d}\bar{s}\bar{s})$ and $\Omega^+(\bar{s}\bar{s}\bar{s})$) in A+A collisions with different A values at SIS100 beam energies are very promising observables which will shed light on the compressibility of nuclear matter at neutron star core densities.

Lepton pairs

Lepton pairs will be measured over a wide range of invariant masses covering low-mass vector mesons including their Dalitz decays and charmonium. The precise measurement of lepton pairs at low invariant masses will allow to analyze modifications of vector meson properties in dense baryonic matter. This observable is expected to be sensitive to chiral symmetry restoration [18]. The slope of the dilepton invariant mass distribution between 1 and 2 GeV/c^2 directly reflects the average temperature of the fireball. The study of the energy dependence of this slope opens the unique possibility to measure the caloric curve which would be a signature for phase coexistence [19]. This measurement would also provide indications for the onset of deconfinement and the location of the critical endpoint. The flow of lepton pairs as function of their invariant mass would allow to disentangle radiation from the early partonic phase from the late hadronic phase. No dilepton data are available at FAIR energies.

Collective flow, correlations and fluctuations

The collective flow of hadrons is driven by the pressure created in the early fireball. For example, the observed difference between the elliptic flow of particles and their antiparticles has been explained by mean-field potential effects in both the partonic and the hadronic phase [20]. A direct proof for a first order phase transition would be the discovery of phase coexistence by observing an enhanced production of composite particles or multi-particle correlations caused by the spinodal amplification of density fluctuations [21]. Higher moments of the net-baryon and the net-charge multiplicity distributions, which are related to the thermodynamical susceptibilities, have been measured by the STAR collaboration in order to search for the QCD critical point [22]. Most of these observables will be measured for the first time at SIS100 energies. Up to now, only the proton flow excitation function has been measured at the AGS [8], and was used to extract the compressibility of nuclear matter [23].

Hypernuclei and hypermatter

Theoretical models predict that single and double hypernuclei, and heavy multi-strange short-lived objects are produced via coalescence in heavy-ion collisions with the maximum yield in the region of SIS100 energies [24, 25]. The discovery and investigation of new hypernuclei and of hypermatter will shed light on the hyperon-nucleon and hyperon-hyperon interactions which are essential ingredients for the nuclear equation-of-state at high densities and low temperatures [26].

Charm

Charm-anticharm quark pairs are produced in primary hard scattering processes and then propagate through the nuclear or partonic medium as it is produced in high-energy heavy-ion collisions. Depending on their interaction with the medium, the charm and anticharm quarks hadronize into D mesons, charmed baryons, or charmonium. The suppression of charmonium due to color screening of the heavy quark potential in the deconfined phase is the first predicted signature for quarkgluon plasma formation [27]. Charmonium suppression was first observed in central Pb+Pb collisions at 158 A GeV [28], and then also found in experiments at RHIC [29] and LHC [30]. At SIS100 energies, the charm production mechanism will be studied for the first time at beam energies close to production threshold. Moreover, exploratory experiments of charm production in collisions of medium size nuclei will be possible. In addition, the propagation of open and hidden charm in cold nuclear matter will be systematically investigated in protonnucleus collisions. Measurements of (open and hidden) charm in collisions of heavy nuclei can only be performed at SIS300 energies.

IV. THE COMPRESSED BARYONIC MATTER (CBM) EXPERIMENT

The CBM detector is designed as a multi-purpose device which will be able to measure hadrons, electrons and muons in heavy-ion collisions over the full SIS100/SIS300 beam energy range. Therefore, no major adjustments have to be made to optimize the experiment for SIS100 beams, only some of the detectors and the DAQ system will be realized in phases (see below). In order to extract the dilepton signals, the physical and combinatorial background of lepton pairs has to be precisely determined, which is notoriously difficult. Measuring both electrons and muons will dramatically reduce the systematical error of the data, because the background sources of electrons and muons are completely different. In order to perform high-precision multi-differential measurements of rare probes the experiment should run at event rates of 100 kHz up to 10 MHz for several months per year. Because of the complicated decay topology of particles like Ω hyperons or D mesons, no simple trigger signal can be generated, so the events have to be reconstructed and selected online by fast algorithms running on a high-performance computing farm. Therefore, the data readout chain is based on a free streaming frontend

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electronics which delivers time-stamped signals from each detector channel without event correlation. The reconstruction algorithms are tuned to run at high speed on modern many-core CPU architectures.

The detector system features a fixed target geometry accepting polar emission angles between 2.5 and 25 degrees in order to cover midrapidity for symmetric collision systems at beam energies between 2 and about 40 A GeV. The setup comprises the following components:

- A large aperture superconducting dipole magnet,
- a Silicon Tracking System (STS) based on doublesided silicon microstrip sensors arranged in 8 stations inside the magnetic field,
- a Micro Vertex Detector (MVD) consisting of 4 layers of silicon monolithic active pixel sensors,
- a time-of flight wall (TOF) based on multigap resistive plate chambers with low-resistivity glass for high-rate operation,
- a Ring Imaging Cherenkov (RICH) detector comprising a CO₂ radiator, a glass-mirror system and a photon detector based on multianode photomultipliers for electron identification,
- a Transition Radiation Detector (TRD) for pion suppression particle tracking,
- a forward hadron calorimeter (Projectile Spectator Detector) for event characterization,
- a Muon chamber (MuCh) system for muon identification consisting of a set of gaseous micropattern chambers sandwiched between iron plates as hadron absorbers,
- a First-Level-Event-Selection (FLES) system for online event reconstruction and selection.

For SIS100, only start versions of the TRD, the MuCh, and the FLES will be built. The TRD comprises only 4 out of 12 layers, the number of absorber and detector stations of the MuCh is reduced, and the FLES has less computing power as compared to the full version required for SIS300. The Technical Design Reports (TDR) on the magnet, on the STS, on the RICH, on the PSD, and on the MuCh have been approved, the TDR on the TOF detector is in evaluation. The TDRs on the DAQ/FLES system, on the MVD, on the TRD and on the Electromagnetic Calorimeter will be submitted in 2015.

Until the start of FAIR, the nuclear matter research program at GSI will be pursued with the HADES experiment at SIS18. At the SIS100 accelerator, the HADES detector can be used to perform di-electron and hadron reference measurements in collision systems with moderate particle multiplicities, such as proton-proton, protonnucleus and nucleus-nucleus collisions with light nuclei.

V. SUMMARY

The goal of the CBM research program at SIS100 is to explore the QCD phase diagram in the region of neutron star core densities. This includes the study of the equation-of-state of nuclear matter and the search for new phases. The start version of the CBM detector will be able to measure rare diagnostic probes such as multistrange hyperons and lepton pairs with unprecedented precision and statistics. Most of these probes will be studied for the first time in the FAIR energy range. In order to achieve the required precision for multi-differential observables, the measurements will be performed at reaction rates between 100 kHz and 10 MHz. The search and exploration of new phases of strongly interacting matter will be extended to higher energies with a completed detector setup once SIS300 will come into operation.

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The CBM experiment in the international context

The CBM Collaboration, January 2015

The exploration of the QCD phase diagram at large baryon-chemical potentials addresses funda-mental scientific questions, and, therefore, is in the focus of heavyion experiments worldwide. Key observables which probe the dense phase of the collision include multi-strange baryons, electro-magnetic radiation (dileptons), and particles containing charm quarks. Important information can be extracted from the particle multiplicities, the phase-space distributions, from particle correlations and fluctuations. In order to measure these multi-differential observables with a very good statistical significance, the experiments have to be operated at very high reaction rates over a sufficient amount of time. According to model calculations, the SIS100 beam energy range is very well suited to study the properties of strongly interacting matter at neutron star core densities.

I. PIONEERING EXPERIMENTS

First systematic experiments on hadron production in heavy-ion collisions have been performed at the Bevalac in Berkeley and at the AGS in Brookhaven. At the CERN-SPS, the NA49 collaboration measured excitation functions of hadrons with limited statistics, in particular for multi-strange baryons at low SPS energies. Dimuon measurements have been performed by NA60 at top SPS energies only. Low-statistics data on di-electrons were taken by the CERES collaboration at a beam energy of 40 A GeV ($\sqrt{s_{NN}}$ = 8.8 GeV).

II. RUNNING EXPERIMENTS

At the CERN-SPS the NA61/SHINE experiment continues to search for the first-order phase transi-tion using light and medium size beams with limited reaction rates (see figure 1). The STAR collaboration at RHIC plans a second beam energy scan. However, the reaction rates at RHIC drop down to a few Hz when decreasing the collision energies below $\sqrt{s}_{NN} = 8$ GeV (see figure 1). Neither STAR at RHIC nor NA61 at SPS will be able to run at energies of $\sqrt{s}_{NN} = 5$ GeV and below, i.e. in the SIS100 energy range. A first complete measurement of rare and penetrating probes in Au+Au collisions at low beam energies ($\sqrt{s}_{NN} = 2.4$ GeV) has recently been accomplished by HADES at SIS18. At SIS100, HADES is very well suited to perform reference measurements (p+p, p+A) and A+A with low multiplicities because of its large acceptance and low material budget.

III. PLANNED EXPERIMENTS

At the Joint Institute for Nuclear Research (JINR) in Dubna, the collider facility NICA together with a multipurpose detector (MPD) is under design. The luminosity limitation of NICA will constrain the research program to the investigation of bulk observables (see figure 1). The Compressed Baryonic Matter (CBM) experiment at the Facility for Antiproton and Ion Research (FAIR) is designed to run at extremely high interaction rates (see figure 1). This feature is the key requirement for the measurement of bulk and rare probes, and of multi-differential observables with unprecedented precision. The combination of high-intensity beams with a high-rate detector system and sufficient beam time provides worldwide unique conditions for the study of nuclear matter at neutron star core densities.



FIG. 1. Interaction rates of existing experiments and experiments under construction.

Common Activities

Test of prototype CBM detector components with proton beams at COSY*

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Teams of the CBM collaboration have performed several in-beam tests of prototype detectors and electronics in 2014. In April at GSI, TOF and TRD detectors were examined in a parasitic ion beam steered onto a target. Prototypes of the TRD, RICH and TOF detectors were under test in a mixed electron-pion beam in November at the CERN-PS. Two campaigns of beamtime took place at COSY, Research Center Jülich, within beam time blocks provided to support FAIR related detector developments. In August, a team spent one week with testing prototype electronics under intense proton irradiation. In December, a week of beam time focused on studies of neutron-irradiated silicon microstrip sensors for the STS detector system, response measurements of a full-size triple-GEM sector for the MUCH detector system, and further studies of radiation effects in FPGA and LDO electronics. We report here on the December test at COSY.

The CBM test bench, 3 m long, is installed in the JES-SICA cave into which the proton beam of COSY is extracted. Intensities from minimum 10^4 to maximum 10^9 protons per seconds can serve testing different objects. While detector systems are preferrably tested at lower impinging particle rates, and only for load tests at higher rates, electronics is required to be tested in high beam intensity conditions. The beam can be focused down to about 0.5 cm r.m.s diameter at the objects under test. Beam defocusing to areas of a few cm² is possible.

The aim of the beam time campaign was to study the performance of two full-size CBM prototype components, double-sided silicon microstrip sensors for the Silicon Tracking System and a full-size GEM sector for the Muon Chambers, as well as several electronics components for the read-out chains. The double-sided silicon microstrip sensors were produced in two technical versions which were to compare. Prior to the experiment, the sensors had been irradiated at the KIT irradiation facility to 2×10^{14} 1 MeV neutron equivalent fluence matching the integrated "lifetime" exposure expected in CBM running conditions. The detectors were operated in a thermally insulated station at a temperature of -8 °C, achieved with a flow of chilled nitrogen gas. The station was part of a telescope shown in Fig. 1 (top) comprising also two reference stations to define the proton tracks, and one further station with a STS prototype module under test. The full-size prototype GEM sector seen in Fig. 1 (bottom) was produced at CERN from 500 by 471 mm GEM foils in a three-foil stack, segmented into several areas, altogether having 1200 read-out pads with progressively increasing size.

The read-out of both the silicon and the GEM detectors was achieved with n-XYTER based front-end electronics and the DABC data acquisition system. The data collected allowed studying the detector response including charge collection properties.

At the downstream end of the test stand, boards with prototype electronics were placed on the beam. Already during detector operation, tests of FPGA electronics at moderate beam intensities allowed investigating single-event upsets. Dedicated runs at highest intensities were done with analog power regulating electronics (LDO) and memory components, after the conclusion of the detector tests.



Figure 1: (Top) Telescope with four silicon detector stations. The second to the right operates the irradiated sensors. (Bottom) A full-size prototype GEM sector was installed further downstream comprising a triple-GEM foil stack.

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A monitorig system for radiation hardness tests of electronic components for future FAIR experiments

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Electronic components installed in the field of reaction products in future experiments at FAIR have to be radiation hard. At present, selected parts undergo exhaustive tests with use of intense minimum ionising particles' beams, mostly 3 GeV protons at Jülich sychrotron facility. A control system based on ARDUINO processor has been developed to monitor the components status in situ.

Monitoring system requirements

For components like DC/DC converters or LDO voltage stabilisers the output voltage level as well as expected transient voltage spikes rate has to be monitored during irradiation. Voltage level monitoring (input and output) requires relatively low readout frequency below 1 Hz and can be implemented on inexpensive ARDUINO-Nano system (Fig.1). It is programmed to control an optocoupler based set of relays to govern applied input voltages (for each of 12 channels separately) and reading an ADC values of output voltages for each channel. System supervises the output voltage level and - if needed - switches off the malfunctioning channels to avoid its influence on other DUTs. Measurement status is logged on a local memory and displayed via implemented web server on connected clients. The control electronics has to be placed far away from the device under test in order to avoid spurious effects due to the irradiation.



Figure 1: Block diagram of the system testing a set of DC/DC converters controlled by ARDUINO processor.

Hardware realisation

A base plate equipped with two sets of clamps and a PCB-holder has been prepared to accomodate different devices under test (DUTs) (Fig. 2). They have to be placed in a row such that the irradiating beam punches through all of them. A small scintillator placed on the beam axis behind tested chips and read out by a photomultiplier monitors the beam intensity. Its signals are also registered by AR-DUINO system on separate counter and stored with time stamps spill by spill. This information helps to estimate precisely beam intensity integral. One raw of electrical clamps is supplied with input voltage (controlled by AR-DUINO via set of relays) for the DUTs. Their outputs are wired via second clamps raw to the multiplexer and ADC on controller board to supervise output voltage levels.



Figure 2: Base plate with PCB card holder and wiring.

ARDUINO control system

The processor itself can be programmed in a C-like programing language with use of different libraries to serve standard functionality (time server, SD-card I/O, internet I/O). The main loop of the program consists of output volt-

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Figure 3: Control output of the monitoring system.

age check channel by channel, input voltage check, counter readout, internet service, timer service. The voltage read out values are compared to the upper and lower threshold values which can be defined for each channel. In case of over- or under voltage in three consecutive readout steps the affected channel is switched off (Fig. 3).

References

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Superconducting Dipole Magnet



The SC dipole magnet 3D modeling for muon option of the CBM detector

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The superconducting dipole magnet is a central part of the CBM experiment detection system [1]. The target station, the Micro-Vertex Detector (MVD) and the Silicon Tracking System (STS) are placed in the magnet gap, which has a height of 140 cm and a width of 250 cm in order to cover a polar angle acceptance of $\pm 25^{\circ}$ and a horizontal acceptance of $\pm 30^{\circ}$. The magnet has to provide a vertical magnetic field with a bending power of $\sim 1 T \cdot m$ over a length of 1 m from the target. One of the options of the CBM detector includes a muon detection system (MuCH), which consists of 6 hadron absorber blocks and 6 tracking detector triplets [2] placed downstream the magnet. This report presents the calculation of the magnitude of the magnetic field and acting forces on the MuCH detector.



Figure 1: 3D model for CBM SC dipole magnet with MuCH system.



Figure 2: Vertical magnetic field component B_y distribution along the beam direction. One half of a simplified 3D model for CBM SC dipole magnet with MuCH system is shown in Figure 1. It is assumed that the first absorber and supporting structure of the MuCH system are made from the nonmagnetic materials. The magnetic field calculations have been performed using 3D TOSCA code [3]. Two plane symmetries of the magnetic field have been used in the modeling. The current density is taken as 43.93 A/mm^2 , which provides the total current through one coil of 1.121 MA. The calculated stored energy is 4.592 MJ. The vertical magnetic field component B_y distribution along the beam direction is presented in Figure 2. The maximal value of the B_y component is ~1.1 T with the field integral of ~1 $T \cdot m$.



Figure 3: Magnetic field saturation picture in the MuCH absorber.

The distribution of the magnetic field in the MuCH absorber is shown in Figure 3. The maximal value of the magnetic field of $\sim 0.25 T$ is in the center of the first absorber.

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No. of absorber	2	3	4	5	6
Force [N]	1358	459	174	0.06	0.1

The results of the calculations for the forces acting on the MuCH absorbers are presented in Table 1. These forces are negligible for the last 2 absorbers.

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Superconducting dipole magnet for the Compressed Baryon Matter (CBM) experiment at FAIR.

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The superconducting dipole magnet is a central part of the CBM detector system. The magnet has to provide the vertical magnetic field with a bending power of 1 Tm on the length 1m from the target. The magnet gap has a height of 140 cm and a width of 250 cm in order to accommodate the target station, Micro- Vertex Detector and Silicon Tracking System providing a polar angle acceptance of $\pm 25^{\circ}$ and a horizontal acceptance of $\pm 30^{\circ}$.

The CBM superconducting dipole magnet [1] is of Htype with a warm iron yoke/pole and cylindrical superconducting coils in two separate cryostats. The potted coil has 1749 turns. The wire, similar to the CMS wire, has Nb-Ti filaments embedded in a copper matrix and is soldered in a copper stabilizer with a total Cu/SC ratio of about 13 in the conductor. The operating current and the maximal magnetic field in the coils are 686 A and 3.25 T, respectively. The coil case made of stainless steel contains 20 liters of liquid helium for one coil. The vertical force in the coils is about 250 t. The cold mass is suspended from the roomtemperature vacuum vessel by six suspension links. Six cylindrical support struts compensate the vertical forces. Design calculations for CBM superconducting dipole magnet have been performed [2]. The code TOSCA was used for calculating electromagnetic forces exerted on the coil, while the structural analysis for the coil case, the coil vessel and the support links was made using the code ANSYS.



Figure 1: CBM dipole magnet with the support.

The energy stored in the magnet is about 5 MJ. The magnet will be self-protecting. However, in order to limit the temperature rise to 100 K in case of a quench, the energy will be dumped in an external resistor [3].

One of the purpose of the magnet support is the vertical and horizontal adjustment of the CBM magnet. A perspective view of the CBM magnet with the support is shown in Fig.1. The design of the CBM magnet is corrected according to Toshiba recommendations.



Figure 2: Results of the stress calculations for the support beam using ANSYS code.

The magnet support consists of two support beams each of them is placed on the base plate. The vertical adjustment of the magnet is provided by 3 hydraulic jacks. 3 roller skids is used for the adjustment in the horizontal plane. They allow to adjust the magnet position along and transversely to the beam direction as well as provide the rotation in the horizontal plane. 6 sets of the magnetic base with digital indicators are used for displacement control. The results of the stress calculation for the beam support using ANSYS code is shown in Fig.2. The design of the support system satisfies to the CBM magnet requirements [1].

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3D CIEMAT code optimization for the CBM magnet quench calculation.

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A superconducting dipole magnet for the CBM experiment will be constructed and installed at CBM cave at GSI(Darmstadt, Germany). The important features of the CBM superconducting dipole magnet is a large gap (high of 1.4m and width of 2.5m) in order to accommodate the target and Silicon Tracking System.

The magnet is H-type dipole, having circular superconducting coils. It will store about 5.15 MJ at its nominal current of 686 A. The coil design for the CBM magnet is based on the design of the FAIR Super-FRS dipole. It has 1749 turns(53 layers with 33 turns per layer). The conductor insulation consist of 2×0.05 mm polyimide tape and 2×0.1 mm glassfiber material (tape or braid), in total 0.3 mm. The detailed information about coil and conductor structure can be found in [1].

To design the quench protection system for the magnet it is important to perform the simulation of the quench process in the coil at different operation conditions. This note presents the results of 3D calculations done with the use of two programs. One of them is currently used at GSI[2]. The other based on 3D CIEMAT code[3] was modified for CBM dipole magnet calculation[1].

The calculation presented here was done for the case when no dump resistor was used for the quench protection. Both calculations take into account the inductance function $L_d(I)$ [1]. The 3D GSI calculation is performed for the uniform field map distribution in the coil using the maximal values $B_m(I)$ and also for the conductor insulation (G10 tape) of 0.3 mm thickness. The modified 3D CIEMAT program takes into account the real field map distribution in the coil and two layer of conductor insulation (0.1mm Kapton, 0.2mm G10). The additional 3D CIEMAT calculations have been performed to investigate the influence of the coil field map distribution and insulation properties on the simulation results.

Fig.1 and Fig.2 present the hot-spot temperature and quench voltage time dependence during the quench, respectively. Blue solid and dash-dotted curves are the results of 3D CIEMAT and GSI computation for uniform coil field map distribution and G10 conductor insulation, respectively. They gives the maximum hot-spot temperature and quench voltage on the level of 130 K and 1240 V, respectively. The difference between the results calculated with the GSI and CIEMAT models is related to the different material data bases used in those programs.

The red curves present the result of 3D calculation for two layer of conductor insulation(0.1mm Kapton, 0.2mm



Figure 1: 3D quench calculation of the CBM dipole magnet – the hot-spot temperature.



Figure 2: 3D quench calculation of the CBM dipole magnet- the quench voltage.

G10) and real field map distribution in the coil. The maximum hot-spot temperature and quench voltage equal to the 170 K and 1200 V,respectively.

The modification of the 3D CIEMAT program was done to perform the CBM magnet quench calculation for the use of two-layer conductor insulation of different type and real field map distribution in the coil. The presented results show that the CBM dipole magnet is a self-protecting.

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Micro-Vertex Detector

Status of the CBM MVD simulation model*

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The MVD simulation model is subject to a major revision and considerable progress has been achieved. In the following its motivation and status are discussed.

Motivation

Due to its proximity to the target and its excellent spatial resolution the MVD is the dedicated detector to resolve secondary vertices. In addition, its capability to clean-up background in di-electron spectra is subject of a dedicated study [1]. However, the primal implementation in simulation lacked in a realistic description (with respect to e.g. the material budget or peculiar sensor features) for advanced studies. These studies are needed to develop strategies to achieve best performances, to analyze critical points and to finalize the concept of the MVD and its tools.

The revision of the MVD model, to be incorporated to the CbmRoot simulation framework, aims at a more realistic description of the current understanding of the MVD. Before, in the standard scenario, the MVD was simplified as two homogeneous discs at 5 cm and 10 cm downstream the target, with an outer (inner) radius of 2.5 cm (0.5 cm) and 5 cm (0.5 cm), respectively. As no representation of individual sensors was included, this simplification possesses many limitations. The limitations involves mainly sensor properties beyond the hit response as e.g. the data parallelism of sensors, the rolling-shutter frame read-out, bandwidth limitations, busy circuits, a definition of a fake hit rate, time stamping and the data format.

The new approach [2] addresses these issues and is based on a segmented geometry with four stations (at 5 cm, 10 cm, 15 cm and 20 cm downstream the target) including all relevant features. Its underlying sensor characteristics are borrowed from MIMOSIS. The detailed geometry was elaborated in CAD. The conversion from the respective description into the ROOT geometry format was conducted by a dedicated tool. In this way we are able to respond very quickly to changes in the detector design.

Along with the proper representation of the gradual material budget, there is the possibility to incorporate the missing features mentioned above, as hits are assigned to sensors now. The data parallelism is incorporated by restructuring the data processing through the three process steps called digitizer, clusterfinder and hitfinder. Here, the corresponding data representations called Monte Carlo (MC) hits, digis (firing pixels) and clusters, which serve as input for the respective process step are assigned to the respective sensors. All further properties of the sensors are incorporated within the digitizer. As previously mentioned digis are particularly important, as they describe the response of the sensor to impinging hits mimicked by the digitizer. Apart from the generated pattern of single hits the interference among hits is important to consider. This is implemented in the digitizer by creating the signal amplitudes and distributions of all hits before jointly discriminating to generate the binary charge measurement. Hits from consecutive events might pile-up and/or neighboring hits merge. This is particularly true due the long integration time of one frame of $\sim 30 \ \mu s$. The respective output is dependent upon the features included as listed above. These features require a definition of the temporal sequence of the recorded MC hits accordingly. Its considerations are relevant especially for the time-based track reconstruction of CBM. The time-based consideration is a necessary condition to use the reconstruction software with real data, too.

In order to verify the performance in the reconstruction (e.g. tracking) matching of all data states is incorporated. All geometry information are accessible via the 'GeoHandler'-Class. For the tracking a simplified representation of the material budget is provided in the form of a map in dedicated files provided together with the digitizer.

In order to study the impact of misalignment the position of the individual sensors can be modified within simulation.

Status

The new MVD geometry and data processing has been incorporated and uploaded to CbmRoot. All functionality has been re-established and can be used within the eventbased reconstruction. Due to constraints on the part of CbmRoot, the time-based reconstruction is not fully available for the time being. Likewise the MVD model does not yet comprise all the details. However, all preparations necessary have been provided. The pile-up of events can be studied via background events. Moreover, further details related to the performance of the sensor (as e.g. aging with the integrated radiation dose, noisy pixels, different pixel geometries) have not yet been treated.

The current representation of the MVD in simulation is the prerequisite to allow for realistic simulations on the performance of the MVD in secondary vertexing and background rejection in di-electorn spectroscopy.

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Non-ionizing radiation hardness of CMOS Monolithic Active Pixel Sensors manufactured in a $0.18 \mu m$ CMOS process^{*}

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Modern 0.18 μ m CMOS processes provide numerous features, which may allow for decisive progresses in the read-out speed and the radiation tolerance of the CMOS Monolithic Active Pixel Sensors (MAPS) to be used in the Micro-Vertex-Detector of CBM. Together with the PIC-SEL group of IPHC Strasbourg, we aim to exploit those features by migrating the successful architecture of our sensors toward this novel technology. This work reports about our findings on the first prototypes manufactured with the new technology.

A weak point of CMOS sensors is the slow diffusion of signal charge in the undepleted active medium. A sufficient radiation hardness was only achievable with very small pixels, which do not provide the required readout speed. A few years ago, this obstacle was alleviated by the upcoming availability of CMOS processes providing a high-resistivity epitaxial layer of 1 k Ω cm. It could be demonstrated that this increases the non-ionizing radiation hardness by more than one order of magnitude. Therefore pixels of this high-resistivity AMS-0.35-process having a pitch of 20 – 30 μ m achieved the design goal of a non-ionizing radiation hardness in the order of 10^{13} n_{eq}/cm² [1].

Using this technology, a first vertex detector based on CMOS sensors is taking data in the heavy-ion experiment STAR since 2014.

Achieving the required non-ionizing radiation hardness, the ionizing radiation hardness and read-out speed of sensors in the AMS-0.35-process were not sufficient for the application in modern vertex detectors, e.g. in ALICE and CBM. Therefore, a novel $TOWER - 0.18 \mu m$ process was exploited and found to provide a higher tolerance to ionizing radiation [2]. Moreover, the smaller feature size allows for the integration of a more complex logic into the pixel providing a faster read-out. An additional feature of this process is the use of very high resistivity epitaxial layers up to 6 k Ωcm . It was expected, that this would improve the non-ionizing hardness further, which would allow for larger pixels and therefore for a faster sensor readout.

To test this assumption, the prototype sensor MIMOSA-34 was designed, irradiated to $10^{13} \text{ n}_{eq}/\text{cm}^2$ and tested hereafter. The sensor provides elongated pixels with a pixel pitch between 22 μ m × 33 μ m and 33 μ m × 66 μ m. Figure 1 shows the response to photons of an Fe-55-source of the largest pixel. Its charge collection efficiency is



Figure 1: Signal response to photons after a radiation dose of $10^{13} n_{eq}/cm^2$.

reduced by radiation damage from 34% to 25% for the seed pixel and from close to 100% to 62% for the charge of the full cluster. The signal to noise ratio, as measured with a Sr-90- β -source, decreases from 49 to 35. According to our experience with other sensors, this signal to noise ratio is sufficient to provide an excellent detection efficiency.

In conclusion, the novel process is likely to provide a tolerance to 10^{13} n_{eq}/cm^2 as needed for CBM even in combination with a 33 μ m \times 66 μ m pixel pitch. Consequently, this pitch seems now limited by the need for matching a spatial resolution of 5 μ m rather than by the radiation tolerance. The latter allows for increasing the pixel pitch of the vertex detector, which comes with significant advantages in terms of readout speed and reduced power consumption.

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An ultra-low material budget Cu-based flexible cable for the CBM-MVD *

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The CBM Micro-Vertex-Detector (MVD) relies on employing a material budget x/X_0 per detector station of 0.3% (first station) to 0.5% (following stations) to allow for a secondary vertex resolution of better than 70 μm with typical pixel pitches of about 20 μ m. To reach this ambitious goal, all components in the acceptance of the detector have to be challenged w.r.t. their impact on the material budget, while at the same time maintaining their cutting edge performance regarding mechanical and electrical properties as well as radiation hardness. In additon, the sensor readout has to be robust with low noise occupancy, which puts strong constraints on the electrical properties of the rather long cables connecting the sensors with the frontend electronics (FEE) being outside the acceptance of the detector. Especially in the outer stations, substantial parts of those cables are placed inside the acceptance and hence contributes to multiple scattering. Those cables are flexible printed circuits (FPC) and provide power to the CMOS Pixel Sensors (CPS), allow to control them, and to read out the hits. The previous generation cable was not specifically optimized for ultra-low material budget being a two-layer copper-based cable with a layer thickness of about $25\mu m$. It was successfully tested in a beamtime with the CBM-MVD prototype [1].

Reducing the dominant factor of the material budget meant reducing the thickness of the copper layer, see Tab. 1. The cable was redesigned with a readout to the side (see Fig. 1), a smaller feature size $(80\mu m)$ and thus a reduced total cable width, and copper traces with a thickness of only $12\mu m$. The cables were manufactured using a commercial technology offered by ILFA [2]

Some problems may arise from the ultra-thin layout though: Without an accompanying ground layer, the traces will not have an excellent controlled impedance. In addition, the resistance of the power supply lines becomes substantial. To compensate for this, their width was increased to $360 \ \mu m$ resulting in visible areas of higher material budget in Fig. 1. Dedicated tests with a new sensor

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Layer	$d [\mu \mathrm{m}]$	x/X_0	Si-equiv $[\mu m]$
Coverlay	26	0.009~%	8.6
Copper	$40\%\cdot 12$	0.033 %	31.3
Polyimide	25	0.009 %	8.2
Sum	63	0.051 %	48.1

Table 1: Material budget of the new cable.



Figure 1: CAD layout of the new ultra-thin FPC showing the bonding zone and the part of the cable situated in the acceptance of the detector (top); an analysis of its material budget in % of x/X_0 (bottom).

test stand will evaluate the effect of the missing shielding and possible impedance mismatch of signal lines as well as the higher resistance of the power supply lines. This test stand comprises a compact, Peltier-based temperature control unit, and a readout chain using a special test mode of the sensor which makes it possible to measure transfer functions. This allows to deduce the temporal and fixed pattern noise of a reference sensor to conduct extensive systematic tests of flex cable generations.

Another possible approach to reach an even smaller material budget employs Aluminium instead of Copper for the conductive layer. Aluminium has a smaller conductivity $(3.5010^7 \text{ S/m vs.} 5.96 \cdot 10^7 \text{ S/m})$ but at the same time a much longer radiation length (88.97 mm vs. 14.36 mm), suggesting an improvement of $\times 3.6$ smaller material-budget. The downside of this non-standard Aluminium-based technology is the lower production reliablity, and thus higher cost and production times.

To summarize, a new ultra-thin design of the FPC for the CBM Micro-Vertex-Detector was created and the cables produced. Its suitability will be analyzed including its electrical performance and integration stability. Further technologies to reduce the material budget even more are being evaluated.

- M. Koziel et al., The prototype of the Micro Vertex Detector of the CBM Exp., Nucl.Instrum.Meth. A732 (2013) 515
- [2] ILFA Industrieelektronik und Leiterplattenfertigung aller Art GmbH, Hannover, Germany

PRESTO: PREcursor of the Second sTatiOn of the CBM-MVD*

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This report summarizes the activities undertaken to construct a precursor of a quadrant of the second MVD-station.

The PRESTO (PREcursor of the Second sTatiOn) project of the CBM-MVD addresses the double-sided integration of 15 MIMOSA-26 sensors (dummies and working sensors, 9 of these on the front in a 3×3 and 6 sensors on the back in a 2×3 arrangement) onto a 8×8 cm² CVD diamond carrier [1] featuring a thickness of 150 μ m. The PRESTO module will employ new flex cables (FPC) [2] providing all signals needed to operate and read out the sensors (10 FPCs in total), see fig. 1.

To assembly this module, new sensor positioning jigs aiming for a sensor positioning precision with respect to the support and the neighboring sensors of below 100 μ m were manufactured. To evaluate the integration concept, the RAL-247 adhesive [3] and the new jigs, a dummy PRESTO module has been assembled employing 50 μ m thin MIMOSA-26 dummies and a 200 μ m thin glass plate which serves as sensor carrier, see fig. 2.

In the process of gluing, the inclusion of air bubbles should be avoided due to the vacuum operation of the MVD and the use of thinned sensors. This triggered a study focusing on optimizing the preparation of the glue, its dispensing and the quality assurance of the results. The number of air bubbles introduced into the glue during its mixing process has been significantly reduced by degassing it in an exicator at about $4 \cdot 10^{-1}$ mbar for about 1 hour. However, this did not prevent the air bubbles to appear after the gluing of the sensors onto the carrier. The introduced air bubbles featured a size of about $100 - 300 \ \mu m$ diameter. To verify their impact on the 50 µm thin sensor dummies, the cured module has been placed inside a small vacuum chamber which has been evacuated for about 48 hours to a value of $4 \cdot 10^{-1}$ mbar. The visual inspection of the sensor dummies using a high precision microscope did not reveal any mechanical damage. Further studies will be addressed with working sensors to check on-the-fly any possible correlation between sensor performance, pressure and bubble sizes.

The gluing of the dummy sensors onto the glass carrier demonstrated that a glue volume of $3-5 \,\mu$ l (different glue volume used for each row of sensors) is sufficient to dispense a uniform and thin (about $10-17 \,\mu$ m) layer underneath the sensors. The horizontal sensor-to-sensor distances were measured to be below 5 μ m. The vertical variation in the distances between the sensor edges were

measured to be of about 20 μ m. The achieved precision is significantly below the envisioned one. Next steps comprise the establishing of procedures for the integration of the FPCs, the exercise of double-sided bonding and the verification of the vacuum compatibility.



Figure 1: Sketch of the arrangement of the sensors and the FPCs with respect to the support carrier within the PRESTO module.



Figure 2: Assembled dummy module of PRESTO.

- [1] Diamond Materials GmbH, Germany
- [2] P. Klaus et al., "Ultra-low material budget Cu flex cable for the CBM-MVD. "GSI annual report 2014.
- [3] Private communication, Simon Canfer Rutherford Appleton Laboratory, Composites and Materials Testing Group, UK.

^{*} This work has been supported by BMBF (05P12RFFC7), EU-FP7 HadronPhysics3, HGS-HIRe, GSI and HIC for FAIR.

The CBM-MVD: Progress in Mechanical Integration *

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This report summarizes the activities undertaken towards the construction of the Micro Vertex Detector (MVD) of the Compressed Baryonic Matter (CBM) experiment.

Quality assurance of 50 µm thin PRESTO sensors: Thinned MIMOSA-26 sensors will be used for assembly the so called PRESTO module. PRESTO addresses the double-sided integration of 15 MIMOSA-26 sensors (dummies and working sensors) onto a $8 \times 8 \ cm^2$ CVD diamond support (see [1] for more details). Sensors will be connected with the R/O system by means of a newly designed ultra-low material budget flex cable employing commercially available processes based on copper traces [2]. Constructing the PRESTO allows to estimate the integration yield providing that the employed sensors are tested prior to assembly. Up to now, 18 MIMOSA-26 AHR sensors thinned to 50 μ m were probe tested using the setup described in [3]. The setup allows testing the standard operation modes of the sensor as well as measure the fixed pattern and temporal noise by the means of so called scurves. 12 sensors were found without a significant number of dead/noisy pixels; they were qualified as fully operational. Four sensors exhibiting some dead rows/columns were marked as faulty. The two remaining sensors were not operational due to a power supply short (one sensor) and problems while powering one out of the four MIMOSA-26 sub-matrices. The estimated yield was then of about 65%which is in agreement with expectations for this type of sensors [4]. The temporal noise was found to be of about 1.6-1.8 mV and the fixed patter noise of about 0.5-1.0 mV. This is by factor of 2-3 higher than the noise specified by a sensor provider. This was nevertheless as expected since the sensor power signals were generated outside the probe card. The addressed probe tests allowed also to establish test procedures required for non-destructive tests of thinned CMOS sensors and can be applied for testing the final MVD sensors.

Development of a custom made glue: An "ideal" adhesive for the integration of the sensors onto their supports should be easy to dispense in a thin and uniform layer—calling for a low viscosity—, radiation hard as well as flexible (to compensate for the thermal expansion mismatches between the sensor and their support material) within the temperature range foreseen for the operation of the MVD sensors. Since there are none "on-shelf" products that meet these requirements, a custom-made, two compound adhesive with a working name RAL-247 was man-

ufactured at the Rutherford Appleton Laboratory (RAL), Composites and Materials Testing Group, UK. The glue features a glass temperature of -45 °C, a viscosity of below 100 mPa·s and a curing time of 48 h at +50 °C. To investigate its radiation hardness, RAL-247 samples were irradiated with X-rays to 100 Mrad and to a proton dose of about $10^{15} n_{eq}$ /cm². The irradiated samples were sent to RAL for further Dynamic Mechanical Analysis tests which unraveled no significant change of properties [5] that confirms the expected radiation hardness at the range of radiation doses expected at the MVD.

Development of the heat sinks for the MVD: The operation of the MVD in vacuum requires a continuous cooling of the sensors to limit radiation induced defects as well as noise. To keep the material budget of the individual MVD station as low as possible, the cooling approach of the MVD employs highly thermal conductive sensor support materials (CVD diamond [6] and encapsulated high performance graphite) in the acceptance of the MVD and actively cooled aluminum-based heat sinks outside of this area. To evaluate the cooling concept and its vacuum compatibility, half-station heat sinks of the first three MVD stations were manufactured at COOLTEK GmbH. The heat sinks incorporate a buried cooling pipe and have thermally been simulated prior their manufacturing using a worst case scenario for the sensor power dissipation plus an additional safety factor of four. These heat sinks are currently being evaluated under laboratory conditions focusing on their vacuum compatibility [7]. The heat dissipation of the MVD sensors is provided by kapton insulated flexible heaters from OMEGA Engineering, INC.

- M. Koziel et al., "PRESTO: PREcursor of the Second sTatiOn of the CBM-MVD." GSI annual report 2014.
- [2] P. Klaus et al., "Ultra-low material budget Cu flex cable for the CBM-MVD. "GSI annual report 2014.
- [3] M. Koziel et al., GSI annual report 2013.
- [4] L. Greiner et al., CPIX 2014, Bonn, Germany
- [5] Private communication, Simon Canfer Rutherford Appleton Laboratory, Composites and Materials Testing Group, UK.
- [6] Diamond Materials GmbH, Germany
- [7] G. Kretzschmar et al.,"Vacuum compatibility of the CBM-MVD." GSI annual report 2014.

^{*} This work has been supported by BMBF (05P12RFFC7), EU-FP7 HadronPhysics3, HGS-HIRe, GSI and HIC for FAIR.

Assessing the vacuum compatibility of the CBM Micro Vertex Detector*

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The CBM Micro Vertex Detector (MVD) will operate in a moderate vacuum of about 10^{-4} mbar to minimize multiple scattering. The vacuum compatibility of the detector needs to be validated with respect to thermal management of the MVD stations and their mechanical integrity during the design and prototyping phase. A dedicated largevolume vacuum vessel, located at the IKF Frankfurt, allows for systematic studies on the selection of material, the detector operation and thermal management in vacuum.

The setup comprises a 260 liter stainless steel vacuum chamber with multiple flanges providing a flexible access setup inside. Full-size MVD modules can be housed and operated, see Fig. 1, right. The chamber is supplied with a combination of rotary and turbomolecular pumps to routinely reach pressures of $2 \cdot 10^{-6}$ mbar, despite of the chamber volume and the variety of feedthroughs for signals and cooling media. The pressure is measured with a penning/pirani sensor system. Special emphasis is put on operating the detector at temperatures below room temperature and hence, providing active cooling inside the vessel is mandatory.

To characterize cooling media and to select a reliable concept of piping inside the vacuum, a dedicated setup was constructed, based on copper pipes and Swagelok fittings. The circuit inside the vacuum chamber was connected to a commercial cooling system (HUBER). With standard silicone oil as cooling liquid, circulated at atmospheric pressure, no leak was observed. However, at pressure of 10^{-2} mbar and one week of pumping residues of the coolant were spotted on the pipe connectors inside the vacuum. Finally, the coolant was changed to glycol, and no leaks were observed any longer, also when replacing the copper pipes bypolyurethane pipes. These studies underline the need of a careful preparation of reliable pipe interconnections and do suggest not to employ coolants which feature strong creeping, like silicone oil.

Outgassing of materials has to be kept at a minimum, both to not spoil the vacuum close to the target and to avoid contamination of surfaces. The setup allows to characterize coarse outgassing of detector components, like (flex) cables, adhesives or electronic components, by employing the so-called throughput method or the gas accumulation method [2]. However, outgassing measurements with higher accuracy request a large probe area compared to the setup area, and hence a dedicated setup.

Evaluating the thermal management of the MVD modules in vacuum is one of the most pressing tasks to be as-



Figure 1: Left: IR picture, taken at 10^{-4} mbar, of a dedicated heater featuring 1.12 W/cm² attached to a copper carrier and heat sink, used to characterzie the setup. Right: Full-size half-station heat sink of the first MVD station located in the vacuum chamber.

sessed with the setup presented here. Emphasis is put on heat-sinks and sensor carriers based on high-performance materials like chemical vapor deposition (CVD) diamond and thermal pyrolitic graphite¹ (TPG). The evaluation is carried out by contact temperature sensors (DS1820) in combination with a high-resolution infrared camera positioned outside of the chamber, observing through a dedicated zincselenide window transparent for infrared. The contact sensors serve as a reference for the infrared-based characterization of the detector setup, and they allow at the same time for a proper calibration of IR camera with respect to the reflectivity of materials and reference measurements. To emulate the expected MVD-sensor heat dissipation, Kapton flexible heaters from OMEGA [3] are glued on materials under evaluation, see Fig. 1.

It is planned to characterize in vacuum full-size detector prototypes like PRESTO (PREcursor of the Second sTatiOn), see [1], with a focus on the long-term operation of MVD modules in vacuum.

- M. Koziel et al., "PRESTO: PREcursor of the Second sTatiOn of the CBM-MVD." GSI annual report 2014.
- [2] P. A. Redhead, "Recommended practices for measuring and reporting outgassing data", National Research Council, p. 4, Ottawa ON K1A 0R6, Canada
- [3] OMEGA Engineering, INC. (www.omega.com)

^{*} Work supported by BMBF (05P12RFFC7), HIC for FAIR and GSI

¹These materials are selected due to their outstanding heat conductivity, allowing at the same time a minimum material budget, which represents another important constrain for the MVD.

Yield studies on a fully integrated sensor for the CBM-MVD^{*}

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The CBM-experiment will study the phase diagram of hadronic matter in the region of highest baryon densities by means of rare probes like open charm particles. Reconstructing those particles calls for a vertex detector providing a unique combination of excellent spatial resolution, light material budget and high rate capability. To match those requirements, we intend to use CMOS Monolithic Active Pixel Sensors, which are developed by the PICSEL group of IPHC Strasbourg and evaluated at the IKF Frankfurt within an common R&D project.

A first fully integrated sensor, MIMOSA-28, was developed in the AMS $0.35 \,\mu\text{m}$ CMOS process and it is used in the STAR-HFT since 2014. However, this sensor does not match the requirements of CBM regarding radiation tolerance and readout speed. Therefore, the sensor architecture was migrated to a novel $0.18 \,\mu\text{m}$ process. This process was found to provide a higher tolerance to ionizing radiation [1]. Moreover, its higher packing density allows for reading two lines in parallel, which accelerates the readout by a factor of two with respect to the elder design.

In 2014, a first fully integrated prototype sensor (FSBB-M0) was realized in the new process [2]. The sensor was realized in two flavors (FSBB-M0a and FSBB-M0b), which differ slightly in the dimensions of some transistors. It features 416 × 416 pixels of 22 × 33 μ m² pitch and it is read out within 40 μ s via a pair of discriminators at the end of each column. Hereafter, the digital data is zero-suppressed and sent out via two 320 Mbps digital links. The sensitive surface of the FSBB is 13.7 × 9.2 mm². The final sensor of the CBM-MVD will presumably consist of three FSBBs. The FSBB-M0 was tested at the CERN-SPS and provided a detection efficiency for minimum ionizing particles of $\gtrsim 99,5\%$, a noise occupancy of $\lesssim 10^{-5}$ and a spatial resolution of < 5 μ m in both dimensions [3], which matches the requirements of CBM.

To test the robustness of the design and to assess the production costs for the CBM-MVD, we measured the production yield of the FSBB. In accordance with our experience, we assumed that flaws due to production mistakes would turn into a measurable deterioration of the noise of the sensors. A total of 25 (17 FSBB-M0a and 8 FSBB-M0b) sensors was bonded on PCB and operated with a suited readout system. By measuring the transfer functions we revealed the temporal noise (TN) of the individual pixels and the fixed pattern noise (FPN), which is caused by the offset of the dark signal of the pixels.





Figure 1: Temporal noise and fixed pattern noise measurement of all 17 FSBB-M0a chips.

The results of the study on the FSBB-M0a are shown in Fig. 1. We found all sensors tested to be operational and they provided a TN = (0.70 ± 0.05) mV and FPN = (0.73 ± 0.14) mV. Only one of the tested sensors showed a higher FPN of ~ 1.2 mV, which might still be acceptable. Similarly good results were observed with the eight FSBB-M0b tested, which all found being operational (not shown).

We conclude that a first full size sensor meets the requirements of CBM with respect to surface size, data rate and spatial resolution. Moreover, the design mostly meets the specification in terms of readout speed. Measurements demonstrated that the sensor provides a good detection of minimum ionizing particles and the production yield was found to exceed 95%.

- D. Doering et al., Noise performance and ionizing radiation tolerance of CMOS MAPS using the 0.18 μm CMOS process, J. of I., 9(05):C0551, 2014.
- [2] F. Morel et al., MISTRAL & ASTRAL: two CMOS Pixel Sensor architectures suited to the Inner Tracking System of the ALICE experiment, J. of I., 9(01):C01026, 2014.
- [3] M. Winter, Private communication.

The CBM MVD read-out electronics*

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Electronics

The CBM Micro-Vertex-Detector (MVD) front-end electronics serve as an intermediating device between the Monolithic Active Pixel Sensors (MAPS) and the DAQ system (based on the TRB3 system developed by HADES). In the current connection scheme, one TRB3 FPGA board can support up to 16 sensors of type "MIMOSA-26" in parallel. The front-end electronics are necessary to supply the sensors with electrical power and to convert between different digital signal standards. The central element of these custom-built PCBs is the converter board. In addition to remote controlled power supplies, signal switches and drivers, it features an ADC section to monitor the sensor's momentary electrical parameters. The sensors have to be supplied with a sensitive external biasing voltage, the socalled clamping voltage, which gets distributed to all sensor pixels. Several generation and distribution schemes were implemented to investigate which setup results in the best noise performance.

Measurements

The MIMOSA-26 provides a test mode to measure the discriminator transfer function¹ of all pixels. The slope steepness is directly related to the temporal noise of the sensor. The read-out sytem was extended to operate and read out the sensor in this test mode. The recorded data is evaluated by a dedicated ROOT-based analysis software. Noise tests with MIMOSA-26 are ongoing. However, preliminary results concerning the influence of the clamping voltage suggest that it is beneficial to generate this reference voltage as close to the sensor as possible and to use decoupling capacitors, if possible, next to the bonding pads on the flex print cable. These results are in particular important for the development of the next generation of cables[2]. Furthermore, the ADC section on the converter board can be used to perform systematic scans in order to characterize the sensors. As an example of such an automatic scan, Fig. 1 shows the dependence of the sensor's current consumption on the discriminator threshold setting.

Laboratory instrumentation

When characterizing sensors, it is desirable to investigate the temperature dependence of certain sensor param-



Figure 1: The current consumption (digital VCC) of a MIMOSA-26 sensor as a function of the discriminator threshold. Data acquired with front-end electronics on-board monitoring devices.

eters. Until recently, such tests were conducted using a large cooling system which circulates coolant through a cooling block to which the sensors under test are attached. The sensors are now operated on a small copper platform which is cooled with a peltier element. A PID controller implemented on a microcontroller senses the temperature of the platform by means of a onewire temperature sensor and regulates the current through the peltier element. The device features a small display and a simple user interface, alternatively it can be remote controlled via a USB connection. The platform can be cooled down to circa -10° C within few minutes while consuming 50 W. Overall, the set-up was greatly reduced in size, while at the same time improved in usability.

PRESTO

Current activities focus on bulding a prototype[1] of a quadrant of the second station of the MVD. For now, MIMOSA-26 sensors are used in this project though they do not qualify to be used in the final detector. Parts of the front-end electronics are currently redesigned to fit the spacial constraints of the set-up.

- [1] M. Koziel, T. Tischler et al., PRESTO: PREcursor of the Second sTatiOn of the CBM-MVD, this issue.
- [2] P. Klaus et al., Ultra-low material budget Cu-based flexible cable for the CBM-MVD, this issue.

^{*}Work supported by BMBF (05P12RFFC7), HIC for FAIR and GSI ¹The firing probability of a binary pixel as a function of discriminator threshold; usually has the form of a sigmoid function.

Silicon Tracking System



Improvement of ultra-light microcables production at LTU for the CBM Silicon Tracking System

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Ultra-light micro-cables are the key component for the CBM-STS. They are employed to realize the analogue signal interconnection between detector and readout for the STS at minimized material budget. Taking into account the complexity of micro-cables and their required quantity a few "bottlenecks" in the production line have been identified and improvements were realized on the production line. Additionally the preliminary technological regimes were defined and a test batch of micro-cables (100 pieces) was manufactured within the framework of the STCU partner project P635.

For the detector modules two kinds of interconnection components will be employed [1-2]:

- ultra-light interconnection microcables based on aluminium-polyimide adhesiveless dielectrics (connecting microcables, interstrip cables, daisy-chain cables, shielding layers).
- meshed spacers based on Kapton or polyimide (narrow and wide meshed spacers).

The typical technological process of micro-cable and spacer manufacturing includes the following main technological operations based on photolithography and chemical wet etching processes: chemical cleaning of the substrate, photoresist coating on the substrate, photoresist exposure, photoresist development, aluminium etching (for interconnecting micro-cables), polyimide etching and finally photoresist removal.

Taking into account that large numbers of components in a considerable design variety need to be produced for the CBM STS (about 58 thousand micro-cables and spacers) the available technological equipment and the production line were analyzed with the aim to identify possible production "bottlenecks" which might result in production yield issues or even a suspension of production. The available equipment allows to produce the required components but two "bottlenecks" were identified:

- equipment for photoresist coating needed duplication,
- an exposure unit for photoresist exposing needed to be duplicated.

The following equipment was in consequence supplied by GSI to LTU Ltd within the STCU partner project, both from Bungard Elektronik, Germany:

- a Dip Coater RDC 21-K type,
- a parallel beam exposure unit EXP8000.

The equipment was installed and tuned in the clean room at the cable production site in Kharkov (Fig. 1). Process parameters for the operation of these machines for the different types of components were investigated and preliminary regimes were chosen.

Based on these parameters, a first pilot batch of microcables was produced and delivered to GSI so that the module assembly processes could be elaborated (48 laminated and 52 non-laminated test microcables 11 cm and 21 cm long). Samples of test cables are depicted in Fig. 2. The cable production line at LTU has been strengthened towards the large scale serial production of micro-cables for the CBM-STS. Technological regimes on the newly installed equipment were investigated and a batch of test microcables produced. This is a starting point for further production process optimization towards yield.



Figure 1: Dip coater RDC 21-K (left) and exposure unit EXP8000 (right) installed at LTU.



Figure 2: Experimental micro-cables for the development of the TAB-bonding assembly steps at GSI.

- [1] V.M. Borshchov et al., CBM Progress Report 2013, p. 41
- [2] C.J. Schmidt et al., CBM Progress Report 2012, p. 18

Manufacturing detector modules for the CBM Silicon Tracking System

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Based on the new module assembly concept [1] and its preliminary test on the first half-detector module mock-up [2], three types of detector modules were developed and 18 module mock-ups manufactured to verify the technical approach. The module mock-ups allowed specifying their exact composition, defining nomenclature and marking of components, and the work-off of the assembly procedure. The work, coordinated by JINR, was co-funded through the BMBF-JINR project 5.2 "Development of ultra-low-mass silicon micro-strip detector systems for precision tracking in high-energy heavy-ion collision experiments" with project partners at GSI and JINR.

The detector module mock-ups have been developed according to the composition of the smallest STS ladder comprising 6 modules:

- 2 double-sensor modules with sensor-to-FEB distance 111 mm (one left and one right type),
- 2 single-sensor modules with sensor-to-FEB distance 212 mm (one left and one right type),
- 2 single-sensor modules with sensor-to-FEB distance 252 mm (one left and one right type).

Each module mock-up includes following components:

- one or two dummy sensor with interstrip cable;
- multilayered connection microcables;
- dummy chips;
- dummy FEBs.

For sensor-to-FEB connection [1,2] following components are foreseen:

- eight multilayered microcables (128 lines for chip to sensor connection). Each multilayered cable includes two connecting layer (FDI-A-24, 64 traces at 113 μ m pitch) and eight meshed spacers (Kapton 50 μ m thick).
- overall meshed spacer for all 8 multilayered microcables (two Kapton spacers 50 μm thick).
- overall shielding layer for all 8 multilayered microcables (FDI-A-24) with glued meshed spacer (Kapton 50 μm thick).

Taking into account abovementioned types of components for each module from 16 to 19 types of components were developed and produced. Also was defined following nomenclature and marking of components for further production:

- 1. AC-P-S-T- *- analog cable, P-side, short, top
- 2. AC-P-L-T- *- analog cable, P-side, long, top
- 3. AC-P-S-B- *- analog cable, P-side, short, bottom
- 4. AC-P-L-B- *- analog cable, P-side, long, bottom
- 5. AC-N-S-T- *- analog cable, N-side, short, top
- 6. AC-N-L-T- *- analog cable, N-side, long, top
- 7. AC-N-S-B- *- analog cable, N-side, short, bottom
- 8. AC-N-L-B- *- analog cable, P-side, long, bottom
- 9. SL-P- *- shielding layer, P-side
- 10. SL-N- *- shielding layer, N-side
- 11. MS-P-N-S- *- meshed spacer, P-side, narrow, short
- 12. MS-P-N-L- *- meshed spacer, P-side, narrow, long
- 13. MS-N-N-S- *- meshed spacer, N-side, narrow, short
- 14. MS-N-N-L- *- meshed spacer, N-side, narrow, long
- 15. MS-P-W- *- meshed spacer, P-side, wide
- 16. MS-N-W- *- meshed spacer, N-side, wide
- 17. ISC-**- interstrip cable,
- 18. DCC-P- daisy-chain cable, P-side,
- 19. DCC-N- daisy-chain cable, P-side
- * base sensor-to FEB distance (111, 212, 252 mm)
- ** length of sensor (42, 62 mm)

Example of cable marking: AC-N-S-T-111 = analog cable, N-side, short, top with sensor-to-FEB distance 111 mm.

According to the above mentioned composition of STS ladder, modules and multilayered connection microcables for three types of modules (111, 212, 252 mm) about 100 photomasks were developed and produced. Using those photomasks for 18 modules more than 1300 microcables and spacers (about 70 components for one module) were manufactured. Six types of assembled modules are depicted in Fig.1. The mock-ups of the detector modules (6 pcs) will be used to assemble the first mock-up of a full-scale ladder [3].



Figure 1: Detector module mock-ups.

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- [2] C.J. Schmidt et al., CBM Progress Report 2012, p. 18
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The first mock-up of a CBM-STS full-scale ladder

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The first mock-up of the CBM STS ladder has been developed and manufactured by the Kharkov team at the assembly site of LTU Ltd (Figs. 3 and 4). The ladder mock-up was developed for verification of ladder assembly route [1,2]. The work was funded and coordinated by JINR.

The ladder mock-up includes the following components, similar as in real full-scale ladder (Fig. 1):

- mock-ups of silicon strip modules (6 pcs) [3];
- containers for the FEBs (2 pcs);
- carbon fiber frame (CF-frame) on the support units (1 pc).



Figure 1: Components of the ladder mock-up.

For the assembly of the ladder mock-up, the sequence of work steps has been developed. It includes following steps:

- mounting and fixation of double-sensor modules #1 and #2 to jig (Fig. 2);
- mounting and fixation of single-sensor modules #3 and #4 with the necessary overlapping of sensors to fixture;
- mounting and fixation of single-sensor modules #5 and #6 with the necessary overlapping of sensors to fixture;
- mounting and fixation of CF-frame to fixture;
- gluing of sensor holders to sensors and CF-frame. Glue polymerization;
- mounting of the FEB mock-ups in the container on thermal paste;
- turning of containers with the FEBs by 90 degree.

The assembled mock-up is depicted in Figs. 3 and 4. The completed work allows us to conclude on the feasibility of the previously selected design ladder for the CBM STS.



Figure 2: Diagram of sensor overlap.

The obtained results will be used for the clarification of technical tasks for sthe pecialists of PLANAR for designing and manufacturing of the optical-mechanical assembly tools. Further efforts of should be aimed at the clarification of the ladders composition, applied materials and geometrical dimensions of all ladder components.



Figure 3: First mock-up of the CBM STS ladder.



Figure 4: Team at the assembly site of LTU Ltd.

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Testing of n-XYTER 2.0 Front-end Boards from JINR

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Sixteen front-end boards (FEBs) each with a n-XYTER 2.0 ASIC were produced with the aim to assemble the first setup for the in-beam tests at JINR's Nuclotron. The PCBs were developed at JINR for the new version of the n-XYTER ASIC. Specialists of LTU Ltd. mounted the ASICs on FEBs using double-layer micro-cables [1]. The power consumption of one chip is about 5 W so every ASIC was mounted on metal radiator plate.

Previous tests of the first prototype of the n-XYTER chip have shown that there is a high temperature coefficient for the DC signal level of about 4%/K. The version 2.0 of the ASIC was designed with the aim to decrease the temperature coefficient. Several output biased potentials were added and finally the ability to change gain by factor of 4 was implemented with the aim to extend the dynamic range. The n-XYTER 2.0 was previously tested on the FEB already available from operating the first prototype of the chip; a mezzanine PCB for the adjustments of new bias potentials was added. Tests had shown that n-XYTER 2.0 is functional and the temperature coefficient was improved by a factor of 200 [2].

Previously two separate interfaces were used to configure the FEB revision D. The first is an I^2C interface for the n-XYTER and the second is an SPI interface for the ADC. The JINR FEBs were suggested to support the new generation of SysCore3 boards, so there is one control interface based on the SPI LVDS protocol. However, it was necessary to operate the FEBs with SysCore2 boards since SysCore3s were not available. So additional adapter boards based on the ATtiny-88 MCU were developed at GSI [3]. It translates the SPI and I²C interfaces from SysCore2 to the SPI interface emulating SysCore3 (see Fig. 1). To adjust external biased potentials of n-XYTER 2.0 a new DAC is employed. With the aim to control DAC, ADC and n-XYTER the ATtiny-88 MCU was implemented on the FEB. To set values of bias potentials one needs to send write commands to the I²C registers 0x31-0x38. These registers are not used by the n-XYTER chip and the MCU on the FEB redirects those commands to the DAC.



Figure 1: Data transmission scheme SysCore2 - FEB.



Figure 2: FEB under testing.

The strategy of adjusting external biases was very simple. The bias for the per-amplifier should be set such that the input potential is equal to the output. Three other biases for the slow and fast shapers should be set such the output DC levels are on adequate level. Another bias is used to set the value of the gain of the slow shaper. Unfortunately, this feature turned out to be useless. The dynamic range remains on the same value independently of the gain. Indeed, the gain could be changed by the factor of 3. The FEBs were tested and calibrated with external and internal calibration circuit. The maximum gain was found on the level of 18 mV/fQ which is about 15% less than for the first prototype of n-XYTER. It could be explained by the manufacturing variation for the different bunches of ASICs (see Fig. 3).

The ASICs on four FEBs were replaced after tests. Since the chips were not tested before mounting it is difficult to conclude whether the problem was in ASICs or in microcables. Indeed, micro-cable mounting turned out to be a good solution. There were no broken connections on the other tested FEBs. The tests showed that the FEBs are fully operative and compatible with the readout system based on the SysCore board.



Figure 3: Histograms for measured gain for negative (left) and positive (right) polarity.

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A scalable neutron source for radiation hardness tests of STS sensors

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During operation of the STS, the silicon strip detectors are expected to be irradiated with large numbers of neutrons, some sectors in excess of $10^{12} n_{eq}/cm^2/month$ [1], with an accumulated dose of $10^{14} n_{eq}/cm^2$ [2].

To test detector performance and particularly neutron induced changes in the semiconducting properties, a neutron source with high flux is necessary. Unfortunately, reactors with sufficient neutron flux are heavily occupied. This leads to irradiation campaigns with very short irradiation times (in the order of minutes) in which the desired neutron dose is achieved [4].

To get a more realistic representation of the irradiation process, an exposure of days or weeks with defined annealing phases is more desirable. To fulfill these goals a scalable neutron source with good accessibility is required.

Present neutron source

The current neutron source consists of a gas cell filled with deuterium gas under a pressure of a few bar. A 2 MeV deuteron beam from the University of Tübingen's Rosenau accelerator passes an entrance window of a few microns thickness to induce deuterium fusion. However, even at this thickness the heat load on the entrance window reduced its mechanical stability, limiting both the beam current and the pressure of the gas cell.

Due to the limitations of both the accelerator and the window currently the neutron production is limited to a rate of $\approx 10^{12} n_{eq}/cm^2/week$. As this rate is about two orders of magnitude below the required total dose, it would take way too long to accumulate with the current setup. To solve these issues, a new gas cell is currently being manufactured, based on [3].

New cryogenic source

The new neutron source currently in production consists of a steel endcap for the accelerator beam pipe. Mounted inside the endcap is the actual cell, cooled by liquid nitrogen. In contrast to [3], the gas cell is cooled by a copper finger reaching into a liquid nitrogen dewar. The entrance window is fixed to a thick copper disk sealing off the gas cell. A technical sketch is shown in Fig. 1. This setup has several advantages over the present cell: The enclosed deuterium gas is more dense by a factor of 4 compared to room temperature, and the lower ambient temperature should increase the durability of the entrance window, allowing higher beam currents.

Combining these effects, it should be possible to in-



Figure 1: Schematic view of the cryogenic source

crease both beam current and beam energy (to the accelerator's limit), which both significantly increases the neutron yield. In addition, the detector can be positioned within a few centimeters of the gas cell, providing maximum solid angle coverage. These improvements should increase the neutron flux by at least one order of magnitude, but the actual gain has to be determined once the cryogenic source is operational.

Before the new source can be put into operation additional tasks have to be performed, including tests of possible window materials and the cooling system.

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Development of a laser test system for the characterization of prototype silicon micro-strip sensors*

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For the characterization and quality assurance of prototype micro-strip sensors produced for the CBM Silicon Tracking System (STS), a semi-automated infra-red pulsed laser test system has been developed [1]. The amount of energy deposited by the laser light is chosen such, that it is equivalent to charge created by a minimum ionizing particle. The purpose of this investigation is to understand the charge sharing and uniformity of sensor performance in the inter-strip regions. Two prototype sensor, namely CBM02 (double-sided, 256 strips/side, pitch = 50 μ m, full read-out) and CBM05 (double-sided, 1024 strips/side, pitch = 58 μ m, one-eighth read-out) have been investigated [2]. The strips on the sensors are read-out via self-triggering n-XYTER based front-end electronics.



Figure 1: Schematic representation of the laser set-up.



Figure 2: Components of Laser Test Stand.

The automated tests are performed at several positions across the sensor. The laser beam is focused to a spot-size of $(\sigma_{spot}) \approx 12 \ \mu\text{m}$. The duration (~ 5 ns) and power (few mW) of the laser pulses are selected such that the absorption of the laser light in the 300 μ m thick silicon sensors produces about 24 000 electrons, which is similar to the charge created by minimum ionizing particles (MIP). The

wavelength of the laser is chosen to be 1060 nm because of the absorption depth being of the order of the thickness of the silicon sensors [3]. Figure 1 shows the measurement set up in a schematic view. Figure 2 shows various components installed in the laser test stand. The laser beam is transmitted through a 6 μ m thick optical fibre to a single focusing system, which focuses the light to a spot of about 12 μ m diameter. The working distance is about 10 mm [1]. The



Figure 3: Charge sharing function (η) as a function of the position of the laser spot on one side of the sensor.

laser focuser is calibrated to a focused position on the sensor surface as a function of the number of strips fired with a signal just above threshold. At this reading the proper focal distance has been achieved. Figure 3 shows a measurement of the charge sharing function (η) in the inter-strip region. The η function is defined as the ratio of charge collected by either strip divided by the sum of both. The EPICS device control is used to control the step motor. A special program with a user interface has been developed to operate and move with the laser over the active area of the sensor to perform several measurements automatically. The data acquisition software DABC accesses the motor position information from EPICS. The on-line and off-line analysis is performed using the Go4 analysis tool.

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Quality assurance of CBM-STS silicon micro-strip sensors using pulsed infra-red laser*

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The Silicon tracking system (STS) of the CBM experiment is aimed to reconstruct the trajectories of the hundreds of charged particles created in heavy-ion collision, and to determine their momenta with a resolution of around $\Delta p/p \approx 1\%$. This precision is prerequisite for high-resolution mass measurements of e.g. rare probes and implies a thin detection system, with high-resolution space-point measurement and capable of interaction rates up to 10 MHz. The STS will comprise 1220 silicon microstrip sensors from which 896 detector modules will be constructed [1]. Quality assurance of the sensors is an important pre-requisite for the detector module production as the assembly steps are non-reworkable to a good extend. These tests can be either invasive or non-invasive as explained below. From the results entered into a database, one can identify sensors or detector modules with certain characteristics and grade them according to their performance.



Figure 1: Amplitude response of a few strips from a detector module scanned with a laser spot.

Invasive methods are the characterization with methods that require physical contact of probes to the objects. The important features are: (i) this allows detailed analyses of the device under test (DUT), (ii) this leaves scratches or marks on the surface, (iii) this is limited to sensors, not to detector modules, (iv) this method involves passive electrical measurements using a wafer prober and micro-probing needles [2].

Non-invasive methods are the characterization with methods that do not require physical contact of probes. The important features are: (i) a few significant parameters of the DUT can be investigated, (ii) this leaves no scratches or marks on the surface, (iii) this is not limited to bare sensors but can be applied to detector modules, (iv) this method in-

volves injection of localized charge using a pulsed infra-red laser [3].

The laser test stand (LTS) is developed with the idea to perform key quality assurance tests on silicon detector modules. The significant parameters that can be analysed or investigated using the LTS are: (i) Uniformity of charge collection (or strip integrity) from scanning the strips. An example of such laser scan is shown in Fig. 1. (ii) Operation voltage from the bias scan. An example of charge collection as function of the bias voltage is shown in Fig. 2 (a). (iii) Charge coupling to neighbour and nextneighbour strips from bias scan. An example is shown in Fig. 2 (a). (iv) Ratio of AC-coupling to inter-strip capacitance from amplitude response at specific positions. An example is shown in Fig. 2 (b). (v) Charge sharing function (η) in the inter-strip region can be determined. Figure 3 shows η -function dependence with the position of the laser spot.



Figure 2: a) Operating voltage determination and charge sharing between neighbouring and next to neighbouring strips and b) Ratio of coupling to inter-capacitance.



Figure 3: Charge sharing measurements in the inter-strip region of a silicon detector module: a) p-side and b) n-side.

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Design and prototyping of a carbon fiber support frame for the central ladders of the CBM Silicon Tracking System

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The ladders of the STS placed in the central part of the station have to be specially designed to pass through the beampipe. The original concept of the beampipe was optimized to conduct experiments at SIS 300 and at SIS 100 with the energy of the incident gold ions above 8 AGeV. Further development of the CBM@SIS100 physical program required tuning of the setup to work with the energy of incident gold ions lowered down to 4 AGeV. The principal change of experimental conditions at low energies relevant to the beampipe and central ladders design is higher multiple scattering of gold ions inside the target. At present, there is no single reliable parameterization of multiple scattering of heavy ions at wide angles. The Cbm-Root (Geant3), Geant4, and FLUKA codes provide a possibility to simulate this process, but since they give different results, the most conservative estimate (3.2 degrees at 4 AGeV given by GEANT4) was used for definition of the beampipe opening angle. The original design of the central ladder suitable for the beampipe with a 1.6 degree opening angle is shown in Fig. 1.



Figure 1: Design of the CF frame of central ladder.

One can see that the middle rib of the carbon fiber (CF) frame is not broken thus providing the necessary rigidity of the construction. The 3.2 degrees opening angle for the beampipe is not compatible with the original design of the central ladder CF frame. One has to increase the diameter of the cylindrical insert by a factor of two. The new type of the central ladder with a 118 mm diameter of the cylindrical part has been designed and built. Figure 2 shows the overall view of such a ladder, the components of the central ladder are shown in Figure 3. In Fig. 4 a mold is presented used in the manufacturing the ladder. The ladder obtained has the necessary rigidity at the mass of the cylindrical part of 5 g. Depending on the result of the ongoing simulations, the mass of the cylindrical part can be reduced by removing the excess material in the regions with low mechanical stress.



Figure 2: Prototype CF frame of a central ladder.



Figure 3: Components of the prototype CF frame.



Figure 4: Mold for the production of the CF frames.

Towards the STS-XYTERv2, a silicon strip detector readout chip for the STS

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The STS-XYTER as a 128+2 channel full-size prototype IC dedicated for silicon strip detector readout in the CBM Silicon Tracking System was fabricated in 2013 [1]. Figure 1 presents the test PCB developed at AGH used for functional verification. It provides on-board 5 separate power domains with dedicated low-noise LDO regulators, an ERNI connector for sensor attachment, interconnects for test interface, test points and the AC-coupled CBMnet interface (HDMI connector). The board is controlled by SysCore V3 (CBMnet) and NI FPGA (test interface) cards.



Figure 1: Test PCB for the STS-XYTER ASIC.

The architecture details of the chip and test results were presented and published in [2]. Detailed tests using silicon sensors (e.g. CBM05) are currently being prepared. Using the same setup it was possible to further evaluate the chip. Figure 2 shows a thermal image of the STS-XYTER chip on the test PCB. The thermal resistance was estimated to be approx. 52 °C/W, but it needs to be verified on the final FEB board in an environment similar to the final application as well. The temperature coefficients measured for various biasing points of of the ASIC evaluated for ambient temperatures of 7–85 °C are:

ADC_vdiscr_ref	$= -0.622 \text{ mV/}^{\circ}\text{C},$
ADC_ibias_corr	$= -0.312 \text{ mV/}^{\circ}\text{C},$
BG_iref	$= +0.154 \text{ mV/}^{\circ}\text{C},$
ADC_vref_n	$= -0.366 \text{ mV}/^{\circ}\text{C},$
ADC_vref_p	$= +0.286 \text{ mV/}^{\circ}\text{C},$
DISCR_bias_t	$= -0.435 \text{ mV}/^{\circ}\text{C}.$

The STS-XYTERv2 which will be an evolution of the STS-XYTER prototype ASIC among the small fixes the changes includes:

• a new concept of the digital back-end (focused on the use of GBTx chip as a data concentrator), reaching hit bandwidths 9.4–47 MHit/s/chip,

- definition of the new communication protocol optimized for the conditions and requirements of the CBM experiment. The preliminary protocol was published [3] and is currently a subject of fine-tuning,
- a configurable front-end (gain, bandwidth) for possible support of gas detectors (MUCH),
- a new pad layout supporting quality test with pogoprobes and reduced connectivity required for regular operation,
- testability and temperature stability improvements of the in-channel ADC,
- further optimization of the analog front-end towards lower noise and better stability.

The STS-XYTERv2 ASIC is currently being under development. It is expected to be taped-out in Q2 of 2015 via Europractice services.



Figure 2: Thermal imaging of the operating ASIC on the test board.

Acknowledgment

We would like to thank the colleagues from GSI and WUT Warsaw for the efforts towards verification and specification of the new requirements.

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A Front-end electronics test board for the CBM Silicon Tracking System*

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The 896 modules of the CBM Silicon Tracking System will be equipped with two front-end electronics boards (FEBs) each, carrying per board eight STS-XYTER ASICs that read out the silicon micro-strip sensors of the modules [1]. The boards will be stacked at the top and bottom layers of the detector, mounted in a shelf structure that is in contact with a cooling plate to remove the power dissipated by the electronics. Due to the spatial contstraints there, the board dimensions are restricted to the limited size, as shown in Fig. 1. At the same time, the board has to provide the infrastructure for achieving the full output band width needed to read out the detector. This translates to realizing up to 5 LVDS pairs per final ASIC, a high-density challenge for the FEB design and prototyping.



Figure 1: Rendering of the STS front-end electronics board comprising 8 STS-XYTER ASICs arranged in a fixed pattern on two double-rows of 4 ASICs each. Power supply section with LDOs on the right. The small components are decoupling capacitors to common and communication ground.

For assembly test purposes, a PCB was produced onto which 8 STS-XYTERv1 ASICs can be mounted but not having any electrical functionality. Only the top and bottom layers are covered with a gold layer for test bonding of ASICs and cables. During its layout, it turned out that only one of the four readout channels of each ASIC could be routed to the digital I/O connector, limited due to the available space in between the ASICs. This technological problem is the subject of current work.

In order to prepare a test equipment for a complete readout chain from sensor to GBTx boards, an intermediate FEB board has been designed that is not constrained to the small dimensions. The PCB, called FEB4, hosts only four ASICs. Its layout is shown in Fig. 2. This PCB comprises the required power supply LDOs. All I/O channels of each ASIC are linked to a connector. In addition, the required high-voltage capacitors (rated 250 V) for bias decoupling have been added to the differential LVDS connections. In Fig. 3(a) the board's assembly pads for passive devices are visible. For the devices' case size, the norm 0201[m] had to be chosen in order to fit them between the ASICs. This board is currently being used for testing of the STS-XYTERv1 chips. One ASIC wire-bonded to the board is shown in Fig. 3(b).



Figure 2: Layout of a front-end board comprising four read-out ASICs and all outgoing LVDS data lines on a somewhat relaxed geometrical footprint (FEB4).



Figure 3: (a) High-density region in between the openings for the STS-XYTER ASICs on FEB4, filled with the full set of LVDS lines, micro-vias and connecting pads for high-voltage decoupling capacitors. (b) STS-XYTERv1 ASIC installed into FEB4 and wire-bonded to its power supply, control and outgoing data lines.

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Status of the CBM STS CAD design

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A virtual model of the planned CBM STS detector system gets designed in the CATIA CAD software in full detail [1]. It is used to visualize the space dependencies of all sub-systems like mechanics, electronics and cooling. In this report the status of the work on this model is shown.

Repository

Several people of the CBM STS collaboration work with the CAD model. Since they work in different institutes all over the world a platform was needed to enable collaborative work. As control system Subversion was chosen because of the instant availability and the ease of use. GSI hosts a Subversion server on which all CAD files are now located. This Repository not only gives access for everybody involved but also brings file versioning and backup.

Sensor layout

The sensor layout has been improved in the area around the beampipe and in the outer edges at the large stations. To optimise the amount of different parts and lengths of cables the readout electronics have been re-arranged to appropriate positions (see Fig. 1 and Fig. 2). Now only 16 different lengths of carbon ladders are needed.



Figure 1: Detailed view of the upper end of ladders. Space between uppermost sensor and electronic not optimised for cables lengths (not shown).

Cooling plates

The detailed construction of the cooling plates has started (see Fig. 3). Different manufacturing methods and their influence to the shape of the plates were considered.



Figure 2: Detailed view with re-arranged electronics. Distances between sensors and electronics shorter and more regular.

Two special joining processes (with and without additional material) for aluminium are tested. At first two different sizes of plates are designed to prove the desired cooling power, pressure stability and the reliability of the production process.



Figure 3: Semi-transparent view of a cooling plate. Length of inside channel is more than 5 m, cross section 4×4 mm. Connectors will be at the upper right corner.

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Long-term operation stability of neutron-irradiated STS prototype sensors*

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The Silicon Tracking System (STS) is the core tracking detector of the Compressed Baryonic Matter (CBM) experiment. The STS silicon sensors [1] will be operated during long periods of time continuously. During the operation a high level of radiation damage is expected to impact on the sensors. The exposure of 1×10^{14} 1 MeV neuton equivalent per cm² is the harshest scenario for sensors in the innermost areas of the STS stations, close to the beam axis, after several years of running. In this work, the long-term stability of the leakage current of highly irradiated prototype sensors has been investigated.

Prototype	Vendor	Sensor	Interconnection	
sensor		size, cm	technology	
CBM05H4	Hamamatsu	6.2×4.2	Double-Metal	
CBM05H4	Hamamatsu	6.2×4.2	External cable	
CBM05C6	CiS	6.2×6.2	Double-Metal	
CBM06C6	CiS	6.2×6.2	External cable	

Table 1: Prototype sensors used for tests.

To study the impact of irradiation on the properties of the sensors, the latest STS prototype sensors have been irradiated to $2 \times 10^{14} n_{eq} \text{ cm}^{-2}$ at KIT, Karlsruhe. The following prototype sensors with two different strip interconnection technologies [1], indicated in Table 1, were used for the tests. All the measurements were performed at -5°C to reproduce the real operating conditions of the CBM experiment. The sensors were placed inside the shielded box with connected N_2 supply to keep the humidity at the lowest possible level.



Figure 1: a) Long-term stability of the leakage current of the CBM06C6 prototype sensor; b) Measurement results of the humidity impact test.

During a single measurement, the leakage current of the sensor at 350 V reverse bias voltage, and the temperature and humidity of the surrounding air were monitored in

steps of 30 seconds. Figure 1a indicates the measurement result of the CBM06C6 sensor prototype during 15 days of continuous operation. The temperature of the air fluctuated within 1°C periodically during the measurement because of the cooling device's operating principle, keeping the mean value of -5.5° C.

$$I(T) \propto T^2 exp(-E_q/2k_B T) \tag{1}$$

This resulted in a leakage current fluctuation due it's temperature dependence that is shown in Eq. 1. Moreover, it was observed that the leakage current is also sensitive to the humidity variation. The correlation between leakage current and the relative humidity curves are shown in Fig. 1 a, b. This can be explained by the introduction and rearrangement of negative charges in a humid air on the oxide surface which leads to surface depletion and consequent increase in the leakage current, as the surface generation becomes added to the bulk leakage current [2], [3].



Figure 2: Leakage current stablity: sensors with doublemetal (left) and external microcable (right) technologies.

Figure 2 shows the results obtained for all prototype sensors for a 110 hours time period. All the presented data points have been normalized to the values at the reference temperature (-5° C) to exclude the temperature variation impact using Equiation 1. The humidity variation for the selected time period was considered to be negligible. The measurement results show stable behaviour of the leakage current for the sensors with both double-metal and external microcable interconnection technologies.

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Development of a compact, highly efficient heat exchanger assembly for bi-phase CO₂ Cooling of the CBM Silicon Tracking System

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Results

The CBM Silicon Tracking System (STS) is a compact detector that consist of double-sided silicon microstrip sensors with an overall volume of about 2 m³ defined by the aperture of the dipole magnet[1]. In order to reduce the material budget of the detector all heat producing readout electronics were moved outside of the acceptance zone, which in turn greatly reduced the space available for cooling. In order to avoid thermal runaway during the operation of the detector, the silicon sensors have to be kept at temperatures below -5° C. This is quite challenging as up to 50 kW of heat is dissipated from the STS Front-End-Electronics (FEE) in a rather small volume with very limited space for heat exchanger plates. We use bi-phase CO₂ cooling due to its superior volumetric heat transfer coefficient, which is about an order of magnitude better than conventional freons. The aim of this research project is to optimize the Front-End-Board (FEB) box housing FEE elements in terms of heat transfer efficiency under the given space constraints.

Open CO₂ Cooling system

In order to find the most effective FEB box design (Fig. 1), a series of Finite Element Method (FEM) studies were conducted as well as an open CO_2 cooling system was built, which allowed us to utilize the bi-phase CO_2 cooling.

The cooling system is designed to absorb about 200 W thermal load under realistic geometrical constraints. One has to verify the cooling efficiency of various FEB box designs. The heat generated by a resistive thermal load will be dissipated in the FEB box and removed by a cooling plate with integrated capillaries of about 2 m total length and about 2 mm diameter[2].



Figure 1: Sample FEB box design with heat distribution information obtained from thermal FEM studies.

To find out the most effective FEB box design, different FEB box were produced with varying thickness of the FEE supporting structure (shelve). These designs were then tested under different heat loads. Table 1 shows the experimental results from selected measurements. The experimentally measured trends were reproduced by the simulations.

Power Applied, W	Maximum Temperature, °C				
	1 mm	3 mm			
140	15	-14.2	-22.6		
200	24	0.2	-15		

Table 1: Experimentally measured maximal temperature on the FEB box in dependence of power applied and shelve thickness

The optimal FEB box design was found to be with shelve thickness of 3mm. Resulting FEB box dimensions are $105 \times 85 \times 35,6 \text{ mm}^3$. This design was proposed to be used in the construction of the STS detector.

To make the operation of the STS detector cooling safer one wants to move further away from the triple point of liquid CO₂ (-56.6° C, 5.11 bar), i.e. eliminate the risk of solidifying the coolant. This is achieved by increasing the CO₂ temperature and pressure in the cooling lines, although this decreases cooling power. Table 2 shows the results of FEM simulations conducted to examine the dependence of maximal FEB box temperature versus coolant temperature. This study shows that safe operation and sufficient cooling can be achieved at -30° C.

Maximum temperature, °C					
T, coolant T@200 W T@140 W					
-40	-10.6	-12.7			
-30	-4.9	-9.9			
-20	0.8	-4.1			
-10	6.5	1.58			

Table 2: Result of simulations showing the expected maximal temperature on the FEB box in dependence of initial coolant temperature and power applied.

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Optical quality assurance procedures for STS silicon sensors

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The CBM Silicon Tracking System (STS) is a compact array of silicon microstrip sensors [1]. The total number of sensors is about 1300 and they will be delivered from different manufacturers and in different form factors [2]. Thus the operation of the detector requires all sensors to be optically quality assured in order to meet the requirements with respect to surface conditions (scratches, durst grains, photo-resist residues, etc) and geometry (wafer thickness and warp, edge parallelity etc.)

For this purpose a clean area was established in a laboratory at the University of Tübingen and an optical inspection setup was built [3]. The setup consists of a XYinspection object table based on closed-loop Movtec SMC-300 linear servomotors with a 5 MP Moticam microscope camera combined with $12 \times$ magnification lens from Navitar company. The setup allows to scan in X-Y-Z range of 200/75/75 mm with a micrometer precision and taking pictures with a resolution of 2592×1944 pixels.

Optical inspection workflow

A typical inspection workflow consists of several steps: preparation for inspection, inspection procedures, inspection report (Fig. 1).



Figure 1: Typical workflow of inspection procedure.

First, a sensor is laid on the inspection chuck, camera parameters are adjusted followed by a self-calibration cycle of the system. In the main part of the program the sensor is moved below the camera to scan the regions of interest, pictures are taken and analyzed to detect various defects and features on the sensor's surface. Lastly, a report that summarize the inspection results is produced. In this report all the technical data are comprised about sensor defects and features with corresponding images containing these defects and features. The report is then stored to disk and uploaded to the STS sensor database.

Method implementation

First, the motors and camera parameters are adjusted if needed (gamma, brightness, color gain, other parameters). Geometrical self-calibration begins with a spiraling pattern search for the nearest alignment mark which is an $120 \times 120 \ \mu\text{m}^2$ object (Fig. 2). The alignment mark is detected by pattern matching algorithms. Information extracted at this step gives a rough estimate of the sensor misalignment with respect to the XY motor axes. This in turn allows to optimize the amount of steps needed to detect all 8 alignment marks of a sensor.

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Figure 2: Sample alignment mark image to use in pattern matching algorithms.

After detecting all of 8 alignment marks and determining their respective coordinates in step motor space, one can solve the minimization problem (1).

$$\vec{x}_m = \mathbf{S} \, \mathbf{R} \, \vec{x}_s \tag{1}$$

Having a stretching matrix S and rotation matrix R from problem solution, coordinates from sensor coordinate space (s) could be translated to motor coordinate space (m), thus enabling us to precisely scan along sensor axes. Specific scans are performed for various geometries (e.g. normal, "baby", daisy-chained sensors) and different manufacturers (CiS, Hamamatsu) of a sensor.

After each step of a moving sequence the picture in the camera's field of view is taken. This image is then analyzed with the NI Vision® package to detect various defects and features on the sensors' surface, such as photoresist residues, scratches, or dust grains. OCR algorithms from the Vision package enable us to read text parts written on the sensor to extract information about sensor's part number and include it later in the report.

When the scan is finished, the quality of the sensor is classified based on a given set of criteria. Lastly a human readable report containing the information on the sensor is produced. The report contains pictures of possible defects and their coordinates in sensor coordinate space.

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The GBT Based Readout Concept for the CBM Silicon Tracking System

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The sensors of the CBM Silicon Tracking System (STS) are read out by frontend boards (FEB) with 8 STS-XYTER ASICs for 128 channels each implementing the analog frontend, analog-to-digital conversion and the readout of buffered hits via multiple serial links. A subsequent stage with data aggregation from several ASIC links and an electrical-to-optical interface is required before transfering the data to the FPGA based data processing boards (DPBs) located in some distance at the detector site where preprocessing and further data transfer occur. The aggregation stage is located in the cooled STS detector box inside the CBM magnet, which implies that the hardware must fulfill conditions in terms of radiation hardness, magnetic field, space contraints and thermal environment.

GBT Devices

A concept was devised for the STS readout to implement the aggregation and optical readout functionality on a separate readout board (ROB) using the GBTX, SCA and Versatile link devices [1] developed at CERN. The devices of the GBT project are mainly designed as interface between on-detector and off-detector electronics for future LHC experiment upgrades in a radiation environment up to tens of Mrad. The GBTX ASIC implements up to 56 SLVS links (E-Links) as electrical frontend interface with link speeds of 80, 160 or 320 Mb/s and a total bidirectional user bandwidth up to 4.48 Gb/s on the high speed serial link. Latencies of data throughput in the GBTX are fully deterministic. The Versatile Link devices are radiation hard optical transceivers and (twin) transmitters in SFP formfactor modules.

The STS Readout Chain

The ROBs for the STS will contain 1 GBTX device as master connected to an optical transceiver (VTRx), 2 GBTX devices connected to an optical twin transmitter (VTTx) and a GBT-SCA (Slow Control Adapter) device for I^2C based control of the 2 GBTX without optical downlink (see Fig.1). The GBTX uplinks will be operated in the widebus mode (without forward error correction) and therefore provide 3x14 frontend links at 320 Mb/s each. Fourty of these links are used to connect to the FEBs. Three types of FEBs will be used with either 1, 2 or 5 readout E-Links per ASIC depending on the local data load, resulting in a maximum of 5, 2.5 or 1 FEBs of the different types connected to a single ROB. With additional spatial contraints from system integration (no connections across quarter stations, no cable crossings) the total number of ROBs for the STS amounts to approx. 1000, with 3000 optical readout links and 1000 control links. For ASIC timing and control, one single E-Link output and one phase adjustable 160 MHz clock are connected from the master GBTX to each FEB; the control responses use any of the readout uplinks. All E-Links between FEBs and ROBs will be AC-coupled in order to allow the connection of a single ROB to multiple FEBs operated at different potentials together with their connected sensors. The ROBs will be located at the sides of the STS detector box outside the detector acceptance. Flexible flat cables of approximately 0.6 m length will connect the stacks of FEBs for a given quarter station of the detector to the corresponding stack of ROBs.

The version 2 of the STS-XYTER ASIC[2] will implement the GBTX E-Link interface with a configurable number of 1 to 5 readout links and a synchronous readout and control protocol that was specifically developed for the STS-XYTER readout via GBTX [3]. A demonstrator board with a single GBTX and Versatile Link components will be available from CERN for initial tests in early 2015 and a CBM ROB prototype with full functionality is currently being prepared. Larger quantities of the devices from the sole production run are expected end of 2015.



Figure 1: The STS readout chain with the readout board based on GBTX and Versatile Link components.

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Radiation hardness tests on electronic components for low voltage power supply of the CBM Silicon Tracking System

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Electronic components installed in the field of reaction products in future experiments at FAIR have to be radiation hard. At present, selected parts like DC/DC converters and LDO voltage stabilisers undergo exhaustive tests with use of intense minimum ionising particles' beams, mostly 3 GeV protons at Research Center Jülich's sychrotron facility COSY.

Testing setup

For components like DC/DC converters or LDO voltage stabilisers the output voltage level as well as expected transient voltage spikes rate due to the Single Event Upsets has to be monitored during irradiation. Voltage level monitoring (input and output) requires relatively low readout frequency below 1 Hz and can be implemented on inexpensive ARDUINO-Nano system [1]. Fast transients have been investigated on 4 trace digital oscilloscope Rhode-Schwarz RTO1044 [2] (triggering threshold has been setup to 15 mV). Measurement results have been recorded in nonvolatile memory and analysed.

Selected ASICs

For the radiation hardness tests several DC/DC converters have been chosen. Selection criteria like circuit efficiency, chip size, low coil inductivity, apropriate output voltage and sufficient output power as well as voltage setting flexibility have been applied. Only one model



Figure 1: Base plate with PCB card holder and wiring.

of the LDO stabilizer produced in rad hard technology has been examined until now. Alltogether 10 test boards with LTC3605 and 3 Boards with LTC3610 (Linear Technology) and 4 boards containing LM2596S (Texas Instruments) have been tested in two beam times. A GaN based ISL75051SRH has been abandoned according to producer information on radiation hardness of only 100 krad. All tested ASICs have been powered on during irradiation runs.

Test results

PCBs with tested chips have been placed in a row along the beam axis such that the irradiating beam punched through all of them. A small ionisation chamber placed on the beam axis behind tested chips has been used to monitor the beam intensity, corresponding to the shape of the



Figure 2: Beam spot on Gafchromic self-developing dosimetric film.

proton beam with optical density corresponding to the integrated beam intensity. The total dose is known from the measurement with the ionisation chamber and position of irradiated chips is marked on the film. By optical scanning a fractional dose can be estimated for each point on the film. This allows to estimate precisely beam intensity integral and - consequenty - the dose at ASIC chips.

Neither of tested DC/DC converters survived more than $4.3*10^9$ protons.

No fast transients have been observed on LDO voltage stabilisers which have absorbed only 10^8 protons (measurement was stopped for technical reasons before planned dose was reached).

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A custom made wafer prober for quality assurance of CBM-STS sensors

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The CBM Silicon Tracking System will be constructed from about 1300 double-sided silicon microstrip sensors with a total area of $\sim 4 m^2$. It will have about 2.1 million readout channels. The double-sided microstrip sensors with strips of 58 μ m pitch have double metalization connecting the short corner strips resulting from the stereo angle of 7.5°. Due to its complex structure, all sensors have to be tested before they are assembled into detector modules. Large volume tests of the sensors require a suitable probe station and automatisation. Due to the relatively large size of 62×62 mm², the CBM microstrip sensors are not well suited for the characterization at conventional probe stations. Therefore, a custom probe station is beeing developed at Tübingen University (see Fig. 1). It consists of optical, mechanical and vacuum systems placed in a shielding box. Components of our probe station set-up are (see schematic view in Fig. 2):

- SourceMeter Keithley 2410
- Picoammeter Keithley 6487
- LCR-Meter QuadTech 7600
- Switching matrix Keithley 708B
- Aerotech linear and rotary motors with NPAQ-MR controller
- Vacuum pump (200 mbar abs.) and shielding box
- NAVITAR optical system with TheImagingSource camera (5 MP resolution)

One of the main requirements is a position repeatability better than 1 μ m to allow an automatic succesive positioning on all 1024 pads of a sensor. It will be fulfilled with Aerotech linear motors providing a precision of ~ 0.4 μ m. The sensors will be fixed on a custom made vacuum chuck mounted on the motors.



Figure 1: QA infrastructure in the clean room.

The probe station allows to investigate the electrical characteristics of the sensors (full depletion voltage) as well as characteristics of individual strips (leakage current, interstrip capacitance, etc). The switching matrix allows to use all connected needles in any combination by any of the measuring devices. It leads to strongly reduced measurement time due to fast reconfiguration of the setup.



Figure 2: Schematic view of the probe station set-up.

It is foresees that all system components will be controlled via LabVIEW. A dedicated software development to automate repetitive measurement steps is in progress.

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Charge sharing in micro-strip sensors: experiment and simulation^{*}

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In December 2013 [1] and December 2014 [2] a prototype setup of the Silicon Tracking Systerm (STS) for the CBM Experiment was tested in a 2.4 GeV/c proton beam at the COSY synchrotron (Jülich, Germany). In the middle station, which could be rotated around its vertical axis, CBM05 prototype sensors (n-side with 0⁰ stereo-angle, pside with 7.5⁰, 285±15 μ m thick) were under a test aiming at studying charge sharing. The n-XYTER read-out chips were triggered by a hodoscope. The equivalent noise charge of about 8 ADC promoted adapting the threshold of 20 ADC in the cluster finder to cut off the noise.

Charge sharing between two fired strips is described by $\eta = S_R/(S_R + S_L)$ with $S_{R(L)}$ being the signals on the right (left) strip of the cluster [3]. The left panel in Fig. 1 shows the measured distribution of η . Positions and widths of the peaks depend on characteristics of the sensor and the readout electronics (e.g. strip pitch, signal-to-noise ratio, coupling capacitance, threshold, etc.). For inclined tracks the η -distribution is essentially asymmetric. The position of the cluster with respect to the left strip can be calculated as $x_{\eta} = p \left(\int_{0}^{\eta} \frac{dn}{d\eta'} d\eta' \right) \left(\int_{0}^{1} \frac{dN}{d\eta'} d\eta' \right)^{-1} = pf(\eta)$, where p is the strip pitch and $f(\eta)$ is obtained from measurements (see the right panel of Fig. 1).



Figure 1: *Left:* η measured for p-side of CBM05 with Gaussians fitting the peaks. *Right:* $f(\eta)$. Perpendicular tracks.

Investigating cluster size distribution at different beam incidence angles is a good tool to verify the simulations of charge sharing in a silicon strip detector (implemented in the advanced model of the digitizer in CbmRoot). Figure 2 presents a typical distribution at one angle. Assuming the n-XYTER calibration [4] to be accurate, we get the reconstructed charge (Fig. 3) smaller than the one modelled. This indicates additional effects. Imposing 20% less charge from the sensor than expected from its thickness alone (on top of the 5% loss due to the trigger signal delay affecting

the signal sampling in the ASIC) yields a better agreement. This is still to be explained.



Figure 2: Cluster size distribution for slightly inclined tracks (10^0) . Experimental data for n-side (the gray filled histogram), simulations with no (the solid line) and 20% (dashed) additional charge loosing.



Figure 3: Most probable registered charge in dependence of track angles. The points show the experimental data from beamtime 2013 (the open triangles – p-side, the filled squares – n-side, the uncertainties in the angle measurements are drawn with bars) and the modelled data are represented by the lines (the solid line – no charge losses in the sensor, the dashed – 20% losses).

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Setting up the STS module and ladder assembly site at JINR-LHEP

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Works on the organization of module and ladder assembly site at LHEP JINR for CBM STS were performed. This assembly site is developed jointly by the specialists from JINR and LTU. The work was supervised and coordinated by JINR.

The assembly site includes: dressing room, changing room and clean room (see Fig. 1). The range of clean room purity should correspond to the ISO 7 class. The total area of the site exceeds 100 square meters, including more than 50 square meters of clean room.



Figure 1: Layout of the assembly site.

In the cleanroom seven workplaces will be created with the following indicated equipment [1-2]:

- 1. Workplace for parts kitting.
- 2. Workplace for modules and components assembling (automatic bonder for TAB-bonding).
- 3. Workplace for bond joints protecting and gluing (dry box, scales, dispenser, oven).
- 4. Workplace for chip-to-FEB wire bonding (semiautomatic bonder for wire-bonding).
- 5. Workplace for modules and components testing.
- 6. Workplace for ladders assembling (opticalmechanical system).
- 7. Workplace for ladders testing.

All work places must be equipped by microscopes and ionizers. Also the area for modules and components storage must be prepared. In the beginning of 2014 space for the construction of the cleanroom was prepared in the building of JINR-LHEP. In the beginning of 2015 the creation of the cleanroom was finished and its certification completed (Fig. 2).



Figure 2: Cleanroom prepared at JINR-LHEP.

Further works on the establishment of an assembly site will comprise: installation of equipment on workplaces, connecting line of the vacuum and compressed air, start-up of the site, training of technical staff of the basic assembly operations. After completion of the abovementioned works, this site will be able to provide assembly productivity (within production stage) in the range of 15 to 16 modules per month and 3 ladders per month [3]. At full load, the staff working in the cleanroom will amount to at least seven technicians.

- Workshop on module and ladder assembly for the CBM Silicon Tracking System, JINR, Dubna, Russia, 6-7 June 2013.
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Charge collection in STS silicon microstrip sensors at their surface layer*

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To provide radiation tolerant devices for the CBM experiment (Silicon Tracker Station) prototypes of silicon microstrip sensors have been produced in two technologies. For the short-long stereo-strips connection, either doublemetallization lines ("double metal" sensor) or a singlemetallization design with an external microcable ("single metal" sensor) have been manufactured. We report here the results of studies performed for those sensors with the Pu (triplet) alpha-source and laser (640 nm wavelength). Both methods provide test of the charge collection at the sensor surface layer where double metallization is laid out. Measurements were carried out exploring discrete electronics and the fast-slow coincidences setup at KINR. This allows studying a charge sharing between adjacent strips of the silicon sensor hit by alphas or laser pulses. The degradation of the cluster finding efficiency in the vicinity to the doublemetal connecting lines in heavily irradiated microstrip silicon sensors has been observed [1].

The CBM05H4 'double metal' and 'single metal' (HAMAMATSU) sensors were full depleted at 80 V. In a two-dimensional ($E_i \ x \ E_{i+1}$) energy distribution of events in adjacent strips 'i' and '(i+1)' three loci for a ²³⁹Pu, ²³⁸Pu and ²³³U alpha-particles source are shifted by ~ 20 % to lower energies for the double metallization sensor in comparison with the single metal one. Also the widths of loci are larger. The evaluation shows that this could be explained by the alpha-particles energy loss and straggling in the SiO₂ isolation layer present only in the sensor with a second metallization layer. Biasing voltage scan has demonstrated expected performance for these sensor types, while CBM06C6 (CiS production) have shown appearance of the dead layer (~ 25 μ m) in the interstrip gap at full depletion voltage.

Also measurements with a 640 nm laser beam (7 μ m spot) scanned over the sensor area were performed for sensors irradiated at the KINR isochronous cyclotron up to the 2*10¹⁴ 1 MeV n_{eq}/cm². Figure 1 shows two dimensional distribution of amplitude of charges originated in the interstrip gap of the CBM05 non-irradiated sensor illuminated by the scanning laser beam. It demonstrates excellent position resolution achieved: beam spot position is indicated by figures of 15 μ m, 18 μ m, 21 μ m etc. Figure 2 illustrates degradation of the charge collection by 30% in the irradiated sensor (the locus of laser events is shifted to lower amplitudes region). Analysis of data for other sensors is in progress. Tests with the ⁹⁰Sr β -source will be made soon exploring the 'ALIBAVA' microelectronics readout system.



Figure 1: CBM05 – non-irradiated sensor: Laser scan in the interstrip gap.



Figure 2: CBM05 – irradiated sensor: Laser scan in the interstrip gap.

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Studies of Correlated Signals in CBM STS Silicon Microstrip Sensors*

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Physically correlated signals in adjacent strips of a microstrip detector appear due to charge sharing. A significant fraction of tracks is reconstructed from two- and threestrip cluster events where analogue read-out improves the position resolution. Non-physically correlated signals originated by cross-talk, pick-up or common mode fluctuations may also occur in read-out channels. Measurements of charge sharing between adjacent strips of the CBM05 and CBM06 prototype silicon sensors designed for the CBM Silicon Tracking System were performed at KINR [1]. In a two-dimensional ($E_i \times E_{i+1}$) energy distribution of physically correlated events loci from an alpha-particle source were clearly observed in adjacent strips i and (i+1) (Fig. 1).



Figure 1: Two-dimensional ($E_i \ge E_{i+1}$) energy distribution in adjacent strips i and (i+1) obtained with alpha-particles.

Detailed studies revealed also non-physical correlated events populating loci from the very low amplitudes along the straight lines and reaching the positions of the alpha particle contribution. Among possible explanations we considered a cross-talk with the channels (i-1) and (i+2) located in close vicinity to the ones under the test. Correlated event studies were carried out recently with n-XYTER readout electronics at GSI. Examples of data obtained are shown in Fig. 2.

In the upper panel physically correlated events at the pside triggered by MIP β -particles from ⁹⁰Sr are observed along the expected line (most probable value) with a sum of amplitudes around 140 ADC counts. The simulated noise distribution is shown in the middle part of Fig. 2. The events populating the loci alongside the straight lines originating from the (0.0 × 0.0) coordinate are apparently correlated non-physical events (see lower Fig. 2). These signals simultaneously appearing at adjacent strips i and (i+1) are initiated either by the digital part of the n-XYTER chip



Figure 2: Two-dimensional ($E_i \times E_{i+1}$) amplitude distribution of events in adjacent strips 'i' and '(i+1)' of the CBM05 sensor. Data taken with ⁹⁰Sr source (upper: p-side; lower: n-side). A simulated noise distribution is shown in the middle panel.

and/or by external powerful electromagnetic sources. It is worthwhile to notice that such events were also observed at n-XYTER channels not connected to the microstrip detector at all though with a low, yet significant amplitude of up to 40 ADC counts. The results of these studies have to be taken into account in the test measurements with a newly designed STS-XYTER microchip as well as in building the infrastructure for power lines, shielding and grounding of the STS detector. Further studies with the ALIBAVA readout system [2] are planned to clarify the origin of the nonphysical correlated events.

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^{*} Work supported by HIC-for-FAIR, H-QM and HGS-HIRe.

Development of a CO $_2$ cooling prototype for the CBM Silicon Tracking System*

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The CBM Silicon Tracking System is based on silicon sensors with double-sided strip readout. These sensors must be kept at least at -5° C to ensure the required performance. Due to this cooling demand the design and manufacturing of a 1 kW prototype called TRACI-XL, shown in Fig. 1, was chosen as the best option as starting point for specifying the technical features and requirements of the final cooling plant. The main heat sources of the detector are the read-out electronics, which dissipate about 40 kW according to the current specifications and they must be removed completely. This does not mean that the final plant will be 40 times bigger but it will allow to scale the experimental results and to get conclusions about the CO₂ nucleate boiling behavior and to start the engineering development of the cooling plates, fluid distribution and other important aspects.





Preparations for the commissioning phase

In order to ensure a correct performance of the plant an exhaustive protocol has been defined. The commissioning phase comprises the following tests:

- Safety verifications: Electrical safety (Electrical cabling, PLC I/O testing, alarms testing), mechanical safety (Pressure test and leak test).
- Basic functionalities tests: Real conditions analog alarm testing, chiller operation, pump operation, accumulator pressure regulation.
- Advanced performance tests: Automatic procedure testing, stable chiller operation over the full operating range, stable pressure (temperature) regulation in every condition, stable flow control.

• Thermodynamic performance: Test with a 1 kW dummy load in a wide range of temperatures, test with gradual power supply, shock test: sudden disconnection of electronics.

The PLC parameters such as pressures, temperatures, mass flow, alarms, interlocks etc. can be forced to bring the plant to extreme conditions and to check that all the safety and recursive procedures work as expected. In addition a 1 kW dummy heat load which simulates the future connected read out electronics was developed. This experimental heat source is based in a 3/4" pipe with a concentric fire rod providing a power of 1 kW and the respective sensors.

Finalizing the assembly stage

Once the concept design phase finished, the mechanical assembly stage (Fig. 2) takes a great relevance because it is the moment to introduce changes into the design after analyzing the evolution of the prototype and detecting possible defects or improvements. Parts of the mechanical frame were adapted to gain in stability and to reduce noise installing materials for vibration damping. Some other parts were relocated in order to facilitate the accessibility to every component in case they must be replaced, or distributed to ensure sufficient ventilation in the plant.



Figure 2: Vacuum pump set-up with condensing unit.

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Low and high voltage powering concept for the CBM Silicon Tracking System.

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Due to the radiation damage to the silicon sensors in the CBM-STS detector their performance will deteriorate in course of experimental activity. Gradually increasing their depletion voltage will improve the efficiency again and prolong their life time. This procedure will be applied to each of almost 1300 sensors separtely what motivates the powering architecture described in this report.

Requirements for powering

The Silicon Tracking Systen of CBM will be operated together with the Micro Vertex Detector inside the 1 T dipole magnet, in a rather small volume of about 2 m³ [1]. To minimize the scattering of the reaction products tracked by the system only silicon sensors, their supporting structure and signal cables will be installed in the detector acceptance. The readout and converting electronics and its cooling as well as power converter will be installed on the detector's perimeter. Altogether almost 40 kW of heat has to be removed from the STS box to reach working conditions of -5 °C for the silicon sensors. Moreover, a very restricted amount of surface is available for connectivity with the outside infrastructure: all the cooling system's tubing, low and high voltage cabeling, data transmission and control link sockets have to be connected on 1.5 m² surface of the upstream wall of the detector. At least two different voltages are necessary for the STS-XYTER read-out ASIC [3, 4] and additional two for the GBTx [5] and optical converter.



Figure 1: Low and high voltage powering scheme for one silicon sensor.

Each sensor will be operated in a floating manner, i.e. the p- and n-sides will sense one half of the depletion potential (positive and negative); the read-out ASICs (and their powering) operate "on top" of the sensors' depletion voltage. The distance between the last component shaping low voltage should be as close as possible to the front end ASIC in order to minimize the amount of noise irradiated into the system. High depletion voltage (low current) can be generated and controlled from the outside of the STS volume. All electronics parts inside the STS box should be radiation hard and stand a magnetic field of at least 1 T.

Proposed powering scheme

The schematics in Fig. 1 shows the proposed power distribution. Both sides of the sensor (central part in the figure) are supplied with positive and negative depletion voltage generated outside of the magnetic field (+200 V and -200 V in this case, red lines) with a common ground. The sensors' strips are connected to the STS-XYTER read-out ASIC on the Front Electronic Board (FEB) with microcables (orange elements). The ASIC's powering of 2.2 V and ca. 4 A (per FEB) will be generated by a FEAST DC/DC converter placed on the side part of the cooling plate [2]. It supplies two LDOs converting the input voltage to 1.8 V (digital) and 1.2 V (analog part) of the ASIC. The latter has to be grounded in the vicinity of the sensor to +200 V or -200 V respectively. Input power of 12 V and about 1 A is delivered from outside for each detector module separately. This construction minimizes grounding loops and assures separation of strong and weak current flow. A GBTx chip is equipped with many e-links and can communicate with more than one FEB simultaneously so GBTx circuitry has to be galvanically isolated from the STS-XYTER chips. GBTx and optical interface require their own power which will be generated from dedicated 12 V lines and additional FEAST converters (uppermost and lowermost parts in Fig. 1 in green). STS-XYTER as well as GBTx power stabilisation will be realised by LDO components placed directly on the corresponding PCB boards. The vertical dashed line in Fig. 1 depicts the border of the high irradiation and magnetic field region (front wall of the STS detector box) and the little circles the electrical connectors to the high (in red) and low (in blue) voltage DC generators.

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Fixtures for quality assurance of STS silicon sensors and STS-XYTER ASIC

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To assure the functionality of the silicon microstrip sensors and the quality of bond contacts of the microcables on the STS-XYTER-chip, fixtures are needed, that preferably allow on one hand for non-destructive handling and measurements as well as easy and fast procedures on the other. Several companies were asked for proposals and aps Solutions GmbH had the most promising one: test sockets with Pogo Pins for contacting. *Pogo Pin* is a registered trademark of a US company, they are also called spring loaded contacts. Formed like a cylinder, it contains two peaked, spring-loaded pins that make secure contacts with two electronic circuits. For the Pogo Pins different combinations on tip shapes, structures, materials and plating are available so that the particular application may be optimized.

Test socket for the silicon sensors

The challenge for the different quality measurements of the double-sided sensors is the need for simultaneous biasing contacts from bottom and top side. This problem can be solved with a fixture that consists of a bottom and a top socket. Both sockets include a Pogo Pin to which the bias voltage is applied via a small pcb. The bias pads on the sensor have a comfortable size of 400 μ m × 150 μ m to facilitate contacting. With the help of a wafer prober equipped with a movable chuck, the strips may then be stepped through for investigation by means of a probe card. The schematical layout of the fixture and its installation on a wafer prober are shown in Figs. 1 and 2.



Figure 1: Draft design of the sensor test socket by WinWay Technology.

Test socket for the STS-XYTER-chip

Each traceline of the microcables that connect the silicon microstrip sensor to the STS-XYTER-readout-chips has to be TAB-bonded onto the pads of the sensors on one side and on the chip on the other. These contacts should be checked before applying the protective glob-top because TAB-bonds without contact may be rebonded. The quality check can be put into practice by taking the chip into opera-



Figure 2: Test socket and probe card on wafer prober.

tion, a minimal set of essential connectivity has been elaborated with the chip designers towards this end. A probe card, that is typically chosen as a good solution for operating a chip without wirebonding, cannot be used for this test because it only works in combination with a wafer prober that assures alignment and positioning. The STS-module (STS-XYTER + microcable + sensor) would need to be placed on the chuck of the prober, inhibitive because of the module size and the fragility of the module. Therefore working with a test socket with Pogo Pins is an appropriate solution. The chip by itself is placed into the socket that will have an opening for the microcable. Several requirements regarding the test pad size, pitch and general arrangement and balance of connections across the chip have to be taken into account. Proposals for the pad layout of the STS-XYTER are under development with consultation of aps Solutions GmbH. Continuative tasks for the execution of tests are the development of a modified STS-XYTER board and suitable software.



Figure 3: Test socket for ASICs by WinWay Technology.

Neutron irradiated prototype CBM-STS microstrip sensors tested for double metal or cable interconnections of the end strips*

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The Silicon Tracking System (STS), the core detector of the CBM experiment, is located in the dipole magnet to provide track reconstruction and momentum determination of charged particles from beam-target interactions. The STS will have double-sided silicon microstrip sensors mounted onto a low-mass carbon fibre support structure. The strips on one side of the double sided silicon microstrip sensors are tilted to have 7.5° stereo angle. This allows to reconstruct multiple hits from the same sensor at the expense of a poorer spatial resolution in vertical direction [1]. To have read out only from one sensor side, the end strips from one edge of the sensor were connected to the end strips on the other end as shown in Fig. 1. This interconnection can be provided via double metallization (DM) or by using external interstrip cables (SMwC). However, the central strips were the full strips without any kind of interconnections (region II in Fig. 1).

Test results of these prototype sensors before and after their exposure to neutron equivalent fluences of $2 \times 10^{14} \text{ n}_{eq} \text{ cm}^{-2}$, as they are expected for the worst case scenario in the CBM experiment, will be disucssed. The sensors were irradiated at Karlsruhe Institute of Technology (KIT), Germany.



Figure 1: Sensor topology to read out inclined sensor strips.

All the measurements were performed in a refrigrator at temperatures between -5^0 C to -10^0 C to limit the radiationinduced effects on detector current and to prevent thermal runaway [2]. Four sensors were selected for the measurement of variation of leakage current with bias voltage (IV), bulk capacitance versus bias voltage (CV), and for charge collection tests for the central strips (region II in Fig. 1) and for the end strips (with these special interconnection scheme, region I in Fig. 1) with a 90 Sr source. In this report only the results from central strips will be discussed. The list of the sensors under test is given in Table 1 along with their sizes, thickness, types of the connections and full depletion voltage before irradiations (extracted from the capacitance-voltage measurements). These sensors were mounted in the printed circuit boards and were wire bonded to read out about 10 strips for each sensor side using selftriggered n-XYTER chip.

Table 1: Specifications for the sensors under tests. The naming convention in the left column encodes the prototype generation (5 or 6), the manufacturer (H = Hamamatsu, C = CiS), the sensor height/strip length in cm (4 or 6), and the wafer number.

name	size	thickness	inter-	$V_{fd} \pm 5$
CBM0-	$\rm cm \times \rm cm$	μ m	connection	V
5H4-W18	6×4	327	SMwC	68
5H4-W10	6×4	331	DM	75
6C6-W14	6×6	293	SMwC	94
5C6-W6	6×6	291	DM	98

Charge collection studies were performed with ⁹⁰Sr for the sensors under test by applying sufficciently high reverse bias. Results are shown in Fig. 2 for all the sensors with either double metal interconnection scheme or single metal with external microcable bonded on its top p-side. As can be seen in Fig. 2, the charge collection efficiency degrades after the irradations. These sensors were also tested inbeam at COSY, Research Center Jülich, in December 2014. Before concluding on the type of the p-strip interconnection scheme, one should also consider the beamtime results about charge collection and detection efficiency of these sensors. This work is still in progress.



Figure 2: Charge collection results with ⁹⁰Sr, comparing the sensors before and after irradiation.

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Development of software tools for the prototype readout chains of the CBM Silicon Tracking System

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Development and characterization of detector prototypes requires powerful, flexible, and reliable software tools, such as data acquisition, slow control and on-line/off-line monitoring systems. The present STS prototype readout chain includes the n-XYTER 1.0 and STS-XYTER 1.0 front-end ASICs, the SysCore versions 2 and 3 (SCV2, SCV3) readout boards, and the FLIB interface board [3]. Whereas the FLIB-based data acquisition system is covered in [4], the present report covers the controls and monitoring tools for the front-end ASICs and readout boards, as well as the USB-based readout system.

Controls

A control server library, which provides a high-level interface to various CBMNet [2] devices, such as the frontend ASICs and the SCV2 and SCV3 readout boards, has been developed. Having in mind its usage for the final experiment, the control server enables sending command sequences to a large numbers of CBMNet slaves in parallel.

Client libraries with device-specific macro commands were also developed. For the systems, based on SCV2s and n-XYTERs, these commands include transactions over the I²C interface (which is needed for n-XYTER configuration), as well as over the SPI interface (which is used for controlling the ADC). Additionally, the possibilities to switch n-XYTER between the self-triggering and externally-triggered operation modes was provided. A possibility to configure the AUX block of the SCV2 was provided as well. For the systems, based on the STS-XYTER ASIC and SCV3 readout boards, only simple configuration scripts with hard-coded default settings are currently available.

In future it is planned to connect the data acquisition system to the control libraries. This will enable to receive the feedback from the system immediately after changing a setting, and to use this information for taking decisions on further adjustments. Thus, for example automatic trimming of the thresholds will be possible. This will also simplify performing various parameter scans and calibrations.

Both the server and the client libraries are provided together with the dictionaries for the CERN ROOT interpreter. This enables to use the ROOT interpreter as convenient environment for interactive system configuration.

On-line and off-line monitoring

The development of the on-line/off-line monitoring tools is still in progress. Unpackers for the n-XYTER and STS-XYTER raw data were implemented in CbmRoot [5]. For the STS-XYTER, basic checks of the self-consistency of the data is performed. Thus, it is checked whether the epoch numbers within an individual epoch message are consistent, and whether the epoch messages from each data link are coming in the right sequence. For the hit messages the bit parity check is performed. Also the correctness of the detector transport message (DTM) number is checked at the stage of microslice unpacking.

An analysis library, evaluating the hit rates per channel, hit amplitude distributions, total data rate, etc. was implemented. It is a simple, but essential system diagnostic tool.

Particular care was taken to optimize the code for high performance, in order to achieve maximum analysis throughput.

USB-based readout for SCV3 and STS-XYTER 1.0

Along with the FLIB-based data acquisition system, a data acquisition system operating over USB has been developed. This enables external R&D groups to quickly deploy the SCV3-based setups, and operate them without the need of using the FLIB board. Same control and on-line analysis tools can be used with systems, read out over USB. Transporting up to 27 MB/s of data was achieved, and it is limited by the USB bus.

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Development of a 124 mm long silicon strip sensor for the CBM STS

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The new segmentation of the CBM STS ladders [1] requires to design and produce a silicon strip sensor with 62 mm width and 124 mm height. This new long sensor will replace the 2 daisy-chained 62 mm sensors.



Figure 1: Two daisy-chained 62 mm sensors.

In Fig. 1 a functional prototype module with read-out of 1/8 of its channels is shown, produced by LED Technologies of Ukraine (LTU) Ltd, Kharkov, Ukraine, using two sensors 6.2 cm by 6.2 cm large compatible with 4 inch wafer technology. Between the two sensors two short daisy-chain-cables are shown. That serve to connect the strips from one sensor to the next. In the final version, all strips of the sensors must be connected. Therefore a daisy-chain-cable with the full width must be produced and bonded onto the sensors. Every sensor also needs a cross connection on the p-side that links inclined strips ending on one lateral side to a corresponding strip on the other lateral side. It is not jet finally resolved, whether such connection should be realised on an additional metal layer or with a seperate microcable. If the sensor is single-metal, additionally for each sensor a interstrip-connection-cable must be bonded on the p-side of the sensor. Together with the CiS Forschungsinstitut für Mikrosensorik und Photovoltaik GmbH, Jena, Germany the plan was developed to produce a single 124 mm \times 62 mm sensor in double-side and double-metal technology on a 6 inch wafer. If it is possible to solve all technological challenges, the production of a module with 124 mm sensorheight would become much simpler. The production and assembly of two interstrip cables and the production and assembly of one daisy-



Figure 2: Layout of the 6 inch wafer with the 124 mm \times 62 mm STS sensor in the middle, around the sensor CBM baby sensors and test features.

chain-cable could be made unnecessary. Also the bonding process of these three cables will be avoided. This reduction of fabrication and manufacturing steps will increase reliability and yield. Additionally the replacement of the daisy-chained sensor by one sensor will reduce the assembly effort because the daisy-chained module must be installed on a special frame before it is mounted on the ladder. In Fig. 2 the layout of the wafer is shown.

At the moment the design of the 124 mm sensor is finished and the production of masks has already started. The design of the AC- pads will follow the classification of pad layout, described in [2].

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Modification of the CBM-STS micro-cable stack-up

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During several years of development of the CBM modules, the STS sensors and the CBM STS-XYTER chips were carefully studied and designed. Despite this careful evolution, the design and study of the connecting part between the sensor and the chip had not been addressed in such intensity. Some studies on the electrical behavior were performed, while all questions of cable stockage were addressed this year. In [1] the cross section of the cable like it was used for the electrical simulation - is described. Figure 1 shows the modified cable stack-up.



Figure 1: Schematic side view of the micro cable stack up for one CBM module. The red layer on the top and the bottom of the cable is the newly introduced insulation layer. In the middle, at the side of the sensor, the meshed layer to reduce crosstalk between the two sensor sides was newly introduced.

The geometry of the signal strands with a height of 14 μ m and a width of 46 μ m is kept, also the pitch between the strands remains 116 μ m on each signal layer. As substrate for the strands 10 μ m thick polyimide will be used. The thickness of the mesh will be kept at 100 μ m, but a study is beeing done to find a mesh material with a lower mean dielectric constant. Also a additional layer of meshed material will be inserted between the microcable for the n- and p-side of the sensor. With this layer the crosstalk between the signals of both sensor sides should be minimized. The shielding layer will be modified. The thickness of the aluminum will be reduced to 14 μ m (instead of 30 μ m) and the polyimide will have a thickness of 10 μ m (instead of 20 μ m). With these changes the same aluminium polyimide film may be used for the signal layers, as well as for the shielding layers. Due to the fact that the sensors of different modules of a ladder are on different potentials, it could be an advantage to introduce a additional layer of polyimide insulation on the outside of the shielding. This allows us to keep the shielding potential for each sensor side and for each sensor in a ladder on a defined and independent level, namely the reference level of the pre-amplifier input stage. With these additional two insulating layers of 10 μ m and the meshed layer in between, the total thickness of the stack is 664 μ m per module.

The modified stack-up of the micro cable was already presented at the 24th CBM Collaboration Meeting in September 2014 [2]. The research for a mesh material with lower dielectric constant is ongoing. This cable stack-up will now be realized for the next module prototype.

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Tooling for CBM STS module assembly

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The CBM STS module assembly needs tooling to simplify and speed up fabrication [1]. For several assembly steps specialized assembly tools are needed. Assembly will comprise the following steps: First, two layers of microcables need to be bonded on to the STS-XYTER chip to form a "chip-cable". Second, 8 chip-cables must be bonded to the CBM STS sensors side by side for readout of the full 1024 channels for every sensor side. Additionally, on singlemetal sensors an interstrip connecting cable must be allocated and bonded on one side of the sensor. It serves to interconnect the inclined strips that end on the sensor side to form a continuous strip over the sensor. Therefore a whole set of assembly tools must be developed and - if needed - improved. To start with simplest element, the tool for the first cable layer on the chip was design, produced and tested. This first version was already shown in [1].



Figure 1: Tool for 1st layer on chip.

In Fig. 1 the improved version is depicted. It has small bumps to avoid crashes between the bond needle and the tool. This change increases the safety of operations and will be an advantage for the mass production by reducing the machine downtime due to such crashes. The chip and the cable in this design were still held by vacuum and manipulated via a bottom-side mechanics. Second, a tool for bonding of the second layer of the micro cable to the chip was designed.Because of the presence of the first layer, already bonded and glued to the chip, the second cable layer needs to be mounted from the top side. The chip is still fixed from the bottom-side, but the jig for micro cable mounting is now above it. This does increase the height of the tool, but this height is not a showstopper, because the operating range of the tab-bond needle is not above the cable but the chip. See Fig. 2.

To assembly the microcables with the chips to the sensor a third tool with a movable bottom-side sensor holder and a top-side mechanics for the microcables was designed. It is shown in Fig. 3.



Figure 2: Tool for 2nd layer on chip.



Figure 3: Tool for 1st and 2nd layer on sensor.

It turned out that a movable sensor holder is not the best way for this assembly step, because the flimsy microcables are destroyed if they're moved too strong. An improvement of this tool is in work. Fortunately it also turned out, that this tool could be used to bond the interstrip connecting cables on the p-side of the sensor (see Fig. 4).



Figure 4: Interstrip cable on sensor.

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Ring-Imaging Cherenkov Detector



Mirror misalignment control system and prototype setup

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An important aspect to guarantee a stable and precise operation of any RICH detector is the alignment of the mirrors. The alignment itself has two aspects: the initial alignment during setup and a misalignment monitoring during operation. For the monitoring, methods have been established based on data or an independent control of the mirror positions. The CLAM method, developed by COMPASS [1] is an example of the latter and is tested for a future realization in the CBM-RICH. This article describes a test setup on a small scale that has been implemented in the RICH prototype and tested in beam during the RICH beamtime at CERN-PS in November 2014.

The principle of the CLAM (Continuous Line Alignment Monitoring) alignment procedure [1] is to monitor over time mirror displacements via photographic images. A grid of retro-reflective material is glued on the inner part of the RICH entrance window.

The grid is made of retro-reflective stripes, forming a regular grid-shaped pattern, and of photogrammetric target dots, glued at each of the stripes crossings and on the mirror frame (Fig. 1 left). A set of four cameras are arranged at the edges of the entrance window and around each camera a set of three LEDs are fixed (Fig. 1 right). The LEDs are switched on to illuminate the grid through the mirrors.

A downscaled version with one camera only has been implemented in the RICH prototype detector and tested at CERN.



Figure 1: CLAM equipments used in the RICH prototype. Retro-reflective grid, with target dots (left). CLAM camera, surrounded by three LEDs (right).

Figure 2 shows two pictures taken for the aligned mirror system (left picture) and with misalignment by 2 mrad of the lower left mirror (right picture). Figure 3 illustrates ring reconstructions using these two setups. For the misaligned case an extreme example is shown with a B axis of the ellipse fit of 3.6; the average radius is 4.6.



Figure 2: Reflection of the grid on the RICH mirrors. Lines not broken at mirror edges is a sign of alignment (left). If they appear broken this reveals misalignment (right). Here lower left mirror misalignment is 2 mrad.



Figure 3: Single event reconstructions for beams going between the two lower mirrors. Ring reconstruction using an aligned setup (left) and a misalignment of 2 mrad (right).

A first qualitative look at mirror displacements can be given, when looking at the continuity of the reflected stripes. Indeed if a mirror is displaced with regard to one of its neighbors, stripes will appear broken at mirror edges (Fig. 2 right). Stripes are then cut into two shifted parts. According to the shift, it is possible to deduce the relative misalignment of mirrors [2].

A quantitative evaluation can also be made with this setup, when considering photogrammetry. From the relative positions of target centers to external marked reference points, the orientation of mirrors can be extracted [3]. This procedure will be implemented in a next step.

Currently the analysis of the beamtime data is ongoing and correction routines for the misalignment are in preparation.

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Acceptance studies of the CBM-RICH photodetector plane*

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The CBM-RICH detector is designed to provide identification of electrons and suppression of pions in the momentum range below 10 GeV/c. This will be achieved using a gaseous RICH detector with focusing mirror elements and a photon detector. In this report we discuss studies in which the dimensions of the photon detector planes were decreased in order to investigate the influence on the reconstruction of low-mass di-electrons.

The distributions of e^{\pm} from different sources on the upper photon detector plane are shown in Figure 1. The signal e^{\pm} as well as background e^{\pm} are located mostly in the inner part of the PMT planes.



Figure 1: Distribution of e^{\pm} from ρ -meson (top), π^0 -Dalitz decay (middle) and γ -conversion (bottom) on the upper photon detector plane for central Au+Au collisions at 25*A*GeV beam energy.

Two cases of PMT plane reduction were studied. The photodector planes were cut a) from **the outer**, left and right sides; b) from **the inner**, left and right (see Figure 2). 10%, 20% and 30% of the size were cut. 10% corresponds to 6 cm, i.e. approximately one row of MAPMTs.

The low-mass di-electron reconstruction was performed with the standard procedure (for more information see [1]). Electron identification was performed with the RICH, TRD and ToF detectors. The combinatorial background was rejected with γ -conversion cut, two topology cuts and transverse momentum cut.



Figure 2: Cut of the PMT plane from a) outer; b) inner side.

The final signal to background ratios and reconstruction efficiencies of mesons for central Au+Au collisions at 8AGeV and 25AGeV beam energies are presented in Table 1. The signal to background ratio stays at the same level when reducing the photon detector planes. However, reconstruction efficiencies change drastically if reducing in particular the inner part of the PMT plane.

Table 1: S/B ratios and reconstruction efficiencies after applying all cuts for central Au+Au collisions at 8AGeV and 25AGeV beam energies.

	Full size	outer side [%]			inner side [%]	
		10	20	30	10	20
	8 A	GeV b	eam en	ergy		
ρ [eff.]	2.29	1.95	1.62	1.2	1.73	0.96
ω [eff.]	2.54	2.16	1.8	1.29	1.92	1.06
ω [S/B]	0.5	0.6	0.49	0.47	0.54	0.45
ϕ [eff.]	3.33	2.82	2.42	1.9	2.51	1.57
φ [S/B]	0.06	0.07	0.06	0.05	0.07	0.035
	25.	4GeV l	beam e	nergy		
ρ [eff.]	2.81	2.3	1.93	1.36	1.95	1.0
ω [eff.]	2.97	2.48	2.05	1.43	2.1	1.1
ω [S/B]	0.13	0.14	0.13	0.14	0.13	0.14
ϕ [eff.]	3.8	3.25	2.63	2.07	2.8	1.63
φ [S/B]	0.05	0.05	0.05	0.07	0.05	0.09

These exploratory studies show that innermost part of the PMT plane is the most important one if looking at global efficiencies only. However, if for some reason the PMT plane cannot be equipped at once with a sufficient number of PMTs, the outer part might be left out in the beginning and equipped at a later time.

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Determination of cross talk in MAPMTs covered with WLS films *

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The sensitivity of PMTs in the shorter wavelength region of the electromagnetic spectrum is limited by the reduced transparency of the PMT front windows for UV light. However, given the behaviour of the Cherenkov spectrum (the total number of photons is proportional to $1/\lambda$), the short wavelength limit is of particular importance when using PMTs in Cherenkov detectors: the more sensitive the photon detector is for short-wavelength Cherenkov photons, the larger is the integrated photon yield. For gaseous Cherenkov detectors, the short wavelength cutoff is given by the radiator gas; it is typically below the cutoff given by the PMT windows. E. g., for CO₂ as foreseen as radiator gas for the Ring Imaging Cherenkov (RICH) detector at CBM [1], the cutoff is $\lambda_{\min} \approx 185$ nm.

Wavelength shifting (WLS) films on PMTs are seen as a cost efficient possibility to extend the sensitivity of the PMTs into the region where the glass of the front window absorbs most of the UV light [2]. However, with respect to multianode PMTs (MAPMTs), one expects an increase of crosstalk between neighboring pixels when using WLS films on MAPMTs due to the isotropic fluorescence of the WLS material. Crosstalk is defined here in the sense of charge sharing between neighboring pixels and was experimentally determined in the following way: we illuminated the central $5 \times 5 \text{ mm}^2$ of a MAPMT pixel (pixel size: $5.8 \times 5.8 \text{ mm}^2$) with single photons from a pinhole. The hits in the illuminated as well as in the adjacent pixels were detected. The crosstalk is then defined by the number of hits in adjacent pixels normalized to the number of hits in the illuminated pixel.

Figure 1 shows the number of hits as function of the MAPMT pixel position for the illumination of the central $5 \times 5 \text{ mm}^2$ of one pixel. In the left plot, an uncoated pixel and in the right plot a pixel coated by a WLS film was illuminated. An enhanced crosstalk is observed in the right plot, especially in the diagonal neighbors.

Figure 2 shows the crosstalk in next neighboring pixels measured for one and the same H8500D-03 MAPMT with and without WLS films. To quantify the overall crosstalk, we consider hits in the next as well as in next-to-next neighboring pixels. Without film, the crosstalk adds up to 3.8 % at 470 nm and also 3.8 % at 245 nm. For WLS coated pixels the crosstalk is 3.8 % at 470 nm and 4.7 % at 245 nm. These numbers show that at 470 nm, a wavelength at which the WLS film is transparent, crosstalk is comparable with



Figure 1: Number of hits per pixel for the illumination of the central $5 \times 5 \text{ mm}^2$ of an uncoated (left) and a WLS coated pixel (right) with single photons. More crosstalk is observed in the neighboring pixels when using WLS films. Note the logarithmic scale of the color coding.

and without coating. At 245 nm, however, the crosstalk is larger by 24 % with WLS coating due to the isotropic fluorescence of the film. However, the effect is small and the Cherenkov ring resolution was not significantly affected for MAPMTs with WLS films when operated in a gaseous RICH prototype detector [3].

uncoated, 245 nm			coated, 245 nm			
0.1	0.6	0.1	0.2	0.7	0.2	
0.8	CP	1.1	1.1	CP	1.0	
0.1	0.7	0.1	0.2	0.8	0.1	
unco	ated, 4	70 nm	coat	ed, 470) nm	
uncoa	ated, 4 0.5	70 nm 0.1	coat	ed, 470	0 nm 0.1	
uncoa 0.1 0.7	ated, 4 0.5 CP	70 nm 0.1 1.1	coat 0.1 0.9	ed, 470 0.6 CP	0 nm 0.1 0.8	

Figure 2: Crosstalk of an uncoated (left) and a different but coated (right) pixel of a H8500-03 MAPMT illuminated at 245 nm (top) and 470 nm (bottom). The charge detected in the pixels in the direct neighborhood of the center pixel (CP) is given in percent with respect to the charge detected in the center pixel (= 100%).

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Optimizing the RICH geometry*

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The RICH detector used so far in simulations (v09a, v14a) was optimized in 2009. Since then two main modifications became necessary related to the CBM dipole magnet located upstream of the RICH. The latter had to be shifted 20 cm downstream. This in turn calls for a slight increase of the mirror and the photon detector (PMT) plane to keep the same acceptance. Second, the magnetic stray field is too large at the photon detector plane for operation of MAPMTs. In order to reduce the fringe field at the photon detector plane, we foresee two measures: Tilting the mirror by 10 degrees and shielding the PMT plane by an external shielding box. The position of the PMT plane has to be adopted accordingly and carefully optimized. In this report, the method for optimization and first results will be presented.

In an extensive study the PMT plane rotation angles around the x-axis and the y-axis, θ_x and θ_y , were scanned systematically to find the optimal θ_x - θ_y -combination, for which the focus of the rings is optimal. The criteria investigated are the ellipticity of the rings, i.e. the ratio of minor to major axis of an ellipse fit B/A, the ring resolution parameter dR^1 , and the incident angle α of photons impinging on the PMT plane with respect to its normal. The best case is given by maximizing B/A and minimizing dR and α . The study was carried out for a mirror rotation angle of -1° (as in the v08a and v14a geometry versions) and 10° . Single electrons and positrons were generated isotropically in space concerning azimuthal and polar angle, and with a flat distribution in transverse momentum from 0 to 4 GeV/c. For a mirror rotation of -1° , it is found that any combination within the following intervals $15^{\circ} < \theta_x < 17^{\circ}$ and $15^{\circ} < \theta_y < 17^{\circ}$ leads to a maximum in B/A of about 0.94 and minimums in dR and α at about 0.17cm and 11.6° respectively.

Figure 1 shows the B/A-ratio as a function of θ_x and θ_y with a mirror rotation angle of 10°. A maximum in the B/A-ratio of about 0.9 is achieved with a θ_x - θ_y combination of 22° and 16° respectively. However any combination in the range of 18° $< \theta_x < 26^\circ$ and 14° $< \theta_y < 18^\circ$ leads to similar results. Within this range dR values also become minimal (0.25 cm). The photon incident angle of the PMT plane, however, does not become minimal anymore for the same tilting angles (θ_x, θ_y). α has a minimum of about 12° at larger values of θ_x and θ_y while it is 15.8° where one has the maximum of B/A. The fact that optimum positions with respect to B/A and dR on one side and α on



Figure 1: B/A ratio as a function of θ_x and θ_y .

the other side differ is probably related to the large tilting angle of the mirror. Still, achieving a B/A ratio of 0.9 is a very promising sign that a RICH geometry with 10° tilting angle of the mirrors can be realized.



Figure 2: B/A and dR distributions on the PMT plane.

Each of the values discussed above is a mean value of a distribution of all Photons/ reconstructed rings on the PMT plane. Figure 2 shows the B/A (left) and dR (right) distributions. Within tolerances both are distributed homogeneously on the plane.

Results presented here already show a very promising design of the RICH with mirror tilting angles of 10° . The setup will be optimized and investigated further before becoming the new standard.

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 $^{^{-1}}dR$ is the distance between each hit in the ring and the fit.

The CBM RICH camera and readout chain for the 2014 CERN PS beamtest *

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Among the main goals for the 2014 CERN PS beamtest was a direct in-beam comparison of the Hamamatsu H8500 to the new H12700 MAPMT, and the test of a new, fully FPGA-based readout chain. For this purpose, a new photon camera was constructed, carrying 4x4 MAPMTs (similar to 2011), with the back side matching the new elecronic readout modules. The new readout chain consists of two major parts: The PADIWA front end module (developed by the GSI electronics group for the PANDA DIRC detectors) serves as discriminator of the anaolg PMT signals. Each PADIWA front-end module provides 16ch, groups of 4 modules were combined for the readout of a single PMT. Figure 1 shows a photograph of the camera backside, equiped with 64 PADIWA readout boards grouped to 16 readout modules.



Figure 1: Photograph of the camera readout electronics and a single 4xPADIWA PMT readout module.

Signal discrimination on the PADIWA is done using the LVDS receivers on the FPGA, which serve as a high speed comparator: The analog signals are first amplified and then connected to one of the two inputs of the differential line receivers on the FPGA. The second receiver input is connected to a channel-individual threshold voltage, which is generated on the FPGA itself using Pulse-width modulation (PWM). The discriminated, logical output pulse (its width corresponding to the Time-over-Threshold) is provided as differential output signal, and transmitted via flat cable to the second main readout component, the TRB3 FPGA-TDC readout board:

The TRB3 [1] is a multi-purpose FPGA board, consisting of 4+1 Lattice ECP3 FPGAs. Each of them can be configured as a FPGA TDC, providing up to 4x64 TDC channels of high precision (up to 10ps RMS). Due to temporary limitations and the fact, that both leading- and trailing edge should be measured, only 16ch per FPGA could be implemented during the beamtime, requiring one TRB3 board



Figure 2: Readout scheme for the CBM RICH prototype readout based on PADIWA frontend and TRB3 TDC.

per MAPMT. A 17th TRB3 board served as data hub, providing two distinct data streams: A CBMnet data stream, received on the central DAQ PC via FLIB interface, and a second, independant TRBnet data stream, being read by a separate DAQ PC only for the RICH data. All individual TRB3 boards were operated synchronously by using a common 200MHz clock generator, allowing for easy synchronization of TDC channels on different boards. A sketch of the full readout scheme is shown in Fig. 2.

The 2014 CERN beamtime was the first full-scale test of the FPGA-based readout chain as we intend to implement it also for the final CBM RICH detector. Utilizing this readout chain we were able to measure clean Cherenkov rings on all camera positions, the detailed analysis of the data is ongoing. As a first result of this test, it turned out that the detection efficiency (measured in terms of detected photons per Cherenkov ring) is some 20-30 % lower as compared to the previous nXYter based readout chain. Two main reasons for this inefficiency were already found: One problem is the transmission of the short discriminated pulses (only 1-2 ns pulse width, corresponding to the PMT signals) from the PADIWA discriminator via flat cable to the TRB3-TDC. Activating output pulse stretching on the PADIWA increases the efficiency significantly, but then does not allow to obtain Time-over-Threshold measurements due to discrete stretching of the trailing pulse. A second problem is the noise level encountered in the full scale system, leading to unnecessary high threshold values in some, but not all channels. Here, a bandwidth reduction via low-pass filter seems to help and has to be further evaluated.

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First evaluation of the 3d Hall effect sensor MagVector2 *

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The Photon sensors of the CBM RICH camera have to be operated inside the fringe field of the CBM dipole magnet. Heavy iron shielding boxes will be needed to reduce the maximum field strength to 1-2 mT in the region of the photon sensors. Design and performance of these shielding boxes will be based on simulations of the actual field distribution using standard simulation software. For fringe fields, these simulations are difficult and subject to large errors due to saturation effects of the dipole yoke, and in particular the field clamps. In order to validate and optimize proper shielding efficiency, we would like to measure the fringe fields close to the photon sensors during operation of the RICH by equipping the sensor PCBs with individual Hall-sensors read out by a common data bus. Nowadays, such Hall sensors are a cheap mass product used in the mobile market as compass sensors. However, these sensors usually have a maximum range of only 1-2 mT, to small for our purpose. Professional probes are much more expensive and rare. We recently started an evaluation of a new sensor device, MagVector2 from Sensima Technologies [1], which seems to match our requirements perfectly for a price of ca 150 \$ per sensor. MagVector2 is a 3D hall probe, with a configurable maximum field range of 100mT / 300mT / 1T / 3T, and a maximum sensitivity of $5\mu T$ (least significant bit, LSB). It is only $3x3 mm^2$, can be operated in both analog and digital mode (16bit resolution), and includes a digital SPI bus control interface.

We have built two PCB test boards for evaluation of this sensor, which also allow for a future use of the sensor in the lab, e.g. for measurements of the μ -metal PMT shielding performance. Readout and control of the sensor via SPI bus is done with a RaspberryPi. The Raspberry is running an EPICS IOC, which maps the full sensor functionality to EPICS Process variables. Figure 1 shows a photograph of the full readout chain.

Using this test setup, we have started to evaluate the performace of the sensor. A first result on the long term stability and noise figure of the sensor is shown in Fig. 2. The sensor was mounted in a calibration Helmholtz coil under constant current, with a calculated B-field at the sensor position of 1.48mT. The sensor was read out every 3 sec, for a total time span of 10 minutes. The Histogram shows the obtained measurement results, which are all very close to the expected value. The variation of measured field values has an RMS in the order of 0.01mT. Further tests include the proper calibration of each sensor axis, determination of the cross talk between individual axis, and the temperature



Figure 1: Photograph of the two MagVector2 sensor PCBs, connected to a RaspberryPi for readout via SPI bus.



Figure 2: Accuracy and noise level for about 200 consecutive field measurements (10 minutes in total) of a fixed B-field inside the Helmholtz coil used for calibration.

coefficient. Based on these tests we conclude, that the Sensima MagVector2 proved to be fully sufficient for a future measurement of the the 3d fringe field in the region of the photon detector with an accuracy well below 1mT.

Mounting the sensor to a XY stage in the lab, we can now measure the magnetic field distribution directly at the Photomultiplier window, if the PMT is operated inside a homogenious magnetic field. With this setup we plan to evaluate a possible benefit of additional magnetic μ -metal shielding surrounding each individual PMT, in addition to the iron shielding boxes surrounding the full CBM RICH photon detector.

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The new H12700 PMT for CBM RICH *

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In detailed studies we could confirm the good single photon detection capabilities of the Hamamatsu H8500-03 Multianode Photomultiplier, qualifying it for the base line design of the CBM RICH detector. The major advantage of the H8500 (besides price) is its large size (2x2 inch) and good geometric efficiency. This allows to compete with smaller, single-photon optimized tubes like e.g. the Hamamatsu R11265 (1x1 inch), despite the fact that these tubes have significantly higher collection- and quantum efficiency due to Super-bialcali photo cathodes. Just recently, Hamamatsu has adapted the beneficial single-photon properties of the R11265 to the larger H8500, resulting in the new H12700 MAPMT: a 2x2 inch, single-photon optimitzed tube with increased quantum efficiency due to SBA cathode. Very recently, the quantum efficiency could be even further optimized for Cherenkov applications by shifting the peak efficiency towards shorter wave lengths ("blue shifted cathode"). We have tested and compared this new H12700 based on first availabe samples, some of the results are summarized below:

Figure 1 shows a comparison of spectral quantum efficiency for several H12700 with standard and blue-shifted cathode, with respect to a typical H8500 tube. Peak quantum efficiency is significantly increased to 30-35 %, the increased UV sensitivity of the blue-shifted cathode is clearly visible. The increased quantum efficiency, combined with a better collection efficiency, results in a significantly higher single photon detection efficiency. This could be confirmed in single photon scans at 405nm, as shown in Fig. 2. The X-axis shows a relative comparison in terms of photon detection efficiency (averaged over the active area). This efficiency is clearly correlated with the Blue Sensitivity Index (Y-axis) from the Hamamatsu data sheets (see [1] for details). The H12700 with blue shifted cathode (blue tri-





Figure 1: Quantum efficiency for standard- (DA0142), SBA- (HA000x) and SBAblue- (ZB00xx) cathode.



Figure 2: Comparison of several H8500 (BA cathode), H12700 (SBA/SBAblue), and R11265 (SBA) MAPMTs in terms of relative single photon detection efficiency (X-axis) and Blue Sensitivity Index from data sheet (Y-axis).



Figure 3: Gain normalized single photon spectra for four Hamamatsu H12700 MAPMTs (upper line), and four H8500 (lower line). Red line: average over all pixels.

angles) are underestimated in this plot due to their shifted peak efficiency.

The improved dynode structure is also reflected in the single photon spectral response, shown in Fig. 3. All H12700 MAPMTs show a much more narrow and better separated single photon peak distribution compared to the H8500. The well pronounced peak at low amplitudes, visible for the H8500, stems form cross talk to neighbouring pixels. This cross talk is substantially lower for the H12700, as confirmed in single photon scans.

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Data analysis for the RICH prototype beamtest data 2014^{*}

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The real-size prototype of the Ring Imaging Cherenkov detector (RICH) was tested for the third time together with other CBM groups at the CERN PS/T9 beam line in November 2014 [1]. For the first time the analysis of the RICH data was fully performed within the CBMROOT framework.

The RICH data was written in HLD file format [2]. The data analysis starts from data unpacking which includes several steps: 1) Retrieving raw messages from the data stream. One MAPMT pixel was read out by one PADIWA channel which is split to two TDC channels - one for the leading edge and one for the trailing edge of a signal [3]. 2) Matching leading and trailing edges. 3) Fine time calibration. The fine time counter in the TDC uses the Tapped Delay Line. The standard calibration procedure based on Look Up Tables is implemented. 4) Synchronization of TDCs. The time offset for each TDC is calculated based on synchronization signal on channel 0. 5) Calibration of channels within one TDC. The first results showed that there is a difference in time required by different channels to transport the signal. The implementation of calibration procedure is ongoing. 6) Creation of raw hits. The raw hits contain the information about leading and trailing time, TDC identifier and TDC channel number.



Figure 1: The distribution of the number of RICH hits with time. Peaks corresponds to the beam spills.

The raw hits are not grouped into events and stored as free streaming data. Figure 1 shows the distribution of the number of RICH hits with time. The implemented event building procedure uses the reference time signal from the hodoscope (or UV-LED pulser, laser pulser, finger scintillator). All raw RICH hits which belong to a time window (300 ns) around the reference time are collected into one event. Then the TDC identifier and the channel number information from the raw hits are converted to X and Ypositions on the PMT plane using corresponding mapping mechanism. After this step the hits are sorted by events and stored in the standard CBMROOT containers, namely *TClonesArray* of *CbmRichHits*. From this step on the standard CBMROOT routines can be used for the further analysis. Rings are reconstructed using an algorithm based on the Hough Transform method and their parameters are derived with high accuracy by circle and ellipse fitting procedures [4]. The algorithms are the same as they are used in the event reconstruction for simulated data.

A number of histograms controlling parameters as number of hits, ring radius etc. are generated automatically, see Figure 2 for an example.



Figure 2: Examples of the analysis results. From left to right: number of hits in event, number of hits in found ring, ring radius, number of hits per pixel, number of hits per PMT.

For a visual representation of events an event display was implemented. Two example events are shown in Figure 3.



Figure 3: Examples of the single events.

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Different layouts of a mirror support structure for the RICH detector*

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The CBM-RICH detector is a gaseous detector with focusing mirror elements made from 6 mm thick spherical glass and a photon detector. The mechanical design of the RICH detector has to provide a mirror mount structure which on the one hand is stable enough in order to hold the mirror tiles in a precise position. On the other hand this mirror support frame is in the CBM acceptance and thus should have low material budget in order to prevent secondary particle production. In this report, simulation studies using a number of different RICH geometries will be presented based on a preliminary mechanical design [1].

The effect of material budget on the tracking performance in the TRD and TOF detectors was studied. The following five RICH geometries were investigated: 1) v08ageometry. This geometry is used as a reference and has only a very approximate material budget implemented. 2) v14a geometry. Nowadays standard geometry based on a complete mechanical design [1]. 3) Nobelts. Same as v14abut without belt structure. 4) Noframes. Same as v14a but without belt structure and main frame. 5) Rohacell. Large Rohacell structures are used to hold the mirror tiles. Figure 1 shows the v14a and Rohacell geometries.



Figure 1: *v14a* (left) and *Rohacell* (right) geometries. The red structures are removed for the *Nobelts* geometry, in addition the outer big frames are removed for the *Noframes* geometry.

The radiation length of two of the five geometries for parallel tracks is shown in Figure 2. The mirror support structure is the dominant source of material budget. One can clearly see the main frame and belt structures for the v14a geometry. For the *Rohacell* geometry the material budget is spread uniformly except for the main frame. This material budget is very similar to the *Nobelts* structure.



Figure 2: Radiation length of the *v14a* (left) and *Rohacell* (right) geometries for parallel tracks.

The tracking performance was studies with simulations for central Au+Au collisions at 25AGeV beam energy embedding 10 additional e^{\pm} in each event. The following geometries were used: $sts_v13d.geo.root$, $trd_v14a_3e.geo.root$ (smearing), $tof_v13b.geo.root$.

Results are summarized in Table 1. The largest effect is seen for the v14a geometry by adding 10% hits compared to v08a and a degradation of 2% in tracking efficiency. However, overall one has to state that despite the partially large and very inhomogeneous material budget the observed degradation is very modest. For the final RICH geometry it might be sufficient to optimize (reduce) the material budget of this proposal. For a final conclusion the effect of electron identification in the TRD still has to be investigated.

Table 1: Summary results of the simulations.

Geometry	v08a	v14a	No B	No F	RC			
N	Number of hits in TRD per event							
All	10660	11900	11460	11480	11620			
1st st.	780	930	880	880	900			
2nd st.	840	980	930	930	950			
5th st.	1040	1170	1120	1125	1140			
10th st.	1410	1510	1470	1475	1485			
N	lumber o	of hits in '	TOF per	event				
All	2400	2530	2490	2485	2505			
Tracking efficiency for primary e^{\pm} [%]								
TRD	79.2	77.0	80.0	79.2	79.6			
TRD+STS	78.5	76.5	79.5	78.6	79.1			

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Muon Detection System



Neutron dose test of active LVDB component to be used for CBM-MUCH detector, using K-130 Cyclotron at VECC

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Introduction

A GEM based detector system is being developed at VECC, Kolkata for use as muon tracker in the Compressed Baryonic Matter (CBM) experiment at the upcoming FAIR facility at Germany [1][2]. MUCH adds to the neutron background immensely. As per FLUKA calculations [3], it is estimated that the electronics will have to withstand a high neutron dose of the order of 10e11 Neq/cm2 for life-time of CBM-MUCH detector. To see the effect of the neutron on the components to be used near the detector, we have performed neutron dose effect with secondary neutrons by bombardment of proton on thick Ta target using Cyclotron at VECC.

Neutron irradiation test

The aim of the neutron tests is to find any physical or characteristics damage on the regulator. In this direction, we conducted the first such test of LTC3605 voltage regulator in VECC cyclotron. As shown schematically in Figure 1, a 15 MeV proton beam with the beam current of 4uA average was bombarded on a thick Ta target to get the secondary neutron. This experiment was performed for about 10days to achieve the required neutron dose. For efficiency measurement over time, input and output voltage and current was periodically moinitored using multimeter and power supply display as shown in Figure 2.



Figure 1: Schematic of the neutron test setup at VECC Cyclotron.



Figure 2: Voltage and current monitoring setup.

Neutrons test results

Figure 3 shows the efficiency of both Gamma radiated and non-irradiated voltage regulator with respect to number. of neutrons falling on the regulator. The plot shows that the efficiency of the regulator is almost stable throughout the irradiation of 7.1x 1010 neutrons/cm2.



Figure 3: Efficiency vs. No. of neutrons/Sqcms

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Total dose effect test of active LVDB component with 60Co Gamma chamber, to be used for CBM-MUCH detector

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Introduction

A GEM based detector system is being developed at VECC, Kolkata for use as muon tracker in the Compressed Baryonic Matter (CBM) experiment at the upcoming FAIR facility at Germany [1][2]. The Muon Chambers (MUCH) consists of alternating layers of six absorbers and detector stations. The harsh radiation dose in CBM owing to high hadronic environment poses severe constraints on the design and selection of the electronic components to be used along with the detectors. To make sure that selected components will work in this environment, we have performed Gamma dose testing one of the proper component in 60Co chamber at UGC-DAE Consortium for Scientific Research, Kolkata.

Gamma irradiation test

The most upstream detector station of MUCH will receive highest dose of 300Gy/2months as was simulated by FLUKA calculation [3] and total CBM-MUCH operating period in 10 years is expected to be of 20 operational months [1], and therefore the CBM readout electronics are to be made to withstand the total dose of 315 KRad.



Figure 1: Gamma irradiation testing setup.

Figure 1 shows the 60Co Gamma chamber has been used as a irradiation source. The equivalent dose rate inside this chamber was of 3.1kGray/hour. Two number voltage regulators were inserted in this chamber, one with load and another without load. As the chamber was a closed enclosure, so there is a possibility of temperature rise due to load. Hence a small fan arrangement was made inside the chamber to run continuously and additionally we have taken out chamber every 10 minutes to further cool it down to ambient room temperature. Input and output voltages and currents were measured every 10minutes. The efficiency which is calculated by the ratio of output power to the input power of voltage regulator, was measured with respect to the cumulative gamma dose.



Figure 2: Efficiency vs. Gamma Dose.

Gamma irradiation Results

Figure 2 shows the efficiency of voltage regulator with cumulative gamma dose up to 8kGy. The efficiency of voltage regulator in the entire irradiation was dropped down from 92.5 percent to 91.5 percent, which is well within the acceptable range of current design of low voltage distribution board (LVDB) to be used for CBM-MUCH electronics.

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A contribution to the GSI scientific report 2014

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Introduction

A Gas Electron Multiplier (GEM) based detector system is being developed at VECC, Kolkata for use as muon tracker in the Compressed Baryonic Matter (CBM) experiment at the upcoming FAIR facility at Germany[1] Muon Chamber (MUCH) is used to detect low momentum muons in an environment of high particle densities. Detecting these set of particles require fast and radiation-hard detector systems, which are positioned in dense arrangements and to be readout by radiation hard front-end electronics (FEE). To read such high data rate, CBM requires precise time synchronization, compact hardware, radiation tolerance, self-triggered front-end electronics. For efficient data aggregation from these FEE's, GBTx (developed by CERN) is planned to be used as a bridge to the Data Acquisition (DAQ) system. As this ASIC is radiation hard, we are restricted to bring these GBTx ASICs to India. This article focuses on the implementation of this GBTx into a FPGA (Field Programmable Gate Array) board for CBM-MUCH detector.

CBM Network and DAQ Structure

The simplified read out architecture of MUCH to be used in CBM experiment is shown in Figure 1 In Muon Chamber fast and highly granulated GEM detector is to be used. The MUCH-XYTER a radiation hard ASIC used for signal detection from MUCH in the CBM environment. The self-triggered ASIC provides both timing and energy information for each incoming signal in its channel. MUCH-XYTER is connected to the Gigabit Transceiver (GBTx) in the back end through SPI-like e-links. The GBTX is a radiation tolerant chip that can be used to implement multipurpose high speed bidirectional optical links for high-energy physics experiments[2]It is connected with Data Processing Board (DPB) through optical fiber. DPB will be placed outside the irradiated area and more complex electronic systems like commercial-off-the-shelf (COTS) FPGA and faster optical links can be used in this layer[3] DPB will be connected to the First Level Event Selector interface Board (FLIB) through 10 Gbps optical link. Finally FLIB will transmit data to the computer using PCIe. As a Part of the development of DAQ here we have concentrated in the implementation of GBTx in FPGA. In the encoder block single error correcting (15, 11) Reed-solomon encoding is used. Input data to the scrambler is 84 bit. When data will enter into the encoder block it will append with four bit header. This channel coding can correct maximum eight symbols consecutively. Output of the encoder is 120 bit data. Interleaving is the reordering of data that is to be transmitted so that consecutive bytes of data are distributed over a larger sequence of data to reduce the effect of burst errors. Data width after interleaver block remains 120 bit. But this 120 bit data cannot be send at a time so a Gearbox is used. It will divide 120 bit data into three 40 bit words and send it to Multigigabit Transceiver (MGT). GBTx frame sent to the transmitter consists of four bit header, four bit data for slow control, 80 bit raw data, and 32 bit data for forward error correction. The GBT frame is shown in Figure 2. Receiver side of GBTx performs just opposite jobs like deinterleaving, decoding and descrambling. Only the framealigner block in receiver side is not present in transmitter side. It consists of:-Pattern Search block, Bitslip Counter, Right Shifter, Write Address generator. Pattern search block continuously check whether proper four bit header is received or not. Until the proper header is received bitslip counter continuously change its value. After receiving correct header write address generator will generate address in the RAM where 40 bit data will be written

Standard frame format					
Header(H)	Show Control(Sc)	User Date(D)	Forward Error Correction (FEC		
4 bit	4 bit	48 54			
	E	xtra wide bu	is frame format		
Header(H)	Shee Control(SC)		User Data(D)		
4 511	4 bit	+	112 bet		

Figure 2: GBTx Frame format

Implementation on FPGA

For implementation of the GBTx code, we have used xilinx KC705 board. Here two clocks are used:- FPGA fabric clock whose frequency is 156.25 MHz and MGT reference clock whose frequency is 120 MHz. FPGA fabric clock is generated internally from Si570 3.3V LVDS I2C Programmable Oscillator. MGT reference clock has to be very low jitter clock. MGT reference clock has been given from External jitter cleaned clock source CDCE62005 from Texus instruments. GBTx is tested both in standard and latency optimized mode. In VECC we are also captured the data from GBTx in computer using PCIe and SGDMA.From the figure 5 it is observed that MGT transceiver is ready and working properly. We have received the same data that we have transmitted.

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Figure 1: DAQ Chain



Figure 3: Internal Architecture of GBTx

Gigabit Transceiver (GBTx)

The simplified block diagram of GBTx is shown in Figure 3. Here pattern generator and pattern checkers are used for testing purpose. But when it is connected with the read out chain they will replace with fifo which will store data from MUCH-XYTER. Scrambler is mainly used for accurate timing recovery in the receiver side. It also reduces inter carrier interference.

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Transition Radiation Detector



Common CBM beam test of the RICH, TRD and TOF subsystems at the CERN PS T9 beam line in 2014*

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A common beam test of the CBM Ring Imaging CHerenkov (RICH), Transition Radiation Detector (TRD) and Time Of Flight (TOF) subsystems was performed at the CERN Proton Synchrotron (PS) accelerator in October/November 2014. The measurements were carried out at the T9 beam line in a mixed beam of electrons and pions with momenta from 0.5 to 6 GeV/c. In addition to the above mentioned detectors, the setup consisted of: two Cherenkov detectors, two fiber-hodoscopes, beam trigger scintillators and a lead-glass calorimeter. The first fiber-hodoscope was placed at the upstream end of the setup, followed by a large volume RICH prototype, five real-size TRD prototypes and one small chamber, two TOF detectors and finally the second fiber-hodoscope at the downstream end, see Fig. 1. The RICH prototype [1]



Figure 1: Setup of CBM in the PS/T9 beam line in 2014.

was based on a mirror focusing setup with CO_2 gas as radiator. The photon camera was modified with respect to the previous year: the 2014 version was composed of 4×4 Hamamatsu multi-anode photo-multipliers (MAPMTs). The RICH camera were tested using a free streaming approach based on the HADES Trigger and Readout Board (TRB3) [2].

The TRD laboratories in Münster [3], Bucharest [4] and Frankfurt [5] have built real-size $(57 \times 57 \text{ cm}^2)$ detector modules based on MWPC technology with cathode pad readout. The signal processing on the TRD modules from Münster and Frankfurt was performed with the Self-triggered Pulse Amplification and Digitization asIC (SPADIC) v1.0 from 2013 [7, 9]. The latter reads out 32 channels in self-triggered mode and implements the CBMnet protocol on the ASIC. The readout of the Bucharest prototypes was based on the Fast Analog Signal Processor (FASP) ASIC, either digitized in a VME-based MADC32, or using the free streaming MAXIM front-end. The TRD test program consisted of a systematic study of different radiator prototypes with a $Xe(80\%)+CO_2(20\%)$ gas mixture in the detection volume, as well as beam momentum and impact angle scan.

Bucharest completed the setup with a segmented TOF prototype, consisting of four partially overlapping RPC cells, combined with a single RPC cell reference TOF prototype from 2011 [6]. These two TOF modules were again tested using a $C_2F_4H_2(90\%)+SF_6(5\%)+C_4H_{10}(5\%)$ gas mixture allowing for fast signal generation. All prototypes under test as well as the the beam monitoring detectors were read out in two parallel hybrid data acquisition systems based on FLIB DAQ [8], DABC and DABC. It was the first successful in beam test of the FLES DAQ system. The CbmRoot based online monitoring was extended to incorporate all new front-end devices.

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Test of Münster CBM-TRD real-size detector and radiator prototypes at the CERN PS/T9 beam line*

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The Münster real-size CBM-TRD 2014 prototype of $57 \times 57 \text{ cm}^2$ shown in Fig. 1 is derived from the design of the ALICE-TRD modules. An amplification region of



Figure 1: Real-size TRD 2014 prototype foil window.

3.5 + 3.5 mm is combined with a 5 mm drift section leading to an active gas volume thickness of 12 mm. This design combines a fast signal creation of the order of 200 ns with high TR-photon absorption probability due to a total gas thickness of 12 mm. Signals are induced on rectangular pads of 7.125 mm width, allowing charge collection on three adjacent pads along the anode wire direction. This design corresponds to the smallest module size next to the beam-pipe, required for 12% of the total CBM-TRD area, and is scalable to detector modules of 95×95 cm² size, which are used in the outer part of each detector layer. TRphoton losses due to material budget between the radiator and the active gas volume have been minimized in order to reach maximum Particle IDentification (PID) performance per module. The entrance window is built from a 25 μ m single side aluminized kapton foil stabilized by a carbon fiber lattice support structure as presented in Fig. 1. This support structure limits the mechanical deformation of the foil to 1 mm/mbar differential pressure. The lattice covers only 2% of the total active area.

The maximum PID performance can only be realized with a radiator optimized to the photon absorption characteristic of the detector. We identified a polyethylene foam foil radiator in previous in beam tests at CERN in 2011 and 2012 [2]. The first radiator prototype H++ was scaled to the full detector surface. The active radiator material is mechanically supported by a light-weight structure build from a PMMA foam (Rohacell). The radiator mounted on a detector is presented in Fig. 2.

In addition to the improved detector and radiator design this beam time was the first one using a FLIB



Figure 2: Side view of a real-size TRD prototype in the PS/T9 beam line in 2014 with a mounted full size foam foil radiator.



Figure 3: Back view of the real-size TRD prototype with 6 SPADICv1.0 ASICs on two 3 ASIC FEBs mounted on the chamber.

based Data AcQuisition (DAQ) system. A combination of SPADIC v1.0 mounted on single FEB and three ASIC FEBs (presented in Fig. 3) and SysCore v3.1 have been used to read out TRD prototypes in beam.

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Construction and test of a new CBM-TRD prototype in Frankfurt *

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A new TRD prototype based on a thin Multi Wire Proportional Chamber (MWPC) without a drift region and with carbon frame was designed at the Institute for Nuclear Physics in Frankfurt (IKF) and tested in the test beam at CERN-PS in November 2014. According to this design, two identical real-size prototypes in outer dimensions of $586 \times 580 \times 38.5 \text{ mm}^3$ were developed with a pitch of 2.5 mm between field and sense wires. Cathode (field) wires made of Cu-Be with a diameter of 80 μ m are placed between gold-plated tungsten anode (sense) wires with a diameter of 20 μ m. The gas gap region, distance between entrance window and pad-plane, is 3.5+3.5 mm (see Fig. 1). The chamber were build with the same type of pad-plane as used in the prototypes from Münster [1].



Figure 1: Schematic drawing of alternating wires, their pitch and diameters.

Applying cathode wires with alternating HV (alternating wires) has an improving result as it reduces the effect of a deformation of the cathode plane by about a factor of 6, which distorts the gas gain inside the detector via electric field deformation [2].

The MWPC with thin and symmetric geometry (3.5+3.5 mm) provides fast signal collection and efficient e/π separation, which is desired in the CBM experiment [3]. The carbon frame, instead of an aluminium or vetronit frame, provides optimum mechanical properties, low thermal expansion, high friction resistance and low material budget. Figure 2 shows the technical drawing of the prototype with the aforementioned components.

Figure 3 shows the gas feed-through that is embedded inside the frame in the corners. Thus, it meets the structural conditions of the TRD chambers, which will have to be mounted close to each other in the final setup.

The data from the CERN-PS test beam in November 2014 are currently being analysed. The development of a



Figure 2: Technical drawing of a TRD prototype with alternating wires and carbon frame.



Figure 3: The gas feed-through inside the frame.

large size $(1.0 \times 1.0 \text{ m}^2)$ prototype of the TRD is planned at the IKF.

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Progress in TRD readout using SPADIC 1.0

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After all features of the SPADIC 1.0 chip had been verified to be functioning in the laboratory [1], the next steps in the development of a readout system for the CBM transition radiation detector have been taken.

During this year's common beam time of several CBM detector subsystems at CERN [3], the latest "rev. B" frontend boards [2] were used to read out TRD modules (depicted in Fig. 1). The design of the front-end boards including the packaged chips has shown to be a viable solution, and a few aspects concerning the low voltage supply and reset mechanism have been identified, which need to be improved in future revisions.



Figure 1: Two SPADIC "rev. B 3x" front-end boards on a TRD module.

Once a proper ground connection between the various components of the detector and readout setup had been found, the noise contained in the measured signals could be reduced to levels not much higher than what had been observed under laboratory conditions without any detector connected to the readout electronics (equivalent noise charge: $2.0\pm1.0 \text{ ke}^- \text{ vs}$. $0.9\pm0.1 \text{ ke}^-$). Examples of measured TRD pulses and a histogram of pulse amplitudes can be seen in Fig. 2.

A significant effort was the development of software components necessary to operate the SPADIC chips in the beam test environment. These include

- libraries to extract the SPADIC data from the *timeslice* objects provided by the FLESnet data acquisition system [4] and to decode the SPADIC data stream into a format understood by the CBMroot analysis framework,
- user interfaces for controlling and monitoring the SPADIC configuration, and



Figure 2: Top: An overlay of approximately 50 recorded pulse shapes. The horizontal axis covers a time interval of 1.8 microseconds, corresponding to 32 samples taken at a rate of 17.5 MHz. Bottom: Distribution of pulse amplitudes for four different channels.

• various automation scripts, for example to load previously determined configurations or to equalize baseline levels between channels.

The operation of the chips was complicated by two known bugs in the SPADIC 1.0 implementation. These are an instability in the charge sensitive amplifier and a glitch in the serial data output. In the near future, an intermediate version 1.1 of the ASIC will be produced, where among a few other smaller improvements these two problems will be solved, but which otherwise remains compatible to SPADIC 1.0 so that the existing infrastructure can be reused in upcoming beam tests.

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Two-dimensional MWPC prototype for CBM-TRD*

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The signal induced on a segmented conductive electrode is used in a large number of MWPC applications for position information. Additionally, the firing anode can be used for orthogonal position information at an increased operational cost. The draw back of such procedure is the poor localization along the wire and the impossibility to operate in conditions of high local occupancies and counting rates.

In the current report the performance of an innovative geometry of the read-out electrode is presented. The 2D information can be extracted in high fluxes without additional anode read-out channels.

The TRD developed in Bucharest for the CBM experiment [1] is characterized by a 4 mm drift and a 2×4 mm amplification region and wire pitches of 1.5 mm for the cathode and 3 mm for the anode wires (see Fig. 1, left). The conductive electrode is segmented in triangular shaped pads of 7.3×27.7 mm² with 0.2 mm spacing arranged as in Fig. 1, right, with respect to the anode wires.



Figure 1: Active volumes (drift, amplification) and elements (anode, cathode wires and the pad plane structure) as well as signal formation in the TRD as simulated with Garfield++ [2].

Due to the varying cross section of the pads with respect to the anode wires in our current set-up and because of the localization of the induced signal, the Pad Response Function (PRF) varies with the position of the firing anode wire along the pads. Thus, one can build an Anode Response Function (ARF) for anode identification. In Fig. 2, left, the method is tested using an uniform illumination of the TRD detector with a ⁵⁵Fe source. For each PRF value nine maxima are found corresponding to the anodes covered by a pad-row. Each local maximum is fitted and the mean and sigma parameters of the Gaussian distributions are extracted (see markers on Fig. 2, left, and the sine interpolation). A very good separation between each curve is obtained for the whole pad height.

In November 2014, the TRD prototype operated with Xe/CO₂ (80/20) was tested with MIPs at CERN-PS. To es-



Figure 2: ARF correlations with PRF as measured with TRD prototype for a uniform illumination with ⁵⁵Fe (left) and with the position measurement by a reference TRD for MIPs (right) respectively. The slope of the fit (p1) gives the measured distance beteen anodes in cm.

timate the resolution of the ARF method a reference position sensitive TRD was mounted orthogonal to it. The reference detector was operated with a rectangular shaped pads geometry for good position resolution across pads. The correlation between position measurements in the reference detector and anode identification by ARF is shown in Fig. 2, right. The measured distance of 2.98 ± 0.05 mm between anode wires is in good agreement with the designed pitch of 3 mm.

The measurement across pads is performed for the time being using the pairing of triangular pads. A resolution of $\approx 500 \ \mu m$ is obtained for ⁵⁵Fe position scan operated with Ar/CO₂ (80/20) and FASP v0.1 [3] FEE.

It was demonstrated that the usage of a varying PRF along pads can provide good local anode identification. The method opens the possibility of using reduced *effective* pad geometries with implications in position resolution at constant read-out costs and experimental material budgets.

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Fast Analog Signal Processor FASP-02 *

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A second version of the FASP ASIC dedicated for high counting rate CBM TRD prototypes developed by the Bucharest group [1, 2, 3, 4] was designed and produced. Similar to the first version [5], it is based on AMS 0.35 μ m N-well technology. The die size is 4.65×3.45 mm. Besides the main features of its previous version, new ones are implemented in FASP-02, considering the specific architecture of the fast TRD prototypes mentioned above, and the results obtained in the tests carried out in the meantime. The most relevant new features are:

- 16 input channels
- selectable positive or negative polarity of the input signals
- multiplexed analog outputs, i.e. selectable semi-Gaussian or flat top
- channel wise clock synchronized logic time for individual ADCs
- channel wise logic time signal generated at the selectable threshold level or at the signal peak detection, according to the user setting
- selectable trigger of neighboring channels relative to the one with the signal over the threshold
- tilted and rectangular pairing of the triangular pads



Figure 1: Photo of the FASP-0.2 ASIC

Good response to double pulses, to high pulse rates, fast recovery from positive/negative overload, base line restoration due to pulse rate shift, detector leakage current, temperature and voltage supply variations are also implemented to FASP-0.2 ASIC. Additionally, the self trigger capability working with a new channel wise input/output interface enhances the performances of the new FASP-0.2 ASIC.

SPECIFICATION	FASP-0.1	FASP-0.2
Average pulse rate	>300kHz	>300KHz
Detector pad capacitance	25pF	25pF
Number of analog channel	8	16
Input polarity (1bit selection)	positive	Positive/negative
Channel pairing	no	yes
Charge input range	0.15fC165fC	0.15fC165fC
Input type	DC single ended	DC single ended
Channel gain	6.2mV/fC	6.2mV/fC
Shaping time /(1bit selection)	20ns and 40ns /yes	100ns/n.a
Analog output type (1bit selection)	semi-Gaussian or peak-sense	semi-Gaussian or peak-sense
Analog output polarity	Positive (single ended)	Positive (single ended)
Analog output voltage swing	01V	01V
Analog output DC voltage level base line (cont.adj)	0.2V1V	0.2V1V
Semi-Gaussian output FWHM	62ns/110ns	290ns
Peak-sense output plateau	typ. 400ns (cont. adj)	typ. 400ns (clock dependent)
Channel ENC (Cdet=25pF)	980e (St=40ns)/1170e (St=20ns)	940e
Crosstalk (max. signal in only one channel, no signals in others)	0.5%	0.012%
Crosstalk (max. signal in 15 ch. no signal in one channel)	0.7%	0.022%
Self trigger capability: variable threshold (cont. adj)	0165fC	0165fC
Logic common event output	negative 20ns width	negative 20ns width
External clock synchronization	no	max. 50MHz
Logic signal channel wise, clock synchronized, output	по	yes
Channel synchronized logic signal occurrence (1bit selection)	n.a	to threshold level / to maximum amplitude
Channel-wise synchronized logic signal for semi-Gaussian output	n.a	negative 20ns to threshold level/ to maximum amplitude
Channel-wise synchronized logic signal for peak-sense output	n.a	neg. 20ns to threshold level/ neg. 14 clock cycle to max. ampl
Channel neighbors trigger enable/disable	n.a	yes

Figure 2: Main specifications for FASP-0.1 and FASP-0.2

The shaping time for the FASP-0.2 is increased to 100 ns in order to meet the requirements of the new TRD prototypes with a drift region of 4 mm. The crosstalk is about ten times lower compared to FASP-0.1. The main specifications for FASP-0.1 and FASP-0.2 are summarized in Table I, where the new features and the modified specifications for FASP-0.2 are described.

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Free running acquisition system for Transition Radiation Detectors - in beam tests *

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The present acquisition system was developed as a test benchmark of a free running concept for high counting rate TRDs [1] based on the FASP ASIC [2] and analog converters of the type foreseen to be implemented in a later stage in a hybrid updated version of the FASP analog processor. This version can operate 64 TRD readout channels with a sampling rate of 2 Msps and 12 bit resolution MAX 11105 ADC. The system is based on a Spartan 6, SP601 evaluation board and a custom designed board for MAX 11105 analog converters [3,4]. Two such systems were built, each of them processing data from 32 pads. In order to merge the correlated data between several sub-detectors, a synchronization signal is used. The main tasks assumed by the system are:

- Data unpacking from the 2 x 32 MAX 11105 and synchronisation management.
- Capture of the MBS_sync signal from a MBS (Multi-Branch System) system [5].
- Packing the data and Ethernet transmission through UDP protocol.

The mixed acquisition system, a trigger driven (MBS) and the free running, generates acquisition files which are later paired by a dedicated software. Data for the TRD were collected based on the free running system described above, while Cherenkov and lead glass information was acquired by the MBS system. The correctness of the data synchronisation is proven by the electron and pion pulse height distributions at three different momenta presented in Figs. 1, 2 and 3.

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Figure 2: Pulse height distributions for electrons (red) and pions (blue) at 1.5 GeV/c momentum



Figure 3: Pulse height distributions for electrons (red) and pions (blue) at 3 GeV/*c* momentum

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Construction and commissioning of a setup to study ageing phenomena in high rate gas detectors

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A setup dedicated to the investigation of ageing properties of gaseous detectors due to materials used for their construction has been constructed and commissioned at the GSI detector laboratory. An outstanding feature of the setup is that tedious and repetive measurements can be conducted fully automatic.



Figure 1: Photograph of the setup mounted in a metallic enclosure and the associated data acquisition system (top). Sketch of the components of the ageing setup (bottom).

The setup consists of three identical Multi Wire Proportional Chambers (MWPCs) mounted onto a moving platform, an X-ray generator to produce ionizing radiation and an ⁵⁵Fe source for gain diagnostics. A second moving platform holds an aluminium collimator plate which has three different apertures. Two of the chambers are flushed with gas which has passed through outgassing boxes containing the materials under investigation. One of the chambers is



Figure 2: Normalised gain of a chamber tested with Gerband 705 (blue) and a chamber tested with RTV-3145 (black) as a function of accumulated charge per unit length of the anode wires.

operated with clean gas for reference purposes. All gas lines are equipped with individual Mass Flow Controller (MFC). The data acquisition and control system based on LabView is configured to allow fully automated measurements during long term tests. Figure 1 shows a photograph of the setup and a sketch of the components.

Before fabrication of the MWPCs, simulations of their electric field and gain had been done using a combination of a gas simulation program (Magboltz) and a electric field simulation program (Garfield). The accuracy of the gas temperature measurement has been greatly improved which allows a very accurate gain measurement. Over a period of eight months, cleaning procedures have been developed and all sources of contamination of the equipment have been eliminated. Thereafter, the setup has been operated with very stable behaviour, evidenced by the fact that around 0.5% peak-to-peak residual variation of the normalised gain has been achieved. Thus, the setup shows the required high stability to be used for precise ageing studies.

First ageing tests have been carried out with two materials over two weeks: Aluminium tape named Gerband 705 and a glue named RTV-3145. At the end of these two weeks, the ageing rate (R) caused by Gerband 705 was about 0.3%/mC/cm while it was 3%/mC/cm for RTV-3145. The blue and black curves of Fig. 2 illustrate the normalised gain of the MWPC contaminated with Gerband 705 and RTV-3145, respectively, as a function of the accumulated charge per the wire length.

Time-of-Flight Detector



Results from a heavy ion beam test @ GSI *

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das ist nur eine Dummy-Version

The CBM Time-of-Flight-wall will be composed of Multi-gap Resistive Plate Chambers (MRPCs) [1]. In order to approach to a final MRPC design several counters from different groups were tested in October 2014 in a heavy ion test beam time at the Hades-cave GSI. A Ca beam of 1.9 AGeV beam energy was used to produce a spray of scattered particles by hitting a 5 mm thick lead target. Therefore a full illumination of the counters has been achieved which is extremely important for determining the counter properties under real battle condition. However, the targeted particle flux was not achieved for different reasons. The setup consist of two parts. An upper part close to the beam line containing the counters under test and a reference MRPC. The counters under test were a narrow strip prototype from Bucharest (called Buc3013) and a PAD-MRPC from Tsinghua, China. They were mounted in an exchangeable way. The stack of counters was sandwiched by plastic scintillator readout by two PMTs. The measured flux at this position was about 1 kHz/cm². The lower part of the setup contained again a counter under test, a reference MRPC and two plastic scintillator. The counter under test was a full size prototype from Heidelberg (called HDMRPC-P2). After half of the beam time it was exchanged by a strip counter from Tsinghua University. This two counters have similar dimensions and the same pickup electrode geometry. However they differ in the construction. The measured flux at this position was about few hundred Hz/cm². Figure 1 depicts the two layers of the setup.

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Figure 1: 3D drawing of the outer CBM ToF-wall as designed for the start version of CBM. For details see text.

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Progress in Ceramic RPCs for the Beam Fragmentation T₀ Counter

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One of the solutions proposed for the start time determination for time-of-flight measurements in the CBM experiment is the Beam Fragmentation T_0 Counter (BFTC) [1]. This detector will be located at the most central part of the ToF Wall, covering partially the region of the PSD. The high fluxes at this region are expected to reach 2.5×10^5 cm⁻² s⁻¹ [2]. Therefore, ceramic RPCs could be used due to their high rate capabilities [3].

The RPCs with grooved ceramic electrodes have already been introduced in previous reports [4]. They consist of double gap stacks, where the outer electrodes are Al_3O_2 ceramics with a Chromium layer deposited on. The floating electrodes are made of Si_3N_4 /SiC ceramics. The full module is formed by three such stacks forming a six-gap RPC. The gas mixture is 90% Freon / 10%SF₆ or 95% Freon / 5% SF₆.

A production of grooved electrodes has been established. Both outer electrodes are grooved on the side facing the gas gap, while the floating electrode is grooved on both sides. This effectively reduces the dark currents of the detector and allows to reach higher electric fields. The current setup of grooving diamond tools is capable of grooving several plates without the need of exchanging the disks. Figure 1 shows the grooving of both outer and inner electrodes. The small differences in the groove shape are due to the higher hardness of the Si₃N₄/SiC ceramics.

Four modules were assembled and tested during the last year. The bulk resistivity of the Si₃N₄/SiC ceramics was $10^{10} - 10^{11} \Omega$ cm. The modules were tested at ELBE (HZDR) and at the T10 beam line (CERN). Analysing the data taken at the test experiments the achieved (max.) detection efficiency ranges between 88% and 95% as shown in Figure 2. Several modules show a plateau not higher than 90%. This has been correlated to the formation of unusual signals in the detector not correlated with gas discharges due to the arrival of an ionizing particle. One such signal is shown in Figure 3.

Further investigations on the efficiency will be performed in the following year with the assembly of new modules and beam tests at ELBE and CERN.

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Figure 1: A photograph of the result of the grooving the floating electrode (left) and outer electrode (right).



Figure 2: Efficiency as a function of the electric field in the gas gap.



Figure 3: Oscilloscope recording of a pulse not correlated with the arrival of a particle.

Cosmic-ray and in-beam tests of 100 Ohm transmission line MGMSRPC prototype developed for the inner zone of CBM-TOF *

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As a solution for the high granularity required for the most inner zones of the CBM-TOF, a new MGMSRPC prototype (called RPC2013), was designed and built. Constructive details of the tested prototype are presented in [1]. The strip structure of the readout and high voltage electrodes, (4.19 mm strip pitch with 2.16 mm width and 200 mm strip length) was decided based on APLAC simulations. The aim was to obtain a differential readout impedance as close as possible to 100 Ω in order to match the input impedance of the front-end electronics. The prototype is based on low resistivity ($\sim 10^{10} \Omega \cdot cm$) glass plates in order to cope with the high values of the counting rate anticipated for the inner zone of the CBM-TOF wall. High counting rate tests performed with MGMSRPCs using low resistivity glass electrodes were already reported [2, 3].

The response of the new prototype was first tested with cosmic rays and radioactive sources in the detector laboratory of Hadron Physics Department from IFIN-HH. The prototype was operated at 2 x 5.5 kV high voltage with $95\%C_2F_4H_2 + 5\%SF_6$ gas mixture. For this measurements the strip signals were processed by fast amplifiers/discriminators NINO chips [4], their differential output being converted by CAEN V1290A TDCs.



Figure 1: Cosmic ray experimental set-up.

The experimental setup used in the cosmic ray test is presented in Fig. 1. The position along the strips, triggered by the plastic scintillators positioned above the detector across the strips, is presented in the left side of Fig. 2 as a function of strip number. The right part of Fig. 2 shows the correlation between the position along the strip and position along the 10 cm length plastic scintillator, readout at both ends.

The in-beam tests of this prototype were performed in an in-beam test campaign of CBM-TOF Collaboration in October 2014 at GSI Darmstadt and at CERN-PS accelerator in November 2014, in an in-beam test campaign of different subsystems of CBM Collaboration. In the CERN in-beam



Figure 2: Cosmic-ray test: left side - position along the strip as a function of strip number; right side - correlation between position along the strips and position in the platic scintillator.

test the MGMSRPC signals were processed by the same electronic chain as in the cosmic ray test. As reference for time resolution estimation was used a plastic scintilator readout at both ends. Preliminary results show a time resolution of 52 ps using pure $C_2F_4H_2$ and of 61 ps using a gas mixture of $95\%C_2F_4H_2 + 5\%SF_6$, after performing walk corrections and subtraction of the contribution of the reference counter. The October 2014 in-beam test was focused



Figure 3: CERN in-beam test time spectrum using a gas mixture of $95\%C_2F_4H_2 + 5\%SF_6$.

on the compatibility with the PADI8 new FEE, aiming to be used in the CBM-TOF wall. The MGMSRPC signals were converted by FPGA TDCs [5]. Data analysis is in progress.

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Electro-Magnetic Calorimeter

Calorimeter optimization for SIS100*

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One of the main goals for the CBM experiment at SIS100 accelerator is a measurement of J/ψ -meson production in AuAu 10 AGeV collisions. Production of J/ψ is subthreshold (i.e. invariant mass of colliding neutrons/protons is less than sum of masses of J/ψ -meson and pair of barions) and the multiplicity is as low as 1.7×10^{-7} according to theoretical calculations.

It is assumed that CBM detector at SIS100 accelerator will consists of STS, magnet, RICH, TOF, calorimeter, PSD and, probably, several planes of TRD. It is proposed to place TOF wall at 6–7 meter from the target because of lower beam energy at SIS100 in comparison with SIS300. In this case, there is enough roam for 1–2 TRD stations between RICH and TOF.

The calorimeter has been located at 7.5 m downstream the target and consisted of two halves. The size of each half has been 408×192 cm² (34×16 modules). The distance between halves has been 216 cm. The cell size has been 6×6 cm². In total calorimeter consists of 1088 modules and 4356 readout channels.

All calculation has been performed using April 2014 trunk version of CBMROOT. The setup consists of STS (version v13c), magnet, RICH (version v08a) and TOF (version v13-5b). The tracking has been performed using STS only and electron identification with RICH and calorimeter. TOF information does not influence on quality of track reconstruction and electron identification because TOF was optimized for hadron identification. So TOF in the simulation performs like a dead material in front of the calorimeter.

 5×10^5 AuAu 10 AGeV central UrQMD events have been transported with GEANT, reconstructed and mixed in "supervent". $10^5 J/\psi \rightarrow e^+e^-$ decays mixed with UrQMD have been used as a signal. The invariant mass of J/ψ has been reconstructed using pair of tracks with different charge. Each track must have transverse momentum greater than 1 GeV/c. χ^2 of the fit into primary vertex should be less than 6. Identification quality of track as an electron in RICH (RICHANN) must be greater than 0.8, χ^2 of calorimeter clusters must be less than 49 (because of occupancy) and $P_E > 0.01$ (criteria based on comparison of energy deposition in calorimeter cluster and momentum of the track taking into account energy resolution of the calorimeter).

Reconstruction efficiency of $J/\psi \rightarrow e^+e^-$ is 0.69%, while the signal to background ratio (taking into account



Figure 1: Invariant mass of J/ψ meson from $J/\psi \rightarrow e^+e^-$. Transverse momentum of each electron (positron) is not less than 1.0 GeV/c (a) and 1.2 GeV/c (b).

branching, multiplicity etc.) is 0.45 (see Figure 1a). Invariant mass peak can be more readable by eyes if one increases P_T cut value, while signal to background ratio stays approximately the same (see Figure 1b).

The reconstruction quality of J/ψ and χ_c mesons has been also studied for proton-nucleus collisions. 10^7 protoncarbon collisions modeled by UrQMD generator have been used for combinatorial background. $50000 J/\psi$ modeled by HSD generator have been used for $J/\psi \rightarrow e^+e^-$ decay reconstruction and χ_c background. Each J/ψ was mixed with proton-carbon collision modeled by UrQMD. Such method of J/ψ background generation results in conservative estimation of background because total energy of all particles produced in the collision exceeds the energy of colliding system. $50000 \chi_c$ modeled by HSD genera-

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			*		
Colliding	γ		π^0		η
system	Efficiency	Efficiency	Signal/(Signal+Background)	Efficiency	Signal/(Signal+Background)
pC 30 GeV	19.9%	6.09%	0.27	3.6%	5.4×10^{-3}
NiNi 10 AGeV	20.9%	7.56%	0.015	4.5%	2.2×10^{-4}
AuAu 10 AGeV	14.0%	4.6%	$3.3 imes 10^{-3}$	2.6%	4.9×10^{-4}

Table 1: The photon, π^0 - and η -meson reconstruction quality.

tor were used for signal. Each signal χ_c was mixed with proton-carbon collision modeled by UrQMD to estimate occupancy effects. J/ψ multiplicity was predicted by HSD generator and reached 5.12×10^{-8} . The multiplicity of χ_c was 1.66×10^{-8} according to HSD generator.

 J/ψ reconstruction method was described earlier. The $J/\psi \rightarrow e^+e^-$ decay reconstruction efficiency has been estimated as 1.23%, signal-to-background ratio has been found more than 300.

 χ_c -meson was reconstructed in $\chi_c \rightarrow J/\psi\gamma$ decay. Invariant mass of e^+e^- pair should differ from the table value of J/ψ mass not more than 80 MeV/c². The photon was reconstructed in calorimeter. The χ^2 of photon cluster should be less than 16. The energy of reconstructed photon should be greater than 0.8 GeV. Reconstruction efficiency of χ_c -meson has been 0.27%. Taking into account branching ratios we expect about 0.9 reconstructed χ_c -mesons per day assuming 10^7 proton-carbon interactions per second. The background is dominated by J/ψ background. The signal-to-background ratio is 1.34 (see Figure 2). Taking into account efficiency of χ_c -meson reconstruction, observability of χ_c should require couple of months of CBM running with 10^7 proton-carbon collisions per second.



Figure 2: Invariant mass of χ_c meson reconstructed from $\chi_c \rightarrow J/\psi\gamma$ decay in proton-carbon collisions. Energy of incoming proton was 30 GeV.

The photon, π^0 - and η -meson reconstruction quality is summarized in Table 1. The efficiency for γ is defined as a ratio between reconstructed and reconstructable photon. The photon is reconstructable if $E_{\gamma} > 0.5$ GeV. The photon is reconstructed if χ^2 of corresponding calorimeter cluster is less than 16. The π^0 and η is reconstructable if they decay in a pair of reconstructable photons. The π^0 and η is reconstructed if both decay photons are reconstructed and the pair has proper invariant mass.

Projectile Spectator Detector



Radiation hardness of the PSD APDs for the CBM experiment*

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The projectile Spectator Detector (PSD) of the CBM experiment is designed to register forward spectator nucleons and fragments emitted in nucleus-nucleus collisions at very low polar angles. It will be used to determine the collision centrality and the reaction plane orientation.

The PSD is a fully compensating modular leadscintillator calorimeter. The Avalanche Photo-Diodes (APD) are used to read out the scintillation light via wavelength shifting fibers. An important characteristic of the APD is its radiation hardness to a neutron fluxes of 10^{13} n/cm² which corresponds to two months of CBM experiment operation.

Two different APD samples, Ketek PM3375 and Zecotek MAPD-3N, were irradiated at the NPI Řež Cyclotron Facility by quasi-monoenergetic secondary neutron beam with energy of 35 MeV. A sample of Zecotek APD was irradiated with a dose of $3.4\pm0.2 \ 10^{12} \ n/cm^2$, while two samples of Ketek APDs were irradiated with $2.5\pm0.2 \ 10^{12} \ n/cm^2$. Doses were measured with a special PIN diode calibrated with a dose equivalent to 1 MeV neutron [1]. The operation temperature during the tests was kept at $22\pm0.5^{\circ}$ C.

The APD characteristics were measured before and after the irradiation. The Capacitance-Voltage (C-V), Current-Voltage (I-V), and Capacitance-Frequency (C-F) characteristics were studied using dedicated testing setup at NPI Řež [2,3]. After irradiation, the C-V technique showed significant decrease of hysteresis and fast but not complete self-annealing. The I-V curve revealed about 1000 times increase of dark current after irradiation. The C-F study showed significant increase of short-living traps in Silicon. The test results suggest an increase of internal APD noise, especially of the high frequency, which dependents on the amount of short-living traps in the APD volume.

Figures 1 (2) show the results of the Ketek (Zecotek) APD tests with LED and cosmic muons. Both APDs have a maximum signal (noise) amplitude of about 0.3 - 0.4 V (0.05 V) which corresponds to 20 - 30 ph.e (3 ph.e). After irradiation both APDs are unable to resolve single photons due to high noise levels. This is not critical for the PSD performance since there are at least 15 ph.e. produced in one PSD module already by a cosmic muon. The signal and noise peaks for irradiated Ketek APD are very close which makes it very difficult to separate signal from noise. On a contrary, signal and noise peaks for Zecotek APDs are



Figure 1: Test results with LED and cosmic muons of Ketek APD before (upper) and after (lower) irradiation.



Figure 2: Test results with LED and cosmic muons of Zecotek APD before (upper) and after (lower) irradiation.

well separated from each other, what allows reliable signal from noise separation even after irradiation.

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DAQ and Online Event Selection

STS-HCTSP, an STS Hit & Control Transfer Synchronous Protocol*

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The data communication between STS detector readout chip (STSXYTERv2 [1]) and the Data Processing Board DPB [2] via the GBTx data combining ASIC [3] requires a robust and optimized protocol.

The specific requirements and a preliminary protocol was published in [4]. During development of the STSXYTERv2 and DPB systems the protocol was further refined.

The protocol specification includes a detailed description of: frames' structure in both uplink & downlink directions, methodology for time-allocating hits and error correction, link synchronization procedures (enabling low-level reset, bit position alignment and optimal adjustment of data/clock delays) and specification of STSXYTERv2-specific registers.

The protocol is optimized for the data structure of the STS detector read-out ASIC but can be reused also in other systems. It maximizes the hit data throughput in the uplink (from ASIC to DPB) direction and data integrity in downlink (from DPB to ASIC) direction. The protocol is fully synchronous. Both uplink and downlink frames use 8b/10b encoding for DC-balance, and the frames in each direction have constant lengths and are transferred continuously.

Downlink frames support 4 request types: $no_{-}op$ (no operation), *WRaddr*, *WRdata*, *RDdata* (used for register access with 14-bit payload). A 4-bit chip address enables both individual chip addressing on FEBs and broadcasting messages. Since full-path delay can reach 1 μ s, multiple commands in-flight are supported by using a sequence number. Each register access command should be acknowledged on the uplink. The error correction scheme is the modified selective repeat ARQ, where not-acknowledged requests are retransmitted and register values can be verified by readback. The frames are 60-bit long (after 8b/10b encoding) and last 375 ns. They consist of K28.5 comma character, 4-bit chip address, 4-bit sequence number, 2-bit request type, 14-bit payload (address/data) and 16-bit CRC (0xC86C).

The uplink communication contains mainly hit data but also control responses and special information (e.g. alerts). After all optimizations a throughput of 9.41 MHit/s/link is achieved, which results in a 71% link occupancy for the design target of 250 khit/s/channel in a 5 links/ASIC configuration. The frames have constant length of 30bits (after 8b/10b encoding), last 92.75 ns and support 5 frame types: dummy hit (equivalent of no_op, used to filling the link when idle and to transfer the timestamp MSB to keep the synchronization), hit (containing: 6-bit channel address, 5-bit ADC value, 10-bit timestamp LSBs, 1bit error status marker), TS_MSB (used for data compression, transfers triplicated 6-bit timestamp MSBs and 4-bit 0x9 CRC), RDdata_ack (acknowledge message for RDdata command, contains 14-bit register content, 3-bit sequence number LSB and 4-bit 0x9 CRC), Ack (general acknowledge message with 2-bit ack-type: ack, nack, alert, 4-bit sequence number, 1-bit configuration parity, 4-bit status, 6-bit current timestamp, 4-bit 0x9 CRC).

The chip has built-in mechanisms for monitoring the link itself and the in-ASIC data flow. Multiple alert states can be configured and generated. The DPB is informed on the alert status by ack frames or error status markers in hit frames. Further information on alerts and means to manage them are foreseen in the ASIC's address space.

The link synchronization procedure is used for tuning of data/clock delays in GBTx ASIC and also for alignment of frame and bit positions. Even though during regular operation the comma characters are periodically transferred they are not used for on-line synchronization but only for link monitoring. During link synchronization, special, 20-bit characters beyond 8b/10b code (SOS: start of sync, EOS: end of sync) are used together with K.28.1 and K.28.5 characters. SOS and EOS can be easily detected in any state of the link and can be used to remotely reset the chip and communication. SOS triggers the procedure. First, using a SOS character, the clock/downlink data phases are adjusted, then K.28.1 is used to adjust the uplink data phases. The procedure is ended by EOS character. Finally bit and frame alignment is made on the first comma characters received through the links during regular operation.

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Towards the Data Processing Boards for CBM experiment*

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The Data Processing Boards (DPB)[1] are important part of the CBM readout and detector control systems, providing concentration (possibly combined with local preprocessing) of readout data, before they are sent to the First Level Event Selector (FLES). Additionally DPBs should provide fast and slow control for the Front End Electronics (FEE), distribute the reference clock, and time-critical information, like synchronization and flow control messages from the Timing and Flow Control system (TFC).

To allow testing of different possible implementations of listed functionalities, the versatile prototyping Open Hardware platform - AMC FMC Carrier Kintex (AFCK) [2] was created. The first version of AFCK is shown in figure 1.



Figure 1: The AFCK board with an FMC card with 4 SFP+ cages connected to the FMC2 connector.

The AFCK board may be used in an MTCA crate or in stand-alone mode. The board is equipped with the XC7K325T FFG900 FPGA, containing 16 high speed GTX transceivers, which can be connected to 2 FMC slots (4 GTXs to each) or to the RTM connector. Another 8 GTXs may be connected to the MTCA backplane ports 0 to 11. This solution allows to test different transceivers mounted on FMC boards, without modifying the AFCK board itself. AFCK is also equipped with flexible clocking system allowing it operate with gigabit links of different speed and also to recover a jitter cleaned clock signal from a high speed receiver. The board is also equipped with 2GB of DDR3 SDRAM which may be used to store the processed data, but also for debugging purposes. Those resources make the AFCK board a suitable platform for development of data concentration and preprocessing algorithms.

First series of AFCK boards was manufactured and functionality tests were performed. High speed communication capabilities were tested with standard IBERT tests provided by Xilinx. Stable 10 Gbps transmission was achieved via GTXs connected to the FMC1 slot, while 5 Gbps transmission was possible via GTXs connected to the FMC2 and RTM (10 Gbps in FMC2 should be achievable in next revision of the board).

A few basic IP core blocks, suitable for use in the prototype DPB firmware were developed or ported and tested. These include the IPbus[3] core allowing to control board via 1 Gbps Ethernet interface and the GBT-FPGA[4] core used to communicate with GBTx ASICs. The Ethernet transmission of readout data at 10 Gbps rate was tested using the FADE IP core and protocol[5]. Stable transmission of 4x10 Gbps data streams was achieved using 4 SFP+ transceivers plugged in FMC board connected to FMC1. Porting of the White Rabbit[6] IP core to the AFCK board is currently in progress.

Results of tests performed with the AFCK board will be used to design the cost optimized version of DPB prototype.

Verification of the STS-XYTER communication protocol developed in collaboration with GSI and AGH [7] was performed in simulations and in hardware, using the KC705 evaluation board. The IPbus accessible controller, allowing to synchronize communication with the model of STS-XYTER (provided by the AGH team) and to control it, was developed and successfully tested. To achieve that, a dedicated environment for hardware-software cosimulation of IPbus connected IP cores was prepared.

Verified blocks used in controller will be used for development of prototype DPB firmware, after porting to the AFCK board.

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High-Level Dataflow Description of FPGA Firmware Components for Online Data Preprocessing*

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FPGA firmware is commonly described with low level hardware description languages like VHDL or Verilog. With FPGAs getting bigger and faster, they become more and more suitable to also perform complex data processing algorithms. Describing complex algorithms with VHDL or Verilog creates code that is hard to maintain and makes it almost impossible to exploit the full capabilities of recent FPGAs. Frameworks are available that allow to describe hardware algorithms on a dataflow level. An existing cluster finding algorithm was ported from VHDL to dataflow description, compared against the original VHDL implementation and tested in hardware.

High energy physics detector readout chains rely widely on Field Programmable Gate Arrays (FPGAs) due to their flexibility and processing capabilities. The functional description of these FPGAs is usually realized with hardware description languages like VHDL or Verilog. These languages give fine control over the low level logic blocks inside the FPGAs like Lookup-Tables and Flip-Flops. The number of logic resources available in FPGAs has increased significantly over the last years and the growth is expected to continue.

The algorithm investigated in this work is the Fast-ClusterFinder [1] that was used in the High-Level-Trigger Read-Out Receiver Card at ALICE in the read-out of the Time Projection Chamber during LHC Run1. This algorithm was implemented in plain VHDL and was developed during a PhD thesis. The VHDL implementation is a rather complex design due to its flow control structures and the number of fixed point and floating point arithmetics. Comparing the size of this implementation with the number of resources available in the most recent generations of FPGAs makes it obvious that the possibilities of new devices cannot be exploited effectively with low level hardware description languages.

The same algorithm was re-implemented in a dataflow description language from Maxeler Technologies [2]. This language uses a Java dialect to describe hardware on an algorithmic level. The compiler resolves the description into a dataflow graph, adjusts latencies, handles data transport, creates vendor specific IP cores and translates the description back into VHDL. The resulting files are then run through the regular vendor tools to create an FPGA configuration file.

The FPGA resource usage of the VHDL and the dataflow implementations are quite comparable as shown in table 1.

Resource Usage	VHDL	Dataflow 1	Dataflow 2
Flip-Flops	\sim 5200	$\sim \! 4800$	$\sim\!6000$
Lookup Tables	~ 4600	$\sim \!\! 4900$	~ 5100
BRAMs	19	19	21
DSPs	8	8	8
Min. clock period	4.4 ns	4.1 ns	3.4 ns

Table 1: FPGA Resource usage comparison of VHDL and two dataflow implementations

The dataflow language allows to control the amount of pipelining to be used for the individual processing steps by specifying a pipelining factor. Column *Dataflow 1* shows the results with a pipelining factor of 0.5, which leads to a timing performance similar to the original VHDL implementation. Column *Dataflow 2* uses the maximum pipelining factor of 1.0 and creates a design that can be run at higher clock frequencies. The code base is the same for both pipelining settings and is significantly smaller and much easier to maintain than the VHDL implementation. Trying out different pipelining levels in VHDL could easily take several weeks alone.

The dataflow implementation was tested in a Max3 Dataflow Engine containing a Virtex-6 FPGA and using the data transport framework provided by Maxeler. Event data is written into the FPGA with the Maxeler software API and the processed results are read back in the same way. The output of the algorithm was compared to that of the VHDL implementation using simulated and real detector data from LHC Run1.

A single instance of the cluster finder implementation from the dataflow description could also be extracted from the dataflow framework and ported to the C-RORC [3], which is used for the read-out of detector data in ALICE and ATLAS for LHC Run2. This allows to create netlists from dataflow implementations and integrate these cores into existing firmware environments. A deeper investigation on the performance of this integration is ongoing.

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A Feature Extraction Framework for Automatic FPGA Firmware Generation *

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Introduction

The design and development of a FPGA real-time data processing platform is a common task in every high-energy particle physics experiment. In most cases, it is a time consuming task that might take up to a couple of years to be developed. Despite the fact that most of the used algorithms in online data processing are very well known, for different hardware platforms and data structures specific implementation of those algorithms is required. In order to overcome those common problems, a framework for automatic firmware generation has been developed, allowing the implementation of common algorithms for feature extraction. A brief overview of the framework as well as its experimental application in the Online Feature Extraction of the CBM Transition Radiation Detector (TRD) experiment will be presented.

Feature Extraction Framework Overview

The feature extraction framework is presented as a graphical user interface, where a user is able to configure a FPGA hardware platform based purely on its feature extraction parameters. Commonly used processing algorithms such as peak-finding, center of gravity calculation, time over threshold and cluster finding are implemented as processing cores inside the framework. The general structure of the framework is shown in Figure 1. The framework user sets the configuration options for all the previously mentioned algorithms by means of a graphical user interface. After the configurations were set and a project was created, an autonomous compilation process is started where first a source code file written in a domain specific language is automatically created, this file serves as input for the framework. A parser then analyses the source code file and populates a semantic model, which from a technical point of view is hardware independent. The framework synthesizer takes the semantic model and generates an intermediate representation called the "Hardware Model". The "Hardware Model" is a hardware-dependent description of a feature extraction platform for a given set of configurations (e.g. a specific FPGA device, development board and processing algorithms). From this point, the framework generator is able to use this representation to generate a set of Hardware Description Language (HDL) sources written in VHDL together with vendor specific project files to perform a HDL synthesis by third party tools [1]. As a result, a bitfile is generated to configure the target FPGA platform. Optionally, a validation platform can be used to communicate the framework to the FPGA development platform in order to test the correct implementation on hardware of the processing algorithms.



Figure 1: Framework structure.

Current Status

The performance of the presented feature extraction framework is currently being tested in the CBM Transition Radiation Detector (TRD). The processing algorithms used for feature extraction were previously tested during a beam test as mentioned in [2][3]. Current results show that there is no significant FPGA resource consumption difference between hand-written code versus automaticgenerated code, however a significant improvement on design-time has been achieved when using the presented framework for automatic firmware generation.

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CBM FLES Input Interface Developments*

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The First-level Event Selector (FLES) is the central event selection system in the CBM experiment. Its task is to select data for storage based on online analyses including a complete event reconstruction. To do so, the FLES timeslice building has to combine data from all input links to time intervals and distribute them to the compute nodes. To allow for efficient timeslice building, detector data streams are partitioned into microslices prior to combining them. Microslices are specialized containers covering a constant timeframe of real time, which is the same for all subsystems. This allows data agnostic, subsystem independent timeslice building. This partitioning will be done by the Data Processing Boards (DPB) as they are the last stage of the read-out tree which has to contain subsystem specific components.

The FLES input interface is realized by a custom FPGA PCIe card, the FLES Interface Board (FLIB). Its purpose is to provides the optical interface to the DPBs as well as the interface to the FLES input nodes. The current development is based on the commercial HTG-K7-PCIE board form Hitech Global. It features a Xilinx Kintex-7 FPGA, a 8x PCIe 2.0 interface, up to eight 10 GBit/s links and optionally 8 GB of DDR3 memory.

The FPGA design includes the protocol for receiving microslices, a pre-processing engine preparing microslices for timeslice building and a custom full off-load DMA engine. Once configured the DMA engine is capable of constantly transferring microslices and meta data to the PCs memory without involving the host CPU. The only task the CPU needs to perform is to acknowledge processed data segments occasionally to allow reusing buffer space. A measurement of the DMA performance for one to four 10 Gbit/s microslice streams is given in Fig. 1. For up to three steams, data is transmitted at full input speed. For four streams, the input data rate exceeds the available PCIe bandwidth. The achieved maximum data rate is 3345 MB/s, which matches the absolute maximum PCIe data rate for the given configuration.

For demonstration and testing the input interface concept in real live applications, the FLIB and flesnet software have been used for read-out in the CERN-PS 2014 testbeam at T9 beamline. In contrast to the final system, current setups lack the DPB layer and do not support the creation of microslices. A specialized FLIB prototype firmware therefore includes a mockup of the DPB design and is capable of directly receiving CBMNet messages as delivered by the CBM front-end electronics. Simplified microslices



Figure 1: FLIB read-out bandwidth



Figure 2: Recorded testbeam data over time

are generated inside the FLIB and subsequently handled in the same way as foreseen for the final setup. Thus the setup is capable of delivering fully build timeslices to any given consumer. In case of the testbeam, timeslices were written to disk and simultaneously published via a ZMQ socket to CBMroot clients for front-end calibration and online monitoring. In addition the firmware and software includes support for front-end configuration and synchronization over CBMnet which is accessible via a ZMQ interface or from within CBMroot.

During the testbeam a single FLIB in conjunction with the flesnet software was successfully used to read-out up to six detector setups in different configurations. Three different flavors of data sources have been employed, Syscore 2, Syscore 3 and TRB boards. Figure 2 shows an overview over five days of data taking. In total 888 GB of data in 84 runs was written to disk without any major read-out related problems. Online performed data consistency checks and first offline analysis did not reveal any issues with the data.

To support future setups including DPBs the FLES interface module is currently under development. It will provide a 10 GBit/s link transferring microslices to the FLIB enabling full featured microslice creation on the DPBs.

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CBM First-level Event Selector Data Management Developments*

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Figure 1: upgraded FLES demonstrator system.

The First-level Event Selector (FLES) is a high performance computing cluster functioning as the central event selection system in the CBM experiment. It combines data from a large number of input links to time intervals and distributes them to the compute nodes, via a high-performance network. Simultaneously, the FLES carries out online analyses and complete event reconstruction on the data. Data rates at this point are expected to exceed 1 TByte/s.

The FLES system will consist on one hand of a scalable supercomputer with custom FPGA-based input interface cards and a fast event-building network and will be constructed largely from standard components. On the other hand special developed software allowing to process the incoming data in real-time builds up the FLES.

A small scale, highly customizable platform, the Micro-FLES cluster was installed at GSI. Eight identical compute nodes provide a total of 192 logic cores and 512 GB memory plus one head node for infrastructural services. This test system enables studies on the development of the FLES such as elaborating performant software for timeslice building.

A timeslice is the fundamental data structure managing access to all detector raw data of a given time interval. In addition to existing timeslice building prototype software based on InfiniBand Verbs investigations of a more high-level interface to the network hardware have been performed using MPI. For this purpose a specialized micro benchmark test suite was developed simulating the FLES timeslice building use case. Benchmark results for simultaneous data transfer on the Micro-FLES are displayed in Fig 2. When communication is established only between three nodes, MPI's performance compares to the maximum data rate of point to point communication for Infiniband Verbs (green curve) on the Infiniband-FDR network. However, the data rate decreases by 15% when all eight nodes of the Micro-Fles are participating in an any-to-any communication. Further tests on bigger compute cluster are neccessary to evaluate the achievable data rates for MPI on a big scale and are currently under investigation.





Figure 2: MPI benchmark on the Micro-FLES.



Figure 3: Perfomance tests for the Micro-FLES2.

In 2014 the FLES demonstrator system was upgraded significiantly to the Micro-FLES2. First, the Micro-FLES2 was equipped with the latest Mellanox dual Connect-IB HCAs (mlx5), in addition to the existing Mellanox dual ConnectX-3 cards (mlx4). Overall the new cards are faster than the old as shown in Fig. 3. A data rate of 6 GB/s can be achieved using only one of the four ports, already. Furthermore, the new cards feature a 16x PCIe 3.0 interface and therefore allow to saturize the full bandwith of both ports. An accumulated data rate of 18 GB/s can be achieved utilizing all Infiniband ports. With this first upgrade the Micro-FLES2 can send data from node to node three times as fast as before (e.g., 18 GB/s instead of 6GB/s). The improved performance is essential for the development of timesslice building software.

Secondly, two further Mellanox SX6036 36-port 56Gb/s switches were installed in order to realize different network setups such as a fat tree. This helps investigating routing issues in the development of software when distributing the incoming data. The previous existing switch was connected with full bidirectional bandwidth to both of the new switches making them leaves of a fat tree. All first ports of mlx4 and mlx5 for each node were connected to leaf-switch1 and all second ports to leaf-switch2. Using this setup the network structure and blocking ratio in case of a fat tree can be configured dynamically via the provided internet interface of the switches. The upgraded Micro-FLES2 provides better performance and a greater flexibility in testing different scenarios allowing to evaluate a greater varity of possibilites for the final system – the FLES.

Maintenance of read-out controller firmwares for GET4 and NXYTER chips *

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Introduction

The read-out controller firmwares for the nXYTER and GET4 chips required some substantial adaptions to keep up with the overall progress of CBM DAQ developments in 2014. In case of the read-out controller for the GET4 chips, the following points needed to be addressed:

- Backport of firmware with CBMNet v2 [1] to the SysCore v2 board
- Putting into service the SysCore v3 [2] firmware for the new GET4 prototypes (GET4 v1.23 [3])
- Implement netlist based build-flow for GET4 module, Auxiliary module and USB module
- Update CBMNet from v2 to v3 for all involved GET4 firmwares (SysCore v2 and v3)

In case of the read-out controller for the nXYTER chips, the following actions had to be taken:

- Provide SysCore v2 firmware with CBMNet v2
- Update CBMNet from v2 to v3 for nXYTER firmwares

Read-Out firmware for GET4 chips

Backport of firmware for SysCore v2 boards A read-out firmware for the GET4 v1.23 chips that can be connected to a CBMNet v2 network was only available for the SysCore v3 board. As there was no GET4 v1.23 adapter hardware for the SysCore v3 available at the beginning of the year, the read-out based on legacy SysCore v2 hardware was desired. This was achieved by porting the existing SysCore v3 firmware back to the SysCore v2 board.

SysCore v3 firmware to read-out the GET4 v1.23 When the new GET4 v1.23 hardware for the SysCore v3 became available in autumn, the firmware had to be put into service. It now runs stably with this new hardware and is planned to be used in the next ToF beamtime at CERN end of February 2015.

Netlist based build-flow For better compatibility with the CBM build server [4], the build flow of the GET4 related firmwares was improved to first build netlists for each module that then can be put together to a full firmware. This allows a better and cleaner distribution of responsibilities among the developers of the different modules. The modules that have been adapted are: the module to interface GET4 chips, the module with basic functionality (Auxiliary module), and the module to transport data via USB. One external module that implemented a comparable netlist build flow is used as well, the CBMNet transport module.

Update CBMNet to version 3 During preparation for autumn beamtimes, CBMNet was updated from v2 to v3. This update was also integrated into the read-out controller firmwares for the GET4 chips.

Read-Out firmware for nXYTER chips

Provide CBMNet version 2 firmware The read-out controller firmware for the nXYTER chip was only available for CBMNet v1 so far, while read-out for the STS-XYTER and the SPADIC chips relied on CBMNet v2. For 2014 beamtimes it was foreseen to use the nXYTER chip in the same setup as STS-XYTERs and SPADICs. The nXYTER was planned as a reference system and also to read-out the fiber hodoscopes. As a downgrade of STS-XYTER and SPADIC setup to CBMNet v1 was not possible, the nXYTER read-out had to be updated to CBMNet v2.

Update CBMNet to version 3 The read-out controller firmware for the nXYTER chips needed the same update as the above-mentioned update to CBMNet v3 in case of GET4 read-out.

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CBM Control System Board with TMS570 Micro-controller

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The Control System

A control system board is being designed to be used as an EPICS IOC (Input Output Controller) for the CBM experiment.

The Micro-controller: TMS570

The selected micro-controller is the cheap TMS570LS series for automotive safety critical applications. It posses interfaces capabilities such as Flex Ray, CAN, LIN and further communication interfaces [1]. The disadvantage of this micro- controller is: It is typically programmed by a very specific TI compiler.

This micro-controller implements ECC on SRAM. Furthermore, the CPU and memory contain Built In Self Test logic (BIST) which is normally used in harsh environments to let the system check it's own functionality, such a design technique is called DFT (Design For Testing). Manufacturers use these kind of design methods to comply with the failure acceptance standards, normally issued for the automotive, medical, space and aviation industry. The Cortex R4 architecture of this processor also implies that the dual CPUs run in lock step (Dual Core Lock Step, DCLS), thus both CPUs run the same set of instructions in parallel to be able to detect errors with redundancy.

SEU tolerant ARM Cortex R4. With DCLS an SEU (Single Event Upset) can be detected. According to [2], the ARM Cortex R4 supports that *all caches and TCMs (Tightly Coupled Memories) can be protected by ECC or parity against SEUs.* This is the case for the TMS570, which has ECC implemented on TCM RAM and parity check for external SDRAM [1]. It is also important to correct such errors. Fortunately, if one refers to the Cortex R4 data sheet one finds out that: *All parity or ECC errors detected on instruction cache reads are correctable* [3].

RTEMS for TMS570

The system will operate with the RTEMS Operating System as it supports EPICS applications, has a free open source license and has real time OS capabilities [4]. The RTEMS BSP (Board Support Package) for TMS570 is still being developed. Fortunately, the last version works and the tests applications run successfully as shown in Fig. 1. The actual problem of this BSP is that there is still no network driver but we are adapting an open source driver of a similar board to it. The TMS570 BSP developers used OpenOCD to program the micro- controller with a

SDRAM initializing code and bootstrap it by writing the RTEMS executable binary in the SDRAM [5] (compiled with open source gcc). The SDRAM initializing C code is generated by a TI program, but the license allows the users to use it and distribute it with minor conditions.

EPICS

EPICS is an Experimental Physics and Industrial Control System. It is structured in OPI (Operator Interface) clients and IOC (Input/Output Controller) servers. The IOCs control devices via a wide range of field busses. A basic IOC was compiled successfully for the TMS570 on RTEMS but no setups were tested yet because the network driver of the operative system for the board is necessary. In order to test the software before building the Control System Board, the TMS570 Hardware Development Kit (HDK) is currently being used.

starting shell Welcome to rtems-4.10.99.0(ARM/ARMv4/tms570ls3137_hdk_sdram) COPYRIGHT (c) 1989-2008. On-Line ApplicationsResearch Corporation (OAR) Login into RTEMS /dev/foobar login Password: Login incorrect /dev/foobar login: rtems Password: RTEMS SHELL (Ver.1.0-FRC):/dev/foobar. Nov 27 2014. 'help' to list commands [/] \$ ls etc scripts dev [/] \$

Figure 1: RTEMS Running on TMS570 HDK

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Implementation and Test of a Flash-Free Configuration Upset Mitigation Strategy for the CBM ToF ROB FPGA*

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Motivation

The Read-Out Board (ROB) for the CBM ToF read-out chain is the connection between the front-end electronics (FEE) and data acquisition (DAQ) and processing further downstream. As such, unlike the rest of the devices in the DAQ chain, it is situated fairly close to the FEE, and therefore exposed to radiation. The ROB requires an FPGA for simple data pre-filtering and compression, whose radiationcaused configuration memory upsets need to be mitigated. So far, mitigation approaches always included a local memory storing the golden copy of the configuration memory and a respective controller, e.g. a local Flash memory and Actel FPGA in the SysCore v.2.x and SysCore v3.x [1,2]. On the one hand, Flash technology has a considerably lower Total Ionizing Dose limit than SRAM based FPGAs, and on the other hand, precautions for upsets in the user logic of the Actel FPGA still need to be taken. Therefore, a new apporach without a local memory or controller exposed to radiation has been developed for the ROB.



Figure 1: Conceptual overview of the mitigation apporach. The SEM Controller is capable of correcting single frame upsets and reporting dobule frame upsets (SECDED), as well as reporting a need for a complete reset in case of multiple upsets per frame.

Approach

The developed approach uses the Soft Error Mitigation Xilinx IP Core (SEM Controller), which is able to autonomously detect and correct Single-Bit Upsets (SBUs), and report on Multiple-Bit Upsets (MBUs) (Figure 1).If a configuration frame has two upsets, the affected frame is reported to a configuration management entity that can be on another level of the DAQ chain. From there, the affected frame can be dynamically overwritten via JTAG without resetting the FPGA. A reset is only necessary when more than two upsets occur in the same frame, since the SEM Controller cannot identify the location of the upsets anymore. The radiation-hardened GBTx, which will be used in the final setup, provides remote JTAG and GPIO connections through the GBT-SCA, and therefore a local controller is no longer required. An AC701 development board is currently running the SEM controller, while the configuration entity is running on a PC, that also monitors events.

Results

The setup has been tested in two beam times at COSY, Juelich in August 2014 and December 2014. An overview of the event distribution can be seen in Figure 2. For the low rate event distribution, which is closer to realistic event rates in the final setup, it would take roughly 10 min to an SBU, and 71 min to an MBU. A full reprogram was needed every 14 hours.



Figure 2: Distribution of different error types for high (2.5E7 protons/second) and low (4.2E6 protons/second) rates. Roughly 90% of all events are SBUs and do not require intervention from outside. Most other errors (8%) are two-bit upsets and handled by the configuration management entity. In rare cases, a full reset was required (CRC).

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Design, Assembly and Test of a Positioning System for Beam-Tests*

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Motivation

The correct alignment of devices under test (DUT) according to the beam is an important and time-consuming task in the setup of beam tests. It can be difficult to adjust the position of a DUT, especially if it is mounted in a simple rigid frame structure, since the structure has to be manually loosened. Particularly during an ongoing test, it is not possible to correct the position. But this may be necessary, if the initial alignment was bad or the beam moved since the setup. Another problem could be the (re)programming of FPGA's. Also if the design is made to be fault-tolerant (e.g. using TMR) the programming interfaces are not. So it would be desirable to move the DUT out of the beam for reprogramming.



Figure 1: Photo of the stage assembled with a Xilinx eval board used in the test-setup for a SEM-Controller test [1]

Approach

For that purpose a remote-controlled Two-Axis positioning system (Figure 1) was developed. It consists of a 100mm z-axis attached to the moveable carriage of a 500mm x-axis. The whole x-axis can be additionally manually adjusted in height to meet the actual requirements. The z-axis carriage holds the carrier for several boardspecific (or general purpose) frames. The axes are driven by two stepper motors (NEMA23 with up to 4A continuous current). The stepper drivers and the pulse controller are connected over cables long enough to be placed away from the stage. In the current version, the pulse controller provides a CAN interface and is capable to handle two stepper drivers and the limit switches (hall sensors) of the axes. The whole system is controlled by a Windows application with support for PS3/XBox wireless controllers as a simple interface for coarse and fine positioning.

Results

The setup has been tested at COSY, Juelich in December 2014. During a stress test with repetitive homing movements the current and different temperatures were measured and recorded. Also the required steps until reaching the limit switches were observed to check for step losses. The temperatures are shown in Figure 2. The combined overall current was around 1.8A with slow movement speeds and 2.5A at higer speeds.



Figure 2: Temperatures during different stress tests. With permanent high speed movement the motor temperatures are just below 40°C at 22°C ambient temperature. The internal power supply was not used at the beginning.

Next Steps

One big functional improvement will be the design of an optional beam detector which allows for autotracking. An SRAM-based beam detector that will allow for autotracking is currently under development.

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Evaluation of FRAM for use in Radiation Environments*

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Ferroelectric Random Access Memory (FRAM) is a non-volatile, low power memory with high read/write speed and high endurance. It stores bit information in semi-permanent electric dipoles formed within a dielectric crystal cell by reversible spontaneous electrical polarization [1]. Each storage cell is composed of either two transistors and two capacitors (2T2C) as shown in Figure 1, or one transistor and one capacitor (1T1C). The MOSFET is built in a conventional CMOS process, while the capacitor typically uses ferroelectric PZT ($Pb(Zr,Ti)O_3$) material. PZT can easily be added to a conventional CMOS process by insertion of two mask layers between substrate contact and metal layers [1].

Specification	FRAM	Flash	SRAM
read time	110 ns	<120 ns	1 ns
write time	180 ns	1s/sector	<1 ns
standby curr.	$5 \mu A$	$5 \ \mu A$	$7 \ \mu A$
r/w current	4 mA	12-24 mA	40 mA
single bit r/w	yes	no	yes
endurance	$10^8 - 10^{12}$	100.000	∞

Table 1: Comparison of FRAM, Flash and SRAM.

Since the FRAM's ferroelectric storage cells are promoted to be unsusceptible against magnetic fields as well as radiation, FRAM is a prominent candidate to replace current technologies in particle accelerators - a comparison is given in Table 1. But the surrounding CMOS transistors are still susceptible to radiation effects. To investigate this assumption, a beamtest has been performed at COSY Jülich in 08/2014, using 2 GeV protons and a total flux of $6 \cdot 10^8 p/s$. Two COTS FRAM chips placed on development boards have been selected for irradiation: Fujitsu MB85RS256B FRAM chip on mikroElektronika MIKROE-1486 break-out board (32 KB plain FRAM array) as well as Texas Instruments MSP430FR5739 FRAM chip on MSP-EXP430FR5739 Experimenter Board (16 MHz 16-Bit RISC Microcontroller with 16 KB FRAM storage). Two boards of each type were irradiated in parallel. The first ones were powered and readout continuously in beam while the second ones were hold completely passive and unpowered. All chips were initialized with a logical 0/1 pattern.

Throughout the beamtest, no upset could be detected in the Fujitsu devices, neither in active read-back mode, nor in passive mode at the end. Unfortunately, the constantly powered device broke down due to a leakage failure after about 160 krad. Current drain raised gradually from an initial operation value of 0.0007 A up to a final value of 0.100 A. After an unpowered annealing period of multiple hours at room temperature, the device was fully functional again and the stored FRAM configuration was still unchanged.



Figure 1: Left: FRAM 2T2C cell circuit according to [2]; Right: MSP430FR5739 bit errors during read-back.

While the passively irradiated Texas Instruments FRAM chip has shown no errors, the actively operated one observed a single failure throughout the test. It lead to an upset of multiple stored bit values in a single continuous chain as depicted in Figure 1. All values remained statically stored within the FRAM cell. A possible causer is the utilized sense amplifier (AMP). Sense AMPs in CMOS are usually realized as 4-transistor latch-type circuits as depicted in Figure 1. In consequence, a Single Event Transient (SET) in the AMP transistor's cross-coupled inverters whose pulse width overlaps with the sensing interval can lead to incorrect cell read results. Reading an FRAM cell is a destructive process - every cell read results in a subsequent cell write. This may have caused the SET's latching into a permanent Single Event Upset (SEU), even in the radiation tolerant FRAM cells. The characteristic structure of the observed upsets furthermore clearly allows to draw conclusions about the internal memory structure: AMPs are arranged in parallel to the memory rows which enables their reuse across the memory columns. If a single AMP is upset, a single bit position within multiple words is affected.

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A CBMNet Bridge for the TRB3 *

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The TRB3 is a flexible and modular FPGA-based data acquisition platform originating from the HADES detector at GSI. Unifying all base-functionality on a universal main board, connectivity to the experimental setup is established using up to five application-specific add-on boards. The platform is used by a number of detectors, amongst them prototypes for CBM-MVD and CBM-RICH.

The board features five inexpensive Lattice ECP3 FP-GAs optimised for a high IO count rather than computational power, which is typically not required for early DAQ stages: one central chip primarily executes managementand network-related tasks while the remaining FPGAs together with their respective add-ons form four independent sub-systems. Applications include FPGA-based TDC- (up to 264 channels/board with a precision of 7.2 ps RMS [1]) and ADC-measurements as well as the read-out of highspeed digital signals, e.g. for the MAPS in case of CBM-MVD. The TRB3 can be operated in a stand-alone fashion only requiring an external power supply and a PC capable of Gigabit Ethernet (GbE); however, large systems are inherently supported by its internal network protocol, Trb-Net, which was originally developed for HADES.

In order to bring forward the integration of TRB3-based experiments into the CBM DAQ, uplink- and synchronisation capabilities have been added to the platform. As most TRB3 applications are intricately build around the TrbNet infrastructure, it was decided not to replace TrbNet but to develop a bridge between both networks. The adoption included the implementation of CBMNet's physical layer, the migration of its high-level functions onto a new FPGA platform as well as the design of protocols to bridge the semantically different network types.

Since TrbNet features a central trigger and read-out scheme, CBM's streaming data transport is emulated using a free-running mode of operation based on periodic pulsers. These cause the frontends to deliver their zerosuppressed data in packets with a temporal binning comparable to FlesNet's timeslices. To reduce data overhead, load adaptive trigger frequencies based on external signals, such as an spill-indicator, are supported.

As shown in Fig. 1, current network typologies foresee a single CBMNet bridge for (possibly) multiple interconnected TRB3s since TrbNet hubs are easily available; in case of bandwidth limitation multiple uplink modules are provisioned in the firmware. An unpacker software building on top of the FlesDAQ infrastructure [2] is available in



Figure 1: A typical TRB3 set-up with CBMNet bridge. If multiple boards are used, they can share a common CBM-Net link. Slow-Control is available only via GbE.

CBMRoot. Additionally, a dual-stack uplink with CBM-Net and GbE is feasible.

Synchronisation with native CBMNet frontends is possible by means of freely configurable DLMs. Several approaches suitable for one to many DLMs are supported and exhibit an event-to-event jitter of < 50 ps RMS after converting TrbNet timestamps into the CBMNet domain.

Graphical user interfaces to configure, monitor and debug the new firmware were developed and enable nonexperts to operate the system. The network bridge was successfully used in conjunction with the current CBM-RICH prototype during a beam time in November 2014 at Cern (PS).

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Status of CBMnet readout and the prototype ASIC^{*}

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Front-end read-out status

The CBMnet protocol is currently present in all stages of the CBM data acquisition (DAQ) network for the TRD and STS readout. Beside the two FEE ASICs using CBMnet links over HDMI cable, the cores are also integrated in the Read-Out Controller (ROC), the FLES Interface Board (FLIB) and further FPGA to FPGA interconnects. For these links Xilinx Gigabit Transceiver over SFPs are used. A typical setup is depicted in 1. To improve the link stability under influence of radiation, a reworked CBMnet Version 3.0 has been developed and implemented, containing a link layer, various physical layer implementations and more network related building blocks to deliver generally required features in CBM network devices. Implementations have been optimized for FPGA and ASIC use. The logic is built in such a way, that a malfunction triggered by a single event effect is detected and the corresponding functional blocks are reset. In this manner, the data acquisition over a long time is possible without any interruption. Larger test beam read-outs with up to three SPADICs per ROC have been tested in laboratory and under beam. The FLIB physical layer implementation has been tested intensively to work reliable under all conditions. The design can handle up to eight links now.



Figure 1: Read-out with FLIB, Syscore3 and SPADIC

Prototyping of a readout aggregation ASIC

A prototype of the readout and aggregation ASIC has been designed together with the Indian Institue of Technology Kharagpur (IITKGP). Therefore, an internship student from IITKGP was visiting the University of Heidelberg for half a year in 2014. This was possible because of successfully raised additional funding from the Heidelberg Center South Asia. This mixed-signal ASIC consists of a full-custom 5Gb/s serializer/deserializer, designed by the IITKGP including design elements such as phase-locked loop, bandgap reference, and clock data recovery, and a digital designed network communication and aggregation part designed by the computer architecture group of the University of Heidelberg.

In addition, there are test structures and an I2C readout integrated to ease bring up and monitoring. A specialty of this test ASIC is the aggregation of links featuring different data rates, running with bundles of 500 Mb/s LVDS [1]. This enables flexible readout setups of mixed detectors respectively readout of various chips. There are 1x, 2x, or 4x LVDS connections available enabling up to 2 Gb/s for a front-end connection. The prototype will be able to run in a mixed configuration, e.g. one 1x, two 2x, and one 4x. A prototype structure diagram depicting the link configuration possibilities is presented in figure 2. As communication protocol for the prototype, a unified link protocol is used including control messages, data messages, and synchronization messages on an identical lane. The design has been successfully simulated, verified, and hardware emulations using Spartan 6 FPGAs. The miniASIC mixed-signal design has been prepared and simulated together with the collaboration partners from the IITKGP. The first chance in 2015 for a submission using the TSMC 65nm LP Europractice process will be taken.



Figure 2: Link connection diagram for HUB ASIC

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CBM Component Database

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The CBM Component Database (DB) is designed and implemented as a part of the CBM Databases project [1] according to the User Requirements Document [2]. The Component DB is used to store and manage the properties of the detectors hardware and electronic components. It contains characteristics, statuses, test results, certificates and other parameters both numeric/strings and images. The current relational DB structure allows to use it for any CBM detector performing minor adjustments. The components of different detectors (STS, Magnet, PSD, RICH, ToF, MUCH, MVD, TRD, ECAL) will be stored in different databases. Data is accessed through the common authorization service. The Component DB has a tree structure. The root of the tree has a name of the CBM facility part such as Magnet, MVD, STS etc. The list of the detector components is stored in the tree. The tree leaf is connected to a table with according names and values. The tests, certificates and statuses are stored in DB as the references. Test of the components are images. The certificates details depend on the component and can be implemented for each detector. The catalog of different statuses can be defined for each detector separately.

The authorization for each detector is needed. The responsible person can work only with the data of corresponding detector. The Web access is organized for viewing, inserting and editing data. The implementation is realized on the basis of client-server interaction. The same schema for all subdetector was produced. Scripts and their usage in according html pages were implemented. Figure 1 presents an example of the Magnet main page. The details of the Magnet component are shown on the right. Figure 2 shows page for editing Magnet details.

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Figure 1: View Mode GUI Example for Magnet

The system implementation is based on the software DBMS PostgreSQL v8.4.20. Basic services are supported:

Edit database tables:	Contractory of the	
	Component	Magnét
 Component 		The Superconducting
	Description	Dipole Ragnet with [w]
Contract	Serial	
• cerupcar	Number	
	Number	0
Testinfo	Туре	
- ADDRESS A	Status	UNKNOWN \$
	Company Name	GSI 0
• Trace	Start Build	1970-01-01
	End Build	1970-01-01
	Plan Start Build	1970-01-01
	Plan End Build	1970-01-01
	Quantity	1 1
	Imgurl:	images/figure_1.jpg
	Select a file:	Browse No file selected.

Figure 2: Edit Mode GUI Example for Magnet

data viewing for detector components, search in navigation mode, inserting and editing data for the detector component, support of the catalogs, authorization services for system access. The authorization is based on affiliation to the detectors group. There are several catalogs such as Manufacturer Companies, Component Categories, Batches Details, Quality Measurement Units, and Quality Criteria. User Guide for The CBM Component DB is developed.

Web-interface allows to work with system from any place with internet access, to reach data from mobile device on according speed level. Current Magnet Component DB is completely implemented, filled with data and available through the link: http://cbmdb.jinr.ru/magnet.main.php. STS and MVD tree structures are defined. They are going to be filled in with data after some specification. The Users Guide for Component DB support is developed and can be used [3].

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4-Dimensional Cellular Automaton Track Finder for the CBM Experiment*

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The CBM experiment at FAIR will focus on the measurement of rare probes at interaction rates up to 10 MHz. The beam will provide free stream of particles, so that some events may overlap in time. It requires the full online event reconstruction not only in space, but also in time, so-called 4D (4-dimensional) event building. A time-slice is reconstructed in parallel between cores within a CPU, thus minimising communication between CPUs. This is a task of the First-Level Event Selection (FLES) package.

The FLES reconstruction package consists of several modules: track finding, track fitting, short-lived particles finding, event building and event selection. The Cellular Automaton (CA) track finder is fast and robust and thereby will be used for the online track reconstruction. This method benefits from enumeration suppression by introducing a phase of building short track segments at an early stage before going into the main combinatorial search. The reconstruction efficiency for the primary tracks with momentum higher than 1 GeV/c in case of event-based analysis (see 3D column of Table 1) is 96.1%.

As a special study of the CA track finder stability the algorithm behavior was investigated with respect to the track multiplicity. For the study a super-event, which includes a number of minimum bias events, was reconstructed with no time information taken into account. In a super-event we combine space coordinates of hits from a number of Au+Au minimum bias events at 25*A* GeV and give it to the CA track finder as an input to reconstruct with a regular procedure. The reconstruction efficiency dependence is stable: the efficiency for all tracks changes by 4% only for the extreme case of 100 minimum bias events in the super-event (see (3+1)D column of table 1), comparing to the case of event-based analysis.

The time information was included to the algorithm. It has resulted in a higher reconstruction efficiency (see 4D column in table 1). In particular the time information drastically decreased ghost and made the reconstruction 3.7 times faster than without the time information ((3+1)D column of Table 1). The speed now is 8.5 ms and comparable with the event-based analysis. The CA track finder was fully parallelised inside the time-slice. The parallel version shows the same efficiency as a sequential one and achieves a speed-up factor of 10.6 while parallelising between 10 Intel Xeon physical cores with a hyper-threading.

The first version of event building based on 4D track finder was implemented. The hits time measurements distribution illustrating the complexity of defining event bor-

Efficiency, %	3D	(3+1)D	4D
All tracks	83.8	80.4	83
Primary high-p	96.1	94.3	92.8
Primary low-p	79.8	76.2	83.1
Secondary high-p	76.6	65.1	73.2
Secondary low-p	40.9	34.9	36.8
Clone level	0.4	2.5	1.7
Ghost level	0.1	8.2	0.3
Time/event/core	8.2 ms	31.5 ms	8.5 ms

Table 1: Track reconstruction performance for 3D eventby-event analysis, super-event (3+1)D and time-based 4D reconstruction for 100 mbias Au+Au collisions at 25A GeV.



Figure 1: Distribution of time measurement in a part of a time-slice at the interaction rate of 10^7 Hz: hit time measurement (light blue), track time (black).

ders in a time-slice is shown Figure 1 with blue color, the resulting distribution of reconstructed track time – with black. Reconstructed tracks clearly represent eventcorresponding groups. The FLES package is ready for the 4D reconstruction of time-slices in CBM.

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On a performance of $J/\psi \rightarrow e^+e^-$ reconstruction algorithms

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The measurement of J/ψ decays is one of the key goals of the CBM experiment. The procedure of the J/ψ registration in its dielectron channel includes a chain of methods and corresponding algorithms for trajectories and momenta reconstruction of charged particles with STS, electron/positron identification with RICH, TRD and TOF, as well as construction of the J/ψ -candidates and their characteristics using the KFParticle package [1]. Taking into account that selection and reconstruction decays of $J/\psi \rightarrow$ e^+e^- are planned to be carried out in real time of the CBM experiment, the used methods and algorithms should be not only effective but also fast.

In this paper the time-consuming estimation of the existing algorithms based on their acceleration via code vectorization by means of SIMD instructions and parallelization between the processor cores that are implemented using different software environments has been carried out (see details in [2]).

Table 1 presents the speedup factors of the algorithms (Cellular Automaton and Kalman Filter in the STS, ring reconstruction with RICH, electron identification in the TRD applying the ω_n^k criterion, KFParticle package) obtained with using SIMD instructions.

STS:	STS:	RICH: ring	TRD:el.id.	KFPar-
CA	KF	reconst.	with ω_n^k	ticle
2	4	2	3.5	2.5

Table 1: Speedup factors of the algorithms obtained with using SIMD instructions

It should be noted that there is a certain reserve to accelerate the computing in this way, because some algorithms, such as the track reconstruction of the charged particle with the TRD is not subjected to vectorization, and others, for example KFParticle package, is not vectorized fully. In the case of the maximum possible optimization and vectorization of all algorithms, the total acceleration factor may be considerably higher.

According to preliminary estimates, the share of central collisions in the real experiment should not exceed 1 %. In this regard, we used the events, corresponding to a mixture of the central (1 %) and Minimum Bias (99 %) AuAucollisions at 25 AGeV to determine the performance of the algorithms. Furthermore, to avoid dependence of the algorithms to the particles multiplicity produced in one AuAucollision, we calculate an average time Δt , which specific algorithm takes for processing a single trajectory. To do it the following formula is used:

$$\Delta t = \frac{t_{mbias}}{N_{mbias}} \cdot 0,01 + \frac{t_{centr}}{N_{centr}} \cdot 0,99,\tag{1}$$

where t_{mbias} is the average time spent by the algorithm on one MB-events and t_{centr} is the same value for one central event; M_{bias} and M_{centr} are average numbers of the reconstructed tracks in one MB and one central event, respectively.

Table 2 presents the average time Δt (in μ s/track or μ s/ring) which $J/\psi \rightarrow e^+e^-$ reconstruction algorithms spend on data processing. Note that the presented results are referred to the SIMD-algorithms (besides the track reconstruction with the TRD) and obtained using one logical CPU core.

STS:	STS:	RICH:	TRD:	TRD:	KFPar-
CA	KF	ring	track	el.id.	ticle
		reconst.	reconst.	with ω_n^k	
164.5	0.5	49	1390	0.5	9.15

Table 2: Average time Δt (in μ s/track or μ s/ring) which described SIMD-algorithms spend on data processing

Table 2 shows that time spent by the algorithm of track reconstruction of charged particles in the TRD, many times exceeds the summing time of all the other algorithms. It should be noted that an alternative approach to track finder in the TRD, based on a Cellular Automaton is now under development [3]. It is expected that the new algorithm will be not inferior in efficiency to the existing method but more reliable and productive.

All of the above algorithms were adapted in software environments (OpenMP, OpenCL and TBB) for parallel computation on high performance hybrid servers constructed on the basis of multi-core CPU and GPU. All algorithms shows a good linear scalability in depending on the number of the cores included in the processing.

The analysis of the algorithms scalability has allowed us to estimate the acceleration of data processing using the technologies for high performance computing and identified "weak" places in the chain of the methods for J/ψ reconstruction (track reconstruction in TRD), over which is under investigation.

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Event Building Process from Time Stream Data

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Upto now all the High Energy Experiments are based on the hardware triggered approach, which means a specific set of hardware, signals the entire elecronics to collect the data, this is known as triggered electronics. This signal define the event boundary, therefore all the available simulation and reconstruction software are working on the event by event basis. On the contrary due to unprecedented interaction rate at the CBM experiment conventional triggered electronics will not work, therefore building of trigger less electronics have been under development. In this scenario, the event boundary will not be defined by any hardware. This implies a novel read-out and data acquisition concept with self-triggered front-end electronics which will generate free-streaming data. To do the analysis from this time stamped free steam data, event association must be performed in software. To simulate the free stream data, work has been under development [1] to change the CBMROOT framework in the direction of putting timestamp on each and every digi (digi is the smallest piece of raw data known as one hit which detected by triggerless electronics).



Figure 1: Simulation and analysis process chain.

To use all the available software for processing of free stream time stamped data, generated by CBM experiment, an event association package has to be introduced at the appropriate place in the simulation, reconstruction and analysis chain which will separate one event to another and also this should cater to actual experiment data processing. Fig. 1 shows proposed process chain for both simulation and real experiment. Fig. 1 shows that all the available hit, track, vertex reconstruction and physics analysis packages can be used if a new process named event building introduced which will convert timestamped data stream into event by event data stream.

Report describes that how we are going to address this issue. Time stamped raw data stream have been generating via simulation and each detector will generate separate raw data stream like STS data stream, MUCH data stream etc and all will be stored in a ROOT Tree. In actual scenario also different detectors will generate different stream of digis with time stamp. As a first step towards the reconstruction of such free-streaming data, we introduced an event-building process which tags physical events based on the time information of the raw data. Process counts the digis in each nano second and put these values in nanosecond vector. Then the process identifies and analyzes dips in the continuous nanosecond vector. Data between two dips indicates probable event candidate, which then further analysed with respect to a number of parameters like minimum and maximum number of digis per event, average event duration etc. Fig. 2 shows the flowchart for event building process. In this process a vector indexed nanosecond created, which contain < No. of Digis in the nanoslice, starting index of first digi of this nanoslice>. Presently our sample set contain free time stream data only for the muon detector system (MUCH).



Figure 2: Flowchart for proposed Event Building

Fine tuning of the eventbuilding process has been going on with respect to MUCH on the basis of different parameters and thereafter same will be developed for the other detector systems. If once event could be defined with respect to all the detector thereafter, all available reconstruction algorithms, working event-by-event basis, could be used without any modification for processing time stamped free stream data.

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Event-by-event extraction of kinetic and chemical freeze-out properties in the CBM experiment*

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The future CBM experiment at FAIR is designed to study properties of strongly interacting matter produced in heavyion collisions at high baryon densities. It will employ high intensity beams and large acceptance detectors. One important task is to extract the thermal parameters of matter at stages of kinetic and chemical freeze-out from the observed data. The extraction of thermal parameters is implemented as a package within the CBMROOT framework.

The kinetic freeze-out temperature of charged pions is extracted from their measured momentum spectrum. In the simplest scenario the particles are assumed to have a Boltzmann momentum distribution with no collective flow. To test the method, a 1000 Monte Carlo (MC) events with thermally distributed pions (T = 128 MeV) were generated and then processed in CBMROOT. Reconstructed STS Tracks, as well as the initial MC Tracks, were used to calculate the average transverse mass of pions $\langle m_T \rangle$, which was then used to estimate the temperature. Due to limited detector acceptance, and due to imperfect reconstruction efficiency, the mean transverse mass of STS tracks differs from the MC one. Therefore, an appropriate correction was performed using the known momentum dependence of acceptance function and reconstruction efficiency. Figure 1 depicts the extracted Boltzmann temperature on the eventby-event level. It is seen that the extracted temperature has a Gaussian-like distribution around the theoretical value of 128 MeV when one uses MC Tracks (blue line) or STS Tracks with proper correction on acceptance (red line). If one neglects this correction on acceptance then one gets essentially different (incorrect) value of temperature (green line). The procedure, developed for this model, can be used as a basis for analysis in the framework of more complex and more realistic models.

The parameters of the chemical freeze-out are extracted by fitting the measured particle ratios in the framework of the Hadron Resonance Gas model. All strange and nonstrange hadrons which are listed in the Particle Data Tables are included and the model is implemented in CBM-ROOT and works similarly to the THERMUS package [1]. The grand canonical ensemble formulation is used and excluded volume corrections are included in the framework of the thermodynamic mean-field approach [2]. The fit can be performed on event-by-event level and also on the inclusive spectra level. Figure 2 shows the extracted temperature and baryonic chemical potential from MC events generated in the thermal model with T = 100 MeV and



Figure 1: The temperature of pions extracted on event-byevent level using the MC tracks (blue line), STS tracks without acceptance correction (green line), and STS tracks with correction on acceptance (red line).

 $\mu_B = 550$ MeV. For each parameter extraction a set of 10 events was used, and the fit error estimates were calculated and depicted as well. The extracted values are consistent with the theoretical input.



Figure 2: The temperature and the baryonic chemical potential extracted from the 10-event sets in the framework of the Hadron Resonance Gas model. The theoretical MC values is shown by the red dot.

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A "vector finding" approach to track reconstruction in CBM MUCH

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The existing track reconstruction method in CBM MUCH is based on the track following approach. It consists in the STS track propagation through the MUCH subsystem using the Kalman filter procedure. Although quite straightforward, this method has some deficiencies such as a necessity to run a prior STS reconstruction or the effect of the absorbers, which blow up the track covariant matrix and make hit selection right behind them rather difficult in high hit density environment (in first stations) or for one-coordinate detectors (straw tubes - Fig. 1).

Here an alternative approach to the track reconstruction task in MUCH is described based on a so-called "vector reconstruction" procedure [1]. The idea is to build track segments (vectors) for each MUCH station and merge them with each other (and with STS tracks at the end) through the absorbers. This approach offers some advantages (beside being alternative): vector finder can be run for all stations in parallel and the procedure is rather simple (straight line fit of a few measurements), there is a possibility to trigger on di-muons, the damaging effect of absorbers is excluded at the first stage of reconstruction allowing to fully exploit coordinate reconstruction accuracy for handling hit combinatorics.



Figure 1: SIS100 CBM muon system configuration with straw tubes comprising two last detector stations.

Vector finder in the magnetic field-free region can be realized very efficiently using the solution of the linear equation system from the Least Squares Method (LSM). It consists in finding the minimum value of the χ^2 - functional (for 2-D detectors):

$$\chi^{2} = \sum_{i=1}^{N_{planes}} \left[\frac{(x(z) - x_{i})^{2}}{\sigma_{x_{i}^{2}}^{2}} + \frac{(y(z) - y_{i})^{2}}{\sigma_{y_{i}^{2}}^{2}} \right]$$

where $x(z) = x_0 + T_x \cdot z$ and $y(z) = y_0 + T_y \cdot z$ are the vector equations in two planes with track parameters (x_0, y_0, T_x, T_y) and sum is taken over the number of planes in the detector station (i.e. the number of points with coordinates (x_i, y_i) and errors $(\sigma_{xi}, \sigma_{yi})$). Similar expression can be written for one-dimensional detectors (straw tubes). The minimum value of χ^2 is found by taking its partial derivatives with respect to track parameters and setting them to 0. As a result, the following system of equations is obtained (for 2-D detectors - GEMs):

$$\sum_{i} \begin{pmatrix} 1 & 0 & z_{i} & 0 \\ 0 & 1 & 0 & z_{i} \\ z_{i} & 0 & z_{i}^{2} & 0 \\ 0 & z_{i} & 0 & z_{i}^{2} \end{pmatrix} \begin{pmatrix} x_{0} \\ y_{0} \\ T_{x} \\ T_{y} \end{pmatrix} = \sum_{i} \begin{pmatrix} x_{i} \\ y_{i} \\ x_{i} \cdot z_{i} \\ y_{i} \cdot z_{i} \end{pmatrix}.$$

Here it is assumed that the measurement errors are the same for all hits in a station, which is a reasonable approximation for MUCH. One can see that the left matrix does not depend on individual hit measurements and can be called a configuration matrix **A**. As such, it can be computed at the initialization stage and kept in memory for the whole processing. The configuraton matrices also define the covariance matrices of the fitted vector parameters $\mathbf{V} = \sigma^2 \cdot \mathbf{A}^{-1}$.

The above formalism is used as follows: for each detector station, different hit combinations are fitted to straight lines. Combinations with high χ^2 -value are rejected. To reduce hit combinatorics, some a priori constraints can be applied (e.g., vector angles). At the next step, vectors from sequential stations are merged through the absorbes, taking into account multiple scattering in the absorber material and covariance matrices of vectors. Again, only vector pairs with low enough matching χ^2 are accepted. At the end, matching with STS tracks is done.

Some results on vector matching in two last stations are presented in Tab. 1. Here the signal muon pair efficiency (from ω decays) is shown along with the average number of background tracks in central Au-Au collisions at 8 AGeV. The background tracks include the "real" tracks, i.e. the ones from real particles (punchthrough hadrons or decay muons) and "ghosts", i.e. combinations of two vectors from different particles. Although the results are very preliminary, one can see that MUCH configuration with straw tubes demonstrates somewhat better performance (due to higher coordinate resolution).

Geometry	Efficiency,%	$\langle Bkg. tracks / event \rangle$		
		"real"	"ghost"	
GEM	4.3±0.3	1.23 ± 0.02	$0.50{\pm}0.01$	
Straws	4.9±0.3	1.22 ± 0.02	$0.30 {\pm} 0.01$	

Table 1: Tracking efficiency for the dimuon signal and background track rate.

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Physics Performance

Sensitivity of the MUCH in extraction of fireball temperature from dilepton spectra*

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The NA60 collaboration reported an excess of muon pairs with respect to the predicted yield at the intermediate mass region $1 < M < 2.5 \ GeV/c^2$ at 158A GeV In+In collisions [1]. The transverse mass distribution of these excess dimuons can well be described by exponential function and thus have thermal origin. In low mass region, the effective temperature increases with invariant mass due to the development of strong radial flow in the late phase of the collision, whereas in the intermediate mass range, the effective temperature drops significantly. This suggests that above 1 GeV/c^2 , the emission source of thermal dimuons is largely partonic in origin, when radial flow has not yet built up [1]. The CBM experiment at FAIR will also going to address the above issue by scanning the dilepton spectra starting from low mass vector meson (LMVM) upto charmonia both in SIS100 & SIS300. The MUCH (Muon Chamber) detector consisting of segmented absorber system & detector layers (sector-shaped gaseous chambers) will be responsible for the muon detection. It is therefore very much important to study the feasibility of precise determination the effective temperature with the MUCH setup by detecting the muons. In this report an attempt has therefore been made to study the sensitivity of MUCH, in extraction of the fireball temperature from the transverse mass distribution.

The simulation has been performed at $E_{lab} = 8A$ GeV central Au + Au collision within the CBMROOT framework (JULY14) for standard SIS-100b (5 absorbers) geometry (Fig.1). Background particles and signal muons (from ϕ decay) have been generated using UrQMD and PLUTO [2] event generators respectively. GEANT3 is used to transport the generated particle through the detector set-up. To account for realistic detector geometry, the readout modules are segmented in pads for obtaining final detectable response. For this present study 1^0 segmentation scheme has been implemented. Further, local maxima finder has been incorporated to the simulation as cluster deconvolution algorithms to reconstruct hits. The hits thus generated are used for the tracking. Invariant mass technique has been used to reconstruct ϕ meson (Fig.2). The reconstructed transverse mass spectra has

	Input ϕ	Reconstructed ϕ
T_{eff} (MeV)	125 ± 0.1	128.1 ± 3.6

Table 1: The effective temperature of input and reconstructed ϕ



Figure 1: Schematic view of MUCH (SIS-100b) with STS and dipole magnet. The first absorber is made of carbon (60cm) and the rest are iron (20+20+30+135).



Figure 2: Reconstructed invariant mass spectrum of $\phi \rightarrow \mu^+ \mu^-$



Figure 3: Transverse mass spectra of ϕ meson for central Au+Au collision at 8A GeV.

been fitted with the simple exponential $1/m_T dN/dm_T \sim \exp(-m_T/T_{eff})$ as shown in Fig.3. The resulting inverse slope known as effective temperature (T_{eff}) is found to be 128.1 ± 3.6 MeV which is in agreement with the input temperature within the uncertainty (Table 1). It is thus concluded that with the SIS-100b geometry the determination of temperature of the fireball is a possibility.

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TOF PID

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 10^6 Au+Au UrQMD events at 4, 10 AGeV (for the setups A, B and C), 25 and 35 AGeV (for the setup C) simulated and reconstructed in the frame of the CbmRoot package have been used for analysis. Setups A: SIS100 with TOF at 6m, B: SIS100 with TOF at 10m, C: SIS300 with TOF at 10m. The TOF resolution σ_{TOF} =80 ps was taken in the TOF hit producer. For global track matching with TOF hits the "nearest hit" mode was selected.

Figure 1 (left) shows distribution of global tracks with the vertex cut for selecting primaries. For different species the PID regions on the plane (p, m^2) are defined in Fig. 1 (right). To increase purity for anti-protons the tracks from



Figure 1: Setup A. Central Au+Au events at 10 AGeV. (left) Distribution of global tracks with the vertex cut on the plane (p, m^2) . (right) PID regions for different species. $\pm 3\sigma_p(p), \pm 3\sigma_K(p)$ and $\pm 3\sigma_\pi(p)$ boundaries are shown by lines.

the "white" region (mostly includes protons) are excluded from the PID analysis. PID efficiency is defined as a ratio of the correctly identified tracks to the all global tracks, PID purity is a ratio of the correctly identified tracks to the all tracks from the PID region.

Figures 2 and 3 present PID efficiency and purity at beam energies 4 and 10 AGeV respectively. At 4 AGeV multiplicity of anti-protons is very low, 3×10^{-5} per event, and statistic is not enough. At 10 AGeV multiplicity of anti-protons is 10^{-2} per event. In spite of high PID efficiency for anti-protons, its PID purity is low $\sim 0.1 - 0.2$ due to large contribution of tracks from protons. PID results weakly sensitive to beam energy (4/10 AGeV) and TRD (with/without TRD). In the momentum region $1 GeV/c PID efficiency is high, <math>\sim 0.9 - 1$, PID purity > 0.8, except for anti-protons.

Figure 4 presents PID efficiency and purity at 10, 25 and 35 AGeV with the setup C. PID efficiency is low sensitive to the beam energy. PID purity is most sensitive for anti-protons, it increases with the energy up to ~ 0.4 at 35 AGeV. For other species PID purity changes within 5 - 10%.



Figure 2: PID efficiency and purity for minimum bias Au+Au events at 4 AGeV with the setups A, B and C.



Figure 3: PID efficiency and purity for central Au+Au events at 10 AGeV with the setups A, B and C.



Figure 4: Setup C. PID efficiency and purity for central Au+Au events at 10, 25 and 35 AGeV.

Reconstruction of Σ hyperons with ECAL at SIS100

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The feasibility of Σ hyperons reconstruction using the ECAL was studied on samples of UrQMD events at the SIS100 energies: 10^7 p+C and 10^6 p+Cu minimum bias events at 10 GeV, 10^6 minimum bias and 10^6 head-on p+C events at 30 GeV. The set-up consists of MVD, STS, TOF and ECAL wall of the size X×Y=5.76 \times 8.64 m² with the beam gap |Y|<0.48 m distanced from a target at 12 m. Reconstructed photons with p>0.3 GeV/c and $\chi^2_{cluster}<1000$ have been taken for the analysis. We analyzed the decays $\Sigma^0 \rightarrow \Lambda\gamma$ and $\Sigma^+ \rightarrow p\pi^0$.

1. $\Sigma^0 \to \Lambda \gamma$. For the reconstruction of $\Lambda \to p\pi^-$ PID information was not exploited. Λ is named by "accepted" if each of its decay products has MC points in at least 4 STS stations and by "reconstructed" if each decay product has the reconstructed track (≥ 70 % of track hits belong to the same MC track). Single track cut: impact parameter in the target plane for positive and negative tracks (in σ) > 4. Vertex quality cuts: χ^2 of the fitted vertex < 2, distance of closest approach < 0.2 cm. Additional topological cuts: impact parameter of the reconstructed mother track < 0.15 cm, position of the fitted decay vertex along the beam axis in the range 3 - 25 cm. The reconstructed Λ within the range $m_{\Lambda} \pm 25$ MeV and reconstructed γ have been chosen as candidates for Σ^0 analysis. Figure 1 (left) shows an example of the invariant mass distributions of signal and background $\Lambda\gamma$ pairs. Table 1 summarize characteristics of



Figure 1: Invariant mass spectra of signal and background $\Lambda\gamma$ (left) and $p\pi^0$ (right) pairs for head-on p+C events at 30 GeV

the analysis: signal yield, acceptance, reconstruction and cut efficiencies, signal-to-background ratios $S/B_{\pm 2\sigma}$ and significances.

2. $\Sigma^+ \rightarrow p\pi^0$. For π^0 candidates the pairs with 0.124 < $M_{\gamma\gamma} < 0.144$ GeV/c were selected. No PID was used to select the proton candidates. The positive tracts with the impact parameter in the target plane (in σ) > 5 have been used to reject the positive primaries. Figure 1 (right) shows an example of the invariant mass distributions of signal and background $p\pi^0$ pairs of selected candidates.

Table 1: $\Sigma^0 \to \Lambda \gamma$

system	yield	acc.	rec.	cut	S/B
	/event	eff.	eff.	eff.	/sign.
pC@10	0.004	0.027	0.45	0.12	0.11/2.2
pCu@10	0.017	0.015	0.45	0.13	0.11/1.2
pC@30	0.009	0.042	0.61	0.26	0.08/2.1
pC@30,b=0	0.029	0.042	0.59	0.30	0.08/3.9

Table 2 summarize characteristics of the analysis. Due to

Table 2: $\Sigma^+ \rightarrow p\pi^0$

system	yield	acc.	rec.	cut	S/B
	/event	eff.	eff.	eff.	/sign.
pC@10	0.008	0.011	0.46	0.03	0.08/1
pCu@10	0.018	0.007	0.47	0.02	-
pC@30	0.010	0.022	0.50	0.14	0.04/1
pC@30,b=0	0.030	0.019	0.56	0.19	0.07/2.1

lower efficiencies we have ~ 5 times lower the number of signal pairs than for the channel $\Sigma^0 \rightarrow \Lambda \gamma$. To estimate S/B for the p+Cu system statistics is not enough.

Results for the head-on p+C events at 30 GeV agree with those obtained with light ECAL in [1].

In order to achieve a reasonable significance level of about 10, two order higher event statistics is required.

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Reconstruction of $\eta'(958)$ with ECAL at SIS100

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The feasibility of $\eta'(958)$ reconstruction using the ECAL was studied on samples of UrQMD events at the SIS100 energies: 10^7 p+C and 10^6 p+Cu minimum bias events at 10 GeV, 10^6 minimum bias and 10^6 head-on p+C events at 30 GeV. The set-up consists of MVD, STS, TOF and ECAL wall of the size X×Y=5.76 × 8.64 m² with the beam gap |Y| < 0.48 m distanced from a target at 12 m. Reconstructed photons with p > 0.5 GeV/c and $\chi^2_{cluster} < 1000$ have been taken for the analysis. We analyzed the decay $\eta'(958) \rightarrow \pi^+\pi^-\eta$ (BR=43%).

In the invariant mass spectrum of MC primaries there is a peak at $m_{\eta'(958)}$. Figure 1 demonstrates an example for p+Cu at 10 GeV. We assume that triples of primaries



Figure 1: Invariant mass spectra of $\pi^+\pi^-\eta$ triples of primaries for p+Cu at 10 GeV

in the range $0.960 < M_{\pi^+\pi^-\eta} < 0.964$ GeV are from "primary" $\eta'(958)$. There is large background, the part of the "primary" $\eta'(958)$ corresponding to the signal is ~60 %.

An example of invariant mass distributions for $\gamma\gamma$ pairs around η mass is shown in Fig. 2. The peak from η



Figure 2: Invariant mass spectra of $\gamma\gamma$ pairs with $p_T^{\gamma\gamma} > 0.2$ GeV/c for p+C at 10 GeV

has $\sigma \sim 20$ MeV. For η candidates the pairs with 0.530<

 $M_{\gamma\gamma} < 0.560$ GeV/c were selected.

PID information was not used to select π^+ and π^- candidates. The impact parameter cut < 4 (in σ) was used to reject secondary charged tracks.

Figure 3 shows an example of invariant mass distributions for selected $\pi^+\pi^-\eta$ triples. Table 1 summarizes char-



Figure 3: Invariant mass spectra of selected $\pi^+\pi^-\eta$ triples for head-on p+C collisions at 30 GeV

acteristics of the analysis: signal yield, acceptance, reconstruction and cut efficiencies, signal-to-background ratios $S/B_{\pm 2\sigma}$ and significances. To estimate S/B for the p+Cu

Table 1:
$$\eta'(958) \rightarrow \pi^+\pi^-\eta$$

system	yield	acc.	rec.	cut	S/B
	x100	eff.	eff.	eff.	/sign.
pC@10	0.09	0.011	0.98	0.29	0.061/1.0
pCu@10	0.45	0.057	0.96	0.12	-
pC@30	0.3	0.035	0.99	0.45	0.014/0.6
pC@30,b=0	1.1	0.030	0.99	0.37	0.014/1.0

system statistics is not enough. In order to achieve a reasonable significance level of about 10, two order higher event statistics is required. The channel $\eta' \rightarrow \pi^0 \pi^0 \eta$ (BR=22%) has one order lower total detection efficiency and needs even more statistics. Due to low branching the channel $\eta' \rightarrow \gamma\gamma$ (BR=2%) also requires higher statistics.

Results for the head-on p+C events at 30 GeV agree with those obtained with light ECAL at 6 m in [1].

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Background rejection in the dilepton analysis with the CBM-Micro Vertex Detector*

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The light vector mesons ρ , ω and ϕ are excellent probes of the strongly interacting matter under extreme conditions. Their leptonic decay channels of interest as leptons leave the hot and dense fireball without strong interaction and may reveal information on the characteristics of the matter created in the collisions. Single electron or positron tracks from incompletely detected γ -conversions and Dalitz decays of π^0 -mesons are the most abundant source contributing to the significant combinatorial background. This study aims at exploring the use of MVD hits topology to reduce this background, despite of the fact that additional background is produced due to the material budget of the MVD.

To do so, electron pairs from meson decays have been simulated from a thermal source for central Au+Au reactions at SIS-100 energies such that the meson spectra are consistent with p_T and rapidity distributions measured by NA49 [1]. The decays of various sources simulated with the Pluto[2] event generator are embedded into the hadronic environment calculated with UrQMD transport model calculations. The magnetic field was set to 100% strength and δ -electrons with energies above 1 MeV have been added equivalent to a 10 kHz interaction rate.

The strategy of background rejection comprises several steps. In order to identify leptons from photon conversions that were produced outside of the target region, each reconstructed track is extrapolated to the primary decay vertex and removed from the analysis depending on its deviation to the vertex. One characteristic for conversion pairs is their small opening angle. A wedge cut is applied taking into account the opening angle of an identified electron to its closest neighbor with particle identification and product of the momenta of the two tracks. As lepton tracks from background sources can predominantly be found at low transverse momenta such tracks are rejected as well [3].

The MVD of the CBM experiment can further contribute to reduce this background by including points from the MVD into the track reconstruction. An improved rejection of pairs originating from the target region could be observed. Previous studies have shown that the MVD stations are also a source for γ conversions which can not be effectively rejected by the vertex extrapolation cut, especially in the first two stations closest to the target. Extrapolating tracks to the first MVD station and requiring that they are in its acceptance helped to better suppress off-vertex tracks from γ -conversions and resulted in an improved signal-tobackground ratio for the low mass vector mesons ρ , ω and

Mass Range $\left[\frac{\text{GeV}}{c^2}\right]$	MVD	S/B	$S/\sqrt{S+B}$
	Stations		
0 - 0.15	0	6.56	31.3
	4	8.27	29.4
0.15 - 0.6	0	0.10	3.7
	4	0.14	3.7
0.6 - 1.2	0	0.15	4.9
	4	0.21	5.4
$\omega \to e^+ e^-$	0	0.67	7.4
	4	0.96	8.0
$\phi \rightarrow e^+ e^-$	0	0.13	0.74
	4	0.19	0.86

Table 1: Signal-to-background ratios and significance for dilepton decays in different mass regions.

 ϕ as depicted in Tab. 1. The invariant mass spectrum of the full cocktail after all analysis steps is presented in Fig. 1.



Figure 1: Invariant mass spectrum after all cuts are applied for central AuAu collisions at 8AGeV.

There have been major updates to the CBM software with more realistic digitization and geometries for the CBM detectors, including the MVD [4]. The effects on the dielectron reconstruction are under investigation.

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Nuclear fragments with CBM at SIS100

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Light nuclear fragments are formed from nucleons at the latest stage of the evolution of the fireball, called the stage of freeze-out. Simple coalescence models [1] predict that the invariant yield of light nuclei with mass A is proportional to the A-th power of the nucleon yield and coalescence factor B_A , which characterizes the coalescence probability. This factor depends on the fireball size, it can be measured in the experiment and used to estimate the reaction volume in which the composite particles are created.

Simulations were performed for 100k minimum-bias Au+Au events at 4A GeV using the Dubna Cascade Model [2] for the hadron setup of the CBM detector at SIS100. Secondary particles were selected using the m^2 -p/Z correlation, where momentum and time-of-flight were reconstructed from STS and TOF information, respectively. This method leads to some contamination of misidentified protons, especially at high momentum values [3].



Figure 1: $y - p_T$ distribution for deuterons from minimumbias Au+Au collisions at 4A GeV [2]

The transverse momentum-rapidity $(y - p_T)$ distribution for deuterons from minimum-bias Au+Au collisions at 4A GeV [2] is presented in Figure 1. The yield is ~1.2 deuteron/event with ~97% of purity selection. The dominant reaction mechanisms are coalescence and projectile fragmentation. Deuterons with rapidity values ~ 1.2 and typical transverse momenta $p_T \sim 0.3$ GeV/c are produced via coalescence, while deuterons with the rapidity values ~ 2.02 come from the fragmentation process.

The $y - p_T$ distribution for tritons from minimum-bias Au+Au collisions at 4A GeV [2] is presented in Figure 2.



Figure 2: $y-p_T$ distribution for tritons from minimum-bias Au+Au collisions at 4A GeV [2].

The yield is ~ 0.046 tritons/event with $\sim 90\%$ of purity selection. Here, the dominant mechanism is coalescence. The purity selection for ³He using the m^2 -p/Z correlation is much worse ($\sim 40\%$) because of the large contamination of the background protons and deuterons. Additional information on the charge of the nuclear fragments is required to improve the purity.

The yields for deuterons and tritons obtained from the simulation of 100k central Au+Au collisions at 4 $A \cdot \text{GeV}$ [2] are ~ 4.1 and ~ 0.24, respectively. The purities of the selection are found to be the same as for the minimum bias events. The dominant reaction mechanism is coalescence for the both nuclei.

In summary, The CBM setup at SIS100 allows to obtain data on the light nuclei production in the mid- and forward rapidity regions. Systematic studies of the light nuclear fragments and hyper-nuclei production with CBM could distinguish different approaches in the description of the relativistic heavy ion collisions [4].

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Low-mass di-electron reconstruction in the CBM experiment*

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One of the main purposes of the CBM experiment at the upcoming FAIR facility is the reconstruction of low-mass vector mesons. The CBM experiment will be capable to reconstruct low-mass vector mesons in both leptonic decay channels: muons and electrons. The current status of low-mass di-electron simulations at 3.5*A*GeV, 8*A*GeV (SIS-100) and 25*A*GeV (SIS-300) will be presented in this report.

The simulations were performed with the latest version of the CBMROOT software (February 2015). UrQMD v3.3 was used to generate the event background. Signals were implemented using the PLUTO decayer with multiplicities from HSD. The following geometries were used in the simulations: STS - v13d, RICH - $v14a_1e$ (8AGev) or $v14a_3e$ (25AGeV), TRD - $v14a_1e$ (8AGev) or $v14a_3e$ (25AGeV), TOF - v13b. The RICH geometry implemented here is based on a CAD design and includes realistic material budget for all components (see [1]). The smearing algorithm was used for the TRD detector response simulation. In order to avoid additional background from gammaconversions in the target a 25μ m Au target was used.

Electron identification was performed using the RICH, TRD and ToF detectors. The identification methods in the RICH and TRD detectors are based on an Artificial Neural Networks with specified input parameters for each detector.

The dominant background in e^+ e^- pairs is random combinations of electrons and positrons from π^0 -Dalitz decay and γ -conversion. The aim of the background suppression strategy is to reject those pairs even if they were partially reconstructed. The following cuts were used to reject combinatorial background. The first cut is a pair cut in which all e^+ e^- pairs with invariant mass below 25 MeV are removed assuming that they originate from γ conversion. In the next two cuts fully reconstructed and identified electrons are combined with potential electron candidates that have momentum information only either because they left the acceptance after/within the STS or they escaped the electron identification because of inefficiencies. The last cut on p_t must be applied very gently, as it can reject the signal as well. In addition another topology cut can be used, which allows to suppress background pairs if one track was not fully identified in all detectors.

For the first time a low-mass di-electron simulation was obtained for central Au+Au collisions at 3.5 AGeV beam energy. Electron identification for this simulation was performed with RICH and ToF information only. The mag-



Figure 1: Invariant mass spectra for 2M central Au+Au collisions at 8 AGeV (left) and 25 AGeV (right) beam energies after applying all cuts.



Figure 2: Invariant mass spectra for 1M central Au+Au collisions at 3.5 *A*GeV beam energy after applying all cuts.

netic field was scaled down by 50 % in order to account for the lower momenta. Invariant mass distributions after applying all background rejection cuts are presented in Figure 1 and 2.

Final S/B ratios and efficiencies for low-mass mesons are presented in Table 1.

Table 1: S/B ratios and efficiencies after applying all cuts.

	3.5AGeV		84	AGeV	25AGeV	
	S/B	Eff.[%]	S/B	Eff.[%]	S/B	Eff.[%]
ρ	-	1.97	-	1.70	-	1.58
ω	0.090	2.31	0.74	1.89	0.17	1.68
ϕ	0.096	2.92	0.07	2.61	0.10	2.40

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Anisotropic flow and reaction plane reconstruction with the CBM experiment^{*}

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The projectile Spectator Detector (PSD) of the CBM experiment is designed to register forward spectator nucleons and fragments emitted in nucleus-nucleus collisions at very low polar angles. It will be used to determine the orientation of the collision reaction plane. The accuracy of the reaction plane determination with the PSD depends on the multiplicity and energy distributions of spectators and the magnitude of their directed flow, v_1 .

The PSD performance is studied with simulated Au+Au collisions in the beam energy range 2-30 AGeV, which corresponds to that of future accelerator rings SIS100/SIS300 at FAIR. To identify the most suitable heavy-ion event generator for the performance study, the simulated directed flow with UrQMD [1], DCM-QGSM [2], LA-QGSM [2], and HSD [3] heavy-ion event generators is compared with experimental data from E895 [4] and STAR [5] Collaborations. Figure 1 shows this comparison in terms of the slope of proton directed flow at midrapidity, $F_v(v_1) =$ dv_1/dy . Protons are used for the directed flow comparison because they are the most abundant particles in this kinematic region. The magnitude of the directed flow generated with different collision generators varies significantly, while DCM-OGSM seems to be the most consistent model in describing the data over the whole energy range. The possibility of collision fragment generation in the spectator region and the qualitative agreement with the experimental data for directed flow justifies the use of DCM-OGSM for the PSD performance study.

The CBM detector response is simulated with the GEANT4 Monte-Carlo package for three different configurations: (1) "PSD-accept." when simulated azimuthal distributions of the particles within geometrical acceptance of the PSD $[0.215^{\circ} < \theta < 5.0^{\circ}$ for $E_{beam} = 2 - 8$ AGeV and $0.115^{\circ} < \theta < 2.7^{\circ}$ for $E_{beam} = 30$ AGeV] were used without simulating the actual PSD response; (2) "PSD-geom.,B=0" when PSD response is simulated without CBM magnetic field (this allows to study the bias due to finite PSD segmentation); (3) "PSD-geom.,B=0" - same as configuration (2) but with magnetic field on.

Reaction plane resolution, quantified in terms of correction factor used in the directed flow measurement, is shown in Fig. 2. Resolution simulated with the DCM-QGSM generator is similar to that of the E877 experiment [6]. The transverse segmentation of the PSD seems to have a small effect. While the CBM magnetic field introduces a signifi-



Figure 1: The slope of proton directed flow at midrapidity simulated with different collision generators is compared with E895 [4] and STAR [5] experimental data.



Figure 2: Reaction plane resolution correction factor for v_1 . Results are from DCM-QGSM model and E877 [6] data.

cant bias, the reaction plane resolution is still high even in presence of the magnetic field.

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Towards e^+e^- conversion *

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Dalitz decays of π^0 and η ($\pi^0/\eta \rightarrow e^+e^-\gamma$) typically are, after all analysis steps the dominant part of the background in the dilepton decay analysis of rare vector mesons, even in view of the good particle ID capabilities of CBM. In order to precisely estimate the amount of Dalitz contributions in the final event sample, one has to measure the multiplicity of π^0 and η ; the branching ratio into Dalitz decays is then well-known. For counting π^0 and η the main decay channel $\pi^0/\eta \rightarrow \gamma\gamma$ is best suited.

The detection of the two photons can be done via conversion $(\gamma \rightarrow e^+e^-)$ in the detector material or in the target itself and a subsequent reconstruction of the conversion electrons with the STS and the RICH detector.

This idea has been successfully applied for example by HADES ([1]) and is now under investigation for CBM as well. So far only an exploratory study is available ([2]). In the report presented here first steps towards a realistic study will be shown using all CbmRoot developments since then.

As a starting point for the understanding of the simulation framework we performed so-called detector tomography studies. These studies consist of photons (generated with the boxgenerator) converting somewhere in the detector material. With a graphical visualisation of the conversion coordinates from MC-true data a cross-check of the implemented geometries is possible as also an identification of parts with a high material budget. The conversion points in the whole CBM detector (top view) are shown in Fig. 1, where the different subdetectors of CBM can be clearly recognized.

The next step towards a full conversion analysis is the reconstruction of π^0 reconstructing the two decay photons via $\gamma \rightarrow e^+e^-$ conversion in the target. In the simulation reconstructed tracks from the GlobalTrack array are matched to MCtracks, thus invariant mass spectra using the four true decay electrons can be calculated. Using MC-true momenta the results fit the theoretical mass for the π^0 . If the invariant mass is calculated based on reconstructed quantities, then the result shown in Fig. 2 is obtained (for 20k central gold-gold collisions at 25 AGeV).

The π^0 peak is clearly visible. A Gaussian fit of the peak-region gives a mean value of ~ 136 MeV/c and a sigma of ~ 11 MeV/c. However, roughly half of the entries result in a wrong, broadly distributed mass. This broadened mass distribution has to be related to wrong momentum reconstruction or multiple scattering of the electrons. More detailed understanding of this finding is necessary as it would be an important efficiency loss in the π^0 recon-

Tomography of the whole CBM detector - XZ plane

Figure 1: Tomography picture of the whole CBM detector in the XZ-plane (top view). The *z*-axis remarks the number of conversions and is therefore an indicator for the material budget.



Figure 2: Invariant mass spectra of π^0 (identified via MC-true) with refitted momenta (at primary vertex) of the e^+/e^- . The fit of the π^0 peak considered the range up to 0.2 GeV/c only.

struction.

The KFParticle package provides the reconstruction of a large variety of particles, including the π^0 . Results can be compared to the direct reconstruction described above, once the full π^0 reconstruction using all identified electrons is established.

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Thermal di-muon at FAIR energy

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The dilepton are expected to serve as a probe to the OGP because they are electromagnetically interacting particles. So the mean free path of the leptons exceed the size of the system formed after the heavy ion collisions and hence the leptons come out of the system undisturbed after their production, carrying the information about the initial state of the system. Further thermal dileptons are important as they carry the information of temperature and chemical potential of the system and they are expected to dominate in the intermediate invariant mass region. Here we have estimated thermal di-muon production in QGP phase at FAIR energy and applied them in MUCH simulation for CBM experiment at FAIR, Germany. We assume that, in heavyion collisions, large initial temperature T_i or large chemical potential μ_i lead to the formation of thermally equilibrated quark-gluon plasma (QGP). The system then evolves in space and time. As a result T and μ decrease then there is a first ored phase transition from QGP to hadronic phase. In QGP phase, dileptons are produced dominantly from quark-antiquark annihilation process. In this process, a quark interact with an antiquark to form a virtual photon which subsequently decays into a lepton pair. In case of massless quark and antiquark, the number of dileptons produced per unit dilepton invariant mass squared M^2 , per unit four-volume, is given by

$$\frac{dN_{\mu^+\mu^-}}{dM^2d^4x} = N\frac{\sigma(M)}{2(2\pi)^4}M^2f_1(\epsilon)F_2(\frac{M^2}{4\epsilon})(\frac{2\pi}{w(\epsilon)})^{1/2}, \quad (1)$$

with $N = N_c N_s^2 \sum_{f=1}^{N_f} (e_f/e)^2$ (= 20/3 for 2 flavour) where N_c , N_s are color and spin degeneracy factors respectively, N_f is the number of flavour, e_f is the electric charge of a quark with flavour f, $\sigma(M) = \frac{4\pi}{3} \frac{\alpha^2}{M^2} \sqrt{\left(1 - \frac{4m_l^2}{M^2}\right)}(1 + \frac{2m_l^2}{M^2})$, α is the fine structure constant, m_l is the mass of the lepton (in our present analysis m_l is the mass of muons), $F_2(E) = -\int_{\infty}^E f_2(E')dE'$, $f_1(f_2)$ is the quark (antiquark) distribution function, $\epsilon(M)$ is the root of the equation $\frac{d}{dE}[lnf_1(E) + lnF_2(\frac{M^2}{4E})]_{E=\epsilon} = 0$, $w(\epsilon) = -\left[\frac{d^2}{dE^2}(lnf_1(E) + lnF_2(\frac{M^2}{4E}))\right]_{E=\epsilon}$. Equation 1 is valid for a static plasma in which T and μ are held fixed. But in heavy-ion collisions, the system will expand with time and as a result T and μ will decrease. For simplicity we assume one dimensional Bjorken expansion for which $d^4x = \pi R_A^2 \tau d\tau dy$, where R_A is the radii of the colliding nuclei, y is the fluid rapidity and τ is proper time. For Au+Au collisions at $\sqrt{s} = 8$ GeV, initial time of

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Figure 1: Reconstructed invariant mass of di-muons.

the thermalized fireball is taken as 1 fm. One can estimate T_i and μ_i applying conservation laws of net-baryon number and entropy. If we assume that the entire evolution of the fireball from the initial time till the freezeout time is strictly adiabatic then one can relate initial entropy density and net-baryon density with freeze-out observables by the relations $s_i \simeq \frac{1}{\pi R^2 \tau_i} (\frac{ds}{dn} \frac{dn}{dy})_f$ and $n_{b_i} \simeq \frac{1}{\pi R^2 \tau_i} (\frac{dn_b}{dy})_f$, where $s_i = c_s^2 ((148/30)\pi^2 T_i^3 + 6\mu_i^2 T_i)$, $\frac{\pi R^2 \tau_i \langle dy \rangle f}{(\frac{ds}{dn})_f} = c_s^2 / 2.04 (37 \pi^4 / 15 + \mu_f^2 \pi^2 / T_f^2) + 4 c_s^2 T_f / \mu_f \text{ and }$ $n_{bi} = 2/3(\mu_i T_i^2 + \mu_i^3/\pi^2)$. c_s is the speed of sound. Using the available experimental data near $\sqrt{s} = 8$ GeV, we have estimated T_i and μ_i as 190 MeV and 1060 MeV respectively. To know the time evolutions of T and μ we have used the equations $n_b \tau = constant$ and $\epsilon \tau^{1+c_s^2} =$ constant assuming $P = c_s^2 \epsilon$ ($c_s^2 = constant$) where P is the pressure and ϵ is the energy density given by $\epsilon = 37\pi^2 T^4/30 + 3\mu^2 T^2 + 3\mu^4/(2\pi^2)$. Using the above mentioned formalism we have estimated invariant-mass and transverse-momentum spectra of thermal di-muon. Using those theoretical calculations we have generated fourmomentum of μ^+ and μ^- and used them in simulation in CBMROOT. To use this we have used FairAsciiGenerator as our primary event-generator. Geometry which is used in this simulation is SIS300. After passing through absorbers and detectors, we have reconstructed the invariant-mass of muon pairs. We have used several cuts like hits in MUCH detectors ≥ 14 , hits in STS detectors ≥ 4 and $\chi^2 < 3$. We have compared reconstructed invariant-mass of muon pairs comming from low mass vector mesons ρ and ω . For ρ and ω , we have used pluto event generator. In Fig. 1 we have shown the reconstructed invariant mass of di-muons. It can be seen that, in low mass region thermal part is burried inside low-mass vector mesons. However, they are important in the intermediate mass region.

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Towards a realistic event generator for in-medium and QGP dileptons

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Until now the hadronic cocktails produced with the event generator Pluto [1] for the HADES and CBM experiments included only a contribution from freeze-out sources.

However as dileptons are radiated from the fireball during the whole space-time evolution, medium effects like the broadening of the ρ should also be included in the simulations. Calculations of the in-medium ρ spectral function by R. Rapp and J. Wambach [2] demonstrate, that a large part of the in-medium ρ mesons feed into the mass region below the ρ/ω pole mass down to zero masses.

The basic idea behind the event generator under development is to simulate an ensemble of events with a transport model like UrQMD [3]. The space-time evolution of these events is then divided into four-dimensional cells (similar approaches have been conducted in [4,5]). Afterwards the quantities needed as input for the Rapp - Wambach spectral function, i.e. temperature T, the baryon chemical potential μ_B (or density ϱ_B) and the collective flow velocity \vec{v}_{coll} , can be extracted locally for each cell.

The observation, that the momentum distributions start after ~ 5 fm/c to resemble Gaussians, suggests a thermalization of the system, thus we have used a Maxwell-Boltzmann fit to determine the temperature of the cell. The net baryon as well as the energy density can be obtained with the four-current method [6].

The temperature and baryon density evolution results in the trajectory of the cell. Figure 1 shows this trajectory followed by the cell at the center of the collision.



Figure 1: Phase-space trajectory of the central cell in Au+Au at 20 AGeV as extracted from UrQMD tranport model calculations. A marker is indicating time evolution in 1 fm/c steps.

The modular structure of Pluto makes it feasible to customize the event generator and incorporate models of inmedium physics, like the Rapp-Wambach spectral function, as well as the emission due to multi-pion annihilation and QGP radiation as plug-ins. If the input parameters to the thermal emission rates exceed a certain threshold we will use the in-medium spectral function for the dileptons emitted from this cell. Otherwise the vacuum spectral functions will be utilized.

Figure 2 shows the hadronic cocktail produced with Pluto for Au+Au collisions at a beam energy of 25 AGeV with the in-medium ρ and ω contributions provided by R. Rapp. In addition the dileptons stemming from QGP radiation are included in the cocktail.



Figure 2: Dilepton cocktail for Au+Au collisions at 25 AGeV produced with Pluto including also in-medium and QGP contributions.

In the upcoming months the focus will lie on the calculation of the dilepton emission rates for different collision systems at FAIR energies with a spectral function package from R. Rapp. Consistency checks will be done as well.

The main objective of this work is then the implementation of this concept into Pluto in such a way as to enable users to pick the collision system of their choice and simulate a realistic dilepton mass spectrum for their analyses.

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Collision centrality determination in the CBM experiment^{*}

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The magnitude of the impact parameter *b* in a heavy-ion collision is not known experimentally. Estimating *b* is important for the study by CBM of many physics observables, e.g. the event-by-event fluctuations of conserved quantities at mid-rapidity or collective flow. The multiplicity of produced particles in the overlap zone of the nuclei can be used as an experimental proxy of the *b* value. All events are sorted in centrality classes, with most central one being the collisions with highest multiplicity ($b \approx 0$) of the produced particles and peripheral one with the lowest multiplicity (when *b* value is about the sum of the radii of the two nuclei). Since the *b* value and particle multiplicity (centrality) class of events only an average \overline{b} value and its spread σ_b can be estimated.

The projectile Spectator Detector (PSD) of the CBM experiment is designed to register forward spectator nucleons and fragments emitted in nucleus-nucleus collisions at very small polar angles. The multiplicity of spectators can also be used as an independent way to determine centrality. In the case of spectator measurements, the most central events correspond to a low spectator multiplicity (small energy deposition in the PSD), while peripheral events result in a large amount of spectators (large energy deposition in the PSD).

The performance of the centrality determination was studied using the DCM-QGSM heavy-ion collision event generator [1]. The PSD was either used as a standalone detector utilizing correlations between the energy deposited in different PSD subevents (segments), or in a combination with the CBM Silicon Tracking System (STS) which measures the multiplicity of produced particles at midrapidity. In the case of the PSD standalone analysis, it was required to have at least 40 GeV of energy in the PSD1 subevent or a total energy in two PSD2 and PSD3 subevents above 15 GeV to exclude very peripheral collisions with only few heavy fragments.

Figure 1 shows the performance of the centrality determination for Au+Au collisions at $E_{beam} = 10$ AGeV. The PSD is positioned at 8 m from the target. Centrality classes are defined by using various detector subevent combinations. The top panel shows the average impact parameter value \bar{b} (central value) and σ_b (as the error bars) versus the centrality estimate from different subevent correlations. The bottom panel presents the same information in terms of impact parameter resolution σ_b/\bar{b} of different centrality es-



Figure 1: Average \overline{b} and width σ_b of the impact parameter distribution (top); impact parameter resolution (σ_b/\overline{b}) vs. centrality (bottom).

timators. The \overline{b} and σ_b were determined from Gaussian fits of the impact parameter distribution for a given centrality class.

The results in Fig. 1 demonstrate that the PSD can be used standalone for the centrality determination and, depending on the collision energy, has a comparable impact parameter resolution σ_b/\bar{b} to that of the STS. This provides an independent method in the CBM experiment for the centrality determination with detected spectator fragments. When used together with the STS detector, the PSD helps to improve the overall centrality determination in the centrality range of 0-40% and allows for centrality determination in narrow classes with a width of at least 5%.

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Multi-strange (anti)baryon enhanced production at FAIR energies

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One of the predicted signatures of the phase transition from nuclear matter to a deconfined phase is the enhanced production of multi-strange particles. Additionally the yield of particles carrying strange (anti)quarks is expected to be sensitive to the fireball evolution and formation of the Quark Gluon Plasma (QGP). In order to estimate the effect of QGP creation in the heavy ion collisions we used PHSD 3.0 model [1] — a microscopic off-shell transport approach that consistently describes the full evolution of a relativistic heavy-ion collision from the initial hard scatterings and string formation through the dynamical deconfinement phase transition to the OGP, as well as hadronization, and to the subsequent interactions in the hadronic phase. The yield of Ω^+ hyperon $(\bar{s}\bar{s}\bar{s})$ seems to be very sensitive to the production mechanism at the FAIR energies. The results of our calculations are shown in Fig. 1, where the red points correspond to the partonic phase mechanism and the blue ones - to subsequent interactions in the hadronic phase. Each point is calculated for 5M central Au+Au



Figure 1: Yields of Ω^+ as a function of the beam energy calculated in the PHSD and HSD models. Each point corresponds to $5 \cdot 10^6$ central Au+Au PHSD (red) or HSD (blue) events.

PHSD (HSD) events. According to the PHSD 3.0 model, most of the Ω^+ particles are produced in the QGP phase.

Multi-strange hyperons will be identified in the CBM experiment by their decays into charged hadrons, which are than detected in the Silicon Tracking System (STS) and the Time-of-Flight (TOF) detector.

To study the performance of multi-strange hyperon reconstruction in the CBM experiment, several sets of $5 \cdot 10^6$ central Au+Au PHSD and HSD events at 4, 6, 10 AGeV for the SIS-100 case and at 15, 25 and 35 AGeV for the SIS-300 energy range have been simulated. The

high statistics allows to calculate also the Ω^{\pm} reconstruction efficiency directly, avoiding signal embedding into the PHSD events. Together with the wide range of the beam energies, it allows to investigate the systematic behavior of different physics observables, e.g. direct and elliptic flow, excitation function and antihyperon-to-hyperon ratios.

The Ω^+ hyperon decays into $\overline{\Lambda}K^+$ with the branching ratio of 67.8% and $c\tau = 2.46$ cm. The STS v13d geometry with 8 double-sided segmented strip detectors, cables and support frames was used for the event reconstruction. Particle identification with the realistic "umbrella" shaped TOF v13a geometry for the SIS-100 energies and v13b for the SIS-300 energies were applied. The KF Particle Finder [2] package was used to reconstruct Ω^+ . A typical reconstructed invariant-mass spectrum is shown in Fig. 2. The red line indicates the fit the signal and background by a polynomial plus Gaussian function.



Figure 2: Reconstructed invariant-mass distribution of $\overline{\Lambda}K^+$ pairs in central Au+Au collisions at 25 AGeV, the red line indicates the signal plus background fit by a polynomial plus Gaussian function.

The Ω^+ reconstruction efficiency results in about 6.2% for central PHSD events. A good signal to background ratio of about 0.36 is observed due to the TOF antiproton particle identification procedure and KF Particle $\overline{\Lambda}$ reconstruction.

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ϕ meson production in Au+Au collisions and its reconstruction feasibility in the CBM experiment

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The CBM experiment at FAIR is aimed to study properties of QCD diagram at high baryon densities and moderate temperatures. One of the most interesting particles among other rare probes is ϕ meson, which consists of $s\bar{s}$ pair and can decay inside the fireball. In that case it carries a direct information about the production of $s\bar{s}$ pairs. Production of ϕ in heavy-ion collisions have earlier been studied in other experiments, such as HADES [1] and NA49 [2], however, the existing up to now data is rather insufficient in the CBM energy range.

To study the production of ϕ mesons at CBM energies and higher, and feasibility of its reconstruction, a minimum bias Au+Au events were generated in the UrQMD-3.4 model at 4–160 AGeV energies. For each energy 1 million of events was generated (see Fig. 1). Among these events only 10% of the most central were considered. The centrality was determined in accordance with the charged multiplicity in the rapidity window of $|y_{c.m.}/y_{beam}| < 0.5$. Additionally, 10⁴ central (impact parameter b = 0 fm) events generated in PHSD-3.0 model [3] were analyzed as well for comparison.

One should note that ϕ meson has a relatively small lifetime ($c\tau \simeq 45$ fm), and there is a certain probability for it to decay inside the fireball. For this reason ϕ meson is not considered as a stable particle in transport models such as UrQMD and PHSD by default. Therefore, in order to calculate the ϕ multiplicity they are forced to be stable with respect to decays in UrQMD and PHSD by adjusting the corresponding flag.

The precise measurements of ϕ/K^- ratio allows to extract the fraction of K^- coming from ϕ decay [1]. The results of calculations for this quantity within UrQMD and PHSD are depicted in Fig. 1. Additionally, experimental data of HADES and NA49 collaborations is shown by symbols with error bars. We note that NA49 data is for Pb+Pb collisions. The data shows a plateau in energy dependence at higher collision energies. This effect is qualitatively well reproduced in UrQMD and PHSD. At low energies $(p_{\text{lab}} \leq 7 \text{ AGeV})$, however, a decrease of the ratio with collision energy is shown by the available data but not by the models. Taking into account that available data in this energy range is rather insufficient, future measurements at CBM may help to clarify the presence of such effect.

In order to study ϕ -mesons reconstruction feasibility 5 millions of central Au+Au events at 6 AGeV were simulated. K^+ and K^- identified in the TOF detector are combined to pairs by the KF Particle Finder package. The resulting invariant-mass distribution for the K^+K^- pairs is shown in Fig. 2 where the ϕ signal is clearly visible.



Figure 1: Energy dependence of ϕ/K^- ratio, calculated in UrQMD and PHSD. Experimental data of HADES and NA49 collaborations is depicted symbols with error bars.



Figure 2: Invariant-mass distribution of K^+K^- pairs for 5 millions of central Au+Au events at 6 AGeV. The shape of combinatorial background is estimated by the mixed-event technique.

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π^0 reconstruction through a γ -conversion method with KF Particle Finder in the CBM experiment^{*}

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The CBM experiment is being designed to study heavyion collisions at extremely high interaction rates and track densities. One of the main observables for CBM are light vector mesons decaying through dilepton channels, that are of the particular importance for the physics program of the experiment. Because of the low branching ratio the key issue for reconstruction of light vector mesons is background suppression. Being a major source of this background, π^0 and γ -conversion have to be carefully studied.

The main decay channel of π^0 is a $\pi^0 \rightarrow \gamma\gamma$ channel with a branching ratio of 98.8%. The γ can be reconstructed in the Silicon Tracking System (STS) when it was converted into an electron-positron pair on the material or support structures of the detector: $\gamma \rightarrow e^+e^-$. To study this decay π^0 reconstruction through a γ -conversion method was implemented in the KF Particle Finder package for short-lived particle reconstruction.



Figure 1: Distribution of γ -particles reconstructed *z*-position. The obtained histogram represents position of the target, a beam pipe window and four stations of the STS detector.

At the first stage tracks from electrons and positrons registered in STS are selected using particle identification (PID) information from the Ring Image Cherenkov Detector (RICH), Transition Radiation Detector (TRD) and Time of Flight (ToF) detector. Selected tracks are combined into γ -candidates. Based on the Kalman filter mathematics, the KF Particle Finder package allows to achieve high reconstruction quality of the particles. For example, distribu-

tion of the reconstructed z-position nicely represents the structure of the detector: the target at 0 cm, the beam pipe window at 26 cm and four stations of the STS detector at 30, 40, 50 and 60 cm (see Fig. 1). Then the γ -candidates within 3σ region around the peak position (0 MeV/c^2) are selected and combined with each other. High quality of the γ -candidates allows reconstruction of π^0 with a width of 1.7 MeV/c^2 and signal to background ratio of 0.77 already for 5 million central AuAu events at 25 AGeV (see Fig. 2).



Figure 2: Mass distribution of $\gamma\gamma$ pairs for 5 million central AuAu events at 25 AGeV using PID information form RICH, TRD and ToF detectors. The peak from π^0 is nicely seen with a width of 1.7 MeV/c^2 and a signal to background ratio of 0.77.

Average gamma conversion factor within the STS detector is about 6.5%. This gives a probability of $4 \cdot 10^{-3}$ for both γ -daughters to produce tracks. Tacking into account efficiency of the track finding, PID detector and particle construction the overall π^0 reconstruction efficiency is about 10^{-6} . However, the big advantage of the method is high resolution and signal to background ratio.

Summarizing, π^0 reconstruction was implemented in the KF Particle Finder package. High quality of the obtained π^0 particles makes it possible to study the background for dielectron decays of the rare probes.

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Rapidity dependent strangeness enhancement of the produced particles at FAIR energies*

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It has now been understood that the width of the rapidity distribution of various produced particles, in addition to kinematic effects, has got a non-trivial baryon density effect as well [1]. The heavy ion collision at FAIR energies, where the baryon density could be something of the order of 5-10 times the normal nuclear matter density, might play a vital role in understanding the role of rapidity distribution of net-baryon density on the width of the rapidity distribution of hadrons containing leading quarks. Furthermore, strangeness enhancement which has been considered as one of the traditional signatures of QGP is studied quite extensively considering strangeness to be conserved both globally and locally. However, Steinheimer et al. [2] predicted from UrQMD calculations that although strangeness is conserved globally, it is not uniformly distributed over rapidity space leading to a local violation of strangeness conservation. Because of the limitation of the detector acceptance, most past and ongoing heavy ion experiments could measure the strangeness enhancement at mid-rapidity only. A number of strange particles do contain leading quark(s) and thus a study of the rapidity dependent strangeness enhancement is of considerable importance. In this work, by generating 93 million UrQMD events, an attempt has therefore been made to study the rapidity dependent strangeness enhancement at FAIR energies.

Following Ref. [3], the strangeness enhancement factor is defined as

$$E_{S} = \left[\frac{(Yield)_{AA}}{\langle N_{\pi^{-}} \rangle}\right]_{central} / \left[\frac{(Yield)_{AA}}{\langle N_{\pi^{-}} \rangle}\right]_{peripheral}.$$

In Fig. 1, E_S is shown as a function of rapidity for various identified particles for Au+Au collisions at 30A GeV. It is interesting that E_S depends strongly on rapidity, and this dependence follows two distinctive patterns. While the enhancement factor at mid-rapidity is found to be maximum for the particles containing leading quarks (filled circle), the same is observed to be minimum at mid-rapidity for the particles containing produced quarks only (open circle). Even though $\Omega^{-}(sss)$, consisting of three produced quarks, is observed to be behaving differently than those hadrons with all its constituents as produced quarks, a slight decrease in the enhancement at mid-rapidity is clearly visible. This apparent anomalous behavior could be due to the contribution of Ξ^- (containing one leading quark), in the production of Ω^- via the $\Xi K^- \to \Omega \pi$ channel.



Figure 1: Strangeness enhancement factor as a function of rapidity for particles containing at least one leading quark (filled circle) and particles containing only produced quarks (open circle) for Au + Au collision at 30A GeV.

To understand the underlying dynamics of such rapidity dependent strangeness enhancement, Fig. 2 shows the widths of the rapidity distribution of identified particles as a function of centrality. Evidently, the different patterns of rapidity dependence of E_S reflect in the dependence of rapidity width on centrality. The width of the rapidity distribution increases when going from central to peripheral collisions for the particles containing leading quarks, a feature that might be attributed to the variation of net-baryon density with impact parameter. Fig.2 also shows that for all particles containing produced quarks only, except Ω^- , the rapidity width follows a decreasing pattern with decreasing centrality for the particles. This observation may be attributed to the fact that the size of the central fireball and hence the scattering effect decreases with the decreasing centrality.



Figure 2: Rapidity width as a function of impact parameter for identified particles for Au + Au collision at 30A GeV.

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Strange meson-baryon interaction in hot and dense nuclear matter: from hadronic models to transport simulations*

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Introduction

We study the dynamics of strange pseudoscalar and vector mesons in hot and dense nuclear matter within a selfconsistent coupled-channel approach based on the mesonbaryon chiral Lagrangian. Our results set up the starting point for implementations in microscopic transport approaches of heavy-ion collisions, particularly at the conditions to be met in the future experiments at GSI/FAIR and NICA@Dubna. Such developments are in progress, exploiting the successful collaboration between the transport groups of Nantes and FIAS-Frankfurt.



Figure 1: In-medium transition probability \mathcal{P} for the elastic K^-p (left) and K^-n (right) reactions. The peaks associated to the $\Lambda(1115)$, $\Sigma(1195)$ and $\Lambda(1405)$ resonances are clearly visible in the vacuum case.

$ar{K}N$ interaction in hot and dense matter

In the $\bar{K}N$ sector we focus on the calculation of inmedium (off-shell) transition rates for the most relevant binary reactions involved in strangeness production close to threshold energies (e.g. $\bar{K}N \rightarrow \pi\Sigma$), with special attention to the role of sub-threshold hyperon resonances ($\Lambda(1405)$), $\Lambda(1115)$, $\Sigma(1195)$ and $\Sigma^*(1385)$), isospin effects (e.g. $\bar{K}p$ vs $\bar{K}n$, cf. Fig. 1) and the angular dependence of the scattering amplitudes and cross sections (s and p waves are accounted for). Together with the spectral function and the nuclear optical potential of strange mesons and hyperons, our results permit a systematic accounting of medium effects in the S = -1 sector regarding the production, propagation and rescattering of light strange hadrons.

Strange vector mesons: K^* , \bar{K}^* and ϕ

We have also pursued recent theoretical developments regarding the dynamics of strange vector mesons $(K^*, \bar{K}^*$ and ϕ) in the nuclear medium, in connection with experimental activity from heavy-ion collisions and nuclear production reactions. Our work focuses on the extension to finite temperatures of previous chiral hadronic models for the vector meson self-energy in dense matter (cf. Fig. 2), where the key mechanisms for medium modification are: (i) the excitation of strange baryon resonances in quasielastic scattering (e.g. $\bar{K}^*N \rightarrow \bar{K}^*N$), which translates into resonance-hole modes that mix with the vector-meson quasiparticle peak; and (ii) the decay into hadronic modes (e.g. $\bar{K}^* \rightarrow \bar{K}\pi$), where the daughter particles are also dressed and low-energy modes are Bose-enhanced.



Figure 2: Temperature evolution of the $\bar{K}^*(K^*)$ width – or self-energy – due to $\bar{K}(K)\pi$ in-medium decays

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K^{*} dynamics in a nuclear medium^{*}

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The K^* and the \bar{K}^* are vector mesons that are composed of a light and a strange quark, i.e. the K^* is composed of a u and a \bar{s} quark and the \bar{K}^* is composed of a u and a squark. We study the in-medium properties of these mesons in a dense and hot nuclear medium. The in-medium properties are based on chirally motivated models and these in-medium effects are parametrised as density or temperature dependent effective masses and widths. For broad in-medium particles we adopt the relativistic Breit-Wigner prescription, i.e. the spectral function

$$A_{i}(M,\rho_{N}) = \frac{\frac{2}{\pi} \cdot C_{1} \cdot M^{2} \cdot \Gamma_{i}^{*}(M,\rho_{N})}{\left(M^{2} - M_{i}^{*2}(\rho_{N})\right)^{2} + \left(M\Gamma_{i}^{*}(M,\rho_{N})\right)^{2}},$$
(1)

where C_1 stands for a normalisation constant, which is determined as the spectral function must fulfil the sum rule $\int_0^\infty A_i(M,\rho_N) dM = 1$, and $i = K/\bar{K}, K^*/\bar{K}^*$.

The in-medium effects are based on the complex selfenergy obtained by solving the strange meson (off-shell) dispersion relation $E^2 - |\vec{p}^2| - M_i^2 - \Pi_i = 0$, i.e. the width of the spectral function is related to the imaginary part of the self-energy as

$$\operatorname{Im}\Pi_i(M,\rho_N) = -\Gamma_i^*(M,\rho_N) \cdot M \tag{2}$$

and the mass shift is related to the real part of the selfenergy as

$$\operatorname{Re} \Pi_{i}(M_{i}^{*}, \rho_{N}) = M_{i}^{2} - (M_{i}^{*})^{2}$$
(3)

(with M_i being the nominal mass in vacuum, i.e. $M_{K^*} = 0.892 \text{ GeV}$). A vacuum width of $\Gamma_V^0 = 42 \text{ MeV}$ has been used throughout all of our calculations for the vector mesons.

We distinguish two scenarios for energies where the medium is dense and is filled with baryonic particles (FAIR; $\mu_B \neq 0, T \approx 0$) and when the medium is hot and filled with pionic particles (RHIC, LHC; $\mu_B \approx 0, T \neq 0$). The behaviour of strange vector mesons is different for these two media. Additionally the behaviour of a strange



Figure 1: The K^* spectral function is shown as a function of the invariant K^* mass μ for different temperatures T. The blue solid line is for the vacuum case, the orange dotted line is for a temperature of T = 0.09 GeV and the green dashed line is for a temperature of T = 0.15 GeV. The same results are shown on a linear (left plot) and on a logarithmic (right plot) scale.

particle is different from the behaviour of a strange antiparticle in a dense nuclear medium, whereas it is the same in a hot nuclear medium (we are dealing with an isotopically symmetric pionic medium).

In figure 1 one can see spectral function for the K^* (and consequently the $\bar{K^*}$) in a hot, pionic medium. The effects of the medium are negligible, there is only a small mass shift and a very small broadening. However, when looking at the logarithmic plot one can see that the K^* gains some enhancement in the low mass region at temperatures T > 0.

For the K^* in a dense nuclear medium the width of the K^* decreases with increasing density since the kaon becomes slightly heavier as a result of the repulsive KN interaction. However, this is compensated by the repulsive self-energy from the K^*N interaction. The resulting K^* self-energy in a $t\rho$ approximation leads to a mildly repulsive K^* mass shift of about 5% (30 MeV) at a density of $\rho_N = \rho_0$. The change in the shape of the spectral function is negligible.

The major effects for the \bar{K}^* in a dense nuclear medium come mainly from both the $\bar{K}\pi$ decay channel and from the highly inelastic \bar{K}^*N interaction, leading to decay widths as large as 200 MeV at normal nuclear matter density $\rho_N = \rho_0$.

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Creation and annihilation of antimatter at FAIR energies*

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The 'Big Bang' scenario implies that in the first microseconds of the universe the entire state has emerged from a partonic system of quarks, antiquarks and gluons – a quarkgluon plasma (QGP) – to color neutral hadronic matter consisting of interacting hadronic states (and resonances) in which the partonic degrees of freedom are confined. Nowadays this early phase can be reproduced in relativistic heavy ion collisions. They show indeed that such a QGP can exists and that it interacts more strongly than hadronic matter. Consequently the concept of a weakly interacting system described by perturbative QCD (pQCD) has to be questioned.

The dynamics of partons, hadrons and strings in relativistic nucleus-nucleus collisions can be analyzed within the Parton-Hadron-String Dynamics approach [1, 2]. In this transport approach the partonic dynamics is based on Kadanoff-Baym equations for Green functions with self-energies from the Dynamical QuasiParticle Model (DQPM) which describes QCD properties in terms of 'resummed' single-particle Green functions [3]. The lattice QCD results, of which the parameters of DQPM are fitted on, lead to a critical temperature $T_c \approx 160$ MeV which corresponds to a critical energy density of $\epsilon_c \approx 0.5$ GeV/fm³.

The aim of this project is to study, with the help of PHSD, the creation and annihilation of anti-matter at the FAIR facility in the future CBM and PANDA experiments. Since anti-matter (or antiparticles) does not exist in our world it has to be created first by strong interactions before its dynamics can be studied in different hadronic or partonic environments. These experiments aim at the exploration of the QCD phase diagram, especially to find out the order of the phase transition between hadrons and partons at high baryonic densities. In addition we will study the optical potential of different hadrons and the in-medium properties of hadrons in the strange and the charm sector. To verify that our approach is adequate for this study we start out with the calculation of the measured spectra of particles and anti-particles at RHIC energies. We have found a good agreement with the PHENIX data for single particle spectra in Au+Au (figure 1) and p+p (figure 2) collisions at mid-rapidity. One can see that the production of particles and anti-particles in pp collisions is very similar while in Au+Au collisions we observe the effects of anti-baryon absorption at low p_T as well as rescattering on the partonic and hadronic levels.



Figure 1: Invariant p_T spectra in Au+Au collisions at $\sqrt{s_{NN}} = 130 \text{ GeV}$ for π^+ , π^- , K^+ , K^- , p, \bar{p} , Λ and $\bar{\Lambda}$ obtained with PHSD, in comparison with the experimental data from the PHENIX collaboration [4, 5]



Figure 2: Invariant p_T spectra in p+p collisions at $\sqrt{s} = 200$ GeV for π^+ , π^- , K^+ , K^- , p and \bar{p} obtained with PHSD in comparison with the experimental data from the PHENIX collaboration [6]

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Simulation results on elliptic flow at FAIR energies

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In high-energy heavy-ion collisions elliptic flow refers to a preferential emission of particles with respect to a given azimuthal angle [1]. The magnitude of this effect is characterized by an elliptic flow parameter, defined as [2]:

$$v_2 = \left\langle \cos 2(\phi - \psi) \right\rangle$$

where ϕ is the azimuthal angle of an outgoing particle, ψ is the azimuthal angle of the impact parameter, and the angular brackets denote averaging over many particles and many events. In this preliminary investigation we report some aspects of the elliptic flow in Au–Au collision at $E_{lab} = 20$ A GeV and 40A GeV, using the UrQMD [3] and the AMPT model (both default and string melting versions) [4]. The results are based on a statistics of 2×10^5 events for each simulation. The initial spatial anisotropy of the created system is quantified by the eccentricity [5]:

$$e_{std} = \left(\sigma_y^2 - \sigma_x^2\right) / \left(\sigma_y^2 + \sigma_x^2\right)$$

where σ_x , σ_y denote the standard deviations of the x, y coordinates of the participating nucleons in the transverse plane. However, even at fixed impact parameter the number of participating nucleons (N_{part}) and their positions can fluctuate from event to event. To address this issue the eccentricity is redefined [5]:

$$e_{part} = \sqrt{(\sigma_y^2 - \sigma_x^2)^2 + 4(\sigma_{xy})^2} / (\sigma_y^2 + \sigma_x^2)$$



Figure 1: v_2 versus N_{part} from AMPT-SM for 20A and 40A GeV

In Fig. 1 we plot v_2 as a function of N_{part} for both incident energies using the AMPT code. We see that the nature of variation of v_2 is almost independent of the incident energy at this energy scale. This also holds for results from UrQMD and AMPT without string melting. Figure 2 compares model results on v_2 at $E_{lab} = 20$ A GeV. Results of all models nearly follow the same pattern, the UrQMD plot being slightly more symmetric than the AMPT plots. Because of the strong asymmetry of the nuclear overlap region in the mid-central collisions, v_2 is large. For the AMPT-string melting model v_2 values of peripheral and mid-central events are found to be the largest.



Figure 2: v_2 versus N_{part} for different models at 20A GeV

In Fig. 3 we have plotted v_2/e_{std} and v_2/e_{part} against N_{part} for all three models at $E_{lab} = 20$ A GeV. Within errors v_2/e appears to scale with N_{part} . Several other aspects of elliptic flow like variation of v_2 with transverse momentum and pseudo-rapidity (not shown here) were also examined.



Figure 3: v_2/e_{std} (left) and v_2/e_{part} (right) versus N_{part}

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Generation of Drell-Yan di-muons at FAIR

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The measured di-muon invariant mass spectrum, in relativistic heavy-ion collision experiments, is a superposition of different sources coming from various origins. In order to disentangle different sources and to estimate their respective experimental acceptances, each process needs to be studied independently using a Monte Carlo (MC) simulation method within the given experimental conditions. In this report we describe our recent efforts to develop a MC code to generate muon pairs from the Drell-Yan (DY) process in the FAIR energy regime. Our approach closely follows the methods developed by the NA50 Collaboration for di-muon simulations [1]. For a complete kinematic description of a particle, one needs to know its charge, mass and momentum. Thus when studying pairs, there are ten independent parameters. The DY process is the electromagnetic annihilation of a quark and anti-quark of the same flavor, with the creation of a virtual photon that decays into a lepton pair. In this case some of the ten parameters are constrained by charge and four-momentum conservation. For complete characterization of the DY pair four independent variables namely, pair mass $(M_{2\mu})$, rapidity in the centre of mass frame (y^*) , transverse momentum p_T and di-muon azimuthal angle are required. Decay of a di-muon into two single muons introduces two additional degrees of freedom which can conveniently chosen to be the polar (θ_{cs}) and azimuthal (ϕ_{cs}) angle of one of the two muons in the Collins-Soper reference frame. For calculation of the DY distributions, we adopt the following parametrization of the kinematic variables in our code. The pair mass and rapidity distributions can be parametrized following the double differential cross section from leading order perturbation theory:

$$\frac{d^2\sigma(AB \to \mu^+\mu^-)}{dy^* dM} =$$

$$K_{DY} \frac{8\pi\alpha^2}{9M^3} \sum_q e_q^2 [F_q^1(x_1, M^2) \times F_{\bar{q}}^2(x_2, M^2) + F_{\bar{q}}^1(x_1, M^2) \times F_q^2(x_2, M^2)]$$
(1)

where M is invariant mass of the produced dilepton, $\alpha = e^2/4\pi$ is the fine structure constant and x_1, x_2 respectively represent the projectile and target nucleons momentum fractions carried by partons with charge e_q in a collision of centre of mass energy \sqrt{s} and can be written as $x_{1,2} = \frac{M}{\sqrt{s}}exp(\pm y^*)$. $F_q(F_{\bar{q}})$ denotes the parton distribution function for quarks (anti-quarks). $K_{DY} \sim 2$ takes

care of higher order contributions. Integrating the above equation over pair mass or rapidity, one gets single differential distributions in pair rapidity or mass. The differential p_T distributions are generated using a Bessel function of the transverse mass m_T as $\frac{dN}{dp_T} \propto p_T m_T K_1(m_T/T)$, where K_1 is the first order modified Bessel function, and T = 170 MeV, consistent with the modeling of p_T distribution in J/ψ simulations. DY pairs are then decayed into two muons in the pair rest frame which are then boosted to the laboratory frame. The distributions of the decay angles are generated with the following parametrization. A uniform distribution is chosen for ϕ_{cs} , and for the polar angle distribution we have used $\frac{dN}{dcos(\theta_{cs})} \propto 1 + \lambda cos^2(\theta_{cs})$, where $\lambda = 1$ as measured by the NA10 experiment.



Figure 1: Invariant mass distribution of the di-muons from the Drell-Yan process, generated over the full phase space

The result of our calculations is displayed in Fig. 1. It shows the invariant mass distribution of the DY muon pairs for 25A GeV Au+Au collisions, generated over the full phase space (4π). The invariant mass is calculated from the four momentum of the two single muons in the lab frame and in the pair mass region $2 \le m_{DY} \le 4 \text{ GeV}/c^2$.

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Heavy-quark dynamics in a hot and dense medium^{*}

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Introduction

We study the dynamics of on- and off-shell heavy quarks Q in the quark-gluon plasma (QGP) as produced in relativistic nucleus-nucleus collisions. The interactions of heavy quarks with the partonic environment at finite temperature T and finite quark chemical potential μ_q are investigated in terms of transport coefficients within the dynamical quasiparticle model (DQPM) designed to reproduce the lattice-QCD (lQCD) results (including the partonic equation of state) in thermodynamic equilibrium. The collisional scattering cross sections σ_{elas}^Q are evaluated for perturbative partons (massless on-shell particles) and for dynamical quasi-particles (massive on or off-shell particles) using the leading order Born diagrams [2, 3].

Charm spatial diffusion coefficient

Based on σ_{elas}^Q in a finite T and μ_q medium [1, 2, 3, 4], the on- and off-shell heavy quark dynamical collisional energy loss and transport coefficients are computed [1, 3, 4]. As an example, the charm spatial diffusion coefficient D_s is shown in Fig. 1 at finite T (top) and finite T and μ_q (bottom) where our non-perturbative DpQCD model (Dressed pQCD using DQPM pole masses for the partons) is confronted with nuclear many-body calculations below and close to the critical temperature T_c from Ref. [5].

The hadronic and partonic D_s join smoothly and show a pronounced minimum close to T_c at $\mu_q = 0$ as well as at finite μ_q . Close to and above T_c its absolute value matches the IQCD calculations for $\mu_q = 0$. The smooth transition of the heavy-quark transport coefficients from the hadronic to the partonic medium corresponds to a crossover transition in line with lattice calculations, and differs substantially from perturbative-QCD calculations (Moore & Teaney) which show a large discontinuity at T_c . This indicates that in the vicinity of T_c dynamically dressed massive partons should be the effective degrees of freedom in the quark-gluon plasma.

The heavy quark scattering cross sections and transport properties [1, 2, 3, 4] form the basis of a consistent study of the heavy quark dynamics in heavy-ion collisions at FAIR, SPS, RHIC and LHC energies where the partonic processes are implemented into the Parton-Hadron-String-Dynamics (PHSD) transport approach.



Figure 1: Spatial diffusion coefficient for heavy quarks, D_s , as a function of T for $\mu_q = 0$ (top) and $\mu_q \neq 0$ (bottom). The hadronic diffusion coefficient is taken from [5]. For partonic environment the result from the DpQCD model is compared to pQCD [6], and lattice calculations from Ref. [7]

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Workshop on the Silicon Tracking System of CBM at FAIR: Towards production readiness

Monastery Heiligkreuztal, Swabian Alb, Germany, 16 - 18 June 2014

The CBM Silicon Tracking System Project held a comprehensive workshop in June 2014, focused on achieving production readiness, the start signal for series construction of the detector components. The meeting was locally organized at Monastery Heiligkreuztal near Tübingen, Germany, by the CBM team of the University of Tübingen (H.-R. Schmidt et al.), offering a pleasant and quiet environment stimulating the project's discussions. The 33 participants comprised physicists and engineers from the STS institutes in Germany, Poland, Russia and Ukraine. During dedicated expert work group sessions, detailed assessment of the current development status and concrete planning of the upcoming tasks on the silicon sensors, the read-out electronics, module and ladder assembly, system integration and cooling emerged. The meeting concluded with detailed input to the project plan, with timeline of tasks, work teams, and milestones to monitor for the STS project's progress.



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Workshop on module assembly for the CBM Silicon Tracking System

Kharkiv, Ukraine, 15 + 16 January 2014

At the beginning of 2014, members of the CBM Silicon Tracking System Project met in Kharkiv, Ukraine, to address technology developments and the planning of the pre-series production of STS detector modules. The meeting was hosted by the company *LED Technologies of Ukraine Ltd* (http://ltu.ua) to which our technology partners previously affiliated with the Ukrainian *State Enterprise for Scientific Research Technological Institute of Instrument Engineering (SE SRTIIE)* had recently moved. The company's main business is modern lighting technology for the ukrainian market. It also comprises an international division, headed by Prof. V. Borshchov, that engages in instrumentation for international scientific research projects.

The concrete outcome of the meeting was a task list and schedule for technology developments needed on module assembly for the CBM STS project. The work could be supported lateron by GSI with funds and assembly machinery through mediation by an STCU project. During the meeting, also work aspects of current and forthcoming participation in the European Projects HadronPhysics3 (work package ULISINT) and HadronPhysicsHorizon (work package NOVITEC, planned) were discussed.



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