Overview of the CBM detector system

Tomáš Balog

GSI Helmholtzzentrum für Schwerionenforschung GmbH, Planckstrasse 1, 64291 Darmstadt, Germany
E-mail: t.balog@gsi.de

Abstract. The Compressed Baryonic Matter (CBM) experiment at the future Facility for Antiproton and Ion Research (FAIR) is a fixed target experiment designed to explore the QCD phase diagram in the region of high net-baryon densities. The CBM detector system will access beams directly from the superconducting synchrotrons SIS100 and SIS300. It is designed for interaction rates up to $10^7$ Hz to enable measurements of rare observables and diagnostic probes created in the early and dense phase of the fireball evolution. The layout of the CBM detector system is adapted to the experimental requirements concerning the acceptance in the laboratory frame (mid and forward rapidities), reaction rates, radiation tolerance, determination of the vertices with accuracy of 50 µm, particle densities (up to 700 particles passing through the active area of the detector in single central Au+Au collision at 25 GeV/nucleon) and selectivity [1, 2].

The technical challenge for the detector system (Fig. 1) is to identify both hadrons and leptons and to filter the rare probes. The measurements will be performed via nucleus-nucleus, proton-nucleus and proton-proton interactions at different beam energies. Proton-proton interactions are required for the baseline determination ("normal nuclear matter"). For the particle identification, especially multi-strange hyperons, hypernuclei, vector mesons decaying into lepton pairs and particles with charm quarks the background suppression is required even at the highest interaction rates [2]. Thus the track reconstruction of each individual particle passing through the detector system has to be made online and filtered with respect to the physics requirements.

Figure 1. Left - electron configuration and right - muon configuration of the CBM experiment [1].

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.
Published under licence by IOP Publishing Ltd
In such case the hierarchical trigger system can not be applied and self-triggered read-out electronics will be used instead. In addition high speed data processing, transition and analysis using fast algorithms are prerequisites for such system. The essential factor is the data transport and computational throughput rather than the decision latency.

The CBM detector system will provide both electron and muon detection systems in order to take advantage of both measurement methods. Muon and electron pairs created during particle decays will be measured during separate runs in order to control the systematic approach of the measurements. The acceptance of the detector systems as coming from the physics requirements is full $2\pi$ for $\varphi$ (azimuth) and from $2.5^\circ$ to $25^\circ$ for $\Theta$ (polar angle). In electron configuration following detectors will be used: Micro-vertex Detector (MVD), Silicon Tracking System (STS), both placed in gap of 1 T superconducting magnet, then Ring Imaging Cherenkov Detector (RICH), Transition Radiation Detectors (TRD), Resistive Plate Chambers for time-of-flight measurements (TOF), Electromagnetic Calorimeter (ECAL) and Projectile Spectator Detector (PSD) as hadronic calorimeter. In muon configuration the RICH detector will be replaced by the Muon Detection System (MUCH) and ECAL will be removed [1].

**Dipole magnet:** The dipole magnet of CBM will be superconducting with a large aperture (Fig. 2). The coils (each with 1749 turns and cooled by liquid helium) will provide a magnetic field with total bending power 1 Tm. The total weight of the magnet will be 160 tons. In the aperture the MVD and STS detector system will be placed [2].

**Figure 2.** Left - engineering view of the CBM dipole magnet and right - magnetic field map [3, 4].

**Figure 3.** Left - engineering view of the MVD, middle - examples of the hit position resolution in MIMOSA-26 sensors and right - radiation hardness measurements for different sensors tested for the development of the MVD.

**Micro-Vertex Detector (MVD):** Micro-Vertex Detector will be built from of Monolithic Active Pixel Sensors (MAPS) with pixel sizes $18 \times 18 \ mu m^2$ and $20 \times 40 \ mu m^2$. Depending on the pixel size
the hit position resolution varies from 3.5 \( \mu m \) to 6 \( \mu m \) resulting in secondary vertex resolution of 50 \( \mu m \) to 100 \( \mu m \) along the beam axis (Fig. 3). The detector will consist of 3 stations placed 5, 10 and 15 cm downstream of the target in vacuum box. The material budget of sensors in each of the stations together with cooling and support structures is kept between 300 \( \mu m \) and 500 \( \mu m \) of silicon equivalent \([2]\). For a SIS300 running scenario the hardness against nonionizing radiation is required to be above \( 10^{13} \) neutron equivalent per cm\(^2\) (n\(_{eq}\)/cm\(^2\)) and for ionizing radiation to be above 3 Mrad. Time resolution of the sensors is expected to be below 30 \( \mu s \). Currently tested chip, called MIMOSA-26, fulfils most of the requirements giving the hit position resolution of about 4 \( \mu m \), and having radiation hardness for non-ionizing radiation well above \( 10^{13} \) n\(_{eq}\)/cm\(^2\) \([3]\).

**Figure 4.** Left - engineering view of the STS, middle - simulated momentum resolution (\( \Delta p/p = 1.3\% \) for high momenta) with realistic material budget of all STS stations and two most right - tracks obtained with a test detector system including three STS stations in a 2.4 GeV/c proton beam \([2]\).  

**Silicon Tracking System (STS):** Following the MVD downstream of the target is the Silicon Tracking System (STS), also placed inside the aperture of the dipole magnet. It will provide the track reconstruction and momentum determination of the charged particles. It will be built out of 8 tracking layers populated with double-sided micro-strip silicon sensors placed from 30 to 100 cm distance from the target. To obtain required momentum resolution \( \Delta p/p \approx 1\% \) the stations have to have an ultra low material budget (Fig. 4). Thus the front-end electronics will be placed outside the active area of the STS and the sensors will be interconnected to the read-out chip via low-mass cables \([2]\). The stations are arranged in four duplets. The strips of the sensors are 2, 4, 6 cm and 12 cm when two sensors with 6 cm strip length are daisy-chained. Each of the sensors comprises 1024 channels with strip pitch 58 \( \mu m \). The stereo angle is 7.5\(^\circ\). The thickness of the used sensors will be 300\( \pm 15 \) \( \mu m \) \([2]\).

**Ring Imaging Cherenkov Detector (RICH):** When CBM will operate in electron configuration the Ring Imaging Cherenkov Detector follows the STS. It is foreseen to be used for the identification and suppression of pions in the momentum range below 10 GeV/c \([1]\). The gas radiator (length 1.7 m) consists of CO\(_2\) where the pion threshold for Cherenkov is 4.65 GeV/c. The Cherenkov radiation will be reflected by mirrors built from 72 mirror tiles with a curvature of 3 m radius and Al+MgF\(_2\) reflective coating (Fig. 5). The photo-detector plane where photons will be reflected will be built from Multi-Anode Photo Multiplier Tubes (MAPMT) and will be shielded from the magnetic field \([2]\).

**Muon Chamber System (MUCH):** In the muon configuration of the CBM experiment the STS is followed by the Muon Chamber System. The main role of MUCH is to detect the muons from J/\( \Psi \) and light vector meson decays in an environment of high particle densities \([1]\). MUCH
Figure 5. Left - engineering view of the RICH detector, middle - Cherenkov light photons as seen in RICH and right - electron-pion identification as measured during beam-time [4].

Figure 6. Left - engineering view of the MUCH detector, middle - efficiency as a function of hit rate showing efficiency above 90% up to 5 MHz/cm$^2$. Right - beam-test setup [4].

Figure 7. Left - engineering view of the TRD detector for electron setup, middle - engineering view of the TRD detector for muon setup and right - pion (black) and electron (red) identification as measured during an in-beam test [4].

will provide particle tracking and perform momentum dependent muon identification using and instrumented hadron absorber. The absorber will be segmented into several layers with triplets of tracking Gas Electron Multiplier (GEM) detectors in the gaps [2]. The design consists from 6 absorber layers made of iron and 18 gaseous tracking chambers (Fig. 6). The expected hit rate reaches 3 MHz/cm$^2$ in the first detector system. At SIS100 a MUCH start version will be used which will consist from three chamber triplets with three absorbers [2].

Transition Radiation Detector (TRD): The Transition Radiation Detector will be used for identification of electrons and pions with $p > \text{GeV/c}$ ($\gamma \geq 1000$) [1]. It will consist out of three transition radiation detector stations. The TRD readout will be realized in rectangular pads.
providing resolution of 300 $\mu$m - 500 $\mu$m across and 3 mm - 30 mm along the pad (Fig. 7) [2]. Every second transition radiation layer is rotated by 90°. The pion suppression factor obtained will be well above 100 at electron identification efficiency 90%. The expected hit rate in TRD is up to 100 kHz/cm². In the SIS100 setup only one station of TRD will be used as an intermediate tracker between the STS and the Time-of-Flight wall [2].

**Time-of-Flight Wall (TOF):** An array of Timing Multi-gap Resistive Plate Chambers will be used for hadron identification via time-of-flight measurements [1]. It will cover an area of 120 m² using pad structures for the inner areas and strip structures for the outer zones. The hit rates in the inner zones are expected to reach 25 kHz/cm² and 10 kHz/cm² in the outer areas. The required time resolution of the chambers is 80 ps (Fig. 8) [2].

**CBM calorimeters:** In the CBM detector the Electromagnetic Calorimeter (ECAL) will be used to measure photons and neutral mesons ($\pi^0$, $\eta$) decaying into photons (Fig. 9) [1]. The Projectile Spectator Detector (PSD) will provide measurements of centrality and reaction plane (Fig. 9). It is designed to determine the number of non-interacting nucleons from a projectile nucleus in nucleus-nucleus collisions. Both calorimeters have a “shashlik” structure build from lead/scintillator layers.

![Figure 8](image1.png)  
**Figure 8.** Left - engineering view of the TOF detector, middle - efficiency and time resolution as a function of the hit rate for pads and right - efficiency and time resolution as a function of the hit rate for strips [3, 4].

![Figure 9](image2.png)  
**Figure 9.** Left - engineering view of the ECAL, middle - engineering view of the PSD and right - centrality determination using PSD as simulated for Au+Au collisions at 10 AGeV.

**References**

[1] B. Friman et al. (Eds.), The CBM Physics Book, Lect. Notes Phys. 814, Springer-Verlag, 2011
[2] GSI Report 2013-4, Technical Design Report for the CBM Silicon Tracking System (STS), October 2013, http://repository.gsi.de/record/54798
[3] GSI Report 2013-1, May 2013, GSI Scientific Report 2012, http://repository.gsi.de/record/52876
[4] CBM Progress Report 2012, April 2013, https://www-alt.gsi.de/documents/DOC-2013-Mar-49.html