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ELEMENTARY PARTICLES AND FIELDS
Experiment

The CBM Experiment—a Status Report*

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Abstract—The CBM experiment is being designed to study strongly interacting matter at high densities with nuclear collisions up to 45 *A* GeV beam energy at the future FAIR centre. With interaction rates unprecedented in heavy-ion collisions, CBM will give access also to extremely rare probes and thus to the early stage of the collisions, in search for the first-order phase transition from confined to deconfined matter and the QCD critical point. The conceptual design of the experiment is consolidated, and the project has entered the R&D and technical design phase. We report on the project status, putting enphasis on recent progress and developments.

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1. INTRODUCTION

Nuclear collisions at incident beam energies from 10 to 45 *A* GeV provide the tool to study strongly interacting matter at moderate temperatures but very high net-baryon densities. Indeed, different models of heavy-ion reactions agree in the fact that in the center of the fireball created at such energies, densities more than ten times the nuclear ground state density are reached for a considerable period of time (see Fig. 1). Moreover, the tentative trajectories of such collisions in the QCD phase diagram as obtained from both the Ultrarelativistic Quantum Molecular Dynamics (UrQMD) model [2] and a 3D fluid hydrodynamic model [3] surpass the conjectured phase boundary from confined to deconfined matter and pass close to the critical point of QCD separating the region of first-order phase transition from that of a cross-over (Fig. 2). These findings motivate the hope that the prominent landmarks of the QCD phase diagram can be experimentally discovered using heavy-ion reactions at intermediate energies.

Several experimental programs have been launched accordingly: the STAR beam energy scan at RHIC, the NA61/SHINE project at CERN-SPS, and the NICA–MPD project at JINR. In contrast to these activities, the CBM (Compressed Baryonic Matter) experiment at the future facility FAIR is being designed to cope with very high interaction rates and gives thus access to extremely rare diagnostic probes such as the production of charm and multi-strange hyperons near threshold.

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The motivation and the experimental program of CBM were described in previous issues of this conference series [4, 5]. In this contribution, we will focus on the current status and latest developments of the CBM project.

2. THE CBM EXPERIMENT

CBM is one of the major scientific projects at the Facility for Anti-Proton and Ion Research (FAIR) which will be constructed in Darmstadt, Germany. Besides serving a variety of physics research areas with anti-proton and rare isotope beams, FAIR will deliver ion beams from 2 to 45 *A* GeV (35 *A* GeV for heavy ions) with intensities of 2×10^9 per second on external targets. A schematical layout of the accelerator complex is shown in Fig. 3.

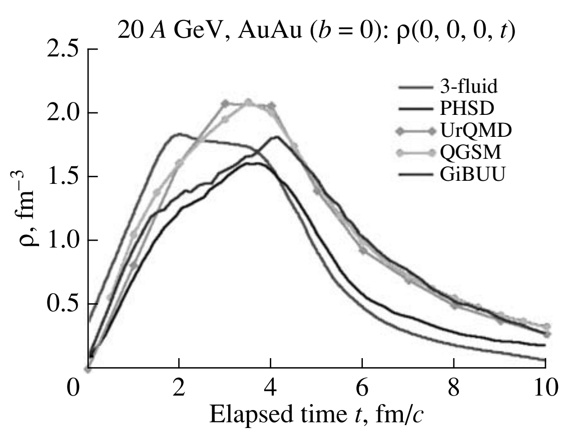

Fig. 1. Net-baryon density in the center of the fireball as function of time, obtained from different model calculations for central AuAu collisions at 20-*A* GeV beam energy [1].

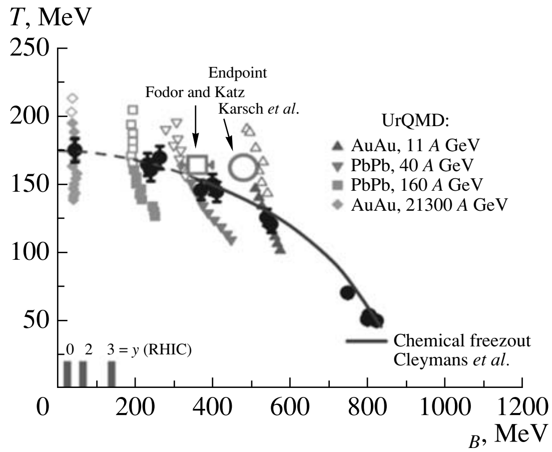

Fig. 2. Trajectory of heavy-ion collisions in the QCD phase diagram obtained from the UrQMD model [2].

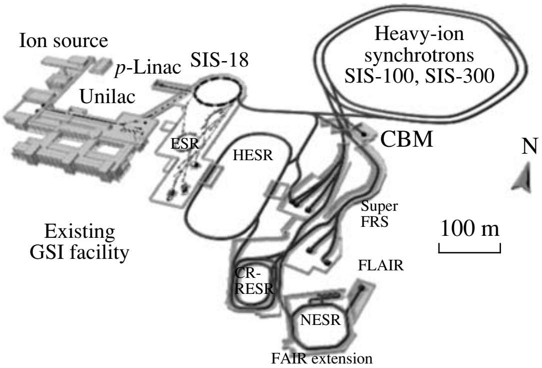

Fig. 3. Schematic layout of the FAIR accelerator center in Darmstadt.

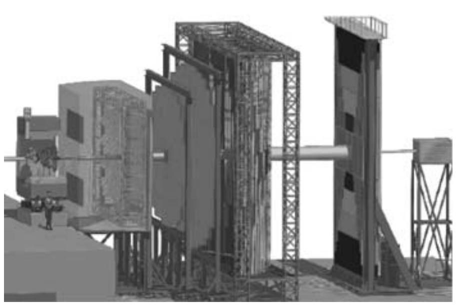

Fig. 4. CBM setup for electron and hadron measurements. The beam enters from the left. The vertex detector and the main tracking system are located inside the dipole magnet. Upstream are RICH and TRD for electron identification, TOF for hadron identification, the electromagnetic calorimeter and a forward calorimeter for event characterization.

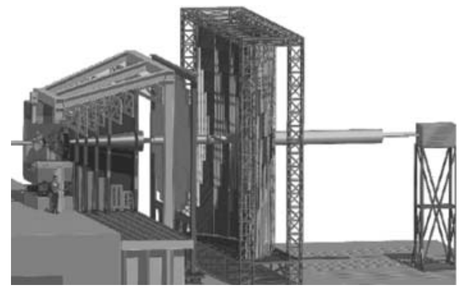

Fig. 5. CBM setup for muon measuerements. The RICH detector of Fig. 4 is replaced by an absorber system interlayed with tracking devices.

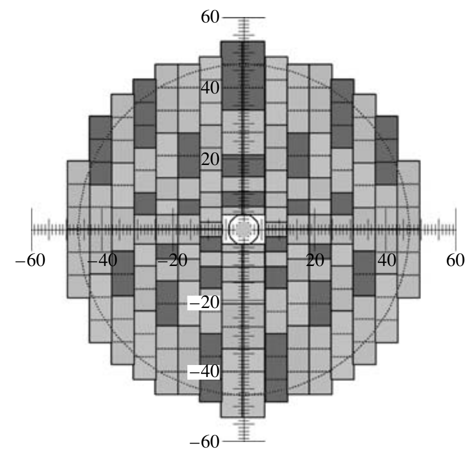

Fig. 6. Design of a STS station made up of double-sided silicon strip sensors.

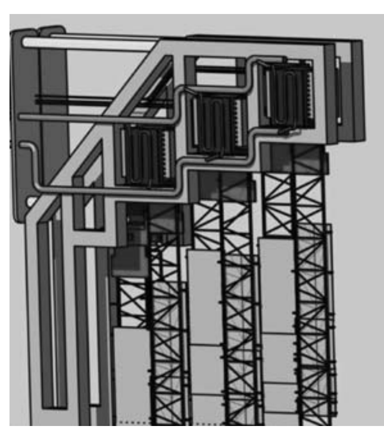

Fig. 7. Detail of STS system integration design, with mechanical support, front-end electronics and cooling.

CBM shall measure hadronic, leptonic and photonic observables in a fixed-target setup with interaction rates up to 10^7 Hz in a large acceptance. It shall cover the measurement of bulk hadrons, multi-strange hyperons, low-mass dilepton pairs as well as hadronic decays of open charm and leptonic decays of charmonia. The experiment thus comprises track reconstruction in a silicon tracking system, electron identification by RICH and TRD detectors, hadron identification by a time-of-flight system, photon measurement in an electro-magnetic calorimeter and micro-vertexing capabilities by a dedicated vertex detector close to the target. Alternatively to the electron detectors, an active absorber system will be used to perform muon measurements. The two setup versions are depicted in Figs. 4 and 5, respectively.

By now, the baseline design of the CBM experiment is consolidated, and the feasibility of the measurement of the main observables was demonstrated [4–6]. The activities are now shifting towards the development of detectors matching the requirements imposed by the variety of physics observables and the extreme interaction rates.

3. DETECTOR DEVELOPMENTS

The measurements of very rare probes like open charm or charmonium requires a high-rate experiment and, consequently, fast and radiation hard detectors as well as read-out electronics. Moreover, only a minimal material budget is allowed for vertex and main tracker in order to be sensitive to displaced decays of charmed hadrons. In most cases, no off-the-shelf solutions meeting the harsh requirements are available; R&D activities on all major detector subsystems are in progress.

The core of the CBM setup is the silicon tracking system (STS) intended for the reconstruction of charged particles produced in the interaction. The STS is an array of eight tracking stations constructed from thin double-sided silicon strip sensors (Fig. 6). It is installed in the gap of a dipole magnet with about 1 Tm field integral and shall determine the particle momenta with a precision of about 1.5%. The sensors will be mounted on a light-weight carbon structure, the signals from the inner part being routed to the front-end electronics at the periphery of the station by ultra-thin cables. The aim is to keep the material budget below 1% radiation length per station. Figure 7 shows a detail of the mechanical design of one STS station. Prototype sensors were already produced and successfully tested in beam [7].

Being located very close to the target, the micro-vertex detector (MVD) has to meet the harshest requirements in terms of radiation tolerance and precision. The two stations of the MVD will be built of Monolithic Active Pixel Sensors (MAPS), which combine excellent position resolution (<3 μm) with low material budget. In the last years, huge progress was made in overcoming previous limitations in radiation tolerance and read-out speed of these type of sensors. The MimoSis1 prototype with a radiation tolerance up to 3×10^{12} $n_{\rm eq}/{\rm cm}^2$ and a readout frame of 40 μs is already close to the specifications for first-generation open charm studies with CBM. A first demonstrator for the MVD detector was successfully operated in beam.

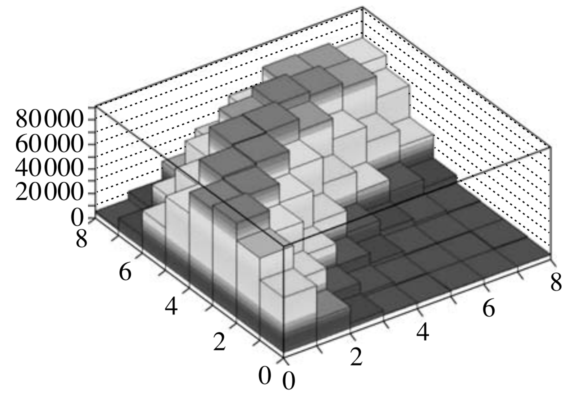

Fig. 8. Part of a Cherenkov ring observed in MAPMT tests with a proton beam in a plexiglass radiator.

First beam tests were also performed with multi-anode photomultipliers (MAPMT) foreseen to equip the RICH photodetector plane [7]. The RICH will focus the Cherenkov light produced by electrons traversing a gaseous radiator into rings on two vertically separated planes, thus discriminating electrons from hadrons for momenta up to 12 GeV. MAPMTs will allow a highly granular readout, resulting in a high electron detection efficiency even in the large track-density environment expected in CBM. Figure 8 shows a quarter of a Cherenkov ring observed in the beam tests with a Hamamatsu MAPMT. R&D work is also ongoing for mirrors and the mounting structures. A full RICH prototype will be assembled and tested in 2011.

High hit densities and rates are also the challenge for the development of the detectors of the muon system (up to 1 MHz/cm^2), where the application of GEM technology is being tested, for the TRD system (up to 200 kHz/cm^2), and for the time-of-flight system (up to 20 Hz/cm^2) built of resistive plate chambers, where different low-resistivity electrode materials are being investigated.

4. DATA ACQUISITION AND EVENT RECONSTRUCTION

At the design interaction rate (10^7 events/s), the expected raw data flow from front-end electronics (FEE) is about 1 TB/s, which has to be reduced to the archival rate of about 1 GB/s by online data selection. The high rates and complicated trigger patterns (e.g., open charm decays) forbid the use of conventional, latency-limited triggers; instead, the FEE will be self-triggered, i.e. autonomously streaming hit information with time stamps through the data acquisition chain (DAQ) to a first-level event selector,

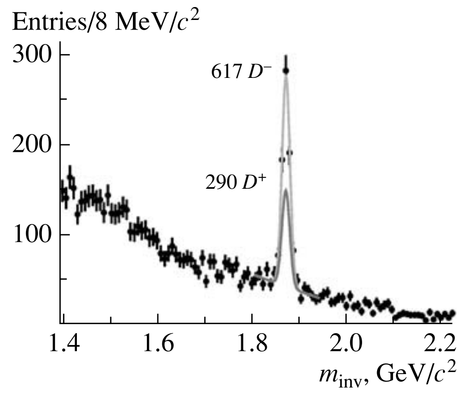

Fig. 9. Simulation of charged D-meson measurement with CBM in the hadronic decay channel for pC collisions at 30-GeV beam energy.

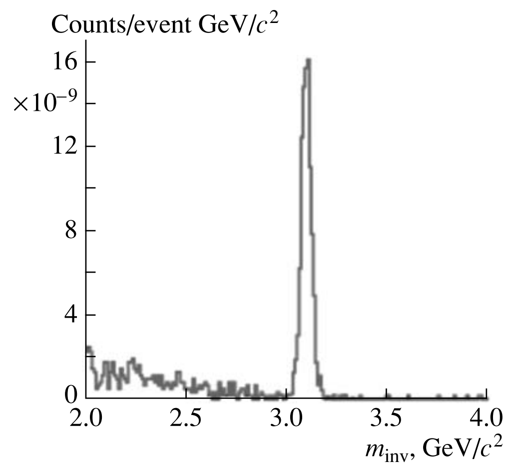

Fig. 10. Simulation of the measurement of $J/\psi \to \mu^+\mu^-$ with CBM for pC collisions at 30-GeV beam energy.

a dedicated computer farm, where the association of hits to physical events, partial event reconstruction and event selection is performed. Two radiation tolerant, self-triggered front-end chips for the silicon tracking system and for the TRD and other gas detectors are under development. The DAQ components (read-out controller, combiner boards, active buffer boards) are developed, and the full chain was succesfully operated in the first beam tests of silicon, GEM and MAPMT detectors read out with the (not radiation hard) nXYTer chip.

The online selection of signal events requires efficient and fast reconstruction algorithms. Huge progress was made recently in the development of such algorithms by employing the features of modern computer architecture like vectorization, multi-threading and multi-core processing. The software for reconstructing tracks in the STS was sped up by several orders of magnitude by the usage of these features [7]. Similar progress was made for the reconstruction of RICH rings and tracking through the muon absorber system and the TRD. With the current software performance, we estimate the required size of the FLES farm to be of the order of 60 000 cores.

5. CBM AT SIS-100

The construction of the FAIR facility will be modular; the current roadmap foresees the completion of the Modularized Start Version, including the SIS-100 accelerator and the CBM cave, by 2017, while the SIS-300 synchroton is likely to come at a later point in time. A part of the CBM physics program can already be started at SIS-100 with heavy-ion beams from 2 to 11 A GeV. In this energy range, a complete characterization of the strangeness production and the measurement of low-mass vector mesons decaying into lepton pairs give access to the nuclear equation of state at the core densities of neutron stars and the in-medium properties of hadrons. Moreover, proton beams up to 29 GeV allow to probe charm production near threshold and its propagation in cold nuclear matter. In this context, the physics feasibility studies performed for higher beam energies, which were reported earlier [4–6], were extended to SIS-100 energies. The studies include the simulation of the anticipated detector response to signals embedded into background events which is then processed through the full reconstruction chain. As examples, Figures 9 and 10 show results of the feasibility studies for the measurement of $D^\pm \to \pi\pi K$ and $J/\psi \to \mu^+\mu^-$ in pC collisions at 30 GeV, both with excellent signal-to-background ratios. In the channels studied so far, no major degradation in physics performance at low beam energies was observed. We conclude that CBM in its current design is suitable for a top-level physics program at SIS-100, to be started with first beams in 2018.

REFERENCES

1. *The CBM Physics Book*, Ed. by B. Friman et al. (Springer, Berlin, Heidelberg, New York, 2010).
2. L. V. Bravina et al., Phys. Rev. C **60**, 044905 (1999).
3. Yu. B. Ivanov, V. N. Russkikh, and V. D. Toneev, Phys. Rev. C **73**, 044904 (2006).
4. V. Friese, PoS CPOD07, 056 (2007).
5. P. Senger, PoS CPOD 2009, 042 (2009).
6. V. Friese, J. Phys. G **37**, 094025 (2010).
7. *CBM Progress Report 2009*, Ed. by W. F. J. Müller and V. Friese (GSI, Darmstadt, 2010).