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Compressed baryonic matter experiment at FAIR

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Abstract. The Compressed Baryonic Matter (CBM) experiment is being planned at the Facility for Antiproton and Ion Research (FAIR), under realization next to the GSI laboratory in Darmstadt, Germany. Its physics programme addresses the QCD phase diagram in the region of highest net baryon densities. Of particular interest are the expected first order phase transition from partonic to hadronic matter, ending in a critical point, and modifcations of hadron properties in the dense medium as a signal of chiral symmetry restoration. Laid out as a fixed-target experiment at the synchrotrons SIS-100/SIS-300, providing magnetic bending power of 100 and 300 T/m, the CBM detector will record both proton-nucleus and nucleus-nucleus collisions at beam energies up to 45 AGeV. Hadronic, leptonic and photonic observables will be measured in a large acceptance. The nuclear interaction rates will reach up to 10 MHz to measure extremely rare probes like charm near threshold. This requires the development of novel detector systems, trigger and data acquisition concepts as well as innovative real-time reconstruction techniques. A key observable of the physics program is a precise measurement of lowmass vector mesons and charmonium in their leptonic decay channel. In CBM, electrons will be identified using a gaseous RICH detector combined with several TRD detectors positioned after a system of silicon tracking stations which are located inside a magnetic dipole field. The concept of the RICH detector, results on R & D as well as feasibility studies and invariant mass distributions of charmonium will be discussed.

1 Introduction

Nuclear collisions at incident beam energies from $10A$ to $40A$ GeV provide the tool to study strongly interacting matter at moderate temperatures but very high net-baryon densities. The CBM experiment will explore highly compressed baryonic matter in heavy-ion collisions from 8-45 AGeV beam energy at the future FAIR accelerator at Darmstadt [1] (see Figure 1). In these collisions strongly interacting matter is created which covers the intermediate range of the QCD phase diagram: Nuclear matter is compressed up to 5-10 times normal nuclear matter density at energy densities of a few GeV/fm^3. At these conditions a first order phase transition between hadronic and partonic matter and the onset of chiral symmetry restoration are expected. An experimental confirmation of these phase boundaries would be of fundamental interest for a better understanding of the strong interaction. The tentative trajectories of such collisions in the QCD phase diagram as obtained from both the UrQMD model [2] and a 3-D 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 (Figure 2).

Several experimental programmes 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.

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In contrast to these experiments, 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.

Among the key observables to investigate these topics are low-mass vector mesons and charmonium decaying into lepton pairs. As leptons leave the hot and dense fireball without further interactions, their study will provide information on the in-medium properties of vector mesons, and on charm production and propagation in hot and dense matter.

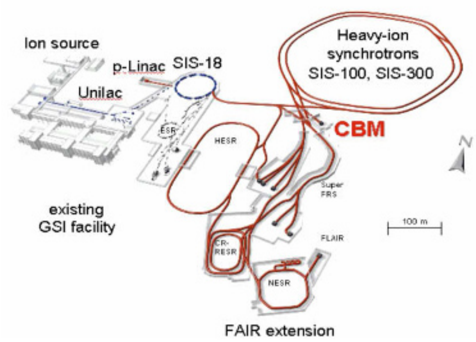

Fig. 1. Schematic layout of the FAIR facility in Darmstadt

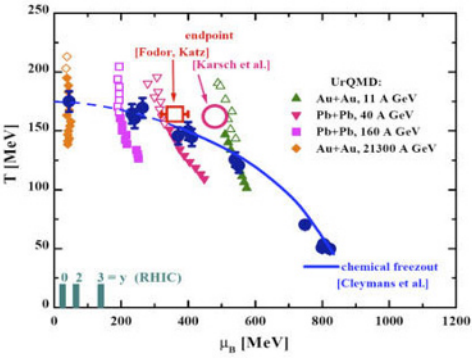

Fig. 2. Trajectory of heavy-ion collisions in the QCD phase diagram obtained from the UrQMD model [2]

2 The CBM experiemnt

The CBM experiment will measure hadronic and leptonic probes with a wide phase space acceptance. The proposed detector system is schematically shown in Fig. 3. The core of CBM will be a silicon tracking system (STS) in a magnetic dipole field for tracking and momentum information. In order to investigate open charm production, an additional micro-vertex detector (MVD) is placed only 10 cm behind the target. This setup is followed by detectors for particle identification: a RICH and TRD detectors for electron and a time-of-flight wall for hadron identification. The setup will be completed by an ECAL for the measurement of direct photons in selected regions of phase space. For muon measurements, the RICH will be replaced by an absorber system interlayed with several tracking detector planes, allowing to follow the tracks reconstructed in the main tracker through the setup (right panel of Fig. 3).

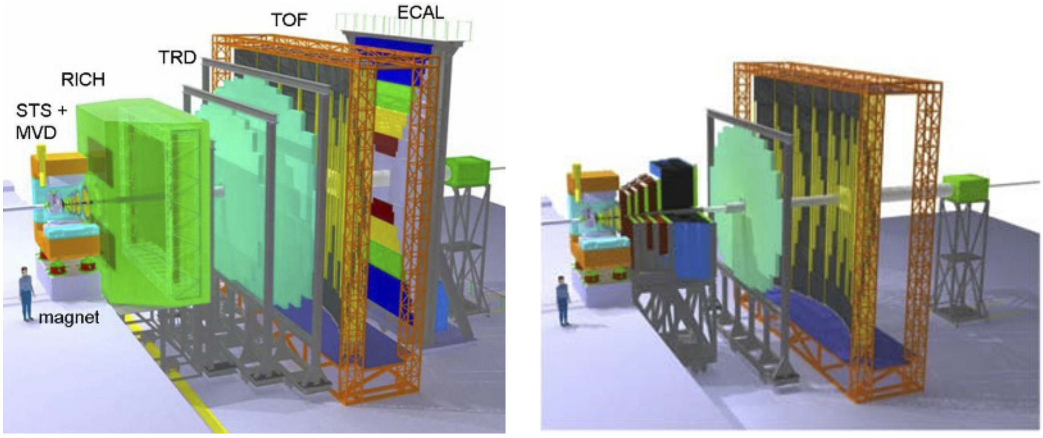

Fig. 3. CBM experimental setup for (left) electron and hadron measurements and (right) muon measurements

3 Open charm

The measurement of the hadronic decays of open charm in the CBM energy regime constitutes a particular challenge because of the very low multiplicity of charmed hadrons. For a sufficient suppression of the combinatorial background, the detection of the displaced decay vertices within a millimeter or less from the interaction point is indispensable. In CBM, a high-precision Micro-Vertex Detector (MVD) will be devoted to this task, using Monolithic Active Pixel Sensors with a single-hit resolution of about 3 μm and low material budget. Two station of these detectors will be operated at 5 cm and 10 cm from the target, respectively. The read-out speed of the devices limits the maximal interaction rate for open charm measurements to 10^6/s. Simulations show that with this detector, a secondary-vertex resolution of about 50 μm - 80 μm, depending on the decay channel under study, can be achieved. This precision allows a clean separation of signal from background as shown in Fig. 4 for the decay channels $D^0 \rightarrow K^-\pi^-\pi^+\pi^+$ and $\Lambda_c^+ \rightarrow pK^-\pi^+$. In terms of signal-to-background ratio, the four-particle decay channel of the D^0 turns out to be favourable over the two-particle decay, since the geometrical and topological constraint of four tracks coming from the same origin is strict enough to overcome the background from four-particle combinatorics. Remarkably, even the measurement of Λ_c seems to be in reach, which would give access to the total charm production.

4 The RICH detector

The RICH detector in CBM is needed for an efficient and clean electron identification for $p \leq 8$ GeV/c in a wide acceptance with a pion suppression of the order of 500 - 1000. The RICH detector has to work reliably in a high rate and high track density environment: up to 1000 charged particles per event are expected in the CBM acceptance for central Au+Au collisions at the highest energies at interaction rates up to 10 MHz. A rather large material budget is located in front of the RICH detector. Therefore a lot of secondary electrons are produced downstream of the RICH being the source of the majority of the rings in the photodetector plane. About 100 rings are expected for central Au+Au collisions at 25 *A*GeV beam energy including about 30% rings from fast pions. In particular in the inner part ring densities are high with many overlapping rings posing a challenge for reliable ring finding. Together with the numerous tracks these conditions lead to a certain probability of ring-track mismatches and the creation of fake rings from random combinations of close hits. This is a strong challenge for a clean and efficient electron identification. Detailed simulations have been carried out evaluating the current RICH performance with respect to electron identification efficiency and purity as well as feasibility studies for the foreseen physics measurements [4].

In order to cope with these challenges we plan a vertically separated RICH detector with CO_2 as radiator gas ($\gamma_{\mathrm{th}} = 33$, $p_{th,\pi} = 4.65$ GeV/c) and PMTs as photodetector. Glass mirrors of 3 m radius, 4-6 mm thickness and a reflective Al+MgF_2 coating developed in cooperation with industry are foreseen for the focussing of the Cherenkov light cones. No further windows are necessary. The photodetector planes are shielded by the magnet yoke, however, additional shielding against the remaining magnetic field will most probably be necessary. The Hamamatsu H8500 MAPMT is currently the most promising candidate for use in the photodetector plane as it offers a good time resolution, a pixel size matching the requirements of CBM, and convenient coverage of the photodetector plane of 2.4 m^2 size and thus approx. 55000 channels. Implementation of this layout in simulations yields 21 hits per electron ring on average using quantum efficiencies for the H8500 as quoted by Hamamatsu with a UV transparent window, and including photon losses due to absorption in the gas and at reflection at the mirror. With a radiator length of 1.7 m the corresponding N_0 is approx. 130-140 cm^{-1}. The total radiation length X_0 of the RICH detector is about 9-10 %.

For testing the Hamamatsu H8500 MAPMTs with a new self triggered readout electronics under beam conditions with Cherenkov photons a proximity focussing setup with a solid radiator (plexiglass) has been chosen. The plexiglass has been positioned at an angle of $\approx 45^o$ respect to the beam axis. An event integrated distribution of hits on the MAPMT surface is shown in figure 6 ; clearly the expected projection of one quarter of the Cherenkov ring is seen. The lower panel in figure 6 shows as an example a picture of a single event and the distribution of MAPMT hits per beam event. With a plexiglass radiator of 8 mm thickness on average, 3.5 MAPMT hits were recorded per beam event. The measured number of MAPMT hits agrres with the expectation.

5 Charmonium

CBM will measure charmonium in both the electron and the muon decay channel. For the electron case, the challenge is the separation of electrons from hadrons exploiting both the Cherenkov radiation in the RICH detector and the Transition Radiation in the TRD. The TOF and ECAL detectors can help for pion suppression at low and high momenta, respectively. Our simulations show that pion suppression factors of more than 10^3 can be reached by combining the information from these detectors. Secondary electrons are suppressed by a cut on the transverse momentum. In the resulting invariant-mass spectrum (left panel of Fig. 7), the J/ψ peak is well visible above the remaining background. A measurement of the $\psi^{`}$ might be feasible, but requires stronger cuts on the lepton candidates. A similar performance is obtained in the muon setup (right panel of Fig. 7). Here, the background mainly consists of wrong matches between tracks in the muon system and tracks reconstructed in the STS.

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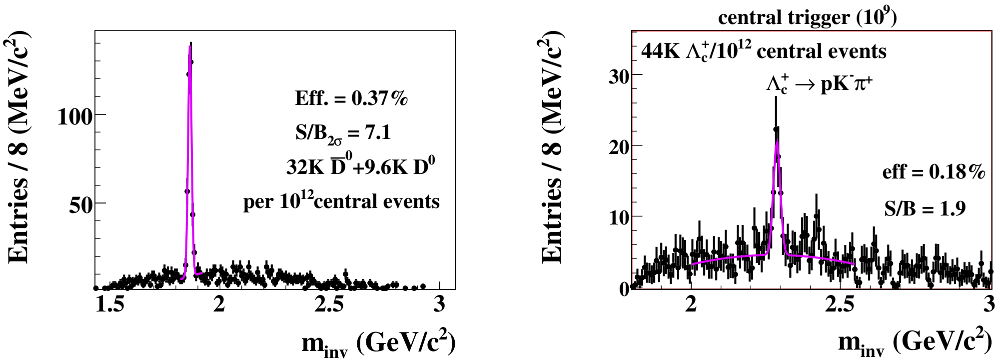

Fig. 4. Invariant-mass signals of the decays $D^0 \rightarrow K^-\pi^-\pi^+\pi^+$ (left) and $\Lambda_c^+ \rightarrow pK^-\pi^+$ (right), obtained from simulation of central Au+Au events at 25A GeV reconstructed with the CBM detector

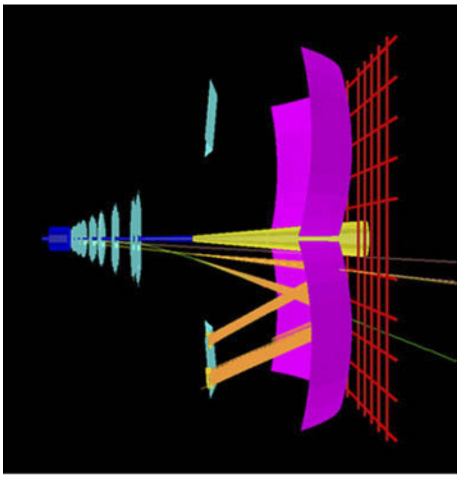

Fig. 5. Layout of the CBM RICH

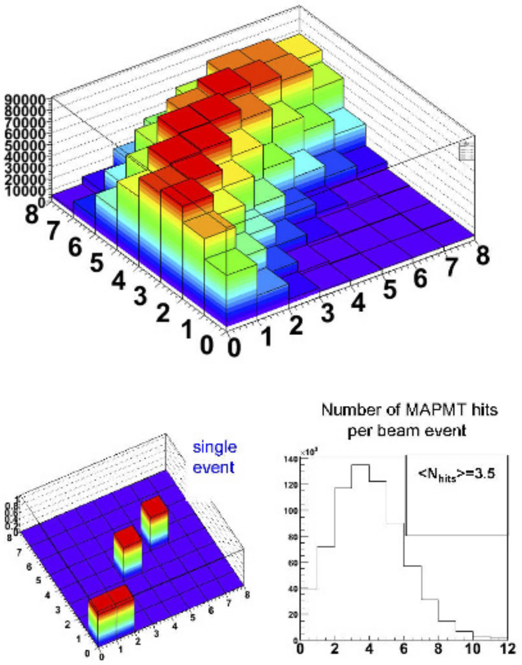

Fig. 6. Event integrated picture of the $\frac{1}{4}$ Cherenkov ring projected onto the H8500 MAPMT. The lower panel shows as an example a picture of a single event and the distribution of MAPMT hits per beam event. The mean number of MAPMT hits per beam event of 3.5 agrees with the expectations.

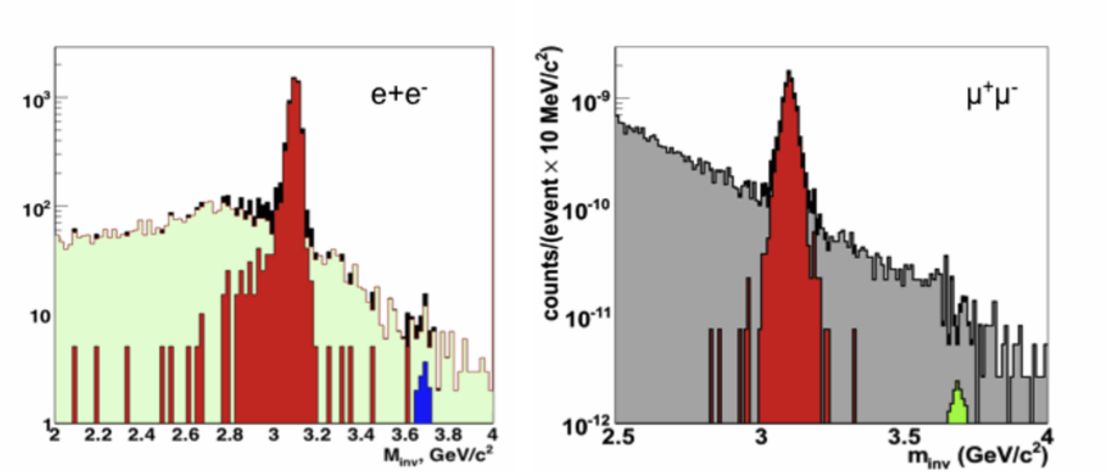

Fig. 7. J/ψ signal in the invariant-mass spectrum of electron pairs (left) and muon pairs (right), obtained from simulation of central Au+Au events at $25A$ GeV. The statistics corresponds to 25 days of data taking at 10 MHz interaction rate.