

Feasibility and design studies for the CBM experiment

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1 Introduction

The CBM Collaboration proposes to build a dedicated heavy-ion experiment to investigate the properties of highly compressed baryonic matter as it is produced in nucleus-nucleus collisions at the future accelerator facility in Darmstadt [1]. Our goal is to explore the QCD phase diagram in the region of moderate temperatures but very high baryon densities. The envisaged research program includes the study of key questions of QCD like confinement, chiral symmetry restoration, and the nuclear equation of state at high densities. The most promising diagnostic probes are vector mesons decaying into dilepton pairs, strangeness, and charm.

2 The detector system

In order to define the detector properties and performance we have started to perform feasibility studies using the GEANT4 simulation code. We have implemented the schematic detector geometry, a realistic material budget, and the magnetic field configuration as calculated with the code TOSCA. Figure 1 shows the experimental setup as used in the simulations.

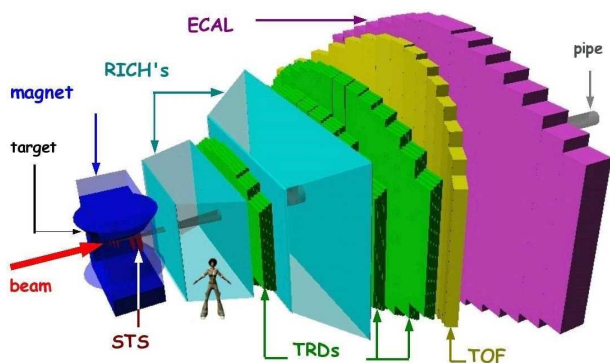


Figure 1: The CBM detector setup as implemented in the simulation tool GEANT4

The major experimental challenge is posed by the extremely high reaction rates of up to 10^7 events/second. These conditions require unprecedented detector performances concerning speed and radiation hardness. The detector layout comprises the following subsystems:

2.1 Silicon Tracking Stations

The experimental concept is to track charged particles directly after the target with a compact detector system. Seven layers of silicon pixel and strip detectors are placed inside the large gap of the dipole magnet. The vertex resolution required for open charm detection is about $50 \mu\text{m}$. To achieve this, we aim at a position resolution of a single

vertex tracker layer below $10 \mu\text{m}$ and a respective material budget below $10^{-3}X_0$. Both requirements could be fulfilled by Monolithic Active Pixel Sensors (MAPS) [2]. However, radiation hardness and readout speed of existing MAPS prototypes are still insufficient for CBM requirements. Therefore, R&D concentrates on these two issues. The bulk area of the tracking stations will be covered by silicon strip detectors with matched strip geometry. The detailed configuration of the tracking detector system is subject of detailed simulations based on realistic detector response and fully developed tracking algorithms.

2.2 Ring Imaging Cherenkov Detectors

The RICH detector provides identification of electrons and suppression of pions in the momentum range of electrons from low-mass vector-meson decays. The performance of the RICH is presently studied in simulations in order to optimize the refraction index of the radiator gas, the geometry and the material of the mirrors and the geometry and granularity of the photodetectors.

2.3 Transition Radiation Detectors

3 TRD stations will serve for particle tracking and for the identification of high energy electrons and positrons ($\gamma > 2000$) which are used to reconstruct J/ψ mesons. The technical task is to develop highly granular gaseous detectors which can stand the high-rate environment of CBM in particular for the inner part of the detector planes which cover forward emission angles. For example, at a distance of 4 m from the target, we expect at small angles particle rates of about 140 kHz/cm^2 for 10 MHz minimum bias Au+Au collisions at 25 AGeV. New concepts for fast gaseous detectors are under investigation.

2.4 Resistive Plate Chambers

An array of Resistive Plate Chambers will be used for hadron identification via TOF measurements. The TOF stop detector of CBM will have an active area of about 150 m^2 when located at a distance of about 10 m from the target. At small deflection angles the pad size is about 4 cm^2 corresponding to an occupancy of below 5% for central Au+Au collisions at 25 AGeV. For 10 MHz minimum bias collisions the innermost part of the detector has to work at 25 kHz/cm^2 . The required time resolution should be well below 100 ps. The technical challenges for RPC development are the rate capability, long term stability and realisation of large arrays with overall excellent timing performance.

2.5 Electromagnetic calorimeter

The electromagnetic calorimeter will be used to measure direct photons, neutral mesons decaying into photons, electrons and muons. Simulations and R&D have been started based on the shashlik type of detector modules as used in HERA-B, PHENIX and LHCb. Particular emphasis is put on a good energy resolution and a high pion suppression factor.

3 Hadron identification by TOF

The determination of the particle mass is based on the measurement of the time of flight, the particle momentum and the particle track length. A particular difficulty is the separation of pions and kaons. Figure 2 shows the K^- identification efficiency as function of laboratory momentum for two different assumptions of the track length (TOF distance 10 m and 15 m, respectively). The purity of the kaon signal is better than 50%.

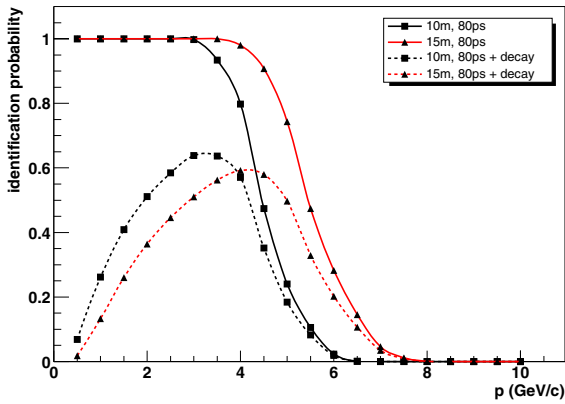


Figure 2: K^- meson identification efficiency as function of momentum assuming a time resolution of 80 ps (with and without decay in flight).

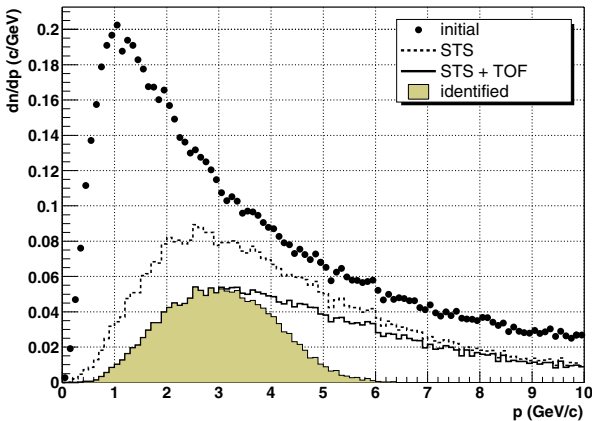


Figure 3: Momentum distributions for K^- from D^0 decay. Full dots: initial distribution. The dotted curve takes into account the acceptance of the Silicon Tracking Station (STS). The full curve denotes the kaons accepted by the TOF wall, the shaded histogram represents those identified by TOF.

Almost perfect $K-\pi$ separation can be obtained up to a momentum of about 4 GeV/c. The efficiency decreases

for small momenta due to the in-flight decay of the kaons between target and TOF. The result is normalized to the number of geometrically accepted kaons. While the position at 15 m improves the mass resolution and therefore increases the efficiency for high momentum kaons, there is on the other hand a substantial loss of (mainly slow) kaons due to their decay in flight.

The identification of kaons will improve substantially the signal-to-background ratio for open charm via hadronic decays. The feasibility of the measurement of $D^0 \rightarrow K^- \pi^+$ mesons assuming ideal particle identification has already been studied within the CBM tracking system [3]. As figure 3 demonstrates, the major part of the K^- from D^0 decays geometrically accepted by the TOF system can be effectively identified.

4 Electron identification by TRD

We have performed a first series of simulations to determine the number of TRD layers required to achieve a pion rejection of the order of 100. The results are presented in figure 4. A detector thickness of 6 mm has been considered. The radiator is of polypropylene fibres of 1, 2, and 3 cm thickness ($N_f = 80, 160, 240$). The simulations employ a regular radiator parametrization, which was tuned to reproduce the measurements performed with ALICE TRD prototypes [4]. A pion efficiency of 1% is achieved with nine radiator/detector layers (see horizontal line). This result will be confirmed in beam tests scheduled for 2004. The final detector parameters of the TRD in CBM will be optimized based on measurements and further simulations. The results shown in figure 4 demonstrate that, in principle, the required performance can be achieved with the present configuration. However, the high-rate capability of the detector (not included in the present simulations) is crucial for operation in CBM and will be subject to detailed investigations in beam tests.

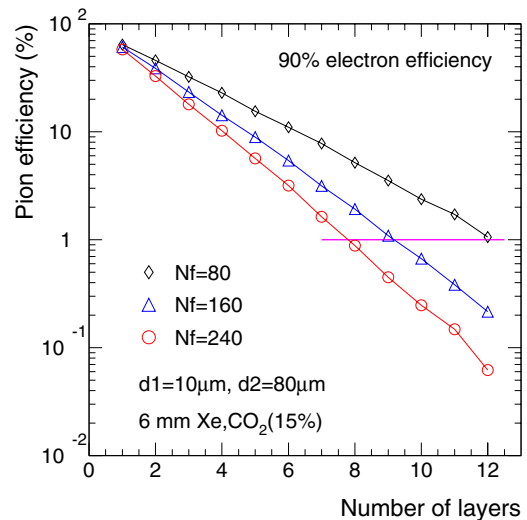


Figure 4: Simulations of the pion efficiency as a function of the number of detector layers. The thicknesses of the foils and gaps are d_1 and d_2 , respectively.

5 Charmonium

The J/Ψ meson will be measured via its decay into e^+e^- . Electron identification will be achieved by information from RICH and TRD detectors [1]. The background for the J/Ψ measurement consists of misidentified charged pions, Dalitz decays of π^0 and η , leptonic decays of ρ and D^0 and electrons from γ conversion in the target and detector material. In the simulation, we used the UrQMD event generator for the hadronic part, assuming a pion suppression of 10^4 , and the PLUTO generator for the leptonic sources. Both were transported through the experimental setup using GEANT4. We assumed ideal track recognition and electron identification (except for the misidentified pions).

Figure 5 shows the single electron transverse momentum distributions for signal and the various background sources. The latter are efficiently suppressed by a cut on transverse momentum $p_t > 1 \text{ GeV}/c$ and on opening angle $\theta > 10^\circ$. The resulting invariant-mass spectra before and after this cut are shown in figure 6, demonstrating that a good signal-to-background ratio can be achieved.

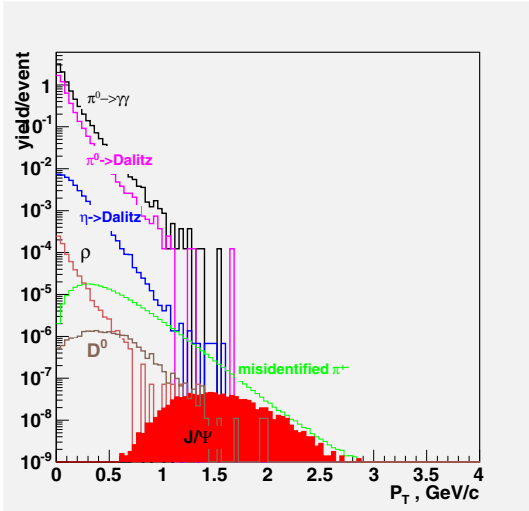


Figure 5: Transverse momentum distributions for electrons from various sources. The yields are normalized to one event.

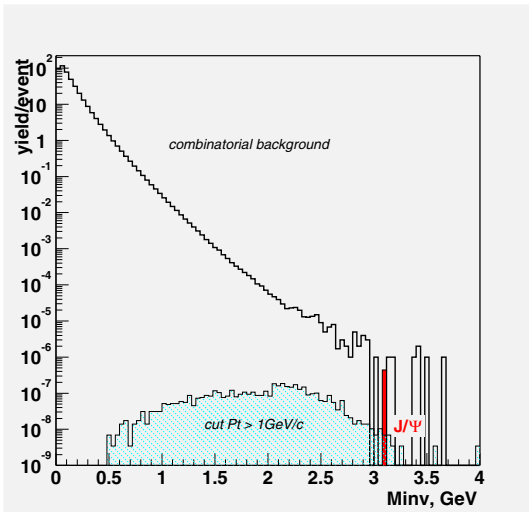


Figure 6: Dielectron invariant-mass spectrum before (full line) and after applying the cut on the single-electron $p_t > 1 \text{ GeV}/c$ and on opening angle $\theta > 10^\circ$ (shaded histogram).

6 Low-mass vector mesons

A similar study has been performed for the dielectron decay of low-mass vector mesons (ρ, ω, ϕ). The main background sources here are again Dalitz decays and γ conversion. The suppression of this background depends crucially on the capabilities of finding the secondary vertex for conversion pairs. Since tracking was not yet available, we assumed that conversions outside the target can be effectively cut out. Even after cuts on the single electron transverse momentum ($p_t < 0.1 \text{ GeV}$) and the pair opening angle ($\theta > 10^\circ$), the combinatorial background dominates the invariant-mass spectrum as shown in figure 7. However, after subtraction of the background obtained from the like-sign pair mass spectra, the $\rho + \omega$ and ϕ signals can be reconstructed. We derive a signal-to-background ratio of about 0.16 for the former and 0.19 for the latter.

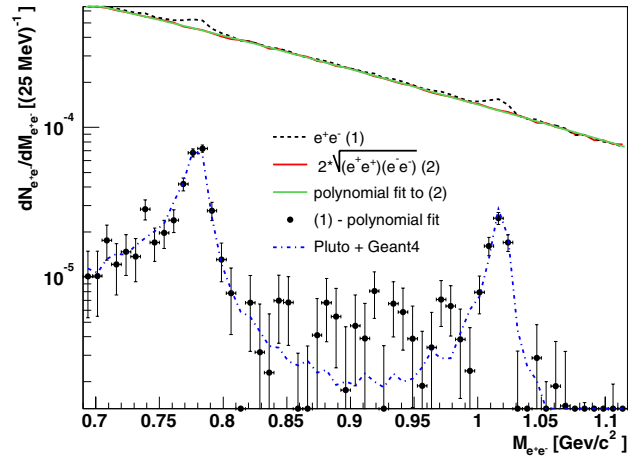


Figure 7: Invariant-mass spectrum of e^+e^- after cuts (see text) in the ρ mass region (dashed line). The green line shows the combinatorial background, the histogram the background-subtracted spectrum. This is compared to the signal simulation input (dashed-dotted).

The next step in the detector simulations will be the inclusion of track finding and fitting algorithms. These will give access to tracking efficiency and momentum resolution, thus enabling a more realistic study of the variables discussed here. The tracking algorithms will be integrated in a common software framework for simulation and analysis which is under development. This will not only technically facilitate the detector simulation but also allow to easily switch between different simulation engines (GEANT3/4, FLUKA) via the Virtual Monte Carlo interface.

- [1] Letter of Intent for the CBM experiment, Darmstadt 2004, <http://www.gsi.de/zukunftspjrojekt/experimente/CBM/LOI2004v6.pdf>
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- [3] V. Friese et al., Feasibility of D^0 measurement with the CBM detector, GSI annual report 2002, p. 42
- [4] A. Andronic et al., physics/0402131