J/ψ reconstruction in the di-muon decay channel with the CBM experiment for p+Au collisions at 30 GeV laboratory beam energy

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Abstract. The study of p+Au collisions at 30 GeV laboratory beam energy is considered as a part of the CBM research program and will be performed in the first phase of FAIR with a start version of the CBM detector at SIS-100. Results of J/ψ reconstruction feasibility studies in di-muon channel in proton-nuclear collisions at SIS 100 energies are presented. The simulated detector concept includes STS and MuCh detectors. The study was performed for a wide range of MuCh detector inefficiency. Also the influence of MuCh stations misalignment on the charmonium reconstruction efficiency was studied. The algorithm allows to reconstruct J/ψ with an efficiency of 31.3 % and the signal to the background ratio of 24.4.

1. Introduction
The Compressed Baryonic Matter (CBM) experiment at the Facility for Antiproton and Ion Research (FAIR) in Darmstadt is designed for the detection of bulk and rare probes, and will benefit from the high-intensity heavy-ion beams provided by the FAIR accelerators. The CBM experiment is aimed to measure rare diagnostic probes never observed before at FAIR energies, and thus has a unique opportunity for the study of the baryonic matter at extremely high densities and moderate temperatures in the laboratory. In this region the QCD (Quantum chromodynamics) phase diagram is only little explored [1].

Measurements at SIS100 (Schwerionensynchrotron) energies will focus on the investigation of the properties of resonance matter in the vicinity of the phase boundary, and, therefore, will provide important information on this transition region of the QCD phase diagram. The measurement of charmonium is one of the key goals of the CBM experiment, since J/ψ mesons are expected to be sensitive to the conditions inside the early fireball [2]. The main difficulty lies in the extremely low multiplicity near J/ψ production threshold at SIS100 energies.
This paper presents results of feasibility studies of charmonium reconstruction in the di-muon channel in p+Au collisions at 30 GeV laboratory beam energy with the standard CBM detector setup. The effect of inefficiencies and layer misalignment in the MuCh detector was studied.

2. Experimental setup

The CBM detector system layout is shown in Fig. 1 with the setup for muon identification. It consists of a Silicon Tracking System (STS) inside a superconducting dipole magnet as the primary tracking device. STS is followed by the muon system consisting of alternating detector and absorber layers. The experimental challenge for muon measurements in heavy-ion collisions at FAIR energies is to identify low-momentum muons in an environment of high particle densities. The CBM concept is to track the particles through a hadron absorber system, and to perform a momentum-dependent muon identification. This concept is realized by segmenting the hadron absorber in several layers, and placing triplets of tracking detector planes in the gaps between the absorber layers. The absorber/detector system is placed downstream of STS which determines the particle momentum. The system has to be as compact as possible in order to reduce meson decays into muons. The actual design of the muon detector system consists of 6 hadron absorber layers (iron plates of thickness 20 cm, 20 cm, 20 cm, 30 cm, 35 cm, 100 cm) and 18 gaseous tracking chambers located in triplets behind each iron slab. The total absorber length in the current design amounts to 2.25 m of iron. The main difficulty for the muon chambers and for the track reconstruction algorithms is the huge particle density of up to 1 hit/cm² per event in the first detector layers after 20 cm of iron. Therefore, the detector development concentrates on the design of fast and highly granulated gaseous detectors based on GEM (Gas Electron Multiplier) technology. In order to provide continuous tracking, a TRD (Transition Radiation Detector) is installed after MuCh. A TOF (Time of Flight) wall completes the setup [3].

3. Feasibility studies

In order to study the feasibility of charmonium reconstruction in the di-muon channel simulations were performed for p+Au collision at 30 GeV laboratory beam energy within the simulation framework CBMROOT [4], which allows full event simulation and reconstruction. Decay muons from J/ψ were simulated with the PLUTO generator [5], where the multiplicity of charmonium production was taken from the predictions of the HSD model [6]. The background p+Au events were produced with UrQMD [7]. Signal embedded into background was transported through the standard CBM detectors using the transport code GEANT3 [8]. The simulated events were reconstructed using different software routines. Track reconstruction in the STS is performed using the L1 reconstruction package [9], which is based on a cellular automaton.
Tracks reconstruction in the MuCh detector is done with the LIT-tracking package [10]. It uses tracks, which were found in the STS, as initial seeds. The LIT-tracking algorithm is based on the track following and the Kalman filter methods. In order to increase the statistics the background was simulated using the event mixing technique [11].

The $J/\psi$-meson reconstruction algorithm includes several steps: muon candidate tracks with more than 15 out of possible 18 hits in the MuCh detector are selected for charmonium search. The next step is to suppress the major source of background: muons from pions and kaons decays. In order to reject these soft muons a cut on the transverse momentum $p_T > 1$ GeV/c of the reconstructed tracks was applied. On the next step the remaining positively charged tracks were combined with negatively charged tracks using the KFParticle package [12]; a good quality geometrical vertex ($\chi^2/\text{ndf} < 3\sigma$) was required to suppress combinatorial background.

An invariant mass spectra after the full analysis is shown in Fig. 2. The study indicates that charmonium can be easily identified above the combinatorial background, which is dominated by muons from weak pion decays. The signal yield is determined by fitting a Gaussian peak on top of a polynomial representing the combinatorial background. For the calculation of the signal-to-background ratio, the distribution was integrated in a $\pm 2\sigma$ window around the peak. The resulting value of $S/B$ ratio is 24.4 and the $J/\psi$ reconstruction efficiency is 31.3%.

![Figure 2. The reconstructed invariant mass spectrum for $J/\psi$ candidates for $p+Au$ collisions at 30 GeV laboratory beam energy](image)

4. MuCh detector inefficiency and misalignment influence on the reconstruction results
For full exploitation of high resolution position sensitive detectors, it is crucial to determine the detector location and orientation with a precision better than their intrinsic resolution. It is a very demanding task to assemble large numbers of detector units in a large and complex detector system to this high precision. Since in real experiments detectors are always misaligned to some extent, we have studied the influence of MuCh detector layers misalignment on the charmonium reconstruction efficiency. Each station layer was shifted in both directions in the detector layer plane by a random value obtained with a uniform distribution with a width of misalignment in order to simulate the misalignment for the track reconstruction step. The muon track and charmonium reconstruction efficiency were studied for the misalignment up to 2 cm. The resulting dependencies are shown in Fig. 3. The muon track reconstruction efficiency decreases from 94.5% in case of perfect alignment to 76.0% in case of 1.0 cm misalignment. The $J/\psi$ reconstruction efficiency decreases from 31.3% to 21.5%.
Figure 3. The charmonium reconstruction efficiency and muon track reconstruction efficiency dependencies on the misalignment of the MuCh station layers.

Also the influence of the detector inefficiency on reconstruction results was studied. In order to implement it in the simulation, before tracking stage each fired digit was rejected with a certain probability. The results are shown in Fig. 4. The muon track reconstruction efficiency decreases from 94.5% in case of perfect digits to 75.5% in case of 90% digit efficiency. The J/ψ reconstruction efficiency decreases from 31.3% to 18.8%.

Figure 4. The charmonium reconstruction efficiency muon and track reconstruction efficiency dependencies on the MuCh detector digit efficiency.

5. Conclusion
The feasibility study of J/ψ reconstruction in the di-muon channel for proton-nucleus collisions at 30 GeV laboratory beam energy shows that the CBM experimental setup allows to reconstruct charmonium with high efficiency (31.3%). The influence of the MuCh detector inefficiency and station layer misalignment on the track and charmonium reconstruction has been studied. The study shows that tracking and particle reconstruction is stable up to 0.5 cm of misalignment and 95% of MuCh detector efficiency.

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