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Application of the Three-fluid Hydrodynamics-based Generator THESEUS to CBM. Proton rapidity-transverse momentum spectra reconstruction and correction.

Elena Volkova,[a,*] **Viktor Klochkov**[a] **and Hans Rudolf Schmidt**[a,b]

[a] *Eberhard Karls Universität Tübingen*

[b] *GSI, Darmstadt, Germany*

E-mail: elena.volkova@uni-tuebingen.de

The Compressed Baryonic Matter experiment (CBM) aims at studying the area of the QCD phase diagram at high net baryon densities and moderate temperatures. It is predicted by the Three-Fluid Hydrodynamics-based Event Simulator (THESEUS) that one of the signatures of the phase transition is a change in shape of the mid-rapidity curvature and yield. In this contribution we present the CBM performance for proton (y) and transverse mass (m_T) spectra. The results are obtained for Au+Au collisions at 3.5-12A GeV/c produced by THESEUS model. These date are treated as if they were experimental. The CBM detector response is simulated with the GEANT3 engine and reconstruction is done using the CbmRoot framework. Protons are identified with Time-of-Flight technique using 2 different approaches. The obtained spectra are corrected for detector biases using the UrQMD event generator. Results are compared with simulated values. Sources of systematic biases are discussed. The CBM detector is sensitive to the difference between 1st order EoS and hadron gas and crossover in the framework of the THESEUS model.

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1. Introduction

THESEUS is 3-fluid hydrodynamic (3FH) based model for heavy ion collisions at SIS100 and SIS300 energies. It is a hydro-based generator, where the 3FH model treats the collision process from the very beginning, i.e. from the stage of cold nuclei. Another unique feature of the current model is that it can describe a hadron-to-quark matter transition of first order which proceeds in the baryon stopping regime [1].

The rapidity and transverse momentum (y-p_T) distributions of net-baryons might show a sensitivity to the different equations of state (EoS) [4–6]. Since experimental information on neutrons is unavailable, and the number of antiparticles at CBM energies is significantly smaller than number of particles, we will use the proton rapidity distribution instead of the net-baryon one. In this report the CBM performance on proton y-p_T spectra reconstruction is studied.

CBM will be a fix-target experiment at the SIS-100 accelerator at FAIR, Darmstadt, Germany. The momentum range for Au beam will be 3.5-12A GeV/c, the detector acceptance will cover the range $2.5° < \theta < 25°$ in azimuthal angle. In this work Au+Au collisions are simulated using the THESEUS model generator with 3 different equation of states (EoS): hadron gas, crossover and 1st order phase transition [1].

2. Event simulations, reconstructions and corrections in CBM

For each EoS Au+Au (central b = 2 fm, semi-peripheral b = 6 fm and peripheral b = 11 fm impact parameters) collisions at beam momentum 4-10 A GeV were simulated by THESEUS with the statistic being around 95000 events. Generated events were passed through the CBM detector simulation and reconstruction software (CbmRoot version Apr21). Magnetic field scale is 100% for 10A GeV and 8 A GeV, 90% for 6A GeV and 60% for 4 A GeV.

For the track reconstruction AnalysisTree data format has been used. Protons were identified by Particle Identification (PID) Framework package [2], that uses Time of Flight information and calculates probabilities to be a given particle species for each EoS, energy and centrality sample. Protons were selected by setting proton probability from PID to be higher than 95%.

For the proton selection correction in experiment, one should use a 2D correction function from a model with known original $y-p_T$ distribution. The correction function could be defined as the ratio between reconstructed and accepted protons and Monte-Carlo generated ones: $corr = N_{reco}/N_{MC}$. Considering THESEUS data as experimental results, UrQMD model [3] has been used for 2D correction function calculation. Therefore, corrected THESEUS experimental $y-p_T$ spectra will be presented as ratio between reconstructed data and UrQMD correction: $N_{corr} = N_{reco}/corr_{UrQMD}$.

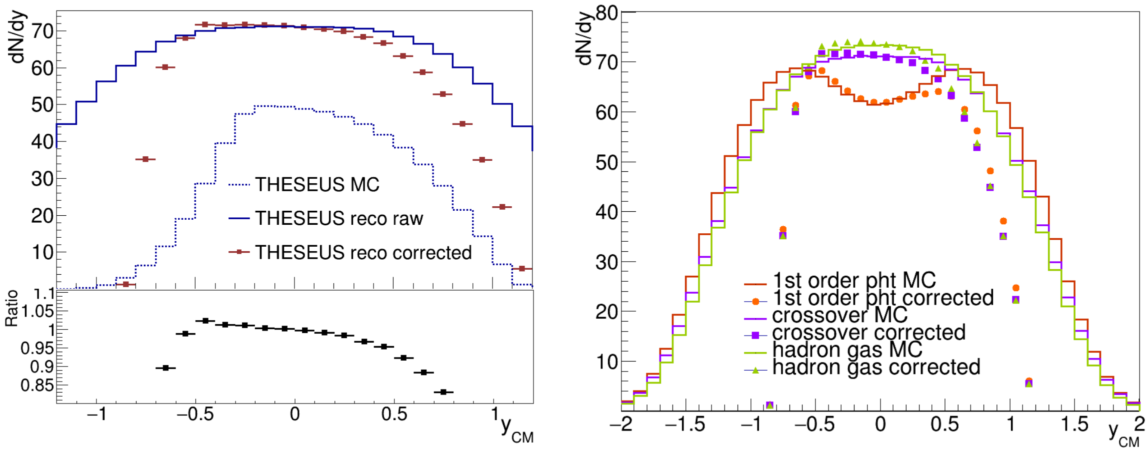
Total error is a sum of N_{reco} and correction error:

$$\Delta N_{corr} = \sqrt{\sum(\partial f/\partial x_i)^2 \delta^2 x_i} =$$
$$\sqrt{(1/corr \cdot \sqrt{N_{reco}})^2 + (N_{reco}/corr^2 \cdot \Delta corr)^2}$$

3. Rapidity and transverse momentum analysis

Rapidity projection of $y - p_T$ original Monte-Carlo, reconstructed in CBM and corrected distributions are shown in figure 1(a). The ratio of corrected and original distribution is up to 5%

in the rapidity window $y \in [-0.5, 0.5]$. In figure 1(b) the rapidity distributions of different EoSs at the same energy and impact parameter are shown. One can see that rapidity shape at midrapidity window $y \in [-0.5, 0.5]$ of a 1st order phase transition differs from the two other EoS. This is a signal of the stopping power change due to phase transition of the hadronic matter into quark-gluonic state [5]. Rapidity shape can be quantitatively calculated by fitting the rapidity distribution with a 2nd order polynomial of the form $P_2(y) = ay^2 + by + c$, and calculating the reduced rapidity curvature C_y:$C_y = y^2_{beam} 2a/c$, where y_{beam} is the rapidity of the beam in the frame of the target [1].



a b

Figure 1: (a): Monte-Carlo generated by model, reconstructed in CBM and corrected rapidity spectra of one of the THESEUS EoS at 10 A GeV, central collision. (b): different rapidity shapes of hadron gas, crossover and 1st order EoSs at the same energy and centrality.

Rapidity curvature spectra for all three EoSs at different impact parameters are shown in figure 2. For central and semi-peripheral collisions at 8 and 10 A GeV 1st order phase transition EoS is distinct from hadron gas and crossover EoSs in CBM experiment.

For p_T projection analysis, rapidity cut $|y| < 0.2$ for all energies has been applied. Original Monte-Carlo generated and corrected p_T distributions with CBM cut applied for 10 A GeV central collisions are shown on figure 3(a). From the ratio of corrected and Monte-Carlo p_T, one can see that lower limit of p_T for analysis is above 0.2 A GeV/c, where p_T is limited by detector efficiency [7]. The difference between EoS in p_T distributions is shown on figure 3(b).

The transverse-momentum spectra are most sensitive to the freeze-out parameters of the model. In fact, inverse slopes of these spectra represent a combined effect of the temperature and collective transverse flow of expansion [8]. The trivial model, that can determine the effective temperature of the source via p_T inverse slope, is Boltzmann distribution:

$$\frac{1}{m_T} fracdNdm_T \simeq \sqrt{m_T} exp(frac{-}m_T T_{eff}), \quad (1)$$

where $m_T = \sqrt{m^2 + p_T^2}$ is the transverse mass.

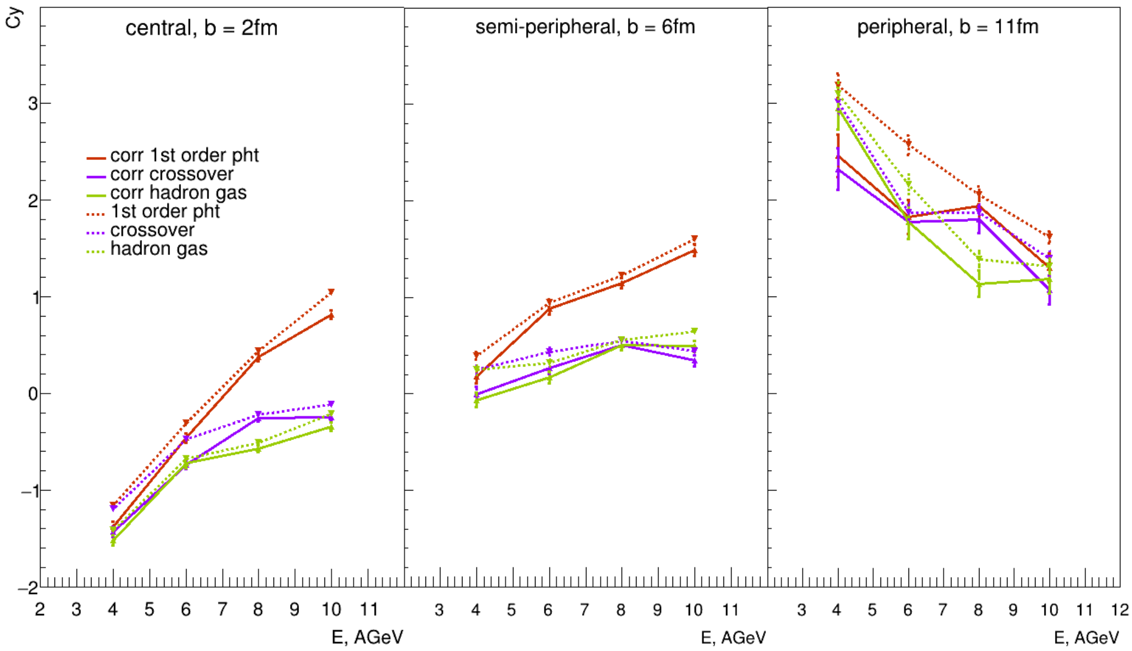
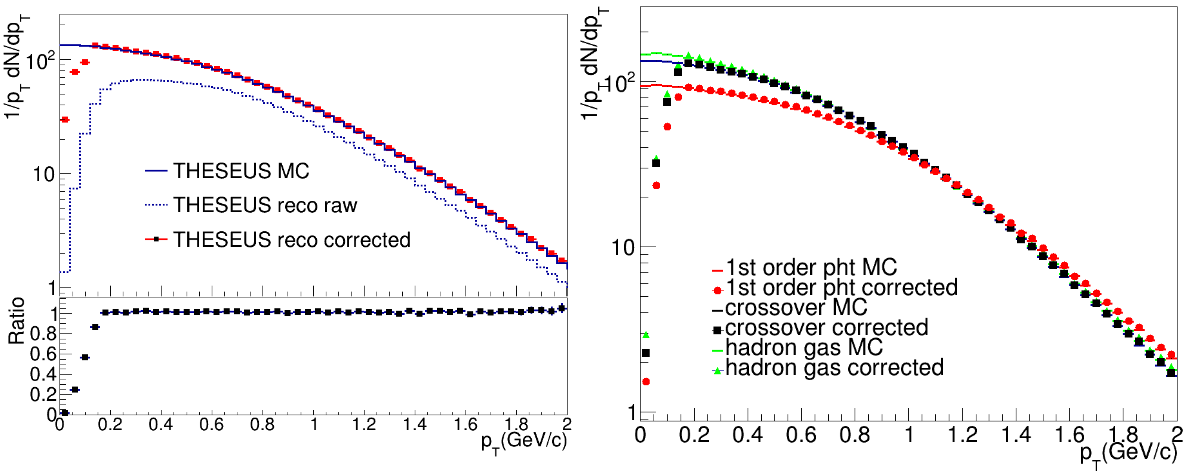


Figure 2: Monte-Carlo generated by model, reconstructed in CBM and corrected rapidity curvature spectra in $y \in [-0.5, 0.5]$ for central (b = 2 fm), semi-peripheral (b = 6 fm) and peripheral (b = 11 fm) events.



a

b

Figure 3: a: Monte-Carlo generated by model, reconstructed in CBM and corrected p_T spectra of one of the THESEUS EoS at 10 A GeV, central collision. b: different p_T shapes of hadron gas, crossover and 1st order EoA at the same energy and centrality.

Effective temperature spectra for 3 EoS and different centralities, are shown in figure 4. Reconstructed and corrected 1st order phase transition effective temperature from Boltzmann fit differences within errors with other two EoS at 8 and 10 A GeV at central collisions.

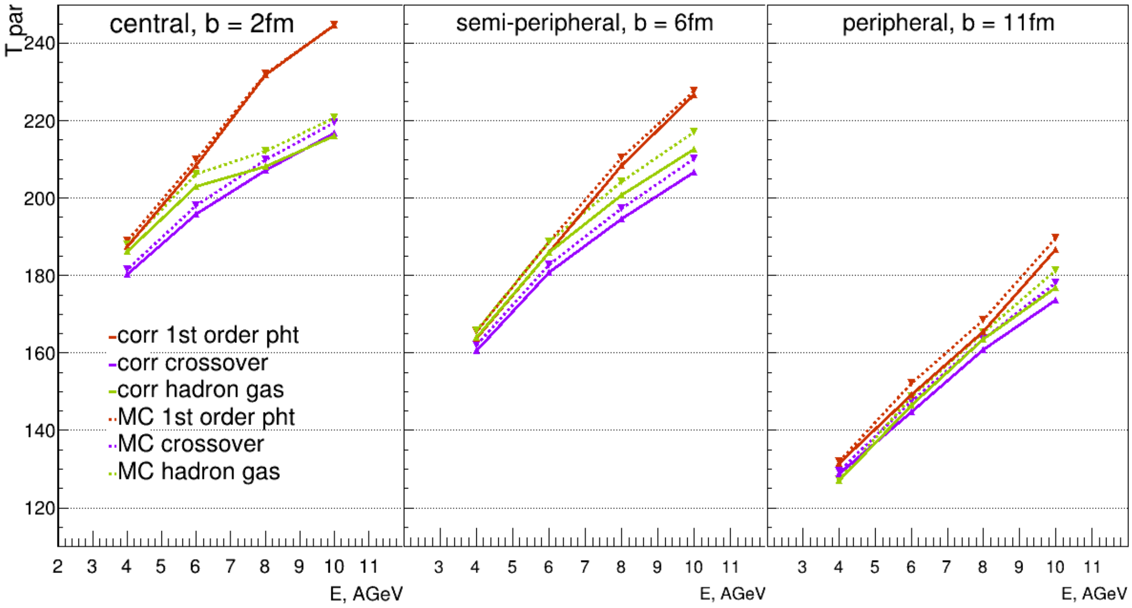


Figure 4: Monte-Carlo generated by model, reconstructed in CBM and corrected effective temperature spectra in $m_T \in [0.2, 1.5]$ GeV/c^2 for central (b = 2 fm), semi-peripheral (b = 6 fm) and peripheral (b = 11 fm) events.

4. Conclusions

THESEUS $y - p_T$ distributions from different EoSs, centralities and energies were simulated for the CBM detector, reconstructed and corrected with efficiency higher then 95%. It has been shown that the difference of rapidity and p_T distributions between 1st order EoS and hadron gas and crossover EoS is larger than systematic errors. Therefore, the baryon stopping signal is robust in CBM, and the detector is sensitive to EoS according to the THESEUS model. However, effective temperature from Boltzmann model does not describe data well and only allows for obtaining a difference within p_T slopes. There is no connection to kinetic freezout temperature from the model due to simplification and lack of radial expansion component.

Further analysis will include more complex model for p_T slope and effective temperature extraction.

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