PHYSICS PERFORMANCE STUDIES OF CBM-TOF DETECTOR

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The future Compressed Baryonic Matter (CBM) experiment at FAIR, Darmstadt, Germany aims at analyzing Au+Au collisions at 10–45 A GeV to study observables related to QCD phase transition, with particular interest to determine the critical point of the QCD phase diagram. The CBM detector setup comprises several subdetectors for the identification of leptons and hadrons. The Time-of-Flight (ToF) detector is one of the core detectors of the CBM experiment that will be used to identify charged hadrons by measuring the time of flight from the collision vertex to the detector. In this work, an attempt has been made to identify light flavored hadrons using the tracking algorithm of the ToF detector of the CBM experiment and estimate their yields for central (impact parameter $b = 0$–3 fm) Au+Au collisions at 10 A GeV beam energy. The effective temperatures of the fireball have also been estimated from the transverse mass spectra of the identified charged hadrons.

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1. Introduction

One of the primary objectives of the relativistic and ultra-relativistic heavy-ion collision programs is to explore the QCD phase diagram [1–3]. In such collisions, nuclear matter far away from normal nuclear matter density and temperature can be produced in the overlapping region of the colliding nuclei. Based on the collision energy and system under investigation, it is possible that nuclear matter at vanishingly low or of zero net-baryon density and extremely high temperature (RHIC and LHC) or of extremely high baryon density and of moderate temperature (FAIR and RHIC-BES) is formed. There is ample experimental evidence that in either situation nuclear matter undergoes a kind of the hadronic-to-partonic phase transition. According to lattice QCD calculations, a theoretical model that is quite successful in describing such high-energy sub-atomic collisions, the hadronic-to-partonic phase transition is of first-order type at high baryochemical potential μ_B (high net-baryon density, B–$\bar{B}$), while at low μ_B (low net-baryon density, B–$\bar{B}$), the deconfined phase transition is of cross-over type. The QCD model calculation suggests that there exists a critical end-point between the cross-over and first-order phase transition at about 160 MeV [4–8]. However, due to experimental difficulties and model dependence, the exact location of the critical point is yet to be ascertained. According to hydrodynamic calculations, the experimental signatures associated with critical point are most evident at beam energies between AGS to top SPS energies.

The Facility for Anti-proton and Ion Research (FAIR) of GSI, Germany is a future facility that is expected to be operational sometime during the last part of this decade and is designed to study nucleus–nucleus collisions from 10 to 45 A GeV. The proposed Compressed Baryonic Matter (CBM) experiment is one of the four major experiments of FAIR that is planned to explore the critical point of the QCD phase diagram [9].

The CBM detector is a complex multi-detector system designed to cope up with interaction rates up to 10^7 Hz to enable measurements of rare observables and diagnostic probes of the hot and dense fireball created in exotic Au+Au collisions. The complex CBM detector system consists of: Micro-Vertex Detector (MVD), Silicon Tracking System (STS), Ring Imaging Cerenkov Detector (RICH), Muon Chamber (MuCH), Transition Radiation Detector (TRD), Time-of-Flight (TOF) detector, Electromagnetic Calorimeter (ECAL), and Projectile Spectator Detector (PSD) [10].

The Time-of-Flight (ToF) detector is an array of Multi-gap Resistive Plate Chambers (MRPC) that will be used for the identification of hadrons in a time-of-flight measurement [11]. The ToF detector will cover an area of 120m ^{2}. While the inner layer will be made up of RPC pads, the strip structures will be used for the outer layer. The hit rates per square centimeter at the inner and outer layers are expected to be 25 kHz and 10 kHz, respectively. The required time resolution for the ToF detector is 80 ps.

In this report, using the tracking algorithm of the CBM FAIRSOFT software for CBM ToF detector, an attempt has been made to identify light flavored particles such as pions ($\pi^{\pm}$), kaons ($K^{\pm}$), and protons (p, $\bar{p}$) to estimate their yields in Au+Au collisions at 10 A GeV. To evaluate the performance of the considered ToF geometry, a few QA plots are drawn and effective temperature of the system produced in such a collision has been estimated from the m_{T} spectra of identified pions, kaons and protons.

2. Results

The ToF is one of the core detectors of the upcoming CBM experiment which is capable of identifying all charged hadrons and will be used in all CBM experiments at SIS 100 [11]. There are mainly two methods of identification of charged hadrons using the CBM-ToF detector. Out of these two, the standard method, that is, the $n\sigma$-approach has been adopted in this analysis for particle identification. In the standard method, m^2 of charged particle is estimated by measuring the time of flight (t), track length (l) from the collision vertex to the ToF detector, and gathering the momentum (p) information from the STS track curvature [11, 12]. The mathematical formula for measuring m^2 is

$$m^2 = p^2\left(\frac{1}{\beta^2} - 1\right), \tag{1}$$

where $\beta = c\times$ (time of flight (t)/track length (l)).

In FAIR-CBM detector assembly, both MVD and STS will be placed in the gap of 1 T superconducting magnet [11]. The UrQMD-3.3 event generator is used to generate Monte-Carlo data for Au+Au collisions at 10 A GeV energy. The CBM simulation setup version CbmRoot-JUN16 and FAIRROOT-nov15p7 are used for this analysis. In Figs. 1 (left) and (right),

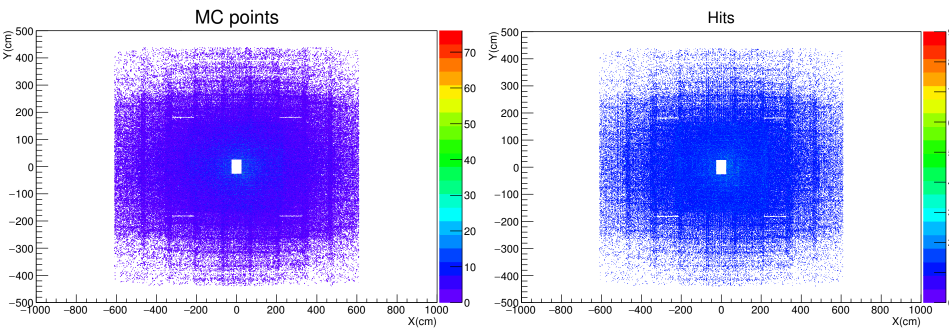

Fig. 1. Monte Carlo (MC) points (left), and hits distributions in Time-of-Flight detector wall (right).

the QA plots for MC-points and hit distributions are shown. It is readily evident from these two plots that both the distributions are in good agreement. In Figs. 2 (upper left) and (upper right), respectively, $1/\beta$ *versus* p/q for different $n\sigma$ cuts are presented and compared with the published result. Figure 3 represents the m^2 distribution plots for the identified π, K, and p. It could be readily seen from Figs. 2 (upper right) and (bottom) that with 2σ cut, the time-of-flight geometry along with the selection criteria (track fit quality cut $\chi^2/(\mathrm{NDF}) < 3$) used for this analysis can well be used to identify π, K, p up to the momentum of 2.5 GeV/c and that our produced plot with 2σ cut agrees well with the published result of Deppner and Herrmann [13].

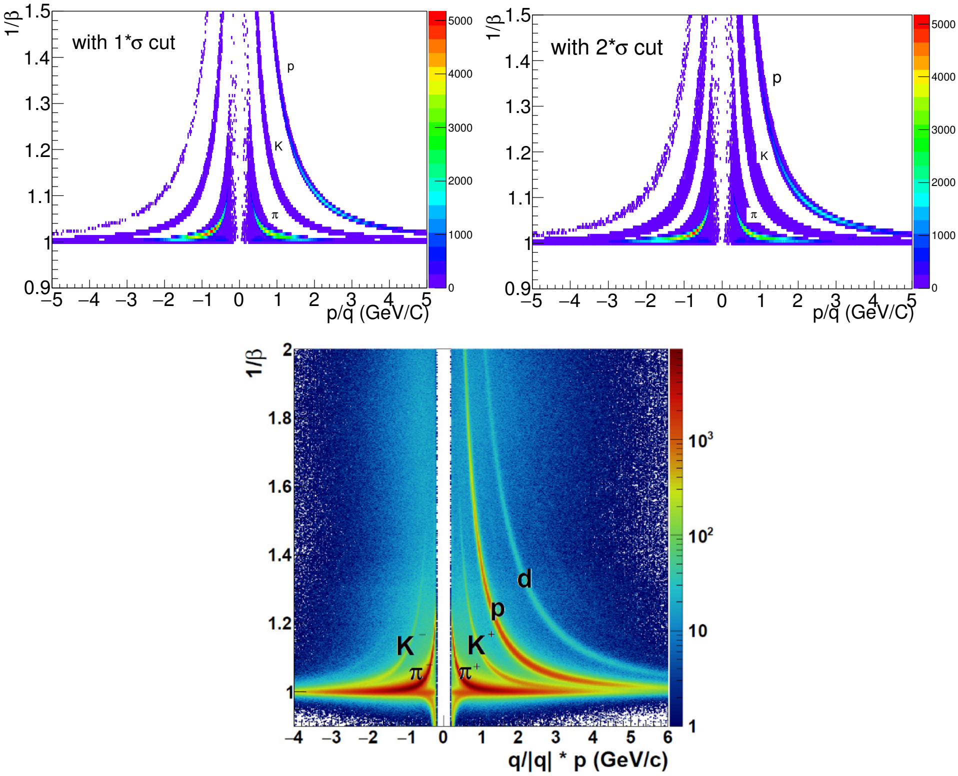

Fig. 2. $1/\beta$ *versus* p/q plots for primary charged particles produced in Au+Au collisions at 10 A GeV beam energy with m^2 cuts (upper left) 1σ, and (upper right) 2σ. (Bottom) published $1/\beta$ *versus* p/q plot of Deppner and Herrmann for the CBM Collaboration [13].

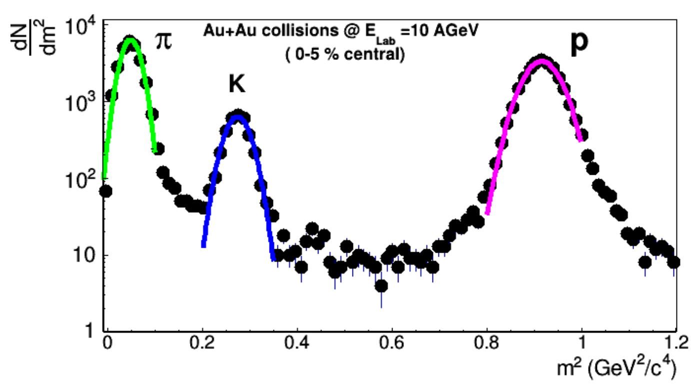

Fig. 3. m^2 distribution of primary particles produced in Au+Au collisions.

To have a check on our particle identification using the considered ToF detector geometry, yet another quality assurance plot is drawn, namely y *versus* p_{T} plot, and is shown in Fig. 4 for identified π, K, and p. All the identified particles are found to be fallen well within the expected $y - p_{\mathrm{T}}$ acceptance for the system under consideration.

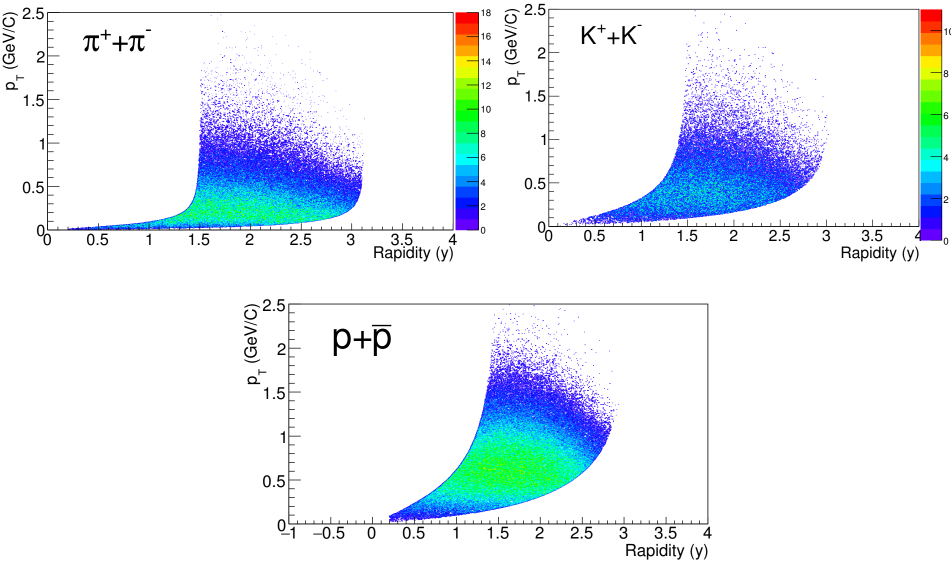

Fig. 4. y *versus* p_{T} acceptance of CBM-ToF detector for (upper left) pions, (upper right) kaons, and (bottom) protons, produced in Au+Au collisions at 10 A GeV beam energy.

In Fig. 5, the m_{T}-spectra of identified charged particles are presented and fitted with the equation

$$\frac{1}{2\pi m_{\mathrm{T}}} \frac{\mathrm{d}N}{\mathrm{d}m_{\mathrm{T}}} = \exp\left(\frac{-m_{\mathrm{T}}}{T_{\mathrm{eff}}}\right) , \tag{2}$$

where $1/T_{\mathrm{eff}}$ is the inverse slope parameter of m_{T}-spectrum and T_{eff} is the estimated effective temperature of the fireball created in such collisions.

The temperatures of the fireball, as estimated from the inverse slope with χ^2/NDF values are listed in Table 1 for π, K, and p.

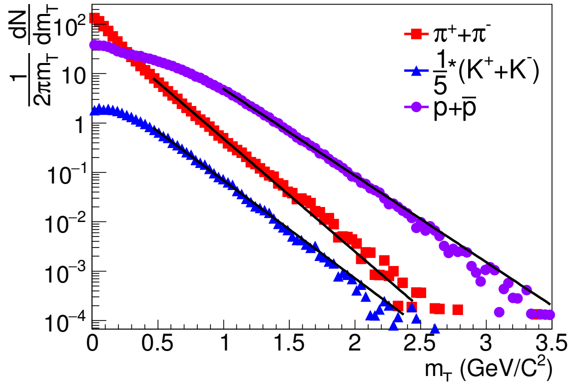

Fig. 5. m_{T} spectra of identified light flavored hadrons $(\pi^+ + \pi^-)$, $(K^+ + K^-)$, and $(p + \bar{p})$.

Table 1. Inverse slope and χ^2/NDF for $(\pi^+ + \pi^-)$, $(K^+ + K^-)$, and $(p + \bar{p})$.

Particles	Inverse slope [MeV]	χ^2/NDF
$\pi^+ + \pi^-$	185.10 ± 18.08	0.0542
$K^+ + K^-$	219.00 ± 25.44	0.0375
$p + \bar{p}$	247.00 ± 19.77	0.0734

3. Summary

From the present study, it is seen that the ToF geometry, as considered in CbmRoot-JUN16 and FAIRROOT-nov15p7, is quite successful in identifying light flavored particles π, K, and p with $n\sigma$-cut equal to 2 and track fit quality cut $\chi^2/(\mathrm{NDF}) < 3$. The m_{T}-spectra for the identified particles follow the expected mass ordering. Even though the inverse slope parameters, as estimated from the present work, are found to be to some extent higher than the expected values, the mass ordering of the inverse slope is quite evident.

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