

Prospects for the study of event-by-event fluctuations at MPD/NICA project

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Abstract. One of the main physics goals of the Multi Purpose Detector (MPD) is to investigate hot and dense baryonic matter in heavy ion collisions at NICA energies to search for the possible critical end point (CEP). Since the location of CEP is not clear the entire accessible region of the QCD phase diagram needs to be explored by scanning the full range of available beam energies. In case of CEP existence it can be observed by abnormal fluctuations of various quantities such as net-proton multiplicity.

This task requires excellent particle identification (PID) capability over as large as possible phase space volume. The identification of charged hadrons is achieved at the momenta of 0.1 – 3 GeV/c. The results of hadron identification and preliminary possibility estimation of the study of event-by-event fluctuations at MPD will be presented.

1 Introduction

The main scientific goal of the NICA/MPD project is to explore the phase diagram of strongly interacting matter in the region of highly dense and hot baryonic matter [1]. The search for the possible critical end point [2] in the QGP diagram requires excellent particle identification capability over as large as possible phase space volume. The identification of charged hadrons is achieved by time-of flight (TOF) measurements which are complemented by the energy loss (dE/dx) information from TPC.

TPC is the main MPD tracking detector of the central barrel. Together with the time of flight system it provides momentum measurements with sufficient resolution (2-3%), vertex determination, two track separation, dE/dx measurements and particle identification at pseudorapidity region $|\eta| < 1.6$. A new approach based on the full simulation of the detector physics and response is required in order to get realistic estimations of the MPD performance instead of a simplified approach at the smeared hit production level. The recent development of the MPD PID is based on the proposed “realistic” tracking algorithm.

To obtain further results, the UrQMD generator has been used (Au + Au collisions, an impact parameter $0 < b < 3$ fm, $\sqrt{s} = 8$ GeV to show the PID performance and $\sqrt{s} = 4, 7, 9$ and 11 GeV with $0 < b < 1$ fm to present preliminary results of event-by-event fluctuations study, 50K events per each data set).

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2 Track selection criteria

In the event that some track is propagating close to the TPC sector boundary, charge collection and momentum reconstruction are hard to implement. In order to exclude tracks with a notable difference between simulated and reconstructed momenta, the following new selection criterion (named the TPC edge cut) has been suggested: if at least 50% of track hits are closer than 1.5 cm to the sector boundary the track should be excluded.

The suggested criterion removes about 4% tracks from the data.

The following selection criteria have been applied to the tracks: $N_{hits} \geq 20$, $|\eta| < 1.6$ and the TPC edge cut.

3 PID parameterizations

3.1 dE/dx parameterization

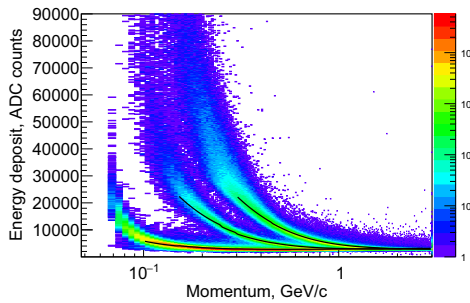


Figure 1: dE/dx vs p

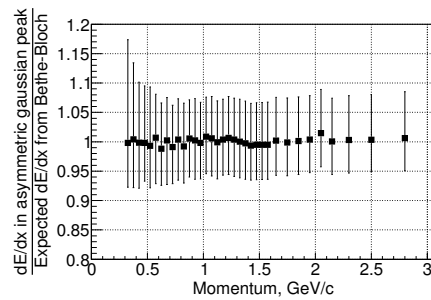


Figure 2: dE/dx quality criterion

The typical distribution of dE/dx on the full momentum is shown in Fig. 1. PID includes the Bethe-Bloch functions with 5 parameters to describe the most probable dE/dx value of each particle species:

$$\frac{dE}{dx} = \frac{a_0}{\left(\frac{p}{E}\right)^{a_3}} \cdot \left[a_1 - \left(\frac{p}{E}\right)^{a_3} - \ln \left(a_2 + \left(\frac{m}{p}\right)^{a_4} \right) \right].$$

The energy deposit has an asymmetric Gaussian shape even if the truncation procedure (0 : 70) is applied. It can be described by the asymmetric Gaussian function:

$$f(x) = \begin{cases} A \cdot \exp\left(-\frac{(x-\bar{x})^2}{2\sigma^2}\right), & \text{for } x < \bar{x}, \\ A \cdot \exp\left(-\frac{(x-\bar{x})^2}{2(\sigma(1+\delta))^2}\right), & \text{for } x \geq \bar{x}, \end{cases}$$

where δ is the asymmetry parameter.

The ratio of dE/dx value in asymmetric Gaussian peak over the dE/dx value expected from the Bethe-Bloch function (Fig. 2) is used to estimate the parameterization quality. The closer the ratio to one the better the Bethe-Bloch description is. Typical width values are 6% and 8%.

The asymmetry may stem from the strong dE/dx dependence in the low momenta region. The truncation procedure can not remove this effect. There can be other reasons of the asymmetry which are not understandable yet.

3.2 Mass squared parameterization

The mass squared resolution growth in momenta should be known in order to use the combined PID. Red lines on the m^2 vs p plot (Fig. 3) depict 3σ bands for protons, kaons and pions.

There is a TPC-TOF mismatch effect which is significant in the low momenta region. Typical example of the TPC-TOF mismatch is shown in Fig. 4. PDG-kaon's m^2 value has been incorrectly reconstructed for $\sim 10\%$ of the tracks with $0.3 < p < 0.4$ GeV/c. For these tracks dE/dx is reconstructed correctly but m^2 is far from the expected value. The fraction of mismatched tracks decreases to 2% in the high momenta region. To reduce the PID inefficiency due to the mismatch effect the TOF information can be ignored and particles can be identified by dE/dx value, but only in the low momenta region ($p < 0.8$ GeV/c).

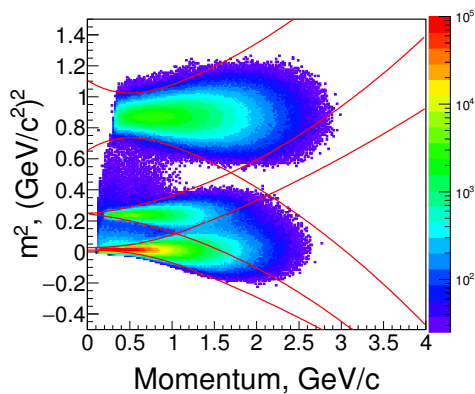


Figure 3: m^2 vs p

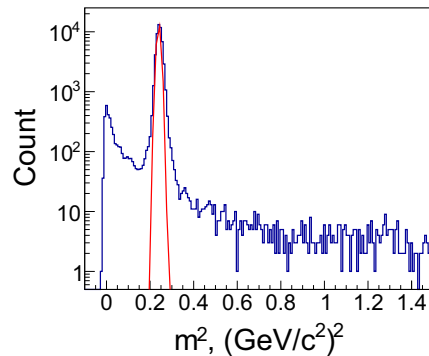


Figure 4: PDG-kaons, $0.3 < p < 0.4$ GeV/c

4 PID results

PID results are presented in the form of efficiency and contamination dependencies on the full momentum (Fig. 5). Here the efficiency is defined as the ratio of correctly identified tracks to all the reconstructed ones. Contamination is defined as the ratio of falsely identified tracks to all the identified ones.

Step-like behavior of efficiency and contamination arises as a result of redirection to dE/dx identification in the low momenta region.

5 Usage of the correction procedure for the measured cumulants

The further analysis is aimed at producing the proton number distributions measured at the MPD facility and applying the correction procedure to achieve the underlying (*i.e.* generated) ones in order to estimate cumulant ratios k_3/k_2 and k_4/k_2 . At NICA energies the anti-proton production in Au+Au collisions is less than 5% of the proton number production, so we have neglected them.

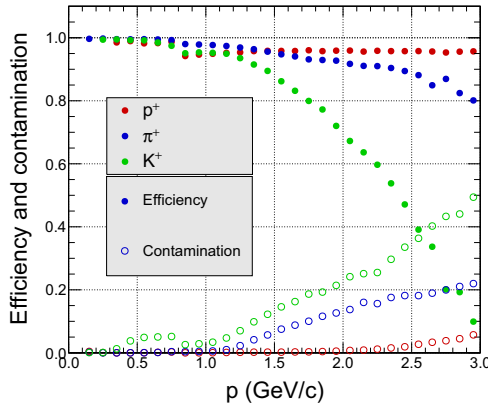


Figure 5: PID efficiency and contamination

Definition of the cumulants and four lowest moments is following:

$$\begin{aligned}
 k_1 &= \langle N \rangle, & \mu &= k_1, \\
 k_2 &= \langle (\delta N)^2 \rangle, & \sigma^2 &= k_2, \\
 k_3 &= \langle (\delta N)^3 \rangle, & S &= \frac{k_3}{k_2^{3/2}}, \\
 k_4 &= \langle (\delta N)^4 \rangle - 3 \langle (\delta N)^2 \rangle^2, & K &= \frac{k_4}{k_2^2}.
 \end{aligned}$$

In order to make a pure identification of protons and eliminate PID contamination to the value less than 1%, the analysis has been carried out at the phase-space area $|y| < 0.5$, $0.3 < p_T < 1.8$ GeV/c (Fig. 6). PID was applied in both dE/dx and $dE/dx + \text{TOF}$ modes in order not to lose protons.

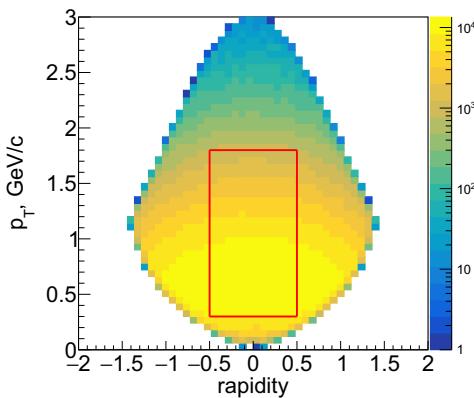


Figure 6: MPD phase-space plot for protons (TPC+TOF)

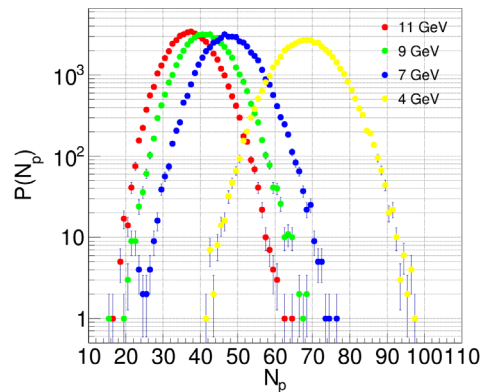


Figure 7: Proton number distributions measured at MPD

Proton number distributions have been produced for several reconstruction data sets with the energies from 4 to 11 GeV (Fig. 7) and compared with generated ones at the same region of p_T and y . In order to know the underlying distribution having the reconstructed one, we may denote detection efficiency p which is defined as the ratio of the average N_p values (reconstructed over simulated). The relation between the cumulants of the underlying distribution to that of the actually measured distribution is given in paper [3]. Denoting cumulants of underlying distribution by K_i and measured cumulants by c_i , we can write their relation:

$$\begin{aligned} pK_1 &= c_1, \\ p^2K_2 &= c_2 - c_1(1-p), \\ p^3K_3 &= c_3 - c_1(1-p^2) - 3(1-p)(f_2 - c_1^2), \\ p^4K_4 &= c_4 - c_1p^2(1-p) - 3c_1(1-p^2) - 6p(1-p)f_2 + 12c_1(1-p)f_2 - \\ &\quad - (1-p^2)(c_2 - 3c_1^2) - 6c_1(1-p)(c_1^2 - c_2) - 6(1-p)(f_2 + f_3), \end{aligned}$$

where factorial moments f_i are defined as:

$$f_i = \left\langle \frac{N_p!}{(N_p - i)!} \right\rangle.$$

The results of the applied correction procedure are presented in Figs. 8 and 9 (only statistical errors are included).

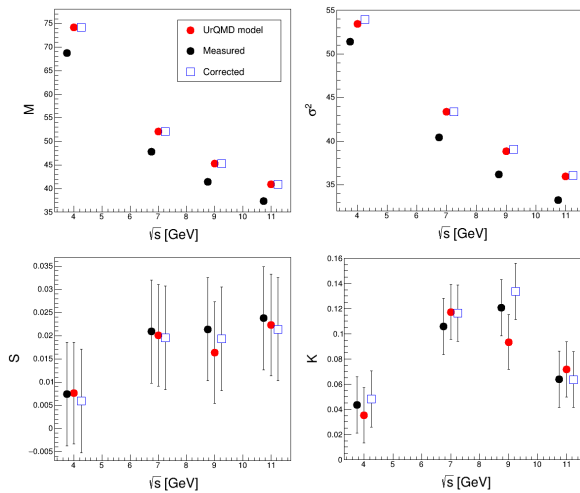


Figure 8: Mean, variance, skewness and kurtosis as a function of $\sqrt{s_{NN}}$

Since statistical errors are large, the additional simulation has to be carried out to increase the number of events.

The assumption that the detection efficiency p is a single number does not imply, that in each event i the number of observed particles is $n_i = pN_i$. The selected phase-space area could be divided into several parts and local detection efficiency $p(y, p_T)$ could be introduced, as it was described in paper [4].

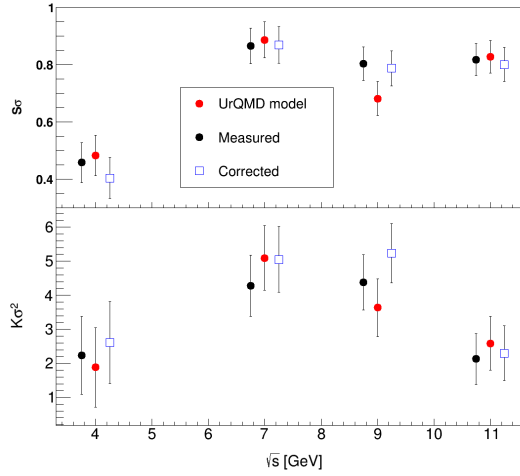


Figure 9: Moments products as a function of $\sqrt{s_{NN}}$

6 Conclusions

The suggested method of particle identification allows one to distinguish π/K up to 1.5 GeV/c and π/p up to 3 GeV/c.

The cumulants of proton distribution have been calculated within phase-space area $|y| < 0.5$, $0.3 < p_T < 1.8$ GeV/c. The correction procedure has been applied to them, however, it can be improved.

References

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- [2] M. Stephanov, Phys. Rev. Lett. **102**, 032301 (2009)
- [3] A. Bzdak and V. Koch, Phys. Rev. C **86**, 044904 (2012)
- [4] A. Bzdak and V. Koch, Phys. Rev. C **91**, 027901 (2015)