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To cite this article: I A Svintsov et al 2017 J. Phys.: Conf. Ser. 798 012067

View the article online for updates and enhancements.
Flow performance in MPD at NICA

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Abstract. The Nuclotron-based Ion Collider fAcility (NICA) in Dubna, Russia is currently under construction at the Joint Institute for Nuclear Research (JINR). A Multi Purpose Detector (MPD) at NICA is designed to study properties of baryonic dense matter in the range of center of mass collision energy from 4 to 11 GeV. We present a performance study for anisotropic transverse flow measurement in Au+Au collisions using the UrQMD event generator and Geant4 simulation of the MPD response. The collision symmetry plane is estimated from event-by-event transverse energy distribution in Forward Hadron Calorimeters (FHCal’s). Performance of the MPD for a measurement of the directed ($v_1$) and elliptic ($v_2$) flow of identified charged hadrons is evaluated based on comparison between reconstructed $v_1$ and $v_2$ values and the input one from the UrQMD model.

1. Introduction

The appearance of the transverse azimuthally anisotropic flow is one of the key observables in the relativistic heavy ions physics. It shows that there’s collectively expanding and strongly interacting medium formed during collision. The interaction area is asymmetric for non-central collisions and hence particle emission is azimuthally anisotropic. The study of collective flow allows for obtaining information about the equation of state and transport properties of the medium under consideration. The magnitude of the anisotropic flow is defined using Fourier coefficients of azimuthal distribution of particles with respect to collision symmetry plane [1]:

$$\frac{dN}{d(\phi - \Psi_n)} = 1 + 2 \sum_{k=1}^{\infty} v_k \cos k(\phi - \Psi_n)$$

(1)

where $v_k\{\Psi_n\} = \langle \cos k(\phi - \Psi_n) \rangle$, $\phi$ - is the azimuthal angle of particle, $k$ - is the harmonic order and $\Psi_n$ is the n-th order symmetry plane angle. $v_1$ is hence called directed flow, $v_2$ - elliptic flow, $v_3$ - triangular flow.

The goal of this work was to perform the collective flow analysis in Au + Au collisions generated using UrQMD model for different energies taken from the NICA beam energy range: 5, 7 and 11 GeV. There is also a comparison of generated (“true”) and reconstructed flow values for identified charged hardrons.
2. Experimental setup

MPD detector was designed as a $4\pi$-spectrometer, capable of detecting charged hadrons, electrons and photons in heavy ion collisions at high luminosities in NICA energy range. In order to achieve this goal the detector comprises precise tracking system and highly-effective particle identification system based on time-of-flight measurement and calorimetry.

![Figure 1. General scheme of the MPD detector.](image1)

![Figure 2. FHCal detector geometry: 45 modules 15x15 cm each.](image2)

In a further analysis the following detector subsystems were used:

- Time-projection chamber for $p_t$ and $dE/dx$ determination of particles
- Forward hadron calorimeter for reaction plane reconstruction
- Time-of-flight chamber for $m^2$ particle identification.

![Figure 3. Acceptance of FHCal and TPC subsystems of MPD (analysis cuts shown with blue lines).](image3)

3. Simulations and analysis

$Au + Au$ events were generated using UrQMD (Ultra-relativistic Quantum Molecular Dynamics) model version 3.4. Three energy points were selected for analysis: 5 GeV (1.25M events), 7 GeV (1.5M events) and 11 GeV (2M events). Further simulations were carried out using Geant4 framework using MPD detector geometry and followed by reconstruction of observable values. Following cuts were used in the analysis:
• $\eta < 1.5$
• $N_{\text{hits}}^{TPC} > 15$
• MotherID = -1 - primary tracks only (Monte Carlo information)
• PID cuts - PDG codes (Monte Carlo information)

Flow coefficients were calculated using event plane method [1]. FHCal information has been used for the estimation of the reaction plane. $Q$-vectors were calculated as follows:

$$q_x^m = \frac{\sum E_i \cos m\phi_i}{\sum E_i} \quad (2)$$

$$q_y^m = \frac{\sum E_i \sin m\phi_i}{\sum E_i} \quad (3)$$

The event plane angle was calculated as follows

$$\Psi_{EP}^m = \frac{1}{m} \tan^{-1} \frac{q_y^m}{q_x^m}$$

where $E_i$ is the energy deposition in the i-th module of FHCal, $\phi_i$ - its azimuthal angle. For $m = 1$ weights had different signs for backward and forward rapidities.

The values of $v_n$ could be calculated as follows:

$$v_n = \frac{\langle \cos n(\phi - \Psi_{EP}^m) \rangle}{\text{Res}_n \{ \Psi_{EP}^m \}} \quad (4)$$

where $\text{Res}_n \{ \Psi_{EP}^m \}$ is so called event plane resolution - the correction factor used to exclude finite multiplicity and acceptance effects. By definition

$$\text{Res}_n \{ \Psi_{EP}^m \} = \langle \cos n(\Psi_{EP}^m - \Psi_m) \rangle \quad (5)$$

where $\Psi_m$ is the n-th order collision symmetry plane, which cannot be measured experimentally. So, in order to estimate event plane resolution, the two-subevent method with extrapolation algorithm was used [1]:

$$\text{Res}_n^2 \{ \Psi_{EP}^A_m, \Psi_{EP}^B_m \} = \langle \cos n(\Psi_{EP}^A_m, \Psi_{EP}^B_m) \rangle \quad (6)$$

$$\text{Res}_n \{ \Psi_{EP}^m \} = \text{Res}_n(\sqrt{2}\chi_{A,B}) \quad (7)$$

where A and B represent two subevents - left(backward rapidity) and right(forward rapidity) FHCal detectors.

In this work $v_1$ and $v_2$ coefficients were calculated with respect to 1-st order event plane ($m = 1$).

4. Results and conclusions

On figure 4 we have event plane resolution dependence on impact parameter $b$, obtained using 2-subevent method. True and reconstructed values are in good agreement for mid-central collisions.

On figure 5 we have $p_t$ dependence of $v_1$ for 2 impact parameter bins - same for $v_2$ on figure 6. 2 million events statistics allows us to go up to 3 GeV/c for protons and up to 2 GeV/c for kaons with reasonable statistical errors.

In this letter performance of flow analysis in the future MPD experiment is discussed. What we see is that reconstructed and generated in UrQMD values of flow coefficients are in good agreement, which indicates the possibility of collective flow study on experiment. Worth noting that there is still some Monte-Carlo information used in this analysis which should be substituted with observable values in the future (realistic PID and DCA cuts).
Figure 4. Event plane resolutions - true (black squares) compared to reconstructed (white squares). Statistical errors aren’t shown.

Figure 5. $v_1$ as a function of $p_t$ for protons (left) and kaons (right) for 2 impact parameter bins.

Figure 6. $v_2$ as a function of $p_t$ for protons (left) and kaons (right) for 2 impact parameter bins.
Acknowledgments
This work was performed within the framework of the Center of Nanostructured Electronics supported by MEPhI Academic Excellence Project (contract No 02.a03.21.0005, 27.08.2013).

References
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