Centrality Determination in Heavy-ion Collisions with MPD detector at NICA*

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Centrality is a key parameter for defining the collision system size in relativistic heavy-ion collisions. The centrality determination provides a tool to compare the anticipated measurements with Multi-Purpose Detector (MPD) at NICA with those of other experiments and with theoretical calculations. The performance for collision centrality determination in MPD experiment using the multiplicity of produced particles is presented.

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1. Introduction

Investigations of properties of the strongly interacting matter at high net-baryon densities is the main scientific mission of the MPD (Multi-Purpose Detector) at the accelerator facility Nuclotron-NICA (JINR, Dubna) [1]. Collisions of relativistic heavy-ions at energies in the range of 4 to 11 GeV per nucleon in the center-of-mass system which are planned at the NICA collider allows for experimental investigation of the matter in the region of high net-baryon densities exceeding that of the normal nuclear matter by 5-10 times. The size and evolution of the matter created in a relativistic heavy-ion collision depends on collision geometry. Experimentally collisions can be characterized by the measured particle multiplicities around midrapidity or by the energy measured in the forward rapidity region, which is sensitive to the spectator fragments. In the present work we use multiplicity of the produced particles for centrality determination. In order to extract collision geometry related quantities, such as the average

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impact parameter or number of participating nucleons, a Glauber Model Monte Carlo approach (MC-Glauber) is employed [2].

2. Centrality determination procedure and performance

A sample of 1M minimum-bias Au+Au collisions for each value of the collision energy $\sqrt{s_{NN}} = 5$, 7.7 and 11.5 GeV simulated with UrQMD event generator [5] was used for the analysis. MPDROOT framework is used to simulate the detector response to particles transported with GEANT4 through the MPD setup. Charge particles tracks are reconstructed in the Time Projection Chamber (TPC) of MPD. Event multiplicity (N_{ch}) calculated from charged tracks within pseudorapidity cut $|\eta| < 0.5$[4]. Figure 1 (left) shows the multiplicity distribution for Au+Au collisions at $\sqrt{s_{NN}} =$ 11.5 GeV and full MPD simulation (black line).

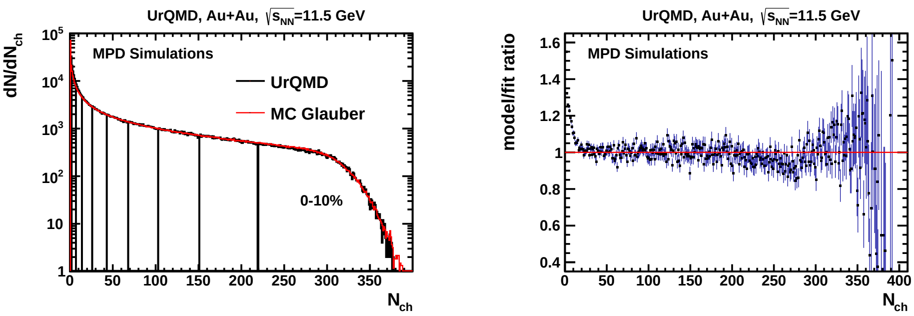

Fig. 1. Left: Track multiplicity distribution from the reconstructed UrQMD events (black line) for Au+Au collisions at $\sqrt{s_{NN}}$ =11.5 GeV compared to the fitted distribution using MC-Glauber approach (red line). Right: ratio of the track multiplicity distribution to the results of MC-Glauber fit.

In the MC-Glauber approach the multiplicity of particles in a heavy-ion collision is modeled as a sum of particles produced from a set of N_a independent emitting sources (ancestors). Each ancestor produces particles according to negative binomial distribution (NBD) with mean value μ and width k

$$M_{MC-Gl}(N_a, \mu, k) = P_{\mu,k} \times N_a, N_a(f) = [fN_{part} + (1-f)N_{coll}]\,, \qquad (1)$$

where N_{part} and N_{coll} are the number of participants and the number of binary collisions simulated with MC-Glauber corresponds to contributions from soft and hard processes. The track multiplicity distribution for the charged particles in TPC is then parameterised with a distribution of

M_{MC-Gl} simulated according to equation (1). The result of the procedure is shown in Fig 1 (left) by red line. The MC-Glauber fit was done for multiplicities above 20. Vertical lines represent event classification for the 10% centrality bins. The right part of Fig 1 shows the ratio of the track multiplicity distribution to the MC-Glauber fit [3]. A value of the multiplicity at which MC-Glauber fit starts to diviate from the multiplicity distribution defines the so called anchor point below which centrality determination is not reliable. This allows to extract the collision geometry related quantities, such as the average impact parameter $\langle b \rangle$ or number of participating nucleons $\langle N_{part} \rangle$ for a given class of centrality.

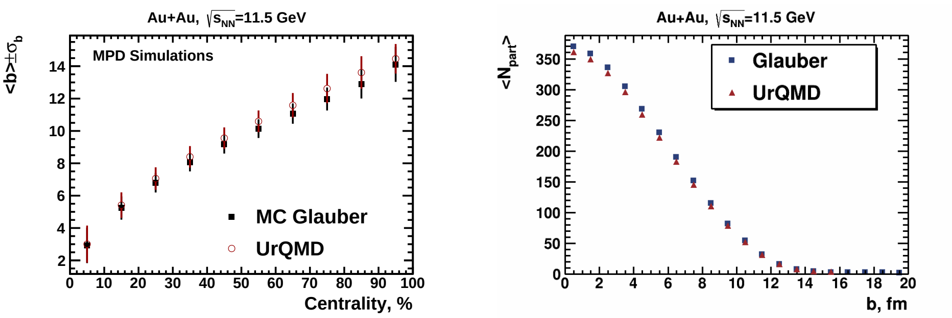

Fig. 2. Centrality dependence of the average impact parameter $\langle b \rangle$ (left panel) and average number of participating nucleons $\langle N_{part} \rangle$ (right panel) for Au+Au collisions at $\sqrt{s_{NN}}$ = 11.5 GeV. The resulting values of $\langle b \rangle$ and $\langle N_{part} \rangle$ extracted from the MC-Glauber model (closed boxes) are compared with the values used in UrQMD generator.

Figure 2 shows the centrality dependence of the average impact parameter $\langle b \rangle$ (left panel) and average number of participating nucleons $\langle N_{part} \rangle$ (right panel) for Au+Au collisions at $\sqrt{s_{NN}}$ = 11.5 GeV. The results for the $\langle b \rangle$ and $\langle N_{part} \rangle$ estimated with MC-Glauber approach (closed boxes) are consistent with the values used in UrQMD generator within 5-10%. The average number of participating nucleons $\langle N_{part} \rangle$ from UrQMD generator was estimated at the passage time of the two colliding nuclei. Figure 3(left) shows the centrality dependence of the average impact parameter $\langle b \rangle$ for Au+Au collisions at $\sqrt{s_{NN}}$ = 11.5 GeV extracted by the same procedure for events generated using transport models: PHSD [6] and SMASH [7, 8]. The resulting $\langle b \rangle$ values are in a good agreement for presented models: UrQMD, PHSD and SMASH and results estimated with MC-Glauber approach. The right part of Fig. 3 shows the centrality dependence of $\langle b \rangle$ for Au+Au collisions at energies $\sqrt{s_{NN}}$ =5 , 7.7 and 11.5 GeV. The good agreement between results indcicates that the geometrical properties of the collision are not changing in the NICA energy range $\sqrt{s_{NN}}$ = 4 - 11 GeV.

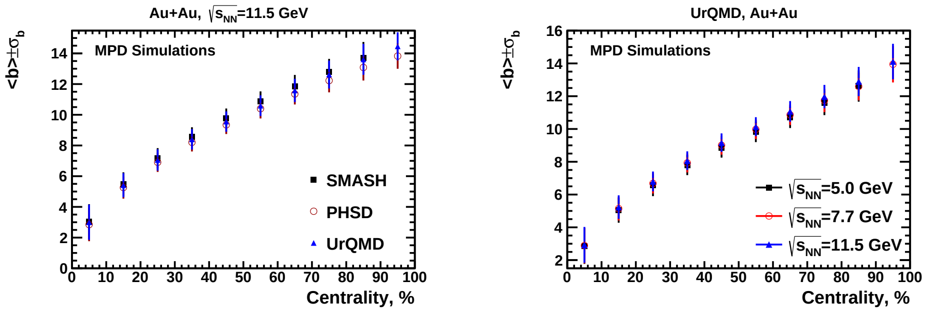

Fig. 3. Centrality dependence of $\langle b \rangle$ for Au+Au collisions at $\sqrt{s_{NN}} = 11.5$ GeV (left panel). Different symbols correspond to the results obtained using transport models: UrQMD, PHSD and SMASH. The right panel shows the centrality dependence of $\langle b \rangle$ for Au+Au collisions at $\sqrt{s_{NN}}$ =5, 7.7 and 11.5 GeV for UrQMD model.

3. Summary

The centrality determination procedure based on multiplicity of the produced particles tested for the full MPD simulation chain using the UrQMD model events for Au+Au collisions at at $\sqrt{s_{NN}}$ =5, 7.7 and 11.5 GeV. This provides a tool to compare the anticipated MPD measurements with those of other experiments and with theoretical calculations.

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