Model analysis of transverse momentum and multiplicity and multiplicity correlations in the NICA range in Bi+Bi collisions as a function of centrality class

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Introduction

In this work, correlations between the mean transverse momentum and the multiplicity of charged particles in Bi+Bi collisions are analyzed using the UrQMD model. Three strongly intensive quantities, as well as second-order transverse momentum cumulants, were chosen as variables for the study. Previously, discrepancies between the EPOS, SMASH, PHSD and UrQMD models were found in the energy dependence of strongly intensive quantities in proton-proton collisions. In the SMASH model, both for strongly intensive quantities and for cumulants for proton-proton collisions, a certain "wave" was previously discovered, which could be evidence of a transition from the resonant regime to strings. This paper also proposes a new method for studying cumulants - the subevent method, which can help eliminate the influence of short-range correlations.

The set of experimental results (see Fig. 1) on the study of correlations between the average transverse momentum and multiplicity allows us to impose significant restrictions on various phenomenological models. For example, a successful description of smoothed positive correlations in high multiplicity events at LHC collision energies was achieved by introducing a color reconnection mechanism in the PYTHIA event generator.

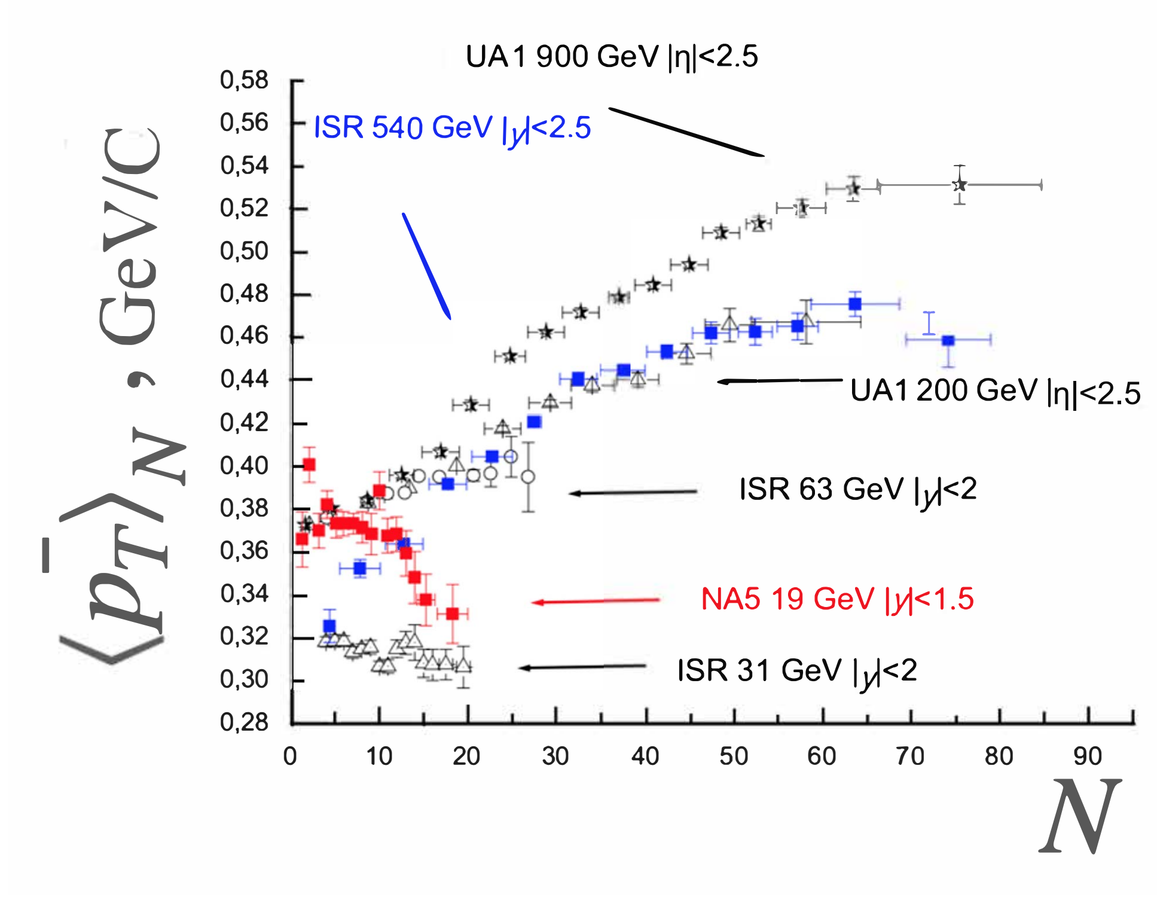

Figure 1:Set of experimental results for $p_t - n$ correlations.

In this research, we analyze the second, third and fourth order cumulants[3], $p_t - n$ strongly intensive observables [4] and two-particle p_t correlation measures [5] in Bi+Bi collisions using the UrQMD-3.4 model. The analysis is performed in two ways: using the standard method, in which the study is carried out over the entire rapidity interval, and also using the sub-event method suppressing the influence of short-range correlations. Dependencies of second-, third-, and fourth-order cumulants on energy were obtained. The paper also provides a comparison of $p+p$ and $Bi+Bi$ collisions that indicated the simultaneous saturation for both systems at $\sqrt{s_{NN}} \approx 5$ GeV.

Definitions and observables

In order to minimize the influence of volume fluctuations strongly intensive observables are used in this analyse:

$$\Sigma[p_t, N] = \frac{1}{\langle N\rangle \omega\,[p_t]}\left[\langle N\rangle \omega\,[P_t] + \langle P_t\rangle \omega\,[N]\right] \tag{1}$$

$$\Delta[p_t, N] = \frac{1}{\langle N\rangle \omega\,[p_t]}\left[\langle N\rangle \omega\,[P_t] + \langle P_t\rangle \omega\,[N] - 2\left(\langle P_T N\rangle - \langle P_T\rangle\langle N\rangle\right)\right] \tag{2}$$

where $P_T = \sum_{i=1}^{N} p_{T_i}$ and $\omega[p_T]$ is the scaled variance of the inclusive p_T spectrum.

$\Delta[p_T, N] = \Sigma[p_T, N] = 1$ - for independent particle production model, $\Delta[p_T, N] = \Sigma[p_T, N] = 0$ in the absence of fluctuations.

Unlike $\Delta[p_t, N]$ and $\Sigma[p_t, N]$, this quantity has the dimension of energy - GeV.

Cumulants are calculated by averaging c_n over a given ensemble of events.

$$\kappa_2 = \frac{\langle C_2\rangle}{\langle\langle p_T\rangle\rangle^2},\ \kappa_3 = \frac{\langle C_3\rangle}{\langle\langle p_T\rangle\rangle^3},\ \kappa_4 = \frac{\langle c_4\rangle - 3\langle c_2\rangle^2}{\langle\langle p_T\rangle\rangle^4} \tag{3}$$

MPD

The MPD is designed as a 4π spectrometer capable of detecting of charged hadrons, electrons and photons in heavy-ion collisions in the energy range of the NICA collider. The major goal of the NICA/MPD project is the study of in-medium properties of hadrons and the nuclear matter equation of state, including a search for possible signals of deconfinement and/or chiral symmetry restoration phase transitions and the QCD critical endpoint in the region of the collider energy $\sqrt{s_{NN}}$ = 4 − 11 GeV [6].

Models and kinematic selection

In this study we used UrQMD event generator for SPS energy range and for NICA energy range. As we want to analyze correlations in realistic experimental environment we apply certain kinematic selection corresponding to MPD:

UrQMD (for MPD))
0.15<p_T<2.0 GeV/c
$\lvert y_{\pi}^{CMS}\rvert$<1
acceptance map cut

Strongly intensive quantities: dependence from energy

The inequalities $\Sigma[p_T, N] \geq 1$, previously observed for all studied systems at all collision energies are holding. But inequalities $\Delta[p_T, N] < 1$ (which hold for $Ar+Sc$) is violated. Similar to b_{corr} the rapid transition at $\sqrt{s} = 4.5$ GeV is predicted in the SMASH model.

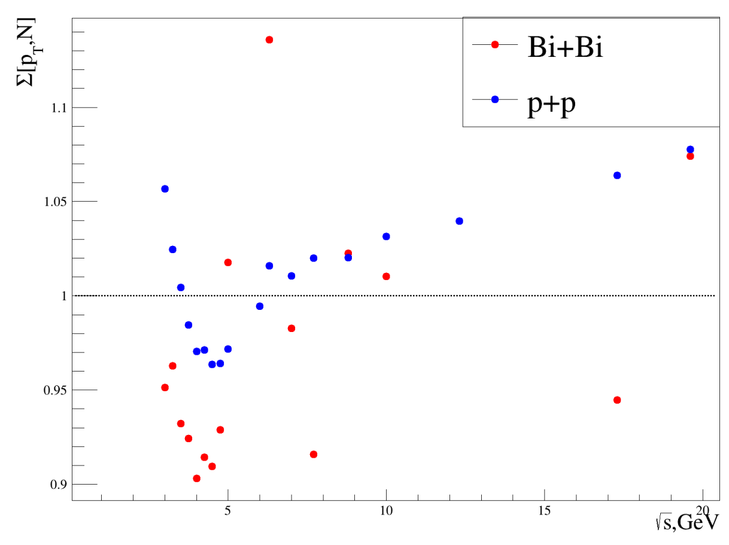

Figure 2:$\Delta[p_T, N]$ as a function of collision energy obtained in UrQMD for Bi+Bi interactions in the MPD energy range.

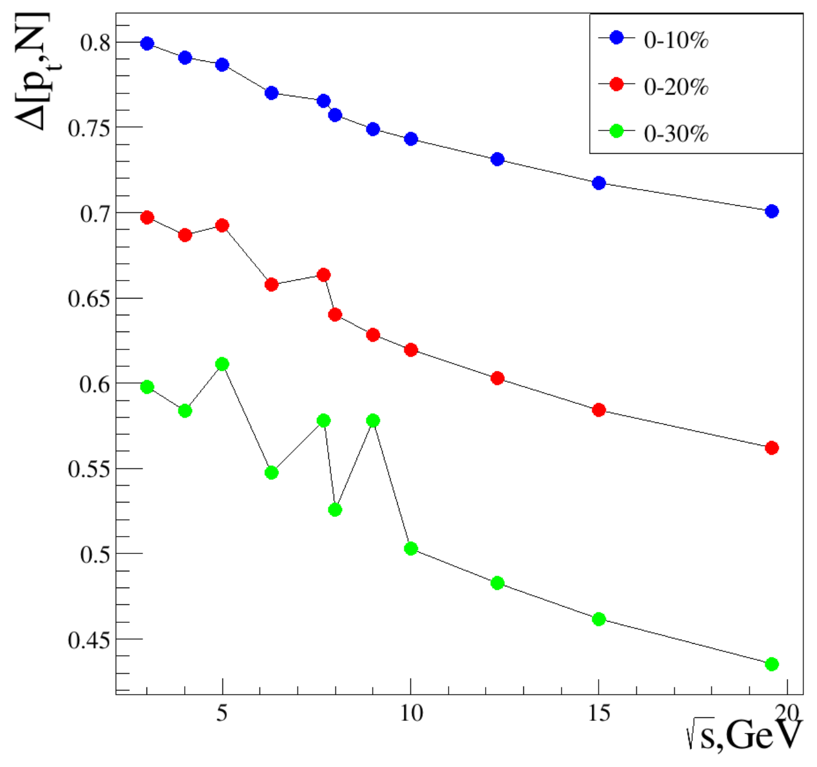

Figure 3:$\Delta[p_T, N]$ as a function of collision energy obtained in UrQMD for Bi+Bi interactions in the MPD energy range.

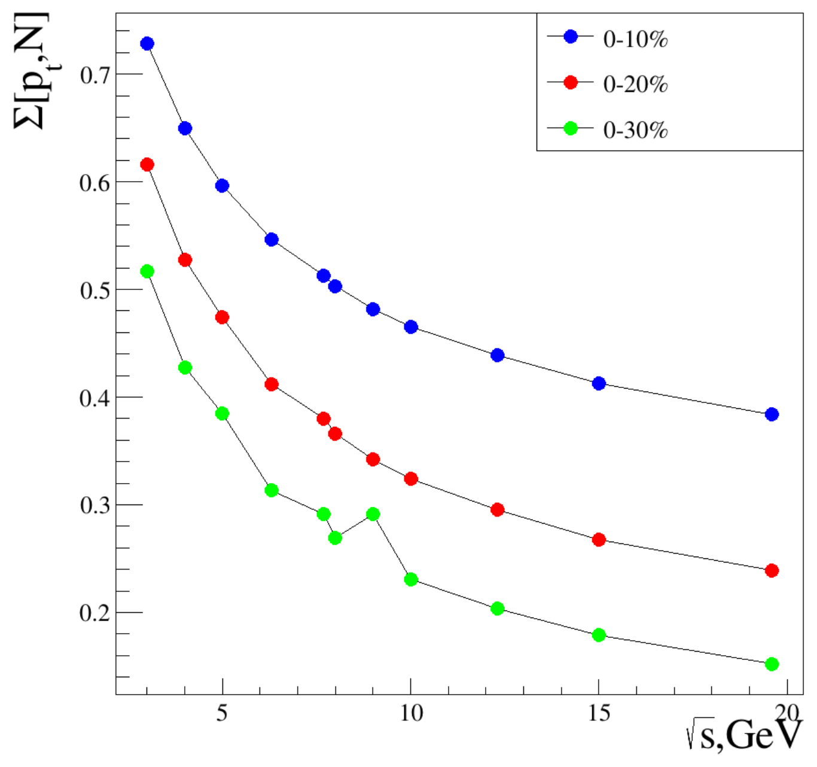

Figure 4:$\Sigma[p_T, N]$ as a function of collision energy obtained in UrQMD for Bi+Bi interactions in the MPD energy range.

Results for cumulats moments

In this work, the second and third order cumulants were also studied depending on the energy.

The n-particle p_T correlator in one event is defined as[3]:

$$C_n = \frac{\sum_{i_1 \neq \ldots \neq i_n} \omega_{i_1} \ldots \omega_{i_n} (p_{T,i_1} - \langle\langle p_T\rangle\rangle) \ldots (p_{T,i_n} - \langle\langle p_T\rangle\rangle)}{\sum_{i_1 \neq \ldots \neq i_n} \omega_{i_1} \ldots \omega_{i_n}} \tag{4}$$

$$K_2 = \frac{\langle C_2\rangle}{\langle\langle p_T\rangle\rangle^2}, \tag{5}$$

$$K_3 = \frac{\langle C_3\rangle}{\langle\langle p_T\rangle\rangle^3}, \tag{6}$$

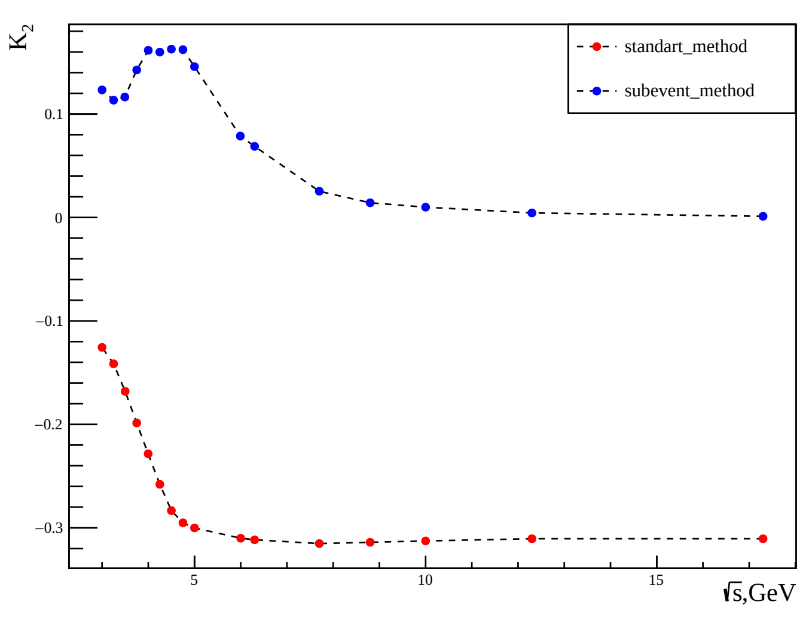

Figure 5:Mean two particle p_T correlator as a function of collision energy obtained in UrQMD for Bi+Bi interactions in the MPD energy range.

Within the independent source picture, each collision consists of a superposition of independent $p+p$-like collisions and interaction between the sources are ignored.Under these conditions, the n^{th}-order cumulant is expected to scale as $\propto 1/N_s^{(n-1)}$, where N_s is the number of sources often taken to be N_{part} (number of participating nucleons) or N_{ch} (charged particle multiplicity).

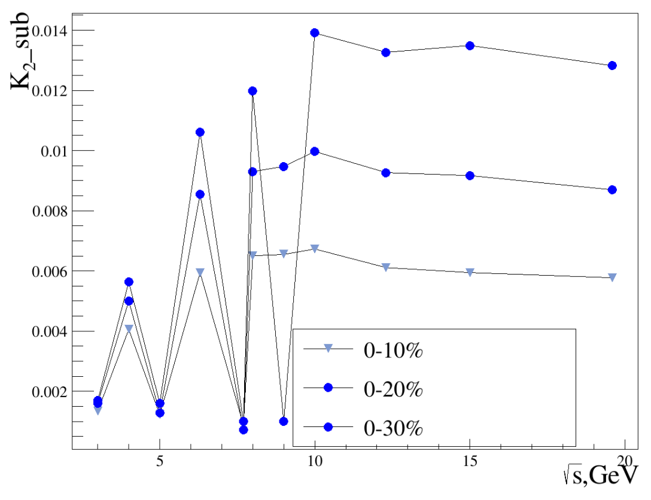

Figure 6:Cumulants seconf order as a function of collision energy obtained with help of subsample method in UrQMD for Bi+Bi interactions in the MPD energy range. Calculations are performed for centrality 0-10%, 0-20%, 0-30%.

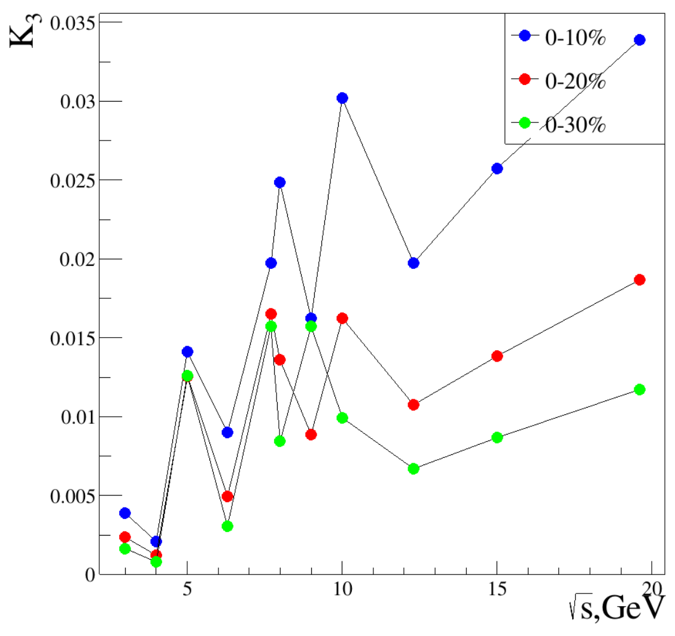

Figure 7:Cumulants third order as a function of collision energy obtained in UrQMD for Bi+Bi interactions in the MPD energy range. Calculations are performed for centrality 0-10%, 0-20%, 0-30%.

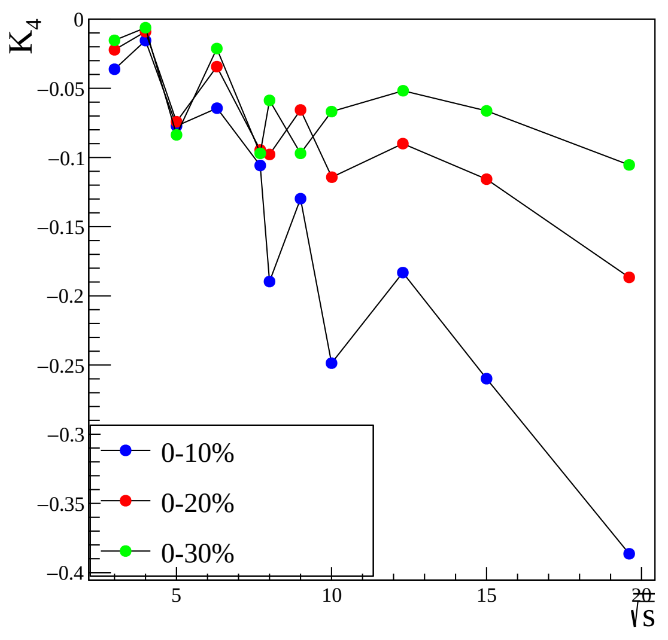

Figure 8:Cumulants four order as a function of collision energy obtained in UrQMD for Bi+Bi interactions in the MPD energy range. Calculations are performed for centrality 0-10%, 0-20%, 0-30%.

The skewness is the third term in a systematic cumulant expansion, whose first and second terms are the mean and the variance, respectively. Hydrodynamics predicts that the event-by-event fluctuations of the mean transverse momentum have positive skew. Calculations are performed for centrality 0-10%.

Summary

In this research, $< p_T > N_{ch}$ correlations in Bi-Bi collisions were studied using for one UrQMD. A number of typical fluctuations observables such as $\Sigma[p_T, N]$, $\Delta[p_T, N]$, $< N > D[p_T, N]$ and the cumulants of p_T were considered. In Figures of the energy dependence of $\Sigma[p_T, N]$, $\Delta[p_T, N]$, $< N > D[p_T, N]$, "waves", are caused by the transition from resonance to the string. Non-trivial p_T cumulants' collision energy dependence predicted by the models for a 'baseline' $p + p$ and $Bi + Bi$ reaction emphasizes difficulties in interpreting future results for $A + A$ collisions and requires further investigations. The third-order cumulant for UrQMD models showed agreement with the prediction of the hydrodynamic model. At low energies K_2 has only negative values for all models, K_3 has only positive values. Significant discrepancies between predictions of UrQMD models are observed indicating that data on Bi+Bi collisions from the NICA experiment, which will be obtained in the future, will limit the prediction of these models, as well as clarify the results obtained.

Acknowledgment

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