NUKLEONIKA 2004;49(Supplement 2):S37–S39

PROCEEDINGS

Modeling Bose-Einstein correlations in heavy ion collisions at RHIC

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Abstract Using UrQMD generated Au-Au collisions, two different methods of introducing Bose-Einstein (BE) correlations among final state particles are applied. New algorithm, which reassigns charges of produced particles but does not alter the original four-momenta, provided by an event generator, is compared to the standard weighting method. Correlation functions C_2 in q_{inv} and Bertsch-Pratt parametrizations are studied. While longitudinal radii are the same in both approaches, the transverse and invariant radii as well as the correlation strength λ are substantially overestimated in charge reassigning approach.

Key words numerical modeling • Bose-Einstein correlations • charge reassigning algorithm

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Received: 5 January 2004

Introduction

Space-time evolution of the heavy ion collisions is usually simulated using microscopic transport models. These models are based on classical Monte Carlo simulations and, therefore, are unable to simulate Bose-Einstein (BE) correlation among produced particles which are of quantum statistical origin. Such correlations can be modeled by different techniques [7] on the level of the so-called afterburners. Most of them introduce two-boson correlations starting from single-particle phase-space distributions, altering thus the original distribution of four-momenta provided by the event generator.

Recently, a new algorithm has been suggested [6], which claims to overcome this limitation. In this approach, the BE correlations are introduced via reassigning charges of produced particles in such a way as to make them look like particles satisfying Bose statistics. In this contribution, we compare these two approaches using UrQMD [1] transport model. The model provides four-coordinates and four-momenta.

Modeling BE correlations

The two-particle momentum correlation function of identical particles is defined [7] as a normalized ratio of corresponding two- and single-particle distributions

(1) $$C_2(q,k) = \gamma \frac{N_2(p_i, p_j)}{N_1(p_i) N_1(p_j)}$$

where $q = p_i - p_j$, $k = ½(p_i + p_j)$ and normalization factor γ guarantees that $C_2(\infty) = 1$.

Usually, a functional dependence of C_2 on relative momentum q is described by the Gaussian parametrization.

Most simple is the q_{inv} parametrization

$$C_2(\vec{q},\vec{k}) = 1 + \lambda(\vec{k})\exp(-R_{inv}^2 q_{inv}^2) \quad (2)$$

where $q_{inv}^2 = -q^2$ and λ is the correlation strength. The parameter R_{inv} characterizes the width of the source distribution.

More general description of $C_2(\vec{q},\vec{k})$ is based on the so-called Bertsch-Pratt parametrization [2, 4, 5] which uses decomposition of the four-vector q into the out-side-longitudinal coordinate system

$$q_{out} = \frac{\vec{q}_t \cdot \vec{k}_t}{|\vec{k}_t|}, \quad q_{side} = \frac{|\vec{q}_t \cdot \vec{k}_t|}{|\vec{k}_t|}, \quad q_{long} = p_{z,i} - p_{z,j} \quad (3)$$

where $\vec{k}_t = \frac{1}{2}(\vec{p}_{t,i} + \vec{p}_{t,j})$ and $\vec{q}_t = \vec{p}_{t,i} - \vec{p}_{t,j}$ are the transverse pair momentum and transverse relative momentum, respectively. The correlation function then takes the form

$$C_2(\vec{q},\vec{k}) = 1 + \lambda(\vec{k})\exp(-R_{out}^2 q_{out}^2 - R_{side}^2 q_{side}^2 - R_{long}^2 q_{long}^2 - 2R_{ol}^2 q_{out} q_{long}). \quad (4)$$

The standard method of introducing BE correlations among particles generated via classical Monte Carlo simulations is the weighting method with two-boson weight

$$w_{ij} = 1 + \cos((p_i - p_j) \cdot (x_i - x_j)). \quad (5)$$

The method computes C_2 using particle momenta and coordinates at the freeze-out. A drawback of this method is that it cannot simulate multi-boson correlations. However, our use of the weighting method is well justified, because the phase-space densities generated by transport models are rather low.

Recently, a new algorithm has been suggested [6], which claims to overcome this limitation. The algorithm is based on reassigning charges of produced pions and results in formation of quantum BE cells in phase-space, in which the number of identical bosons is enhanced [6]. It conserves the energy-momenta and does not alter any single particle inclusive distribution.

Very briefly, the algorithm consists of the following two steps. Firstly, pion (i) is chosen randomly and +, – or 0 charge is assigned to it randomly with weights proportional to $P_+ = n_+/n$, $P_- = n_-/n$ and $P_0 = n_0/n$, where $n = n_+ + n_- + n_0$ is the total number of pions π^+, π^- and π^0 in event. This pion defines a new phase-space cell. Secondly, the additional pions (j) are added to the cell with weight [6]

$$P_{ij} = \exp(-\tfrac{1}{2}\,(x_i - x_j)^2(p_i - p_j)^2). \quad (6)$$

All accepted pions in the cell are assigned to the same charge as pion (i). The process of adding the pions to the cell continues until first failure, i.e. when the generated random number $r \in (0,1)$ becomes greater than P_{ij}.

The algorithm of producing new cells proceeds until all pions in event are used, event by event. In this way, four-momenta, freeze-out coordinates and total charge of the system provided by the event generator are kept intact, but the individual charges of particles are not.

Event simulation

The UrQMD [1] transport model was chosen to simulate central Au-Au collisions at CMS energy per nucleon pair $\sqrt{s_{NN}}$ = 200 GeV with maximum impact parameter $b_{\max}$ = 3 fm. The maximum CMS evolution time was set to t_0 = 500 fm/c. Using a PC equipped with 2.4 GHz Pentium IV processor 4000 events were generated. The CPU time to generate one central Au-Au event was about 300 s.

The output from the UrQMD model containing final particles is an ASCII file compliant with OSCAR 1997A format. Particle entries of the event-body contain the particle listing number, ID, four-momentum vector (p_x,p_y,p_z,E), mass m and freeze-out four-coordinates of the particle (x,y,z,t). In order to facilitate further processing, a small code was written to convert the output OSCAR-file into the ROOT-file with particle entries stored as a set of TParticle objects [3].

Using the BE correlated UrQMD events obtained from both methods (5) and (6), the correlation function (1) is constructed by taking the ratio, bin by bin, of normalized histogram of real pairs with normalized histogram of mixed pairs. The real pairs are pion pairs that belong to the same event and mixed pairs are pions that are picked up randomly from different events. The following cuts are used. Pions with pseudo-rapidity $|\eta| < 1$ and like-charged pion pairs

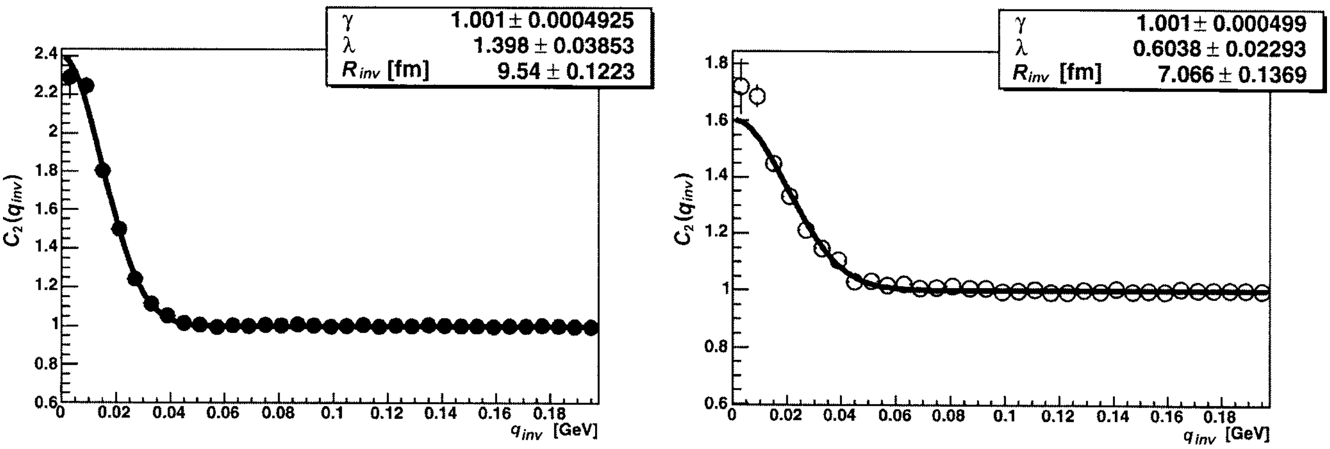

Fig. 1. The q_{inv} parametrization (2) of the correlation function for $\pi^-\pi^-$ pairs using charge reassigning algorithm (left panel) and the weighting method (right panel) with the Gaussian fit.

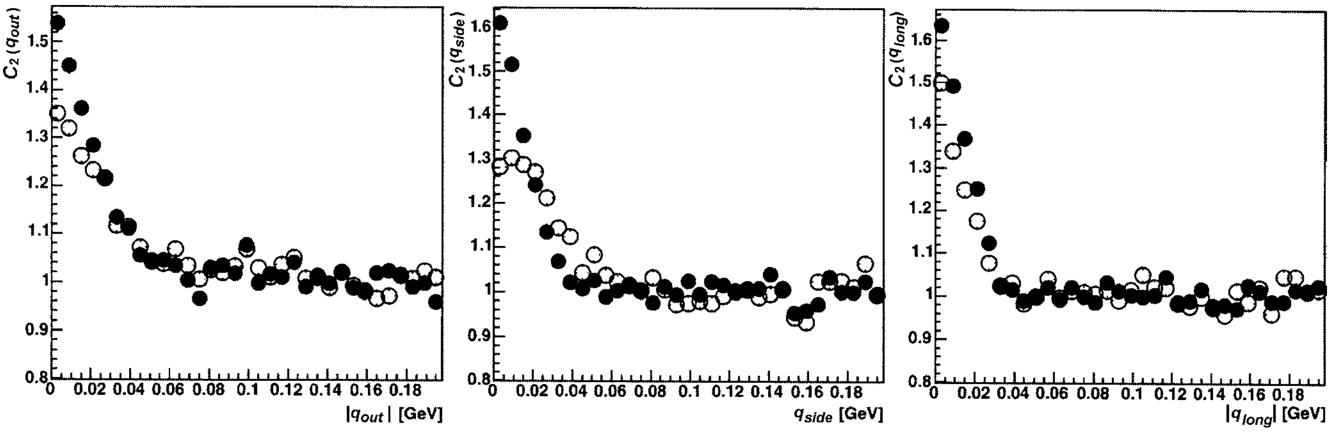

Fig. 2. The $|q_{out}|$, q_{side} and $|q_{long}|$ projections of Bertsch-Pratt parametrization of the 3D correlation function (4) for $\pi^-\pi^-$ pairs. The correlations modeled by charge reassigning algorithm (black symbols) are compared to the weighting method (open symbols).

in the k_t–Y_{ij} bin with transverse pair momentum $0.1 < k_t < 0.2$ GeV/c and pair rapidity $|Y_{ij}| < 0.2$ are selected. The UrQMD model provides all pion pairs with $-Q^2 = (p_i - p_j)^2 = (\Delta E)^2 - (\Delta\vec{p})^2 < 0$ and in order to keep the value of weight (6) below unity, only the pion pairs with space-like variable $-R^2 = (x_i - x_j)^2 = (\Delta t)^2 - (\Delta\vec{x})^2 < 0$ are accepted. Moreover, additional cut $R < 50$ fm is used.

Results and conclusions

The q_{inv} parametrization (2) of the correlation function for $\pi^-\pi^-$ pairs is plotted in Fig. 1. On the left panel, the Gaussian fit gives $R_{inv} = 9.54 \pm 0.12$ fm and $\lambda = 1.40 \pm 0.04$. The correlation function obtained as a result of the weighting method (5) is shown on the right panel for a comparison, $R_{inv} = 7.07 \pm 0.14$ fm, $\lambda = 0.60 \pm 0.02$.

Figure 2 shows $|q_{out}|$, q_{side} and $|q_{long}|$ projections of the 3D correlation function (4). The 3D correlation histogram is projected with $0 < |q_{out}|, q_{side}, |q_{long}| < 0.03$ GeV/c cut applied to each unprojected variable. Neglecting the small parameter R_{ol}, the five-parameter fit of the correlation function yields the following radii of the modeled source, $R_{out} = 6.53 \pm 0.15$ fm, $R_{side} = 9.13 \pm 0.20$ fm, $R_{long} = 9.35 \pm 0.19$ fm and $\lambda = 1.44 \pm 0.04$. The weighting method yields $R_{out} = 4.82 \pm 0.16$ fm, $R_{side} = 4.90 \pm 0.14$ fm, $R_{long} = 9.16 \pm 0.29$ fm and $\lambda = 0.66 \pm 0.03$.

To summarize, applying the charge reassigning algorithm described in the previous section on the UrQMD generated Au-Au collisions results in the two-pion momentum correlations shown in Figs. 1 and 2. While the transverse radii R_{out} and R_{side} and also R_{inv} are substantially overestimated in the charge reassigning method, the longitudinal dynamics described by R_{long} is the same for both methods. Moreover, the correlation strength λ for the charge reassigning method acquires the unphysical value ($\lambda > 1$). Therefore, the algorithm [6] fails to reproduce the BE correlations. This may be due to the too gradual decrease of the weight (6), therefore we plan to use different weight (6) in the future.

This work was supported by the Grant Agency of the Czech Republic under contract 202/04/0793.

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