Pion femtoscopy in p+Au and Au+Au collisions at √s_{NN} = 200 GeV using transport approach

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Abstract. Correlation femtoscopy provides information about the space-time structure and evolution of the fireball created in ultra-relativistic nucleus-nucleus collisions. The dependence of the femtoscopic radii on transverse pair momentum and charged particle multiplicity of an event reflects the mechanism of collective behavior. In this work, the femtoscopic radii of identical charged pions were calculated in the UrQMD model for Au+Au and p+Au collisions at √s_{NN} = 200 GeV and compared to each other at the same multiplicities. The physics implications of this comparison will be discussed.

1. Introduction
Correlation femtoscopy technique allows one to measure space-time extents of the particle-emitting source created in high-energy collisions [1]. It is based on the quantum statistical (QS) correlations between identical particles [2–6]. The extracted so-called femtoscopic radii do not allow one to measure the emission zone volume because it changes shape and size during the collision evolution. It is also affected by dynamically generated space-momentum correlations due to the radial expansion of the system. Thus, the correlation femtoscopy probes a “homogeneity length”.

Studies of multiparticle correlations produced in small systems (like p+p) reveal striking similarities to those observed in nucleus-nucleus collisions, which are not yet understood. In this work, we study the identical pion femtoscopic correlations at similar charged particle multiplicity classes and pair transverse momentum regions produced in p+Au and Au+Au collisions at √s_{NN} = 200 GeV in the UrQMD model [11,12].

2. Correlation function
Femtoscopy uses a two-particle correlation function, C(q) = A(q)/B(q), as a tool to measure emitting-source radii, where q = p_1−p_2 – relative four-momentum of the first and second particle from the pair, respectively, A(q) – relative momentum distribution of identical particles produced in the same collision (contains quantum statistical correlations), and B(q) is distribution, which is identical to A(q) in all aspects except that it does not contain QS correlations.

Monte Carlo generators do not contain QS correlations. However, one can add those as an afterburner by adding femtoscopic weights. A pair’s weight, w, can be calculated as:

\[ w = 1 + \cos(q\Delta x), \]  

(1)
where $p_i$ and $x_i$ are particle four-momentum and freeze-out four-coordinate, respectively. The correlation function, $C(q)$, is usually constructed as the ratio of the weighted to unweighted two-particle relative momentum distributions.

In the current work, we performed one-dimensional analysis that is based on the measurement of the invariant relative four-momentum:

$$Q_{inv} = \sqrt{(\Delta p)^2 - (\Delta E)^2},$$

$$\Delta p = p_1 - p_2, \quad \Delta E = E_1 - E_1,$$

where $p_i$ and $E_i$ are particle three-momentum and energy, respectively. To extract femtoscopic radii, correlation functions were fitted by:

$$C(Q_{inv}) = 1 + \lambda e^{-R_{inv}^2 Q_{inv}^2},$$

where $\lambda$ is the correlation strength. The $R_{inv}$ characterizes the invariant size of the particle-emitting source, assuming Gaussian source profile.

The dependence of the femtoscopic radius on transverse momentum reflects the dynamics of the system evolution, while the dependence on charged particle multiplicity (or collision centrality for large systems) originate from the geometry of the collision \cite{7-10}. Small systems (like p+Au or d+Au) are also sensitive to the initial conditions \cite{14}.

3. Results

We studied the identical pion femtoscopic correlations in p+Au and Au+Au collision at $\sqrt{s_{NN}} = 200$ GeV using the Ultrarelativistic Quantum Molecular Dynamics model (UrQMD) \cite{11,12}. Pions were selected by the PDG code within the momentum range from 0.15 to 2 GeV/c at midrapidity ($|\eta| < 0.5$). Correlation functions of identical charged pions were constructed for 4 pair transverse momentum ($k_T$) ranges (0.15-0.25), (0.25-0.35), (0.35-0.45) and (0.45-0.55) GeV/c for 3 charged particle multiplicity ($N_{ch}$) ranges: 1-10, 11-20, and 21-30. The $N_{ch}$ is defined as a multiplicity of charged particles with $p_T > 0.1$ GeV/c and $|\eta| < 0.5$.

Figure 1 shows obtained pion correlation functions for p+Au (blue triangles) and Au+Au (brown triangles) collisions with the $0.25 \leq k_T \leq 0.35$ GeV/c for 1 $\leq N_{ch} \leq 10$ (a) and 21 $\leq N_{ch} \leq 30$ (b).

Blue and brown lines represent fits to the correlation functions with Eq. \ref{eq:3} obtained for p+Au and Au+Au collisions, respectively. The fits underestimate correlation functions at $Q_{inv} < 0.05$ GeV/c suggesting that the emitting source is not Gaussian (at least in one-dimensional case). This effect can be studied in more details using, for example, three-dimensional correlation functions.

Figure 2 shows the $k_T$ dependence of the extracted femtoscopic radii for p+Au (blue circles) and Au+Au (red circles) collisions.

Left (a), middle (b), and right (c) panels in Fig. 2 represent results obtained for 1 $\leq N_{ch} \leq 10$, 11 $\leq N_{ch} \leq 20$, and 21 $\leq N_{ch} \leq 30$, respectively. For all cases $R_{inv}$ decrease with increasing $k_T$ due to the collective transverse flow \cite{13}. Pion femtoscopic radii measured in p+Au collisions are consistent with those in Au+Au at 1 $\leq N_{ch} \leq 10$. For the larger charged particle multiplicities $R_{inv}$ for Au+Au collisions are generally larger than for p+Au at the same $k_T$. The difference between pion radii measured in p+Au and Au+Au systems increase with increasing charged particle multiplicity, $N_{ch}$.
Figure 1. (Color online) Correlation functions and their fits for identical charged pions with $0.25 \leq k_T \leq 0.35 \text{ GeV/c}$ from p+Au and Au+Au collisions at $\sqrt{s_{NN}} = 200 \text{ GeV}$ obtained for UrQMD. (a) Results for $1 \leq N_{ch} \leq 10$ and for (b) $21 \leq N_{ch} \leq 30$.

Figure 2. (Color online) One-dimensional pions source radii, $R_{inv}$, dependence on pair transverse pair, $k_T$, p+Au (blue circles) and Au+Au (red circles) collisions at $\sqrt{s_{NN}} = 200 \text{ GeV}$ from UrQMD. (a), (b), and (c) panels show results measured for $1 \leq N_{ch} \leq 10$, $11 \leq N_{ch} \leq 20$, and $21 \leq N_{ch} \leq 30$, respectively.

4. Conclusions
In this proceedings, we report on the estimation of one-dimensional pion femtoscopic radii, $R_{inv}$, in p+Au and Au+Au collisions at $\sqrt{s_{NN}} = 200 \text{ GeV}$ obtained for the UrQMD model. The dependence $R_{inv}$ on pair transverse momentum, $k_T$, was studied for charged particle multiplicity ranges: $1 \leq N_{ch} \leq 10$, $11 \leq N_{ch} \leq 20$, and $21 \leq N_{ch} \leq 30$. Pion femtoscopic radii measured in p+Au collisions are consistent with those in Au+Au at $1 \leq N_{ch} \leq 10$. The difference between pion radii measured in p+Au and Au+Au systems increase with increasing charged particle multiplicity for the same $k_T$.

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