Pion femtoscopy in p+Au and d+Au collisions at $\sqrt{s_{NN}} = 200$ GeV in the STAR experiment

Eugenia Khyzhniak[1] **(for the STAR collaboration)**

[1] National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Kashirskoe highway 31, Moscow, 115409, Russia

E-mail: `evkhizhnyak@mephi.ru`

Abstract. In heavy-ion collisions, particle-emitting source appears. It is important to understand how the emission source size would change with different collision species. It can be studied using femtoscopy technique since femtoscopy allows one to measure spatial and temporal characteristics of the particle-emitting source.

In this talk, we present one-dimensional source radii of charged pions obtained for p+Au and d+Au collision systems at $\sqrt{s_{NN}} = 200$ GeV. Radii dependence on the transverse momentum of the pion pairs will be discussed.

1. Introduction

The correlation femtoscopy technique allows one to measure the spatial and temporal extents of the emitting region in high-energy heavy-ion collisions. These correlations emerge from the quantum statistics, Coulomb, and strong final state interactions. The spatio-temporal structure of the particle-emitting source is essentially defined by the dynamics of the collision processes [1]. The system expansion dynamics are influenced by transport properties of the medium, phase transition/critical point and the event shape. Examination of the spatial and temporal scales of the particle-emitting source is one of the ways to study the process of particle production [2]. Small colliding systems (for example p+Au or d+Au) are sensitive to the initial conditions. Therefore, the detailed nature of particle production becomes important [3, 4].

In this proceedings, we present invariant radii of charged pions obtained for p+Au and d+Au collision at $\sqrt{s_{NN}} = 200$ GeV collected in the STAR experiment. The pion-pair transverse momentum dependence of the source radii indicates the collective expansion of the system and allows to probe the different regions of the homogeneity in both p+Au and d+Au systems. The dependence of the invariant radii on pair transverse momentum and charged particle multiplicity is presented.

2. Femtoscopy

The femtoscopy method was employed to measure the space-time extents of the particle-emitting region at kinetic freeze-out. It is based on the quantum statistical correlations between two identical particles [5–8]. The femtoscopic correlations are calculated as a function of relative momentum of the pair, expressed as $Q_{inv} = \sqrt{(\mathbf{p_1} - \mathbf{p_2})^2 - (E_1 - E_2)^2}$, where $\mathbf{p_1}$, $\mathbf{p_2}$ are particles 3-momenta, and E_1, E_2 are energies of the particles. In order to estimate the particle-emitting source parameters, one needs to reconstruct the correlation function, $C(Q_{inv})$, that is defined as:

$$C(Q_{inv}) = \frac{A(Q_{inv})}{B(Q_{inv})}, \tag{1}$$

where $A(Q_{inv})$ is a distribution of two-particle relative momentum that contains Bose-Einstein statistics, Coulomb and strong interactions, and $B(Q_{inv})$ is the reference distribution that has all experimental effects as in the first one, $A(Q_{inv})$, except for physics correlation between two particles. The $B(Q_{inv})$ distributions were reconstructed by event mixing technique [9].

To extract the invariant radius, R_{inv}, from the correlation function we do fitting procedure with the following function [10, 11]:

$$C(Q_{inv}) = N(1 - \lambda + \lambda K_{Coul}(Q_{inv})(1 + G(Q_{inv})))D(Q_{inv}), \tag{2}$$

where N is a normalization factor, λ is a correlation strength parameter, $D(Q_{inv})$ is a non-femtoscopic contribution (which in this work is equal to 1), $K_{Coul}(Q_{inv})$ is a squared like-sign pion pair Coulomb wave-function integrated over a spherical Gaussian source [12, 13], and $G(Q_{inv}) = e^{-Q_{inv}^2 R_{inv}^2}$ - Gaussian form of the emission source.

One can study the dynamics of the system evolution via measurement of the pair transverse momentum ($k_T = \frac{|\mathbf{p_{1T}} + \mathbf{p_{2T}}|}{2}$) dependence of the correlation function [14].

3. Analysis details

This analysis uses the data of p+Au and d+Au collisions at $\sqrt{s_{NN}} = 200$ GeV collected by the STAR experiment. Events were accepted for analysis if z-position of the collision vertex was within 40 cm from the center of the Time Projection Chamber (TPC) [15]. At the same time, the radial component of the collision vertex position should not exceed 2 cm. Several collisions can occur in the collider during the readout of the event in the experiment in the gas volume of the TPC - it may be lead to pile-up. In order to have an independent estimate of the position of the collision point in STAR, two VPD [16] detectors are located at a distance of ~ 5.7 m from the center of the experiment, two VPD detectors are located along the beam axis. Detectors allow one to reconstruct z-coordinate of a collision vertex by the timestamps of the signals caused by photons, which were emitted from the collision region. In order to remove the pile-up, the events, where the difference of the z-positions of the primary vertex obtained from TPC and VPD was larger than 5 cm in absolute value, were removed from the analysis. Particle tracks were selected in the $p \in [0.15, 0.8]$ GeV/c momentum range and pseudorapidity was selected in the midrapidity region: $|\eta| < 0.5$. The particle identification was performed using information about ionization energy losses of charged particles in the sensitive volume of TPC. In order to remove two-track effects, such as track-merging and track-splitting, only tracks with splitting level (SL) [17], $-0.5 < SL < 0.6$, average separation of two tracks from the pair within TPC volume > 10 cm and fraction of merged hits (FMR), $FMR \in [-1.1, 0.1]$, were used in the analysis. The splitting level value provides an information about whether the two tracks from a pair are really two tracks or possibly one track reconstructed as two tracks with similar momenta. There may be also an opposite situation when two particles reconstructed as one track. The influence of this effect was estimated by the FMR [17].

Different sources of the systematic uncertainties influence differently on correlation function for the studied collision systems, pion pair transverse momentum and multiplicity ranges. The systematic errors from different sources are summed up quadratically. The following sources of systematic uncertainties were considered:

- Selection criteria of the events (position of the primary vertex): $< 5\%$
- Selection criteria of the tracks (momentum of the tracks, tracking efficiencies): $< 6\%$
- Selection criteria of the pairs (two track effects – merging, splitting): $< 2\%$

- Fit range: $< 3\%$
- Coulomb radius: $< 3\%$

4. Results

To obtain invariant radii of the emission source correlation functions were constructed with Eq. (1) and were fitted with Eq. (2). Figure 1 shows the example of the correlation functions constructed for identical charged pion pairs from d+Au and p+Au collisions at $\sqrt{s_{NN}} = 200$ GeV for the multiplicity range $11 < N_{ch}^{|\eta|<0.5} < 20$, and transverse momentum range $k_T \in [0.25, 0.35]$ GeV/c. Also, Fig. 1(a) shows the fit to the correlation functions with Eq. (2), where $G(Q_{inv}) = e^{-Q_{inv}^2 R_{inv}^2}$ has a Gaussian form, whilst the Fig. 1(b) shows the fit to the correlation functions with the same Eq. (2), but the $G(Q_{inv}) = e^{-Q_{inv} R_{inv}}$ has an exponential form. It was done to test whether the emitting source has Gaussian or Lorentzian shape. However, for the current analysis the Gaussian assumption was used and all further results were obtained with this assumption. Red and blue lines represent fit of the correlation functions by Eq. (2). The correlation functions are reasonably described by the fits.

Figure 2 shows the dependence of the radii and correlation strength parameter on the transverse momentum of the pion pair for both p+Au and d+Au collision systems at $\sqrt{s_{NN}} = 200$ GeV. It is seen that the radii decrease with increasing k_T and increase with increasing particle multiplicity. Also, it is seen that the correlation strength parameter decreases with particle multiplicities. It is seen that the invariant radii have a weak dependence on the colliding systems and the difference between two colliding systems becomes smaller with increasing of the pair transverse momentum. Also, it is seen that the radii increase with increasing colliding system size.

Statistical and systematic uncertainties are shown as vertical lines and boxes on Fig. 2, respectively. It is seen from the Fig. 2, that, for almost all cases, statistical uncertainties are smaller than the marker size.

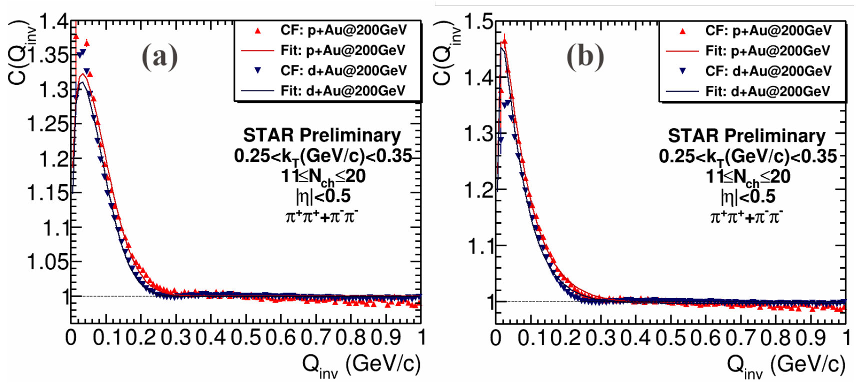

Figure 1. (Color online) Fit with Gaussian (a) and Exponential (b) forms to the correlation functions constructed for identical charged pion pairs from d+Au and p+Au collisions at $\sqrt{s_{NN}} = 200$ GeV for the multiplicity range $11 < N_{ch}^{|\eta|<0.5} < 20$ and transverse momentum range $k_T \in [0.25, 0.35]$ GeV/c.

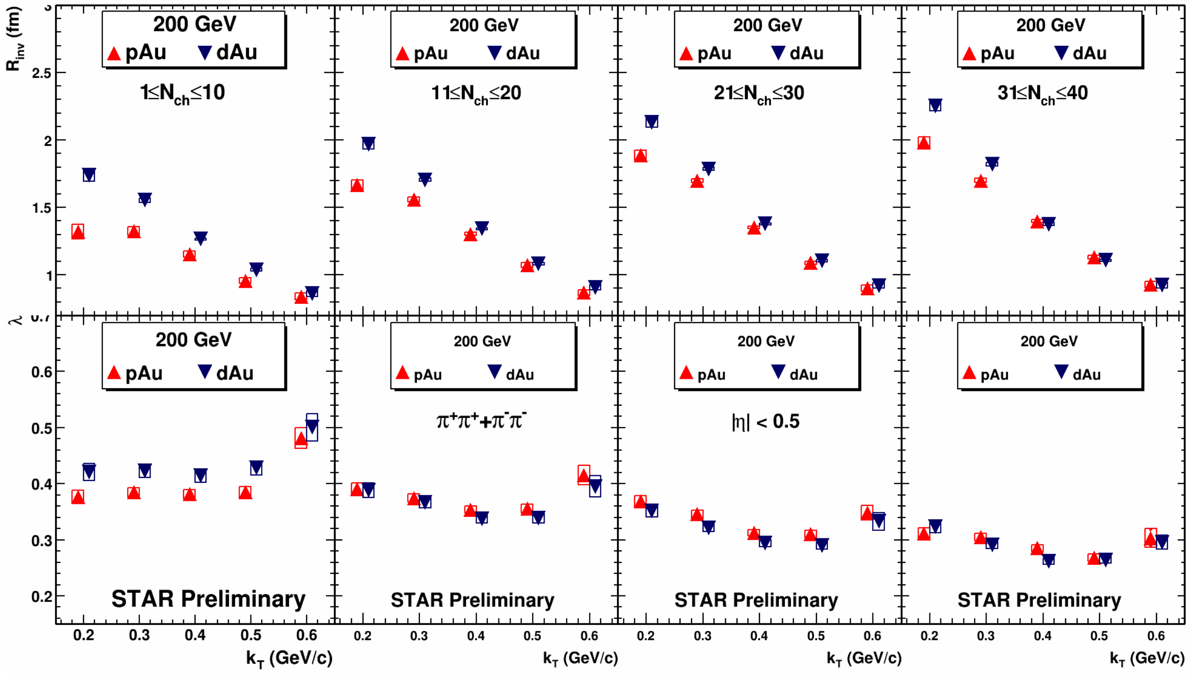

Figure 2. (Color online) Identical charged pion invariant radii (top row) dependence and correlation strength parameter (bottom row) on k_T and multiplicity for p+Au and d+Au collisions at $\sqrt{s_{NN}} = 200$ GeV.

5. Conclusions

The identical charged pions invariant radii dependence on the pair transverse momentum and multiplicity for p+Au and d+Au collision at $\sqrt{s_{NN}} = 200$ GeV has been presented and discussed. It was shown that the radii increase with increasing multiplicity. For each studied multiplicity region, charged pion invariant radii decrease with increasing transverse momentum of a pair. This study also shows that charged pion R_{inv} has a weak dependence on the colliding systems and the difference between two colliding systems becomes smaller with increasing of the pair transverse momentum. The invariant radii increase with increasing colliding system size.

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