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# Two-pion and two-kaon femtoscopic correlations in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV from STAR

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## Abstract

Measurement of femtoscopic correlations in heavy-ion collisions can provide information about spatial and temporal parameters of the particle emission region at kinetic freeze-out. In this work we present the measurement of two-pion and two-kaon femtoscopic correlations in 200 GeV Au+Au collisions at RHIC. The collision centrality and transverse momentum dependence of the three-dimensional radii, $R_{out}$, $R_{side}$ and $R_{long}$ is discussed.

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## 1. Introduction

One of the main aims of relativistic heavy-ion collisions is to create and study a new state of matter — quark-gluon plasma (QGP). This matter undergoes the rapid hydrodynamic expansion, followed by hadronization and particle rescattering. Two-particle correlations at small relative momentum, also known as correlation femtoscopy or HBT, Hanbury-Brown and Twiss intensity interferometry, are widely used to extract the spatial and temporal extent of the particle-emitting source at the last stage of relativistic heavy-ion collision evolution, kinetic freeze-out [1]. Usually femtoscopic analyses study the most abundant pions, but with the datasets available at RHIC and LHC it is possible to study the correlations of other particle species, e.g. kaons. Kaons can provide complementary information to pions because they are less affected by the feed-down from resonance decays, have a smaller cross-section with the hadronic matter and contain strange quarks.

## 2. Correlation femtoscopy

The femtoscopic correlation function is defined as a ratio of the conditional probability to observe two particles together divided by the product of probabilities to observe each of the particles separately. Experimentally, the correlation function is measured as a ratio of a signal distribution, $A(q)$, that contains quantum statistical (QS) correlations to a background distribution, $B(q)$, that does not contain QS correlations:

$$C(q) = A(q)/B(q), \tag{1}$$

where $A(q)$ is the relative 4-momentum ($q$) distribution of particles from the same event (collision), and $B(q)$ is a relative 4-momentum distribution of pairs where each particle is taken from different events (event-mixing technique). The mixed events should have similar properties, e.g. collision centrality, acceptance, etc. In order to get more information about the particle-emitting source, the momentum difference is calculated in the longitudinally co-moving system (LCMS), where the longitudinal pair momentum vanishes, and is decomposed according to the Betsch-Pratt convention ($q_{out}$, $q_{side}$, $q_{long}$) [2, 3], where the "long" axis points along the beam direction, "out" is oriented along the pair transverse momentum direction, and "side" is orthogonal to the other two.

The source radii are extracted from the correlation functions by the standard Bowler-Sinyukov fit [4, 5] of the $C(q_{out}, q_{side}, q_{long})$ to separate the QS correlations and Coulomb interaction:

$$C(q_{out}, q_{side}, q_{long}) = N\left(1 - \lambda + \lambda K(q_{inv})[1 + \exp(-R^2_{out}q^2_{out} - R^2_{side}q^2_{side} - R^2_{long}q^2_{long})]\right), \tag{2}$$

where $N$ is a normalization factor, $\lambda$ represents the strength of the correlations, and $R_{out}$, $R_{side}$, and $R_{long}$ are the source radii in the "out", "side" and "long" directions, respectively. The function $K(q_{inv})$ is the Coulomb part of two-particle wave function integrated over the assumed spherical Gaussian source with a fixed radius. In the current analysis, the value of this radius is set to 5 fm. The $q_{inv}$ quantity is the invariant 4-momentum difference.

# 3. Analysis details

The femtoscopic analysis presented in this proceeding is applied to the Au + Au $\sqrt{s_{NN}}$=200 GeV data taken by the Solenoidal Tracker At RHIC (STAR) in 2011. STAR has uniform acceptance and full azimuthal coverage. The main detector of STAR is a Time Projection Chamber (TPC) [6]. Particle identification was performed using combined information from TPC and from Time of Flight (TOF) [7] detectors. Particles are identified via specific ionization energy loss, $dE/dx$, in the TPC gas and square of mass determined by TOF. The collision centrality was estimated using charged particle multiplicity at midrapidity ($|\eta|$ <0.5). Only collisions reconstructed within ±30 cm from the center of TPC were used in the analysis. In order to exclude interactions with the beam pipe, a cut on the radial position of the vertex (defined as $V_R = \sqrt{V_x^2 + V_y^2}$, where $V_x$ and $V_y$ are the vertex positions along the x and y directions) <2 cm was applied. Pion and kaon candidates were required to originate from the collision vertex by requiring the extrapolated distance of closest approach (DCA) to this vertex to be less than 2 cm. In order to have high track reconstruction efficiency and purity of identified particles, only tracks with $|\eta|$ <1 and momentum $0.15 < p < 1.45$ GeV/c were accepted for the analysis. Other track quality cuts were also applied.

## 4. Results and discussions

Figure 1 shows a sample of projected $\pi^{\pm}\pi^{\pm}$ (red circles) and $K^{\pm}K^{\pm}$ (blue crosses) correlation functions with fits (lines) performed according to Eq. 2. Particle pairs were selected for average transverse pair momenta $0.4 < k_T < 0.5$ GeV/c, where $k_T = (p_1 + p_2)_T/2$, and $p_1$ and $p_2$ are the three-momenta of the first and the second particle. For the projection on one of the directions, the relative momenta in the other two $q$ directions are required to be less than 50 MeV/c.

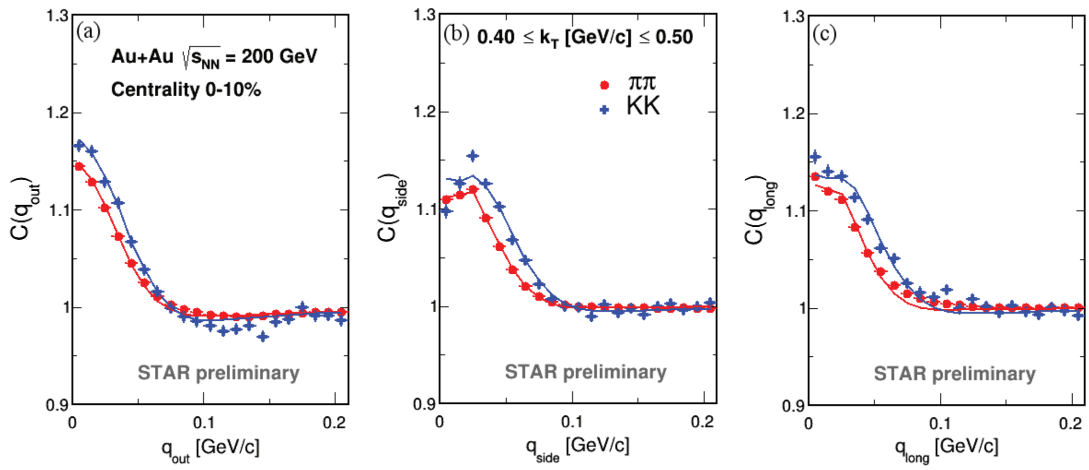


**Figure** 1: (Color online) Sample fit projections onto the $q_{out}$ (a), $q_{side}$ (b) and $q_{long}$ (c) axes for pions (red circles) and kaons (blue crosses). The projections are from 0–10% central, 200 GeV Au+Au collisions with $0.4 < k_T < 0.5$ GeV/c. Lines represent fits to the data with Eq. (2).

The extracted $K^+K^+$ (solid triangles) and $K^-K^-$ (open triangles) source radii as a function of centrality and transverse pair momentum are shown in Figure 2. The analysis was performed for 4 centrality classes (0–10%, 10–30%, 30–50%, and 50–80%) and 6 transverse pair momentum bins. The correlation functions for positive and negative kaon pairs were constructed separately. It is seen that the source radii extracted for positive and negative kaons are consistent within the uncertainties. The decrease of

$R_{out}$ and $R_{side}$ with increasing $k_T$ is an effect of the expansion and the transverse flow. The longitudinal expansion of the system results in the decrease of $R_{long}$ with increasing $k_T$.

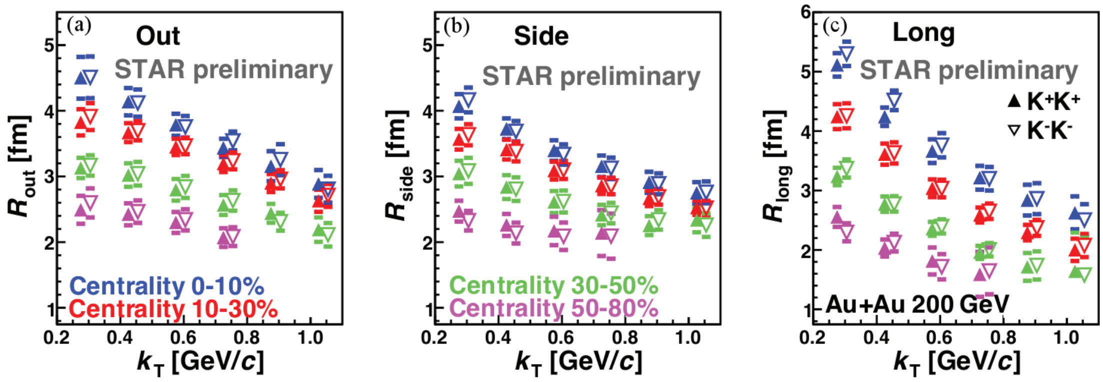


**Figure** 2: (Color online) Transverse pair momentum dependencies of (a) $R_{out}$, (b) $R_{side}$, and (c) $R_{long}$ measured for four centrality classes (0–10%, 10–30%, 30–50%, and 50–80%) for positive (solid triangles) and negative (open triangles) kaon pairs from Au+Au collisions at $\sqrt{s_{NN}}$=200 GeV.

A comparison of pion and kaon source radii for 0–5% (blue symbols) and 30–40% (red symbols) Au+Au collisions are shown in Figure 3. The current analysis extended the previous pion femtoscopic measurements [8] to higher pair transverse mass $m_T = \sqrt{k_T^2 + m^2}$ using the TOF detector, which allows identification of pions and kaons up to momenta $p$=1.45 GeV/c. The caps represent systematic uncertainties for kaon and published pion results. The systematic uncertainties for the current pion measurement are under study. Within uncertainties, the $m_T$ dependencies of $R_{side}$ for kaons and pions are similar suggesting the $m_T$-scaling in the sideward direction. This may indicate that spatial extent of pion and kaon emitting sources are similar. The $R_{out}$ values for kaons are larger than those for pions. The $R_{long}$ for kaons and pions have different dependence on $m_T$. Pion and kaon source radii with similar dependences on $m_T$ as aforementioned have been reported for Pb+Pb collisions at $\sqrt{s_{NN}}$=2.76 TeV [9].

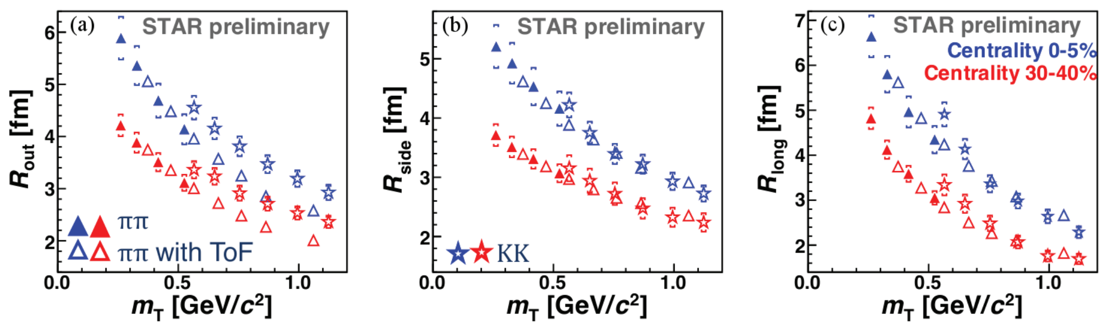


**Figure** 3: (Color online) Transverse mass dependencies of (a) $R_{out}$, (b) $R_{side}$, and (c) $R_{long}$ for kaons (stars) and pions (triangles) from Au+Au collisions at $\sqrt{s_{NN}}$=200 GeV for 0–5% (blue symbols) and 30–40% (red symbols) centralities. Solid triangles represent pion results previously measured by STAR [8].

## 5. Conclusions

Preliminary results of two-pion and two-kaon femtscopic correlations measured in Au+Au collisions at $\sqrt{s_{NN}}$=200 GeV by the STAR experiment have been presented. The emitting-source radii, $R_{out}$, $R_{side}$, and $R_{long}$, are extracted from a three-dimensional analysis. The femtoscopic radii decrease with increasing transverse mass and decreasing charged particle multiplicity. Qualitatively, the observed centrality and transverse pair momentum dependencies are typical for collectively expanding sources. Further comparisons to hydrodynamic models are in progress.

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