# NON-IDENTICAL PARTICLE FEMTOSCOPY AT STAR*

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Heavy-ion collisions allow us to study properties of nuclear matter — *e.g.* Quark–Gluon Plasma (QGP) state, where quarks and gluons are deconfined. To study space-time parameters of the source size at the final stage of the collision evolution (kinetic freeze-out), the method of femtoscopy is used. This method enables estimation of source characteristics which cannot be measured directly. Measuring the correlations of non-identical particles, one can obtain information about asymmetry in emission process between two kinds of particles. In this paper, we present a status report of a STAR analysis of pion–kaon, pion–proton and kaon–proton correlations in Au+Au collisions at $\sqrt{s_{NN}} = 39$ GeV.

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## 1. Introduction

The correlation femtoscopy is used to study the space-time characteristics of the source of the order of $10^{-15}$ m and $10^{-23}$ s. It allows us to measure the size of the particle-emitting source and emission duration. Studies of non-identical particle combinations provide information about space-time asymmetry in the emission process, such as relative position of the average emission points and mean times of particle emission [1]. The shape of the non-identical particle correlation function depends on Final State Interactions (FSI) only.

To study the QCD phase diagram of nuclear matter, a Beam Energy Scan (BES) program was designed at Relativistic Heavy Ion Collider (RHIC). This program uses collisions of gold nuclei at energies from $\sqrt{s_{NN}} = 7.7$ up to 62.4 GeV to achieve three goals: to examine properties of the first

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order phase transition between hadron and quark matter, to detect a critical point between cross-over area and the first order phase transition, and to find collision energy below which signatures of QGP phase are turned off [2].

In this proceeding, we report the preliminary results of the femtoscopic measurements of non-identical particles in the STAR experiment at $\sqrt{s_{NN}} =$ 39 GeV.

## 2. Non-identical particle femtoscopy

Non-identical particle correlations at low relative momentum result from Final State Interactions: Coulomb and strong forces. In pion–kaon and pion–proton femtoscopy, Coulomb interaction is dominant, but for kaon–proton pairs, the strong force is also important [3].

Momentum distributions are calculated in the Pair Rest Frame (PRF) reference system, where the center-of-mass of the pair rests. The pair relative momentum $k^*$ is the momentum of the first particle in PRF.

One of the most advanced representations of the correlation function is spherical harmonic decomposition [4]. The correlation function ($C(k^*)$) is defined as

$$C\left(\vec{k^*}\right) = \sqrt{4\pi} \sum_{lm} C_{lm}\left(\vec{k^*}\right) \cdot Y_{lm}(\theta, \phi)\,, \tag{1}$$

where $\theta$ and $\phi$ — polar and azimuthal angles, respectively.

The component $C_0^0$ is sensitive to the size of the emitting source and $C_1^1$ is sensitive to the emission asymmetry [5].

## 3. Results

### *3.1. Cuts and particle identification*

In this work, only 0–10% central Au+Au collisions at $\sqrt{s_{NN}} = 39$ GeV are analyzed. The cuts for data selection are shown in Table I.

Information from Time Projection Chamber (TPC) and Time-of-Flight (ToF) detectors is used to identify particles via measuring the ionization energy loss ($\mathrm{d}E/\mathrm{d}x$) in the TPC detector and particle velocity by the ToF detector. Only statistical uncertainties are presented.

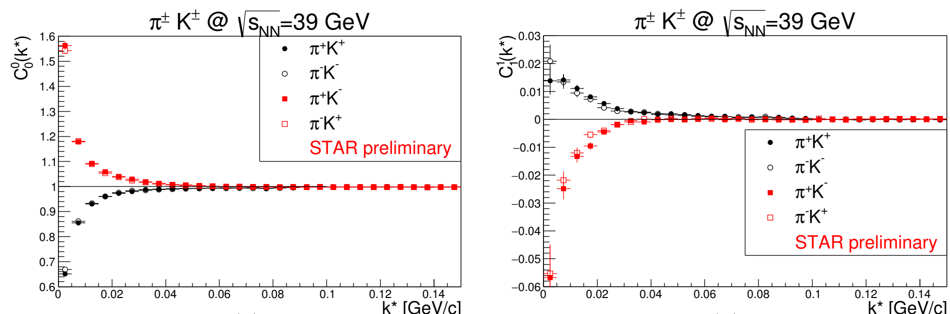
### *3.2. Spherical harmonics*

Figure 1 (a) presents $C_0^0$ components for all combinations of pions and kaons. The range of correlation for these pairs combinations is similar so the source sizes of these pairs would be similar as well. $C_1^1$ components for pion–kaon pairs are shown in figure 1 (b). These results show that asymmetries in emission process exist for every type of pion–kaon pair. An estimation of the source parameters is under way.

TABLE I

List of used cuts.

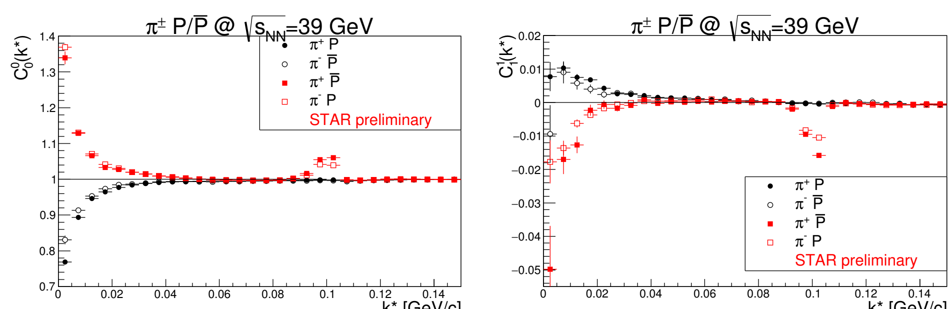
| | $\pi$ | $K$ | $p$ |
|---|---|---|---|
| $p_{\mathrm{T}}$ [GeV/$c$] | [0.1, 1.2] | [0.1, 1.2] | [0.4, 2.5] |
| $p$ [GeV/$c$] | [0.1, 1.2] | [0.1, 1.2] | [0.4, 3.0] |
| ToF threshold [GeV/$c$] | 0.2 | 0.41 | 0.8 |
| Mass window $m^2$ [GeV$^2$/$c^4$] | [0.01, 0.03] | [0.21, 0.28] | [0.76, 1.03] |
| $\lvert N\sigma \rvert$ | $< 3.0$ | | |
| Pseudorapidity $\lvert\eta\rvert$ | $< 0.5$ | | |
| Distance of closest approach (DCA) [cm] | $< 3.0$ | | |
| $Z$ vertex [cm] | $[-30, 30]$ | | |




(a) (b)

Fig. 1. (a) Spherical harmonics $C_0^0$ components for pion–kaon pairs. (b) Spherical harmonics $C_1^1$ components for pion–kaon pairs.

Figures 2 (a) and (b) present results for pion–proton pairs. Products of lambda hyperon decay are visible as a peak at $k^* \sim 0.1$ GeV/$c$. These results lead to similar conclusions as for the pion–kaon pairs.




(a) (b)

Fig. 2. (a) Spherical harmonics $C_0^0$ components for pion–proton pairs. (b) Spherical harmonics $C_1^1$ components for pion–proton pairs.

Figure 3 (a) shows $C_0^0$ components for kaon–proton pairs. Conclusions from these functions are similar to those for other types of pairs — source sizes are similar. From figure 3 (b), one can see that asymmetries are not seen in the $C_1^1$ component of the $K^{\pm}p/\bar{p}$.

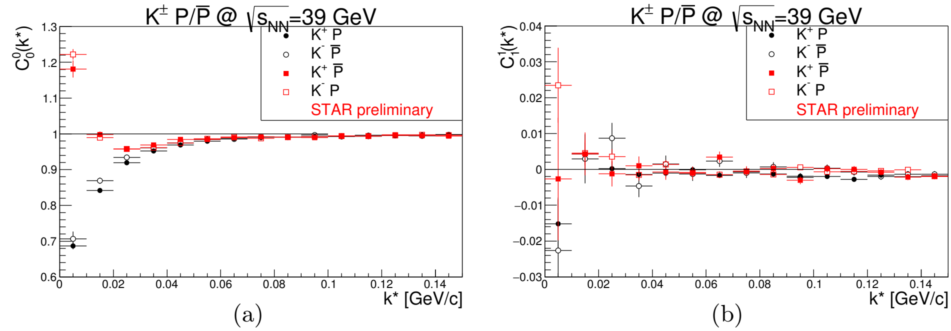



Fig. 3. (a) Spherical harmonics $C_0^0$ components for kaon–proton pairs. (b) Spherical harmonics $C_1^1$ components for kaon–proton pairs.

## 4. Summary

In this paper, we presented the results of non-identical particle femtoscopy for Au+Au collisions at $\sqrt{s_{NN}} = 39$ GeV. For the like-sign and opposite-sign source, sizes seem to be similar. Further calculations are required to obtain sizes of the sources. The asymmetry in the emission process is observed for all pion–kaon and pion–proton pairs. Asymmetry for kaon–proton pairs is not visible. It can be deduced from the $C_1^1$ functions that most of the pions are emitted closer to the systems center and/or later than most of the kaons and protons.

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