NON-IDENTICAL PARTICLE FEMTOSCOPY AT STAR*

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The space-time parameters of the particle-emitting source can be examined in heavy-ion collisions at high energies via femtoscopy measurements. Two-particle correlations at small relative momentum use quantum statistics and final-state interactions. This method provide estimation of source characteristics which cannot be measured directly. Information about asymmetry in the process of emission of two types of particles can be obtained by measuring correlations of non-identical particles. In this paper, status report on femtoscopic measurements of pion–kaon, pion–proton and kaon–proton systems in Au+Au collisions at selected STAR energies is presented.

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1. Introduction

The Solenoidal Tracker at RHIC (STAR) has a comprehensive program called Beam Energy Scan (BES) which is designed to study the QCD phase diagram of strongly interacting nuclear matter [1]. This program uses collisions of gold nuclei for beam energies from $\sqrt{s_{NN}} = 7.7$ to 200 GeV, so it covers significant part of the QCD phase diagram.

The correlation femtoscopy allows us to measure the size of the particle-emitting source and emission duration, which are of the order of 10^{-15} m and 10^{-23} s, respectively. Information about space-time asymmetry in the emission process can be examined using non-identical particle correlations [2].

In these proceedings, we report the preliminary results on the femtoscopic measurements of non-identical particles in the STAR experiment at energies $\sqrt{s_{NN}} = 7.7$, 11.5 and 39 GeV.

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2. Non-identical particle femtoscopy

Two-particle femtoscopy allows us to study the space-time characteristics of the source at the final stage of the collision evolution through the correlation function (CF). Measuring correlations of non-identical particles, one can obtain information such as relative position of the average emission points and mean times of particle emission [2].

Non-identical particle correlations at low relative momentum depend on Final State Interactions (FSI) only [2]. The dominant interaction in pion–kaon and pion–proton femtoscopy is the Coulomb one, but in kaon–proton pairs, the strong force is not negligible [3].

The Pair Rest Frame (PRF) reference system is used to calculate the momentum distribution. The center-of-mass of the pair rests in PRF system, so the pair relative momentum k^* is the momentum of the first particle in this system.

2.1. Spherical harmonics

Spherical harmonic decomposition is one of the most advanced representations of the correlation function [4–7]. Spherical harmonics (Eq. (1), Eq. (2)) allows to decompose it into a set of one-dimensional functions. The correlation function ($C(k^*)$) is defined as

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

$$C_l^m\left(\vec{k^*}\right) = \int_\sigma C\left(k^*,\theta,\phi\right) Y_l^m(\theta,\phi)\mathrm{d}\sigma\,, \tag{2}$$

where θ and ϕ are polar and azimuthal angles, respectively.

The component C_0^0 is sensitive to the size of the emitting source and $\Re C_1^1$ is sensitive to the emission asymmetry [7].

2.2. Time and space asymmetry

There are two types of asymmetry in particle emission process — space and time asymmetries (Fig. 1). Time asymmetry is the case when particles are emitted from the same place, but at different times. If the faster particle is emitted later, the *catching up* scenario takes place. In this scenario, particles interact longer and correlation effect is stronger. *Moving away* scenario occurs when the faster particle is emitted earlier — particles interact shorter and correlation effect is weaker.

There are the same scenarios in the case of space asymmetry, but one considers if the faster particle is emitted closer to the center of the source or further.

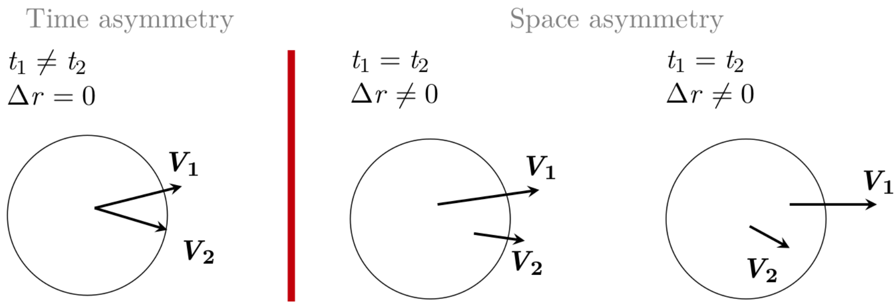


Fig. 1. Two types of asymmetry (t — emission time, r — emission point distance from the center, V_1, V_2 — velocity of the particle).

3. Results

3.1. Cuts and particle identification

In this analysis, 0–10% central Au+Au collisions at $\sqrt{s_{NN}} = 39$ GeV are analyzed in the case of pion–proton and kaon–proton pairs. In the case of pion–kaon pairs, the three centrality bins (0–10%, 10–30% and 30–70%) are analysed at Au+Au collisions at $\sqrt{s_{NN}} = 39$ GeV, and one centrality bin (0–10%) at Au+Au collisions at $\sqrt{s_{NN}} = 7.7$ and 11.5 GeV. The cuts for data selection are shown in Table I.

TABLE I

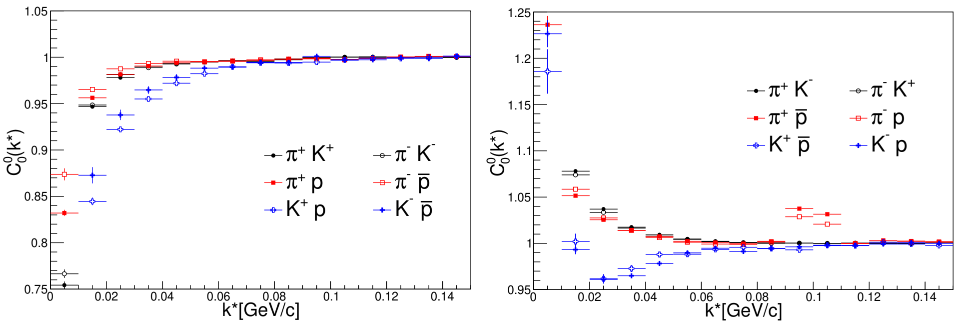
List of used cuts.

	π	K	p
p_{T} [GeV/c]	[0.1, 1.2]	[0.1, 1.2]	[0.4, 2.0]
p [GeV/c]	[0.1, 1.2]	[0.1, 1.2]	[0.4, 2.0]
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		

To identify particles, information from Time Projection Chamber (TPC) and Time-of-Flight (TOF) detectors is used. The TPC detector allows to measure the ionization energy loss ($\mathrm{d}E/\mathrm{d}x$), momentum of the particle and also it allows to reconstruct the track of the particle. In the TOF detector, particle velocity is measured. Only statistical uncertainties are presented.

3.2. Spherical harmonics

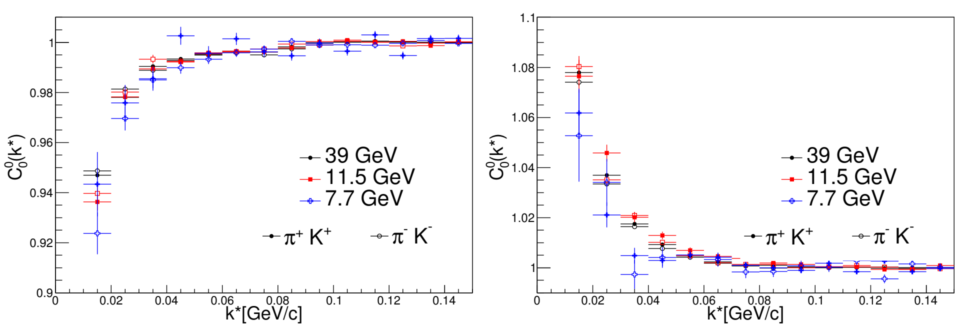
Figure 2 (a) presents C_0^0 components for systems with like-sign particle combinations. These functions are dominated by the Coulomb interaction. Interactions in unlike-sign particle combinations (presented in Fig. 2 (b)) are more complicated. For kaon–proton systems, there is another shape of the correlation function due to a different and non-negligible strong interaction. Also for pion–proton systems, the shape of C_0^0 component is different — there is a visible peak around $k^* = 0.1$ GeV that corresponds to the weak decay of Λ.



(a) (b)

Fig. 2. Spherical harmonics C_0^0 components for like-sign pairs (a) and unlike-sign pairs (b) of pion–kaon, pion–proton and kaon–proton systems.

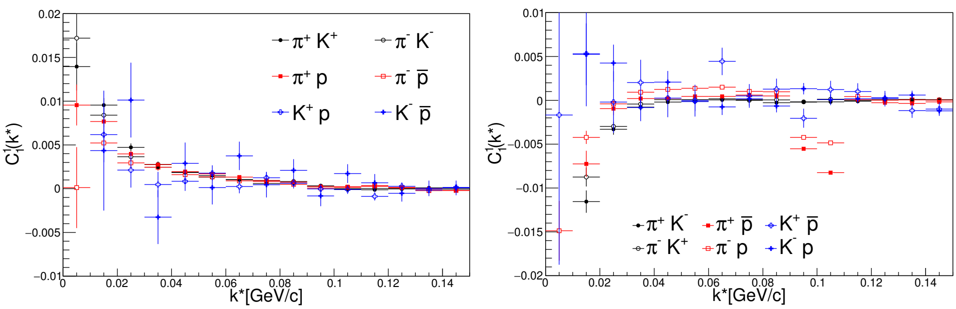
Figures 3 (a) and 3 (b) present results for pion–kaon pairs at different energies $\sqrt{s_{NN}}$. No significant dependence of the correlation function on the collision energy can be seen.



(a) (b)

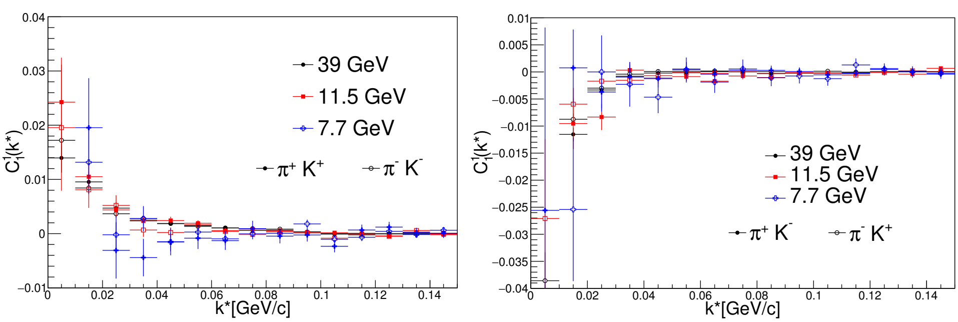
Fig. 3. Spherical harmonics C_0^0 components for like-sign pairs (a) and unlike-sign pairs (b) for collision energies $\sqrt{s_{NN}} = 7.7, 11.5$ and 39 GeV.

$\Re C_1^1$ components for like-sign particle combinations are shown in Fig. 4 (a). Plots for unlike-sign pairs are shown in Fig. 4 (b). These results show that asymmetries in emission process exist for every analyzed system. Figures 5 (a) and 5 (b) show $\Re C_1^1$ components for pion–kaon systems at energies $\sqrt{s_{NN}}$ = 7.7, 11.5 and 39 GeV. In these plots, we can also see a clear signal of emission asymmetry. An estimation of source parameters for every type of pair is under way.



(a) (b)

Fig. 4. Spherical harmonics C_1^1 components for like-sign pairs (a) and unlike-sign pairs (b) of pion–kaon, pion–proton and kaon–proton systems.



(a) (b)

Fig. 5. Spherical harmonics C_1^1 components for like-sign pairs (a) and unlike-sign pairs (b) for collision energies $\sqrt{s_{NN}}$ = 7.7, 11.5 and 39 GeV.

One can compare the shape of correlation functions to draw a qualitative conclusion about the ordering of particles. There is an opposite tendency of C_0^0 and $\Re C_1^1$ components for all particle combinations (*e.g.* comparing Fig. 2 (a) to Fig. 4 (a)) which indicates that lighter particles are emitted closer to the center of the source and/or later than heavier particles. This shows that heavier particles have stronger boost by flow towards the edge of the source than lighter particles [2, 8].

4. Summary

In this paper, the results of non-identical particle femtoscopy for Au+Au collisions at $\sqrt{s_{NN}} = 7.7$, 11.5 and 39 GeV are shown. It is shown that there is a visible system dependency of the source size and there is no significant dependence on energy for pion–kaon system. The strong interaction appearing in kaon–proton system requires further analysis. The clear asymmetry signal in emission process is observed for particle combinations with different masses at BES energies and this asymmetry does not disappear for low energies. It can be deduced from the shape of spherical harmonics components that lighter particles are emitted closer to the center of the source and/or later than heavier particles.

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