Geometry and dynamics of particle production seen by femtoscopic probes in the STAR experiment

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Abstract. The main goal of studying heavy-ion collisions is to understand the properties of the matter under extreme conditions. The spatial and temporal characteristics of particle emission can be extracted using the femtoscopy technique. From non-identical particle correlations one can obtain information about asymmetry in emission process between two kind of particles. Such asymmetry can provide information about which type of particles are emitted earlier and/or closer to the center of the source.
In these proceedings, results on femtoscopic observables of pion, kaon and proton non-identical particle combinations and transverse mass dependence of three-dimensional femtoscopic observables for charged kaons in Au+Au collisions at energy $\sqrt{s_{NN}} = 39$ GeV will be reported.

Keywords: femtoscopy, Beam Energy Scan, STAR, correlations, heavy-ion collisions

1 Introduction

The Solenoidal Tracker at RHIC (STAR) is a large detector system at Relativistic Heavy Ion Collider (RHIC)[1]. A comprehensive program called Beam Energy Scan (BES) designed to study the phase diagram of nuclear matter, has been launched at RHIC. It uses gold ion collisions at collision energy ($\sqrt{s_{NN}}$) in the range from 7.7 up to 200 GeV. The program studies the phase transition signatures and aimed to find a localization of the critical point between cross over and the first-order phase transitions [2].

2 Femtoscopy

Femtoscopy is the only one tool to perform studies of the particle-emitting source which has a size and life time of the order 10^{-15} m and 10^{-23} s, respectively. Through two particle correlations at low relative momentum, which measure their statistical effects and interactions between them in the final state, one can study space-time characteristics of the source.

The correlation function ($C(\mathbf{q})$), which is used in femtoscopy, is defined as a ratio of probability of observing two particles with momenta $\mathbf{p_1}$ and $\mathbf{p_2}$ to a product of probabilities of observing such particles independently. This function is determined by a pair wave function ($\psi(\mathbf{q},\mathbf{r})$), which includes information about quantum-statistical effects and interactions, and emission function ($S(\mathbf{q},\mathbf{r})$), which contains space-time information about the source:

$$C(\mathbf{q}) = \int d^3 S(\mathbf{q},\mathbf{r})|\psi(\mathbf{q},\mathbf{r})|^2 \tag{1}$$

where $\mathbf{q}$ is a difference between momenta $\mathbf{p_1}$ and $\mathbf{p_2}$, and $\mathbf{r}$ is a difference between the position of the first and second particle in the pair, respectively.

Kaon femtoscopy provides complementary information to pions. Strange particles provide cleaner signal as compared to pions, because they are less affected by resonance decays. Such correlation depends on quantum-statistical effects and final state interactions, which are Coulomb and strong forces. In case of identical kaon pairs strong interaction is assumed to be negligible [3].

Non-identical particle femtoscopy is a useful tool to study geometry and dynamics of particle production, like measurements of asymmetries in emission proces [4].

3 Identical kaon femtoscopy

Geometrical source characteristics are determined through fitting procedure using Bowler-Sinyukov approach [5, 6]:

$$C(q_o, q_s, q_l) = 1 - \lambda + \lambda K(q_{inv})(1 + exp[-R_o^2 q_o^2 - R_s^2 q_s^2 - R_l^2 q_l^2]) \tag{2}$$

where λ is the correlation strength, $R_{o,s,l}$ are the radii of the particle-emitting source in out, side and long directions, respectively (using Bertsch-Pratt parametrization [7, 8]), and $K(q_{inv})$ is the Coulomb factor.

Figure 1 shows the transverse mass ($m_T = \sqrt{k_T^2 + m^2}$, $k_T = |\mathbf{p_{T,1}} + \mathbf{p_{T,2}}|/2$) dependence of the extracted femtoscopic radii for pions and charged kaons measured in Au+Au collision at $\sqrt{s_{NN}} = 39$ GeV. Obtained sizes are smaller for peripheral collisions. The radii decrease with increasing m_T. The radii in *long* and *out* directions are larger for kaons than for pions at the same transverse mass, that indicate breaking of m_T-scaling.

4 Non-identical particle femtoscopy

The correlation function, $C(k^*)$, can be represented as the decomposition into spherical harmonic components [9–11]:

$$C(k^*) = \sum_{l,m} C_l^m(q) Y_l^m(\theta,\phi), \qquad C_l^m(q) = \int_\Omega C(k^*,\theta,\phi) Y_l^m(\theta,\phi) d\Omega \tag{3}$$

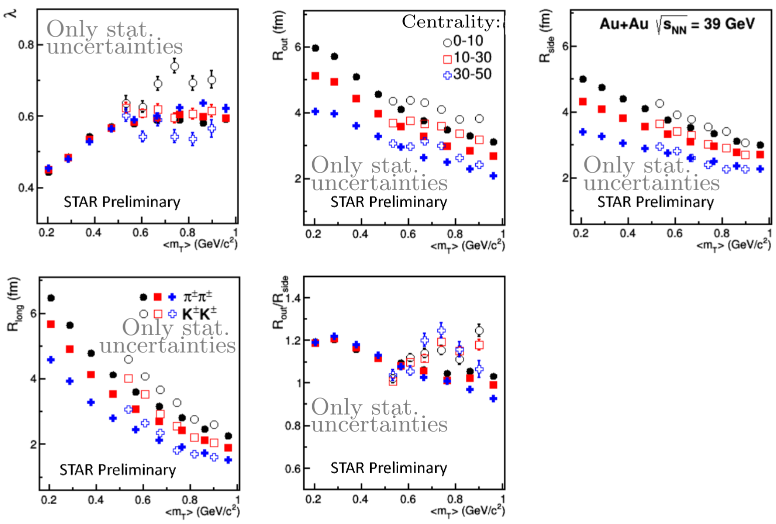


Fig. 1. Transverse mass dependence of sizes of kaon and pion source at $\sqrt{s_{NN}} = 39$ GeV.

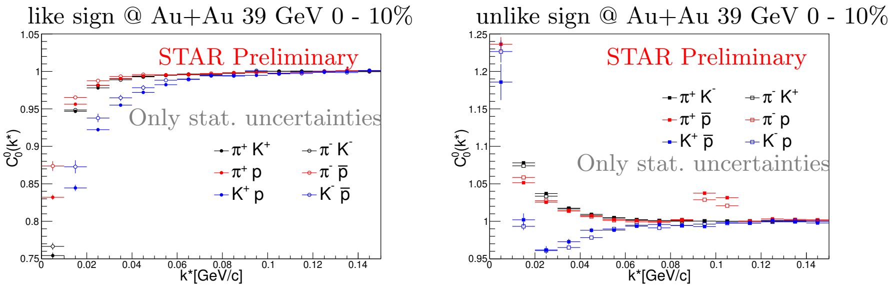
where k^* is the particle momentum in Pair Rest Frame, θ and ϕ – polar and azimuthal angles, respectively. The C_0^0 component is sensitive to the system size and C_1^1 is sensitive to the emission asymmetry.

Figure 2(a) presents C_0^0 components for different particle system with like-sign particle combinations for 0-10% of the most central Au+Au collisions at $\sqrt{s_{NN}} = 39$ GeV. These correlations are dominated by the Coulomb interaction. Interactions between unlike-sign particle combinations (Fig. 2(b)) are more complicated. For pion-proton unlike-sign pairs there is a visible peak around $k^* = 0.1$ GeV/c that corresponds to the Λ hyperon decay. The shape of the correlation functions of kaon-proton pairs is determined by the non-negligible contribution from strong interaction. Figures 3(a) and 3(b) show that asymmetries in the emission process existed for each analysed pair combination.

5 Summary

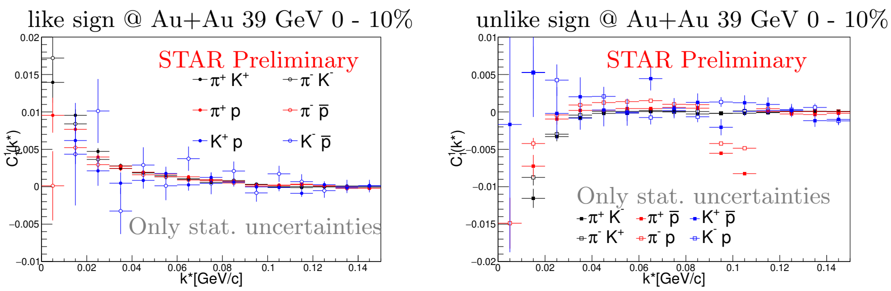
For Au+Au collisions at $\sqrt{s_{NN}} = 39$ GeV pion and kaon source sizes seem to follow different transverse mass dependence, which indicate breaking of the transverse mass scaling. There is a different shape of correlation functions for various non-identical particle combinations. In case of Kp the strong interaction is not negligible and requires further investigation.

An emission asymmetry is observed for particle combinations with different masses produced in Au+Au collisions at $\sqrt{s_{NN}} = 39$ GeV. The clear asymmetry signal implies collective (and dynamical) effects. Shape of both components of spherical harmonics (C_0^0 and C_1^1) suggest that lighter particles are emitted closer



(a) (b)

Fig. 2. Spherical harmonics C_0^0 components for like-sign pairs (a) and unlike-sign pairs (b) for different particle combinations.



(a) (b)

Fig. 3. Spherical harmonics C_1^1 components for like-sign pairs (a) and unlike-sign pairs (b) for different particle combinations.

to the center of the source and/or later than heavier particles.

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