

Kaon femtoscopy at the STAR experiment

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Kaon femtoscopy at the STAR experiment

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Abstract. The properties of the quark-gluon plasma have been extensively studied in high-energy nuclear collisions at RHIC. Femtoscopic measurements of two-particle correlations at small relative momenta reveal the space-time characteristics of the system at the moment of particle emission. In comparison to analyses using the most abundant pions, like-sign kaons provide a cleaner probe of the emission source as they less frequently result from resonance weak decays. Additionally, kaons contain strange quarks so these measurements can be sensitive to different effects and earlier collision stages. Pairs of like-sign kaons exhibit correlations due to Coulomb interactions and Bose-Einstein quantum statistics. The system of unlike-sign kaons contains a narrow $\phi(1020)$ resonance in the final state. Femtoscopic measurements have been predicted to be particularly sensitive to the source size and momentum-space correlations in the region of this resonance.

In this proceedings, we present the STAR preliminary results on the like-sign and unlike-sign kaon femtoscopic correlation functions in 200 GeV Au+Au collisions at RHIC. Collision centrality and the transverse pair momentum k_T dependence of the radius parameters will be discussed. The results from unlike-sign kaon correlation functions will be compared with model predictions [1].

1. Introduction

Two-particle interferometry is a unique method which allows us to study spatial and temporal characteristics of a system created during the ultrarelativistic heavy-ion collisions at the moment of particle emission. This technique was for the first time used by G. Goldhaber [2] and his collaborations in study of angular distribution of identified pion pairs in proton-anti-proton annihilation in 1960. Since then the femtoscopic measurements of two-particle correlations at the low relative momenta became a standard tool for the extraction of the source sizes. Based on the typical extents which are of the order of tens of femtometers the two-particle interferometry method is called femtoscopy, as introduced by Richard Lednický [3]. Nowadays femtoscopic analyses span many particle species and include even non-identical interacting particle [4, 5, 6].

2. Two-particle correlation femtoscopy

The two-particle correlation function used in femtoscopy relates the space-time structure of the particle emitting source and the particle interaction via:

$$CF(p_1, p_2) = \int d^3r S(r, k^*) |\psi_{1,2}(r, k^*)|^2, \quad (1)$$

where $S(r, k^*)$ is the source function and $\psi_{1,2}(r, k^*)$ is the relative two particle wave function. The source function describes the emission of two particles at the relative distance r with the



relative momentum $(2k^*)^2 = -(p_1^\mu - p_2^\mu)^2 = q_{inv}^2$, where p_1^μ and p_2^μ are the four-momenta of the first and second particle, respectively.

Experimental three-dimensional correlation functions are constructed in the so-called "out-side-long" system, where the $\vec{q}$ is decomposed into three components: q_{out} , q_{side} and q_{long} [7]. In order to extract source radii R_{out} , R_{side} and R_{long} , the experimental correlation function for identical particles, where the correlation is caused by the quantum statistics and the Coulomb interaction, is fitted by the standard Bowler-Sinyukov form [8]:

$$CF(q_{out}, q_{side}, q_{long}) = N \left[(1 - \lambda) + \lambda K(q_{inv}) \left(1 + e^{-R_{out}^2 q_{out}^2 - R_{side}^2 q_{side}^2 - R_{long}^2 q_{long}^2} \right) \right], \quad (2)$$

where $K(q_{inv})$ is the Coulomb function integrated over the source of size R_{inv} , N is the normalization and λ is the correlation strength. This approximation is based on the separation of the Coulomb interaction from the effect of the quantum statistics.

3. STAR Experiment

The results presented in this paper were obtained from Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV measured by the Solenoidal Tracker at RHIC (STAR)[9] in 2011. The STAR is a multipurpose detector which excels in tracking and identification of charged particles at mid-rapidity with full azimuthal coverage which makes it ideal for multi-particle high statistics measurements. The most important subdetectors for kaon identification are the Time Projection Chamber (TPC)[9] and the Time of Flight detector (ToF)[10] which was fully installed in 2010.

4. Like-sign kaon femtoscopy

In comparison with the previous STAR analysis [11], thanks to higher statistics, it is now possible to construct experimental like-sign kaon correlation functions for more bins in centrality and transverse pair momentum $k_T = (p_1 + p_2)_T / 2$. The presented analysis is performed for 4 centrality bins and 4 k_T bins. Measured correlation functions are corrected for kaon misidentification and momentum resolution. Figure 1 shows the STAR preliminary results on femtoscopic radii from like-sign kaon correlation functions from Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. The typical k_T and centrality dependence can be observed. While the transverse flow and expansion of the system are encoded in the falling of R_{out} and R_{side} with increasing k_T , the longitudinal flow exhibits a decrease of R_{long} with the increasing k_T . Such a behavior of source radii R_{out} , R_{side} and R_{long} confirms our expectation that the system under study undergoes space-time evolution and expands.

5. Unlike-sign kaon femtoscopy

In the previous section we have presented the results on measurements with identical charged kaons where the correlation is caused by Bose-Einstein quantum statistics and Coulomb interaction. The structure of the correlation function for unlike-sign kaons is more varied (see Figure 2). While at the low relative momenta the attractive Coulomb interaction and the strong interaction in s-wave can be observed, at higher $q_{inv} \sim 256$ MeV/c the strong interaction in p-wave through $\phi(1020)$ is presented. The measurement of space-time extents using unlike-sign kaon correlations can be a complementary study which should provide an additional information about the studied system. It has been predicted [1] that the correlation function will be sensitive to the space-time extents in the region of resonance in a system where the narrow, near-threshold, resonance is present. The height of peak should then scale as the inverse volume of the system i.e. as $\sim r^{-3}$ [1]. Figure 2 introduces the STAR preliminary results on unlike-sign kaon correlation functions from Au+Au collision at $\sqrt{s_{NN}} = 200$ GeV. The left panel of Figure 2 shows the correlation function for 5 different centralities. The sensitivity on the transverse

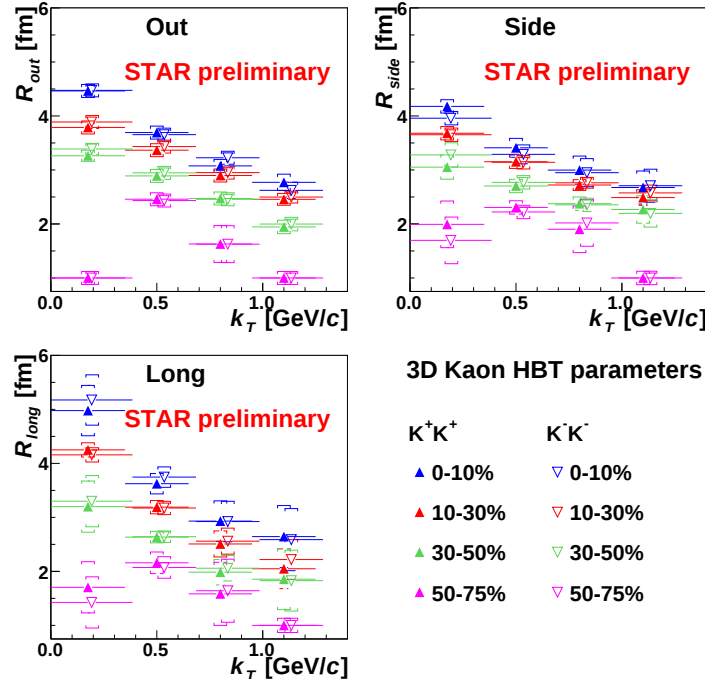


Figure 1. Fit results of three-dimensional K^+K^+ and K^-K^- correlation functions.

pair momentum k_T is presented in the right panel of Figure 2. In both cases it can be seen that the correlation function is sensitive to the source size. Especially in the region of the resonance a strong sensitivity can be observed. The experimentally measured and corrected correlation

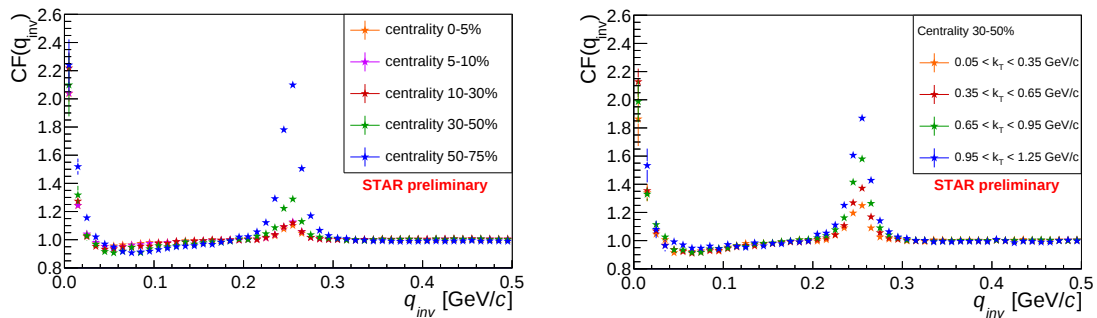


Figure 2. Left: Centrality dependence of one-dimensional K^+K^- correlation function from Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. Right: k_T dependence of one-dimensional K^+K^- correlation function for centrality 30-50% from Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV.

functions of unlike-sign kaons can be compared to the theoretical prediction. In this analysis the Lednický model [1] of final state interaction is examined. Lednický model includes the treatment of the $\phi(1020)$ resonance in the final state. This model is used for the calculation of the two-particle wave function $\psi(r, k^*)$ which is included in the theoretical correlation function (see Eq. 1). The source function $S(r, k^*)$ in Eq. 1 is parameterized by the Gaussian and its size is equal to the source size obtained from the one-dimensional like-sign kaon correlation function. For the correct comparison which takes into the account the effects presented during the construction of the experimental correlation function, the theoretical function is scaled by

the λ parameter via relation $CF = (CF^{theo} - 1)\lambda + 1$. Figure 3 shows the comparison of the experimental unlike-sign kaon correlation functions from Au+Au collisions at $\sqrt{s_{NN}}=200$ GeV to the theoretical calculations for the most central (0-5%) and peripheral (50-75%) collisions for $0.35 < k_T < 0.65$ GeV/c. The Lednický model is able to reproduce the overall shape of the correlation function especially for central collisions. However, the model underestimates the correlation strength in the region of the resonance for the peripheral collisions. The observed behavior can possibly be interpreted as a breakdown of the femtoscopic formalism which was developed for measurements at the very low relative momenta.

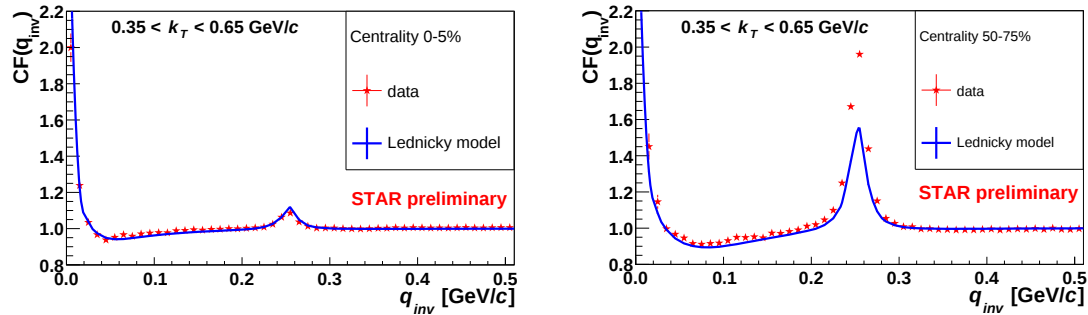


Figure 3. Comparison of experimental K^+K^- correlation functions from Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV to theoretical calculations for 2 different centralities for $0.35 < k_T < 0.65$ GeV/c.

6. Conclusions

In this paper, preliminary results of STAR analysis of like-sign as well as unlike-sign kaon femtoscopy in Au+Au at $\sqrt{s_{NN}} = 200$ GeV have been presented. The source radii R_{out} , R_{side} and R_{long} have been obtained from three-dimensional like-sign kaon correlation function. The measured unlike-sign kaon correlation function exhibits strong centrality and k_T dependence in the region of the $\phi(1020)$ resonance. The experimental data have been compared to the theoretical FSI model prediction. The model reproduces overall the shape of correlation function, however for peripheral collisions the model underpredicts the strength of the correlations in the region of the resonance.

Acknowledgments

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