Neutral kaon femtoscopy in STAR*

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Properties of nuclear matter can be studied by relativistic heavy-ion collisions in high-energy experiments like STAR. One of the methods to learn about properties of nuclear matter is femtoscopy, which relies on information carried by particles produced in the collisions. Using femtoscopic observables, space-time characteristics of the source can be extracted. During heavy-ion collisions mostly pions are produced, and therefore pion femtoscopy is a particularly useful tool. High statistics data sets from RHIC have also made it possible to study the strange particle correlations. The lightest strange hadrons are charged and neutral kaons. The strong interaction, which conserves the strangeness quantum number, is responsible for the kaon production. It is possible to study the neutral kaons, K^0_S, which can be measured through their decay products to charged pions.

In these proceedings, one-dimensional correlation functions of neutral kaon pairs in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV measured by the STAR experiment at RHIC are presented.

1. Introduction

To study the Quantum Chromodynamics (QCD) phase diagram, the comprehensive program called Beam Energy Scan (BES) was started at Relativistic Heavy Ion Collider (RHIC) in 2010 [1]. The Au+Au collisions at $\sqrt{s_{NN}}$ = 7.7, 11.5, 14.5, 19.6, 27, 39 and 62.4 GeV were collected during the first phase of the BES program. The main aims of the BES program include:

- to study the phase diagram at different energies and find areas in which QGP signatures are turned off,
- to search for the first-order phase transition and a critical point,
- to study first order phase transition between Hadron Gas (HG) and Quark-Gluon Plasma (QGP).

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The Solenoidal Tracker at RHIC (STAR) during the first phase of BES program gathered data, which were used for femtoscopic analysis. This method uses measurements of momentum of emitted particles in order to study properties of system created in heavy-ion collision.

1.1. The method of femtoscopy

In 1954, Robert Hanbury Brown and Richard Q. Twiss created the method to measure the angular sizes of the astronomical objects using the Michelson interferometry [2]. Femtoscopy method applied to two particles originates from the HBT technique used in astronomy. It aims to examine the particle emitting source (sizes of order 10^{-15} m and life times 10^{-23} s) throught measurements of particle's momentum distributions. Figure 1 shows the two-particle interference mechanisms used in astronomy (left) and particle physics (right).

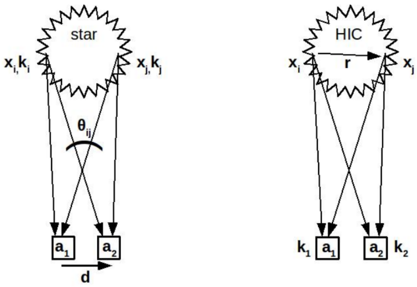


Fig. 1: Schematic diagram of intensity interferometry used in astronomy (left) and particle physics (right)[3].

1.2. Correlation function

The correlation function (CF) is described as a ratio between probability of observing two particles with momenta $\vec{p_1}$ and $\vec{p_2}$ (P_2) and the probability of observing these two particles separately (where P_1 is the probability of observation of single particle):

$$CF(\vec{p_1}, \vec{p_2}) = \frac{P_2(\vec{p_1}, \vec{p_2})}{P_1(\vec{p_1})P_1(\vec{p_2})} \tag{1}$$

Theoretical correlation function is determined by the emission function, $S(\vec{q}, \vec{r})$, which contains all space-time characteristics of the effective source and pair wave function, $\psi(\vec{q}, \vec{r})$, which includes information about statistical effects and interactions:

$$CF(\vec{q}) = \int d^3r S(\vec{q}, \vec{r}) |\psi(\vec{q}, \vec{r})|^2 \tag{2}$$

where $\vec{q}$ is a difference between momenta $\vec{p_1}$ and $\vec{p_2}$, and $\vec{r}$ is a difference between the position of the first and second particles in the pair. Through measurements of quantum statistical effects and interactions one can learn source parameters, like its size [4].

Experimentally, in the one-dimensional case, the correlation function is defined as a ratio of signal (A) to background (B), where signal measures relative momentum distribution (q_{inv}) of pairs from the same collision and background measures of pairs from different collisions with similar properties. For pairs constructed from different events the quantum statistical effects and final state interactions are absent:

$$CF(q_{inv}) = \frac{A(q_{inv})}{B(q_{inv})} \tag{3}$$

The q_{inv} is definde as [5]:

$$q_{inv} = \sqrt{(p_1 - p_2)^2 - (E_1 - E_2)^2} \tag{4}$$

where E_1 and E_2 are the energies of the 1^{st} and 2^{nd} particle from the pair respectively.

2. Neutral kaon correlation function

Figure 2 shows correlation functions for neutral kaons which depend on:

- Quantum Statistical effects (QS) - Bose-Einstein statistics, which increases the probability of finding two particles with similar momentum
- Final State Interactions (FSI):
  - Strong Interaction (SI)
  - Coulomb Force (COUL) in the case of neutral kaons it is absent

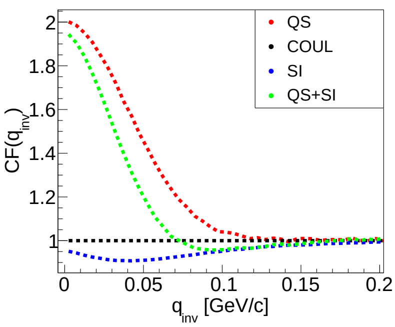


Fig. 2: Correlation function, CF(q_inv), of the kaon pairs from Therminator model [6] for central Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV.

2.1. Parametrization

The parametrization was done using Gaussian fit (Eq. 5) taking into account the QS effects only, where λ is the correlation strength and R_{inv} is the one-dimentional radius of the particle-emitting source:

$$C(q_{inv}) = 1 + \lambda \exp[R^2_{inv} q^2_{inv}] \tag{5}$$

3. Results

3.1. Selection criteria

In this analysis, minimum-bias (centrality corresponding to $0-80\%$ of the total hadronic cross section of the collision) Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV were used. Kaon identification was performed using information from two detectors, namely the Time Projection Chamber (TPC) and the Time-Of-Flight (TOF). Identification of particles in TPC was done via specific ionization losses (dE/dx). TOF determines velocity of a particle based on its time of passage through the length of the detector. Using information from TOF detector, particles with momentum above threshold are uniquely identified. Table 1 shows criteria for particle's selection for π^+ and π^- (daughter particles of the K_S^0 candidates). Criteria for neutral kaons are presented in Table 2.

Table 1: Daughter criterias of selection

p_T [GeV/c]	0.2-1.2
DCA to the primary vertex [cm]	>1.3
$\lvert n_{\sigma\pi}\rvert$	<3
$\lvert n_{\sigma K,p}\rvert$	>3
mass [GeV/c^2]	0.07-0.2

Table 2: Neutral kaon selection criteria

p_T [GeV/c]	0.2-1.5
$\lvert\eta\rvert$	<0.5
V^0 DCA to the primary vertex [cm]	0-0.3
DCA of daughters [cm]	0-0.3
decay length [cm]	>2
Armenteros q_T [GeV/c]	0.12-0.22
Armenteros $\lvert\alpha\rvert$	<0.7
invariant mass range [GeV/c^2]	0.488-0.51

3.2. Correlation function

Figure 3 shows $K_s^0 K_s^0$ correlation functions with Gaussian fit (Eq. 5) before and after applying the pair purity correction. The purity correction was done using the equation:

$$C_{corrected}(q_{inv}) = \frac{C_{measured}(q_{inv}) - 1}{PairPurity(q_{inv})} + 1 \tag{6}$$

where PairPurity is defined as a product of single particle purity. Purity of K_s^0 is calculated as a ratio of number of K_s^0 candidates in the specic range of distribution of invariant mass (Table 2) to number of all considered $\pi^-\pi^+$ pairs in this range.

After purity correction a stronger correlation (larger value of the λ parameter and smaller size of the source) as compared to one before applying purity correction is observed. Values of radii before and after correction are presented in Table 3 and Table 4.

Table 3: Radius of the particle-emitting source before purity correction.

Centrality	Radius [fm]	λ
0-80%	5.08 ± 0.19	0.630 ± 0.051

Table 4: Radius of the particle-emitting source after purity correction.

Centrality	Radius [fm]	λ
0-80%	4.72 ± 0.20	0.701 ± 0.056

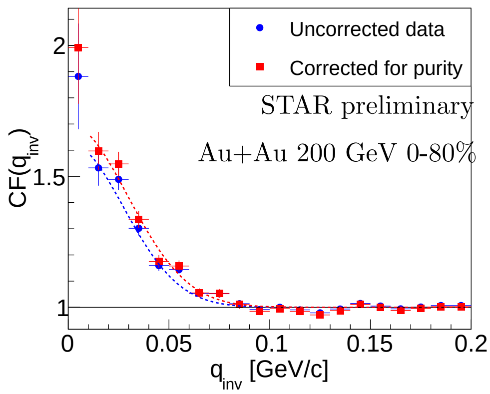
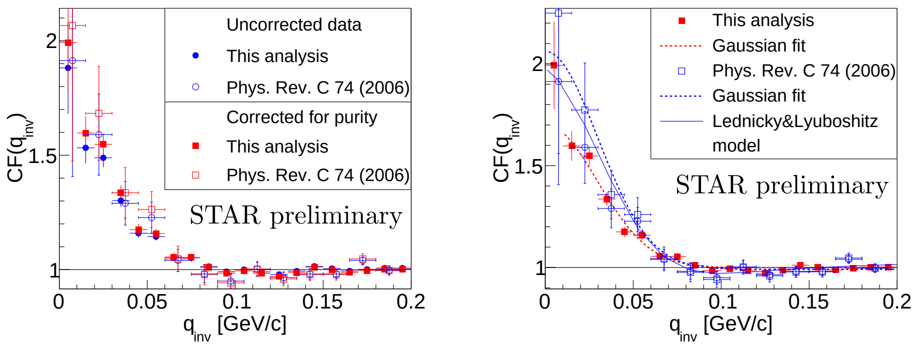


Fig. 3: The $K^0_S K^0_S$ correlation functions with fits before (blue points) and after (red points) purity corrections. The uncertainties of CF are statistical only.



(a) The $K^0_S K^0_S$ correlation function from central Au+Au collisions at $\sqrt{s_{NN}} =$ 200 GeV.

(b) Fits to the $K^0_S K^0_S$ correlation function.

Fig. 4: Comparison with previous STAR results.

3.3. Comparison with previous result

The first statistically meaningful results from $K^0_S K^0_S$ femtoscopy in Au+Au collisions at collision energy $\sqrt{s_{NN}} = 200$ GeV were published by the STAR Collaboration in 2006 [7]. In that analysis, data from the Zero Degree Calorimeter (ZDC) and the Central Trigger Barrel (CTB) were used. The radius of the particle emitting source was obtained using Gaussian fit as 5.02 ± 0.61 fm.

Figure 4 presents the comparision between previous results with recent ones. Both measurements: previous and current ones are consistent with each other within estimated uncertainties.

4. Summary

In these proceedings, one-dimensional neutral kaon correlation functions measured by the STAR experiment for minimum-bias (0-80%) Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV have been presented.

To parametrize the experimental correlation functions Gaussian fits were used, which gave similar values of the radii of the effective source and λ parameter as in previous STAR results. The purity correction for neutral kaons slightly reduces the size of the measured particle-emitting source and increases the statistical uncertainties. As expected, value of λ parameter increased and source size decreased.

5. ACKNOWLEDGMENTS

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REFERENCES

[1] G. Odyniec, *Future of the Beam Energy Scan program at RHIC*, EPJ Web Conf. (2015).

[2] R. Hanbury Brown and R. Twiss, *A new type of interferometer for use in radio astronomy*, Phil. Mag. (1954).

[3] M. Steinpreis, *Neutral kaon femtoscopy in Pb-Pb collisions at* $\sqrt{s_{NN}} = 2.76$ *TeV at the LHC with ALICE*, Ph.D thesis (2014).

[4] R. Lednicky, *Correlation femtoscopy*, Nucl.Phys. (2006).

[5] G. Bertsch, et al., *Pion interferometry in ultrarelativistic heavy-ion collisions* Phys. Rev. C (1988).

[6] M. Chojnacki, A. Kisiel, W. Florkowski, W. Broniowski, *THERMINATOR 2: THERMal heavy IoN generATOR 2*, Comput.Phys.Commun. (2012).

[7] B. I. Abelev, et al., *Neutral Kaon Interferometry in Au+Au collisions at* $\sqrt{s_{NN}} = 200$ *GeV*, Phys. Rev. C (2006).