Femtoscopic measurements of two-kaon combinations in Au+Au collisions at the RHIC energies

Diana Pawłowska[1,*] for the STAR Collaboration

[1]Faculty of Physics, Warsaw University of Technology, Koszykowa 75, 00-662 Warsaw, Poland

Abstract. Femtoscopic measurements allow one to study the geometric characteristics of the homogeneity region created during the heavy-ion collisions. The lightest strange hadrons are charged and neutral kaons, which enhancement of the productions is one of the Quark-Gluon Plasma signatures. Analyzing high statistic data taken by the STAR experiment, it is possible to study the short-lived neutral kaons identified through their decays products: positive and negative pions. Thanks to the $K^0_S K^{\pm}$ analysis, one can also study the production of a_0 resonance, which might be a tetraquark. These proceedings will present the femtoscopic analysis of charged and neutral kaons correlations in Au+Au collisions at $\sqrt{s_{NN}}$ = 39 GeV and 200 GeV measured by the STAR experiment.

1 Introduction

The Solenoidal Tracker at RHIC (STAR) is currently the only experiment at the Relativistic Heavy Ion Collider (RHIC). The main reason for designing this experiment was to measure the properties of hot and dense matter at high collision energy and to find the Quark-Gluon Plasma (QGP). Thanks to data taken by the STAR experiment, it is possible to measure the femtoscopic characteristic between two strange particles (like kaons), which could provide different information about the collision interaction region in addition to what was deduced from pion studies. This is due to the collective effects (kaons are heavier than pions, so they have smaller thermal velocities and the collective flow more strongly confines their source volumes) responsible for forming a strongly interacting source. When selecting different particles, we analyze only some parts of this source - Figure 1.

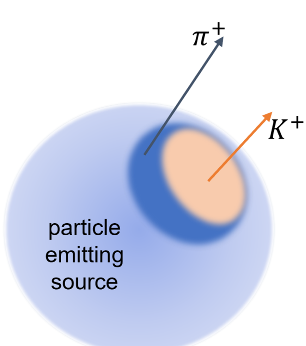


Figure 1. Particle emitting source.

Kaon femtoscopy uses data from the Time Projection Chamber (TPC) and Time of Flight (TOF) to identify particles. TPC is used to register the charged particle tracks in three-dimensional space and to provide information on ionization energy loss. TOF determines the particle's velocity using a given particle's time of flight and

*e-mail: diana.pawlowska.dokt@pw.edu.pl

path length. Combining information from both detectors, the full particles' characteristics regarding their momentum and mass are extracted.
The situation is different when particles from weak decays are analyzed and identified based on their decay products. This is much more difficult because one must reconstruct daughters and pair them up. In the case of neutral kaons, decay products are positively and negatively charged pions.

2 Femtoscopy technique

Femtoscopy measures correlations arising from quantum statistical (QS) effects and final state interaction (FSI), probing space-time characteristics of the source emitting given particle pairs. This technique allows one for measurements on the scale of the femtometers and time of the order of 10^{-23} s. The correlation function is expressed by the ratio of the probability of measuring two particles with specific momentum $P_2(\vec{p_1}, \vec{p_2})$ difference to the product of the possibilities of finding these particles independently $P_1(\vec{p_1})P_1(\vec{p_2})$:

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

The theoretical $K_S^0 K_S^0$ correlation function is described by the Lednicky-Lyuboshitz model [1], which takes into account strong FSI:

$$CF(q_{inv}) = 1 + \lambda\left(e^{[-R_{inv}^2 q_{inv}^2]} + \alpha\left[\left|\frac{f(k^*)}{R_{inv}}\right|^2 + \frac{4\Re f(k^*)}{\sqrt{\pi}R_{inv}}F_1(q_{inv}R_{inv}) - \frac{2\Im f(k^*)}{\sqrt{\pi}R_{inv}}F_2(q_{inv}R_{inv})\right]\right), \tag{2}$$

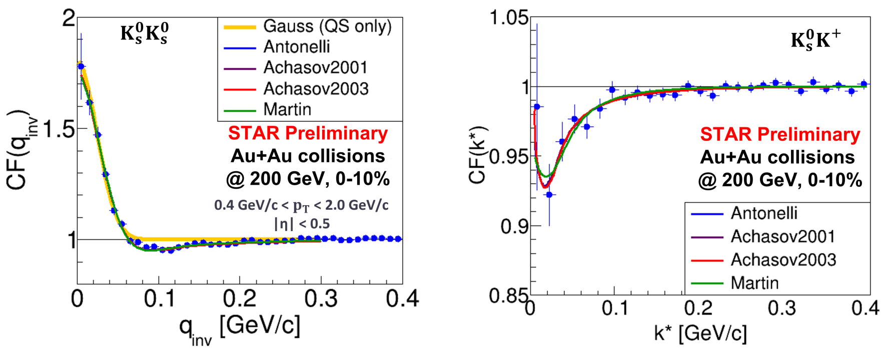
where $\alpha = 0.5$ for $K_S^0 K_S^0$ correlation, $F_1(z) = \int_0^z dx e^{x^2-z^2}/z$ and $F_2(z) = (1-e^{-z^2})/z$ are analytic forms, $f(k^*)$ is s-wave $K_S^0 K_S^0$ scattering amplitude depending on near-threshold resonances $f_0(980)$ and $a_0(980)$, written in terms by theirs masses and decay couplings (the most popular parametrizations are described in [2]-[5]), $q_{inv} = \sqrt{(\vec{p_1} - \vec{p_2})^2 - (E_1 - E_2)^2}$ is pair relative momentum (k^* is a first particle momentum in pair rest frame), R_{inv} is the size of the particle-emitting source and λ is the chaoticity parameter.
In the case of $K_S^0 K^\pm$, the Lednicky-Lyuboshitz model is also used. However, a component related to QS effects does not exist; only the strong interaction is present (see Eq. 2). In the case of $K_S^0 K^\pm$, the interaction depends only on the properties of one resonance - a_0.

3 Results

$K_S^0 K_S^0$ measurements were performed for Au+Au collisions at $\sqrt{s_{NN}} = 39$ GeV and 200 GeV and for $K_S^0 K^\pm$ combination only for the top RHIC energy.

3.1 $K_S^0 K_S^0$ and $K_S^0 K^+$ correlation functions

An example of the correlation function for two neutral kaons for central Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV is shown in Figure 2a, while the $K_S^0 K^\pm$ combination in Figure 2b. The shape of the functions for identical and non-identical pairs of particles is different. The QS effects are dominant in the case of the $K_S^0 K_S^0$ system. However, QS (which relies on the Gaussian parameterization) is not sufficient to describe the shape of the correlation function around around $q_{inv} = 0.1$ GeV/c, i.e. a dip structure. Only including the strong FSI (Lednicky-Lyuboshitz parametrization) allows us to describe the area of the correlation function below the unity. The parameterization of the function for $K_S^0 K^\pm$ only considers the strong interaction related to the a_0 resonance.



(a) (b)

Figure 2. $K_S^0K_S^0$ (a) and $K_S^0K^+$ (b) correlation functions for Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV with theoretical fits with the Lednicky-Lyuboshitz parametrization.

3.2 Centrality dependence for all kaon combinations

Figure 3 shows the comparison of the source sizes from all K_S^0 and $K^{\pm}$ combinations for the top RHIC energy as a function of the centrality, where decreasing dependence with increasing collision centrality is observed. The obtained results of the $K^{\pm}K^{\pm}$ [6], $K_S^0K_S^0$, and the $K_S^0K^+$

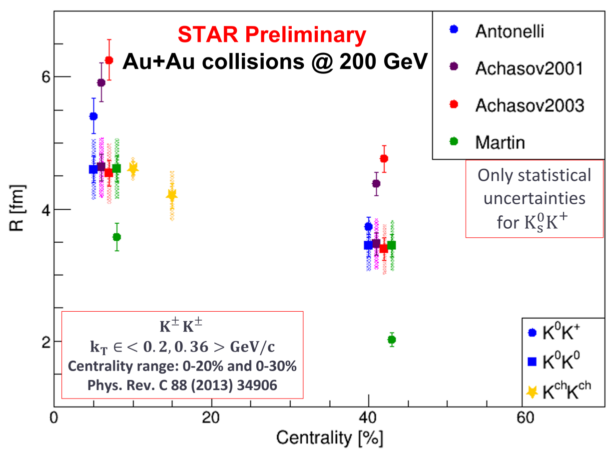


Figure 3. Centrality dependence of the particle emitting source sizes for the $K^{\pm}K^{\pm}$ [6], $K_S^0K_S^0$, and $K_S^0K^{\pm}$ systems for Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV. The circle markers represent the results from $K_S^0K^+$, the squared markers correspond to $K_S^0K_S^0$ radii, and the star markers are from the $K^{\pm}K^{\pm}$ analysis. Different colors describe different Lednicky-Lyuboshitz parametrizations. For $K_S^0K^{\pm}$ only statistical uncertainties are shown.

results favor the Antonelli parameterization, which suggests a_0 resonance to be a four-quark state. On the other hand, based on Achasov2003 parametrization, the bigger the resonance mass leads to the larger source size (offers a much larger radius for $K_S^0K^+$ system).

3.3 Energy dependence for $K_S^0K_S^0$ system

The obtained source sizes also indicate a clear dependence on the collision energy. Figure 4 shows that the collisions at higher energy give larger size of the homogeneity region as expected. The extracted source radii are consistent among different parameterizations except the case with QS only, indicating the significance of including strong FSI. This again confirms how important it is to consider this impact in fits. This figure also presents calculations from two theoretical models - UrQMD [7] and Therminator2 [8]. The model calculations agree with the data within their uncertainties.

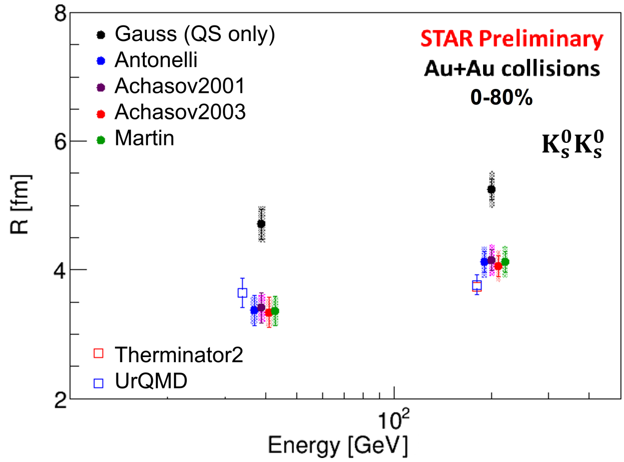


Figure 4. Energy dependence of the source sizes observed for the $K^0_S K^0_S$ combination in Au+Au collisions. The filled markers are results from the experiment, and the empty markers correspond with model predictions.

4 Summary

In these proceedings, the results from femtoscopic measurements of all kaon combinations in Au+Au collisions at $\sqrt{s_{NN}}$ = 39 GeV and 200 GeV have been presented. The obtained results show the importance of considering the strong FSI in the parameterization in the case of $K^0_S K^0_S$ correlation functions. The comparison of the source sizes from the measurements of all systems $K^{\pm}K^{\pm}$, $K^0_S K^0_S$, and $K^0_S K^{\pm}$ implies that the a_0 resonance is favored to be a tetraquark because of consistent source radii for all the combinations by using the Antonelli parameterization.

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