Pion-kaon femtoscopy in Au+Au collisions at STAR

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Abstract. In non-identical particle correlations, e.g. pion-kaon femtoscopy, one can obtain information about source size and asymmetry in emission processes of pions and kaons. Such asymmetry give us knowledge of which type of particles is emitted first/second and/or from which region of the source. The studies of non-identical particle femtoscopy for Beam Energy Scan energies give us the opportunity to study how the source size and asymmetry in particle emission depend on the initial conditions of the collision. It also allows one to examine these parameters in the vicinity of the theoretical critical point. In these proceedings, we present STAR results of pion-kaon femtoscopy at mid-rapidity in Au+Au collisions at $\sqrt{s_{NN}} = 7.7$, 19.6 and 39 GeV.

1. Introduction

Femtoscopy, the momentum correlations of two or more particles with small relative momenta in their center-of-mass are used to measure source sizes of the order 10^{-15} m. With this technique, the size of the particle-emission source formed during heavy-ion collisions can be measured. Correlations of non-identical particles provide information about the space-time asymmetry between two sources of particle emission such as the relative position of the sources and the average times of particle emissions [1]. The spacial shift is coming from the transverse flow of particles with different masses [2]. By analyzing the size of the emission source and the asymmetry of the space-time at the Beam Energy Scan (BES) program energies, we will examine the characteristics of the source as a function of the initial conditions after collision. As part of the BES program, the STAR (Solenoidal Tracker at RHIC) experiment collected Au+Au data at $\sqrt{s_{NN}} = 7.7, 11.5, 14.5, 19.6, 27, 39$ GeV. These proceedings show an analysis at center-of-mass energies 7.7, 19.6 and 39 GeV. The results for $\sqrt{s_{NN}} = 19.6$ GeV may be particularly interesting because they contain information from the region possibly near the critical point, as hinted at by the proton kurtosis measurement [3][4]. Near a critical point, fluctuations may occur of strangeness [5], which may manifest as a smaller number of pairs and therefore cause abnormal correlation functions.

2. Methodology of non-identical particle femtoscopy

Non-identical particle correlations result from Final State Interactions: Coulomb and strong force. The dominant influence on the correlation of pions and kaons is the Coulomb force [6].

To calculate the correlation function $C(k^*)$ one should calculate the ratio of k^* distribution of pairs taken from the same event (correlated pairs) and k^* distribution constructed with pairs taken from different events (uncorrelated pairs). The k^* is the magnitude of the three-momentum of either particle in the pair rest frame.

The correlation functions can be calculated in two groups of pairs, which are divided depending on the space-time separation between pion and kaon emission points. The first group represents the case where the pions catch up with the kaons, whereas the second case is when the pions move away from the kaons. From each group, a different correlation function is constructed, $C_+(k^*)$ and $C_-(k^*)$, where the sign index reflects the sign of $\vec{v} \cdot \vec{k}^*_\pi$, with $\vec{v}$ the pair velocity and $\vec{k}^*_\pi$ the pion momentum vector in the PRF (pair rest frame) [7]. When both correlation functions are identical, the average space-time emission points of pions and kaons coincide. If the correlation function C_+ shows a larger deviation from unity than C_- it can be concluded that the pions are emitted closer to the center of the source than kaons. In this case pions with a larger velocity will tend to catch up with the kaons, and the Coulomb correlation strength will be enhanced compared with the case where the pions are slower than the kaons [6].

The longitudinally comoving system (LCMS) is used in this analysis. In the LCMS, the *out* axis is parallel to the pair velocity, the *long* axis is the beam axis and the *side* axis is perpendicular to the other two. Correlation functions are prepared for three projections of $\vec{k}^*_\pi$: k_{side}, k_{long} and k_{out}. The corresponding projections of the three-vector $\vec{r}^*$, the relative distance between the particle freeze-out points in the PRF, are r^*_{out}, r^*_{side}, and r^*_{long}. Due to azimuthal symmetry and symmetry about $mid-rapidity$: $\langle r_{side} \rangle = \langle r_{long} \rangle = 0$ [8]. Thus C_+/C_- ("double ratio"), defined with respect to the signs of k^*_{side} and k^*_{long}, should not deviate from unity.

3. Results

The cuts used for selecting pions and kaons measured in Au+Au collisions at $\sqrt{s_{NN}} = 7.7$, 19.6 and 39 GeV are shown in Table 1. In this analysis, we use information from the Time Projection Chamber (TPC) and the time-of-flight (TOF) detector [9][10]. If the particle had a momentum greater than 0.55 GeV/c it had to be registered by both detectors. In identification of particles registered in TPC detector, the particles that were within 3 standard deviations (N σ) of the Bichsel function were selected. Tracks with the distance of closest approach (DCA) to the primary vertex less than 3 cm were selected. Only statistical uncertainties are represented.

Table 1. Selection criteria used in the analysis at $\sqrt{s_{NN}} = 7.7$, 19.6 and 39 GeV. The TPC particle identification cuts for $\sqrt{s_{NN}} = 7.7$ and 19.6 GeV energies are different from the 39 GeV one.

	7.7 GeV / 19.6 GeV	39 GeV
analysed	3.4 M / 17.5 M events	91.2 M events
π momentum	[0.1, 1.2] GeV/c	[0.15, 0.7] GeV/c
K momentum	[0.1, 1.2] GeV/c	[0.3, 0.8] GeV/c
N σ for π and K	< 3.0	< 3.0
π m^2	[0.0176, 0.022] GeV^2/c^4	[0.017, 0.026] GeV^2/c^4
K m^2	[0.23, 0.26] GeV^2/c^4	[0.22, 0.27] GeV^2/c^4
$|\eta|$	< 0.5	< 0.5
DCA	< 3 cm	< 3 cm

3.1. The comparison of correlation functions for $Au + Au$ collisions at 7.7, 19.6 and 39 GeV
The magnitude and the shape of the correlation functions for Au+Au collisions at $\sqrt{s_{NN}} = 7.7$, 19.6 and 39 GeV are the same (Fig. 1). The similarity of these functions (taking into account the statistical errors) means, that the source created in collisions at these three energies have the same size. The work on the estimation of the source is still in progress.
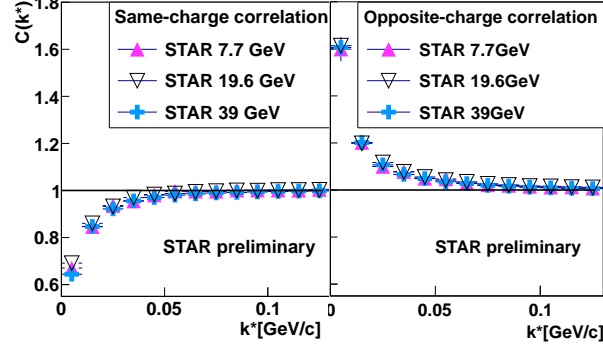
Figure 1. The comparison of pion-kaon correlation functions for $Au + Au$ collisions at $\sqrt{s_{NN}}$ = 7.7, 19.6 and 39 GeV for the minimum-bias collisions $(0 - 80\%)$. Results are presented for two types of correlations: same-charge correlation $(\pi^+ K^+ + \pi^- K^-)$, opposite-charge correlation $(\pi^+ K^- + \pi^- K^+)$.

3.2. The asymmetry in Au + Au collisions at $\sqrt{s_{NN}}$ = 7.7, 19.6 and 39 GeV
Within the larger uncertainties at $\sqrt{s_{NN}}$ = 7.7 GeV, the "double ratio" functions at $\sqrt{s_{NN}}$ = 7.7, 19.6 and 39 GeV agree well and show similar trends (Fig. 2). This indicates that the asymmetry in the emission process is observed for all the presented energies and is consistent. The same trend in asymmetry was also observed for higher energy, e.g., $\sqrt{s_{NN}}$ = 130 GeV [11]. Sizeable transverse flow is observed even for the lowest BES energy. Work on defining the size of the asymmetry is in progress.
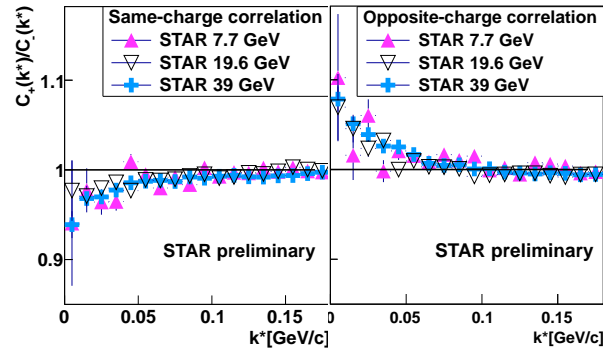

Figure 2. Comparison of C_+/C_- functions for pions and kaons for $Au + Au$ minimum-bias $(0 - 80\%)$ at $\sqrt{s_{NN}}$ = 7.7, 19.6 and 39 GeV for the "out" direction. Results are presented for both types of correlations: same-charge correlation $(\pi^+ K^+ + \pi^- K^-)$, opposite-charge correlation $(\pi^+ K^- + \pi^- K^+)$.

4. Summary
In these proceedings, we present an analysis of femtoscopy correlation functions and asymmetry calculations for Au+Au collisions at $\sqrt{s_{NN}}$ = 7.7, 19.6 and 39 GeV. It is shown that the source sizes of these energies look similar and that such behaviour is observed for same-charge and opposite-charge correlations. Further calculations have to be made to get exact source sizes. The asymmetry in the emission is observed for all investigated energies here. The shape of the C_+/C_- function indicates that most of the pions are emitted closer to the system's center

or/and later than most of the kaons for these collisions. This indicates that transverse flow is sizeable even for low energy collisions such as $\sqrt{s_{NN}} = 7.7$ GeV. At this stage, we do not observe abnormal correlation functions and asymmetry functions at $\sqrt{s_{NN}} = 19.6$ GeV.

5. Acknowledgements

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