Bose–Einstein correlations of charged kaons in $p+p$ collisions with the STAR detector

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Abstract.
We report the results of charged kaon Bose–Einstein Correlations (BEC) measured in proton-proton collisions at $\sqrt{s}$ =200 and 510 GeV with the STAR detector at Relativistic Heavy Ion Collider (RHIC). The one-dimensional correlation functions are studied as a function of the charged particle multiplicity. The femtoscopic radii, R, and the correlation strength, λ, are extracted. The dependence of the source radii and the correlation strengths on the particle multiplicity are investigated.

1. Introduction
Particle correlations carry information about the multiparticle production process. Two–particle Bose–Einstein Correlations (BEC) at low relative momenta (also known as *correlation femtoscopy* or *HBT intensity interferometry*) are sensitive to the quantum statistics and allow one to measure the space–time extent of the particle emitting source [1, 2]. These correlations originate from the symmetrization of the two–particle wave function of identical particles and lead to an enhancement of pair particle production with small relative momenta. The first BEC were observed in the $p\bar{p}$ annihilation as an enhancement of the identical–pion production with small opening angles [3, 4]. In the 1970s they were refined by Kopylov and Podgoretsky [5, 6] and shown to be useful for the study of the emitting source parameters. Since then the femtoscopic analysis was extensively used in many experiments [7, 8]. In "elementary" leptonic and hadronic collisions the BEC measurements provide a test of different models [9, 10]. Usually the femtoscopic analysis is applied for pions however using kaons may provide additional information about the particle emitting source.

2. Charged kaon femtoscopic analysis
The results presented in this paper are based on the analysis of the $p+p$ collisions at $\sqrt{s}$=200 and 510 GeV measured by Solinoidal Tracker At RHIC (STAR) in the 2012 and 2011 runs, respectively. The STAR Time Projection Chamber (TPC) was used for charged particle tracking, reconstruction of the particle momentum, and particle identification by measuring the ionization energy loss (dE/dx) [11]. The TPC has a full 2π azimuthal acceptance and covers the pseudorapidity range $|\eta| < 1.3$. The multiplicity of each collision was determined via the measured number of charged particles within the pseudorapidity range $|\eta| < 0.5$ and the transverse momentum $p_T > 0.15$ GeV/c. To ensure a more uniform detector acceptance and

reduce pile-up interactions, only events with the position of the reconstructed primary vertex within ±50 cm of the center of STAR along the beam direction were used in the analysis. All tracks in the TPC were required to have more than 15 measured space points along the trajectory. The tracks with pseudorapidity $|\eta| > 1$ were excluded from the analysis. In order to avoid track splitting, the ratio of the number of reconstructed space points to possible space points along the track was required to be greater than 0.52.

The charged kaon identification in the momentum range $0.2 < p < 0.55$ GeV/c was performed by using the information from TPC. It was required that the measured energy loss of a track must be less than two standard deviations, σ, from the predicted energy loss of a kaon and more than 2σ from the energy loss prediction of any other hypothesis. In the momentum range $0.55 < p < 1.55$ GeV/c, charged particle identification was performed by measuring the flight time (t_{TOF}) in the Time-Of-Flight (TOF) system [12, 13]. The particles with $0.18 < m^2 < 0.35$ (GeV/c^2)^2 were selected as kaons. The m^2 is calculated by $m^2 = p^2\left((t_{TOF} \cdot c/l)^2 - 1\right)$, where l is the flight path length of the particle and c is the speed of light.

Usually the femtoscopic correlation functions are sensitive to the two-track reconstruction effects (track splitting and track merging) due to the fact that the particles at low relative momenta have close trajectories. In hadronic collisions the track splitting (one single particle is reconstructed as two tracks with close momenta) and track merging (two particles are reconstructed as one track) effects have a small influence on the correlation functions. However the same cuts as were used for removing these effects in STAR analysis of $Au+Au$ collisions [14] were applied.

The one-dimensional correlation function $C(Q)$ of two particles with the three-momenta $\mathbf{p_1}$ and $\mathbf{p_2}$ is constructed as a ratio:

$$C(Q) = A(Q)/B(Q), \tag{1}$$

where $A(Q)$ is the measured two-particle distribution in the given event. The quantity $B(Q)$ is the reference distribution, where the quantum statistical correlations are absent, and is constructed by mixing particles from different events. The quantity $Q = \sqrt{(\mathbf{p_1} - \mathbf{p_2})^2 - (E_1 - E_2)^2}$ is the relative four-momentum of the particles. In order to extract the emitting source radius, R, the correlation functions were fit by the Bowler–Sinyukov formula:

$$C(Q) = N\left(1 - \lambda + \lambda K(Q)(1 + e^{-R^2Q^2})\right) D(Q), \tag{2}$$

where N is a normalization factor, λ is the strength of the correlations, and $K(Q)$ is the Coulomb function integrated over a spherical source of 1 fm. The quantity $D(Q)$ is the "baseline" term that takes into account all non-femtoscopic correlations which arising, for instance, due to the energy and momentum conservation [15]. In the current analysis, a quadratic polynomial was used for the $D(Q)$.

The two–kaon correlation functions were studied for the three multiplicity ranges: (1–6), (7–12) and (>12). In order to correct for the non-femtoscopic effects, the Monte Carlo event generator PYTHIA-6.4.28 [16] with Perugia 0 Tune [17] was used. Since the PYTHIA event generator does not contain Bose–Einstein correlations and final state interactions (Coulomb and strong), the deviations of the simulated correlation functions from unity will correspond to the non-femtoscopic correlations. The comparison of the simulated charged kaon correlation functions, where PYTHIA events were filtered through the analysis cuts, to the experimentally measured distributions for each collision energy and multiplicity bin is shown in Fig. 1. The experimentally measured (solid circles) and Monte Carlo simulated (empty circles) correlation functions were normalized in the region $0.5 < Q < 0.8$ GeV/c such that the correlation functions $C(Q) \to 1$. One may see that PYTHIA gives a good description of experimental correlation functions in the region $Q > 0.5$ GeV/c. The decrease of the measured experimental correlation functions at low momenta, $Q < 0.1$ GeV/c, is due to the Coulomb repulsion between the kaons.

In order to correct for the non-femtoscopic effects, one may construct the double ratio which is defined as a ratio of the experimentally measured correlation function to the simulated one. Fig. 2 shows these double ratios for $p + p$ collisions at $\sqrt{s}$ =200 (top panels) and 510 GeV (bottom panels) and the three multiplicity ranges.

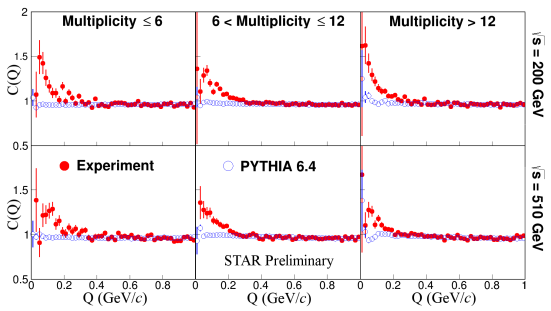

Figure 1. Correlation functions for charged kaon pairs from $p + p$ collisions at $\sqrt{s}$ = 200 (top panels) and 500 GeV (bottom panels) measured by STAR (filled circles) and simulated with the PYTHIA event generator (open circles). Columns from left to right show the three multiplicity ranges.

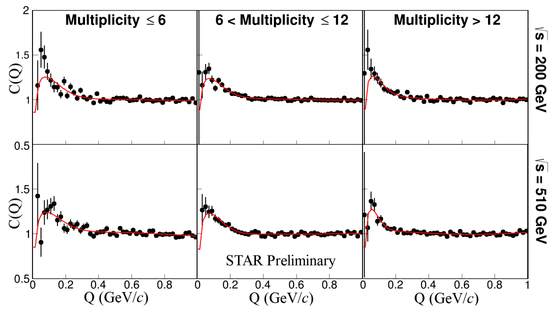

Figure 2. Charged kaon correlation functions after the correction on the PYTHIA simulated distributions obtained for $p+p$ collisions at $\sqrt{s} = 200$ (top panels) and 500 GeV (bottom panels) and the three event multiplicity ranges. The lines show the fits to the data by using the Eq. 2.

The correlation functions were fitted with the function shown as Eq. 2. Due to the imperfections of the simulation in the $Q > 0.8$ GeV/c region, the non-femtoscopic term $D(Q) = 1 + aQ + bQ^2$ was used. Fig. 3 shows the extracted source radii (a) and correlation strengths (b) parameters measured at $\sqrt{s}$ =200 (stars) and 510 (squares) GeV as a function of the particle multiplicity. Only statistical uncertainties are shown.

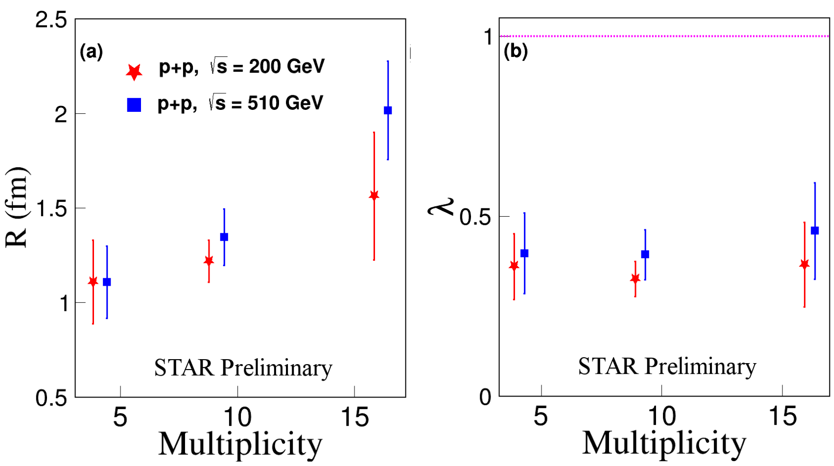

Figure 3. The extracted emitting source radii (a) and correlation strength (b) as a function of particle multiplicity measured at $\sqrt{s} = 200$ (stars) and $\sqrt{s} = 510$ (squares) GeV. Error bars are statistical only.

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As one can see the source radii slightly increase with the particle multiplicity for both collision energies. The observed multiplicity scaling may be understood as the increase of the initial geometrical region of overlap of the colliding objects [18]. The measured femtoscopic parameters, R and λ, are consistent for both energies within the statistical errors.

3. Summary

The systematic femtoscopic analysis of two–kaon correlation functions from $p+p$ collisions at $\sqrt{s}$ =200 and 510 GeV measured by STAR has been presented. The one–dimensional correlation functions were studied for the three event multiplicity ranges: (1–6), (7–12) and (>12). The measured emitting source parameters, λ and R, are generally independent of the collision energy. A slight increase of the source radii with event multiplicity for both $\sqrt{s}$ =200 and 510 GeV collision energies has been observed.

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