Measurement of the charged kaon correlations at small relative momentum in the SELEX experiment

Grigory Nigmatkulov on behalf of the SELEX Collaboration[†]

National Research Nuclear University "MEPhI", Moscow, Russia, 115409

We report the first measurement of charged kaon Bose–Einstein correlations produced by 600 GeV/c Σ^-, π^- and 540 GeV/c p beams in the SELEX experiment. The SELEX (E781) experiment at Fermilab is a fixed target three–stage magnetic spectrometer designed for study hadroproduction at high acceptance for forward interactions ($x_F \geq 0.1$).

One–dimensional charged kaon correlation functions were obtained for all three beams and three pair transverse momentum ranges. The femtoscopic parameters for the radii and correlation strength of the kaon source were extracted. The fit results show the decrease of the emission source radii with the increase of the pair transverse momentum.

1. Introduction

A measurement of the two-particle correlations at small relative momentum (also known as correlation femtoscopy) allows to measure spatio-temporal parameters of the particle-emitting source [1–4]. Previously correlation femtoscopy studies were performed for lepton-lepton [5], lepton- and hadron-hadron [6], and heavy ion collisions [7]. The high-statistics data from different experiments at powerful accelerators and development of theoretical formalism has expanded the information extracted from correlations from the original source size measurements to the extraction of the shape, extent and dynamical timescale of the emission region. These analyses usually study pions, however, measurements of heavier particles can complete the extracted information.

[†] SELEX Collaboration: Bogazici University, Carnegie-Mellon University, Centro Brasileiro de Pesquisas Físicas, Fermi National Accelerator Laboratory, Institute for High Energy Physics (Protvino), Institute of Theoretical and Experimental Physics Max-Planck-Institut für Kernphysik, Moscow State University, Petersburg Nuclear Physics Institute, Tel Aviv University, Universidad Autónoma de San Luis Potosí, University of Bristol, University of Iowa, University of Michigan-Flint, University of Rome "La Sapienza" and INFN, University of São Paulo, University of Trieste and INFN

In this paper, the preliminary results of study of pair transverse momentum dependencies of charged kaons emission source parameters for different initial state conditions in the SELEX experiment will be presented.

2. Data analysis

In this proceedings the most important features of the experimental setup used in current analysis will be listed. The detailed description of the SELEX experiment can be found elsewhere [8]. SELEX (E781) is a three-stage magnetic spectrometer, designed for hadroproduction study at forward interactions ($x_F \geq 0.1$). The negatively charged 600 GeV/c beam contains approximately equal fractions of Σ and π, meanwhile the positively charged beam contains 92% of protons and 8% of π. Beam particle was identified as a meson or a baryon by a transition radiation detector. Interactions were happen in a composite target (2 Cu and 3 C separated by 1.5 cm one by another), wich total thickness equals to 5% of an interaction length for protons. Downstream of the target 20 planes of vertex silicon strip detectors with about 5 μm space resolution were placed. A particle momentum was measured by deflection of the track position by two magnets M1 and M2 in a system of proportional wired chambers and silicon strip detectors. Momentum resolution of a typical 100 GeV/c track was $\sigma_p/p \approx 0.5\%$. Charged particle identification was performed with a Ring Imaging Cherenkov detector (RICH) [9], which separated kaons from pions in a wide momentum range up to 165 GeV/c. In current analysis we used only particles with momentum from 45 to 165 GeV/c, identified by the RICH detector as kaons, and distance of closest approach to the primary vertex less than 20 μm [10].

3. Correlation functions

Identified kaons from the same event were combined to the pairs in order to form the signal distribution A(Q) of relative momentum:

$$Q = \sqrt{(\vec{p_1} - \vec{p_2})^2 - (E_1 - E_2)^2}, \tag{1}$$

where $\vec{p_1}$, E_1 and $\vec{p_2}$, E_2 are momentum and energy of the first and the second particle respectively. Pairs combined from different events were used in order to construct uncorrelated background distribution B(Q) (also known as an event mixing technique). A correlation function is defined as a ratio:

$$C_2(Q) = \frac{A(Q)}{B(Q)} \cdot D(Q), \tag{2}$$

where $D(Q)$ is so-called correlation baseline that describes all non-femtoscopic correlations, for instance, the correlations caused by the momentum-energy conservation [11]. In the simplest case non-femtoscopic effects can be parameterized by a 2nd order polynomial:

$$D(Q) = 1 + aQ + bQ^2. \tag{3}$$

The correlation function of identical spinless bosons should increase at small relative momentum except for very small values where Coulomb interaction becomes dominant. In order to extract the size of the emission region one can use a Gaussian form:

$$C_2(Q) = N(1 - \lambda + K(Q)(\lambda e^{-R^2Q^2})) \cdot D(Q), \tag{4}$$

where N is a normalization parameter, λ – shows the fraction of particles emitted independently, R – radii of the emission source, and the factor $K(Q)$ is the Coulomb function [12, 13]. For the estimation of the baseline without Bose–Einstein correlations and final state interactions the Monte Carlo event generator PYTHIA-6.4.27 [15] with the Perugia 2011 tune [16] was used.

Current analysis was performed for Σ^-, π^- and p beam types, and for three pair transverse momentum ranges k_T: (0–0.3), (0.3–0.55), (0.55–0.85) GeV/c. Here the transverse momentum of a pair is defined as:

$$k_T = |\vec{p_{T1}} + \vec{p_{T2}}|/2, \tag{5}$$

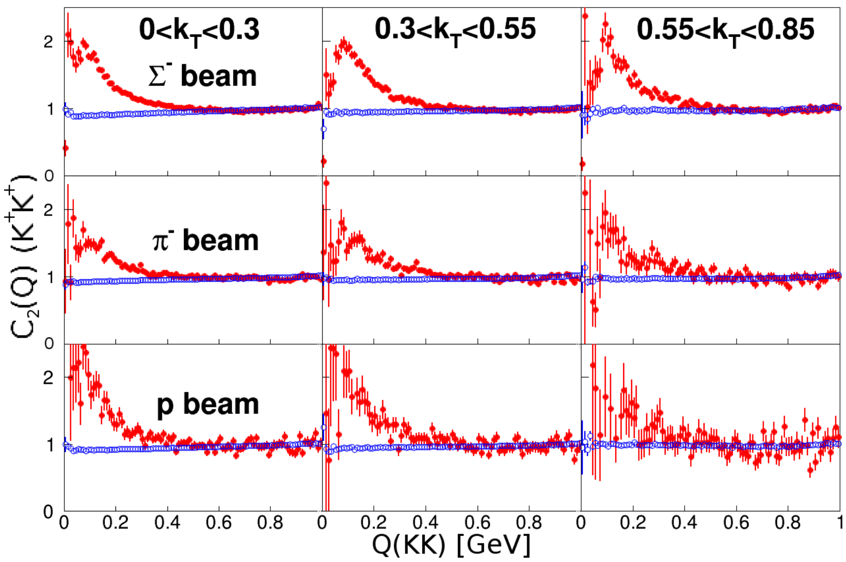
where $\vec{p_{T1}}$ and $\vec{p_{T2}}$ are transverse momenta of the first and the second particle respectively.

Fig. 1 shows a comparison between experimental correlation functions and correlation functions obtained from the Pythia event generator using Perugia 2011 tune (blue open circles). It becomes clear, that simulated correlation functions (baseline) reproduce experimental for each beam type and k_T region, i.e. they describe all long-range correlations.

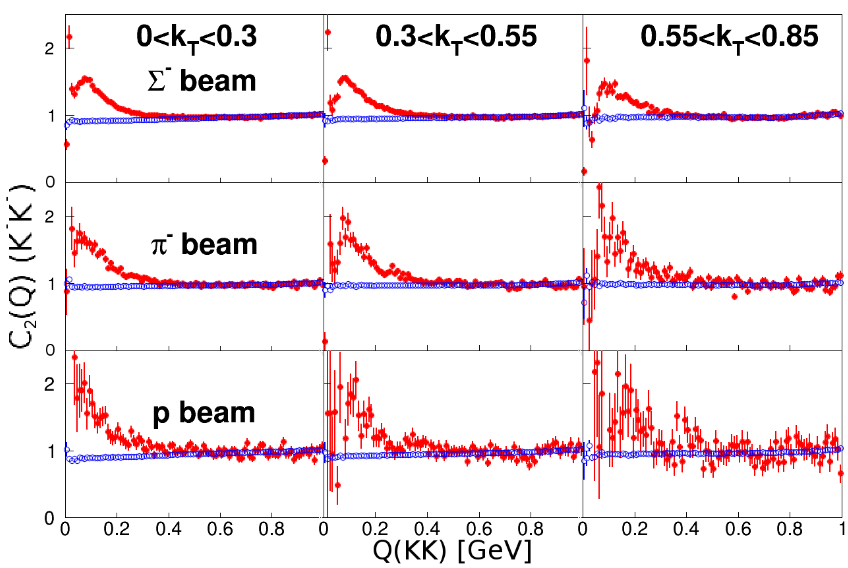
Due to the fact that Pythia does not contain Bose-Einstein correlations and final state interactions, but describes non-femtoscopic effects, it is necessary to correct experimental distributions on the simulated correlation functions. Fig. 2 represents the correlation functions obtained with this correction. Correlation functions were fitted by Eq. 4, where the Coulomb function $K(Q)$ was integrated over a spherical source of 1 fm.

Fig. 3 shows the source radii dependencies on pair transverse momentum k_T. The source radii decreases with k_T for all beam types. It can be also seen that the source radii is less for the meson than for the baryon beams.

The decrease of the source radii with k_T was previously measured in heavy ion collisions and interpreted as a collective hydrodynamic expansion

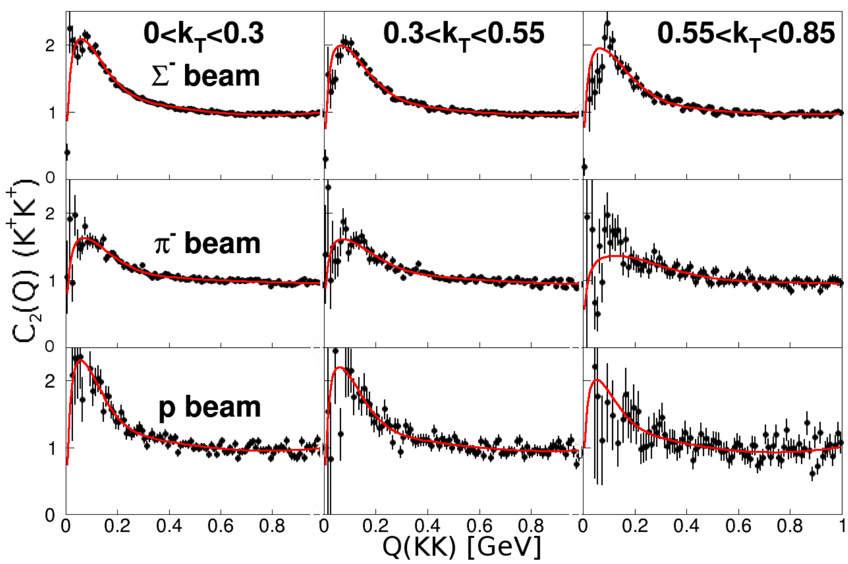


(a) Correlation functions of the K^+K^+ system

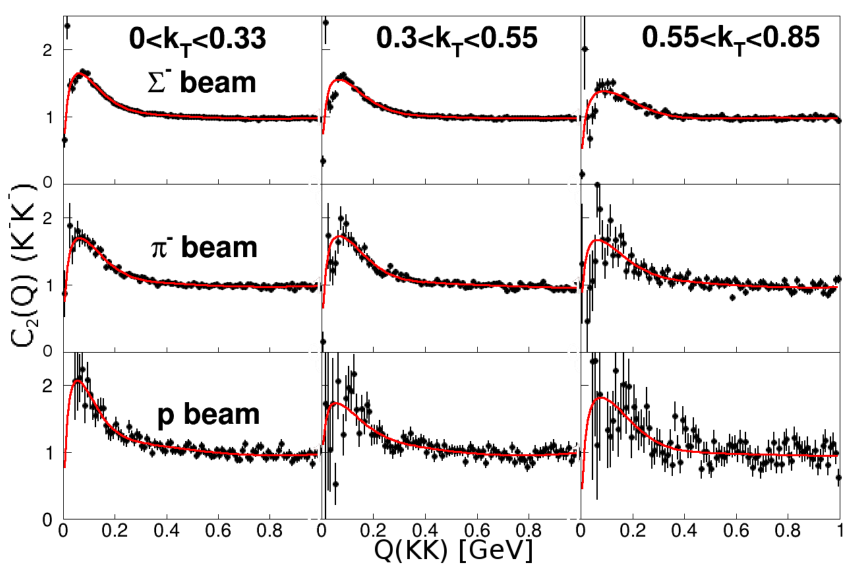


(b) Correlation functions of the K^-K^- system

Fig. 1: Comparison of experimental and simulated correlation functions obtained for three k_T bins: (0–0.3), (0.3–0.55), (0.55–0.85) [GeV/c]. From top to bottom rows represent Σ^-, π^- and p beams respectively. Solid circles show experimental correlation functions, open circles represent baselines obtained from Pythia.

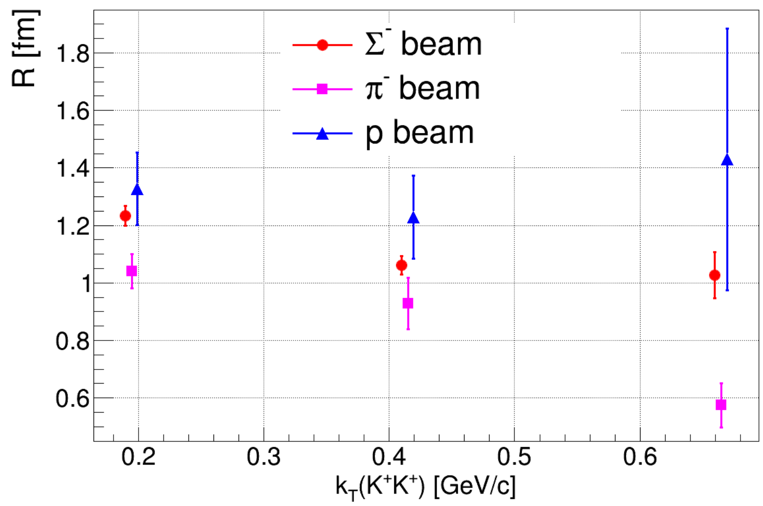


(a) K^+K^+ correlation functions

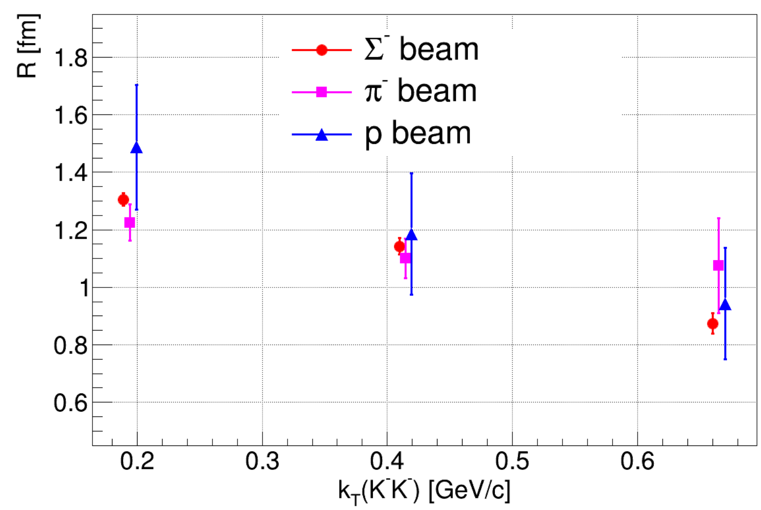


(b) K^-K^- correlation functions

Fig. 2: Correlation functions obtained after the correction on baselines for three k_T bins: (0–0.3), (0.3–0.55), (0.55–0.85) [GeV/c]. From top to bottom rows represent Σ^-, π^- and p beams respectively.



(a) K^+K^+ source parameters



(b) K^-K^- source parameters

Fig. 3: k_T dependencies of the emission source radii. Red circles, magenta squares and blue triangles show the source radii obtained for Σ^-, π^- and p beams respectively.

of the created matter [7, 17]. The similar behavior was observed for pp collisions at RHIC and LHC, but it still lacks a firm interpretation for the events with low multiplicities. At high multiplicities hydrodynamic phase contribution is becoming more significant role and the experimental data have a better description by theory.

4. Summary

Charged kaons correlations at small relative momentum have been measured in the SELEX experiment for Σ^-, π^- and p beams and three k_T regions. The emission source radii parameters have been extracted. The decrease of the source radii for all beam types with the pair transverse momentum k_T has been observed.

Acknowledgments

The reported study was partially supported by RFBR, research project No. 11-02-01302a.

References

[1] G. Goldhaber, S. Goldhaber, W.Y. Lee, and A. Pais, Phys. Rev. **120**, 300 (1960).

[2] G.I. Kopylov and M.I. Podgoretsky, Sov. J. Nucl. Phys. **15**, 219 (1972).

[3] G.I. Kopylov and M.I. Podgoretsky, Phys. Lett. **50**, 472 (1974).

[4] G.I. Kopylov, V.L. Lyuboshits, and M.I. Podgoretsky, JINR-P2-8069.

[5] W. Kittel, Acta Phys. Polon. **32**, 3927 (2001).

[6] G. Alexander, Rept. Prog. Phys. **66**, 481 (2003).

[7] M. Lisa, S. Pratt, R. Soltz, and U. Wiedemann, Ann. Rev. Nucl. Part. Sci. **55**, 311 (2005).

[8] J.S. Russ *et al.* (SELEX Collaboration), ICHEP'98 Proc. Int. Con. on High Energy Physics, **II** 1259 (1998), hep-ex/9812031.

[9] J. Engelfried, I.S. Filimonov, J. Kilmer, A.P. Kozhevnikov, V.P. Kubarovsky, V.V. Molchanov, A.V. Nemitkin, E. Ramberg, V.I. Rud, and L. Stutte, Nucl. Instrum. Meth. A **502**, 285 (2003).

[10] G.V. Sinev and G.A. Nigmatkulov, Bull. Russ. Acad. Sci. Phys., **77**, 800 (2013); G.V. Sinev and G.A. Nigmatkulov, Izv. Ross. Akad. Nauk., **77**, 833 (2013).

[11] Z. Chajęcki and M. Lisa, Phys. Rev. C **78**, 064903 (2008); Phys. Rev. C **79**, 034908 (2009).

[12] M.G. Bowler, Phys. Lett. B **270**, 69 (1991).

[13] Y. Sinyukov, R. Lednicky, S.V. Akkelin, J. Plutta, and B. Erazmus, Phys. Lett. B **432**, 248 (1998).

[14] K. Aamodt *et al.* (ALICE Collaboration), arXiv:1212.5958.

[15] T. Sjostrand, S. Mrenna, and P. Skands, J. High Energy Phys. **05**, 026 (2006).

[16] P.Z. Skands, Phys. Rev. D **82**, 074018 (2010).

[17] S. Pratt, Phys. Rev. Lett. **53**, 1219 (1984).