

**Charged kaon femtoscopic correlations in  $pp$  collisions at  $\sqrt{s} = 7$  TeV**B. Abelev *et al.*\*

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Correlations of two charged identical kaons ( $K^{\text{ch}}K^{\text{ch}}$ ) are measured in  $pp$  collisions at  $\sqrt{s} = 7$  TeV by the ALICE experiment at the Large Hadron Collider (LHC). One-dimensional  $K^{\text{ch}}K^{\text{ch}}$  correlation functions are constructed in three multiplicity and four transverse momentum ranges. The  $K^{\text{ch}}K^{\text{ch}}$  femtoscopic source parameters  $R$  and  $\lambda$  are extracted. The  $K^{\text{ch}}K^{\text{ch}}$  correlations show a slight increase of femtoscopic radii with increasing multiplicity and a slight decrease of radii with increasing transverse momentum. These trends are similar to the ones observed for  $\pi\pi$  and  $K_s^0K_s^0$  correlations in  $pp$  and heavy-ion collisions. However at high multiplicities, there is an indication that the one-dimensional correlation radii for charged kaons are larger than those for pions in contrast to what was observed in heavy-ion collisions at the Relativistic Heavy-Ion Collider.

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**I. INTRODUCTION**

Extremely high-energy densities achieved in heavy-ion collisions at the Large Hadron Collider (LHC) may entail the formation of the quark-gluon plasma (QGP), a state characterized by partonic degrees of freedom [1]. Studying the QGP is the main goal of the ALICE experiment (a large ion collider experiment) [2]. The system created in ultra-relativistic  $pp$  collisions at LHC energies might be similar to the system created in noncentral heavy-ion collisions because of the large energy deposited in the overlapping region and therefore may also manifest a collective behavior. The highly compressed, strongly interacting system is expected to undergo longitudinal and transverse expansions. Experimentally, the expansion and the spatial extent at decoupling are observable via Bose-Einstein correlations.

Bose-Einstein correlations of two identical pions at low relative momenta were first shown to be sensitive to the spatial scale of the emitting source by G. Goldhaber, S. Goldhaber, W. Lee, and A. Pais 50 years ago [3]. The correlation method since developed and known at present as “correlation femtoscopy” was successfully applied to the measurement of the space-time characteristics of particle production processes in high-energy collisions, especially in heavy-ion collisions (see, e.g. [4–6]). Bose-Einstein correlations of identical particles were widely studied in heavy-ion collisions at the Relativistic Heavy-Ion Collider (RHIC) [7] and were found to confirm the hydrodynamic type of collective expansion of the fireball created in such collisions. In heavy-ion collisions the decrease of the correlation radii with increasing particle momentum was usually considered as a manifestation of

a collective behavior of the matter created in such collisions [6]. Event multiplicities reached in 7 TeV  $pp$  collisions at the LHC are comparable to those measured in peripheral A + A collisions at RHIC, making the study of the particle momentum dependence of the correlation radii an important test of the collectivity in  $pp$  collisions.

The ALICE Collaboration has already studied two-pion correlation radii in  $pp$  collisions at 900 GeV [8] and 7 TeV [9] and  $K_s^0K_s^0$  correlation radii in  $pp$  collisions at 7 TeV [10]. Two-pion Bose-Einstein correlations in  $pp$  collisions at  $\sqrt{s} = 900$  GeV and 7 TeV have been successfully described within the EPOS + hydro model [11]. It was shown that the hydrodynamic expansion substantially modifies the source evolution compared to the “classical” EPOS scenario with independent decay of flux-tube strings, allowing one to describe the transverse momentum dependence of the correlation radii at high multiplicities.

The main reasons for carrying out the present  $K^{\text{ch}}K^{\text{ch}}$  ( $K^+K^+ + K^-K^-$ ) femtoscopy analysis are (1) to study the transverse mass,  $m_T$ , dependence of the correlation radii (“ $m_T$  scaling” is expected to be an additional confirmation of the hydrodynamic type of expansion [6]) and (2) to get a clearer signal (kaons are less affected by the decay of resonances than pions).

Previous  $K^{\text{ch}}K^{\text{ch}}$  studies carried out in Pb-Pb collisions at SPS by the NA44 and NA49 Collaborations [12] and in Au-Au collisions at RHIC by the PHENIX Collaboration [13] revealed scaling in transverse mass: the source sizes versus  $m_T$  for different particle types ( $\pi$ , K) fall on the same curve.

$K^{\text{ch}}K^{\text{ch}}$  studies were performed with combined data from  $\alpha\alpha$ ,  $pp$ , and  $p\bar{p}$  collisions at ISR by the AFS Collaboration [14], in  $e^+e^-$  collisions at LEP by the OPAL and DELPHI Collaborations [15], and in ep collisions by the ZEUS Collaboration [16]. Due to statistics limitations, only one-dimensional radii were extracted in these experiments; no multiplicity and transverse momentum studies were performed.

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In this paper we present the measurements of Bose-Einstein correlations for charged kaons in  $pp$  collisions at  $\sqrt{s} = 7$  TeV, performed by the ALICE Collaboration at the LHC. The present study is the first femtoscopic  $K^{\text{ch}}K^{\text{ch}}$  study to be carried out in  $pp$  collisions and in more than one multiplicity and pair transverse momentum,  $k_{\text{T}}$ , range.

The paper is organized as follows: in Sec. II we describe the ALICE experimental setup and data-taking conditions for the data sample used in this work. In Sec. III we present the correlation measurements and the correlation functions. In Sec. IV we show the main results obtained in this work: the one-dimensional radii extracted from the data. We discuss various observed features and compare the results with  $K_s^0K_s^0$  and  $\pi\pi$  radii previously measured by the ALICE Collaboration. Finally in Sec. V we summarize our results.

## II. DATA ANALYSIS

Approximately 300 million minimum-bias events at  $\sqrt{s} = 7$  TeV, recorded in 2010, were analyzed. The ALICE time projection chamber (TPC) and inner tracking system (ITS) were used for charged-particle track reconstruction and the determination of the primary vertex of the collision.

The TPC identifies charged particles according to their ionization trajectories in the Ne-CO<sub>2</sub> gas. The ionization electrons drift up to 2.5 m from the central electrode to the end caps to be measured on 159 padrows, grouped into 18 sectors. The position at which the track crosses the padrow is determined with a resolution of 2 mm and 3 mm in the drift and transverse directions, respectively. The ITS consists of six silicon layers, two innermost silicon pixel detector (SPD) layers, two silicon drift detector (SDD) layers, and two outer silicon strip detector (SSD) layers, which provide up to six space points for each track.

The forward scintillator detectors VZERO were included in the minimum-bias trigger, and their timing signal was used to reject the beam-gas and beam-halo collisions. The minimum-bias trigger required a hit in one of the VZERO counters or in one of the two inner layers of the SPD. The VZERO detectors are placed along the beam line at +3 m and -0.9 m from the nominal interaction point. They cover a region  $2.8 < \eta < 5.1$  and  $-3.7 < \eta < -1.7$ .

ALICE provides excellent particle identification capabilities, using the measurement of specific particle energy loss ( $dE/dx$ ) in the TPC and the ITS and the time of flight ( $t_{\text{TOF}}$ ) information obtained in the time-of-flight (TOF) detector. The TOF detector is based on multigap resistive plate chambers (MRPCs) in a cylindrical configuration at radius 370–399 cm from the beam axis, with about 153,000 readout channels of dimension  $3.5 \times 2.5$  cm<sup>2</sup>. The start time of the collision (event time zero) is measured by the T0 detector, an array of Cherenkov counters located at +350 and -70 cm along the beam line. If the T0 signal is absent, the start time is estimated from the particle

arrival times at the TOF. The overall time-of-flight resolution depends on the TOF timing signal resolution (better than 100 ps), the accuracy of the reconstructed flight path and the uncertainty in the event start time. The resulting time-of-flight resolution is about 160 ps.

The following criteria were applied for the event selection:

- (i)  $z$  position of the reconstructed vertex within  $\pm 10$  cm around the geometrical center of the ALICE detector.
- (ii) At least one particle in the event reconstructed and identified as a charged kaon. (In fact, the correlation signal is constructed from events having at least two same-charged kaons (a pair). The one-kaon events do contribute to the mixed background. It was verified that including the one-kaon event in the mixed background does not change the shape of the correlation function.)

The criteria for track selection are listed below:

- (i) The kaons were selected in the kinematic ranges:  $|\eta| < 1.0$  and  $0.15 < p_{\text{T}} < 1.2$  GeV/ $c$ .
- (ii) Tracks must include at least 70 space points (or clusters) out of a maximum possible 159 in the TPC and two space points in the ITS (of maximum 6).
- (iii) The quality of a track was determined by the  $\chi^2/N$  value for the Kalman fit to the constructed position of the TPC clusters ( $N$  is the number of clusters associated with the track); the track was rejected if the value was larger than 4.0 (2 degrees of freedom per cluster).
- (iv) In order to reduce the number of secondary particles it was required that the particle trajectory distance from the primary vertex was less than 0.2 cm in the transverse plane and less than 0.25 cm in the beam direction.

Usually the femtoscopic correlation functions of identical particles are very sensitive to two-track reconstruction effects because particles have close momenta and thus close trajectories. The “splitting” of the tracks means that one track was reconstructed as two, and “merging” means that two different tracks were reconstructed as one. For the correlation structures measured in  $pp$  collisions, with characteristic widths  $\sim 0.2$  GeV/ $c$ , track splitting and track merging in the event reconstruction are small effects, but we applied the standard femtoscopic double track cuts (see for details [9]):

- (i) antisplitting cut: Pairs that share more than 5% of clusters in the TPC were removed.
- (ii) antimerging cut: Pairs that are separated by less than 3 cm at the entrance of the TPC were removed.

Pair cuts were applied in exactly the same way for real (signal) and mixed (background) pairs.

In the present analysis, the limit  $p_{\text{T}} < 1.2$  GeV/ $c$  for kaon selection on the TPC and TOF signals was used in order to ensure a high purity of the kaon sample. Kaons

were selected by requiring that the deviation of the specific ( $dE/dx$ ) energy loss in the TPC from that calculated with a parametrized Bethe-Bloch formula be within some number of sigma standard deviations ( $N_{\sigma_{\text{TPC}}}$ ). A similar  $N_{\sigma_{\text{TOF}}}$  method was applied for the particle identification in the TOF using the difference between the measured time of flight and the calculated one as a function of the track length and the particle momentum at each tracking step and for each particle mass.

More details on the particle identification are given in Ref. [17], where it is shown in particular that the fraction efficiency of the particles reconstructed by the TPC with associated signal in the TOF (the TOF matching efficiency) deviates from 30% up to 55% in the  $p_T$  region (under study in our paper). In the present analysis, strict cuts on TPC and TOF signals for kaon selection were used in order to provide the better purity of the kaon sample. The relative contribution of the kaons from the sample with TOF signal to the full sample of the identified kaons used in this analysis is about 60%.

In the present analysis strict cuts on TPC and TOF signals for kaon selection were used in order to provide the better purity of the kaon sample. If the TOF signal was not available, the following cuts were taken:

- (i)  $N_{\sigma_{\text{TPC}}} < 1$  for  $p < 0.35$  GeV/ $c$ ,
- (ii)  $N_{\sigma_{\text{TPC}}} < 2$  for  $0.35 < p < 0.6$  GeV/ $c$ .
- (iii) At larger momenta the tracks were rejected because of significant pion contamination.

If the TOF signal was available, we required that  $N_{\sigma_{\text{TOF}}} < 3$  and  $N_{\sigma_{\text{TPC}}} < 3$ .

Figure 1 shows the transverse momentum dependence of the kaon purity (the ratio of correctly identified kaons to all identified ones) obtained with Monte Carlo (PYTHIA) simulations. The contamination comes mainly from

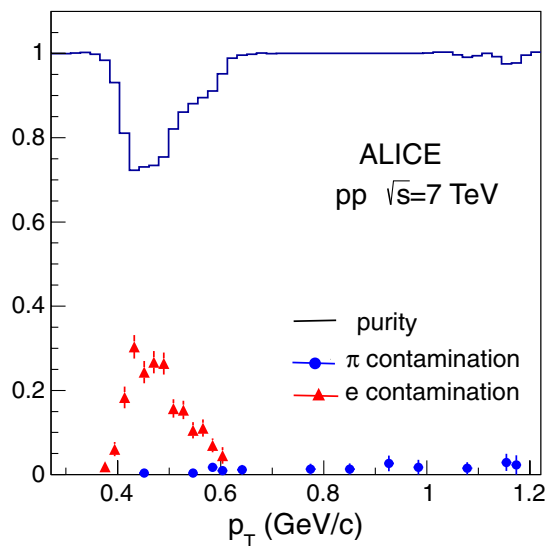


FIG. 1 (color online). Purity and contaminations of selected kaons in  $pp$  collisions at  $\sqrt{s} = 7$  TeV.

$e^+/e^-$  with maximum  $\sim 25\%$  for  $0.35 < p_T < 0.6$  GeV/ $c$  and also from pions at the level  $\sim 1-3\%$  for  $0.35 < p_T < 1.2$  GeV/ $c$ . In consequence, the probability of selecting an  $ee$  or a  $\pi\pi$  pair instead of a  $KK$  pair, even in the case where the contamination is maximal, is still rather low, smaller than  $\sim 6\%$ . The probability of selecting an  $eK(\text{Ke})$  pair instead of a  $KK$  pair can reach  $\sim 37\%$  for  $0.35 < p_T < 0.6$  GeV/ $c$ . The probability of selecting a  $\pi K(\text{K}\pi)$  pair instead of a  $KK$  pair is less than  $\sim 6\%$  for  $0.35 < p_T < 1.2$  GeV/ $c$ . Note that such contamination modifies only the strength of correlation and not the shape of the correlation function. Using the Monte Carlo information and also the purity of kaons estimated from the measured TPC  $dE/dx$  distributions and a realistic single-particle kinematics, we have estimated the purity of kaon pairs at low relative momentum as  $p = 0.84 \pm 0.05(\text{stat}) \pm 0.15(\text{syst})$ ,  $0.61 \pm 0.03(\text{stat}) \pm 0.12(\text{syst})$ ,  $0.79 \pm 0.04(\text{stat}) \pm 0.07(\text{syst})$ ,  $1.0 \pm 0.05(\text{stat}) \pm 0.05(\text{syst})$  for pair transverse momentum  $k_T = |\mathbf{p}_{T,1} + \mathbf{p}_{T,2}|/2$ : (0.2–0.35), (0.35–0.5), (0.5–0.7), (0.7–1.0) GeV/ $c$ , respectively.

### III. CHARGED KAON CORRELATION FUNCTIONS

Momentum correlations are usually studied by means of correlation functions of two or more particles. Specifically, the two-particle correlation function  $\text{CF}(\mathbf{p}_1, \mathbf{p}_2) = A(\mathbf{p}_1, \mathbf{p}_2)/B(\mathbf{p}_1, \mathbf{p}_2)$  is defined as the ratio of the two-particle distribution in a given event  $A(\mathbf{p}_1, \mathbf{p}_2)$  to the reference one,  $B(\mathbf{p}_1, \mathbf{p}_2)$ , where  $\mathbf{p}_1$  and  $\mathbf{p}_2$  are the momentum vectors of the two particles. In the present analysis the reference distribution is constructed by mixing particles of a given class, as described below.

The analysis was performed in three multiplicity ranges based on the measured charged-particle multiplicity,  $N_{\text{ch}}$ : (1–11), (12–22), (>22), and in four ranges of pair transverse momentum  $k_T$ : (0.2–0.35), (0.35–0.5), (0.5–0.7), (0.7–1.0) GeV/ $c$ . Event multiplicity was determined as the number of charged particles emitted into the pseudorapidity range  $|\eta| < 1$  and transverse momentum range  $0.12 < p_T < 10$  GeV/ $c$ . For each class of events, we calculated the charged-particle pseudorapidity density  $dN_{\text{ch}}/d\eta$  corrected for the detection efficiency obtained with Monte Carlo. The considered event multiplicity ranges (1–11), (12–22), >22 correspond to mean charged-particle densities,  $dN_{\text{ch}}/d\eta$ , of 3.2, 8.1, and 17.2, respectively, with systematic uncertainties of  $\sim 5\%$ .

The numerators and denominators of positive and negative kaon distributions were summed up before constructing the ratio ( $K^+K^+$  and  $K^-K^-$  correlation functions were found to coincide within errors thus justifying the procedure). The function is normalized to unity in the range  $0.5 < q_{\text{inv}} < 1.0$  GeV/ $c$ , where  $q_{\text{inv}} = \sqrt{|\mathbf{q}|^2 - q_0^2}$ ,  $\mathbf{q} = \mathbf{p}_1 - \mathbf{p}_2$  and  $q_0 = E_1 - E_2$ . The range for normalization was chosen outside the Bose-Einstein peak.

The correlation function is fitted by a single Gaussian [18],

$$CF(q_{\text{inv}}) = (1 - \lambda + K(q_{\text{inv}})(\lambda \exp(-R_{\text{inv}}^2 q_{\text{inv}}^2)))D(q_{\text{inv}}), \quad (1)$$

where the factor  $K(q_{\text{inv}})$  is the Coulomb function integrated over a spherical source of 1 fm. The function  $D(q_{\text{inv}})$ , “baseline,” takes into account all nonfemtoscopic correlations, including the long-range correlations due to energy-momentum conservation. The parameters  $R_{\text{inv}}$  and  $\lambda$  describe the size of the kaon source and the correlation strength, respectively. The  $\lambda$  parameter depends also on purity and decreases if the purity is not 100%. The  $R_{\text{inv}}$  is measured in the pair rest frame.

The baseline was fitted by a standard quadratic polynomial,

$$D(q_{\text{inv}}) = 1 + aq_{\text{inv}} + bq_{\text{inv}}^2. \quad (2)$$

To estimate the systematic errors due to the fitting procedure, other functions with derivatives equal to zero at  $q_{\text{inv}} = 0$  were also employed, such as

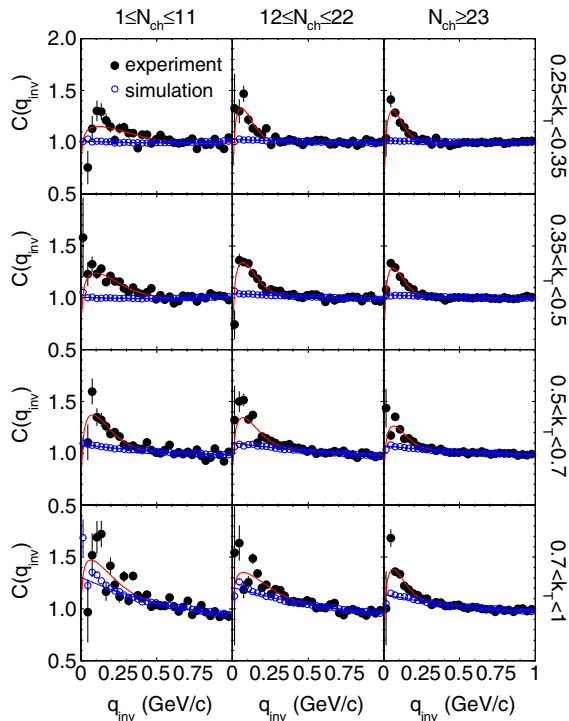


FIG. 2 (color online). Correlation functions versus  $q_{\text{inv}}$  for identical kaons from  $pp$  collisions at  $\sqrt{s} = 7$  TeV (solid circles) and those obtained with PERUGIA-2011 (open circles). Positive and negative kaon pairs are combined. The three columns represent the samples with different charged-particle multiplicities: (1–11), (12–22), (>22); the four rows represent the four pair transverse momentum ranges: (0.2–0.35), (0.35–0.5), (0.5–0.7), (0.7–1.0) GeV/ $c$ . The lines going through the points represent the Gaussian fits discussed in the text.

$$D(q_{\text{inv}}) = \sqrt{1 + aq_{\text{inv}}^2 + bq_{\text{inv}}^4} \quad (3)$$

and the Gaussian,

$$D(q_{\text{inv}}) = b(1 + \exp(-aq_{\text{inv}}^2)). \quad (4)$$

The PERUGIA-2011 tune [19] of the Monte Carlo event generator PYTHIA [20] describes well the kaon spectra in  $pp$  collisions at LHC energies. Therefore, it was used to simulate the correlation function without the Bose-Einstein effect.

## IV. RESULTS AND DISCUSSION

Figure 2 presents the experimental two-kaon correlation functions and those obtained from a simulation using PERUGIA-2011 (open circles) as a function of the invariant pair relative momentum. As one can see, the Monte Carlo simulation reproduces well the experimental correlation function at large  $q_{\text{inv}}$ , i.e. the long-range correlations. The model does not contain the Bose-Einstein effect, so the enhancement at low  $q_{\text{inv}}$  is due to nonfemtoscopic correlations in PYTHIA, probably arising from minijets. The baseline points, obtained from PERUGIA-2011, were fitted to Eq. (2). The parameters  $a$  and  $b$  were used in the fitting of the experimental points by Eq. (1). The same method was used to model the baseline for the ALICE  $\pi\pi$  correlation studies in 0.9 [8] and 7 TeV [9]  $pp$  collisions. Figures 3 and 4 and Table I present the one-dimensional  $\lambda$

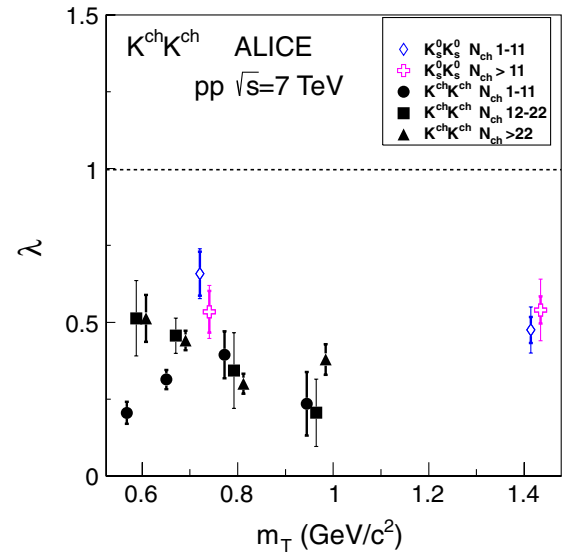


FIG. 3 (color online).  $\lambda$  parameters of  $K^{\text{ch}}K^{\text{ch}}$  versus  $m_T$  extracted by fitting correlation functions shown in Fig. 2 to Eq. (1) and the baseline to Eq. (2). For comparison, the  $K_s^0 K_s^0$  [10]  $\lambda$  parameters measured by ALICE in 7 TeV  $pp$  collisions are also shown. Statistical (darker lines) and total errors are shown. The points corresponding to the second and third multiplicity bins are offset by 0.03 GeV/ $c^2$  for clarity.

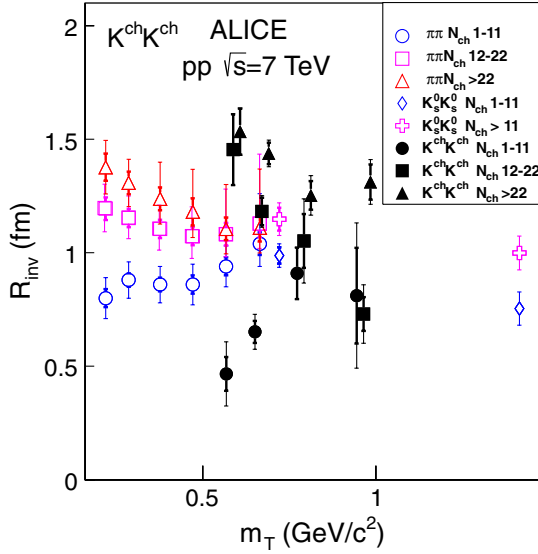


FIG. 4 (color online). One-dimensional charged kaon radii versus  $m_T$  extracted by fitting correlation functions shown in Fig. 2 to Eq. (1) and the baseline to Eq. (2). For comparison, the  $\pi\pi$  [9] and  $K_s^0 K_s^0$  [10] radii measured by ALICE in 7 TeV  $pp$  collisions are also shown. Statistical (darker lines) and total errors are shown. The points corresponding to the second and third multiplicity bins are offset by  $0.03 \text{ GeV}/c^2$  for clarity.

parameters and Gaussian radii versus  $m_T = \sqrt{k_T^2 + m_K^2}$ , including statistical and systematical errors.

In order to estimate the systematic error from the choice of baseline functional form, we repeated the fitting procedure using the baseline fitted with Eqs. (3) and (4). The radii obtained in the three ways differ by less than 4% at low multiplicities (or  $k_T$ ) and by up to 10% at high multiplicities (or  $k_T$ ). The systematic errors estimated from varying the  $q_{\text{inv}}$  fit range are below 2% and up to 15% at low and high multiplicities (or  $k_T$ ) bins, respectively. The systematic errors from splitting and merging effects were estimated by using different start points for the fit of the

correlation function, 0.03 and 0.06  $\text{GeV}/c$ . The obtained systematic errors are about 2%–6%. The systematic error connected to the Coulomb function in Eq. (1) was calculated in the following way: at first, the radius of the spherical source was taken equal to 1 fm, then the fitting procedure was repeated using these radii  $\pm 3\sigma_R$  (where  $\sigma_R$  is the total error) as the argument of the Coulomb function. The obtained systematic error is about 2–4%.

The  $m_T$  dependence of  $\lambda$  shown in Fig. 3 demonstrates that  $\lambda$  varies within the range  $\sim 0.3$ – $0.5$  (except the first point at lowest multiplicity and lowest  $k_T$ , which is  $\sim 0.2$ ). As seen in Fig. 3, the  $\lambda$  parameters for  $K^{\text{ch}}K^{\text{ch}}$  are generally smaller than those for  $K_s^0 K_s^0$  [10]. There are several reasons for the  $\lambda$  parameter to be less than the ideal case of unity. Possible causes may be a partially coherent source, a contribution to the observed kaons from decays of long-lived resonances, a deviation from the Gaussian parameterization due to a mixture of sources with different radii (see e.g. [21]), or a particle misidentification. The latter cause influences mostly the  $K^{\text{ch}}K^{\text{ch}}$  sample in the momentum range  $0.4 < p_T < 0.6 \text{ GeV}/c$  (Fig. 1). For the future, it seems desirable to improve the PID and thus increase the purity and improve the description of nonfemtoscopic correlations using different models.

The  $K^{\text{ch}}K^{\text{ch}}$  correlation radii in Fig. 4 show an increase with multiplicity in agreement with the  $\pi\pi$  radii, at 900 GeV [8] and 7 TeV [9], and the  $K_s^0 K_s^0$  radii [10], as was observed for  $\pi\pi$  correlations in heavy-ion collisions [22]. These radii also decrease with increasing  $m_T$  for the large multiplicity bins  $N_{\text{ch}}$  (12–22) and  $N_{\text{ch}} (>22)$ . Such a tendency was found for pions [9] and neutral kaons  $K_s^0 K_s^0$  [10] in  $pp$  collisions and pions in heavy-ion collisions at LHC energies [22]. In the low multiplicity bin  $N_{\text{ch}}$  (1–11) charged kaons show a completely different  $k_T$  dependence of the radii: these radii increase with  $k_T$ . This effect is qualitatively similar to that of pions [9].

It was observed that  $\lambda$  parameters (Fig. 3) are correlated with the radii (Fig. 4). Such a correlation can result from

TABLE I.  $K^{\text{ch}}K^{\text{ch}}$  source parameters vs  $k_T$  for  $\sqrt{s} = 7 \text{ TeV}$   $pp$  collisions. Statistical and systematic errors are listed.

$k_T$ range (GeV/c)	$N_{\text{ch}}$	$dN_{\text{ch}}/d\eta$	$\langle k_T \rangle$ (GeV/c)	$\lambda$	$R_{\text{inv}}$ (fm)
0.20–0.35	1–11	3.2	$0.28 \pm 0.04$	$0.20 \pm 0.04 \pm 0.03$	$0.47 \pm 0.07 \pm 0.12$
0.35–0.50	1–11	3.2	$0.42 \pm 0.05$	$0.31 \pm 0.03 \pm 0.02$	$0.65 \pm 0.05 \pm 0.06$
0.50–0.70	1–11	3.2	$0.59 \pm 0.06$	$0.39 \pm 0.08 \pm 0.03$	$0.91 \pm 0.10 \pm 0.06$
0.07–1.00	1–11	3.2	$0.80 \pm 0.08$	$0.23 \pm 0.10 \pm 0.20$	$0.81 \pm 0.21 \pm 0.24$
0.20–0.35	12–22	8.1	$0.28 \pm 0.04$	$0.51 \pm 0.12 \pm 0.03$	$1.45 \pm 0.15 \pm 0.02$
0.35–0.50	12–22	8.1	$0.42 \pm 0.05$	$0.46 \pm 0.04 \pm 0.04$	$1.18 \pm 0.06 \pm 0.03$
0.50–0.70	12–22	8.1	$0.59 \pm 0.06$	$0.34 \pm 0.07 \pm 0.10$	$1.05 \pm 0.12 \pm 0.14$
0.70–1.00	12–22	8.1	$0.80 \pm 0.08$	$0.21 \pm 0.04 \pm 0.10$	$0.73 \pm 0.07 \pm 0.10$
0.20–0.35	>22	17.2	$0.28 \pm 0.04$	$0.51 \pm 0.08 \pm 0.03$	$1.53 \pm 0.10 \pm 0.02$
0.35–0.50	>22	17.2	$0.42 \pm 0.05$	$0.44 \pm 0.03 \pm 0.04$	$1.44 \pm 0.04 \pm 0.03$
0.50–0.70	>22	17.2	$0.59 \pm 0.06$	$0.30 \pm 0.03 \pm 0.04$	$1.25 \pm 0.06 \pm 0.06$
0.70–1.00	>22	17.2	$0.80 \pm 0.08$	$0.37 \pm 0.05 \pm 0.06$	$1.31 \pm 0.08 \pm 0.08$

the nonperfect fit results if the fit quality depends on  $m_T$ . The reasons for such a dependence are (1) nonideal description of the baseline by PERUGIA-2011, especially at large  $k_T$ , (2) non-Gaussian shape of the source due to resonance contribution, and (3) nonspherical shape of the source. The last two points mean that our one-dimensional Gaussian fit is only an approximate description of the source. In  $pp$  collisions, the effect of this non-Gaussian shape of the correlation function due to different sizes in the  $x$ - $y$ - $z$  directions plays a more important role than in heavy-ion collisions. This requires a detailed three-dimensional analysis, which is foreseen for  $K^{\text{ch}}K^{\text{ch}}$  correlation functions with the new large set of data recorded by the ALICE Collaboration in 2011 and 2012.

The  $m_T$  dependence of the radii in heavy-ion collisions was interpreted as the manifestation of the strong collective hydrodynamic expansion of the created matter [6]. The observed similar behavior in  $pp$  collisions, shown in Fig. 4, has the following specific features: (1) at low multiplicity the radii increase with  $k_T$  and (2) there is no distinct  $m_T$  scaling; the kaon radii seem to be larger than the pion ones. The model calculations performed in [11] can successfully describe the different behavior of pion correlation radii in low and high multiplicity bins, suggesting that the contribution of the hydrodynamic phase is negligible in low-multiplicity events, while for events with high multiplicity, it is substantial.

As shown in [23], due to the small size of the created system in  $pp$  collisions, the flow of resonances may play a significant role in large multiplicity bins, where essential hydrodynamic collective flow is expected [11]. According to simple chemical model calculations [10], the influence of this flow should be relatively smaller for kaons than for pions, leading to the effect that the kaon radii can be larger than the pion ones. The measured  $K^{\text{ch}}K^{\text{ch}}$  correlation radii displayed in Fig. 4 support such an hypothesis; however, a detailed theoretical study is needed.

## V. SUMMARY

The ALICE Collaboration has measured charged kaon correlation functions in  $pp$  collisions at  $\sqrt{s} = 7$  TeV at the LHC. In agreement with the previous measurements in  $pp$  and heavy-ion collisions at lower energies, the extracted correlation radii  $R_{\text{inv}}$  increase with the event multiplicity and decrease with the pair transverse mass/momentum. The novel features are some hints to the increase of the radii with  $m_T$  in the low-multiplicity bin and to the fact that kaon radii are larger than pion ones. These peculiarities deserve further experimental and theoretical studies.

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