Conference Paper

Femtoscopy with ALICE at the LHC

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Abstract

Femtoscopy allows one to measure the space-time characteristics of particle production using correlations resulting from the effects of quantum statistics and final state interactions. We present the results of femtoscopic analyses for different two-particle systems measured by ALICE in Pb-Pb, p-Pb and pp collisions, pointing out the similarities and differences between small and large systems. Results for kaons provide a cross-check of the information about the dynamics of the source and the importance of the hadronic rescattering phase. The recent femtoscopic results for baryon-(anti-)baryon pairs and kaon pairs allow one to study the strong interaction parameters and cross-sections.

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1. Introduction

The main objective of ALICE [1] is to study the state of matter created at extremely high energy densities achieved in heavy-ion collisions at the Large Hadron Collider (LHC) with possible formation of the quark-gluon plasma (QGP), a state characterized by partonic degrees of freedom [2]. The highly compressed strongly-interacting system undergoes longitudinal and transverse expansions. Experimentally, the spatial extent at decoupling and expansion characteristics can be measured via Bose-Einstein correlations. The Bose–Einstein enhancement of the production of two identical pions at low relative momenta was first observed in $\bar{p}$p collisions about 50 years ago [3]. Since that time the correlation method using correlations resulting from the effects of quantum statistics and final state interactions has been developed and now it is known as "correlation femtoscopy". The method was successfully applied to the measurement of the space–time characteristics of particle production (see, e.g., [4, 5] and references therein). The source radii extracted from these correlations describe the system at kinetic freeze-out, i.e. at the last stage of particle interactions.

ALICE has excellent capabilities to study femtoscopy observables due to good track-by-track particle identification (PID), particle acceptance down to low transverse momenta p_T, and good resolution of secondary vertices [1]. ALICE performed a number of different femtoscopic analysis. We will consider here only traditional quantum-statistical femtoscopy correlations with long-lived particles: pions, kaons and protons for different collision system such as Pb-Pb, pp and p-Pb.

2. Results

The measurements of the radii from pion femtoscopic correlations in Pb–Pb collisions at 2.76 TeV performed by ALICE collaboration [6, 7] demonstrated that the homogeneity volume at the LHC is two times larger than at RHIC; the decoupling time measured using longitudinal femtoscopic radii is $\sim$ 40% larger than at RHIC. Pion femtoscopy showed genuine effects of collective flow in heavy-ion collisions manifesting in decrease of the source radii with increasing pair transverse mass $m_T = \sqrt{k_T^2 + m^2}$ [10], where $k_T = |\mathbf{p}_{T,1} + \mathbf{p}_{T,2}|/2$ is the average transverse momentum of the corresponding pair and m is the particle mass. The linear scaling of radii with cubic root of final state multiplicity predicted by hydrodynamic model [8] was observed [7].

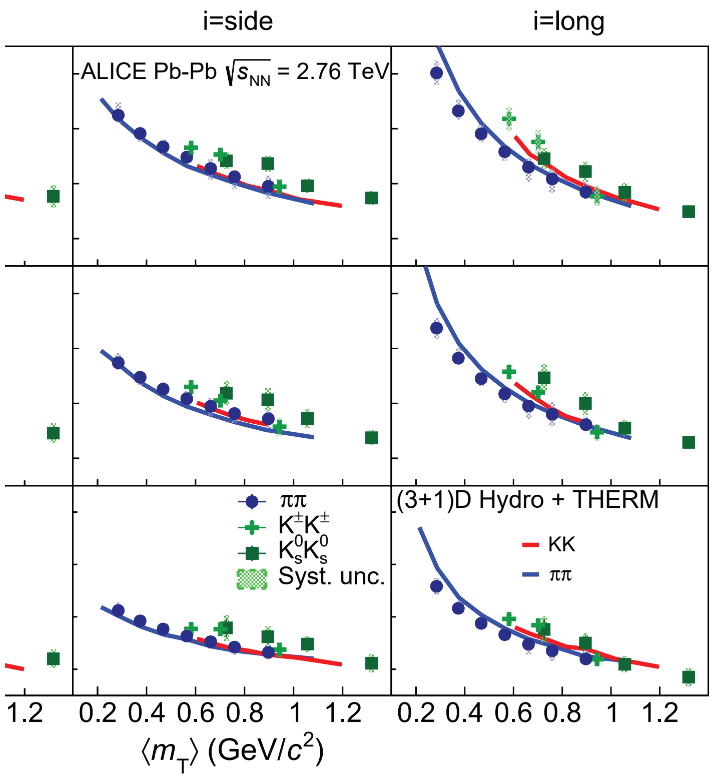

Figure 1: The 3D LCMS radii vs. m_T for charged (light green crosses) and neutral (dark green squares) kaons and pions [7] (blue circles) in comparison with the theoretical predictions of the (3+1)D Hydro + THERMINATOR-2 model [8] for pions (blue solid lines) and kaons (red solid lines) (from [13]).

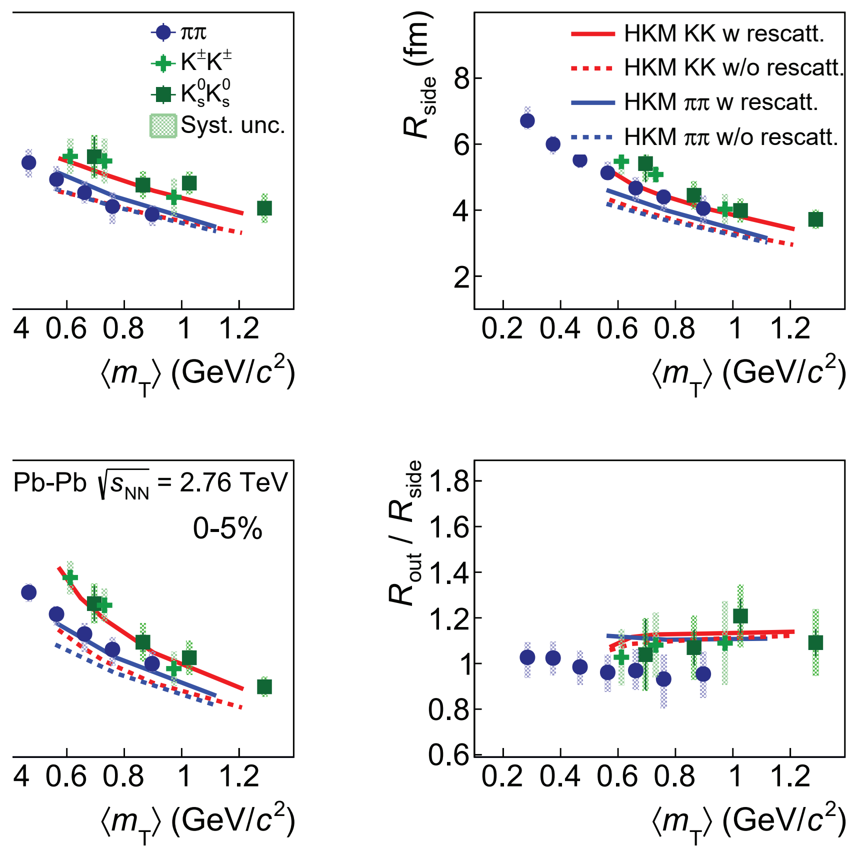

Figure 2: The 3D LCMS radii vs. m_T for 0–5% most central collisions in comparison with the theoretical predictions of HKM [11] for pions (blue lines) and kaons (red lines) (from [13]).

If the hydrodynamic scenario of heavy ion collisions is correct all particle species should participate in the same collective behavior. ALICE published the study of one-dimensional correlation radii of different particle species: $\pi^\pm\pi^\pm$,$K^\pm K^\pm$,$K^0_S K^0_S$, pp, and $\overline{pp}$ correlations in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV for several intervals of centrality and transverse mass [9]. The decrease of the source radii with increasing transverse mass was observed for all types of particles, manifesting a fingerprint of collective flow in heavy-ion collisions. The one-dimensional femtoscopic radii demonstrated the approximate m_T-scaling as it was expected by hydrodynamic model considerations [10].

The most abundant particle species after pions are kaons. ALICE has recently performed 3D analysis of kaon femtoscopy [13]. The comparisons of measured three-dimensional radii with (3+1)D Hydro + THERMINATOR-2 model calculations [8, 11] (Fig. 1), and those where the hydrodynamic phase is followed by the hadronic rescattering phase [11] (Fig. 2) have shown that pion femtoscopic radii are well reproduced by both approaches while the behavior of the three-dimensional kaon radii can be described only if the hadronic rescattering phase is present in the model. The m_T scaling

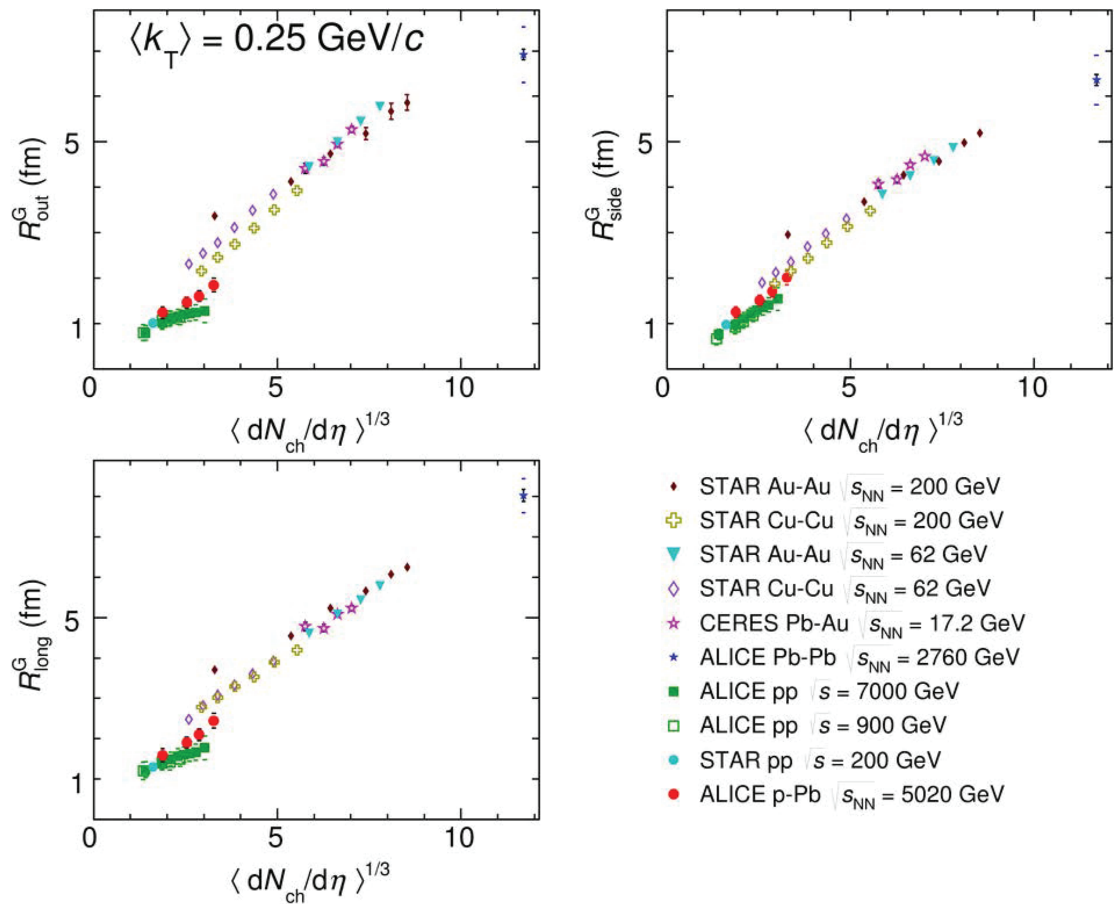

Figure 3: Comparison of femtoscopic radii (Gaussian), as a function of the charged-particle multiplicity density, measured for various collision systems and energies by CERES, STAR, PHENIX, and ALICE (from [14]).

expected by pure hydro-dynamical models appears to be broken in our data. The scaling of pion and kaon radii with k_T was observed instead. The extracted emission time for pions is smaller than the one for kaons, which can be explained by the different influence of resonances on pions and kaons production during the rescattering phase where kaon rescattering can proceed through the K^*(892) resonance (with lifetime of 4–5 fm/c) [12].

The system created in ultrarelativistic pp and p-Pb collisions at LHC energies might be similar to the system created in non-central heavy-ion collisions. The question arises if the size differences are significant or just multiplicities are important. The ALICE collaboration has already studied pion correlations in pp and p–Pb collisions via three-pion cumulant analyses [14] at $\sqrt{s_{\rm NN}} = 2.76$ TeV and in three-dimensional analysis at 5.02 TeV [15]. The p-Pb radii measured at similar multiplicities are 10–20% higher than those observed in pp collisions but below those observed in A–A collisions. The results disfavor models which incorporate substantially stronger collective expansion in p–Pb collisions as compared to pp collisions at similar multiplicity [16].

It was demonstrated that the three-dimensional femtoscopic radii scale roughly with the cube root of the charged-particle multiplicity density for all collision energies and initial system types, but the slope parameters for pp and A-A systems are significantly different (Fig. 3).

3. Conclusion

Femtoscopy allows measurements of space-temporal sizes of the systems created in different types of collisions. It provides an independent information about collectivity, in particularly through study of m_T (k_T) dependences of radii for different particle types. Femtoscopy provides strong constraints on the physical assumptions used in the models to describe the dynamics of different collisions.

References

[1] K. Aamodt *et al.* [ALICE Collaboration], JINST **3**, S08002 (2008).

[2] N. Cabibbo, G. Parisi, Phys. Lett. B**59**, 67 (1975) 67; E. V. Shuryak, Phys. Rept. **61** (1980) 71

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

[4] M.I. Podgoretsky, Fiz. Elem. Chast. Atom. Yad. **20**, 628 (1989) [Sov. J. Part. Nucl. **20**, 266 (1989)]

[5] R. Lednicky, Phys. of Atomic Nuclei **67**, 71 (2004) [arXiv:0903.1296 [nucl-ex]]

[6] K. Aamodt, *et al.* [ALICE Collaboration], Phys. Lett. B **696** 328 (2011)

[7] J. Adam, *et al.* [ALICE Collaboration], Phys. Rev. C **93** 2, 024905 (2016)

[8] A. Kisiel, M. Galazyn, P. Bozek, Phys. Rev. C **90** 064914 (2014)

[9] J. Adam *et al.* [ALICE Collaboration], Phys. Rev. C **92** (2015) 5, 054908, [arXiv:1506.07884 [nucl-ex]]

[10] S. Pratt, Phys. Rep. Lett. **53** 1219 (1984); M. Lisa, S. Pratt, R. Soltz, U. Wiedemann, Ann. Rev. Nucl. Part. Sci. **55**, 357 (2005)

[11] V.M. Shapoval, P. Braun-Munzinger, Iu.A. Karpenko, Yu.M. Sinyukov, Nucl. Phys. A **929** 1 (2014)

[12] Y. M. Sinyukov, V. M. Shapoval and V. Y. Naboka, Nucl. Phys. A **946**, 227 (2016)

[13] S. Acharya *et al.* [ALICE Collaboration], arXiv:1709.01731 [nucl-ex].

[14] B. B. Abelev *et al.* [ALICE Collaboration], Phys. Lett. B **739**, 139 (2014)

[15] J. Adam *et al.* [ALICE Collaboration], Phys. Rev. C **91**, 034906 (2015)

[16] P. Bozek and W. Broniowski, Phys. Lett. B **720**, 250 (2013)