OVERVIEW OF ALICE RESULTS IN FEMTOSCOPY*

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In this report, results of femtoscopic analyses with $\pi^{\pm}\pi^{\pm}$, $K^0_{\rm S}K^0_{\rm S}$, $K^{\pm}K^{\pm}$, pp, $\bar{p}\bar{p}$, $p\bar{p}$, $\bar{p}\Lambda$ and $p\bar{\Lambda}$ in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV registered by ALICE at the LHC are presented and compared with results from pp collisions at $\sqrt{s} = 7$ TeV, where available. Results from heavy-ion collisions are compatible with the hydrodynamic prediction of the scaling of the π, K and p emission source sizes with the transverse mass. We also show that the femtoscopic radii scale linearly with the cube root of charged particle density. The scaling parameters in Pb–Pb and pp collisions are clearly different which indicates that the initial state influences the size at freeze-out. Moreover, baryon–antibaryon correlations are investigated in the context of smaller baryon yields measured in ALICE compared to the predictions of thermal models. New possible applications of femtoscopy are introduced, namely the measurements of poorly known interaction potentials (*e.g.* $p\bar{\Lambda}$).

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1. Introduction

Femtoscopic techniques enable the measurement of the size of the source created in heavy-ion collisions via two-particle correlations at low relative momenta [1]. Evolution of the matter created in such collisions is successfully described by hydrodynamic models [2]. In particular, it is predicted that the size of the emitting region for particles with different masses decreases with increasing pair transverse mass [3].

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The ALICE Collaboration reported that p/π^+ ratio cannot be reproduced by thermal models simultaneously (at the same freeze-out temperature) with other hadron production rates [4]. Baryon annihilation in the rescattering phase was suggested as its possible explanation [5]. Baryon–antibaryon correlation functions should reflect the contribution from strong Final State Interactions (FSI) responsible for annihilation.

2. Data analysis

In the analysis, about 30 million Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV recorded by ALICE [6] were used. Centrality of the events was determined using the forward scintillator hodoscopes (VZERO detectors), which were also used for the triggering. Selected events occurred within 8 cm of the nominal interaction point in the beam direction. Tracks were reconstructed from at least 80 points (out of maximum 159) measured in the Time Projection Chamber (TPC), the χ^2 per point was required to be less than 4. Identification of charged particles was based on the specific ionization energy loss in the TPC and the information from the Time-of-Flight detector (TOF) in combination with the momentum of particle deduced from the curvature of its trajectory in magnetic field supplied by the ALICE magnet. K^0_{S}, Λ and $\bar{\Lambda}$ particles were reconstructed using their decay topology from a combination of daughter tracks measured in the TPC and TOF. Particles within the pseudorapidity range $|\eta| < 0.8$ were accepted, which corresponds to the region of uniform acceptance of the TPC. Selections based on the distance of closest approach to the primary vertex were used to reduce the contamination from secondary particles.

Particles from the same event were grouped into pairs to form the distribution of relative momentum. To obtain the correlation function, the signal was divided by the background created as the distribution of relative momentum of pairs composed of particles from different events. Pair selection accounting for track splitting (one particle falsely reconstructed as two tracks) and merging (two particles mistakenly taken as one track) was applied. It was based on the ratio of detector signals (clusters) shared by two tracks to all clusters and the angular distance between two tracks inside the TPC. In the pion analysis, the relative momentum was calculated in Longitudinally Co-Moving System (LCMS) [7] and decomposed into *out* (along the pair transverse momentum), *long* (along the beam axis) and *side* (perpendicular to the others) directions. For other pair types, relative momentum was calculated in one dimension in the Pair Rest Frame (PRF).

3. Results

Correlations of identical pions were fitted with the Bowler–Sinyukov formula [8] to obtain femtoscopic radii. As one can see, in the left panel of Fig. 1 radii in *out*, *side* and *long* directions decrease with pair transverse momentum ($k_{\rm T} = \frac{1}{2}|\vec{p}_{{\rm T},1} + \vec{p}_{{\rm T},2}|$). This is consistent with the "homogeneity length" mechanism present in hydrodynamic models [9]. Furthermore, radii increase with decreasing event centrality which reflects the fact that the larger the initial size of the system (corresponding to larger number of produced particles) the larger the size of the system at freeze-out. In the middle and right panels of Fig. 1, the pion radii from Pb–Pb collisions at ALICE are compared with data from other heavy-ion experiments and *pp* collisions. Looking at the global trend for heavy-ion data, it can be noticed that the scaling with the cube root of charged particle density is fulfilled for $R_{\rm long}$ and $R_{\rm side}$ (within large statistical uncertainty). On the other hand, a clear deviation from linear scaling of $R_{\rm out}$ measured by ALICE is observed. However, this was predicted as a consequence of the modification of the freeze-out shape in a hydrodynamic model [10]. In the middle and right

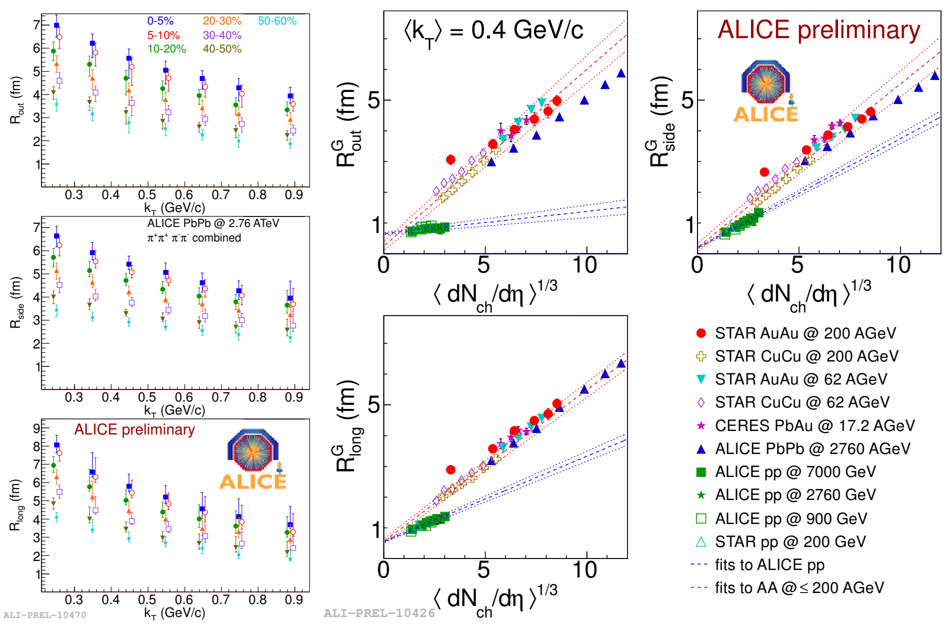

Fig. 1. Left panel: Femtoscopic radii for Pb–Pb collisions in 7 centrality and 7 $k_{\rm T}$ bins, in *out*, *side* and *long* directions from top to bottom. Middle and right panel: comparison of femtoscopic radii in *pp* and heavy-ion collisions as a function of cube root of charged particle density.

panels of Fig. 1, one can also observe that pion radii from pp collisions scale linearly with $\langle \frac{dN_{\rm ch}}{d\eta} \rangle^{1/3}$, but the scaling parameters are distinctly different than in heavy-ion data. For the same event multiplicity, the radii in pp collisions are evidently smaller than the ones in heavy-ion collisions which indicates that the system with smaller initial size leads to smaller size at the final-state.

To obtain the femtoscopic radii from $K^0_{\rm S}K^0_{\rm S}$ correlations, a parametrization including Bose–Einstein statistics and strong interactions was applied [11]. In the case of charged kaons, we used the Bowler–Sinyukov formula. Results extracted from $K^0_{\rm S}K^0_{\rm S}$ and $K^{\pm}K^{\pm}$ are consistent with each other and, therefore, combined in Fig. 2. Radii clearly increase with event multiplicity and decrease with pair transverse momentum in agreement with the collectivity in hydrodynamics models.

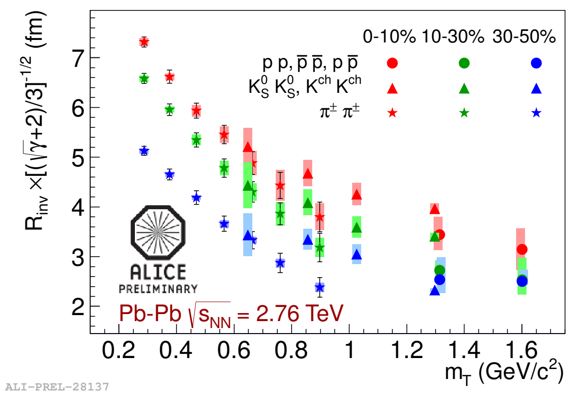

Fig. 2. $m_{\rm T}$ dependence of the radius parameter scaled by kinematic factor extracted from correlations of pions, charged kaons, neutral kaons and protons.

In femtoscopy, the following equation is used [12]

$$C(k^*) = \int S(k^*, r^*) \Psi(k^*, r^*) d^4 r^* \,, \tag{1}$$

where k^* is pair relative momentum, r^* is pair relative separation, C is the measured correlation, S is the source function, and Ψ is the pair wave function containing information about the interaction. In general, we do know the two-particle interaction. We measure the correlation to extract the information about the source function (*e.g.* width of the source distribution assuming the Gaussian shape). For instance, Ψ for $\bar{p}\bar{p}$ system (presented in Fig. 3) includes contributions from Fermi–Dirac statistics, Coulomb repulsion (both producing anti-correlation) and strong FSI (resulting in distinctive peak for $k^* \approx 20$ MeV$/c$ whose height is related to the femtoscopic

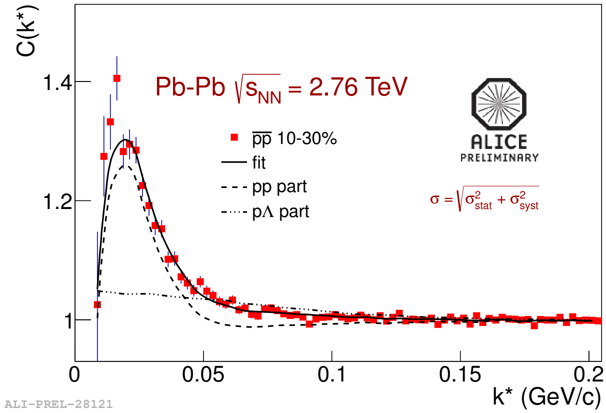

Fig. 3. The example of the fit to the $\bar{p}\bar{p}$ correlation function, taking into account contribution from residual correlations (see the text for details).

radius). For $p\bar{p}$ (left panel of Fig. 4), correlations arise due to the Coulomb attraction (maximum for the lowest values of k^*) and annihilation from the strong FSI (observed as wide negative correlation). The fact that we need both effects to describe the shape of the correlation function is compatible with the baryon annihilation in the final state. Radii from femtoscopy are extracted using Eq. (1) and taking into account residual correlations. They are the result of correlating primary particles with those from weak decays (correlation with parent particle feeds down into daughter correlation function). As it can be seen in Fig. 2, proton radii are in agreement with $m_{\rm T}$ scaling $\left(m_{\rm T} = \sqrt{k_{\rm T}^2 + m^2}\right)$ for particles with different masses which is consistent with collectivity in the system created in heavy-ion collision.

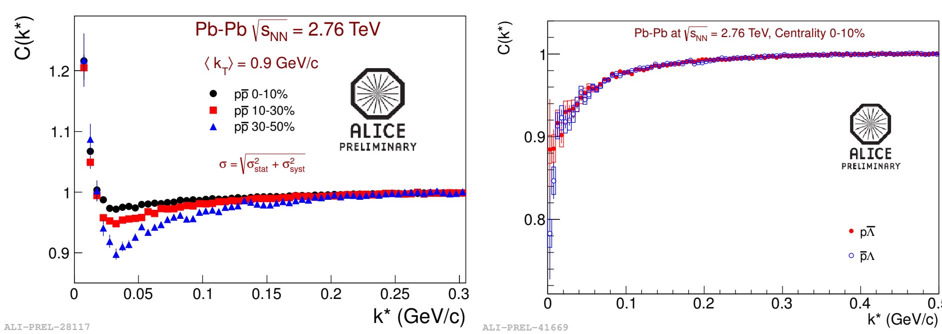

Fig. 4. $p\bar{p}$ (left panel) and $p\bar{\Lambda}$, $\bar{p}\Lambda$ (right panel) correlation functions from the Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV.

Femtoscopic measurements may also be useful in the determination of poorly known interaction potentials. Following Eq. (1), if we measure $p\bar{\Lambda}$ correlations and use the radius obtained from proton correlations (assuming the sizes of $\bar{\Lambda}$ and p sources are comparable), one should be able to extract some information about $p\bar{\Lambda}$ interaction characteristics. In the right panel of Fig. 4, $p\bar{\Lambda}$ and $\bar{p}\Lambda$ correlation functions are shown. We observe a broad negative correlation which can be explained by the existence of the annihilation in the strong FSI for these pairs. Hence, annihilation may affect all baryon yields. Interaction potentials for different baryon–antibaryon combinations possibly extracted from femtoscopy might thus be useful in modelling the phase of hadronic rescatterings.

4. Summary

We presented results of femtoscopic radii of π, K and p sources measured in heavy-ion collisions, which exhibit approximate $m_{\rm T}$ scaling, in agreement with hydrodynamic predictions. It was also reported that pion radii scale linearly with cube root of charged particle density, both in Pb–Pb and pp collisions, however, different scaling parameters suggest that the initial state plays a key role while determining femtoscopic radii. Noticeable anticorrelations observed in baryon–antibaryon correlations are consistent with strong FSI annihilation which may cause the decrease of baryon yields at LHC energies.

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