

OVERVIEW OF BARYON FEMTOSCOPY IN THE ALICE EXPERIMENT*

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The Large Hadron Collider has provided collisions of Pb ions at $\sqrt{s_{NN}} = 2.76$ TeV. At these energies, a significant number of baryons are produced per event, enabling the study of two-baryon correlations. The matter produced in these collisions is described in the frame of hydrodynamics, which predicts a decrease of the apparent source size with transverse mass of the particle. The femtoscopic analysis for baryons, presented here, enables to test this prediction at masses much higher than pions. Baryon yields reported by ALICE are below expectations from thermal models. Annihilation in final-state baryon rescattering has been proposed as an explanation. Such processes should also be reflected in baryon–antibaryon correlations, which are presented here.

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1. Introduction

The CERN Large Hadron Collider (LHC), has produced Pb–Pb collision at the center-of-mass energy 2.76 TeV per nucleon. About 60 million of such events have been registered by A Large Ion Collider Experiment (ALICE) in November and December of 2010 and 2011. The matter created in such collision is expected to undergo a rapid collective expansion, which results in the development of radial and elliptic flow [1]. These phenomena are successfully modeled by hydrodynamics [2], which also predicts that the apparent source size of the emitting region will decrease with increasing transverse mass $m_T = \sqrt{k_T + m^2}$ of the pair [3], where $k_T = \frac{1}{2}|p_{T,1} + p_{T,2}|$ is

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the transverse momentum of the pair. An important feature of this prediction is that scaling should persist for particles of different mass. ALICE has measured the size of the source via the femtoscopy technique for pions [4]. In this work, we present similar preliminary study for protons, which tests the scaling at m_T up to three times higher than the one achieved for pions.

Baryon yields have been measured in ALICE to be significantly below expectations from the thermal model at freeze-out temperature of 165 MeV, which is the temperature describing the yields at lower energies and the yields of pions and kaons at the LHC energies [5]. Some models attribute this decrease to baryon annihilation via final-state rescattering [6]. Strong interaction responsible for these inelastic processes is reflected in the baryon–antibaryon pair wave function [7] as a non-zero imaginary part of the scattering length. It contributes to the two-baryon femtoscopic correlation function and produces a wide anti-correlation, up to a few hundred MeV in pair relative momentum k^* . We show measurements of such functions for proton–antiproton as well as proton–antilambda pairs.

2. Experimental description

About 60 million Pb–Pb collisions recorded by ALICE [8] have been used. Centrality has been determined from the response of the VZERO hodoscope, whose two parts are located at $-3.7 < \eta < -1.7$ and $2.8 < \eta < 5.1$. Events from the range of 0–50% of the total hadronic cross-section have been used, divided into three ranges: 0–10%, 10–30% and 30–50%. Only events which occurred within 10 cm of the nominal interaction point were accepted. Tracks of particles have been reconstructed from space-time points provided by the Inner Tracking System (ITS) silicon detector (consisting of 2 layers each of pixel, drift and strip detectors), the Time Projection Chamber (TPC) gas-filled detector and the Time-Of-Flight (TOF) detector. Identification was possible thanks to the energy loss information from the TPC as well as time-of-flight information from TOF, together with the measurement of particle’s momenta from the curvature in uniform magnetic field of 0.5 T provided by the ALICE Magnet. Distance of Closest Approach (DCA) of the track to the primary vertex was required to be smaller than 0.1 cm in transverse plane and 2.0 cm in longitudinal direction, to suppress secondary particles. Standard reconstruction quality requirements were also applied. V_0 particles were reconstructed via their V_0 decay topology from non-primary pions and protons, using additional quality criteria for V_0 particles, such as \cos of the pointing angle [9].

Good tracks were combined into pairs and stored in the histogram as a function of the momentum of the first particle k^* in the Pair Rest Frame (PRF). Pair of particles coming from the same event formed the signal A . When two particles come from two different events, they are not correlated

and form the background B . The correlation function is then constructed as $C = A/B$. With this procedure, the effects of single-particle acceptance, present both in A and B , are divided out. The analysis is performed separately for pairs with k_T in range (0.3,1.0) and (1.0,3.0) GeV/ c .

The experimental correlation function is then fitted with a formula that is derived from the Koonin–Pratt equation

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

where S is the source function describing the source shape and size and Ψ is the pair wave function containing all information about the two-particle interaction. S in our case is a Gaussian in Pair Rest Frame, and is characterized by its width R_{inv} , known as the femtoscopic radius. Ψ for identical proton pairs contains contributions from the wave-function (anti-)symmetrization, as well as Coulomb and Final-State Interaction (FSI). For proton–antiproton pairs only the FSI are relevant, while for proton– Λ pairs only the Strong interaction occurs. In all cases, the formula from Eq. (1) is integrated numerically or analytically and fitted to the experimental correlation function to find the R_{inv} value which provides the best description. In addition, some of the pairs contain a particle that comes from a weak decay. In such case, the original parent particle is correlated, and this correlation feeds down into the correlation function for the daughter particle, but smeared by the decay kinematics. This contribution is known as “residual correlation” and is an important factor in our fits.

3. Results

In Fig. 1, an example of the antiproton–antiproton correlation function is shown. The system at the LHC has practically zero net baryon density, so p – p and \bar{p} – \bar{p} correlations are expected to be the same. The function is fitted with theoretical formula, which includes the pure proton–proton interaction as well as residual correlation from the p – Λ pairs. The former has a positive (larger than unity) peak at 20 MeV and becomes negative (meaning correlation below unity) for larger k^* , due to the Coulomb repulsion. The former is positive, the sum of both contributions is needed to describe the observed correlation. Equivalent procedure is repeated for three centrality ranges, two pair momentum k_T ranges and three pair types (p – p , p – \bar{p} , \bar{p} – \bar{p}). The resulting radii are shown in Fig. 2, for combinations of pair types and k_T for which the analysis is ready. The analysis for other combinations is in progress. A tendency of the radii to grow with decreasing k_T and decreasing centrality (increasing event multiplicity) can be seen, after taking into account the fact that the presented systematic uncertainties are correlated

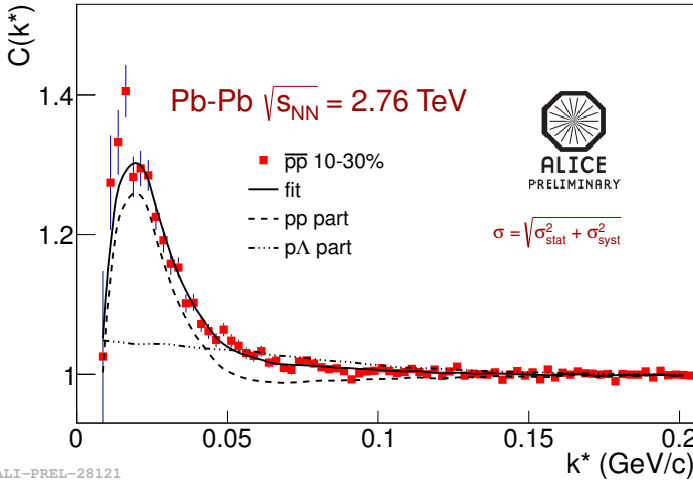


Fig. 1. Correlation function for antiproton pairs. Lines represent the results of the numerical fit: dashed is the pure proton–proton component, dash-dotted is the residual correlation from proton– A , full line is the combination of the two.

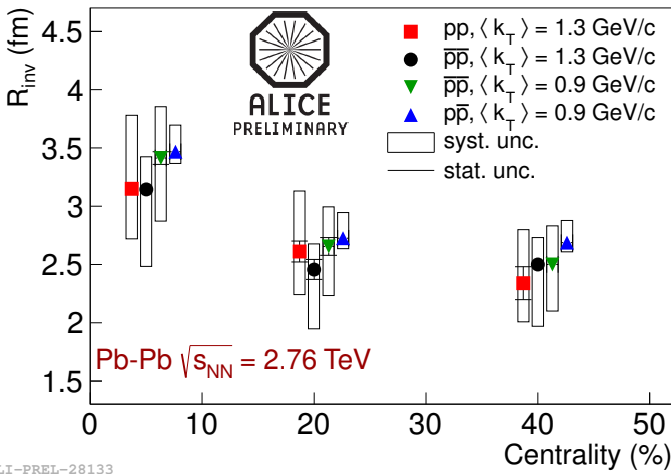


Fig. 2. Femtoscopic radii for three pair types, three centrality ranges and two pair momentum ranges.

point-to-point. Both effects are in qualitative agreement with hydrodynamic predictions, although no quantitative calculation for protons is available at the moment. Radii are significantly smaller than for pions at lower transverse mass, consistent with the m_T scaling common for particles of different mass.

For the $p\text{-}\bar{p}$ system, Ψ includes the contribution from the annihilation from the Strong FSI. This contribution is essential to correctly describe the correlation function shape. This confirms that we observe final state baryon annihilation in Pb–Pb collisions.

In Fig. 3, we show the preliminary correlation functions for the proton– $\bar{\Lambda}$ and proton–antiproton. The latter is a baryon–antibaryon pair, the strong annihilation signal in this case is expected and observed. The former is a baryon–antibaryon pair, but not a particle–antiparticle pair. Strong interaction for such systems is not known, or known with very large uncertainties [10]. The example shown exhibits a very broad negative correlation, up to a few hundred MeV wide in k^* . Such a structure can only be explained by the existence of the Strong FSI annihilation for such pair types. Therefore, final state baryon annihilation is not limited to particle–antiparticle pairs. This underlines the importance of measuring such correlations and extracting the interaction potentials for as many baryon–antibaryon pairs as possible. These potentials can then be used to calculate the interaction cross-section, an become an input to rescattering codes. With this additional information, new improved calculation of baryon yields will be possible.

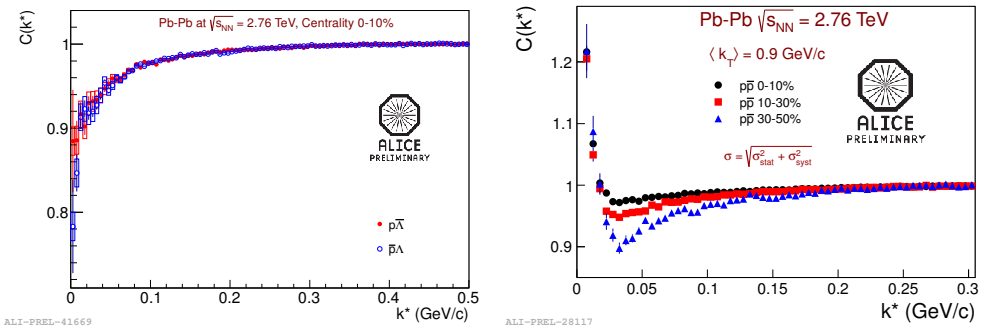


Fig. 3. Example correlation function for the proton– $\bar{\Lambda}$ systems (left panel) and proton–antiproton system (right panel)

4. Summary

We have shown results of two-particle correlations for pairs consisting of protons, Λ s and their antiparticles. Femtoscopic radii have been extracted for protons, and are found to be qualitatively consistent with expectations for a collectively expanding system predicted by hydrodynamics. Significant negative correlation is observed for various baryon–antibaryon pairs, which is consistent with annihilation in the Strong FSI. Such processes may lead to a decrease of baryon yields at the LHC energies, although quantitative estimation requires a realistic calculation with a model including final-state rescattering.

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