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Femtoscopy in $\sqrt{s_{NN}} = 5.02$ TeV p+Pb collisions with ATLAS

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Abstract

Bose-Einstein correlations between identified charged pions are measured for p+Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV with the ATLAS detector using a total integrated luminosity of 28 nb^{-1}. Pions are identified using ionisation energy loss measured in the pixel silicon detector. Two-particle correlation functions and the extracted source radii are presented as a function of collision centrality as well as average transverse pair momentum (k_T), rapidity ($y^\star_{\pi\pi}$), and azimuthal angle with respect to the second-order event plane. Pairs are selected with a rapidity $-2 < y^\star_{\pi\pi} < 1$ and with an average transverse momentum $0.1 < k_T < 0.8$ GeV. The effect on the two-particle correlation function from jet fragmentation is studied, and a new method for constraining its contributions to the measured correlations is described. The measured source sizes are substantially larger in more central collisions and are observed to decrease with increasing pair k_T. A correlation with the local single-particle multiplicity $dN_{ch}/dy^\star$ is demonstrated. The cross term R_{ol}, which couples radial and longitudinal expansion, is measured as a function of rapidity, and a departure from zero is observed with 5.1σ combined significance for $y^\star_{\pi\pi} > -1$ in the most central events. The azimuthal modulation of the radii in central events is observed to be consistent with that predicted by hydrodynamics and observed in A+A collisions.

Keywords: Femtoscopy, HBT, flow in small systems

1. Introduction

Multi-particle correlations in proton-lead (p+Pb) [1, 2, 3] and proton-proton (p+p) [4] collisions exhibit long-range azimuthal correlations similar to those observed in lead-lead (Pb+Pb) collisions, in which they are attributed to collective expansion of the quark-gluon plasma. Hydrodynamic models can describe the observed correlations in p+Pb [5, 6, 7], but the extent to which they are appropriate in "small" systems remains an open question.

Bose-Einstein correlations between charged pion pairs can be used to measure the spacetime extent of particle production with a technique called femtoscopy (see Reference [8] and references therein). The k_T and ϕ_k dependence of the measured Hanbury Brown and Twiss (HBT) radii, which are interpreted as the size of the particle-emitting region at freezeout, can be used to address the questions raised by angular correlation results. While femtoscopic methods have already been applied to p+Pb systems at the LHC [9, 10], the results presented here are obtained using a new data-driven technique to constrain the significant background contribution from jet fragmentation, and they provide the first measurements of the dependence of these source radii on the rapidity $y^\star_{\pi\pi}$ [11]. They also provide the first measurements in p+Pb systems

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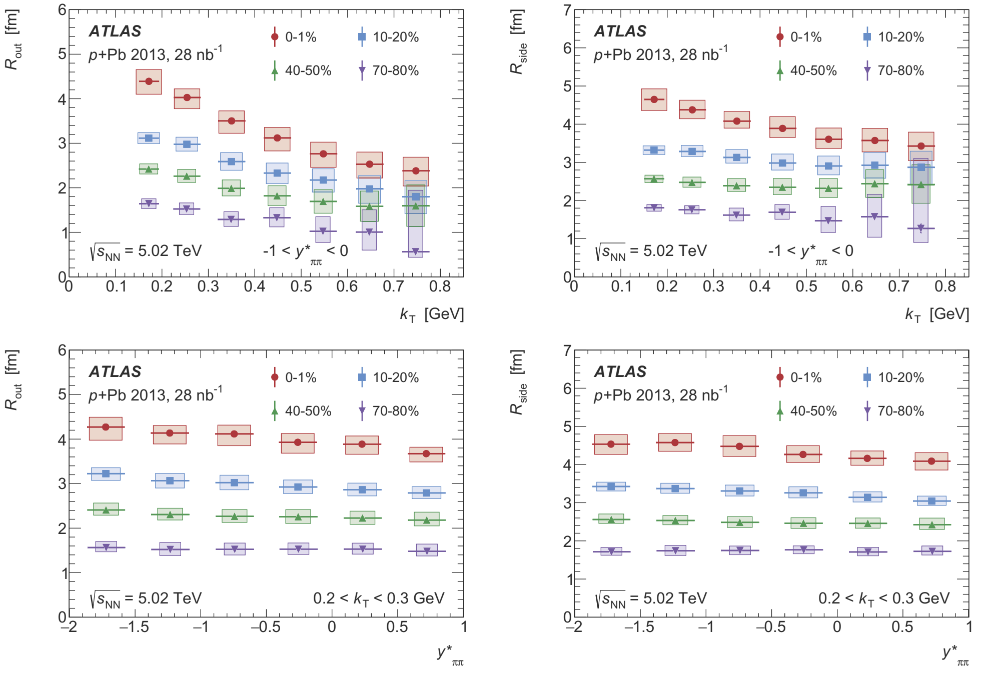

Figure 1. Three-dimensional transverse HBT radii R_{out} and R_{side} as a function of the average transverse momentum k_{T} (top) and rapidity $y^{\star}_{\pi\pi}$ (bottom) of pion pairs [11]. The widths of the boxes vary between centrality intervals only for visual clarity.

of the modulation of the source as a function of the azimuthal angle ϕ_k with respect to the second-order event plane Ψ_2 [12]. This modulation has been observed in A+A collisions [13, 14, 15], where the in-plane reduction and out-of-plane extension of the source is understood to be a consequence of hydrodynamic evolution.

2. Experimental Analysis

The data used in this analysis were collected by the ATLAS detector [16] during the 2013 p+Pb run at the Large Hadron Collider (LHC) with a nucleon-nucleon centre-of-momentum energy of $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV. Charged particles are reconstructed with the inner detector, which consists of a silicon pixel detector, a semiconductor tracker made of double-sided silicon microstrips, and a transition radiation tracker made of straw tubes. All three subdetectors are composed of a barrel and two symmetrically placed end-cap sections. Pions are identified using measurements of the charge deposited in layers of the pixel detector. The forward calorimeters, located in a pseudorapidity range of $3.1 < |\eta| < 4.9$, are used to estimate the centrality of each collision [16].

The two-particle correlation functions are fit to functions of the form [11]

$$C_{\mathbf{k}}(\mathbf{q}) = \left[(1-\lambda) + \lambda K(\mathbf{q}) C_{\mathrm{BE}}(\mathbf{q})\right] \Omega(\mathbf{q}) \,, \tag{1}$$

where K is a correction factor for final-state Coulomb interactions and Ω represents non-femtoscopic background, which arises due to jet fragmentation. The Bose-Einstein part of the three-dimensional correlation functions are taken to be of an exponential form

$$C_{\mathrm{BE}}(\mathbf{q}) = 1 + e^{-\|R\mathbf{q}\|} \,, \tag{2}$$