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Measurement of jet fragmentation in 5.02 TeV proton–lead and proton–proton collisions with the ATLAS detector

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Abstract

A measurement of the fragmentation functions of jets into charged particles in $p+\mathrm{Pb}$ collisions and pp collisions is presented. The analysis utilizes 28 nb^{-1} of $p+\mathrm{Pb}$ data and 26 pb^{-1} of pp data, both at $\sqrt{s_{\mathrm{NN}}}=5.02$ TeV, collected in 2013 and 2015, respectively, with the ATLAS detector at the LHC. The measurement is reported in the centre-of-mass frame of the nucleon–nucleon system for jets in the rapidity range $|y^*|<1.6$ and with transverse momentum $45<p_{\mathrm{T}}<260$ GeV. Results are presented both as a function of the charged-particle transverse momentum and as a function of the longitudinal momentum fraction of the particle with respect to the jet. The pp fragmentation functions are compared with results from Monte Carlo event generators and two theoretical models. The ratios of the $p+\mathrm{Pb}$ to pp fragmentation functions are found to be consistent with unity.
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Keywords: Relativistic heavy-ion collisions; Jets; Fragmentation into hadrons

1. Introduction

Heavy-ion collisions at the Large Hadron Collider (LHC) are performed in order to produce and study the quark–gluon plasma (QGP), a phase of strongly interacting matter which emerges at very high energy densities; a recent review can be found in Ref. [1]. Measurements of jets and jet properties in heavy-ion collisions are sensitive to the properties of the QGP. In order to quantify jet modifications in heavy-ion collisions, proton–proton (pp) collisions are often used as a

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reference system. Using this reference, rates of jet production in Pb + Pb collisions are observed to be reduced compared to that expected from the rates in pp collisions, appropriately scaled to account for the nuclear thickness in Pb + Pb collisions [2,3]. Charged-particle fragmentation functions are also observed to be modified in Pb + Pb collisions compared to pp collisions [4–6]. Both of these effects are interpreted as arising predominantly from the modification of the parton showering process in the final stages of the collision.

In addition to final-state differences emerging from the presence of the hot and dense matter, jet production in Pb + Pb collisions may also differ from that in pp collisions due to effects arising from the presence of the large nucleus. For example, nucleons bound in a nucleus are expected to have a modified structure compared to the free nucleon [7], and partons may lose energy in the nuclear environment before scattering [8]. Proton–nucleus collisions are used to differentiate between initial- and final-state effects in Pb + Pb collisions. The inclusive jet production rate in proton–lead (p + Pb) collisions at 5.02 TeV was measured [9–11] at the LHC and found to be only slightly modified after normalization by the nuclear thickness function. Measurements made at the Relativistic Heavy Ion Collider with deuteron–gold collisions yield similar results [12] (interestingly, Refs. [9,12] observe a centrality dependence to inclusive jet production). High transverse momentum (p_{T}) charged hadrons originate from the fragmentation of jets and provide a complementary observable to that of jet production. The CMS Collaboration observed a small excess in the charged-particle spectrum measured in p + Pb collisions for $p_{\mathrm{T}} > 20$ GeV particles compared to that expected from pp collisions [13]. Measurements of charged-particle fragmentation functions for jets in different p_{T} intervals in p + Pb and pp collisions are crucial for connecting the jet and charged-particle results. Therefore, the measurements reported here are necessary both to establish a reference for jet fragmentation measurements in Pb + Pb collisions and to determine any modifications to jet fragmentation in p + Pb collisions due to the presence of a large nucleus.

In recent years many of the features of Pb + Pb collisions which were interpreted as final state effects due to hot nuclear matter were also observed in p + Pb collisions at the LHC and in d + Au collisions at RHIC. These features include long-range hadron correlations [14–17] and a centrality-dependent reduction in the quarkonia yields [18–21]. There is considerable debate about whether these features arise from the same source as in Pb + Pb collisions [22] or from other effects such as initial state gluon saturation [23]. Measurements of jets in p + Pb collisions showed no effects that would be attributable to hot nuclear matter, however additional measurements of jet properties in these collisions could help to constrain the source of the modifications observed in other observables.

In this paper, the jet momentum structure in pp and p + Pb collisions is studied using the distributions of charged particles associated with jets which have a transverse momentum $p_{\mathrm{T}}^{\mathrm{jet}}$ in the range 45 to 260 GeV. Jets are reconstructed with the anti-k_t algorithm [24] using a radius parameter $R = 0.4$. Charged particles are assigned to jets via an angular matching $\Delta R < 0.4$,[1] where ΔR is the angular distance between the jet axis and the charged-particle position. Results on the fragmentation functions are presented both as a function of the ratio between the

[1] ATLAS uses a right-handed coordinate system with its origin at the nominal interaction point (IP) in the centre of the detector and the z-axis along the beam pipe. The x-axis points from the IP to the centre of the LHC ring, and the y-axis points upward. Cylindrical coordinates (r, ϕ) are used in the transverse plane, ϕ being the azimuthal angle around the beam pipe. The pseudorapidity is defined in terms of the polar angle θ as $\eta = -\ln\tan(\theta/2)$. Rapidity is defined as $y = 0.5 \ln \frac{E+p_z}{E-p_z}$ where E and p_z are the energy and the component of the momentum along the beam direction. Angular distance is measured in units of $\Delta R \equiv \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$.

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