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Measurement of angular and momentum distributions of charged particles within and around jets in Pb+Pb and *pp* collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV with ATLAS at the LHC

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Abstract

Studies of the fragmentation of jets into charged particles in heavy-ion collisions can help in understanding the mechanism of jet quenching by the hot and dense QCD matter created in such collisions, the quark-gluon plasma. These proceedings present a measurement of the angular distribution of charged particles around the jet axis in $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV Pb+Pb and *pp* collisions, done using the ATLAS detector at the LHC. The measurement is performed inside jets reconstructed with the anti-k_t algorithm with radius parameter $R = 0.4$, and is extended to regions outside the jet cone. Results are presented as a function of Pb+Pb collision centrality, and both jet and charged-particle transverse momenta.

Keywords: jets, fragmentation functions, jet shapes

1. Introduction

Ultra-relativistic nuclear collisions at the Large Hadron Collider (LHC) produce hot, dense matter called the quark-gluon plasma, QGP [1, 2]. Hard-scattering processes in these collisions produce jets which interact with the QGP, and comparing the rates and the characteristics of these jets in heavy-ion or *pp* collisions provides information on its properties.

Measurements of the transverse jet profile [3] and the longitudinal fragmentation functions [4–7] showed an excess of both low and high momentum particles inside the jet compared to *pp* collisions, suggesting that the energy lost by jets through the jet-quenching process is being transferred to soft particles within and around the jet [8, 9]. Measurements of yields of these particles as a function of transverse momentum and distance between the particle and the jet axis have the potential to constrain the models of jet energy loss processes in Pb+Pb collisions.

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These proceedings present a measurement of charged particle p_{T} distributions inside and around jets produced in pp and Pb+Pb collisions at center-of-mass energy of 5.02 TeV [10]. The measured yields are defined as[1]:

$$D(p_T)D(p_{\mathrm{T}},r) = \frac{1}{N_{\mathrm{jet}}}\frac{1}{2\pi r}\frac{\mathrm{d}^2 n_{\mathrm{ch}}(r)}{\mathrm{d}r\mathrm{d}p_{\mathrm{T}}} \quad (1)$$

where N_{jet} is the total number of jets; $2\pi r dr$ is the area of the annulus at a given distance r from the jet axis, where $r = \sqrt{\Delta\eta^2 + \Delta\phi^2}$ ($\Delta\eta$ and $\Delta\phi$ are the relative differences between the charged particle and the jet axis, in pseudorapidity and azimuth respectively) and dr is the width of the annulus; $n_{\mathrm{ch}}(r)$ is the number of charged particles within a given annulus. The ratios of the charged-particle yields measured in Pb+Pb and pp collisions, evaluated as $R_{D(p_{\mathrm{T}},r)} = D(p_{\mathrm{T}},r)_{\mathrm{Pb+Pb}}/D(p_{\mathrm{T}},r)_{pp}$, allows quantifying the modification in yields from the pp to the Pb+Pb system.

2. Datasets

The measurements described in these proceedings use 25 pb^{-1} of $\sqrt{s}$ = 5.02 TeV pp data and 0.49 nb^{-1} of $\sqrt{s_{NN}}$ = 5.02 TeV Pb+Pb data collected in 2015. The data were recorded using the ATLAS calorimeter, inner detector, trigger, and data acquisition systems [11].

The performance of the detector and the analysis procedure is tested using pp and Pb+Pb Monte Carlo (MC) samples. The pp hard scattering events are generated using the A14 tune [12] and the NNPDF23LO PDF set [13], while the Pb+Pb sample is generated with Powheg+Pythia8 overlaid on top of events from an enhanced minimum-bias Pb+Pb data sample. The detector response is simulated using Geant4 [14, 15].

3. Data Analysis

Reconstructed tracks are associated with a reconstructed jet if they fall within $\Delta R < 0.6$ of the jet axis. The measured track yields are corrected for the tracking efficiency, fakes, underlying event, bin migration due to jet energy and track momentum resolution, and effects from the finite jet and track angular resolutions. These cuts, corrections, and other effects are described in detail in [10].

The fakes are determined based on the MC samples, while the underlying event (UE) contribution is evaluated using the MB Pb+Pb sample, and corrected ofr the the correlation with the jet energy resolution [4]. Bin migration effects are removed by a two dimensional Bayesian unfolding procedure, with a separate one dimensional Bayesian unfolding to correct the jet spectra. The jet and track angular resolution effects are corrected for by a bin-by-bin unfolding procedure.

4. Results

The yields of charged particle distributions, $D(p_{\mathrm{T}},r)$ as well as the ratios $R_{D(p_{\mathrm{T}},r)}$ inside and around $R = 0.4$ anti-k_t jets with $|y^{\mathrm{jet}}|$ <1.3, and $126 < p_{\mathrm{T}}^{\mathrm{jet}} < 158$ GeV are shown in Figure 1. A broadening (narrowing) of the $D(p_{\mathrm{T}},r)$ distribution for $p_{\mathrm{T}} < 4$ GeV ($p_{\mathrm{T}} > 4$ GeV) particles inside the jet in central Pb+Pb collisions compared to pp collisions is observed [10]. $R_{D(p_{\mathrm{T}},r)}$ is above (below) unity at all r for charged-particles with $p_{\mathrm{T}} < 4$ GeV ($p_{\mathrm{T}} > 4$ GeV), and increases (decreases) for $r < 0.3$, and is approximately constant thereafter. For peripheral collisions (60–80% collision centrality), $R_{D(p_{\mathrm{T}},r)}$ has no significant r dependence and the distributions do not significantly deviate from unity.

These observations agree with inclusive jet fragmentation function measurements [7], and suggest that the energy lost by jets through the jet quenching process is being transferred to particles with $p_{\mathrm{T}} < 4.0$ GeV at larger radial distances. This is qualitatively consistent with theoretical calculations [8, 9].

[1] ATLAS uses a right-handed coordinate system with its origin at the nominal interaction point (IP) in the center of the detector, and the z-axis along the beam pipe. The x-axis points from the IP to the center of the LHC ring, and the y-axis points upward. Cylindrical coordinates (r,ϕ) are used the transverse plane, ϕ being the azimuthal angle around the z-axis. The pseudorapidity is defined in terms of the polar angle θ as $\eta = -ln\tan(\theta/2)$. $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$ gives the angular distance between two objects with relative differences $\Delta\eta$ and $\Delta\phi$ in pseudorapidity and azimuth respectively.

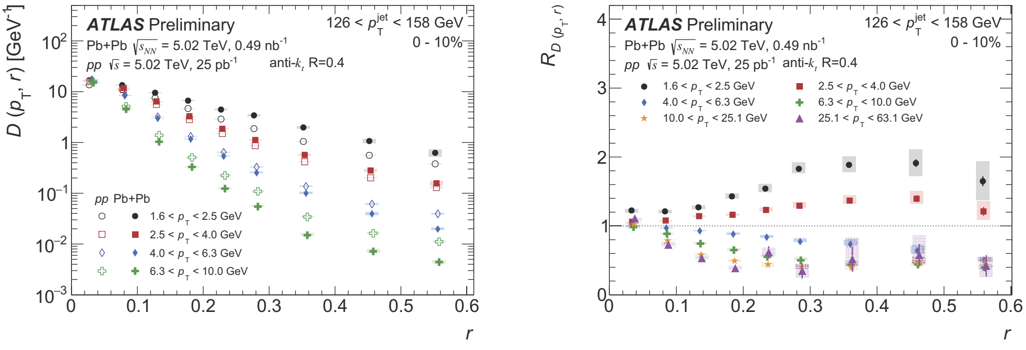

Fig. 1. Left: Closed (open) symbols show $D(p_{\mathrm{T}}, r)$ distributions in 0–10% Pb+Pb (pp) collisions as a function of angular distance r for $126 < p_{\mathrm{T}}^{\mathrm{jet}} < 158$ GeV for four p_{T} selections. Right: Ratios of $D(p_{\mathrm{T}}, r)$ distributions in 0–10% Pb+Pb collisions to pp collisions as a function of angular distance r for $126 < p_{\mathrm{T}}^{\mathrm{jet}} < 158$ GeV for six p_{T} selections. The vertical bars on the data points indicate statistical uncertainties while the shaded boxes indicate systematic uncertainties. There are no uncertainties on the r values. Figures are from Ref. [10]

5. Summary

These proceedings present a measurement of the yields of charged particle distributions, $D(p_{\mathrm{T}}, r)$ inside and around $R = 0.4$ anti-k_t jets with $|y^{\mathrm{jet}}| < 1.3$. The yields are measured for $126 < p_{\mathrm{T}}^{\mathrm{jet}} < 316$ GeV in Pb+Pb and pp collisions at 5.02 TeV as a function of charged particle p_{T} and the angular distance between the jet axis and charged particle, r.

Centrality dependent modifications to the yields when compared to those measured in pp collisions are observed. The magnitude of these modifications increases with increasing collision centrality. The $R_{D(p_{\mathrm{T}},r)}$ distributions for charged particles with $p_{\mathrm{T}} < 4$ GeV ($p_{\mathrm{T}} > 4$ GeV) show an enhancement (suppression) up to an angular separation of $r \sim 0.3$. No significant r dependence is observed for $0.3 < r < 0.6$. The $D(p_{\mathrm{T}}, r)$ distribution for low (high) p_{T} particles inside the jet in central Pb+Pb collisions compared to those in pp collisions show a broadening (narrowing).

These ATLAS measurements done using the LHC provide more information on the differential distributions of charged particles within jets as compared to the inclusive measurement of jet fragmentation functions, and may improve our understanding of the physics of soft gluon radiation and the response of the jet to the QGP.

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