Dijet asymmetries in Pb+Pb and pp collisions with the ATLAS detector

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Abstract. Measurements of dijet p_T correlations in both Pb+Pb and pp collisions at a nucleon–nucleon centre-of-mass energy of $\sqrt{s_{NN}} = 2.76$ TeV are presented. The measurements were performed with the ATLAS detector at the Large Hadron Collider (LHC) using Pb+Pb and pp data samples with integrated luminosities of $0.14\ nb^{-1}$ and $4.0\ pb^{-1}$, respectively. Jets were reconstructed using the anti-k_t algorithm with $R = 0.4$. A background subtraction procedure was applied to correct the jets for the large underlying event present in Pb+Pb collisions. The leading and subleading jet transverse momenta are denoted p_{T_1} and p_{T_2}. An unfolding procedure is applied to the two-dimensional p_{T_1}-p_{T_2} distributions to account for experimental effects in the measurement of both jets. Distributions of $\frac{1}{N}\frac{dN}{dx_J}$, where $x_J = \frac{p_{T_2}}{p_{T_1}}$, are presented as a function of p_{T_1} and collision centrality. The distributions are found to be similar in peripheral Pb+Pb collisions and pp collisions, but highly modified in central Pb+Pb collisions. The results are qualitatively consistent with expectations from partonic energy loss.

1. Introduction

Jets have been an important tool for probing the hot, dense medium produced in heavy-ion collisions known as the quark-gluon plasma (QGP). Partons are expected to lose energy in interactions with the QGP, resulting in "jet quenching". This phenomenon is expected in Pb+Pb collisions at the LHC where a direct observation can be made using reconstructed jets. Dijets are an effective probe of jet quenching because jets originating from the same hard scattering can lose different amounts of energy as they traverse the medium whereas in pp collisions the jets are expected to be balanced.

Previous measurements of the dijet asymmetry, $A_J = (p_{T1} - p_{T2})/(p_{T1} + p_{T2})$, where p_{T1} and p_{T2} are the transverse momentum of the leading and subleading jets in the event, respectively, show that the dijets become increasingly asymmetric in more central collisions [1-3]. However, these measurements were not corrected for experimental resolution so they can not be compared directly to theoretical calculations. These proceedings present a new measurement of the dijet asymmetry in Pb+Pb and pp collisions [4] at $\sqrt{s_{NN}} = 2.76$ TeV using the observable $x_J = p_{T1}/p_{T2}$ that has been fully corrected for detector effects.

2. Experimental setup, data selection, and jet reconstruction

This measurement was performed using the ATLAS detector, which is described in Ref. [5]. This result made use of the inner detector, calorimeter, and trigger systems. The inner detector measures charged particles to $|\eta| < 2.5$. The calorimeter system consists of a steel-scintillator

calorimeter ($|\eta| < 1.7$) and an electromagnetic ($|\eta| < 3.2$) and Liquid Argon (LAr) hadronic ($1.5 < |\eta| < 3.2$) calorimeter. The Pb+Pb data were selected by a combination of minimum-bias and jet triggers corresponding to a luminosity of 0.14 nb^{-1}. The centrality was determined by using the sum of the transverse energy in the forward calorimeter that covers $3.2 < |\eta| < 4.9$. The pp data were obtained from a combination of jet triggers that are used in different p_T ranges where the trigger is fully efficient. The pp data has a total luminosity of 4.0 pb^{-1}. A Monte Carlo (MC) sample was produced using the PYTHIA version 6.423 generator using AUET2D parameters. This was followed by a GEANT simulation of ATLAS [7, 8] and then embedded in real minimum bias heavy-ion data. The sample consisted of hard-scattering (not just dijet) events using multiple ranges of momentum transfer.

Jets are reconstructed using the anti-k_t algorithm [9] with $R = 0.4$ and utilize an event-by-event underlying event (UE) subtraction procedure described in Ref.[10] that includes the effects of harmonic modulation due to flow. Previous results accounted for the second harmonic modulation. In this measurement, that procedure has been extended to account for the third and fourth order harmonic modulation. Following the background subtraction, the jets are corrected using an energy scale calibration factor determined from MC simulations. Separately, an *in situ* calibration is applied to account for known differences between the the detector response in the data and the MC sample [12].

3. Data analysis, unfolding and systematics

In this analysis, dijet pairs were selected by finding the two highest jets in each event with $p_T > 25$ GeV and $|\eta| < 2.1$ where $p_{T1} > p_{T2}$. The pairs were required to have $\Delta\phi > 7\pi/8$. A two-dimensional $p_{T1} - p_{T2}$ distribution was filled in Pb+Pb and pp collisions using different trigger samples based on the leading jet p_T. The distributions are symmetrized to account for bin migration across the diagonal where the leading and subleading jets can switch roles due to the effects of experimental resolution. The 2D symmetrized distributions are shown in Fig. 1 for two different Pb+Pb centralities and for pp collisions.
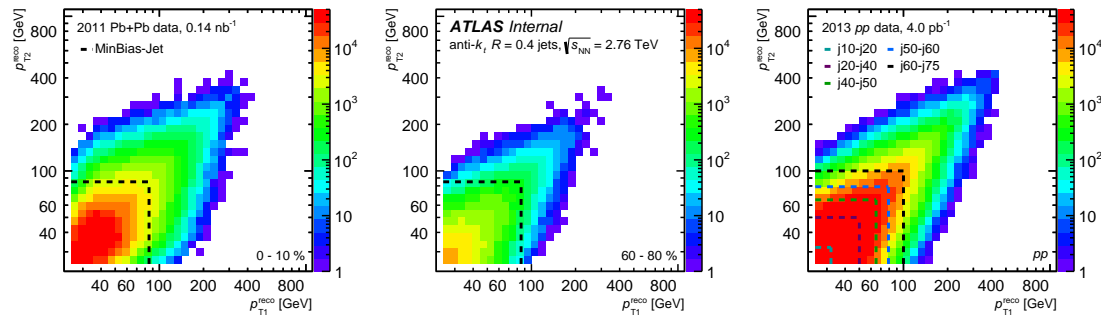

Figure 1. Symmetrized 2D $p_{T1} - p_{T2}$ distributions for Pb+Pb data 0-10 % (left), Pb+Pb data 60-80 % (middle), and pp (right). The dashed lines indicate the trigger boundaries [4].

The pairs have a combinatoric background contribution from uncorrelated pairs that arise from jets not originating from the same hard scattering. It is expected to be uniform in $\Delta\phi$ except for a small harmonic modulation due to imperfect removal of the background in the reconstruction. To account for residual flow harmonics, the background is assumed to be of the form $C(\Delta\phi) = Y(1 + 2c_3\cos 3\Delta\phi + 2c_4\cos\Delta\phi)$, which is motivated by flow harmonics. The coefficients c_3 and c_4 are determined in the region where $\Delta\eta > 1.0$, and the amplitude of the underlying event Y is estimated in the region $1.0 < \Delta\phi < 1.4$ using those coefficients. These

estimates are used to determine the combinatoric contribution in the signal region which is subtracted bin-by-bin from the $p_{T1} - p_{T2}$ distribution.

The 2D $p_{T1} - p_{T2}$ distributions were corrected for bin migration due to experimental effects using a 2D unfolding procedure [11]. A four-dimensional response was generated from the MC sample in measured and true p_{T1} and p_{T2}. The Bayesian unfolding is an iterative procedure that requires a choice of number of iterations and prior. The prior is generated from the truth $p_{T1} - p_{T2}$ distribution in PYTHIA. The number of iterations is determined by balancing the amplification of statistical error at large number of iterations with bias due to the choice of the prior.

After unfolding, the 2D $p_{T1} - p_{T2}$ distribution is restored to a leading/subleading jet distribution by reflecting the distribution of the diagonal and projecting into the observable $\frac{1}{N}\frac{dN}{dx_J}$ as a function of x_J. Figure 2 shows these distributions before and after unfolding. The effect of unfolding is to move jets in pp and peripheral collisions to more balanced configurations at $x_J = 1$. In central Pb+Pb collisions the effect is to move jets to more asymmetric configurations at $x_J = 0.5$.
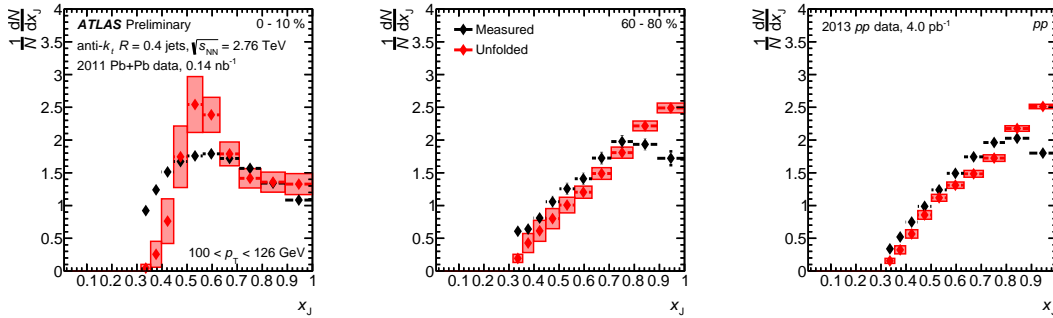

Figure 2. Distributions of $\frac{1}{N}\frac{dN}{dx_J}$ before (black) and after (red) unfolding for Pb+Pb data 0-10 % (left), Pb+Pb data 60-80 % (middle), and pp (right) [4].

Systematic uncertainties on the measured $\frac{1}{N}\frac{dN}{dx_J}$ distributions arise from uncertainties in the response matrix used in the unfolding. These are estimated by varying the jet energy scale (JES) and resolution (JER) in the MC sample. The JES uncertainty is applied as a function of p_T, η, and centrality and is the dominant uncertainty in the measurement. The JER has a dominant contribution due to the underlying event that is described well in the MC because of the data overlay. The analysis also has systematics due to the background subtraction and the unfolding procedure. The systematic due to the background subtraction was determined by varying the $\Delta\phi$ range used to estimate the amplitude of the background. The systematic uncertainties due to unfolding were determined by varying the number of iterations, reweighting the prior, and accounting for statistical effects in the response matrix.

4. Results

The final corrected results for Pb+Pb compared to pp collisions are shown in Figure 3. The figures on the left show the centrality dependence in the p_{T1} bin from 100-126 GeV. This demonstrates that as more central collisions are probed the dijets become more asymmetric. The most probable configuration for pp is $x_J = 1$ and for central Pb+Pb it is $x_J = 0.5$. As the Pb+Pb collisions become more peripheral the distribution becomes more similar to the pp distribution. The figures on the right show the leading jet p_T dependence of the most central collisions (0-10%) compared the pp collisions. A drastic leading jet p_T dependence is observed where the Pb+Pb collisions become like the pp at higher p_{T1}.
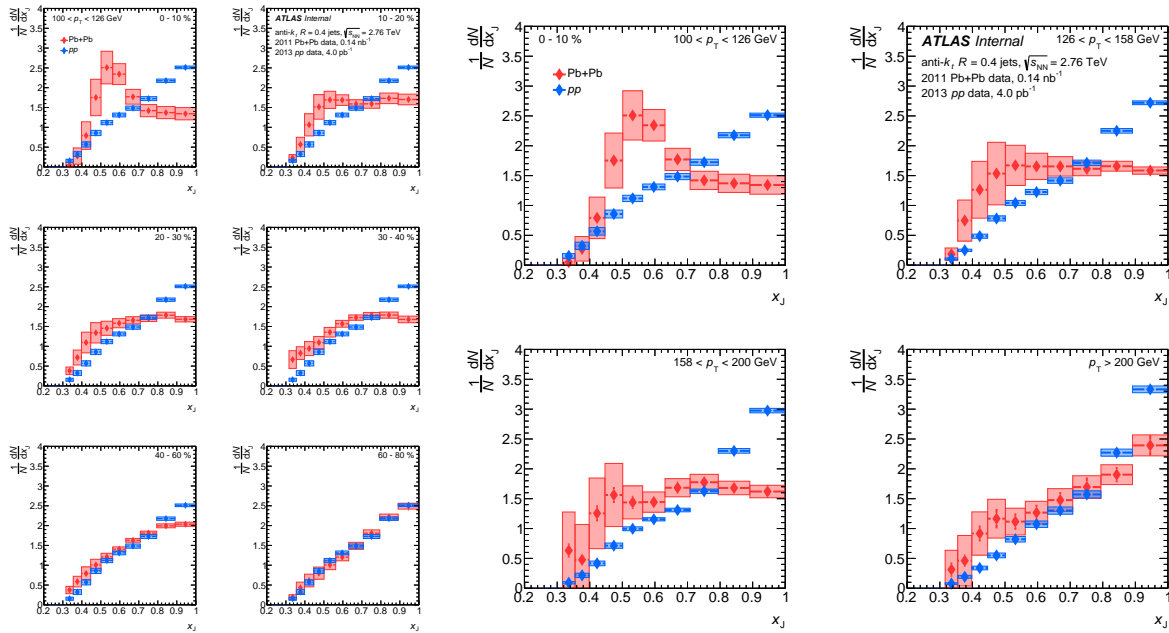
Figure 3. Distributions of $\frac{1}{N}\frac{dN}{dx_J}$ in Pb+Pb (red) and pp (blue) collisions for $100 < p_{T1} < 126$ GeV for different collision centralities (left six figures) and for 0-10% centrality for different leading jet p_T (right four figures). The error bars represent the statistical errors and the bands represent the systematic errors [4].

5. Conclusion

These proceedings presented a new measurement of the dijet asymmetry in Pb+Pb and pp collisions at $\sqrt{s_{NN}}$ =2.76 TeV. The result has been measured differentially in centrality and leading jet p_T and has been fully corrected by an unfolding procedure to account for experimental resolution. The results show more asymmetric dijet pairs in Pb+Pb data compared to pp data, which is consistent with jet quenching. The results demonstrate that the jets become more symmetric with increasing leading jet p_T. This measurement is qualitatively consistent with previous measurements of the dijet asymmetry, but since the measurement has been fully corrected for detector effects it can be directly compared to theoretical models of jet quenching.

Acknowledgments

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