Inclusive jet production in p +Pb collisions at 5.02 TeV with the ATLAS detector at the LHC

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Abstract

Measurements of reconstructed jets in high-energy proton-lead collisions over a wide rapidity and transverse momentum range can serve as a detailed probe of the partonic structure of nuclei over a large (x, Q^2) range. Inclusive jet production may be sensitive to the nuclear modification of parton distribution functions and such effects as the energy loss of the initial state partons entering into the hard scattering. Furthermore, any modification of jet production in p +Pb collisions can provide context for the strong suppression observed in central 2.76 TeV Pb+Pb collisions which is attributed to the formation of a hot nuclear medium. We present a measurement of inclusive jet production in p +Pb collisions with the ATLAS detector at the LHC. While the jet rate in minimum bias p +Pb events is seen to be only slightly enhanced above the geometric expectation, the centrality-dependent yields are observed to be modified, with systematically stronger effects at higher p_T and at more forward (proton-going) rapidities.

Keywords: heavy ion physics, nuclear parton, distribution functions, proton-nucleus collisions, centrality

1. Introduction

Inclusive jet production in proton-nucleus (p +A) collisions may be a sensitive probe of the partonic structure of the nucleus and its possible modification in the high partonic density environment[1]. More generally, benchmarking jet rates in so-called “cold nuclear” systems provides crucial context in which to interpret the observed strong suppression of the jet production in nucleus-nucleus collisions commonly ascribed to final state effects[2]. Finally, there are suggestions that measuring high- x processes in p +A collisions may reveal interesting features of the proton wavefunction[3, 4]. Previous measurements of the nuclear modification of hadrons and jets in d +Au collisions at RHIC have tended to focus on the forward region[5], where shadowing effects are expected to be important, or mid-rapidity[6], where jet rates are expected to test high- Q^2 initial state or impact-parameter dependent nPDF effects[7].

In these proceedings, we present measurements of the centrality- and rapidity-dependent nuclear modification factors for high transverse momentum (p_T) jets over five units of rapidity (y^*) by the ATLAS detector[8] at the LHC. The data are described in more detail in [9]. The centrality dependence of the per event jet yield, $(1/N_{\text{evt}})(d^2N/dp_T dy^*)$, is investigated through the central-to-peripheral ratio,

$$R_{\text{CP}}^{\text{cent}} = (1/R_{\text{coll}}) (1/N_{\text{evt}})(d^2N/dp_T dy^*)|_{\text{cent}} / (1/N_{\text{evt}})(d^2N/dp_T dy^*)|_{\text{peri}} \quad (1)$$

where R_{coll} is the ratio of the mean number of colliding nucleons $\langle N_{\text{coll}} \rangle$ in the two centrality selections. Furthermore, the jet rate at fixed centrality can be compared to the expectation from pp collisions (where in lieu of a pp reference at the appropriate energy we use a PYTHIA 6.4 reference tuned to ATLAS data),

$$R_{\text{pPb}}^{\text{PYTHIA, cent}} = (1/N_{\text{evt}})(d^2N/dp_T dy^*)|_{\text{cent}} / \frac{1}{T_{\text{pA}}}(d^2\sigma/dp_T dy^*)|_{\text{PYTHIA}} \quad (2)$$

where T_{pA} is the mean nuclear thickness seen by the proton in events of the given centrality class and $d^2\sigma/dp_T dy^*$ is the PYTHIA jet cross-section. The R_{CP} and $R_{\text{pPb}}^{\text{PYTHIA}}$ measure deviations in the jet yield from the geometric expectation of an incoherent superposition of an equivalent number of nucleon-nucleon collisions (under which $R_{\text{CP}}, R_{\text{pPb}} = 1$).

2. Data selection and centrality determination

The data used in this work are from the LHC proton-lead ($p+\text{Pb}$) run in early 2013, in which 4 TeV protons collided with $4 \times \frac{Z}{A} = 1.57$ TeV Pb ions, resulting a nucleon-nucleon center-of-mass energy $\sqrt{s_{\text{NN}}} = 5.02$ TeV and an overall rapidity shift of $\Delta y = 0.465$ in the direction of the proton beam. Results are reported in the nucleon-nucleon center of mass frame as a function of rapidity y^* . The convention used in this work follows that of the pilot $p+\text{Pb}$ run in September 2012, where (unlike in some other works) $y^*, \eta > 0$ and $y^*, \eta < 0$ correspond to the downstream nucleus and proton directions, respectively.

A combination of minimum bias and high-level jet triggers (which use a simplified version of the UE subtraction and calibration procedure to reconstruct jets online) were used during the $p+\text{Pb}$ data-taking, including six jet triggers of different thresholds in the ATLAS barrel ($|\eta| < 3.2$) and a forward jet trigger ($|\eta| > 3.2$). All $p+\text{Pb}$ events were required to pass the minimum bias definition of at least one hit in each of the two minimum bias trigger scintillator (MBTS) hodoscopes, situated at $\pm 2.1 < \eta < \pm 3.9$, with a time difference less than 10 ns between them and a reconstructed vertex with at least two good quality charged tracks. Events consisted with diffractive excitations of the proton were identified by the presence of a rapidity gap (defined by the absence of calorimeter clusters) in the downstream Pb direction, and were not used in this analysis. Finally, events consistent with multiple in-time $p+\text{Pb}$ collisions were rejected if they contained two reconstructed vertices with $\Sigma p_T > 5$ GeV of associated tracks. After selection cuts, the total luminosity sampled by the highest- p_T jet triggers comprises approximately $\int \mathcal{L} = 25 \text{ nb}^{-1}$.

The centrality of $p+\text{Pb}$ collisions is characterized[10] through the sum of the transverse energy in the Pb-going hadronic forward calorimeter ($\Sigma E_{\text{T}}^{\text{Pb}}$), which is situated at $3.2 < \eta < 4.9$. Using standard techniques, the events are categorized by their percentile in the minimum bias $dN/d\Sigma E_{\text{T}}^{\text{Pb}}$ distribution after accounting for an estimated event selection efficiency for inelastic $p+\text{Pb}$ events of $98 \pm 2\%$. The centrality selections range from the 0–10% most central events to the 60–90% events (the most peripheral selection does not extend to 98%, since the composition of $p+\text{Pb}$ events with such low activity is not yet well understood). A Glauber MC analysis with an inelastic nucleon-nucleon cross-section of $\sigma_{\text{NN}} = 70 \text{ mb}$ was used to model the $\Sigma E_{\text{T}}^{\text{Pb}}$ distribution in the FCal and calculate the mean T_{pA} in each centrality selection.

3. Jet selection and corrections

Jets were reconstructed according to an ATLAS procedure common between Pb+Pb, $p+\text{Pb}$ and $p+p$ collisions. First, ATLAS calorimeter cells are collected into $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$ calorimeter towers at the EM scale. Then, an η -dependent underlying event (UE) is estimated in each calorimeter layer. Jets are reconstructed using the anti- k_t algorithm with $R = 0.4$ on the UE-subtracted towers. The final set of jets are corrected for any inadvertent inclusion of jets into the UE estimate, and are corrected to the full hadronic scale through a calibration derived from MC simulation, described below. Offline jets matched to online jet triggers described above are selected for use in the analysis. To avoid any corrections for the trigger efficiency, each jet p_T bin is populated exclusively by the highest-luminosity trigger which is simultaneously $> 99\%$ efficient in the bin.

The performance of the jet reconstruction over $-4.4 < y^* < +0.8$ was evaluated with an MC simulation, consisting of 6 million PYTHIA QCD dijets with the same $\sqrt{s}$ and center of mass rapidity shift with respect to the laboratory frame as the data and a GEANT4 simulation of the ATLAS detector response. The reconstruction efficiency for $p_T > 25$ GeV jets was determined to be $> 99\%$ at all rapidities. Furthermore, the mean relative energy scale difference between the reconstructed and truth jet p_T was evaluated to be $< 1\%$ at all measured y^* and p_T . The reconstructed spectrum is corrected for the p_T bin migration introduced by this small difference in the energy scale and by the jet energy resolution. In the kinematic regions reported, the corrections are on the order of 10–20%. A separate MC study, using PYTHIA dijets overlaid onto real $p+\text{Pb}$ events, is used to determine the centrality-dependence of the correction factors. At sufficiently high p_T , there is no effect from the mild $p+\text{Pb}$ UE and the jet response is centrality independent. The data-overlaid MC is used to determine the minimum p_T in each rapidity for which this is true, and the jet yields are only reported above this minimum p_T , which is > 100 GeV at mid-rapidity but decreases to > 25 GeV at $y^* = -4$.

Figure 1. Summary of jet R_{CP} results. The top and bottom rows show the 0–10%/60–90% and 30–40%/60–90% centrality selections. The jet R_{CP} is shown at multiple rapidities y^* in each plot. In the left plots, the R_{CP} is plotted as a function of jet p_T , while on the right, the same data is replotted as a function of the total jet energy $p_T \cdot \cosh(y^*)$.

Since the R_{CP} is the ratio of jet yields in different $p+Pb$ events, many of the systematics cancel between the numerator and denominator. The remaining dominant systematic uncertainty arises from the difference in the correction factors introduced by the differences in the shape of the jet spectra at different centralities. On the other hand, since the R_{pPb}^{PYTHIA} is the ratio of the corrected $p+Pb$ spectrum to an MC reference, the dominant systematic uncertainty is the uncertainty on the jet energy scale in data.

4. Nuclear modification factor for jets

Figure 1 summarizes the jet R_{CP} (using 60–90% $p+Pb$ collisions as the reference) as a function of y^* and p_T . At sufficiently high p_T , the R_{CP} is suppressed (< 1) at all rapidities. At fixed y^* , the suppression increases systematically with p_T . At fixed p_T , the suppression increases systematically with more forward going ($y^* < 0$) rapidities. Finally, the suppression is monotonically stronger in successively more central events. The right panels of Figure 1 plot the R_{CP} for many rapidities as a function of the total jet energy p , where $p = p_T \cdot \cosh(y^*)$. It can be seen that the $R_{CP}(p_T, y^*)$ at all observed y^* is consistent with a single function of the total jet energy alone, $R_{CP}(p)$.

Figure 2 summarizes the jet R_{pPb}^{PYTHIA} (using a PYTHIA reference spectrum tuned to reproduce ATLAS data) as a function of y^* and p_T . At mid-rapidity, the minimum bias (0–90%) R_{pPb}^{PYTHIA} is consistent with a slight enhancement (≈ 1.15 – 1.20) at mid-rapidity and with unity at more forward rapidities. In all rapidity bins measured, the R_{pPb}^{PYTHIA} is consistent with a flat p_T dependence. However, this is not the case with the centrality-dependent R_{pPb}^{PYTHIA} . In central (0–10%) events, the R_{pPb}^{PYTHIA} systematically decreases with p_T below the minimum bias value, while in peripheral (60–90%) events, it systematically increases with p_T above the minimum bias value.

Figure 2. Summary of jet R_{pPb}^{PYTHIA} results. The four left-most panels show the 0–90% R_{pPb}^{PYTHIA} and the four right-most panels show the centrality-dependence of the quantity. Each panel shows the R_{pPb}^{PYTHIA} vs. jet p_T at a different rapidity y^* .

5. Discussion

These proceedings present a measurement of inclusive jet production in p +Pb collisions at 5.02 TeV with the ATLAS detector at the LHC. The nuclear modification factor is measured with respect to peripheral collisions and with respect to a PYTHIA 5.02 TeV reference spectrum as a function of y^* , p_T and p +Pb event centrality. The results indicate a large, p_T - and y^* -dependent suppression in the rate of jet production in central events relative to peripheral ones. On the other hand, no strong modification in minimum bias events is observed within sensitivity. Thus, the large effects in the R_{CP} arise from the combination of a moderate suppression in central events and a moderate enhancement in peripheral events. Finally, the R_{CP} at all rapidities studied is consistent with being a function of only the total jet energy $p_T \cdot \cosh(y^*)$, which may admit an interpretation of the modifications as arising from initial state effects.

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