High-p_{T} probes of p+Pb collisions with ATLAS

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Abstract. Measurements of high p_{T} processes in ultrarelativistic proton–nucleus collisions are sensitive to changes in the partonic densities arising from the presence of the nuclear environment. Additionally, such measurements benchmark the so called "cold nuclear matter" effects and provide the reference for understanding the large suppression of high-p_{T} processes observed in nucleus–nucleus collisions. Furthermore, measurements of the centrality dependence of jet production at forward (proton-going) rapidities may shed light on the behavior of the proton wavefunction at large Bjorken-x. The latest ATLAS results for inclusive jets and charged particles in 28.9 nb^{-1} of 5.02 TeV proton–lead collisions at the LHC are presented. The centrality in these collisions is characterized through the sum of the total transverse energy in the lead-going forward calorimeter. The nuclear modification factors $R_{p\mathrm{Pb}}$ and R_{CP} are presented as a function of transverse momentum, rapidity and centrality. The jet R_{CP} in a large rapidity region is found to be modified in a way that depends only on the total jet energy.

1. Introduction

Measurements of high transverse momentum (p_{T}) processes of proton–lead (p+Pb) collisions probe the partonic structure of the nucleus and its possible modification [1], and provide constraints on how initial state effects may influence the observed suppression of these processes in lead–lead collisions. More generally, they test the relationship between hard process rates and the soft particle activity used to classify the geometry of nuclear collisions and, at high-x, may reveal novel features of the proton wave function [2]. In these proceedings, inclusive jet and charged hadron measurements in $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV p+Pb collisions by the ATLAS detector [3] at the LHC are presented as a function of jet or hadron p_{T} and center of mass rapidity, y^*. The data are described in more detail in Refs. [4, 5].

Modifications to inclusive jet or hadron production rates were investigated through the nuclear modification factor $R_{p\mathrm{Pb}} = (1/N_{\mathrm{evt}})(\mathrm{d}^2N/\mathrm{d}p_{\mathrm{T}}\mathrm{d}y^*)/(T_{\mathrm{pA}}\mathrm{d}^2\sigma/\mathrm{d}p_{\mathrm{T}}\mathrm{d}y^*)$, where the numerator is the per-event jet or hadron yield, T_{pA} is the mean nuclear thickness seen by the proton in events of the given centrality interval and $\mathrm{d}^2\sigma/\mathrm{d}p_{\mathrm{T}}\mathrm{d}y^*$ is the jet or hadron cross-section in pp collisions evaluated at the same $\sqrt{s}$. The modifications were also explored through the central-to-peripheral ratio, R_{CP}, which is the ratio of the $1/T_{\mathrm{pA}}$-scaled yield in a given centrality interval with respect to the yield in the 60–90% interval. The R_{CP} and $R_{p\mathrm{Pb}}$ measure deviations in the yield from the geometric expectation of an incoherent superposition of an equivalent number of nucleon-nucleon collisions (for which $R_{\mathrm{CP}} = 1$ and $R_{p\mathrm{Pb}} = 1$).

2. Data selection and centrality definition

The data used in this work primarily comprise 28.9 nb^{-1} of p+Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV, and also 4.0 pb^{-1} and 156 pb^{-1} of pp data at $\sqrt{s} = 2.76$ TeV and 7 TeV, respectively, to

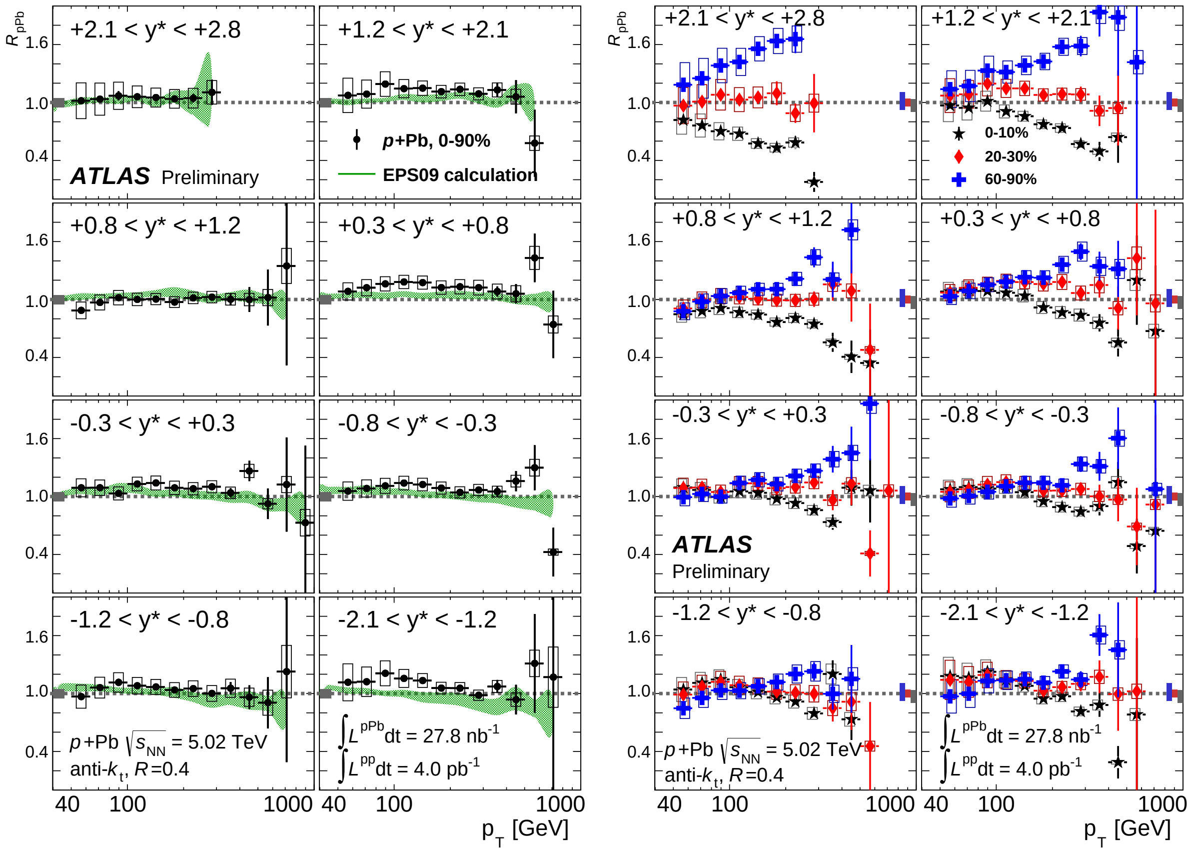

Figure 1. Jet R_{pPb} as a function of p_T, with each panel a different selection on the center of mass rapidity y^* for (left) 0–90% events and (right) centrality-selected events. From Ref. [4].

construct the reference jet and hadron spectra at 5.02 TeV. All data sets were recorded using a combination of minimum bias and high level jet triggers. The minimum bias trigger condition was the presence of at least one hit in each side of the minimum bias trigger scintillator (MBTS) detector in p+Pb collisions, and the presence of a track reconstructed by the high-level trigger in pp collisions. Offline, a reconstructed vertex was required for all datasets. Additionally, p+Pb events were required to pass a number of additional cuts designed to select a set of events for which a centrality analysis was applicable and to which geometric parameters could be assigned. The centrality of p+Pb events was characterized through the sum of the total transverse energy, ΣE_T^{Pb}, in the Pb-going forward calorimeter $-4.9 < \eta < -3.1$ (in this work $y^*, \eta > 0$ denote the proton-going direction). A Monte Carlo (MC) Glauber-based analysis with nucleon–nucleon inelastic cross-section $\sigma_{\mathrm{NN}} = 70$ mb along with a modified wounded nucleon (WN) model was used to estimate T_{pA} in each centrality interval. More details are given in Ref. [6].

3. Jet and charged particle reconstruction and corrections

The jet reconstruction procedure closely follows that used in Pb+Pb collisions, which utilizes an iterative estimation and subtraction of the underlying event (UE) pedestal. Jets were reconstructed by applying the anti-k_t algorithm with $R = 0.4$ to calorimeter cells collected into $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$ towers, and their kinematics updated to account for the UE subtraction procedure. The final set of jets was first corrected for any inadvertent inclusion of jets into the UE estimate, then corrected to the full hadronic scale through a calibration derived from MC

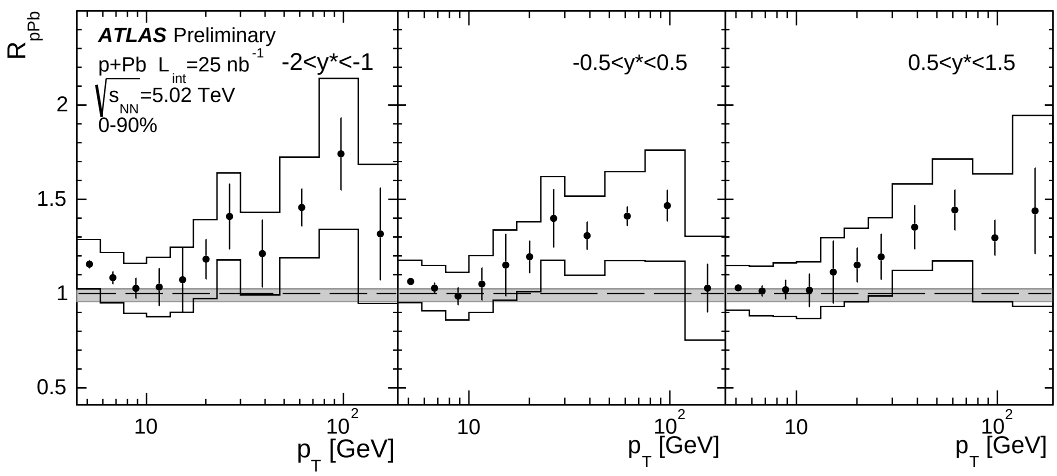

Figure 2. Charged particle $R_{p\mathrm{Pb}}$ vs. p_{T}, shown at three different rapidities. From Ref. [5].

simulation and finally received a small *in situ* energy scale correction. To avoid any corrections for the trigger efficiency, each p_{T} interval was populated exclusively by offline jets matched to the highest-luminosity trigger which was $> 99\%$ efficient in that interval. The performance of the jet reconstruction was evaluated with MC simulations of PYTHIA jet events overlaid onto minimum bias p+Pb events. The reconstruction efficiency was determined to be $> 99\%$ for $p_{\mathrm{T}} > 25$ GeV jets. The jet energy scale closure was found to be better than 2% (1%) for all $p_{\mathrm{T}} > 25$ GeV (> 100 GeV) jets. The detector-level jet spectra were corrected for p_{T} interval migration effects resulting from defects in the energy scale and finite energy resolution through a bin-by-bin correction procedure.

Charged tracks were reconstructed in the inner detector (ID) following an algorithm optimized for measurements in pp collisions, and selected for use in the analysis after the requirements of p_{T}-dependent quality cuts, such as a minimum number of hits in the pixel and silicon micro-strip components of the ID system. To further reduce the contribution of poorly reconstructed tracks or tracks from secondary particles, tracks were required to leave eight hits in the transition radiation tracker, and restricted to $|\eta| < 2.0$. To extend the p_{T}-reach of the measurement, tracks associated with jets matched to high p_{T} threshold jet triggers were used. The full charged particle spectrum was constructed by combining charged particles measured in minimum bias events with those associated with a number of jet triggers, with each trigger used exclusively in the p_{T} region where it was $> 99\%$ efficient. The raw spectrum was corrected for the presence of tracks associated with secondary particles, finite p_{T} resolution and reconstruction efficiency, using the same MC samples used above to determine the jet performance.

4. Nuclear modification factors for high-p_{T} jets and charged particles

The left panel of Figure 1 shows the $R_{p\mathrm{Pb}}$ for 0–90% events and a pQCD-based calculation incorporating the EPS09 nPDF set. The pp reference was derived from the measured jet cross-section at 2.76 TeV, interpolated using x_{T} scaling (derived from ATLAS measurements of jet spectra at 2.76 and 7 TeV) to 5.02 TeV. At all rapidities, the $R_{p\mathrm{Pb}}$ is consistent with a slight p_{T}-dependent enhancement above unity, in line with the expectations from EPS09. However, the centrality-dependent $R_{p\mathrm{Pb}}$, shown in the right panel of Figure 1, features strong deviations in the jet yield from the geometric expectation. The jet yield is suppressed in central collisions and enhanced in peripheral collisions. Furthermore, the modifications are systematically larger

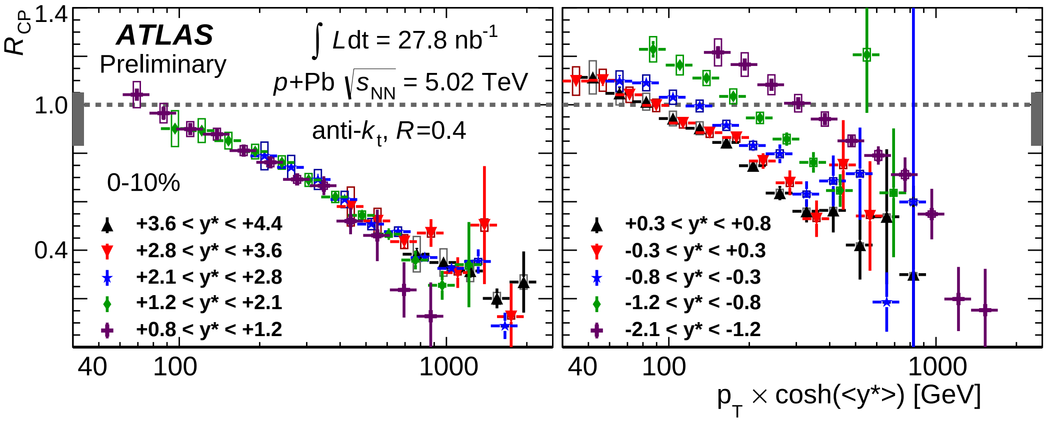

Figure 3. Jet $R_{\rm CP}$ as a function of $p_{\rm T}\cosh(y^*)$, plotted for different y^* values. From Ref. [4].

at higher $p_{\rm T}$ and at more forward rapidities.

The charged particle $R_{p\rm Pb}$ is shown in Figure 2. The *pp* reference was derived from ATLAS charged particle cross-sections in *pp* collisions at 2.76 TeV and 7 TeV, interpolated to 5.02 TeV using a linear dependence in $\sqrt{s}$. The variation in the result when the interpolation was performed as a function of $\log(s)$ or using $x_{\rm T}$ scaling were included in the systematic uncertainties. The $R_{p\rm Pb}$ is consistent with unity for $p_{\rm T} < 20$ GeV, but systematically increases at high-$p_{\rm T}$, reaching a 30–40% excess at $p_{\rm T} \approx 60$ GeV in all rapidity intervals studied.

Finally, to explore the kinematic dependence of the jet modifications, the data were presented as a function of $p_{\rm T} \times \cosh(y^*) \approx p$, where p is the approximate total jet energy. Figure 3 shows the $R_{\rm CP}$ at all rapidities studied as a function of p. When plotted this way, the $R_{\rm CP}$ values for rapidities in the range $0.8 < y^* < 4.4$ follow a single trend that is a function of p alone.

5. Conclusion

In these proceedings, measurements of the nuclear modification factor for jets and charged hadrons at high-$p_{\rm T}$ by ATLAS are presented. In minimum bias p+Pb collisions, the jet rate is in line with expectations while the particle rate has a systematic enhancement. Together, these results are challenging to explain within standard nPDF-based frameworks and the assumption of minimal jet modification. Additional information, such as from measurements of other hard probe rates or of the fragmentation function in p+Pb collisions may be needed for a more complete understanding of these effects. Furthermore, the centrality-dependent jet rates feature strong deviations from expectations. At forward rapidities, the modifications are consistent with a function of the approximate total jet energy p alone. However, forward jet production at fixed p arises dominantly from parton–parton configurations in which the partonic x in the proton equals $2p/\sqrt{s}$. Therefore, the modifications are controlled by the proton x only and indicate the influence of an initial state proton, rather than nuclear, effect [7].

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