Measurement of Jets and Jet Suppression in √s_{NN} = 2.76 TeV Lead-Lead Collisions with the ATLAS detector at the LHC

Aaron Angerami† on behalf of the ATLAS Collaboration
†Columbia University, Nevis Labs, Irvington, NY, 10533, USA
E-mail: angerami@cern.ch

Abstract. The first results of single jet observables in Pb+Pb collisions at √s_{NN} = 2.76 TeV measured with the ATLAS detector at the LHC are presented. Full jets are reconstructed with the anti-k_{t} algorithm with R = 0.2 and 0.4, using an event-by-event subtraction procedure to correct for the effects of the underlying event including elliptic flow. The geometrically-scaled ratio of jet yields in central and peripheral events, R_{CP}, indicates a clear suppression of jets with E_{T} > 100 GeV. The transverse and longitudinal distributions of jet fragments is also presented. We find little no substantial change to the fragmentation properties and no significant change in the level of suppression when moving to the larger jet definition.

1. Introduction

Energetic jets produced in high energy nuclear collisions serve as probes of the hot, dense medium created there by the phenomenon of “jet quenching” [1]. This is understood as the process by which a quark or gluon loses energy and suffers a modification of its parton shower in a medium of high color charge density. The RHIC experiments have investigated this phenomenon, particularly through the measurement of the R_{AA} of single hadrons [2, 3]. The observed violation of binary scaling indicates a breakdown of factorization in heavy ion collisions [1]. However, the published RHIC measurements have only provided indirect evidence for jet quenching due to the absence of results providing full jet reconstruction.

Dijet pairs where each jet traverses a different length of plasma should be sensitive to energy loss, especially in the extreme scenario where one jet is entirely extinguished by the medium [4]. The recent ATLAS measurement of dijet asymmetry experimentally addresses this possibility and was the first published measurement of fully reconstructed jets in heavy ion collisions [5]. By itself, the observed modification of the dijet asymmetry in Pb+Pb collisions relative to p+p is strongly suggestive of jet quenching; to definitively prove the quenching of jets further measurements are needed.

The single jet production rates are expected to be modified by jet quenching. Calculations of radiative energy loss predict a dependence of the measured suppression...
on the radius of the jet in the \( \eta - \phi \) plane \([6]\). In the absence of a measured p+p spectrum, the central to peripheral ratio, \( R_{\text{CP}} \), can be used:

\[
R_{\text{CP}} = \frac{1}{N_{\text{coll}}^{\text{cent}}} \frac{1}{N_{\text{evt}}^{\text{cent}}} \frac{\frac{dN^{\text{cent}}}{dp_T}}{\frac{dE_T}{d\eta d\phi}} = \frac{1}{N_{\text{coll}}^{\text{periph}}} \frac{1}{N_{\text{evt}}^{\text{periph}}} \frac{\frac{dN^{\text{periph}}}{dp_T}}{\frac{dE_T}{d\eta d\phi}} \tag{1}
\]

Jet quenching can also cause modifications in jet fragmentation relative to the vacuum case \([7]\). This can be investigated experimentally by considering charged particles inside the jet and their momenta with respect to the jet axis defined in terms of the angular separation between the hadron and the jet direction, \( \Delta R = \sqrt{(\Delta \eta)^2 + (\Delta \phi)^2} \). Measurements of the transverse momentum, \( j_T = p_T^{\text{frag}} \sin \Delta R \) and longitudinal momentum fraction, \( z = \frac{p_T^{\text{frag}}}{E_T} \cos \Delta R \), of charged hadrons within a jet show how medium effects may redistribute energy among jet fragments.

### 2. Jet Reconstruction

The most important features of the analysis procedure are presented here; a more detailed account can be found in reference \([8]\). The jet reconstruction procedure in heavy ion collisions assumes that the energy of the jet is superimposed on the background from the underlying event:

\[
\frac{d^2 E_{\text{tot}}}{d\eta d\phi} = \frac{d^2 E_{\text{bkgr}}}{d\eta d\phi} + \frac{d^2 E_{\text{jet}}}{d\eta d\phi}. \tag{2}
\]

Since the background is not known it must be estimated from the rest of the event. This is accomplished by considering the \( \eta \)-dependent average background level in regions unbiased by jets and the \( E_T \) modulation due to elliptic flow.

\[
\frac{d^2 E_{\text{bkgr}}}{d\eta d\phi} \sim \langle \frac{d^2 E_T}{d\eta d\phi} \rangle [1 + 2v_2 \cos(2(\phi - \Psi_2))] \tag{3}
\]

The measurements of jet observables that follow use this subtraction scheme on jets reconstructed with the anti-\( k_t \) algorithm \([9]\). This algorithm is infrared-safe to all orders and produces cone-like jets that are geometrically well-defined with a size controlled by a parameter \( R \). Measurements with both \( R = 0.2 \) and \( R = 0.4 \) are reported here. Calorimeter towers of size \( \Delta \eta \times \Delta \phi = 0.1 \times 0.1 \) are used as inputs to the reconstruction. Each tower is composed of several longitudinal sampling layers weighted using energy-density dependent factors to correct for calorimeter non-compensation and other energy losses \([10]\). An overall, multiplicative energy scale correction is applied to each reconstructed jet \([11]\).

The raw spectra are corrected for resolution and residual jet energy scale errors by using a bin-by-bin unfolding procedure based on Monte Carlo studies. Samples of PYTHIA p+p jet events and HIJING Pb+Pb events were simulated, run through a full GEANT description of the ATLAS detector, merged into a single event and finally reconstructed in an identical fashion to the data. From these, per-bin correction factors were extracted and used to correct the data. Variation of these correction factors as well
as the jet energy resolution and centrality variation of the jet energy scale are included in the systematic uncertainties indicated by the grey shaded regions in the figures.

For the fragmentation analysis, high quality tracks are selected based on impact parameter with respect to the primary vertex and number of hits in the Inner Detector. All tracks within $\Delta R < 0.4$ of a jet position are associated with a jet. To remove the contribution from the underlying event a background distribution is determined outside the jet region and subtracted. A bin-by-bin correction was derived using the same procedure as used in the $R_{CP}$ measurement. The sources of systematic uncertainty are also the same as those in the $R_{CP}$ measurement with additional uncertainties due to the background subtraction procedure.

![Figure 1. $R_{CP}$ for $R = 0.2$ jets. Left: $R_{CP}$ as a function of jet $E_T$ for three centrality bins. Right: $R_{CP}$ as a function of centrality for three $E_T$ intervals. Error bars on the data points indicate statistical uncertainties, shaded errors represent combined systematic errors from jet energy resolution, jet energy scale variation with centrality and $N_{coll}$.](image)

3. Results

Data recorded by ATLAS during the 2010 lead ion run is used in this analysis corresponding to a total integrated luminosity of $7 \, \mu b^{-1}$. Events are selected using minimum bias event criteria chosen to select in-time collisions and reject non-collision and photo-nuclear backgrounds, resulting in a dataset containing 47 million events. These events are partitioned into centrality classes based on the amount of transverse energy deposited in the forward calorimeter ($3.2 < |\eta| < 4.9$). Jets are restricted to the region $|\eta| < 2.8$ and $|\eta| < 2.1$ in the $R_{CP}$ and fragmentation analyses respectively.

The $R_{CP}$ is shown in figure 1 for the jets using $R = 0.2$ and in figure 2 for the jets using $R = 0.4$. The $60 - 80\%$ centrality interval is used to define the peripheral reference. The most central collisions ($0 - 10\%$) exhibit a factor of two suppression relative to peripheral collisions, that varies weakly with jet $E_T$. At fixed $E_T$ the $R_{CP}$...
shows a monotonic variation decrease with centrality. The maximal suppression of the R = 0.4 jets is similar to that of the R = 0.2 jets.

The fragmentation distributions are shown in figure [3]. For this measurement the 0 – 10% interval is compared to a peripheral reference of 40 – 80%. The $j_T$ distribution in central events does not show substantial broadening relative to the peripheral, which is consistent with the lack of $R_{CP}$ variation noted between the two sizes. The $z$ distributions do not show substantial modifications between central and peripheral, suggesting that for jets of this size the suppression of jet yields do not arise by strong modification of the jet fragmentation function.

In summary, ATLAS has directly observed the suppression of single inclusive jet yields. The measured $R_{CP}$ for two jet definitions indicate a significant suppression of these high energy jets. Combined with the $z$ distributions, these results suggest that inside the angular range $\Delta R < 0.4$, jets lose energy without having their transverse and longitudinal structure heavily modified, and that the lost energy is either recoverable at larger angles or removed from the jet entirely and deposited in the medium.

[1] A. Majumder and M. Van Leeuwen, 2010. arXiv:1002.2206 [hep-ph].
[2] K. Adcox et al., Phys. Rev. Lett. 88 (2002) 022301.
[3] C. Adler et al., Phys. Rev. Lett. 89 (2002) 202301.
[4] J. D. Bjorken, fermilab-PUB-82/059-THY (1982).
[5] G. Aad et al., Phys. Rev. Lett. 105 (2010) 252303.
[6] I. Vitev, S. Wicks, and B.-W. Zhang, JHEP 11 (2008) 093.
[7] N. Armesto, L. Cunqueiro, C. A. Salgado, and W.-C. Xiang, JHEP 0802 (2008) 048.
[8] ATLAS Collaboration, ATLAS-CONF-2011-075, 2011.
[9] M. Cacciari, G. P. Salam, and G. Soyez, JHEP 04 (2008) 063.
Figure 3. Distributions of jet fragment momenta with respect to the jet axis. $D(j_T)$ the transverse component (left) and $D(z)$ the longitudinal fraction (right) are measured using the $R = 0.4$ jets. The 0-10% central collisions are compared to 40-80% peripheral. The yellow and orange band show the systematic uncertainty from the subtraction of the underlying event contribution.

[10] ATLAS Collaboration, ATLAS-CONF-2010-053, 2010.
[11] ATLAS Collaboration, ATLAS-CONF-2010-056, 2010.