Measurements of Jet Suppression with ATLAS

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Abstract

Measurements of inclusive jet suppression in Pb+Pb collions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV with the ATLAS detector are reported. The centrality, p_{T} and jet size dependence of the central-to-peripheral ratio, R_{CP}, is presented. The results indicate that jets are suppressed by approximately a factor of two in the most central collisions, and a significant dependence on the jet size is observed. The path length dependence of jet quenching is studied through measurements of inclusive jet suppression as a function of angle with respect to the event plane. The azimuthal modulation of the jet yield is quantified by its second Fourier coefficent, v_2, which is significant in all p_{T} and centrality ranges presented.

1. Introduction

Jets produced in relativistic heavy ion collisions provide a crucial tool for studying the hot, evanescent form of matter produced in those collisions. The radiation of color charges in the vacuum has been studied extensively in high energy experiments through measurements of jets. The pattern of radiation in the vacuum is characterized a parton shower. A natural extension of this phenomenon is to consider how the vacuum parton shower may be modified when occurring in a medium of deconfined color charges.

The rate of inclusive jet production is sensitive to energy loss. If jets emerge from the medium with a lower p_{T} due to energy loss, the steeply falling production spectrum will be modified, resulting in an overall reduction of the jet yield, or suppression, at a given p_{T} value. The effects of this suppression can be studied by comparing the jet production rates in different centrality intervals while accounting for the variation due to the geometric enhancement of hard scattering rates. To account for the geometric effects, the jet yields in each centrality bin are scaled by the average number of binary collisions, N_{coll}, obtained from a Glauber Model. The suppression can then be quantified by the central-to-peripheral ratio, R_{CP},

$$R_{\mathrm{CP}}(p_{\mathrm{T}})\Big|_{\mathrm{cent}} = \frac{\left.\dfrac{N_{\mathrm{jet}}}{N_{\mathrm{evt}}N_{\mathrm{coll}}}\right|_{\mathrm{cent}}}{\left.\dfrac{N_{\mathrm{jet}}}{N_{\mathrm{evt}}N_{\mathrm{coll}}}\right|_{\mathrm{periph}}} . \quad (1)$$

Quenching effects may cause a broadening of the parton shower causing the jet's energy to be deposited outside the nominal jet cone. Such "out-of-cone radiation" may be recovered by increasing the radius of the jet definition resulting in a change in the observed suppression [1, 2, 3].

The dependence of the quenching on the in-medium path length can also be studied by exploiting the initial collision geometry in which the finite impact parameter results in a collision region which is azimuthally anisotropic. The orientation of the impact parameter vector can be inferred in each event from the global elliptic flow by considering the Fourier expansion of the azimuthal particle distribution and identifying the phase of the contribution from the second harmonic, the event plane angle Ψ_2. As the jets are not in thermal equilibrium with the system their production is uncorrelated with the event plane angle. However, jets oriented in the direction of the event plane need to propagate a shorter distance to the medium surface than out-of-plane jets [4]. Such path-length effects may cause the jet yield to vary as a function of angle with respect to the event plane, $\Delta\phi = \phi_{\rm jet} - \Psi_2$.

Two separate analyses of inclusive jet suppression are presented here. The first follows closely from a recent ATLAS paper [5] where the jet $R_{\rm CP}$ was measured as a function of centrality, $p_{\rm T}$ using the anti-k_t algorithm [6]. This algorithm which produces geometrically regular jets with an effective cone radius controlled by the parameter, $R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$, and the R-dependence of the jet suppression was studied as well. The second is a measurement of the $\mathrm{d}^2N_{\rm jet}/\mathrm{d}p_{\rm T}\mathrm{d}\Delta\phi$ distributions in different centrality bins [7]. As in the case of the global elliptic flow, the $\mathrm{d}^2N_{\rm jet}/\mathrm{d}p_{\rm T}\mathrm{d}\Delta\phi$ distribution should have a significant second harmonic component due to the the π-symmetric collision geometry. The distributions were fit to obtain values of the second Fourier coefficient, $v_2^{\rm jet}$, as functions of $p_{\rm T}$ and centrality to quantify the magnitude of the variation.

2. Jet Reconstruction

Jets were reconstructed from energy deposits using the ATLAS calorimeter [8] The effects of the underlying event on the jet kinematics, including the elliptic flow, were removed by performing an event-by-event determination of the mean transverse energy density and elliptic modulation of the $E_{\rm T}$ distribution [5, 9]. These two quantities were used to construct a background estimate which was subtracted from each calorimeter cell. An iterative procedure was used to ensure that jets do not bias the determination of the background. The subtracted cells were taken to be massless four-vectors and the jets' kinematics were constructed from the four-vector sum of the cells contained within the jet. A $p_{\rm T}$- and R-dependent jet energy scale calibration was applied using a procedure analogous to that used by ATLAS in the analysis of jets in pp collisions [10].

3. Event Selection

The measurements presented here were performed using the ATLAS calorimeter, inner detector, trigger, and data acquisition systems [8] using two separate data samples. The inclusive jet measurements were recorded during the 2010 lead ion run with an integrated luminosity of 7 μb^{-1}. The events were recorded using the ATLAS heavy ion minimum bias trigger, event selection and centrality definition [11]. The azimuthally dependent measurement was performed with data recorded in 2011 corresponding to a total integrated luminosity of 0.14 nb^{-1}. Events were selected using a heavy ion jet trigger algorithm seeded by minimum bias triggers. The jet trigger algorithm reconstructs anti-k_t jets with $R = 0.2$, using a background subtraction procedure that is identical to the offline reconstruction but does not include the elliptic flow subtraction [7]. For the lowest $p_{\rm T}$ jets the jet trigger was not fully efficient and thus a minimum bias triggered sample was used for jets in the range $45 < p_{\rm T} < 60$ GeV.

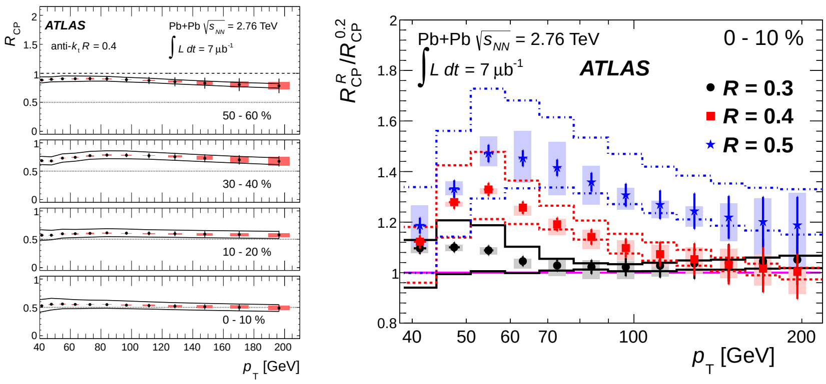

Figure 1: Left: unfolded R_{CP} values as a function of jet p_T for $R = 0.4$ anti-k_t jets in four bins of collision centrality. Dotted lines indicate $R_{CP} = 0.5$. Right: ratios of R_{CP} values between $R = 0.3, 0.4$ and 0.5 jets and $R = 0.2$ jets as a function of p_T in the 0–10% centrality bin. The error bars show statistical uncertainties. The error bars, shaded boxes and solid lines indicate statistical, uncorrelated systematic and correlated systematic errors respectively [5].

4. Inclusive Jet Suppression

The inclusive suppression measurement was performed using 2010 data sample. Jets reconstructed with $R = 0.2,\ 0.3,\ 0.4$ and 0.5 over the kinematic range $38 < p_T < 210$ GeV and $|\eta| < 2.1$ were used. Both detector effects and underlying event fluctuations can distort the measurement of the jet's energy. The result is that for a given jet, the distribution of measured energy will have a finite width known as the jet energy resolution (JER). Due to the steeply falling spectrum, such resolution effects cause a systematic upward shift in the measured yield at a given jet p_T, an effect which is worse in more central collisions and for larger R values. This effect directly counters the effects of jet suppression, and it must be well understood and corrected to obtain a meaningful measurement. These effects were corrected for using an unfolding method based on the singular value decomposition of the response [12]. The jet spectra were also corrected for inefficiency resulting from the jet reconstruction and fake rejection criteria [5].

The R_{CP} as a function of p_T for $R = 0.4$ jets is shown on the left of Fig. 1 for various centrality bins. The results indicate an R_{CP} that is nearly independent of p_T and has a value of $R_{CP} \sim 0.5$ in the most central collisions while varying smoothly to more peripheral collisions. The R dependence of the suppression is shown in the right panel of Fig. 1, where the R_{CP} ratio measured with a particular R value, R^R_{CP}, is divided by the corresponding value for $R = 0.2$ jets. The statistical error bars shown account for the full statistical correlation between jets of different R values propagated through the unfolding procedure. The results in Fig. 1 indicate a significant dependence of R_{CP} on jet radius in the most central collisions. For $p_T < 100$ GeV the $R^R_{CP}/R^{0.2}_{CP}$ values for both $R = 0.4$ and $R = 0.5$ differ from one beyond the statistical and systematic uncertainties.

5. Azimuthal Variation of Jet Suppression

The analysis of the azimuthal variation of the suppression was performed using the 2011 data sample using $R = 0.2$ jets over the range, $45 < p_T < 210$ GeVand $|\eta| < 2.1$. The $\mathrm{d}^2N_{\mathrm{jet}}/\mathrm{d}p_T\mathrm{d}\Delta\phi$ distributions were corrected for the experimental resolution in determining Ψ_2 through standard

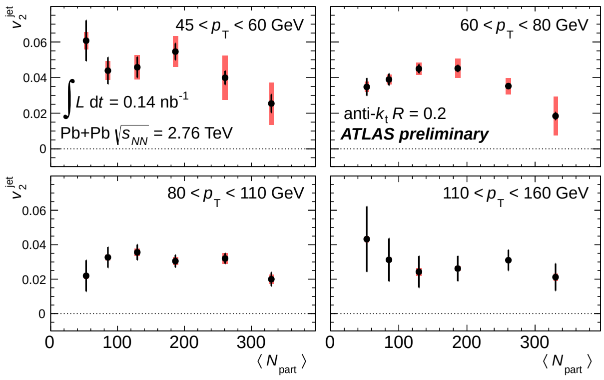

Figure 2: Variation of v_2^{jet} with number of participants, N_{part}, in four bins of jet p_{T}. The error bars indicate statistical uncertainties and the shaded boxes indicate systematic uncertainties [7].

techniques [13, 11]. As the response may vary as a function of $\Delta\phi$, in particular through limitations of the elliptic flow subtraction, each bin in $\Delta\phi$ must be unfolded separately. The smaller JER resulting from a smaller value of R allows for a simpler bin-by-bin unfolding procedure to be used over the p_{T} range presented here. As the v_2^{jet} is not sensitive to the overall jet yield at a fixed p_{T} and centrality, but only to the variation with $\Delta\phi$, this quantity is not dependent on the magnitudes of the bin-by-bin correction factors, but only to their $\Delta\phi$ variation. An extensive evaluation of the $\Delta\phi$ dependence of these correction factors and jet performance indicated no significant systematic $\Delta\phi$ variation. Therefore the bin-by-bin corrections were taken to be independent of $\Delta\phi$, which cancel in the determination v_2^{jet}. A systematic uncertainty was included by introducing a $\Delta\phi$ dependence to the corrections to account for uncertainties in the JER.

Figure 2 shows the variation of v_2^{jet} with the number of participants, N_{part}, for the four lowest p_{T} bins included in the analysis. A clear variation of v_2^{jet} with N_{part} is seen in the 60–80 GeV bin which has the best statistical precision and the smallest systematic uncertainties. The results in the 45-60 GeV and 80–110 GeV bin show similar variations, but those variations are not as significant due to the larger uncertainties.

References

[1] I. Vitev, S. Wicks, B.-W. Zhang, JHEP 11 (2008) 093. arXiv:0810.2807.
[2] I. Vitev, B.-W. Zhang, Phys. Rev. Lett. 104 (2010) 132001. arXiv:0910.1090.
[3] Y. He, I. Vitev, B.-W. Zhang. arXiv:1105.2566.
[4] M. Gyulassy, I. Vitev, X. Wang, Phys. Rev. Lett. 86 (2001) 2537–2540. arXiv:nucl-th/0012092, doi:10.1103/PhysRevLett.86.2537.
[5] ATLAS Collaboration, submitted to Phys. Lett. B (Aug 2012). arXiv:1208.1967.
[6] M. Cacciari, G. P. Salam, G. Soyez, JHEP 04 (2008) 063. arXiv:0802.1189.
[7] ATLAS Collaboration, ATLAS-CONF-2012-116.
[8] ATLAS Collaboration, JINST 3 (2008) S08003.
[9] A. Angerami (2012). arXiv:nucl-ex/1208.5043.
[10] ATLAS Collaboration, submitted to Eur. Phys. J. C. arXiv:1112.6426.
[11] ATLAS Collaboration, Phys. Lett. B 707 (2012) 330–348. arXiv:1108.6018.
[12] A. Hocker, V. Kartvelishvili, Nucl. Instrum. Meth. A 372 (1996) 469–481. arXiv:hep-ph/9509307.
[13] A. M. Poskanzer, S. Voloshin, Phys. Rev. C 58 (1998) 1671–1678. arXiv:nucl-ex/9805001.