Jet path length dependence in Pb+Pb Collisions with the ATLAS detector

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Abstract

The phenomenon of events containing highly asymmetric dijet pairs is one of the most striking results in heavy ion physics. It has provided the first direct observation of in-medium jet energy loss at the LHC. New results showing the variation of the dijet asymmetry with the angle between the leading jet and the second order Event Plane are presented. This observable effectively probes the path-length dependence of the dijet asymmetry at fixed centrality and can provide a better understanding of the correlation of the parton energy-loss with the underlying geometry. Correlated production of nearby jets is also shown. Two neighbouring jets originating from the same hard scattering should have more similar path lengths in the medium compared to the two jets in the dijet event topology, therefore measuring neighbouring jets may probe differences in quenching that do not result from different path length. The production of nearby jets is quantified using the rate, $R_{\Delta R}$, of “neighbouring” jets that accompany “test” jets. The centrality dependence of $R_{\Delta R}$ as well as the ratios of the $R_{\Delta R}$ values in collisions of different centrality and the values in the 40–80% centrality range are presented.

Keywords: Heavy Ions, Elliptic flow, Dijets, Multijets

1. Introduction

In ultra-relativistic heavy ion collisions the phenomenon commonly referred to as “jet quenching” occurs if partons participating in the hard scattering lose energy in interactions or by induced gluon radiation while traversing the hot and dense medium [1, 2]. Another concurrent phenomenon is the large anisotropy in the distribution of particles in the plane transverse to the beam axis, the so-called “elliptic flow”, or soft particle v_2 [3]. Experimentally the observation of large asymmetrical dijet events was the first indication of jet quenching at LHC [4, 5]. Such an observation was followed by measurements of inclusive jet suppression [6] and the variation of the suppression with the jet azimuthal angle with respect to the elliptic flow plane [7]. The inclusive jet measurements are sensitive to the average partonic energy loss. However, measurements of the dijet imbalance as a function of elliptic flow may provide insight into the physical mechanisms responsible for jet quenching as the collective behaviour of the

produced medium give rise to unequal path lengths of the two parton showers. The latter observable constitutes, thus, a valuable information on the interplay between soft and hard probes of the heavy ion collisions. A complementary observable is the measurement of the correlations between jets that are at small relative angles. Here any different energy losses should originate in other cause as generally the two parton showers will traverse similar path lengths. Both measurements have been performed in Pb+Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV using the ATLAS detector [8] and corresponding to a total integrated luminosity of 0.14 nb^{-1} .

2. Correlation between dijet asymmetry and event shape

The correlation between dijet asymmetry and event shape was motivated by the observed azimuthal dependence of jet yields [7]. In the current analysis the asymmetry is studied for different angles that the leading jet

makes with respect to the second order Event Plane, EP, angle. The idea is that by selecting on the angle between the leading jet and the EP one can have control on the path length traversed by the jet pair. Jet pairs that are out-of-plane traverse more QCD medium than in-plane ones. The strength of this correlation is quantified by fitting the EP-angle dependence of the event averaged dijet asymmetry to a second order harmonic of the form:

$$\langle A_J \rangle = A_J^0 \left(1 + 2c_2 \cos(2(\phi^{\text{lead}} - \Phi_2)) \right), \quad (1)$$

where ϕ^{lead} is the azimuthal angle of the leading jet in the dijet pair and Φ_2 is the second order EP-angle. The coefficient of the second order harmonic, c_2 , quantifies the EP-angle dependence of the dijet asymmetry. The mean value of A_J as a function of the difference between the leading jet and the EP-angle shows a small modulation as can be seen in Fig. 1. In fact the “observed” c_2^{obs} is quite small but is negative, indicating that the asymmetry is slightly larger when the leading jet is out-of-plane than when the jet is in-plane. Figure 2 shows the coefficient c_2 as a function of the collisions centrality for the three jet distance parameters, $R = 0.2, 0.3$ and 0.4 , after correcting for the EP resolution as well as applying Monte Carlo derived correction factors. The corrected c_2 increases in absolute magnitude from central to mid-central events. The line is a fit to a constant function to determine the averaged value of the c_2 over centrality. The maximum $|c_2|$ measured is in the 40–60% centrality range and is approximately 2%. Details of this analysis can be found in [9].

3. Neighbouring jets

While inclusive jet measurements are sensitive to average partonic energy loss and dijet measurements probe differences in quenching due to different path lengths in medium, neighbouring jets probe differences in quenching that do not result from difference in path length. “Neighbour” is a jet that lies away from a “test” jet within a given annulus, ΔR , and $\Delta\phi < \pi/2$. The rate of neighbouring jets that accompany a test jet, $R_{\Delta R}$, is defined by:

$$R_{\Delta R}(E_T^{\text{test}}, E_T^{\text{nbr}}) = \frac{\sum_{i=1}^{N_{\text{jet}}^{\text{test}}} N_{\text{jet},i}^{\text{nbr}}(E_T^{\text{test}}, E_T^{\text{nbr}}, \Delta R)}{N_{\text{jet}}^{\text{test}}(E_T^{\text{test}})} \quad (2)$$

where $N_{\text{jet}}^{\text{test}}$ is the number of test jets in a transverse energy bin, E_T^{test} , and $N_{\text{jet},i}^{\text{nbr}}$ is the number of neighboring jets that accompany that test jet. Figure 3 shows the centrality dependence of the per-test-jet normalised E_T spectra of neighboring jets, with distance parameter

$d = 0.4$, for different lower thresholds of the test jet transverse energy, $E_T^{\text{test}} > 80, 90$, and 110 GeV. The neighboring jet yields have been corrected for combinatorial background (consisting in neighbouring jets that come from different hard scattering) and unfolded for jet E_T bin migration. For the same threshold of the test jet E_T the yield is suppressed with increasing centrality. A systematic difference between the peripheral collisions and the other centralities is observed. These distributions have been fitted to a power-law function, $\propto (1/E_T)^n$, and the power index n was extracted for the three jets distance parameters and centrality bins. Power indices regarding the neighboring jets E_T spectra of peripheral and central collisions differ by two standard deviations for both $d = 0.3$ and $d = 0.4$ jets, suggesting that the E_T spectra are less steep in central collisions [10]. As in the inclusive R_{AA} analysis [6], the $\rho_{\Delta R}$ quantifies the nuclear modification factor of the produced neighbouring jets with the 40–80% centrality range used as the reference. The top panel of Fig. 4 shows $\rho_{\Delta R}$ as a function of the test jet E_T for different thresholds of the neighbouring jet E_T , $E_T^{\text{nbr}} > 30, 45$, and 60 GeV. Within the same centrality range and for the same E_T threshold of the neighbouring jet there is no dependence with test jet E_T within uncertainties. The suppression factor of 0.5–0.7 in central collisions is consistent with the inclusive jet yields result, R_{AA} [6]. The plots in the bottom panel show $\rho_{\Delta R}$ as a function of the neighbouring jet E_T for three thresholds of the test jet E_T . In this case a decrease of the suppression with increasing E_T of the neighbouring jet is observed. Details of this analysis can be found in [10].

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Figure 1: The $\langle A_J \rangle$ as a function of $2|\phi^{\text{lead}} - \Psi_2|$ together with fits to the second order harmonic term. Ψ_2 is the measured second order EP-angle that differs from the “true” second order EP-angle, Φ_2 . The error-bars represent statistical uncertainties only. The fitted c_2^{obs} (i.e., c_2 not corrected for EP-resolution) parameters are also indicated.

Figure 2: The c_2 corrected for the EP-resolution and MC-derived correction factors as a function of centrality. The vertical grey bands indicate systematic uncertainties and the vertical bars indicate statistical errors. The shaded bands indicate the statistical and systematic uncertainties added in quadrature. The three panels correspond to three jet radius distance parameters, as indicated in the plots. Lines show fits to the constant function. The fitted $\langle c_2 \rangle$, averaged over centrality, is also given.

Figure 3: The $dR_{\Delta R}/dE_T^{nbr}$ distributions for $d = 0.4$ jets evaluated as a function of E_T^{nbr} . The three different columns show the $dR_{\Delta R}/dE_T^{nbr}$ distributions evaluated for three different lower bounds on the test-jet transverse energy, $E_T^{test} > 80, 90$, and 110 GeV. The four different centrality classes are denoted by different markers in each plot. The shaded bands indicate systematic uncertainties, vertical error bars represent statistical uncertainties. The data points and horizontal uncertainties for 10–20%, 20–40%, and 40–80% centrality class are shifted along the horizontal axis with respect to 0–10% centrality class for clarity.

Figure 4: The ratio of $R_{\Delta R}$ for three bins of collision centrality to those in 40–80% collisions, $\rho_{R_{\Delta R}} = (R_{\Delta R}|_{cent})/(R_{\Delta R}|_{40-80})$ for $d = 0.4$ jets. The $\rho_{R_{\Delta R}}$ is evaluated as a function of E_T^{test} for three different choices of lower bound on E_T^{nbr} (upper) and as a function of E_T^{nbr} for three different choices of lower bound on E_T^{test} (lower). The shaded bands indicate systematic uncertainties, vertical error bars represent statistical uncertainties. The data points and horizontal uncertainties for 10–20%, 20–40%, and 40–80% centrality class are shifted along the horizontal axis with respect to 0–10% centrality class for clarity.