

Elucidating Jet Energy Loss in Heavy Ion Collisions

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Very soon the LHC will provide beams for heavy ion collisions at 5.52 TeV/nucleon. This center-of-mass energy results in a large cross-section for producing high- E_T (> 50 GeV) jets that are distinct from the soft, underlying event. This brings with it the possibility of performing full jet reconstruction to directly study jet energy loss in the medium produced in heavy ion collisions. In this note, we present the current state of jet reconstruction performance studies in heavy ion events using the ATLAS detector. We also discuss the possibilities of energy loss measurements available with full jet reconstruction: single jet R_{AA} and di-jet and γ -jet correlations.

1. INTRODUCTION

Over the last eight years, the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL) has been providing heavy ion collisions in the attempt to create the Quark-Gluon Plasma (QGP) within the laboratory. Some of the most striking data from the first few years at RHIC were results from the apparent interaction of hard scattered partons in the medium produced at RHIC. Single high- p_T particles are suppressed relative to binary collision-scaled $p + p$ rates[1]; di-jets, measured from pairs of high- p_T hadrons, are suppressed relative to $p + p$ and have a strongly modified angular correlation[2]; and heavy quarks, both charm and bottom, are suppressed as well[3]. These data have been interpreted as the loss of energy of a colored parton traversing a colored medium, analogous to energy loss in QED. However, many of the details underlying QCD energy loss are not well understood. On the one hand, energy loss models are able to reproduce the single particle suppression with very different assumptions on the rate of energy loss[4]. On the other, multiple high- p_T particle correlations may suffer from a bias for the jet to lose little if any energy[5, 6]. This is observed in data where the measured jet properties are quite similar between $p + p$ and $A + A$, and they have only slightly more constraining power on models.

To overcome such biases, it is necessary to move beyond multi-particle correlations and measure jets directly in heavy ion collisions. This note highlights the current status of jet reconstruction and energy loss measurements expected to be made with the ATLAS detector at the Large Hadron Collider (LHC). The large acceptance and nearly hermetic electromagnetic and hadronic calorimeters were designed for jet measurements and are uniquely suited to perform these measurements in heavy ion collisions. Such measurements will result in an increased understanding of how colored partons lose energy in a colored environment, a direct test of QCD.

2. JET RECONSTRUCTION

Unlike e^+e^- annihilation or $p + p(\bar{p})$ collisions, heavy ion collisions result in a large, soft, underlying event. The charge particle multiplicity in central (head-on) $Pb + Pb$ collisions is expected to be between $dN/d\eta=1500-3000$. To put this in perspective, an average of 70-150 GeV would exist in an $R = \sqrt{\Delta\phi^2 + \Delta\eta^2} = 0.4$ radius cone from the underlying event alone. Therefore, jet clustering algorithms must be modified to handle such large backgrounds. Such a modification is not unlike the pile-up event subtraction[7] necessary at full LHC luminosity.

Both a seeded cone algorithm and the k_T algorithm have been explored for use in heavy ion collisions within ATLAS[8]. For the rest of this note we will focus on seeded cone jet results. The underlying event energy is removed by the following steps. First, regions of high energy in the calorimeter are identified as possible regions with a jet. Next, the average E_T from the cells are calculated as a function of η and for each longitudinal calorimeter segment, excluding the regions in the first step. This average is then subtracted from *all* calorimeter cells. Finally, 0.1×0.1 towers in $\Delta\eta \times \Delta\phi$ built from a sum of subtracted cells are used as input to an $R=0.4$ cone algorithm with a tower threshold of $E_T > 5$ GeV.

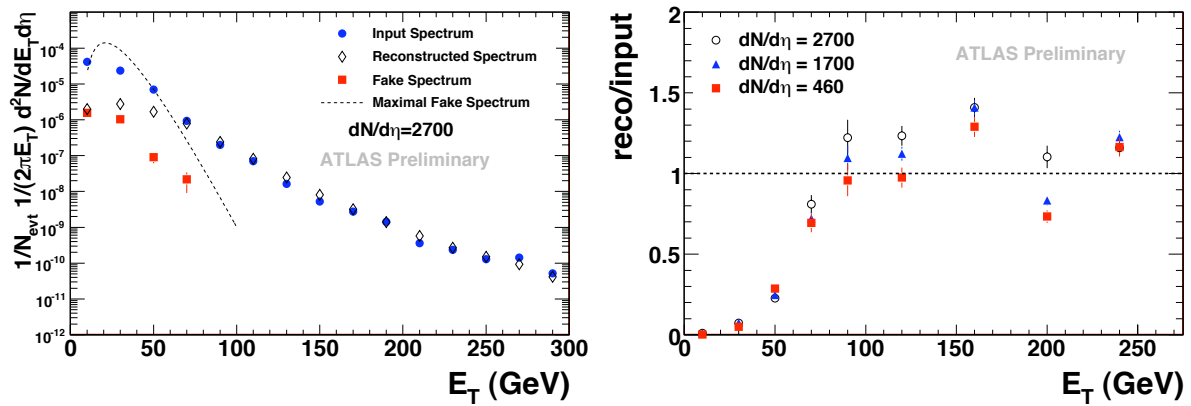


Figure 1: *Left*: Binary-scaled PYTHIA jet spectrum (blue circles) compared to the raw reconstructed spectrum (open diamonds), the maximal fake rate (dashed line), and the residual fake rate (red squares). The raw reconstructed spectrum is uncorrected for efficiency and E_T resolution. *Right*: Ratio of raw reconstructed spectrum to the binary scaled expected spectrum for three different underlying event multiplicities. The 20% difference at $E_T > 70$ GeV before corrections indicates the level of sensitivity expected for jet R_{AA} measurements. The non-statistical fluctuations in the data result from combining data sets from different E_T ranges.

The left panel of Fig. 1 shows the comparison of the input, reconstructed, maximal, and final fake rate spectra. The input and reconstructed distributions are from di-jet PYTHIA events embedded in unquenched HIJING with $dN/d\eta=2700$. The raw reconstructed spectrum is not corrected for efficiency and E_T resolutions. The raw fake spectrum is evaluated by running the jet algorithm with background subtraction directly on unquenched HIJING with a requirement that no jets with $E_T > 10$ GeV are produced. The final fake rate is determined after a cut on the shape of the energy distribution within the jet has been made. Such a cut is also applied to the raw spectrum. For 70 GeV jets, the efficiency is 70%, the energy resolution is 25%, and the fake fraction is 3%.

3. MEASURING JET ENERGY LOSS

Once jets can be reliably measured, their modification due to interactions with the medium will be explored. In this section we discuss modification of single jet rates[9] and the increased acoplanarity of di-jets because of the incoherent multiple scattering in the medium[10].

The right panel of Fig. 1 shows the ratio of raw reconstructed to input spectra. Since the raw spectrum is uncorrected for efficiency and E_T resolution, this represents a worst case scenario in the measurement of the jet R_{AA} defined as

$$R_{AA} = \frac{\text{Yield}_{A+A}}{\langle N_{coll} \rangle \text{Yield}_{p+p}} \quad (1)$$

Such a variable will be sensitive to details of energy loss. For example, if jets were perfectly reconstructed, $R_{AA}=1$. However, because collisional energy loss will impart energy to the medium, all lost energy will not be recovered and $R_{AA} < 1$. Further, energy loss due to radiation outside of the cone size or the jet area will cause $R_{AA} < 1$ of jets. A non-perturbative energy loss scenario based on AdS/CFT arguments would result in an $R_{AA} \ll 1$ [11]. Therefore, studying the jet R_{AA} as a function of cone size, seed E_T , etc. should be sensitive to the details of jet energy loss[9].

Fig. 2 shows two examples of jet azimuthal decorrelations to be measured in ATLAS. The left panel shows the reconstructed di-jet and the right panel shows the reconstructed γ -jet $|\Delta\phi|$ distributions. In a $2 \rightarrow 2$ process, the produced hard scattering products are directly back-to-back, *i.e.* at $|\Delta\phi| = \pi$. Initial and final state radiation results in a natural broadening to this distributions. Further, radiation from in-medium energy loss will also broaden

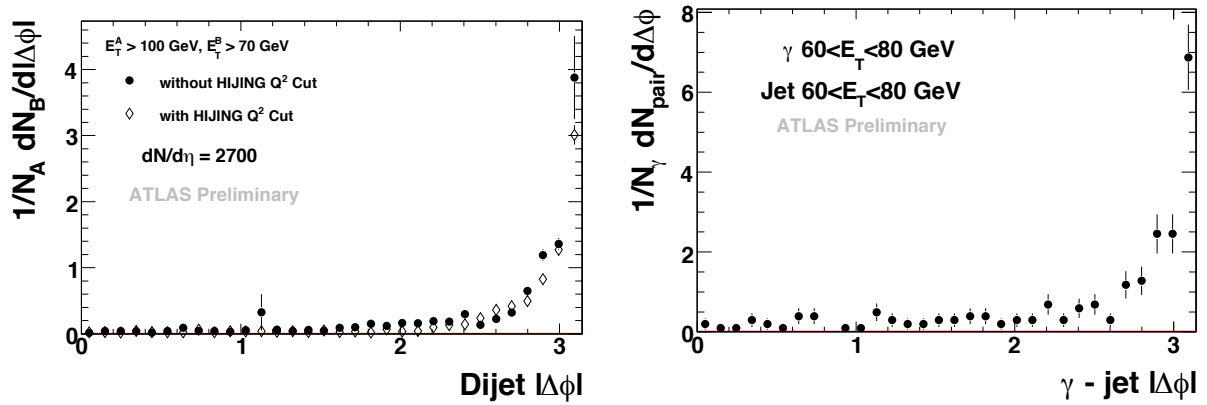


Figure 2: *Left*: Correlations between pairs of reconstructed jets for “trigger jet” $A > 100$ GeV and “associated jet” $B > 70$ GeV. *Right*: Correlations between reconstructed isolated photons and reconstructed jets for both the γ and jet from 60-80 GeV. The clear peaks at $\Delta\phi = \pi$ are indicative of $2 \rightarrow 2$ hard scattering. Multiple scattering and incoherent energy loss is expected to broaden these distributions[10].

this distribution[10]. However, this broadening has not been measured at RHIC[12]. This could indicate that the broadening is small or it is a consequence of the bias to little energy loss of the two-particle correlation measurements.

4. CONCLUSION

ATLAS expects to perform ground breaking measurements in QCD energy loss studies using fully reconstructed jets. This note highlighted the current status of cone jet reconstruction and measurements of jet rates and jet correlations as sensitive tests of QCD energy loss.

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