Measurement of multijets and the internal structure of jets at ATLAS

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1 Introduction

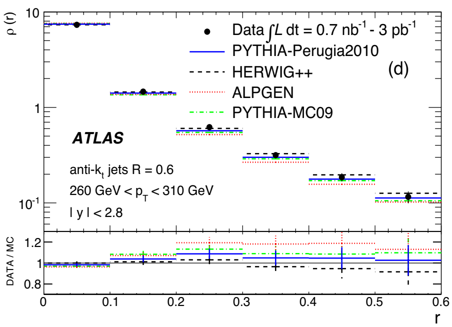
Studies of the jet shapes, internal structure of jets, and of events with high jet multiplicities, provide a stringent test of QCD at the Large Hadron Collider (LHC). These important standard model processes may also hide, or reveal, new physics. We present measurements of jet shapes, multijet cross sections and distributions, of the subjet structure in high-p_T jets, and of the distribution of charged particle inside jets, with the data recorded by the ATLAS experiment in 2010 and 2011, in proton-proton collisions at $\sqrt{s} = 7$TeV.

2 Jet Shapes Measurement

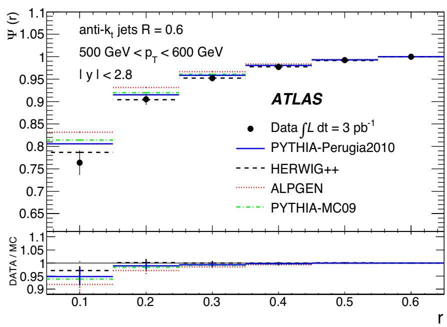
At high energies, the jet shape is determined by multigluon emissions from primary parton whereas fragmentation is sub-leading. Measurement of the jet shapes at the LHC provides a test of parton shower models and their implementation. The jet shape is sensitive to the quark/gluon final state mixture and the running of strong coupling constant, α_s. Since gluons radiate more than quarks, the shape of the jet initiated from a gluon is broader. However, the jet shapes is also sensitive to underlying event in the final state. The ATLAS measurement [1], is based on 0.7 nb^{-1} to 3 pb^{-1} of data, depending on the jet transverse momentum p_T bin. One and only one vertex is required to select events to avoid pile-up. Jets are reconstructed using the Anti-kT algorithm with distance parameter (in $y - \phi$ space) R=0.6 and $p_T > 30$GeV and rapidity in the region $|y| < 2.8$. The data are corrected for detector effects and compared to several leading-order QCD matrix elements plus parton shower Monte Carlo predictions.

Both differential and integrated jet shapes have been measured as a function of jet p_T and y, as examplified in Figure 2. Error bars indicate the statistical and systematic uncertainties added in quadrature. The predictions of PYTHIA-Perugia2010 (solid lines), HERWIG++ (dashed lines), ALPGEN interfaced with HERWIG and JIMMY (dotted lines), and PYTHIA-MC09 (dashed-dotted lines) are shown for comparison.

The measured jets become narrower with higher p_T and the jet shapes present a moderate jet rapidity dependence. The full set of data points (124 tables) have been made available in the Durham repository as inputs to new Monte Carlo tunes. As Pythia-Perugia2010 tune described the data best, it was selected to unfold jet cross-section measurement, [6]. Recently, a comparison to new tunes have been provided in [5].



(a) The measured differential jet shape, $\rho(r)$, in inclusive jet production for jets with $|y| < 2.8$ and $260 < p_T < 310$GeV.



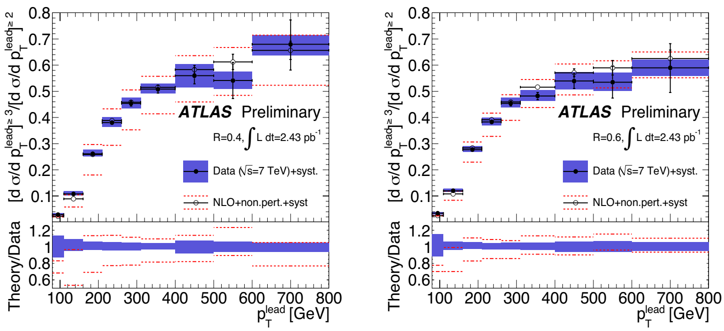
(b) The measured integrated jet shape, Psi(r), in inclusive jet production for jets with $|y| < 2.8$ and $500 < p_T < 600$GeV.

Figure 1: Examples of the differential and integrated jet shapes, compared to various Monte Carlo predictions for Anti-Kt jets with R=0.6.

3 Multi-Jets Measurement

Multi-jets probe high-order perturbative QCD. Multi-jet cross-section ratios are calculable at next-to-leading order (NLO) can be used to extract α_s. It is also useful to understand multi-jets as a background to new physics. In this measurement, the jet measurements are corrected for all experimental effects and are unfolded to the particle-level final state. Jets are reconstructed with the Anti-kT algorithm with R=0.4 using topological calorimeter clusters as input and event with upto 6 jets in the final state are considered. Also Anti-kT jets with R=0.6 employed for the NLO analysis, which focuses on 3 jet events. Only data selected using multi-jet triggers with symmetric p_T thresholds, at Level 1 of the trigger chain are used to reduce sensitivity to detailed modeling of the HLT performance. At least one vertex with 5 tracks is required to get rid of beam background and jets with $|y| < 2.8$ and $p_T > 60$GeV are used after cleaning cuts, against calorimeter noise, cosmics and beam background. The Jet Vertex Fraction cut, which requires 70% of the associated charged particles to come from the event vertex is employed. Events with at least 2 good jets, with at least one jet $p_T > 80$GeV are selected and jet energies are calibrated using a MC-based calibration which is the source of the main systematic: JES (Jet Energy Scale), [8, 7]. This measurement corresponds to an integrated luminosity of 2.43pb^{1}, [2].

The differential cross-section versus leading, second, third and fourth leading jet have been measured as a function of jet p_T. The agreement between data and Alpgen is observed to be good. Also the differential cross-section for events with 2 or more, 3 or more and 4 or more jets have been presented as a function of H_T, the scalar sum of the p_T of the selected jets in the event. H_T is a useful quantity to characterize the phase-space of QCD. For both cross-section measurements, PYTHIA-AMBT tune is observed to be steeper than data. Here, in Figure 3, the ratio of the three-to-two jet differential cross-section is presented. The results are compared to next-to-leading-order pQCD calculations with the MSTW 2008 NLO pdf set. The systematic uncertainties on the theoretical prediction are shown as dotted red lines above and below the theoretical prediction. With the current statistics, there is yet no sensitivity to α_s. The results have been updated with more statistics in [4] since the PLHC conference.



(a) Anti-Kt jets with R=0.4

(b) Anti-Kt Jets with R=0.6

Figure 2: Ratio of the three-to-two jet differential cross-section ratio as a function of the leading jet p_T. A plot of the ratio of the next-to-leading-order calculation to the data is presented in the figure beneath.

4 Measurement of Jet Mass and Substructure

A measurement of the jet mass and substructure can help identify boosted objects which can decay hadronically such as the top quark and electroweakscale objects created well above threshold such as the Higgs boson. For a study of substructure, it is useful to define the splitting scale as $\sqrt{d_{12}} = min(p_{Ta}, p_{Tb}) \times \delta R_{a,b}$, where a and b are the two jets before the final clustering step. As such boosted objects can be wide, it is important to study different jet algorithms with large radius to understand their performance. In this study, Cambridge/Aachen with and without filtering and Anti-Kt algorithms were considered with radius of R=1.0 or 1.2. The Cambridge/Aached filtering searches for mass splittings with large mass difference and reclusters while filtering out large angle radiation and also requies that $R_{qq} > 0.3$. As the Jet Energy Scale (JES) and Resolution (JER are only provided for jets reconstructed with Anti-Kt the JES and JER for the Cambridge/Aachen jets had to be determined separately for this analysis. Jets with $|y| < 2.0$ and $p_T > 300$GeV were considered and since $\delta R \approx 2m/p_T$, this method is sensitive to object masses of ≈ 100GeV. The events in the study were selected using the highest unprescaled jet trigger, L1_J95, efficient for jets with $p_T > 300$GeV for large jet radius and after a requirement of exactly one primary vertex to avoid pile-up. This measurement, [3] corresponds to an integrated luminosity of 35 pb^{-1}.

In Figure 4, the invariant mass spectrum and $\sqrt{d_{12}}$ spectrum for anti-kt jets with R=1.0, $p_T > 300$GeV and $|y| < 2$, is shown. A good aggrement between data and various Monte Carlo models is observed and is encouraging for future studies. Cambridge/Aachen filtering has been shown to be effective against pile-up and will be used in new physics searches.

5 Conclusions

In this paper, results were presented on jet shapes, multi-jet measurements and jet mass and structure measurements with the ATLAS detector at the Physics at the LHC Conference in Perugia, Italy, in June 2011. These three measurements show that good agreement can be achieved between data and some Monte Carlo predictions. The jet shapes have since been used as a default input into Monte Carlo tunes. The other jet measurements will continue to be updated as ATLAS accumulates more statistics.

References

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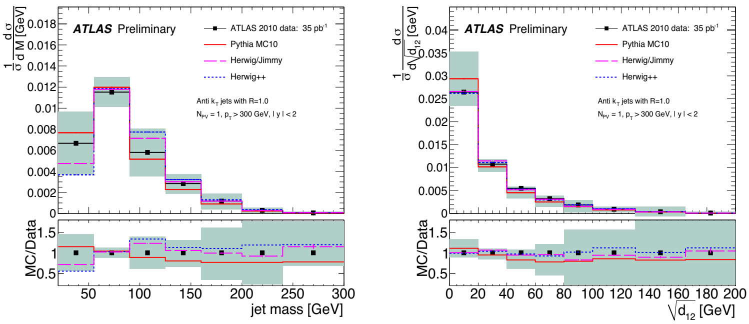

(a) Invariant mass spectrum

(b) $\sqrt{d_{12}}$ spectrum

Figure 3: Invariant mass spectrum and $\sqrt{d_{12}}$ spectrum for anti-kt jets with R=1.0, $p_T > 300$GeV and $|y| < 2$, fully corrected for detector effects. Systematic uncertainties are depicted by the shaded band

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