Inclusive jet cross section measurement in ATLAS

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Abstract. The inclusive jet cross section has been measured in proton-proton collisions at a center-of-mass energy of 7 TeV using the ATLAS detector at the LHC. The full 2010 data set has been used, consisting of a total integrated luminosity of 37 pb$^{-1}$. The anti-$k_t$ algorithm is used to identify jets with two jet radius parameters, R = 0.4 and R = 0.6. Jet shapes have been measured in order to validate the models for parton shower, fragmentation into hadrons, and the underlying event contributions contained in the event generators. The inclusive jet cross section measurement is presented as a function of jet transverse momentum and rapidity, for jets with transverse momentum from 20 GeV to 1.5 TeV in a rapidity range $|y|$ up to 4.4. The data are compared to expectations based on next-to-leading order QCD corrected for non-perturbative effects, and to predictions obtained using POWHEG. In addition to a validation of the theory in a new kinematic regime, the data also provide sensitivity to parton distribution functions in a region where they are currently poorly constrained.

1. Introduction
The jet cross section measurement is a fundamental test of QCD and any deviation could point to the presence of new physics. It also provides information on the parton distribution functions (PDFs) and the strong coupling.

The first measurement of the inclusive jet cross section in ATLAS was done using an integrated luminosity of about 17 nb$^{-1}$ for jets with $p_T > 60$ GeV and $|y| < 2.8$ [1]. In this article, a measurement of the inclusive jet cross section for jets with $p_T > 20$ GeV and $|y| < 4.4$ [2] is presented, based on 37.3±1.2 pb$^{-1}$ of integrated luminosity collected by ATLAS. The ATLAS detector is described in these proceedings [3].

2. Jet reconstruction and calibration
Jets are reconstructed using the anti-$k_t$ algorithm, with jet radius parameter $R = 0.4$ and $R = 0.6$, run over calorimeter topoclusters [3]. The analysis is based in the full 2010 data set of pp collisions at $\sqrt{s} = 7$ TeV collected by the ATLAS detector, corresponding to an integrated luminosity of about 37 pb$^{-1}$. Events are considered when the detector components relevant for this analysis were operating at the nominal conditions.

Events are then required to have at least one primary vertex with five or more tracks pointing to it in order to remove backgrounds such as cosmic ray muons. For events containing a jet with $p_T > 20$ GeV, this requirement has an efficiency well above 99%.

Jets with calibrated $p_T > 20$ GeV and $|y| < 4.4$ are selected, and required to pass quality criteria established to reject jets not coming from a proton-proton collision. Fake jets may
originates from rare noise bursts in the calorimeter, cosmic rays or beam background. A detailed description of the jet energy calibration can be found in another article of these proceedings [4].

Due to the increase of the instantaneous luminosity during 2010, it became necessary to apply prescales to some triggers used in this analysis in order to limit their trigger rate. For each jet $p_T$ and rapidity bin, a trigger is used to select jets such that is fully efficient ($>99\%$) and that the prescale is as low as possible. Prescales are taken into account in the luminosity calculation.

3. Unfolding to the particle level
Measurements are corrected for detector effects back to the particle level with a bin-by-bin unfolding procedure, using PYTHIA 6.423 with the AMBT1 tune simulated samples. In order to improve the agreement between the MC and the data, the MC is reweighted in order to scale its prediction, that uses a modified LO PDF, to that of a NLO PDF. The hadronization corrections are derived in each $p_T$ and $|y|$ bin by computing the ratio between the inclusive jet $p_T$ distributions using truth jets (including muons and neutrinos) and using calorimeter simulated jets.

In order to justify this procedure, it is important to validate the QCD description contained in the event generators, such as parton shower cascades, and the fragmentation and underlying event models. This is done in the measurement of jet shapes in proton-proton collisions at $\sqrt{s} = 7$ TeV presented in [5]. This measurement is based on data collected by the ATLAS experiment corresponding to 3 pb$^{-1}$ of total integrated luminosity, and uses jets reconstructed with the anti-$k_t$ algorithm with $R = 0.6$, in the kinematic range $30$ GeV < $p_T$ < $600$ GeV and $|y| < 2.8$. The events are required to have one and only one reconstructed primary vertex with a z position within 10 cm of the origin of the coordinate system, which suppresses pile-up contributions from multiple proton-proton interactions in the same bunch crossing, beam-related backgrounds and cosmic rays. The differential jet shape in four representative jet $p_T$ bins is shown in Figure 1. The differential jet shape $\rho(r)$ as a function of the distance $r = \sqrt{\Delta y^2 + \Delta \phi^2}$ to the jet axis is defined as the average fraction of the jet $p_T$ that lies inside an annulus of inner radius $r - \Delta r/2$ and outer radius $r + \Delta r/2$ around the jet axis. The dominant peak at small $r$ indicates that the majority of the jet momentum is concentrated close to the jet axis. As expected, jets get narrower as the $p_T$ increases. The data are compared to predictions from HERWIG++, ALPGEN, PYTHIA-Perugia2010, and PYTHIA-MC09. The jet shapes predicted by PYTHIA-Perugia2010 provide a reasonable description of the data, while HERWIG++ predicts broader jets than the data at low and very high $p_T$. ALPGEN is similar to PYTHIA-Perugia2010 at low $p_T$, but produces jets significantly narrower than the data at high $p_T$. PYTHIA-MC09 tends to produce narrower jets than the data in the whole kinematic range under study. Apart from the results reported in [5], jet shapes at calorimeter level have been computed for $|y| > 2.8$ in order to validate the MC samples in the forward region.

4. Systematic Uncertainties
- The JES uncertainty is the largest contribution to the uncertainty of the inclusive jet cross section measurement. At low $p_T$ it goes from $+30\%/-20\%$ in the central region to $+80\%/-50\%$ in the most forward region, and decreases with increasing jet $p_T$.
- The unfolding factors have been recomputed varying the jet $p_T$ in the MC in order to take into account the jet energy and angular resolution, and the differences on the cross section shape in data and in MC. These unfolding factors have been compared to estimate the systematic uncertainty, that is typically between 2\% and 5\%, except for the lowest $p_T$ bin where it goes up to 20\%.
- The uncertainty on the luminosity measurement is 3\%.
The efficiency of matching track jets to calorimeter jets has been evaluated in both data and Monte Carlo to estimate the modeling of the calorimeter jet reconstruction efficiency in the MC. The difference is smaller than 2% (3%) for jets with $p_T > 20 \text{ GeV}$ (30 GeV), and is taken as a systematic uncertainty.

In this analysis, jets are selected with triggers that are 99% efficient. A conservative 1% uncertainty overall has been considered to account for the trigger inefficiency.

The systematic uncertainty on the efficiency of the jet quality criteria is taken as a systematic uncertainty on the cross section, and it is always below 1%.

5. Results and conclusions

The inclusive jet cross section unfolded to the hadron level as a function of the jet $p_T$ is shown in Figure 2 for different $|y|$ regions up to $|y| < 4.4$. It is measured from 20 GeV to 1.5 TeV and spans up to ten orders of magnitude. The data are compared to NLO predictions corrected for non-perturbative effects. The NLO predictions are obtained from NLOJET++4.1.2 program with CTEQ 6.6 PDFs, and the corrections for non-perturbative effects are derived using samples produced with PYTHIA 6.423 with the AMBT1 tune and applied to NLO predictions. These corrections are obtained bin-by-bin, comparing the cross section with and without hadronization and underlying event. The correction is dominated by the underlying event at low $p_T$ (1.5 at 20 GeV), and tends to 1 as the $p_T$ increases. The uncertainty on the NLO predictions is obtained adding in quadrature uncertainties from the PDFs, the choice of factorization and renormalization scales, and the value of the strong coupling constant. It is combined with the uncertainty on the non-perturbative corrections, estimated from the maximum difference of the corrections with AMBT1 with respect to other PYTHIA tunes and to HERWIG++. The total uncertainty in the predictions is typically between 10% and 20%.

Figure 3 shows the ratio of the measured cross section in data and the theory prediction, that are in agreement within uncertainties. The cross section in data is lower than the cross section predicted by NLO predictions in the forward region and at high $p_T$.

In Figure 4, data are compared to results using CTEQ 6.6, MSTW 2008, NNPDF 2.1, and HERAPDF 1.5. All cross sections are normalized to that obtained with CTEQ 6.6. Predictions using MSTW 2008, NNPDF 2.1, and HERAPDF 1.5 are closer to data than those using CTEQ 6.6, but all have the tendency to produce higher cross sections than data at high $p_T$ in the forward region. This may be due to the fact that PDFs are currently poorly constrained in this kinematic region.

Finally, Figure 5 shows the comparison of data and POWHEG predictions with MSTW 2008. POWHEG is showered with both PYTHIA and HERWIG. Data are also compared to NLO predictions with MSTW 2008, used to normalize both data and POWHEG predictions. Even if POWHEG predictions agree with data within uncertainties, they tend to produce larger cross section at low $p_T$ and, mainly POWHEG+HERWIG, smaller cross sections at high $p_T$. POWHEG predictions are different depending on whether they are showered with PYTHIA or HERWIG.

References

[1] The ATLAS Collaboration, Measurement of inclusive jet and dijet cross sections in proton-proton collisions at 7 TeV center-of-mass energy, with the ATLAS detector, Eur. Phys. J. C 71 2 1512 (2011)

[2] The ATLAS Collaboration, Measurement of inclusive jet and dijet cross sections in proton-proton collision data at 7 TeV center-of-mass energy using the ATLAS detector, ATLAS-CONF-2011-047 (2011): http://cdsweb.cern.ch/record/1338578

[3] Peter Loch, Jet measurements in ATLAS, 2011 (these proceedings)

[4] Doug Schouten, In-situ measurements of the jet energy scale in ATLAS, 2011 (these proceedings)

[5] The ATLAS Collaboration, Study of jet shapes in inclusive jet production in pp collisions at $\sqrt{s} = 7 \text{ TeV}$ using the ATLAS detector, Phys. Rev. D 83 052003 (2011)
Figure 1. The measured differential jet shape, $\rho(r)$, in inclusive jet production for jets with $|y| < 2.8$ in six representative $p_T$ bins. 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.
Figure 2. Inclusive jet cross section as a function of $p_T$ in different regions of $|y|$ for jets identified using the anti-$k_t$ algorithm with $R = 0.4$ (top) and $R = 0.6$ (bottom). For displaying purposes, the cross sections are multiplied by the factors indicated in the legend. NLO QCD calculations with additional non-perturbative corrections are overlaid on top of the data. The error bars indicate the statistical uncertainty on the measurement, and the shaded band indicates the quadratic sum of the systematic uncertainties. The data points do not include an overall uncertainty of 3% due to the luminosity measurement.
Figure 3. Inclusive jet cross section as a function of $p_T$ in different regions of $|y|$ for jets identified using the anti-$k_T$ algorithm with $R = 0.4$ (top) and $R = 0.6$ (bottom). The plots show the ratio of the data to the theoretical prediction. The error bars indicate the statistical uncertainty on the measurement, and the shaded band indicates the quadratic sum of the systematic uncertainties. The data points do not include an overall uncertainty of 3% due to the luminosity measurement.
Figure 4. Inclusive jet cross section as a function of $p_T$ in different regions of $|y|$ for jets identified using the anti-$k_t$ algorithm with $R = 0.4$ (top) and $R = 0.6$ (bottom). The theoretical error bands obtained by using different PDF sets (CTEQ 6.6, MSTW 2008, NNPDF 2.1, HERA 1.5) are shown. The data points and the error bands are normalized to the theoretical estimates obtained by using the CTEQ 6.6 PDF set.
Figure 5. Inclusive jet cross section as a function of $p_T$ in different regions of $|y|$ for jets identified using the anti-$k_t$ algorithm with $R = 0.4$ (top) and $R = 0.6$ (bottom). The ratios of the POWHEG predictions showered by PYTHIA and HERWIG and the data to the NLO predictions corrected for the non-perturbative effects is shown. The ratio shows only the statistical uncertainty on the POWHEG prediction. The total systematic uncertainties on the theory and measurement are shown.