ATLAS measurements of photons, jets and subjets

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Abstract

Comprehensive measurements of inclusive and dijet cross sections are presented, spanning the dijet mass range from 70 GeV to 4 TeV. Inclusive photon and diphoton cross sections have also been measured over a wide range of mass and transverse momentum, using proton-proton collisions at $\sqrt{s} = 7\,\text{TeV}$ at the LHC. These measurements constitute precision tests of QCD in a new energy regime, and show sensitivity to the parton densities in the proton. In addition, charged particles, subjets and jet shapes have been measured, to investigate jet fragmentation and to study new variables developed to reduce sensitivity to soft QCD and pileup, and to improve the identification of boosted heavy particles decaying to hadrons.

1 Introduction

Measurements of prompt photons and jets at the LHC provide precision tests of perturbative QCD and help constrain the parton densities in the proton in a new kinematic regime. For example, photon production with an associated jet is particularly sensitive to the gluon content and photon fragmentation function. Quantifying the detector response to photons and jets not only improves the calibration, but aids understanding of backgrounds to key channels such as Higgs ($H \to \gamma\gamma$), and to searches for new physics beyond the Standard Model. The composite nature of jets formed by two- and three- body decays enables boosted objects to be identified from their jet substructure, which differs to that from quark and gluon initiated jets. These proceedings begin with a synopsis of the reconstruction methods before summarizing the latest ATLAS measurements of photon and jets, and finally recent studies of jet substructure are reviewed.

2 Photon and jet reconstruction and calibration

Photons are reconstructed in ATLAS [1] using a finely segmented, multi-layer liquid argon-lead sampling calorimeter, in which the lateral and longitudinal shower shapes allow suppression of hadronic background. Photon showers are measured inside a cone of angular radius $R = \sqrt{(\eta - \eta^{\gamma})^2 + (\phi - \phi^{\gamma})^2} < 0.4$, centred around the photon direction in the (η) pseudorapidity and azimuthal angle (ϕ) plane. Isolated photons are identified if the transverse energy within this cone is less than 3 GeV, after removing the central core of photon energy.

Jets are reconstructed as four-vector summations of noise-suppressed three dimensional calorimeter clusters, grouped by the anti-k_t or Cambridge-Aachen clustering algorithm [2]. The jet energy scale is derived from the simulation with an uncertainty of $< 5\%$ after corrections for the non-compensating calorimeter, dead material, out-of-cone effects and pile-up, and is validated in-situ using the photon+jet and Z+jet direct transverse momentum balance [3, 4].

3 Measurements

3.1 Photons

The kinematic reach of prompt photon measurements has been extended from a photon transverse energy E_{T} of $15-100$ GeV [5] to the range $45-400$ GeV [6, 7] and the measurements are consistent in the overlap bins. Some discrepencies are apparent below 25 GeV for central photons, which has helped to constrain the gluon parton distribution functions (PDFs) [8].

Differential diphoton cross-section measurements [9] generally agree well with the DIPHOX and ResBos next-to-leading-order (NLO) predictions, except for a discrepancy at low azimuthal separation $\Delta\phi_{\gamma\gamma}$, as shown in Fig 1. The discrepancy is improved by $\gamma\gamma$NNLO calculations [10].

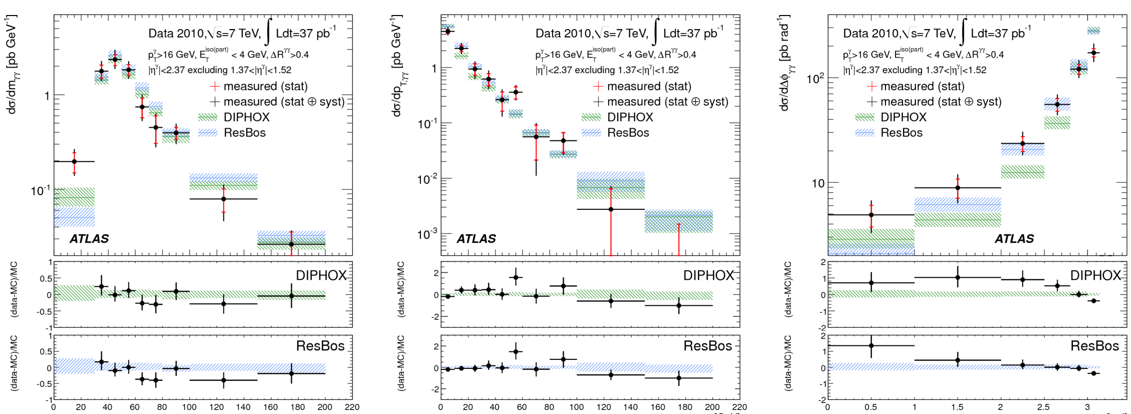

Figure 1: Differential diphoton cross-section as a function of diphoton invariant mass $m_{\gamma\gamma}$, total transverse momentum $p_{\mathrm{T}_{\gamma\gamma}}$ and azimuthal separation $\Delta\phi_{\gamma\gamma}$ [9].

In a recently published analysis [11] of the first 37 pb^{-1} recorded by ATLAS, the cross section for the production of an isolated photon associated with jets is calculated in six different angular configurations of the jet and photon rapidity. This division of the phase space enables access to regions of differing fragmentation contributions and parton momentum fractions. NLO pQCD predictions are found to be in fair agreement with the data, except for photon transverse energy $E_T^\gamma \leq 45$ GeV, where theory overestimates the measured cross section, again indicating that NNLO predictions are necessary.

3.2 Jets

Existing ATLAS measurements of inclusive and dijet jet cross sections [12] have been extended [13] to include jet rapidities up to $|y| < 4.4$ and to span jet transverse momenta from 20 GeV to 1.5 TeV and dijet masses from 70 GeV to 5 TeV. Comparisons with NLO pQCD predictions show good agreement over many orders of magnitude, covering $7 \times 10^{-5} < x < 0.9$ in the parton momentum fraction.

The 2011 data corresponding to $4.8 \pm 0.2\,\text{fb}^{-1}$ were used to measure the dijet double-differential cross section [14] as a function of m_{12}, the invariant mass of the

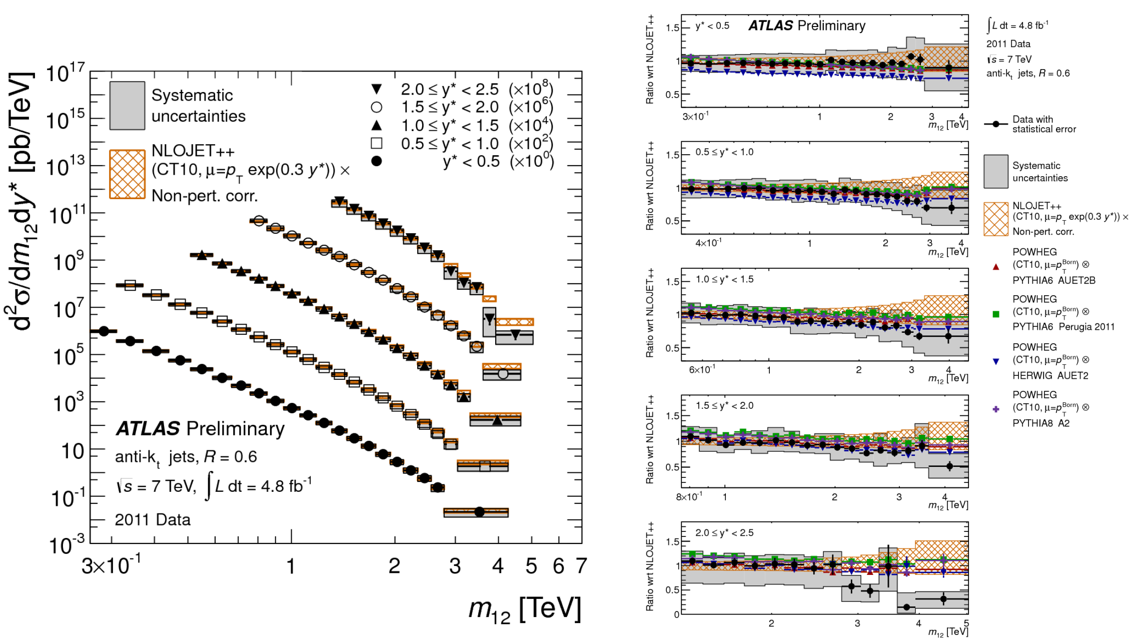

Figure 2: Dijet double-differential cross section as a function of dijet mass, binned in half the absolute rapidity difference between the two leading jets, $y^* = \frac{|y_1 - y_2|}{2}$. The results are shown for jets identified using the anti-k_t algorithm with R = 0.6. [14].

two leading (highest transverse momentum) jets. The cross-sections shown in Fig 2 are binned in y*, which is half the absolute rapidity difference between the two leading jets. In general there is good agreement between data and NLO pQCD predictions including non-perturbative corrections, while a negative trend emerges in data at large y*and m_{12}.

3.3 Subjets

When a heavy object decays hadronically the Lorentz boosted products are typically so tightly collimated that they are reconstructed as a single merged jet in ATLAS. The mass and internal substructure of composite jets can be exploited to identify boosted objects of interest, while suppressing hadronic background. Recent measurements [15] of the jet mass were made in the p_T range 200 − 600 GeV and are shown in Fig 3 for a restricted window of 300 − 400 GeV. While PYTHIA [16] tends to be too soft and HERWIG++ [17] too hard, applying splitting and filtering [18] recovers the constituent subjets and improves the agreement with the prediction.

A deeper insight into jet properties has been gained by direct measurements [19] of subjet characteristics and simulation studies of correlations between the key variables, including: angularity, planar flow, eccentricity, width, p_T and mass. The studies show that splitting and filtering largely eliminates the dependence of the jet mass on pile up interactions.

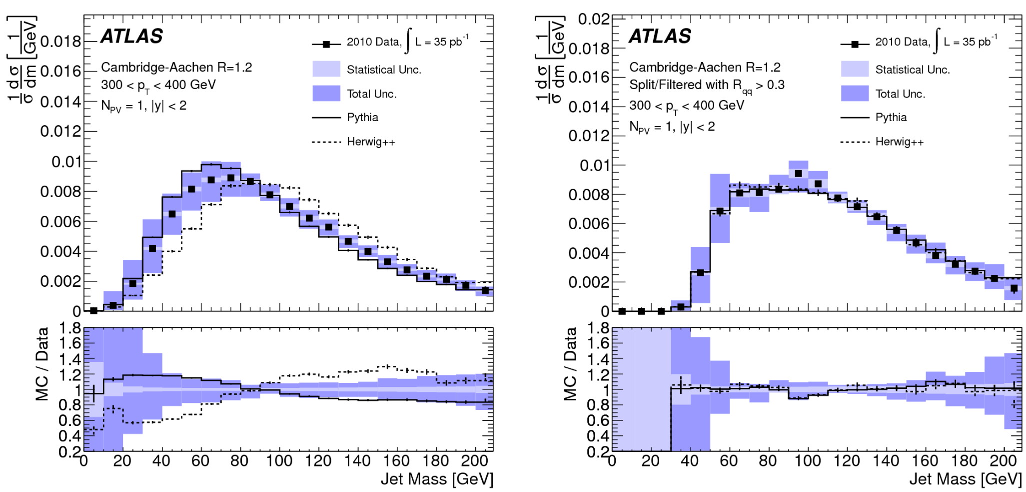

Figure 3: Normalised cross-section as a function of mass of *Cambridge-Aachen* jets with $R = 1.2$, before (left) and after (right) splitting and filtering [15].

4 Conclusion

Comprehensive measurements of photons, jets and subjets provide precision tests of perturbative QCD in a new kinematic regime. The photon and diphoton cross sections have helped constrain the gluon parton distribution functions and indicate NNLO calculations are necessary to best describe the data. Measurements of inclusive and dijet cross sections agree well with NLO pQCD over many orders of magnitude, while constraining parton distribution functions for high mass dijets. Jet substructure observables have been measured leading to improved understanding of jet substructure techniques, which are useful for identifying boosted hadronic topologies in seaches for new physics.

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