Jet and photon physics in ATLAS and CMS

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Differential cross-section measurements of jet and photon production and jet substructure observables are multi-faceted physics analyses that can be used to probe the strong coupling and proton structure, to test new theoretical predictions and to improve non-perturbative models. This contribution presents highlights from new measurements by the ATLAS and CMS collaborations at the LHC.

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1 Introduction

Differential cross-section measurements of jet and photon production and jet substructure observables are multi-faceted physics analyses that are used to probe the strong coupling (α_S) and proton structure, test new theoretical predictions, and improve non-perturbative models. The range of physical scales probed by such measurements can span orders of magnitude, from the highest-energy interactions produced by the LHC to the softest emissions within jets that are sensitive to models of hadronisation. Several new jet and photon cross-section measurements from the ATLAS [1] and CMS [2] collaborations at the LHC are summarized in these proceedings.

2 CMS inclusive jet cross-section measurement

The CMS Collaboration has recently published a double-differential measurement of the inclusive jet cross-section in early Run 2 data[3] for anti-k_t jets with radius parameters $R = 0.4$ and $R = 0.7$ in bins of transverse momentum (p_{T}) and absolute jet rapidity ($|y|$). Jets within the central detector region ($|y| < 2.0$) are selected if their p_{T} is greater than 97 GeV.

The use of different jet radii for such measurements results in data that are sensitive to different QCD effects: $R = 0.4$ jets are more sensitive to fragmentation effects producing out-of-cone radiation, while $R = 0.7$ jets receive larger non-perturbative corrections due to multi-parton interactions (MPI). In both cases, large uncertainties related to the choice of Parton Distribution Functions (PDFs) are observed for events with high-p_{T} jets, indicating sensitivity of the measured data to the high-x gluon PDF. The availability of complementary measurements with multiple jet radii will benefit future QCD studies such as PDF fits and Monte Carlo tunes.

The measured data are compared to fixed-order QCD predictions of the inclusive jet cross-section at next-to-leading-order (NLO) and next-to-next-to-leading-order (NNLO) in order to simultaneously fit PDFs (at NLO), extract α_S (at NNLO and NLO) and/or top quark mass m_t (at NLO). These extractions also include inclusive deep inelastic scatting cross-section data from HERA and top quark pair production triple-differential cross-section data previously measured by CMS [4]. The extracted value of α_S at NNLO is $\alpha_S = 0.1170 \pm 0.0019$ (NNLO), where the uncertainty is dominated by fit-related contributions.

The measured data are demonstrated to provide additional sensitivity to the high-x gluon PDF. This reduces systematic uncertainties in a simultaneous fit for α_S and m_t at NLO, compared to a previous CMS study that fit only top cross-section data. A third study presented in this result also constrains possible contributions from BSM effects simultaneously with PDFs and α_S, providing an interpretation in terms of limits on four-quark contact interactions in a Standard Model Effective Field Theory.

3 ATLAS diphoton differential cross-section measurement

Diphoton production is a critical background for precision Higgs physics, and provides a complementary handle on QCD dynamics with colourless probes. The ATLAS collaboration has recently published a differential cross-section measurement of isolated photon pairs [5].

The non-prompt photon background from jets is estimated using a Poisson likelihood fit in uncorrelated isolation and identification observables for each photon, in each analysis bin. Systematic uncertainties related to this fit are the dominant source throughout most of the analysis. The uncertainty for extreme values of certain observables (*e.g.* at large $m_{\gamma\gamma}$) remains statistically limited. The small but non-negligible background of photon production from uncorrelated pile-up interactions is also estimated with a data-driven approach, using tracking and calorimeter-pointing information from converted photons.

The measured data are compared to several predictions including fixed-order calculations from NNLOJET (NNLO) and DIPHOX (NLO) as well as to updated predictions from the SHERPA Monte Carlo generator (v2.2). The binning of the measurement is extremely fine, made possible by the excellent detector resolution of ATLAS and the large Run 2 dataset statistics. Good agreement is observed between the data and predictions with the highest theoretical precision. The NNLOJET predictions tend to provide the best description of regions dominated by perturbative QCD effects, while the SHERPA predictions provide a good description of regions sensitive to collinear and soft emissions due to the inclusion of QCD resummation effects through the parton shower (PSD).

4 CMS jet angularities cross-section measurement

The CMS Collaboration has recently published a differential measurement of generalized jet angularities [6]. These jet substructure observables are measured in both dijet and Z+jet events, providing measurements in samples with different admixtures of quark and gluon jets.

Predictions from several MC generators are also compared to the measured data, and many aspects of the jet definitions are varied (jet radius, soft-drop grooming [7], charged *vs.* all jet constituents, *etc.*). The description of the measured data by the various MC generators is

found to strongly depend on the quark/gluon composition of the underlying samples. The three IRC-safe observables measured in this study are compared to new QCD predictions with next-to-next-to-leading-logarithmic analytical resummation in the Z+jets sample [8]. Agreement between the measured data and theoretical predictions is found to depend on the angular weighting parameter β used to construct angularity observables. The agreement is found to be best for the jet thrust ($\beta = 2$), while the description of the Les Houches Angularity is poorer ($\beta = 0.5$). This is likely attributable to the LHA's sensitivity to emissions in the core of jets, which has been previously noted in phenomenological studies [9].

ATLAS and CMS have both recently made measurements of jet substructure observables using only charged jet constituents [10,11], often alongside measurements using the charged+neutral constituents [12,13]. While colinear safety is sacrificed by such measurements, the increased precision and detector resolution can be significant. This charged-particle-based approach should particularly be considered in measurements intended for use in MC tuning studies (Figure 1). Some measurements made only with charged particles have nevertheless been compared to theoretical predictions by making additional MC-based hadronisation corrections [14] (Figure 2).

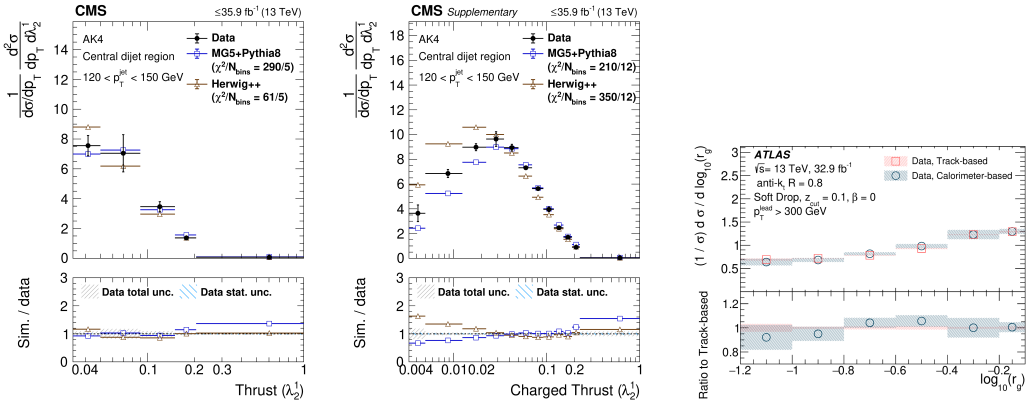

Figure 1 – Comparisons between charged- *vs.* all-particles measurements of generalized jet angularities by CMS (a,b) and the soft-drop jet r_g by ATLAS (c).

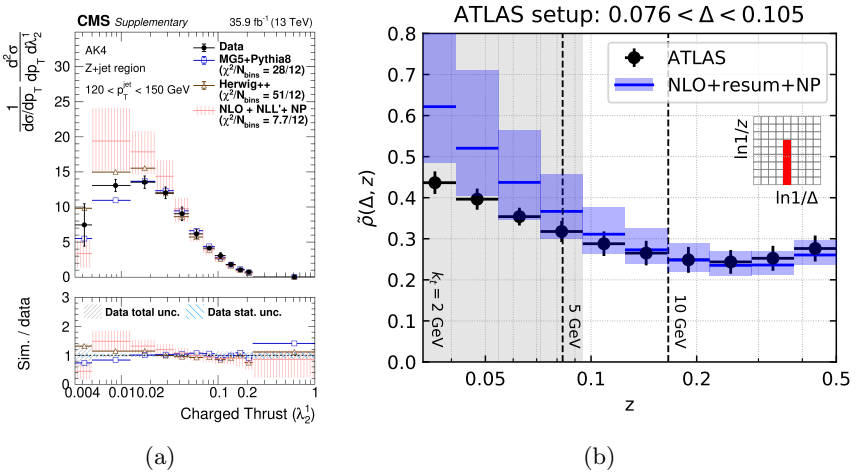

Figure 2 – Comparisons between unfolded data and analytical predictions, corrected for differences between the all- *vs.* charged-particles pictures. Data are reproduced from a measurement of generalized jet angularities by CMS (a) and a measurement of the Lund jet plane by ATLAS, with calculation by Lifson *et al.* (b).

5 ATLAS b-fragmentation measurement

Improved understanding of b-fragmentation will benefit many physics studies at the LHC, particularly in the precision top and Higgs sectors. The ATLAS Collaboration has recently published a measurement of b-hadron fragmentation [15]. This measurement studies the exclusive decay of B-mesons via $B^{\pm} \to J/\Psi K^{\pm}$ inside of jets with p_{T} between $50 - 100$ GeV.

The transverse ($p_{\mathrm{T}}^{\mathrm{rel}}$) and longitudinal ($z$) momentum profiles of the $B^{\pm}$ decay are compared to a wide variety of MC predictions. Data in the large-z region are particularly sensitive to the hadronisation model and tune used in simulation. At small-z, the data are found to be sensitive to gluon splitting and large differences are observed between HERWIG parton shower models.

6 Concluding remarks

Several recent measurements by the ATLAS and CMS Collaborations have been summarized, which probe diverse aspects of perturbative and non-perturbative QCD at the LHC. The unfolded data have been made publicly available via the HEPData platform. Implementations of each analysis are also available in the Rivet package for use in future PDF fits, MC tunes and QCD studies.

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