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PROBING PERTURBATIVE QCD WITH THE ATLAS DETECTOR*

Giuseppe Callea

on behalf of the ATLAS Collaboration

University of Glasgow and SUPA-School of Physics and Astronomy, UK

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This contribution gives an overview of the recent measurements of the differential cross sections for final states involving photons and/or jets at the centre-of-mass energies of 8 and 13 TeV, published by the ATLAS Collaboration. The results are compared with the state-of-art theoretical predictions. Two measurements of dijet correlations allowing the strong coupling constant to be extracted are also presented.

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1. Introduction

The study of the production of jets and photons at the Large Hadron Collider (LHC) provides a powerful tool for understanding perturbative QCD (pQCD). Jet production measurements are used to constrain the gluon density in the proton and can be exploited to extract the strong coupling constant (α_{s}) in specific final-state topologies. On the other side, the production of prompt photons in proton–proton collisions provides a testing ground for pQCD in a cleaner environment than in jet production, since the colorless photon originates directly from the hard interaction. This paper presents the measurements of the cross section of final states involving photons and/or jets at center-of-mass energies of 8 and 13 TeV with the data collected by the ATLAS detector at the LHC [1] together with two methods to extract α_{s}.

2. Physics with jets

2.1. Inclusive and dijet production at 13 TeV

The inclusive jet and dijet cross sections have been measured at 13 TeV, using the 3.2 fb^{-1} ATLAS dataset [2]. The jets are reconstructed using the

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anti-k_{T} algorithm [3] with radius parameter $R = 0.4$. The cross sections are measured double-differentially in the jet transverse momentum and rapidity, as shown in Fig. 1 (left). NLO and NNLO pQCD calculations, corrected for non-perturbative and electroweak effects, are compared to the measured cross sections. A fair agreement has been found when considering the jet cross sections in individual jet rapidity bins independently. No significant deviations between measured cross sections and the fixed order NNLO QCD calculations [4] are observed. The double-differential dijet production cross sections are presented as a function of the dijet invariant mass and absolute rapidity separation between the two leading jets (y^*). A fair agreement has been found in the comparison between the measured cross sections and the fixed-order NLO QCD calculations, as shown in Fig. 1 (right).

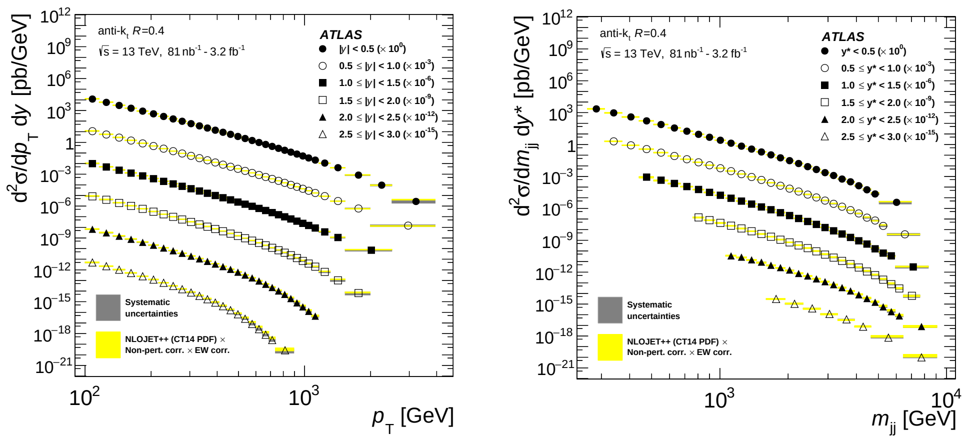

Fig. 1. Differential cross sections for inclusive jet production as a function of p_{T} (left) and for dijet production as a function of m_{jj} (right) along with comparisons to NLO predictions with the MMHT2014 PDF set [2].

2.2. Measurement of transverse energy–energy correlations

Transverse energy–energy correlations (TEEC) in multi-jet events have been measured using the 8 TeV ATLAS dataset [5]. The data were binned in six intervals of the scalar sum of the transverse momenta of the two leading jets, H_{T}, and compared to the NLO pQCD predictions, corrected for hadronisation and multi-parton interaction effects. The comparison shows that the data are compatible with the theoretical predictions, within the uncertainties. The results are then used to determine α_{s} and its evolution with a chosen scale $Q = H_{\mathrm{T}}/2$, by means of a χ^2 fit to the theoretical predictions for both TEEC in each energy bin. The fit results are shown in Fig. 2 (right) together with other experiment determinations. α_{s} has been measured with good precision and its running tested to unprecedented scales of the order of 1 TeV. The presented results are limited by the scale uncertainties ($\mu_{\rm R}$ and $\mu_{\rm F}$), which amounts to the 6% of the value of $\alpha_{\rm s}(m_Z)$.

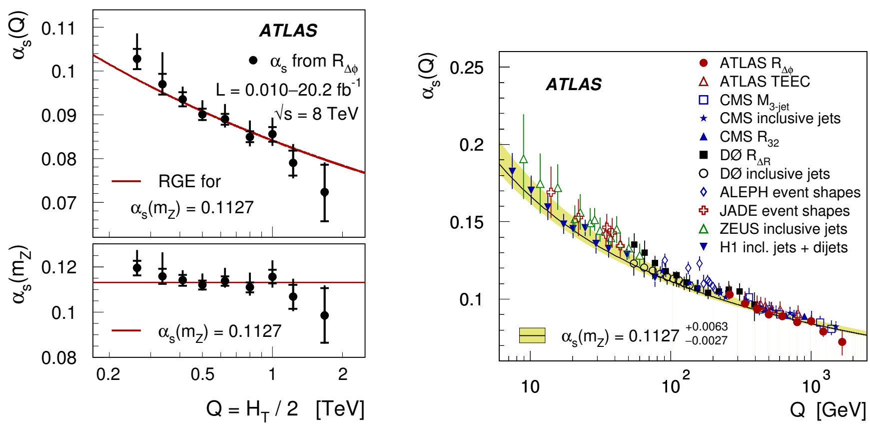

Fig. 2. (Color online) Left: $\alpha_{\rm s}(Q)$ experimental results (top) obtained in the measurement of the azimuthal decorrelations analysis together with the RGE prediction for $\alpha_{\rm s}(m_Z) = 0.1127$ and (bottom) individual $\alpha_{\rm s}(Q)$ values evolved to $Q = m_Z$ [6]. Right: Scale dependence of $\alpha_{\rm s}$ values obtained from the TEEC [5] (red stars) and from the azimuthal decorrelation measurements (red dots), together with other experiment determinations and the global $\alpha_{\rm s}(Q)$ fit [6].

2.3. Measurement of azimuthal decorrelations

The azimuthal decorrelations, defined as the fraction of the dijet cross section for which the azimuthal separation between the leading jets is smaller than a given value $\Delta\phi_{\rm max}$, have been measured at 8 TeV using the ATLAS dataset of 20.3 fb^{-1} [6]. It represents a method to determine $\alpha_{\rm s}$ and probe pQCD at high scales ($260 < Q < 1675$ GeV). The data are presented as a function of $H_{\rm T}$, in three y^* bins and four values of $\Delta\phi_{\rm max}$. The agreement between data and the NLO predictions is good in each region. The data/theory ratios indicate that the predictions best perform for $\Delta\phi_{\rm max} = 7\pi/8$. Therefore, for the determination of $\alpha_{\rm s}$, the data for this $\Delta\phi_{\rm max}$ value are integrated over the $0 < y^* < 1$ region and their $H_{\rm T}$ dependence is fitted to pQCD predictions. The results, shown in Fig. 2 (left), are compatible with those obtained in Subsec. 2.2 and with the global $\alpha_{\rm s}$ fit.

3. Physics with photons

3.1. Inclusive photon production

Inclusive isolated-photon production at 13 TeV has been studied using a dataset with an integrated luminosity of 3.2 fb^{-1} [7]. Cross sections as a function of $E_{\rm T}^{\gamma}$ are measured in four different regions of the photon pseudorapidity, η^{γ}, for photons with $E_{\rm T}^{\gamma} > 125$ GeV. In Fig. 3 (left), the NLO pQCD predictions of JETPHOX are shown, providing an adequate description of the data within uncertainties. Figure 3 shows that the fixed-order NLO QCD calculations of JETPHOX and the multi-leg NLO QCD plus parton shower calculations of SHERPA describe the measured differential cross sections as a function of $|\cos\theta^{*}|$ within uncertainties.

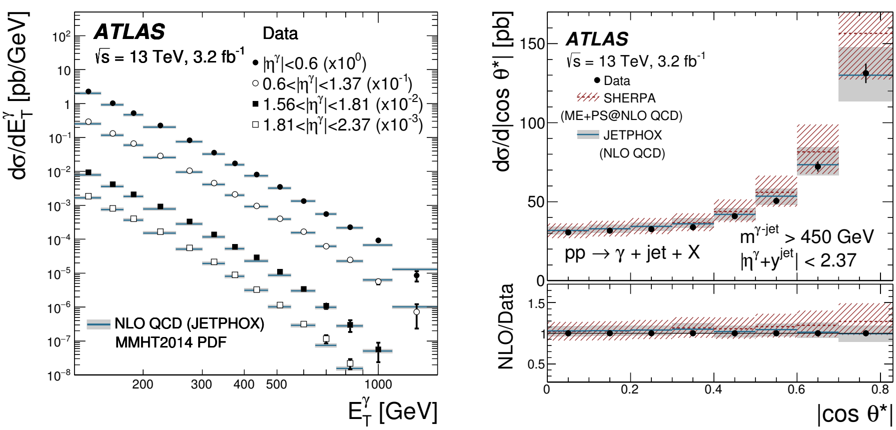

Fig. 3. (Left) Differential cross sections for inclusive photon production as functions of $E_{\rm T}^{\gamma}$ in four pseudorapidity bins [7]. (Right) γ + jet differential cross section as a function of $|\cos\theta^{*}|$ [8].

3.2. Photon + jet production

The dynamics of the isolated-photon production in association with a jet have been studied at 13 TeV using a dataset with an integrated luminosity of 3.2 fb^{-1} [8]. Photons are required to pass the same requirements as in Subsec. 3.1, while jets are required to have $p_{\rm T}^{\rm jet} > 100$ GeV. The differential cross sections are presented as a function of the main variables of the γ-jet system, including the invariant mass of the γ-jet system and the scattering angle in the center-of-mass frame ($|\cos\theta^{*}|$).

3.3. Photon + heavy flavor jet production

The photon + heavy flavor jet (b/c) measurement has been studied at 8 TeV using a dataset with an integrated luminosity of 20.3 fb^{-1} [9]. A requirement on the jet flavor has been introduced, using the MV1c neural network algorithm, trained to identify b-jets with enhanced rejection of c-jets. $\gamma + b$ differential cross sections as a function of $E_{\rm T}^{\gamma}$ are shown in Fig. 4 (left) together with the 4 and 5 flavor number scheme (FNS) NLO predictions. The 5FNS better describes the data for E_T^γ up to 200 GeV. Both FNS underestimate the data at higher E_T^γ values, this indicates that higher-order calculations are needed for a better description of the data in this region. Since the $\gamma + c$ measurement is sensitive to the intrinsic charm hypothesis, the measured differential cross sections are compared to different predictions using PDF sets with varying sizes of its contribution (BHPS and NNPDF FittedC). Good agreement is obtained across the whole range of the measurement within uncertainties, as shown in Fig. 4 (right), except for the BHPS2 PDF set which deviates the most at high E_T^γ.

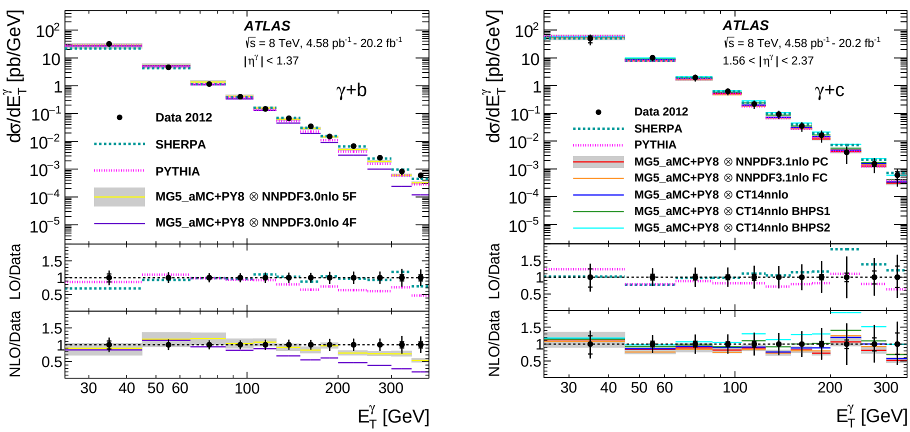

Fig. 4. Differential cross sections for $\gamma + b$ (left) and $\gamma + c$ (right) jets as a function of E_T^γ, compared to the NLO pQCD predictions, together with the LO predictions of PYTHIA and SHERPA [9].

3.4. Triphoton production

Measurements of the production of three photons have been studied at a center-of-mass energy of 8 TeV [11]. Differential cross sections are measured as functions of the main variables of the triphoton system. As shown in Fig. 5 (right), the NLO pQCD calculations underestimate the measured inclusive fiducial cross section by factors of 2.3 and 1.6 for MCFM and MadGraph5, respectively. In the latter, the implementation of the parton shower improves the measurement. The NNLO calculations, available for the computation of diphotons [10], but not for triphotons, would certainly improve the description of the measured fiducial cross section, as shown in Fig. 5 (left).

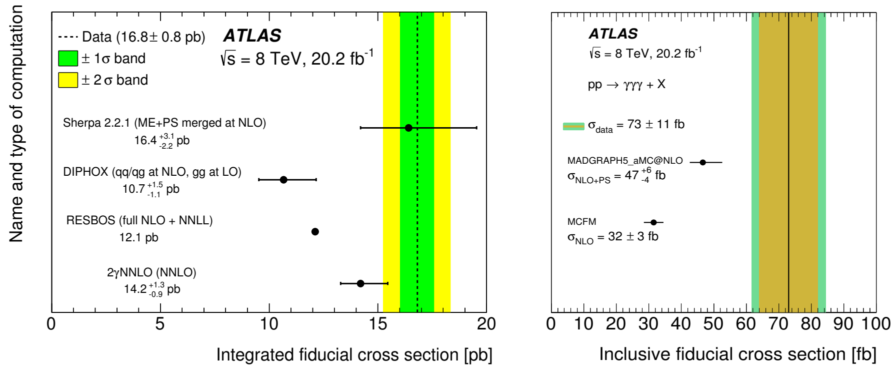

Fig. 5. (Color online) Left: Fiducial cross sections for the diphoton production compared with the NLO and NNLO predictions [10]. The dark gray/green (light gray/yellow) band represents the one- (two-) standard deviation uncertainty, including both the statistical and systematic uncertainties in the measurement. Right: Fiducial cross sections for the triphoton production compared with the NLO predictions, the gray/gold (dark gray/green) band represents the systematic (systematic + statistical) uncertainty [11].

4. Summary

In this paper, high-precision measurements involving photons and jets in proton–proton collisions at 8 TeV are presented together with the first results at 13 TeV. All the measurements are in good agreement with the pQCD predictions within the theoretical uncertainties, especially those coming scale uncertainties. For the future, the ATLAS Collaboration plans to improve these studies with higher statistics in order to explore the new energy regime opened by the LHC at 13 TeV and to provide valuable physics inputs to PDF and α_{s} fits.

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