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Photon and Jet measurements in pp collisions at the LHC

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In this contribution we discuss the main results on prompt photon and jet measurements at the LHC in proton-proton collision. We review critically the data to theory comparisons and we outline the possible future directions as discussed at the workshop.

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1. Introduction

The ATLAS and CMS collaborations have carried out a number of measurements involving jets and photons using the data accumulated in proton-proton collisions from 2010 to 2012. In 2010 and 2011 both collaborations have collected approximately 37 pb^{-1} and 5 fb^{-1} of integrated luminosity at a center of mass energy of 7 TeV. At the start of the 2011 data taking period of the LHC, both experiments also collected pp collision data at $\sqrt{s}$ = 2.76 TeV corresponding to an integrated luminosity of 0.20 pb^{-1}. In 2012, approximately 21 fb^{-1} of data were acquired at a center of mass energy of 8 TeV. In the following sections we will briefly review the main available measurements which are performed mainly using 2010 and 2011 data and outline possible future developments.

2. Jet measurements

On the jet side the inclusive double differential jet cross sections have been measured by both experiments covering a rapidity range up to 4.4 and extending up to jets with a transverse momentum of 1 TeV (Ref. [1] and Ref. [2]). The di-jet double-differential cross sections have been studied as a function of the di-jet invariant mass and jet rapidity. Moreover the jet activity between the two highest p_T^{jet} jets has been studied in di-jet events (Ref. [3]). The data are compared to expectations based on next-to-leading order (NLO) QCD calculations (NLOJET++ [4]) corrected for non-perturbative effects, as well as to next-to-leading order Monte Carlo generators (POWHEG [5] interfaced with PYTHIA [6] or HERWIG [7]). In general a good agreement is found between data and the various predictions. In several cases the experimental uncertainties are of the same order or smaller than the corresponding theoretical ones. In the di-jet with rapidity gap analysis, the POWHEG NLO + Parton Shower di-jet Monte Carlo generator gives a generally good description of data, no stricking evidence that BFKL inspired description of HEJ [8] can improve significantly the agreement. Some tensions between data and theoretical predictions is observed in the inclusive jet cross sections ratios between 2.76 and 7 TeV center-of-mass data (Fig. 1).

In this measurement the main experimental systematic uncertatinies cancel out in the ratio, thus giving great sensitivity to the gluon PDF. Discrepancies between the data and predictions are visible mainly in the central region ($|y| < 0.8$) for $p_T^{jet} < 50$ GeV and in the forward region for $p_T^{jet} > 50$ GeV. While the prediction from NLO + Parton Shower Monte Carlo generators seem to agree with data in the forward region, the origin of the disagreement in the central regions is still unclear. An attempt to use these data to re-fit the PDF leads to a slightly harder gluon spectrum at high x and to a reduced uncertainty (Fig. 2). However the harder gluon spectrum is not sufficient to explain the disagreement in the central region.

The measurement of α_S has also been performed by both the CMS (Ref. [12]) and the ATLAS (Ref. [13]) collaborations. The measured values, extrapolated to M_Z are

$$\alpha_S^{CMS}(M_Z) = 0.1148 \pm 0.0014(\mathrm{exp}) \pm 0.0018(\mathrm{PDF})^{+0.0050}_{-0.0000}(\mathrm{scale})$$
$$\alpha_S^{ATLAS}(M_Z) = 0.111 \pm 0.006(\mathrm{exp})^{+0.016}_{-0.003}(\mathrm{theory})$$

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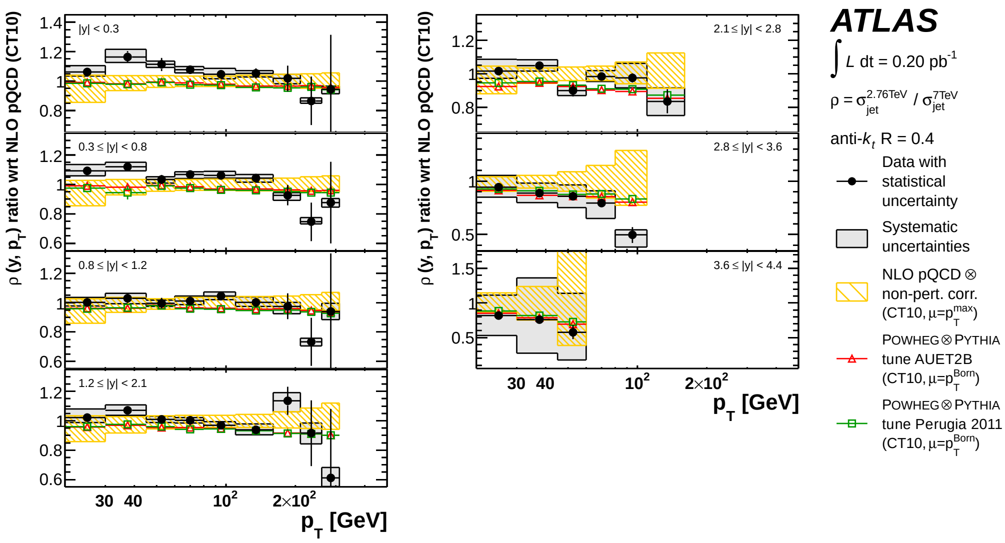

Figure 1: Ratio of the inclusive jet cross-section at $\sqrt{s}$=2.76 TeV to the one at $\sqrt{(s)}$=7 TeV (Ref. [9]), shown as double ratio to the theoretical prediction calculated with the CT10 PDFs as a function of pT in bins of jet rapidity, for anti-kt jets with R=0.4. Also shown are POWHEG predictions using PYTHIA for the simulation of the parton shower and hadronisation with the AUET2B tune (Ref. [10]) and the Perugia 2011 tune (Ref. [11]). Only the statistical uncertainty is shown on the POWHEG predictions. Statistically insignificant data points at large p_T are omitted. The 4.3% uncertainty from the luminosity measurements is not shown.

The ATLAS and CMS measurements are obtained from data samples corresponding to 37pb^{-1} and to 5 fb^{-1} of integrated luminosity respectively. The larger data sample used for the CMS measurement not only results in a smaller statistical uncertainty, but it also consents to apply higher p_T^{jet} thresholds allowing to extract α_s from a phase space region which is likely less sensitive to scale variations. The scale sensitivity of the various observables used by the two collaborations is a point that would highly benefit from more studies and from discussion with theorists. Given the present experimental and theoretical uncertainties the ATLAS and CMS measurement agree and no deviation is observed of the evolution of the strong coupling constant from the expected theoretical behaviour.

Recent studies (Ref. [14]) have highlighted the potential of jet substructure techniques to identify the hadronic decays of boosted heavy particles. These studies all rely upon the assumption that the internal substructure of jets generated by QCD radiation is well understood. Jet invariant mass, k_t splitting scales and N-subjettiness have been studied together with grooming techniques by both experiments (Ref. [15] and [16]). Leading-order (LO) parton-shower Monte Carlo predictions for these variables are found to be broadly in agreement with data. Generally these results show that jet mass and substructure quantities can be successfully reproduced by leading-order parton-shower Monte Carlo. This result bodes well for future analyses aiming to exploit the jet substructure techniques.

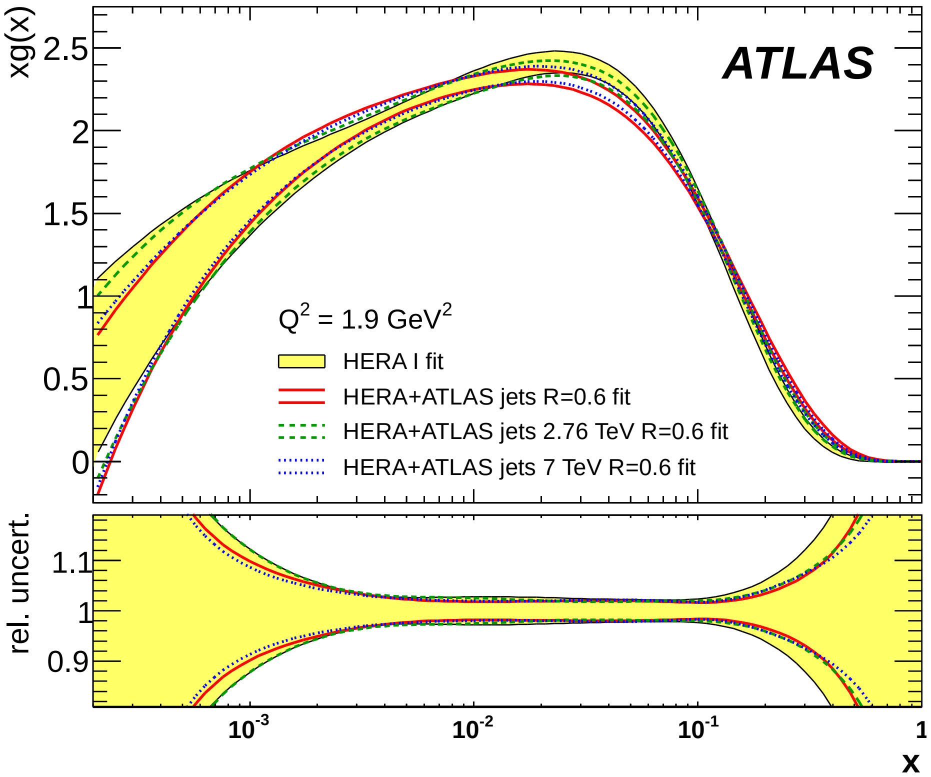

Figure 2: Momentum distributions of the gluon xg(x) together with their relative experimental uncertainty as a function of x for Q^2=1.9GeV^2 (Ref. [9]). The filled area indicates a fit to HERA data only. The bands show fits to HERA data in combination with both ATLAS jet datasets, and with the individual ATLAS jet datasets separately, each for jets of R=0.6 size. For each fit the uncertainty in the PDF is centred on unity.

3. Photon measurements

Inclusive isolated photon production cross sections have been measured by both collaborations (Ref. [17], [18] and [19]) and the data have been compared with NLO predictions from JETPHOX [20] and LO MC generators like PYTHIA and HERWIG. The agreement with the predictions has been found to be good except in the low p_T range for ATLAS where some tension is observed. PYTHIA and HERWIG are found to be in agreement with data when the QED radiation photons are taken into account. Isolated photon cross section data from ATLAS have been used as additional inputs in the NNPDF fit (Ref. [21]): the central value is not affected while the uncertainty on the gluon PDF is slightly decreased showing a potential usage of the photon data to constrain the gluon PDF.

Differential cross sections as a function of p_T^γ for photon plus jets production were measured by both experiments (Ref. [22] and [23]) and compared with JETPHOX, PYTHIA, HERWIG and SHERPA [28] predictions. Diphoton production has been measured as a function of $M_{\gamma\gamma}$, $P_{T,\gamma\gamma}$, $\Delta\phi_{\gamma\gamma}$ and $\cos\theta^*_{\gamma\gamma}$ (Ref. [24] and [25]) and compared with NLO DIPHOX [26] and NNLO

(Next-to-Next-to-leading order) 2gNNLO [27] predictions : the agreement is fairly good, except in the regions dominated by fragmentation contribution which is not implemented in 2gNNLO. Among the MC generators SHERPA is showing the best agreement with data in the largest part of the phase space tested in the analyses. The CMS collaboration has studied the possibility to discriminate between different Matrix Elements -Parton Shower matching schemes by looking at the rapidity measurements in Z or photon+jet events (Ref. [29]). While the Z+jet measurement shows some discriminating power, the photon+jet channel suffers from rather large error bars and does not yet allow yet to draw quantitative conclusions.

4. Summary

The results discussed above show that the capability of the NLO/NNLO calculations and the NLO + Parton Showers Monte Carlo generators to describe the data is overall fair with the exception of a few regions of the phase space. Actually this is true for the very inclusive quantities which have been measured up to now, namely the p_{T}^{jet} and y distributions of all jets for example. One of the primary goal for the next run of the LHC will be to analyze more exclusive final states, trying to understand what are the limits of the accuracy of the calculations we have. The second key point will be the comparison with the new NNLO calculations which have been recently released (Ref. [30]). Understandig the details of jet physics is a mandatory task at LHC to be able to detect unexpected signals of new physics. An intense round of discussions between experimentalists and theorists is considered crucial in order to define a set of new measurements to be addressed with new data and using the most recents calculations and generators. Photon physics is currently missing any NLO + PS generators which would be desireable, but the agreement with the SHERPA and PYTHIA (when including radiation photons) is averall fair. NNLO calculations work nicely except in the fragmentation enanched regions since they are not including this contribution.

Precise measurement of the photon+jet events is both useful to understand one of the largest background to the measurement of the Higgs decaying to two photons and to constrain the gluon PDF in the medium x region allowing to reduce the theoretical uncertainty on the Higgs production cross sections.

As a conclusion it turns clearly out that jets and photons measurements play and will play a central role in understanding LHC pp collisions data and in benchmarking the available MC generators. This will be the key to be ready to understand signals of new physics which might manifest in an unexpected way.

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