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Photon, di-photon and photon plus jet production measured with the ATLAS detector

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Isolated prompt photons provide a direct probe of short-distance physics, complementary to that provided by measurements of jets or vector-bosons. The data are sensitive to the gluon density of the proton. The inclusive prompt photon cross sections have been measured over a wide range of transverse momenta; the di-photon cross section has also been measured as a function of di-photon mass, total transverse momentum and azimuthal separation; the cross section for photons produced in association with jets is also measured. The results are compared to the predictions of next-to-leading-order QCD.

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1. Introduction

These proceedings will concentrate on the recent photon cross section results from the ATLAS experiment [1]. Three processes are reported covering inclusive photons, photon plus jet dynamics and di-photons. For the production of single photons the main processes are the Compton $qg \to q\gamma$, annihilation $q\bar{q} \to g\gamma$ and fragmentation (from the soft fragmentation of a coloured parton). Similarly for di-photons there are also three key processes: Born $q\bar{q} \to \gamma\gamma$, Box $gg \to \gamma\gamma$ and again fragmentation, where at least one of the two photons is produced from soft fragmentation.

QCD measurements made at the LHC will be able to set the most stringent tests of existing models, as they profit from high luminosity, i.e. small statistical uncertainties, and precision detectors, i.e. reduced systematic uncertainties. A first motivation for studying photons at the LHC arrises from the new kinematic phase space probed, which allows the photon measurements to test perturbative QCD in this new region and its evolution from existing measurements. Secondly, as the dominant production process for single photons is via the Compton process this enables the measurements to investigate the gluon content of the proton. In the case of the photon plus jet and di-photon measurements, they also provide a handle on improving the modelling of the fragmentation contribution. Finally, understanding standard model (SM) photon production is also important for quantifying the irreducible background in Higgs measurements and searches for new physics beyond the SM.

2. Reconstruction

The key parts of the ATLAS detector [1] for photon measurements are the liquid Argon electromagnetic (EM) calorimeter that surrounds the inner tracking detector, which itself consists of three types of tracking detector and also a 2 T solenoid magnet. In the EM calorimeter photons are reconstructed by clustering the energy deposits in the cells. These clusters are classified as unconverted photons in the case when the inner detector has no matching track, or converted in the cases for one or two matching tracks.

The three layers of the EM calorimeter provide shower shape variables to distinguish photons from jets. The depth and width of the shower is enough to rule out most cases leaving a dominant background of π^0 decays to two photons. In this case the distribution on energy in the first layer of the calorimeter (which consists of thin strips in η) is used to distinguish the two photon energy peaks from the π^0 decay. For photon candidates, this selection has a background rejection factor (N_{jets}/N_{fakes}) of ~ 5000 and has an efficiency of 50% at 20 GeV rising above 90% at 100 GeV [2].

One of the key parameters in the photon definition at both experimental and theoretical levels is isolation. This is the requirement on the amount of energy surrounding the photon. Both experimentally and theoretically this is calculated by using a cone of radius 0.4 in η-ϕ space. For the leading-order (LO) theoretical predictions the energy is summed from all particles in the cone (other than the photon), whereas at next-to-leading-order (NLO) partons are used. Experimentally the photon cluster is removed from the cone and extra corrections are made to correct for pile-up and underlying event effects using the “jet-area” method [3].

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3. Inclusive photon

The aim of the latest inclusive photon analysis [4] was to reach a higher E_T^γ than the previous measurements [5, 6]: these had reached 400 GeV whereas the new measurement reaches 1 TeV. Another difference between the measurements was that in the 2011 analysis a 7 GeV isolation energy cut was used, where 4 GeV was used in 2010. Figure 1a shows the measured E_T^γ cross section for the region $\eta^\gamma < 1.37$. The results show the highest disagreement to NLO (Jetphox [7, 8]) at low E_T^γ, which matches the trend of the previous results. In the region above 500 GeV, where there is good agreement, it is worth noting that the fragmentation contribution is negligible in the NLO prediction. The two LO (Pythia [9] and Herwig [10]) predictions follow the shape well, but differ in normalisation. Regarding PDF's it can be seen that there is a $\sim 5\%$ difference between the two PDF's used within the NLO calculation and that the PDF uncertainty (mainly from the gluon) starts to become important above 700 GeV, as the total NLO uncertainty starts to become larger than just the scale uncertainty. Along with the cross section detailed above, also measured are the E_T^γ (for the region $1.52 < \eta^\gamma < 2.37$), total and η^γ cross sections: the latter is shown in figure 1b and shows similar agreement to theory as in the E_T^γ cross section.

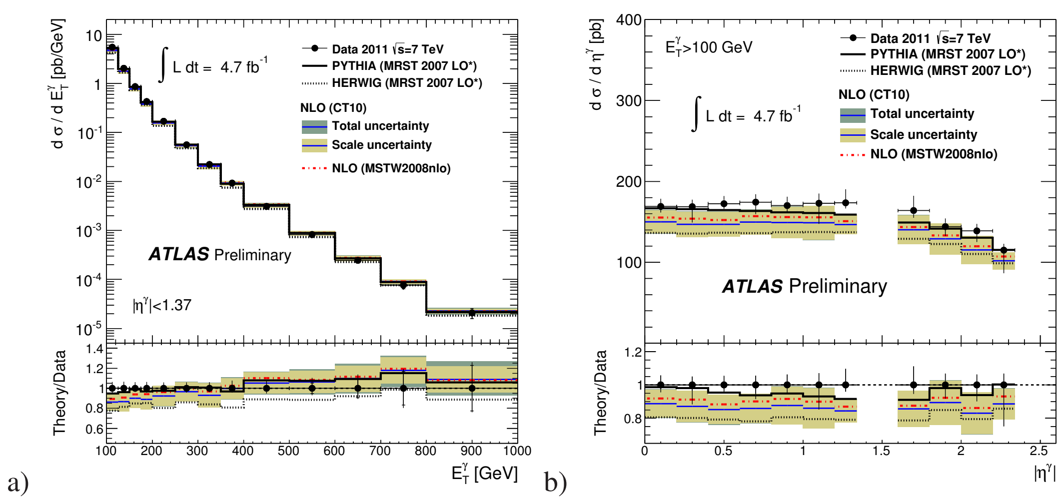

Figure 1: Inclusive photon cross section as a function of: E_T^γ (a, for $\eta^\gamma < 1.37$) and $|\eta^\gamma|$ (b) [4].

4. Photon plus jet

As good agreement has been seen between data and NLO in the inclusive case when the fragmentation contribution is small, it is worth trying to get a better understanding of this contribution. To be able to do this the photon plus jet system is studied, for which ATLAS has made two measurements in 2010 data. The first [11] concentrated on looking at whether the photon and jet are on the same/opposite sign ($\eta^\gamma y^{jet} \geq 0$ or < 0) of the detector. By also using a range of jet y cuts this provides different amounts of fragmentation to each cross section. The overall result showed the same disagreements at low E_T in all configurations, buts needs reduced theoretical and experimental uncertainties to really distinguish the fragmentation contributions.

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The latest result [12] expands the first measurement by measuring the cross section in a range of variables: E_T^γ, p_T^{jet}, $|y^{jet}|$, $\Delta\phi^{\gamma j}$, $m^{\gamma j}$ and $|cos\theta^{\gamma j}|$. In general there is good agreement in all the variables and often the experimental errors are smaller than those from theory, as shown for example by the $m^{\gamma j}$ result in figure 2a. For E_T^γ there is the familiar disagreement at low E_T to the other measurements. In the case of $\Delta\phi^{\gamma j}$, see figure 2b, the NLO three-body final state means that the photon and jet are in separate hemispheres therefore it has to have $\Delta\phi^{\gamma j} > \pi/2$. As this does not match the data this distribution is also compared to Pythia, Herwig and Sherpa [13]: where Pythia and Sherpa perform better than Herwig. Figure 2c shows good agreement between NLO and data in the $|cos\theta^{\gamma j}|$ distribution. Here extra constraints are applied ($|\eta^\gamma + y^{jet}| < 2.37$, $m^{\gamma j} > 161$ GeV and $|cos\theta^{\gamma j}| < 0.83$) to remove any distortions due to the restrictions on E_T^γ, η^γ, p_T^{jet} and $|y^{jet}|$. This distribution is important as the region at high $|cos\theta^{\gamma j}|$ is sensitive to the fragmentation contribution. This sensitivity is clearly shown in figure 2d where, after normalising the LO shapes at low $|cos\theta^{\gamma j}|$, the data is much closer to the shape of the direct contribution. The difference in shape between the contributions is due to the spin of the exchanged particle, therefore being closer to the direct shape is consistent with the dominance of processes where a quark is the exchanged particle.

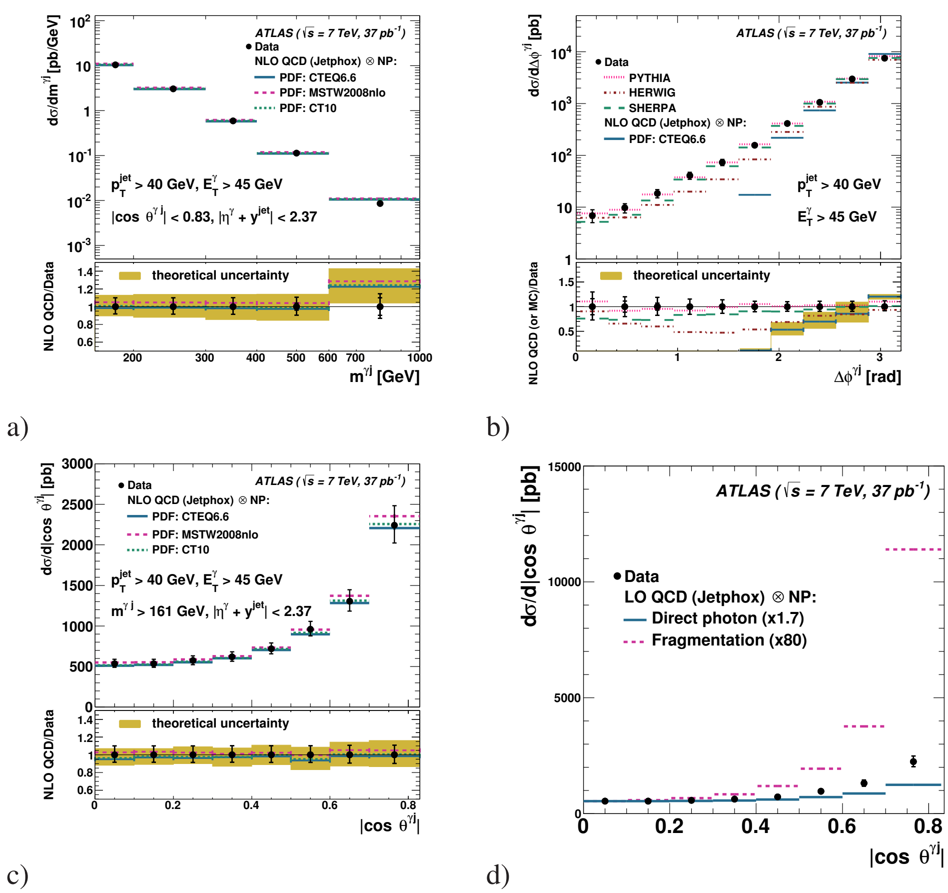

Figure 2: Photon plus jet cross section as a function of: $m^{\gamma j}$ (a), $\Delta\phi^{\gamma j}$ (b) and $|cos\theta^{\gamma j}|$ (c). Also (d) shows the different LO contributions to the $|cos\theta^{\gamma j}|$ cross section [12].

5. Di-photon

In 2011 data there is also an update [14] of the di-photon cross section (previously measured in 2010 [15]). It is essential to understand these processes as they are irreducible backgrounds to any new physics in the di-photon channel. The process itself has backgrounds, and now rather than just the photon-jet background there are also jet-jet backgrounds. In the inclusive, photon-jet and 2010 di-photon measurements a sidebands method is used to subtract the background: based on the identification criteria and isolation. For the updated measurement a 2D template fit of the isolation distribution is used, which now corrects for signal leakage into the background templates. The resulting cross section is measured in terms of $m_{\gamma\gamma}$, $p_{T,\gamma\gamma}$, $\Delta\phi_{\gamma\gamma}$ and $cos\theta^*_{\gamma\gamma}$ (in the Collins-Soper frame [16]). Figures 3a and b show that generally Sherpa does better at modelling the shape than Pythia. To match the results from data both distributions are rescaled by a factor of 1.2. The additional NLO contributions in Sherpa help it to model $p_{T,\gamma\gamma}$ better as clearly shown in 3a. However, Sherpa does not have agreement with data everywhere, it differs at large $m_{\gamma\gamma}$ and $cos\theta^*_{\gamma\gamma}$. Figure 3c shows that NNLO (2γNNLO [17]) does better than NLO (Diphox [18], complemented by Gamma2mc [19]). The agreement is not over the entire range though, as without soft gluon re-summation it creates an excess at $\Delta\phi_{\gamma\gamma} \approx \pi$. The NNLO prediction is also lacking the fragmentation contribution, this can be clearly seen at high $cos\theta^*_{\gamma\gamma}$ in figure 3d.

6. Conclusions

These proceedings have covered the new ATLAS results on inclusive, photon plus jet and di-photon cross sections. In general, all are in good agreement with theory. However, as seen in the previous results there is disagreement at low E_T. Measurements of the photon plus jet and di-photon systems show the impact of the fragmentation contribution. In the latter analysis it shows the importance of having NNLO calculations for predicting photon production.

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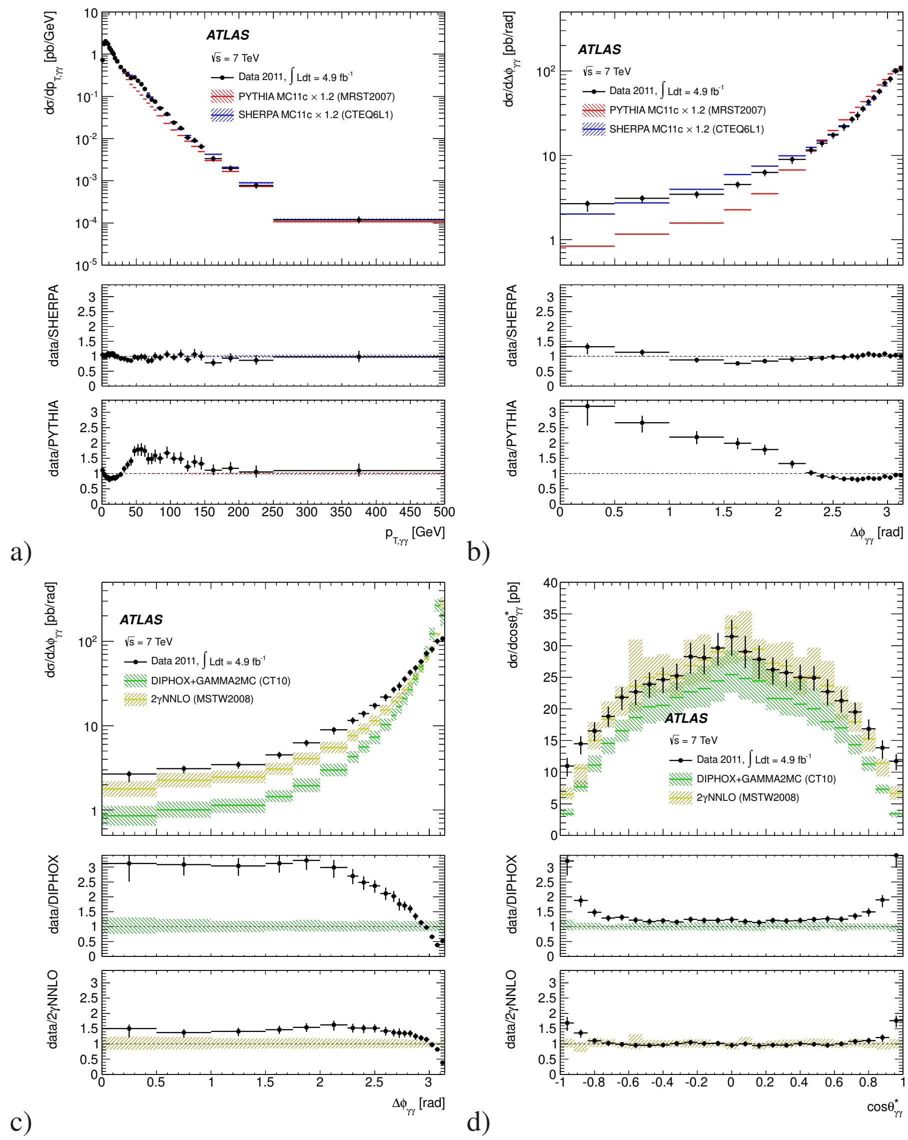

Figure 3: Di-photon cross section as a function of: $p_{T,\gamma\gamma}$ (a, at LO), $\Delta\phi_{\gamma\gamma}$ (b at LO, c at NLO) and $cos\theta^{*}_{\gamma\gamma}$ (d, at NLO) [14].

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