Measurement of the inclusive isolated prompt photon cross-section in *pp* collisions at $\sqrt{s} = 7$ TeV using 35 pb^{-1} of ATLAS data ☆

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ABSTRACT

A measurement of the differential cross-section for the inclusive production of isolated prompt photons in *pp* collisions at a center-of-mass energy $\sqrt{s} = 7$ TeV is presented. The measurement covers the pseudorapidity ranges $|\eta| < 1.37$ and $1.52 \leqslant |\eta| < 2.37$ in the transverse energy range $45 \leqslant E_T < 400$ GeV. The results are based on an integrated luminosity of 35 pb^{-1}, collected with the ATLAS detector at the LHC. The yields of the signal photons are measured using a data-driven technique, based on the observed distribution of the hadronic energy in a narrow cone around the photon candidate and the photon selection criteria. The results are compared with next-to-leading order perturbative QCD calculations and found to be in good agreement over four orders of magnitude in cross-section.

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The production of prompt photons at hadron colliders provides means for testing perturbative QCD predictions [1], providing a colorless probe of the hard scattering process. The measurement of the inclusive production of prompt photons could be used to constrain the parton distribution functions; in particular it is sensitive to the gluon content of the proton [2] through the $qg \to q\gamma$ subprocess, which at leading order dominates the inclusive prompt photon cross-section at the LHC.

ATLAS has recently published a measurement of the inclusive photon cross-section in *pp* collisions at $\sqrt{s} = 7$ TeV using an integrated luminosity of 880 nb^{-1} [3]; a similar measurement has been performed by the CMS Collaboration [4] using an integrated luminosity of 2.9 pb^{-1}. Analogous measurements have been perfomed in $p\bar{p}$ collisions at a lower center of mass at the Tevatron [5,6], and in deep inelastic *ep* scattering at HERA [7,8]. This Letter presents the measurement of the differential production cross-section of isolated prompt photons with transverse energies E_T above 45 GeV using 34.6 ± 1.2 pb^{-1} of *pp* collision data at $\sqrt{s} = 7$ TeV collected in 2010. Isolated prompt photons in the pseudorapidity ranges $|\eta| < 0.6$, $0.6 \leqslant |\eta| < 1.37$, $1.52 \leqslant |\eta| < 1.81$ and $1.81 \leqslant |\eta| < 2.37$ are studied.[1]

In the following, all photons produced in *pp* collisions and not coming from hadron decays are considered as *prompt*: they include both *direct* photons, which originate from the hard subprocess, and *fragmentation* photons, which are the result of the fragmentation of a colored high-p_T parton [9,10]. *Isolated* photons are considered: from a theoretical perspective, photons are isolated if the transverse energy E_T^{iso}, within a cone of radius $R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} = 0.4$ centered around the photon direction in the pseudorapidity (η) and azimuthal angle (ϕ) plane,[2] is smaller than E_T^{cut}. In JETPHOX [9], used for next-to-leading order (NLO) calculations, E_T^{iso} is calculated from all partons. Similarly, a corresponding isolation prescription is applied experimentally on the reconstructed objects, based on the energy reconstructed in an $R = 0.4$ cone around the photon candidate, corrected for the effects associated with: the energy of the photon candidate itself, the underlying event and the collision pileup [3]. The main background to these isolated prompt photons is composed of photons from decays of light neutral mesons, such as the π^0 or η.

Photons are detected in ATLAS by a lead-liquid Argon sampling electromagnetic calorimeter (ECAL) with an accordion geometry, divided into a barrel section covering the pseudorapidity region $|\eta| < 1.475$ and two endcap sections covering the pseudorapidity regions $1.375 < |\eta| < 3.2$. It consists of three longitudinal layers. The first layer has a high granularity along the η direction (between 0.003 and 0.006 depending on η, with the exception of the regions $1.4 < |\eta| < 1.5$ and $|\eta| > 2.4$), sufficient to provide an event-by-event discrimination between single photon showers and

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[2] See footnote 1.

showers coming from a π^0 decay. The second layer has a granularity of 0.025×0.025 in $\eta \times \phi$. A third layer is used to correct for the leakage beyond the electromagnetic calorimeter for high-energy showers, while in front of the accordion calorimeter a thin presampler layer, covering the pseudorapidity interval $|\eta| < 1.8$, is used to correct for the energy absorbed before the calorimeter.

The ECAL energy resolution is parametrized as $\sigma(E)/E = a/\sqrt{E \text{ (GeV)}} \oplus c$ with the largest contribution coming from the sampling term a, corresponding to approximately 10% (20%) in the barrel (endcap) region. For energies above 200 GeV the global constant term c, estimated to be $(1.2 \pm 0.6)\%$ $((1.8 \pm 0.6)\%)$ in the barrel (endcap) for the 2010 data, starts to dominate [11]. In front of the electromagnetic calorimeter the inner detector allows the reconstruction of tracks from the primary pp collision point and also from secondary vertices, permitting an efficient reconstruction of photon conversions in the beam pipe and inner detector up to a radius of $\sim$80 cm. Further details of the inner detector, the electromagnetic calorimeter and the whole ATLAS detector are documented in Ref. [12].

Event samples simulated with PYTHIA 6.4.21 [13] are used to study the characteristics of signal and background events. To estimate systematic uncertainties related to the choice of the event generator and the parton shower model, alternative samples are generated with HERWIG 6.5 [14]. Events used in this analysis are triggered using a single-photon trigger with a nominal transverse energy threshold of 40 GeV. The trigger efficiency, $\varepsilon^{\text{trig}}$, is measured using a bootstrap method to be $(99.4^{+0.6}_{-0.2})\%$ for prompt photon candidates with $E_\text{T} > 45$ GeV passing the selection criteria presented below. The same trigger condition was used for the whole dataset, even though the mean number of events per collision rose from <1 to $\sim$3 as the instantaneous luminosity increased during 2010. Collision candidates are selected by requiring a primary vertex with at least three associated charged particle tracks, consistent with the beam interaction region. The total number of selected events in data after these requirements is almost 1.7 million, with a negligible amount of non-collision background.

Photon candidates are formed from clusters of energy deposits reconstructed in the electromagnetic calorimeter [15]. Clusters without matching tracks are classified as *unconverted* photon candidates. The presence of one or two tracks coming from a conversion vertex is used to distinguish *converted* photons from electrons. Converted photon clusters are rebuilt with a wider size in ϕ, to account for the opening angle between the conversion products due to the magnetic field. A specific energy calibration [15] is then applied separately for converted and unconverted photon candidates to account for energy loss in front of the ECAL and both lateral and longitudinal leakage. Photon clusters are removed if their barycenter lies in the transition between the barrel and endcap regions of the electromagnetic calorimeter, corresponding to $1.37 < |\eta| < 1.52$, where larger uncertainties related to the efficiency measurement are expected. Clusters containing cells overlapping with the small number of regions with problematic calorimeter readout or with very noisy cells are also removed. Over 0.8 million photon candidates with $E_\text{T} > 45$ GeV remain in the data sample.

A measurement of the transverse isolation energy E_T^{iso} is associated with each photon candidate, computed by summing the calorimeter energy in a cone of $R = 0.4$ around the candidate, as detailed in Ref. [3]. Corrections to this isolation energy are derived from simulation to remove the energy of the photon itself that leaks into the isolation cone. An event-by-event correction [16,17] is applied to subtract the estimated contributions from the underlying event and in-time pileup (i.e. from additional proton–proton interactions). The correction to E_T^{iso} is typically 900 MeV. After this subtraction, the remaining fluctuations are dominated by electronic noise from the calorimeter measurement. The effect of the out-of-time pileup, associated with collisions taking place in previous bunch-crossings, is found to be minimal (i.e. shifts of 200 MeV at most, towards lower isolation energies). The corrections mentioned above allow E_T^{iso} to be directly compared to parton-level theoretical predictions.

All photon candidates having reconstructed isolation energy <3 GeV are considered as experimentally isolated. This definition is similar to applying a 4 GeV cut on the particle-level isolation, defined as the transverse energy of all stable particles in a cone of radius $R = 0.4$ around the photon direction (with the underlying event removed as before). The small difference between the two, caused by noise and other detector effects, is taken into account in the uncertainties associated with the photon reconstruction efficiency $\varepsilon^{\text{reco}}$ discussed below. The particle-level isolation can in turn be related to the parton-level isolation in JETPHOX that is used for the NLO predictions. The efficiency of the isolation criteria is found to be similar (i.e. within a few percent) at both the particle-level and the parton-level for simulated photons passing the selection described below.

As in Ref. [3], the reconstruction and preselection efficiency $\varepsilon^{\text{reco}}$ is computed from simulated prompt photons as a function of the true photon E_T. It is defined as the ratio between the number of photons reconstructed in a given $|\eta|$ interval with reconstructed $E_\text{T}^{\text{iso}} < 3$ GeV, and the total number of true prompt photons with true pseudorapidity in the same $|\eta|$ interval, and with particle-level transverse isolation energy <4 GeV. The estimated $\varepsilon^{\text{reco}}$ for photons with $45 < E_\text{T} < 400$ GeV is $\sim$85% (75%) in the barrel (endcap) region. The main inefficiency ($\sim$10%) is due to the acceptance loss originating from a few inoperative optical links in the calorimeter readout. A similar reduction is caused by the isolation requirement in the pseudorapidity region $1.52 \leqslant |\eta| < 1.81$ where the calorimetric isolation suffers from larger detector effects. The systematic uncertainty on $\varepsilon^{\text{reco}}$ associated with the experimental isolation requirement is evaluated from the prompt photon simulation by varying the value of the isolation criterion by the average difference ($\sim$500 MeV) observed for electrons from $W \to e\nu$ events in data and simulation. The estimated uncertainty varies between 3 and 4% depending on η. The uncertainty associated with the imperfect knowledge of the material in front of the ECAL is estimated by comparing the expected efficiencies in a sample simulated with the nominal ATLAS setup, and one with increased material. It varies between 1 and 2.5%, depending on η.

Shape variables computed from the lateral and longitudinal energy profiles of the shower in the calorimeters are used to discriminate signal from background [15,18]. As detailed in Ref. [3], selection criteria on these variables, optimized independently for unconverted and converted photons, are applied to reconstructed photon candidates. The requirements on these variables are applied in stages resulting in *tight* candidates: firstly jets are removed whilst still keeping a high photon efficiency and then secondly wide or closely spaced showers (i.e. those consistent with jets or meson decays) are rejected. The selection criteria have been revised to minimize the systematics on the efficiency extraction, especially in the region $1.81 \leqslant |\eta| < 2.37$. The photon identification efficiency ε^{ID} is computed from simulation as a function of transverse energy in each pseudorapidity region. It is defined as the efficiency for reconstructed (true) prompt photons, with measured $E_\text{T}^{\text{iso}} < 3$ GeV, to pass the identification criteria mentioned above.

Following the same method as in Ref. [3], the value of ε^{ID} is determined after correcting the simulated shower shapes for the observed average differences with respect to data. In the present analysis, however, the corrections are estimated for unconverted and converted photons separately. This helps to reduce the systematic uncertainties associated with the correction procedure. The