A measurement of the production cross section for two isolated photons in proton–proton collisions at a center-of-mass energy of $\sqrt{s} = 8$ TeV is presented. The results are based on an integrated luminosity of $20.2 \text{ fb}^{-1}$ recorded by the ATLAS detector at the Large Hadron Collider. The measurement considers photons with pseudorapidities satisfying $|\eta_{\gamma}| < 1.37$ or $1.56 < |\eta_{\gamma}| < 2.37$ and transverse energies of respectively $E_{T,1} > 40 \text{ GeV}$ and $E_{T,2} > 30 \text{ GeV}$ for the two leading photons produced in the interaction. The fiducial cross sections are corrected for detector effects and measured differentially as a function of six kinematic observables. The measured cross section integrated within the fiducial volume is $16.8 \pm 0.8 \text{ pb}$. The data are compared to four calculations with relative uncertainties varying from 5% to 20%.

**1 General description of the measurement**

More than 99% of the high-energy photon pairs produced at the Large Hadron Collider originate from processes predicted by perturbative quantum chromodynamics (pQCD), offering a natural testing ground for strong interactions. We present in this document ATLAS cross-section measurements for isolated photon pair production in $\sqrt{s} = 8$ TeV proton–proton collisions. Significant improvements in the analysis were achieved so that the uncertainties were reduced by up to a factor of two compared to the previous ATLAS publication based on $\sqrt{s} = 7$ TeV data.

Integrated fiducial and differential cross section measurements are performed. Both require the determination of the number of background events in the selected sample ($N_{\text{bkg}}$), the corrections related to detector inefficiencies and resolution, and the integrated luminosity of the $\sqrt{s} = 8$ TeV ATLAS data sample, $\mathcal{L} = 20.2 \pm 0.4 \text{ fb}^{-1}$. The critical part of the measurement consists in getting accurate estimates of $N_{\text{bkg}}$. Six observables of interest are studied: the diphoton invariant mass $m_{\gamma\gamma}$, the absolute value of the cosine of the scattering angle with respect to
the direction of the proton beams \(| \cos \theta^* \phi |\), the diphoton transverse momentum \(p_{T,\gamma\gamma}\), the opening angle between the photons in the azimuthal plane \(\Delta \phi_{\gamma\gamma}\), and two observables which were not included in the previous analysis, \(\alpha_T\) and \(\phi^*_{\eta}\). The \(\alpha_T\) and \(\phi^*_{\eta}\) observables are less sensitive to the energy resolution of the individual photons and therefore are more precisely determined than \(p_{T,\gamma\gamma}\), as shown in Figure 1 (a). Hence, they are ideally suited to probe the region of low \(p_{T,\gamma\gamma}\), in which QCD resummation effects are most significant. Measurements of \(p_{T,\gamma\gamma}\), \(\alpha_T\) and \(\phi^*_{\eta}\) for diphoton production (which originates from both the quark–antiquark and gluon–gluon initial states) are important benchmarks to test the description of the low transverse-momentum region by pQCD and complementary to similar measurements performed for Drell-Yan events (in which quark–antiquark initial states dominate).

## Event selection

The data used in this analysis were recorded using a diphoton trigger with transverse energy thresholds of 35 GeV and 25 GeV for the \(E_T\)-ordered leading and subleading photon candidates, respectively. The shapes of the energy depositions in the electromagnetic calorimeter are required to match those expected for electromagnetic showers initiated by photons. Photons reconstructed within \(|\eta| < 2.37\) are retained, while those near the region between the barrel and end-caps (1.37 < \(|\eta| < 1.56\)) are excluded from the analysis. After the final energy calibration has been applied, only events with \(E_{T,1}\) and \(E_{T,2}\) greater than 40 GeV and 30 GeV, respectively, and angular separation between the two photons \(\Delta R_{\gamma\gamma} > 0.4\) are selected. In addition, the two photon candidates must be isolated from additional activity in the detector. For this purpose, the track isolation energy \(p^\text{iso}_T\) is defined as the scalar sum of the \(p_T\) of tracks with \(p_T > 1\) GeV and within a cone of size \(\Delta R = 0.2\) around the photon candidate, and the calorimeter isolation energy \(E^\text{iso}_T\) is defined as the scalar sum of the \(E_T\) of positive energy topological clusters within

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\(a\)The ATLAS experiment uses a right-handed coordinate system with its origin at the nominal interaction point (IP) in the center of the detector and the z-axis along the beam pipe. The x-axis points from the IP to the center of the Large Hadron Collider ring, and the y-axis points upward. Cylindrical coordinates \((r, \phi)\) are used in the transverse plane, \(\phi\) being the azimuthal angle around the beam pipe. The pseudorapidity is defined in terms of the polar angle \(\theta\) as \(\eta = -\ln \tan(\theta/2)\). Angular distance is measured in units of \(\Delta R = \sqrt{(\Delta \eta)^2 + (\Delta \phi)^2}\). The transverse energy is defined as \(E_T = E / \cosh(\eta)\).
3 Sample composition

The main background in the selected sample originates from high $p_T$ neutral mesons such as $\pi^0 \rightarrow \gamma \gamma$ carrying most of the energy of the associated jet. About 22% of the events in the selected sample include such objects among the selected photon candidates. Another source of background originates from misreconstructed electrons and represents typically 3% of the events in the selected sample. It is dominated by $Z \rightarrow ee$ decays and thus located in terms of invariant mass near the $Z$ boson mass.

Two data-driven methods giving compatible results, and validated using pseudo-data generated with known signal and background composition, are used to subtract the jet and electron background. The method used to derive the final results is an extended maximum-likelihood fit to the two-dimensional distribution of the calorimeter isolation variables ($E_{T,iso}$) of events passing the signal selection. The yields associated with five components are extracted simultaneously: diphoton ($\gamma \gamma$), $\gamma + \text{jet}$ ($\gamma j$), jet + $\gamma$ ($j\gamma$), jet + jet ($jj$) and dielectron ($ee$) events. The fit is performed in the integrated signal region and in each bin of the observables studied. The main uncertainty in the signal yield arises from the modeling of $E_{T,iso}$ for photons. Figure 1 (b), shows the distributions of $E_{T,iso}$ in the integrated signal region and the projections of the five components after the maximization of the likelihood. The composition in the different bins for which the $m_{\gamma\gamma}$ differential cross section is measured is shown in Figure 2 (a).

4 Final results and comparison to theory

The cross sections are measured in a fiducial region defined at particle level to closely follow the criteria used in the event selection. The same requirements on the photon kinematics are applied. The photons must not come from hadron or $\tau$ decays and the transverse isolation energy of each photon at particle level must be below 11 GeV. The estimated number of diphoton events in each bin is corrected for detector resolution, reconstruction and selection efficiencies using an iterative Bayesian unfolding method. The measured fiducial cross section is:

$$\sigma_{tot}^{fid} = 16.8 \pm 0.1 \text{ (stat)} \pm 0.7 \text{ (syst)} \pm 0.3 \text{ (lumi)} \text{ pb} = 16.8 \pm 0.8 \text{ pb.}$$

The main uncertainties originate from uncertainties in the photon identification efficiency (±2.5%), the modeling of the calorimeter isolation (±2.0%) and the integrated luminosity.
Figure 3: (a) $m_{\gamma\gamma}$ and (b) $\phi^*_\eta$ differential cross section measurements, compared with the four QCD predictions described in the text.

(±1.9%). The measurements are compared to fixed-order predictions at NLO (DIPHOX)\textsuperscript{14} and NNLO (2γNNLO)\textsuperscript{15} precision in pQCD, and to computations combining NLO matrix elements and resummation of initial-state gluon radiation to NNLL (RESBOS)\textsuperscript{16} or matched to a parton shower (SHERPA 2.2.1)\textsuperscript{17}, see Figure 2 (b) and Figure 3. The theoretical uncertainties are dominated by missing higher-order corrections. Fixed-order computations are unable to describe the regions sensitive to soft gluon emissions (e.g. low $\phi^*_\eta$), whereas the inclusion of soft-gluon resummation or a parton shower provides a good description of the latter. SHERPA 2.2.1 provides an improved description of the data for all observables compared to the other computations and gives predictions in good agreement with all the measurements.

References