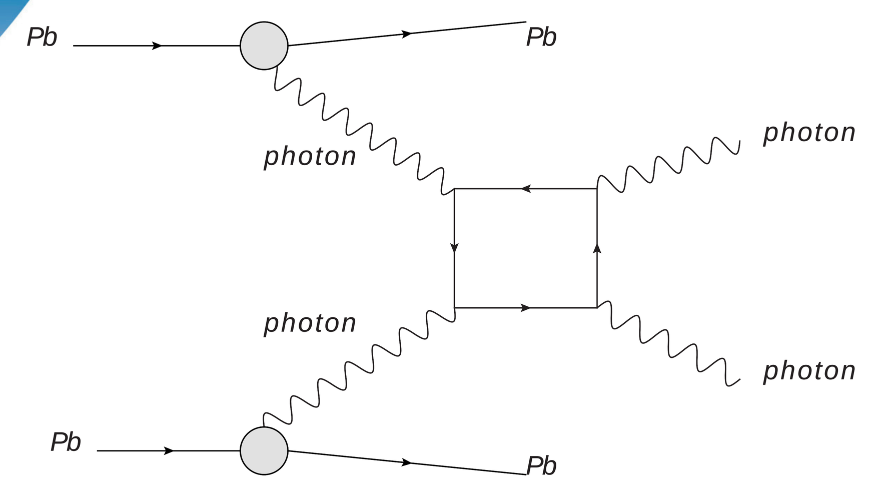
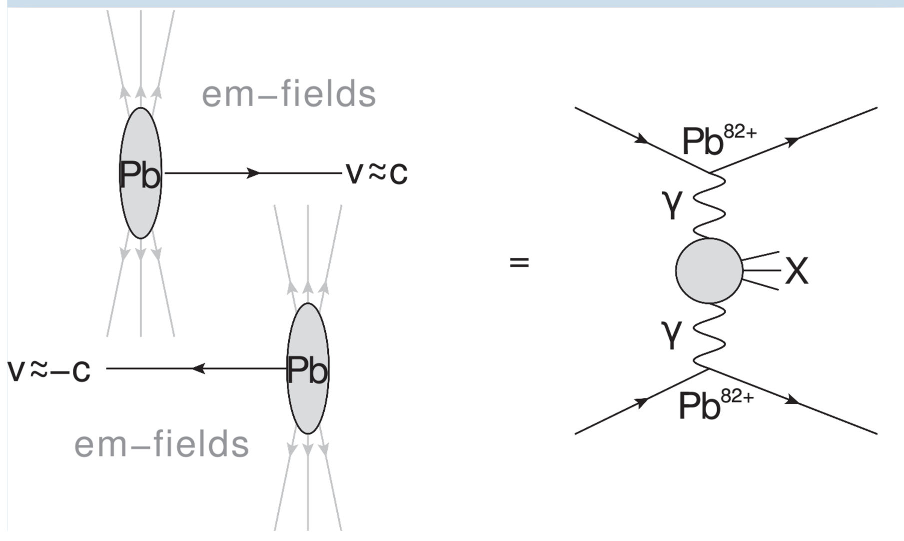
EVIDENCE FOR LIGHT-BY-LIGHT SCATTERING IN HEAVY-ION COLLISIONS WITH THE ATLAS DETECTOR AT THE LHC[1]

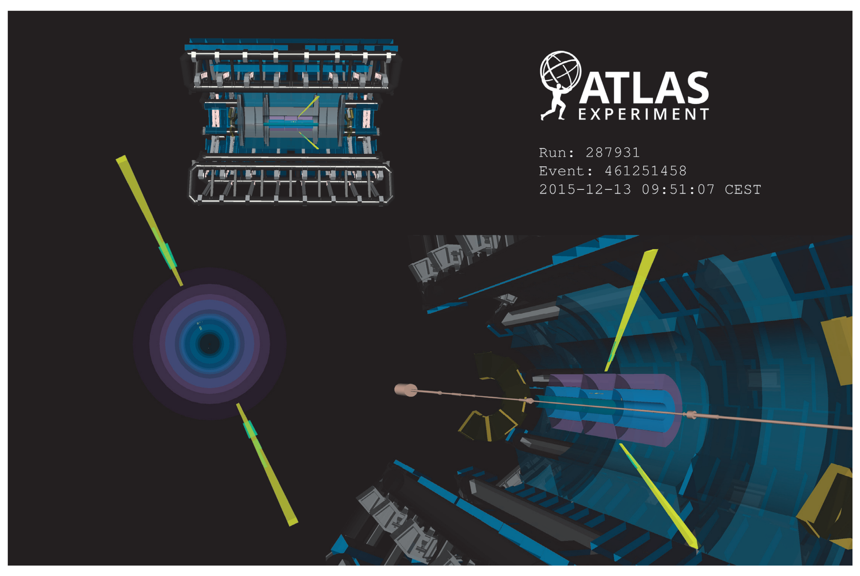


Introduction and measurement strategy

Light-by-light scattering is a quantum-mechanical process that is forbidden in the classical theory of electrodynamics. The $\gamma\gamma \to \gamma\gamma$ reaction proceeds in first order via virtual one loop box diagram involving fermions, which is a $\mathcal{O}(\alpha_{em}^4 \approx 3\times10^{-9})$ process, making it challenging to test experimentally. **Ultra-peripheral collisions** (impact parameters larger than **twice the size of the nuclei)** of heavy, ultra-relativistic ions can be used to study this process. EM field strength between nuclei reaches (for Pb) up to 10^{25} Vm^{-1}, while the strong interaction does not play a role. The EM fields **associated with each nuclei** can be treated as a beam of quasi-real photons with small virtuality. The photon flux from each nucleus scales as Z^2, extremely enhancing the **LbyL** cross section in Pb+Pb, compared to *pp* collisions. The final state of interest is the **exclusive production of a photon pair** with no further activity in the detector. In particular, no tracks from charged particles which come from the primary event vertex are expected.



A **dedicated trigger** for events with moderate activity in the calorimeter but little additional activity in the Inner detector is used. The fiducial cross section of the process $\mathrm{Pb{+}Pb}(\gamma\gamma) \to \mathrm{Pb}^{(*)} + \mathrm{Pb}^{(*)}\,\gamma\gamma$ at $\sqrt{s_{NN}}$ of 5.02 TeV is measured in a data set recorded with the **ATLAS** detector in 2015 corresponding to an integrated luminosity of $480\pm30\ \mu\mathrm{b}^{-1}$.

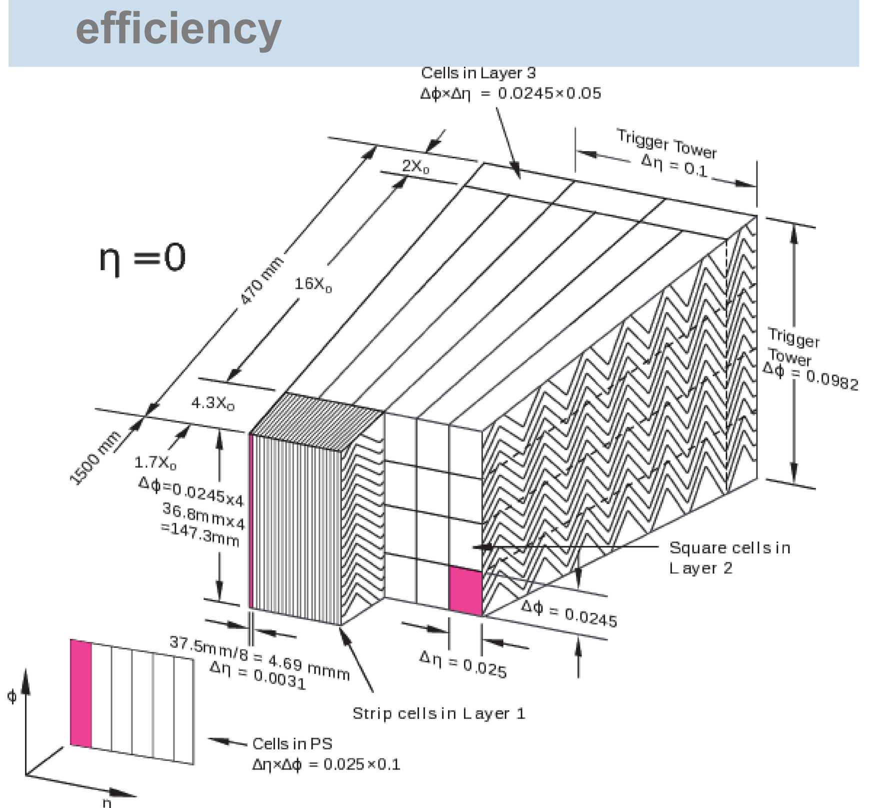


Photon PID

- Photon particle-identification (PID) in **ATLAS** is defined in terms of requirements on quantities describing associated EM showers (**shower shapes**)
- Standard PID working points in **ATLAS** are optimized for photons with $E_T > 20$ GeV
- Therefore, **dedicated PID** is defined, and is optimized for **low E_T** photons ($E_T > 3$ GeV) in terms of 3 shower-shape variables

Name	Description
$W_{\eta 2}$	Lateral width of the shower in the middle layer
E_{ratio}	Ratio of the energy difference associated with the largest and second largest energy deposits to the sum of these energies in the strip layer
f_1	Fraction of energy reconstructed in the first sampling of the electromagnetic calorimeter with respect to the total energy of the cluster

- Background-enhanced region ($p_T^{\gamma\gamma} > 2$ GeV) is used to optimize selection criteria on shower shapes for best **signal significance** and **efficiency**



Uncertainties

- **Photon reconstruction efficiency** is studied in simulation and in data using the tag&probe method on $\gamma\gamma \to e^+e^-$ events where one of the electrons emits a hard bremsstrahlung photon
- **Photon PID efficiency** is studied in Monte Carlo simulation and in data using $\gamma\gamma \to l^+l^-$ events with FSR photons
- **Photon cluster energy resolution** is extracted from data by examination of EM clusters from electrons in $\gamma\gamma \to e^+e^-$ events, and **photon energy scale** determined in a similar way

The correction C accounts for effects of the detector. It is defined as the ratio of the number of generated signal events satisfying the selection criteria after particle reconstruction and detector simulation to the number of generated events satisfying the fiducial criteria before reconstruction.

Source of uncertainty	Detector correction (*C*)
	0.31
Trigger	5%
Photon reco efficiency	12%
Photon PID efficiency	16%
Photon energy scale	7%
Photon energy resolution	11%
Total	24%

Event selection

Events with **exactly 2 photons** satisfying the PID, detector geometrical acceptance and a minimum transverse energy requirement, are selected. A **veto** on events with additional **charged-particle tracks** is imposed. A selection on the **invariant mass of the diphoton** is used to reject diphoton events from meson decays without affecting the signal. The signal photons have well **balanced transverse momentum**, allowing for further background rejection with negligible effect on the signal.

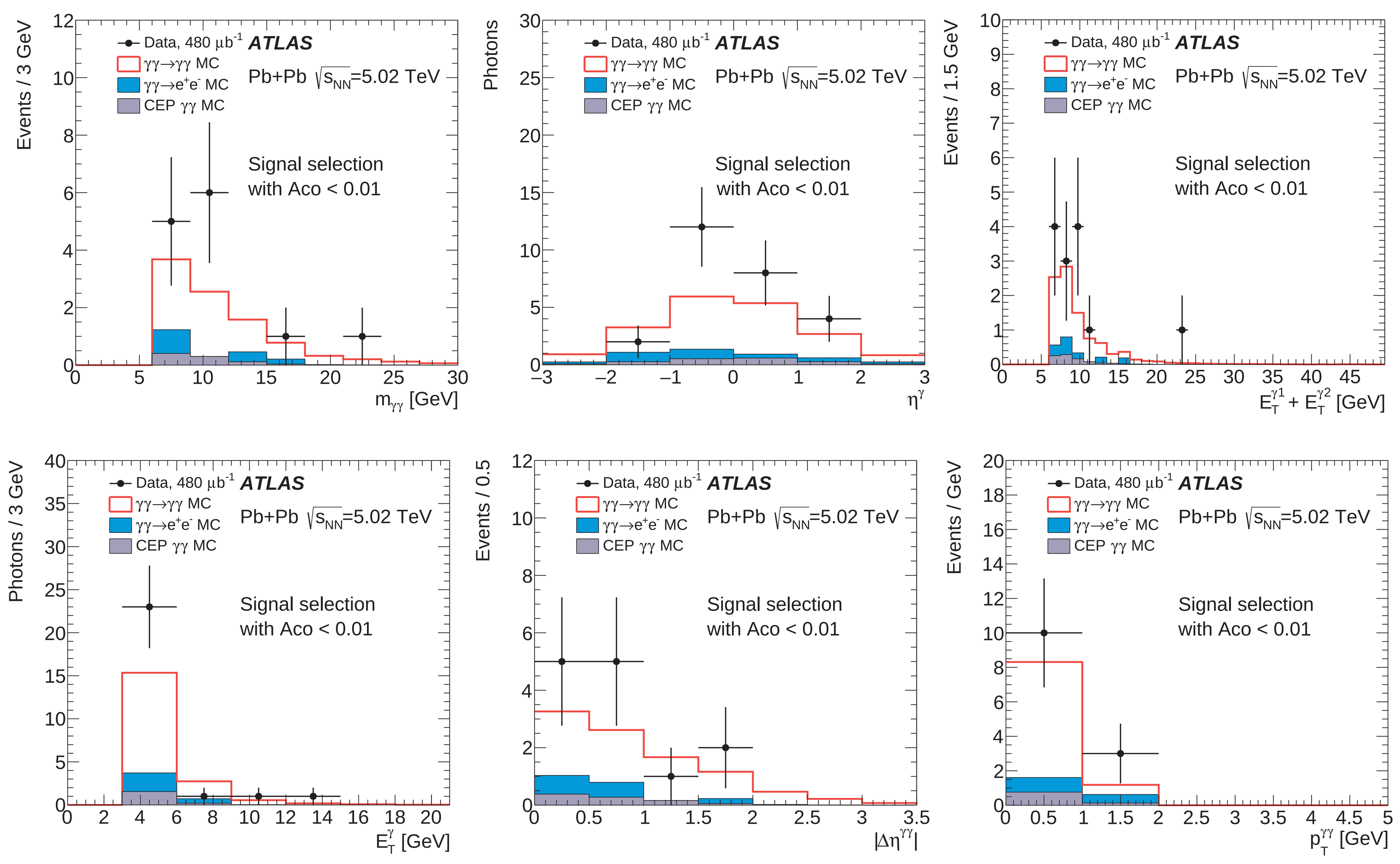
Description	Value
Photon transverse energy	$E_T > 3$ GeV
Detector acceptance	$\lvert\eta_\gamma\rvert < 2.4$
Number of photons	$N_\gamma = 2$
Track veto	$N_{\mathrm{tracks}} = 0$
Diphoton invariant mass	$M_{\gamma\gamma} > 6$ GeV
Diphoton transverse momentum	$p_T^{\gamma\gamma} < 2$ GeV
Diphoton acoplanarity $\mathrm{Aco} = 1 - \frac{\Delta\varphi_{\gamma\gamma}}{\pi}$	Aco < 0.01

Background estimation

Possible background contributions stem from **misidentified electrons** from the $\gamma\gamma \to e^+e^-$ process, a **QCD-induced process** of central exclusive production ($gg \to \gamma\gamma$) that can mimic light-by-light scattering and other sources which could **fake photons** (such as calorimeter noise or clusters induced by cosmic-ray muons).

Background source	Estimation method	Suppressed by	SR estimate
$\gamma\gamma \to e^+e^-$	Simulation with data-driven cross-check	$N_{\mathrm{tracks}} = 0$	1.3 ± 0.3
CEP $gg \to \gamma\gamma$	Simulation with data-driven normalization	Aco < 0.01	0.9 ± 0.5
Other hadronic	Data-driven using control trigger	$N_{\mathrm{tracks}} = 0$ and Trigger requirements	0.3 ± 0.3
Cosmic, noise	Data-driven ABCD method	Photon PID and $p_T^{\gamma\gamma} < 2$ GeV	0.1 ± 0.1
Total			2.6 ± 0.7

Kinematic distributions

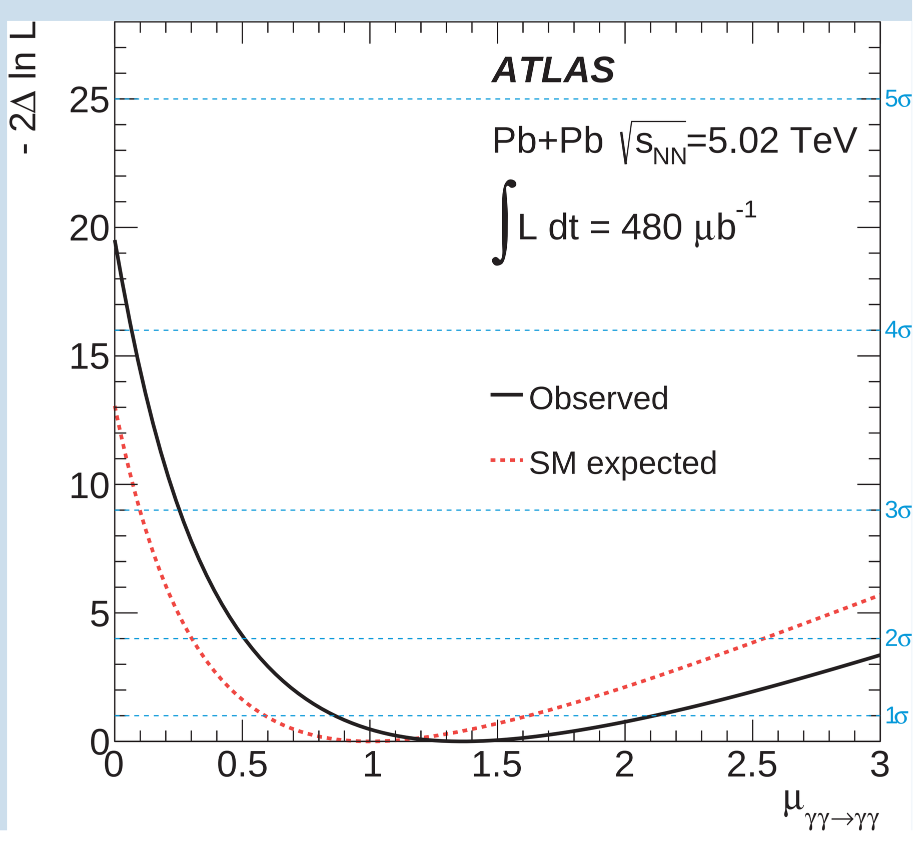


Results and conclusion

After full signal selection 13 events are observed in data whereas 7.3 signal events and 2.6 background events are expected. After correcting the background-subtracted yield by C, which accounts for detector effects, the measured **fiducial cross section** is

$$\sigma_{\mathrm{fid}} = 70 \pm 24\,(\mathrm{stat.}) \pm 17(\mathrm{syst.})\ \mathrm{nb}$$

which is in agreement with the SM predictions $\sigma_{\mathrm{fid}} = 45 \pm 9$ nb [2] and $\sigma_{\mathrm{fid}} = 45 \pm 10$ nb [3] within uncertainties. The excess corresponds to a **statistical significance** of 4.4σ over the background only hypothesis.



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[1] arXiv:1702.01625v1 [hep-ex]
[2] M. Klusek-Gawenda, P. Lebiedowicz, A. Szczurek; arXiv:1601.07001v1 [nucl-th]
[3] D. d'Enterria, G. G. da Silveira; arXiv:1305.7142v3 [hep-ph]

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