Light-by-light scattering in ultra-peripheral Pb+Pb collisions in the ATLAS experiment
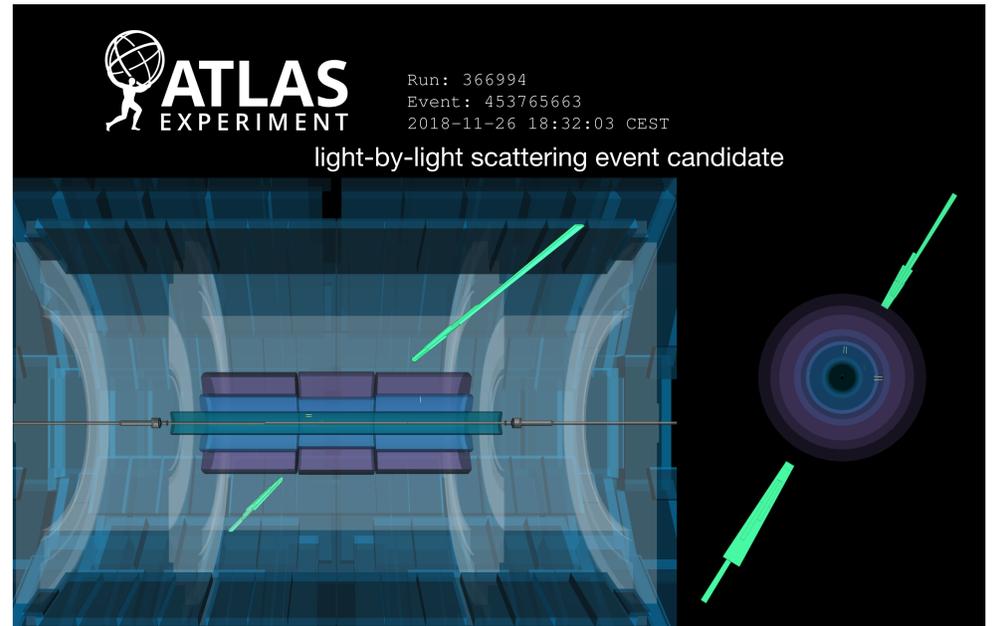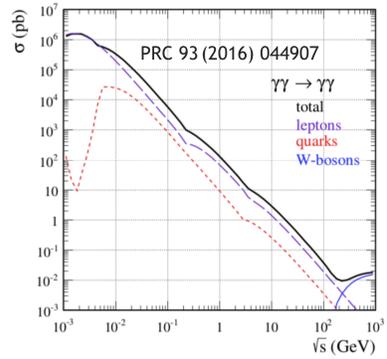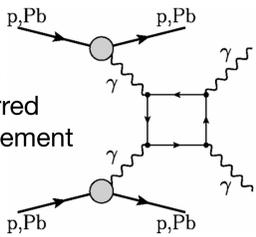
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on behalf of the ATLAS Collaboration

IS2021
The VIᵗʰ International Conference on the
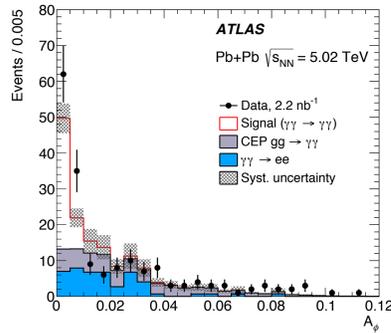INITIAL STAGES
OF HIGH-ENERGY NUCLEAR COLLISIONS

What is light-by-light scattering

- **Light-by-light** (LbyL) scattering is a QED process, which proceeds via virtual one-loop box diagrams involving charged fermions and $W^\pm$ bosons
- Due to its tiny cross-section, first direct evidence was not possible until 2017 [1], what was confirmed by the **8.2σ observation in 2019** [2]
- New measurement [3] combines the available Pb+Pb datasets from 2015 and 2018, used in [1] and [2], respectively
- Measurements are performed in **ultra-peripheral heavy-ion (HI) collisions** - preferred because of Z^4 enhancement in the cross-section compared to pp collisions
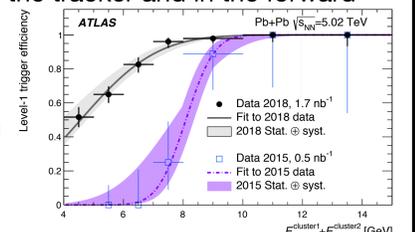
PRC 93 (2016) 044907
$\gamma\gamma \to \gamma\gamma$
total
leptons
quarks
W-bosons

Run: 366994
Event: 453765663
2018-11-26 18:32:03 CEST
light-by-light scattering event candidate

Event selection

- LbyL scattering signature consists of: **two low-E_T, back-to-back photons** without any additional activity in the detector
- A dedicated diphoton trigger was designed to collect LbyL events with high efficiency
- Photon **identification** procedure based on **neural network** was developed and optimized for low-E_T photons to maintain 95% PID efficiency
- Selected events have two photons each with transverse energy $E_T^\gamma > 2.5$ GeV, pseudorapidity $|\eta_\gamma| < 2.37$,
- Track veto - to suppress $\gamma\gamma \to e^+e^-$ background,
- Diphoton invariant mass $m_{\gamma\gamma} > 5$ GeV
- Diphoton transverse momentum below 1 GeV
- Diphoton acoplanarity below 0.01 - to suppress CEP gg $\to \gamma\gamma$ background

ATLAS
Pb+Pb $\sqrt{s_{NN}} = 5.02$ TeV
- Data, 2.2 nb⁻¹
Signal ($\gamma\gamma \to \gamma\gamma$)
CEP gg $\to \gamma\gamma$
$\gamma\gamma \to ee$
Syst. uncertainty

Trigger efficiency

- **Trigger selection** was **developed** for 2015 data taking and further **optimized** for 2018
- Trigger consists of following elements: Level-1, selecting events with low activity in the calorimeter, and HLT requiring low activity in the tracker and in the forward direction
- The Level-1 trigger efficiency is measured using EM clusters from exclusive dielectron events
- The **performance** of Level-1 trigger **improved** in 2018 wrt 2015

ATLAS
Pb+Pb $\sqrt{s_{NN}} = 5.02$ TeV
- Data 2018, 1.7 nb⁻¹
Fit to 2018 data
2018 Stat. ⊕ syst.
Data 2015, 0.5 nb⁻¹
Fit to 2015 data
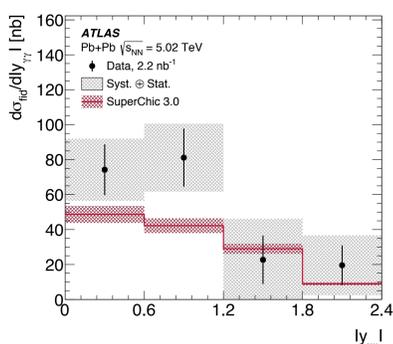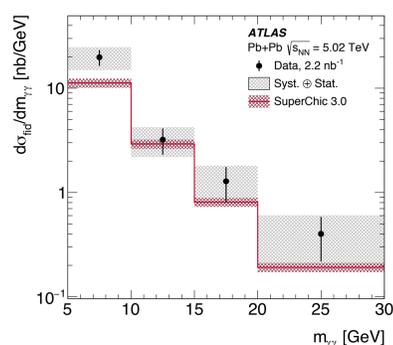2015 Stat. ⊕ syst.
$E_T^{cluster1} + E_T^{cluster2}$ [GeV]

Differential cross-sections

- Cross-section is measured in a fiducial phase space, defined by the requirements reflecting event selection
- The measured **integrated fiducial cross-section** is $\sigma_{fid} = 120 \pm 17(\text{stat.}) \pm 13(\text{syst.}) \pm 4 (\text{lumi.})$ nb, while the predicted values are 80 ± 8 nb from [4] and 78 ± 8 nb from the SuperChic v3.0 MC generator [5]
- Differential fiducial cross-sections are **unfolded to particle level** in the fiducial phase space to correct for bin migrations due to detector resolution effects
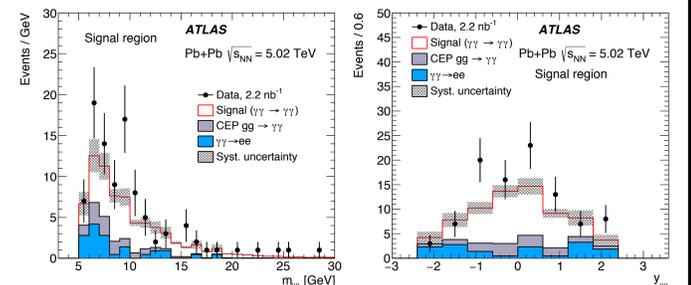- They are determined using an **iterative Bayesian unfolding method** with one iteration for all distributions
- The full set of systematic uncertainties is considered
- The unfolded differential fiducial cross-sections are compared with the predictions from SuperChic v3.0
- **No significant differences** between predictions and data are seen

ATLAS
Pb+Pb $\sqrt{s_{NN}} = 5.02$ TeV
- Data, 2.2 nb⁻¹
Syst. ⊕ Stat.
SuperChic 3.0
$d\sigma_{fid}/dm_{\gamma\gamma}$ [nb/GeV]
$m_{\gamma\gamma}$ [GeV]

ATLAS
Pb+Pb $\sqrt{s_{NN}} = 5.02$ TeV
- Data, 2.2 nb⁻¹
Syst. ⊕ Stat.
SuperChic 3.0
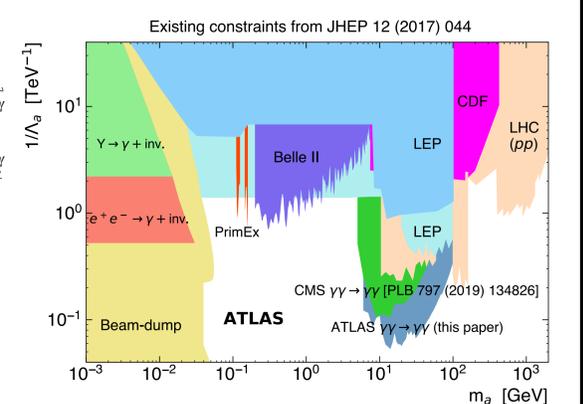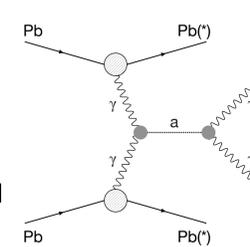$d\sigma_{fid}/d|y_{\gamma\gamma}|$ [nb]
$|y_{\gamma\gamma}|$

Diphoton kinematic distributions

- Uncorrected diphoton distributions are compared with predictions for the sum of signal and background contributions
- Main **background** sources are estimated using **data-driven** techniques
- 97 events are observed in data where 45 signal events and 27 background events are expected
- **Shapes** of the distributions are **in good agreement** but data excess visible in both distributions

ATLAS
Pb+Pb $\sqrt{s_{NN}} = 5.02$ TeV
Signal region
- Data, 2.2 nb⁻¹
Signal ($\gamma\gamma \to \gamma\gamma$)
CEP gg $\to \gamma\gamma$
$\gamma\gamma \to ee$
Syst. uncertainty
$m_{\gamma\gamma}$ [GeV]
$y_{\gamma\gamma}$

ALP search

- ALPs are **hypothetical**, (pseudo-)scalar **particles** that appear in many theories with a spontaneously broken global symmetry
- ALPs may **decay to two photons** [6]
- Events for the ALP signal were generated using Starlight for various ALP masses (m_a) ranging between 5 and 100 GeV
- The **search** is performed using $m_{\gamma\gamma}$ distribution
- Simulated LbyL events are normalized to the data yield, after subtracting $\gamma\gamma \to e^+e^-$ and CEP gg $\to \gamma\gamma$ contributions and excluding the mass search region
- ALP contribution is fitted individually for every mass bin using a maximum-likelihood fit

Existing constraints from JHEP 12 (2017) 044
$\Upsilon \to \gamma + $ inv.
Belle II
$e^+e^- \to \gamma + $ inv.
PrimEx
LEP
CDF
LHC (pp)
LEP
Beam-dump
CMS $\gamma\gamma \to \gamma\gamma$ [PLB 797 (2019) 134826]
ATLAS $\gamma\gamma \to \gamma\gamma$ (this paper)
$1/\Lambda_a$ [TeV⁻¹]
m_a [GeV]

- **No significant deviation** from the **background-only hypothesis** is observed
- The result is used to estimate the upper limit on the **ALP cross-section** and **ALP coupling** $1/\Lambda_a$ at 95% confidence level
- The obtained **exclusion limits** are the **strongest so far** for the mass range of $6 < m_a < 100$ GeV

References: [1] Nature Physics 13 (2017) 852 [2] Phys. Rev. Lett. 123 (2019) 052001 [3] arxiv:2008.05355 [4] Phys. Rev. C 93 (2016) 044907 [5] Eur. Phys. J. C 79 (2019) 39 [6] Phys. Rev. Lett. 118 (2017) 171801