Light-by-light scattering in ultra-peripheral Pb+Pb collisions in the ATLAS experiment

Motivation:
Light-by-light scattering is a rare $O(\alpha_{EM}^4)$ QED process → can be observed in heavy-ion collisions due to large EM fields associated with relativistic ions → sensitive to NEW Physics (axion-like particles, aQGC, ...)

Previous LHC measurements:
- ATLAS Nat. Phys. 13 (2017) 852 (~4σ evidence)

This analysis:
- Combine 2015 and 2018 Pb+Pb data with 2.2 nb
- Differential cross-section measurements
- BSM interpretation: search for the production of axion-like particles (ALP)

Signal Selection:
- Criteria:
  - Exactly two photons with $E_T > 2.5$ GeV and $|\eta| < 2.37$
  - Invariant diphoton mass $m_{\gamma\gamma} > 5$ GeV
  - Veto extra activity in MLL 
  - No tracks with $p_T > 100$ MeV
  - No pixel tracks with $p_T > 50$ MeV and $|\Delta \eta (\gamma, \text{track})| < 0.5$
  - Back-to-back topology → $p_T^\gamma < 1$ GeV (2 GeV for $m_{\gamma\gamma} > 12$ GeV)
  - Acoplanarity $(1 - \frac{\Delta \phi (\gamma, \gamma)}{\pi}) < 0.01$

Trigger Performance:
- Level-1 trigger efficiencies determined using $\gamma \gamma \rightarrow e^+e^-$ process in data
- Triggered by independent support triggers
- Efficiency at Level-1 improved in 2018 wrt. 2015
- Applied to simulated events to correct yields
- High Level Trigger (HLT) efficiency is higher than 99%

Results:
- Measured fiducial cross section: $\sigma_{\text{exp}} = 120 \pm 17$ (stat.) $\pm 13$ (syst.) $\pm 4$ (lumi.) nb
- Theory prediction:
  - $\sigma_{\text{theory}} = 78\pm 8$ nb (SuperChic 3 MC)
  - $\sigma_{\text{exp}} = 80\pm 8$ nb (Phys. Rev. C 93 (2016) 044007)

Search for ALP $\gamma \gamma \rightarrow a \gamma \gamma$ Production
- Axion like particles (ALP):
  - $(\text{pseudo-})$ scalar particles with typically weak interactions with SM particles
  - Have identical signature as SM Light-by-light scattering

- Idea:
  - Search for new narrow resonances via $\gamma \gamma \rightarrow a \gamma \gamma$ reaction using cut-and-count method
  - Signal: $\gamma \gamma \rightarrow a \rightarrow \gamma \gamma$, BR($a \rightarrow \gamma \gamma$)=100%
  - Background: LbyL, $\gamma \gamma \rightarrow e^+e^-$, CEP $gg \rightarrow \gamma \gamma$

- Results:
  - 95% CL limits on ALP production cross section and ALP coupling to photons
  - Largest excess observed around 10 GeV (~2.1σ)
  - The most stringent limit established for diphoton masses of $6 < m_a < 100$ GeV

Data, 2.2 nb
ATLAS Preliminary
CENTRAL EXCLUSIVE PRODUCTION
$gg \rightarrow \gamma \gamma$

Photon reconstruction:
- Using $e^+e^-$ events where a hard bremsstrahlung photon was radiated
- Efficiency is 60% for $E_T=2.5$ GeV, and reaches 90% at $E_T=6$ GeV

Photon identification:
- Using $\gamma \gamma \rightarrow l^+l^-\gamma$ events
- Neutral network based PID, optimized for low-$E_T$ photons
- Efficiency exceeds 90%

Good modelling in MC simulation:
- Differences between data and MC simulation included in corrected efficiencies

Background Processes:
- Exclusive production of electron pairs $\gamma \gamma \rightarrow e^+e^-$ → evaluated using a data-driven method
- Central Exclusive Production (CEP) $gg \rightarrow \gamma \gamma$
- Gluonic initial state → nuclear breakup, larger initial transverse momentum and broader shape of acoplanarity distribution
- Evaluated from a control region in data (acoplanarity>0.01)
- Total background in SR: 27±5 events

Analysis of 2015+18 Pb+Pb Data With 2.2 nb$^{-1}$
- 97 events observed, 45 signal and 27±5 background events expected

Differential distributions:
- Cross sections for diphoton: $m_{\gamma\gamma}$, $|y_{\gamma\gamma}|$, $p_T^{\gamma\gamma}$, $p_T^{\gamma\gamma}$, and $|\cos \theta^{\gamma\gamma}|$
- Good agreement in shape, differences in the normalisation

ATLAS-CONF-2020-010

This work was supported in part by the National Science Centre, Poland, grant DEC-2016/23/B/ST2/01409 and by PL-Grid Infrastructure