Observation of light-by-light scattering and new results from ultra-peripheral heavy-ion collisions in the ATLAS experiment

Yahya TAYALATI

on behalf of the ATLAS Collaboration

EPS-HEP conference 2019

Ghent, Belgium
Outline

- Standard Model light by light scattering
- Experimental evidences and new ATLAS measurements
- New results from ultra-peripheral heavy-ion collisions (UPC)
One-loop process

- The standard Model predicts the possibility of light by light scattering via 1-loop diagrams
- Loops contains virtual charged particles ($q,l,W^\pm$) from SM
- Heavy ions create huge EM fields ($10^{14}$T) from coherent action of Z protons: cross section $Z^4$
- UPC provide a flux of quasi-real photons probing the nuclear structure
- The process sensitive to BSM physics
First evidence

- **2015 Pb+Pb data 0.48 nb-1**

- **Event selection:**
  2 back to back photons and nothing else in the central detector
  
  \[ E_T > 3 \text{ GeV} \text{ and } |\eta| < 2.4, \ m_{\gamma\gamma} > 6 \text{ GeV} \]
  
  \[ P_{T_{\gamma\gamma}} < 2 \text{ GeV} \]
  
  \[ \text{Acoplanarity} = 1 - \frac{|\Delta\phi|}{\pi} < 0.01 \]

- **Results:**
  
  13 events observed (7.3 signal events and 2.6 background events are expected)

  The excess corresponds to 4.4\sigma statistical significance over background only hypothesis
New Measurements

- **2018 data:**
  - 1.73 nb\(^{-1}\) data
  - More than 3 times stat w.r.t. 2015 dataset

- **Improvements:**
  - Strong emphasis was put to improve the trigger strategy (especially at the Level-1)
  - Trigger with higher efficiency at low \(E_T\)
  - NN Photons PID instead of cut based
  - Better background rejection
New Measurements

Signal:
- \( \gamma \gamma \rightarrow \gamma \gamma \) Generator: Superchic3
  100k events (167 nb)

Background Considered:
- Exclusive dielectron production \( \gamma \gamma \rightarrow e^+e^- \)
  Generator: Starlight
  1.5 M events (419 b) \( 3.6 < M_{\text{inv}} < 8 \text{ GeV} \)
  0.5 M events (116 b) \( M_{\text{inv}} > 8 \text{ GeV} \)
- Central Exclusive Production (CEP) \( gg \rightarrow \gamma \gamma \)
  Generator: Superchic3
  100k events

Negligible Background
- Fakes (calo noise, cosmics)
- Others, found negligible (exclusive di-meson production (e.g. \( \pi^0 \pi^0 \)), \( \gamma \gamma \rightarrow \tau \tau \), \( \gamma \gamma \rightarrow q\bar{q} \), \( \gamma \gamma \rightarrow e\gamma\gamma \), \( \gamma \gamma \rightarrow \eta_b \rightarrow \gamma \gamma \), \( \gamma Pb \rightarrow Y \rightarrow 3\gamma \), ion bremsstrahlung)
Photon Performance studies

Reconstruction efficiency is extracted from data $\gamma\gamma \rightarrow e^+e^-$ events
Tag and prob : 1 electrons and 2 charged-particle tracks

Neural network based PID
Trained on background photons from data + photons from the signal MC

arXiv: 1904.03536 (accepted for PRL)
Signal selection

❖ Two photons

- Identification: NN working point
- $E_T > 3$ GeV, $|\eta| < 2.37$

❖ LbyL scattering topology

- $m_{\gamma\gamma} > 6$ GeV
- Veto extra particle activity

**to suppress e+e- background**

- Requiring no tracks ($p_T > 100$ MeV)
- and no pixel tracks ($p_T > 50$ MeV, $|\Delta \eta| < 0.5$ photon-pixelTrk matching)

**to suppress fakes and CEP background**

- $p_{T_{\gamma\gamma}} < 1$ GeV ($2$ GeV for $m_{\gamma\gamma} > 12$ GeV)
- Diphoton acoplanarity $< 0.01$
Results

• 59 events observed (where $12 \pm 3$ background events expected)
• Observed signal significance over the background only hypothesis is of $8.2\sigma$ (expected $6.2\sigma$)
• Updated cross-section: $\sigma = 78 \pm 13$ (stat) $\pm 8$ (sys) nb
• SM predictions: $51 \pm 5$ nb  
  $50 \pm 5$ nb

Results

ATLAS

Run: 366994
Event: 453765663
2018-11-26 18:32:03 CEST

m_{\gamma\gamma} = 29 \text{ GeV}

ATLAS-CONF-2019-002
Two-particle azimuthal correlations

- 2018 data (1.73 nb\(^{-1}\), 5.02 TeV)
- Dedicated photo-nuclear event trigger
- Looking to charged-particle tracks in the event
- A template fitting method is employed to subtract the non-flow contribution

\[
Y^{\text{HM}}(\Delta \phi) = F Y^{\text{LM}}(\Delta \phi) + G \left\{ 1 + 2 \sum_{n=2}^{3} v_{n,n} \cos(n \Delta \phi) \right\}
= F Y^{\text{LM}}(\Delta \phi) + Y^{\text{ridge}}(\Delta \phi).
\]
Two-particle azimuthal correlations

Flow coefficients $v_2$ as a function of charged-particle multiplicity

Flow coefficients $v_2$ as a function of particle $p_T$
Using LHC as a photon-photon collider works very well:

- Light-by-light scattering was observed with the ATLAS detector using data from Pb+Pb collisions at 5.02 TeV from 2018

- The signal significance gives an observation with 8.2σ

  Measured fiducial cross-section: $\sigma = 78 \pm 13$ (stat) $\pm 8$ (sys) nb

- UPC data will improve the understanding of the strong electromagnetic fields surrounding the nucleus, which enable future UPC measurements utilizing these high energy probes
exclusive dielectron pairs are used for various aspects of the analysis

• MC simulation normalized to integrated luminosity

arXiv:1904.03536
Kinematic distributions for $\gamma\gamma \rightarrow \gamma\gamma$ event candidates:

arXiv:1904.03536
Acoplanarity distributions for different selections in pair rapidity.
Invariant mass distributions of the di-photon system for photons from the LbyL signal and background processes in 5.02 TeV Pb+Pb collisions with an integrated luminosity of 10 nb$^{-1}$. The shaded band in cyan represents expected statistical uncertainties.
ATLAS 2016 represents the exclusion limit derived from the recent LbyL cross section measured in Pb+Pb collisions by ATLAS.
<table>
<thead>
<tr>
<th>Source of uncertainty</th>
<th>Detector correction (C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.350</td>
</tr>
<tr>
<td>Trigger efficiency</td>
<td>2%</td>
</tr>
<tr>
<td>Photon reco efficiency</td>
<td>4%</td>
</tr>
<tr>
<td>Photon PID efficiency</td>
<td>2%</td>
</tr>
<tr>
<td>Photon energy scale</td>
<td>2%</td>
</tr>
<tr>
<td>Photon energy resolution</td>
<td>2%</td>
</tr>
<tr>
<td>Photon angular resolution</td>
<td>2%</td>
</tr>
<tr>
<td>Alternative signal MC</td>
<td>1%</td>
</tr>
<tr>
<td>Signal MC statistics</td>
<td>1%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>7%</strong></td>
</tr>
</tbody>
</table>

\[ \sigma_{\text{fid}} = \frac{N_{\text{data}} - N_{\text{bkg}}}{C \times \int L dt} , \]
Backup

- First preliminary measurement of high-mass (beyond 10 GeV) exclusive dimuon events in ultra-peripheral heavy-ion collisions.
- The results are compared with the STARLIGHT 1.1 Monte Carlo

\[ \text{Pb} + \text{Pb} \rightarrow \mu^+ + \mu^- + \text{Pb} (*) + \text{Pb} (*) \]
Cross-sections measurement taking into account 2 contributions

\[ H_T \equiv \sum_i PT_i \]

\[ y_{\text{jets}} \equiv \frac{1}{2} \ln \left( \frac{\sum_i E_i + \sum_i p_{zi}}{\sum_i E_i - \sum_i p_{zi}} \right) \]

\[ z_y \equiv \frac{m_{\text{jets}}}{\sqrt{s}} e^+ y_{\text{jets}}, \quad x_A \equiv \frac{m_{\text{jets}}}{\sqrt{s}} e^- y_{\text{jets}} \]