Light-by-light scattering at low diphoton energies from ultraperipheral heavy-ion collisions at the LHC

- M. K-G, W. Schäfer and A. Szczurek, *Phys. Lett.* B761 (2016) 399, Two-gluon exchange contribution to elastic $\gamma\gamma \to \gamma\gamma$ scattering and production of two-photons in ultraperipheral ultrarelativistic heavy-ion and proton-proton collisions;
- Z. Citron, M. K-G et al., *CERN Yellow Rep. Monogr.* 7 (2019) 1159-1410, Future physics opportunities for high-density QCD at the LHC with heavy-ion and proton beams, Report from Working Group 5 on the Physics of the HL-LHC, and Perspectives at the HE-LHC.

**Equivalent Photon Approximation**

1. **Light-by-light scattering**
   - Elementary cross section
   - Fermionic boxes
   - Resonances
   - Pionic background
   - Nuclear cross section

**ULTRAPERIPHERAL collisions**

$b > R_{\min} = R_1 + R_2 \approx 14 \text{ fm}$
**Light-by-Light**

**AA → AAγγ for M_{γγ} < 5 GeV?**

**Continuum**

**Resonances**

**Background**

---

**σ (pb)**

- γγ → γγ
- fermionic contributions
- leptons
- quarks
- mesonic contributions
- scalars
- pseudoscalars
- tensors
- \(f_4(2050)\)

![Graph showing σ (pb) vs. s (GeV)]

**σ(γγ → π^0π^0) [nb]**

- Crystal Ball
- Belle

![Graph showing σ(γγ → π^0π^0) vs. W_{γγ} = M_{ππ} [GeV]]

---

**References**


The role of meson exchanges in light-by-light scattering.

π^+π^- and π^0π^0 pair production in photon-photon and in ultraperipheral ultrarelativistic heavy-ion collisions.
ALICE cuts

- boxes
- bkg
- mesons

LHCb cuts

**Graphs:**

- Left graph: 
  - $\gamma\gamma$ signal
  - $\pi^0\pi^0$ background
  - $\eta' (958)$
  - $\eta (1S)$
  - $\eta_c (1P)$
  - $\eta_c (2S)$

- Right graph: 
  - $\gamma\gamma$ signal
  - $\pi^0\pi^0$ background
  - $\eta' (958)$
  - $\eta (1S)$
  - $\eta_c (1P)$
  - $\eta_c (2S)$

**Energy and Cross Section Table:**

<table>
<thead>
<tr>
<th>Total nuclear cross section [fb]</th>
<th>Energy $W_{\gamma\gamma} = (0 - 2)$ GeV</th>
<th>$W_{\gamma\gamma} &gt; 2$ GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fiducial region</strong></td>
<td>ALICE</td>
<td>LHCb</td>
</tr>
<tr>
<td>Boxes</td>
<td>4 890</td>
<td>3 818</td>
</tr>
<tr>
<td>$\pi^0\pi^0$ bkg</td>
<td>135 300</td>
<td>40 866</td>
</tr>
<tr>
<td>$\eta$</td>
<td>722 573</td>
<td>568 499</td>
</tr>
<tr>
<td>$\eta'$ (958)</td>
<td>54 241</td>
<td>40 482</td>
</tr>
<tr>
<td>$\eta_c (1S)$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\eta_c (1P)$</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>$\eta_c (2S)$</td>
<td></td>
<td>2</td>
</tr>
</tbody>
</table>
Experimental Resolution & Scalar Asymmetry & "Unwanted" BKG

\[ A_S = \frac{|\vec{p}_T(1) - \vec{p}_T(2)|}{|\vec{p}_T(1) + |\vec{p}_T(2)|} \]

\[ A_S \]

\[ M_{\gamma\gamma} \]

80% of the signal events at \( A_S < 0.02 \)
**Conclusion**

- Maxwell classical theory
  - light doesn’t interact with each other
- Quantum theory
  - interaction of photons through quantum fluctuations

- **σ(γγ → γγ) ∝ α_\text{em}^4** → very small

- Photon beams
  - High-power lasers
    - K. Homma, K. Matsuura, K. Nakajima, PTEP 2016 (2016) 013C01
    - *Testing helicity-dependent γγ → γγ scattering in the region of MeV*
  - Ultrarelativistic heavy-ion collision
    - Cross section ∝ Z^4
    - Quasi-real photons

- UPC of heavy-ion opens a possibility to measure or to test the γγ → γγ scattering:
  1. mesons decay (W_{γγ} < 4 GeV),
  2. pionic background (W_{γγ} < 2 GeV),
  3. fermionic boxes (W_{γγ} > 2 GeV),
  4. VDM-Regge (W_{γγ} > 30 GeV),
  5. 2-gluon exchange (W_{γγ} > 30 GeV).

- Measurable cross section;
- ATLAS/CMS have observed 13→59→70/14 events confirming LbL scattering in UPC;
- ALICE and LHCb could measure LbyL scattering for W_{γγ} > 2 GeV in Pb-Pb and Ar-Ar collisions with very good statistic. Run 5: L_{\text{int}}^{\text{Ar-Ar}} = (3 - 8.8) pb → 1460–4280 signal events;
- Importance of η & η' for W_{γγ} < 2 GeV.