Study of $\gamma\gamma \to \gamma\gamma$ processes in UPC with future FoCal and ALICE 3 detector

THE HENRYK NIEWODNICZAŃSKI INSTITUTE OF NUCLEAR PHYSICS POLISH ACADEMY OF SCIENCES

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Introduction

The huge collision energies and strong electromagnetic fields that accompany heavy-ion collisions at the LHC favor the observation of rare processes. In 2017, the ATLAS experiment was the first to present results demonstrating the occurrence of light-by-light (LbL) scattering in ultraperipheral heavy-ion collisions [1]. However, contemporary detectors are capable of measuring photons in the transverse momentum range above 2 GeV [2], where the main contribution is fermionic loop. The future ALICE FoCal [3] and ALICE 3 [4] detectors offer opportunities to investigate also other processes.

Nuclear cross section

The formalism is based on an equivalent photon approximation. The cross section for particle production due to collision of photon fluxes is given by the formula:

$$\sigma_{A_1A_2\to A_1A_2X_1X_2} = \int \sigma_{\gamma\gamma\to X_1X_2}(W_{\gamma\gamma}) \times N(\omega_1,b_1)N(\omega_2,b_2)S^2_{abs}(b) \times \frac{W_{\gamma\gamma}}{2} dW_{\gamma\gamma} dY_{X_1X_2} d\bar{b}_x d\bar{b}_y d^2b,$$

where $\sigma_{\gamma\gamma\to X_1X_2}(W_{\gamma\gamma})$ is the elementary cross section, which is a measure of the probability of producing particles with energy $W_{\gamma\gamma}$ for interacting photon beams, $N(\omega_i,b_i)$ describes the photon flux which is dependent on the form factor of the nucleus. Results of latest ATLAS data [5] compared with different theoretical approaches are presented in Figure 1.

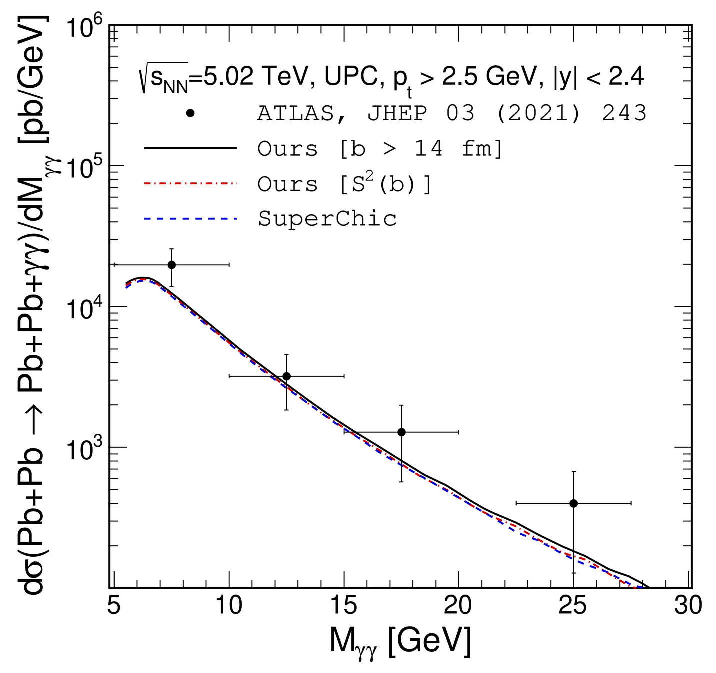

Figure 1: Differential cross section as a function of two-photon invariant mass at $\sqrt{s_{NN}} = 5.02$ TeV. The ATLAS experimental data are collected with theoretical results including a sharp cut on impact parameter ($b >$ 14 fm - solid black line) and smooth nuclear absorption factor $S^2_{abs}(b)$ (dash-dotted red line).

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P. Jucha, M. Kłusek-Gawenda, A. Szczurek, *Light-by-light scattering in ultraperipheral collisions of heavy ions at two future detectors*, Physical Reviev D **109** (2024) 014004.

17-24 July 2024

Elementary cross sections studies

Apart from the continuum process associated with the fermionic loop, typical for light-by-light scattering, other mechanisms are also considered. Their diagrams are shown in Figure 2. In the last work, special emphasis was placed on the VDM-Regge process described by the amplitude:

$$\mathcal{M} = \Sigma_{i,j} C_i^2 C_j^2 \left(C_{\mathbb{P}} \left(\frac{s}{s_0}\right)^{\alpha_{\mathbb{P}}(t)-1} F(t) + C_{\mathbb{R}} \left(\frac{s}{s_0}\right)^{\alpha_{\mathbb{R}}(t)-1} F(t) \right) + \Sigma_{i,j} C_i^2 C_j^2 \left(C_{\mathbb{P}} \left(\frac{s}{s_0}\right)^{\alpha_{\mathbb{P}}(u)-1} F(u) + C_{\mathbb{R}} \left(\frac{s}{s_0}\right)^{\alpha_{\mathbb{R}}(u)-1} F(u) \right).$$

and its interference with the fermionic loop. The results are presented in Figure 3.

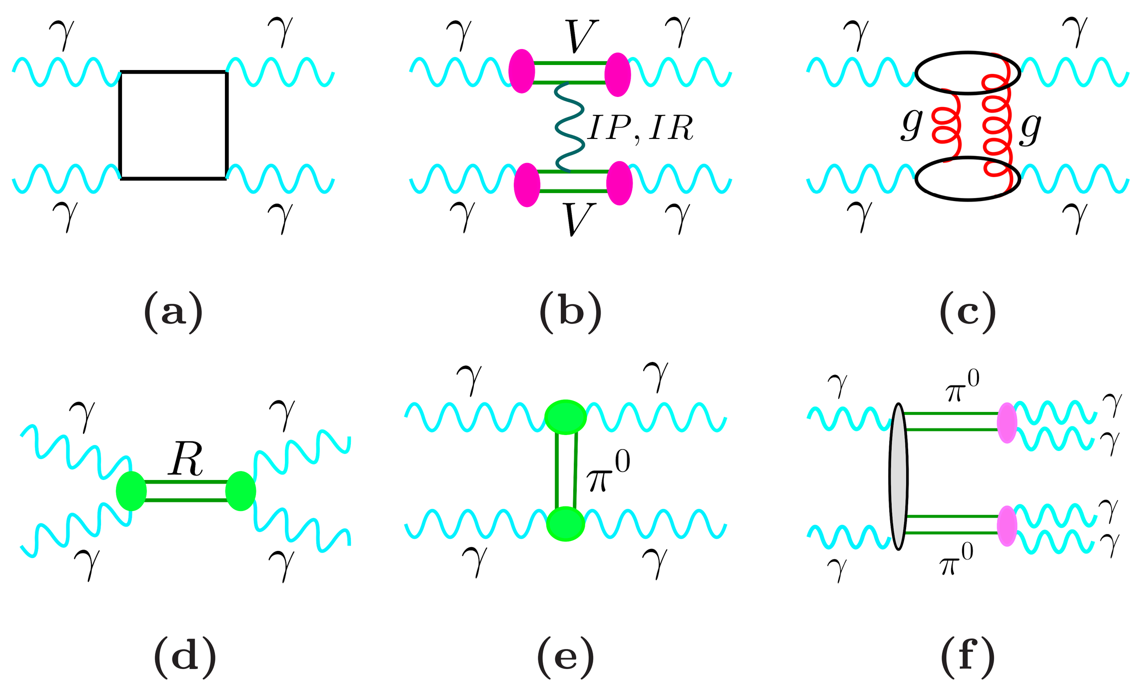

Figure 2: Feynman diagrams of the LbL scattering mechanisms: (a) fermionic loop, (b) VDM-Regge, (c) 2-gluon exchange, (d) low-mass resonances in the s-channel, (e) π^0 resonance in the t-channel, (f) two-π^0 background.

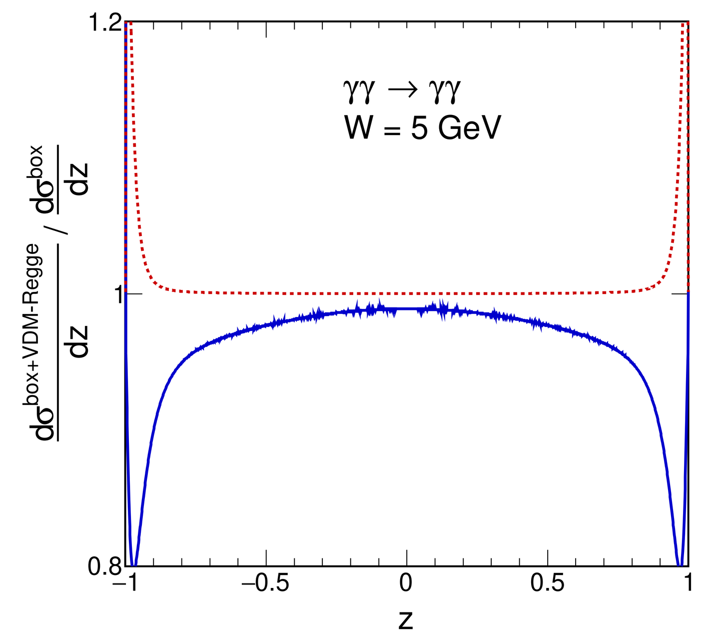

Figure 3: The ratio of the coherent (blue) and incoherent (red) sum of the box and VDM-Regge contributions divided by the cross section for the box contribution alone for W = 5 GeV.

Predictions for experiments - diphoton invariant mass

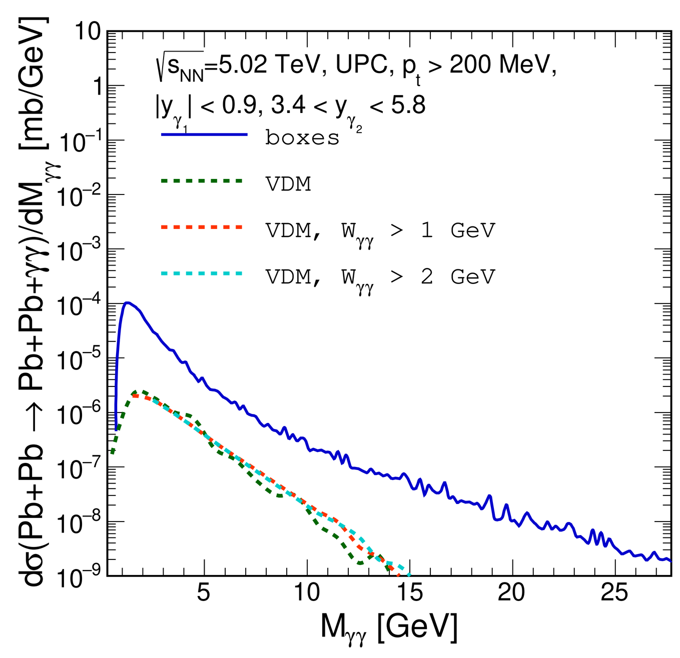

Figure 4: Results for the FoCal detector in association with mid-rapidity ALICE detector. For $M_{\gamma\gamma} \approx 10$ GeV the VDM-Regge is about 10% of main continuum contribution.

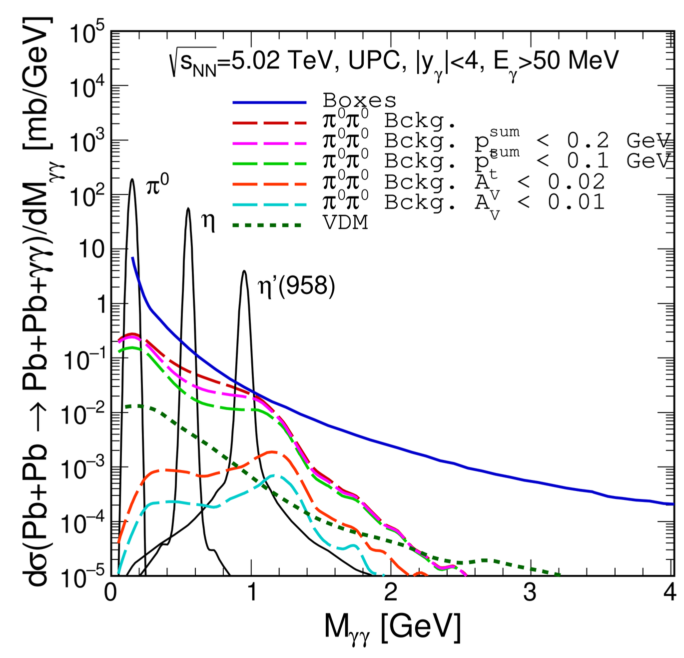

Figure 5: Results for the ALICE 3 experiment. The low-mass measurement gives opportunity to measure light meson resonances.

Conclusion

Recent studies show the impact of interference between the LbL scattering continuum and the VDM-Regge. The VDM-Regge process is essential for $|\cos\theta| \approx 1$, and its influence is rather destructive for coherent sum. Also, the predictions for future experiments were calculated. **Measuring photon at low $M_{\gamma\gamma}$ and $p_{t,\gamma}$, a kinematical region currently unavailable, but planned with the FoCal detector and ALICE 3 experiment shows the potential to investigate LbL scattering mechanism that have so far been unverifiable.** LbL scattering is a relatively new topic in experimental physics. Our predictions indicate that new mechanisms are theoretically and experimentally demanding. Nevertheless, the planned expansion of existing detectors or the construction of new ones creates an unique opportunity to verify complex picture.

References

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