Search for light-by-light scattering in PbPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV

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Introduction

The elastic light-by-light (LbyL) scattering, $\gamma\gamma \rightarrow \gamma\gamma$, is a pure quantum mechanical process that proceeds at leading order in the fine structure constant, $\mathcal{O}(\alpha^4)$, via virtual box diagrams containing charged particles. In the standard model (SM), the box diagram of Fig. 1 involves charged fermions (leptons and quarks) and boson ($W^{\pm}$) loops. Despite its simplicity, LbyL scattering was unobserved before LHC because of its tiny cross section $\sigma_{\gamma\gamma} \propto \mathcal{O}\ (\alpha^4) \approx 3.10^{-9}$. The feasibility to study this process at LHC was provided in Ref.[1] and evidence for its observation has been claimed by the ATLAS collaboration [2] in ultra-peripheral PbPb collisions at $\sqrt{s_{NN}} =$ 5.02 TeV.

The final-state signature of interest here is the exclusive production of two photons, Pb-Pb $\rightarrow$ Pb$\gamma\gamma$ Pb where the diphoton final-state is measured in the central detector, and the incoming Pb ions survive the electromagnetic interaction and are scattered at very low angles with respect to the beam. Hence, it is expected to detect two low-energy photons and no further activity in the detector, in particular no reconstructed charged-particle tracks coming from the interaction region.

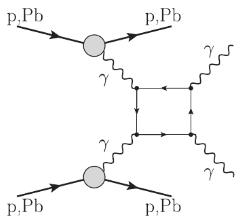

FIG. 1: Schematic diagram of elastic $\gamma\gamma \rightarrow \gamma\gamma$ collisions in electromagnetic proton or ion interactions at the LHC.

Data and Monte Carlo Samples

We present the ongoing study of LbyL scattering, $\gamma\gamma \rightarrow \gamma\gamma$ using Pb-Pb collisions, recorded by the CMS experiment in 2015 at $\sqrt{s_{NN}} = 5.02$ TeV, corresponding to an integrated luminosity of 388 μb^{-1}. The MADGRAPH V.5 MC event generator [3], modified as discussed in [1], was used to simulate the leading-order exclusive diphoton cross section including all quark and lepton loops. The exclusive QED, $\gamma\gamma \rightarrow e^+e^-$, background where electrons can be misidentified as photons, was generated with STARLIGHT [4]. The central-exclusive diphoton production gg$\rightarrow \gamma\gamma$ (CEP) is simulated using SUPERCHIC 2.0 [5], in which the proton-proton cross section has been scaled by $A^2R_g^4$, where $A = 208$ and $R_g \approx$ 0.7 is a gluon shadowing correction, and further normalized in a region of the PbPb data where such background is dominant.

Event Selection

The events were selected by applying a dedicated UPC trigger, which requires at least two Egamma object with $E_T > 2$ GeV and at least one HF empty of hadronic activity. The photon reconstruction algorithm at CMS are optimized to reconstruct the photons with $E_T > 10$ GeV, while most photons in this analysis have E_T between 2-10 GeV. Therefore, the thresholds of photon E_T , electron p_T and supercluster seed E_T were reduced to 1 GeV from the default of 10 GeV. Exclusive $\gamma\gamma \rightarrow \gamma\gamma$ events are selected by requir-

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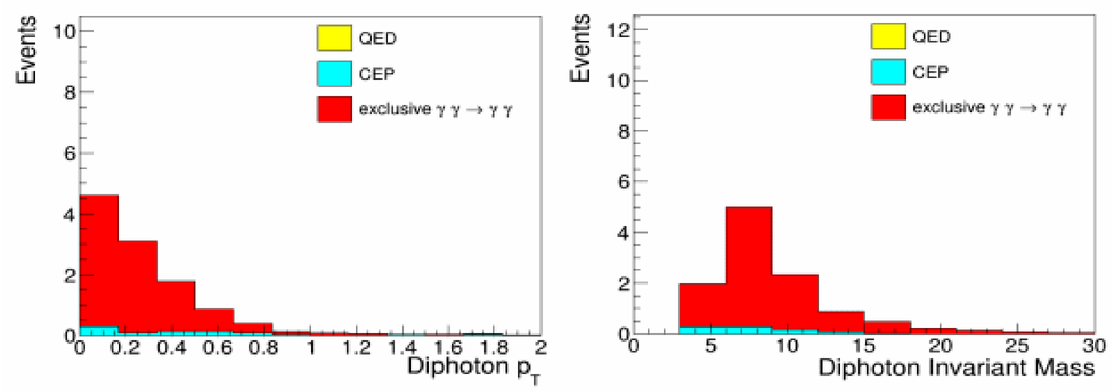

FIG. 2: Diphoton $p_{\rm T}$ (left) and invariant mass (right) distributions for MC expectations for LbyL process (red) [1], QED (yellow) [4] and CEP (blue) [5] backgrounds compared [6].

ing exactly two photons with $E_{\rm T} > 2$ GeV and$|\eta| < 2.4$, and further they are required to satisfy the identification criteria. The exclusivity selection criteria are designed to reject events having particles in the range $|\eta| < 4.9$, not associated with the two photon candidates. More specifically, it is required that there should be no additional towers above noise thresholds in the calorimeters (EB, EE, HB, HE and HF). An additional tower in the EB is defined as a tower above the noise threshold, and outside a region of $\Delta\eta < 0.15$ and $\Delta\phi < 0.7$ of either photon (electron), while in the EE the region is $\Delta\eta < 0.15$ and $\Delta\phi < 0.4$. An additional tower in the HB, HE and HF is defined as any tower above noise threshold. The noise thresholds are determined from data samples with no bunch crossing (unpaired events), and are estimated to be 0.55, 3.16, 1.43, 2.11, 3.94, and 3.6 GeV for the EB, EE, HB, HE, HF Plus, and HF Minus respectively, and are applied in energy rather than E_T . In order to reduce the QED background, events with at least one hit in the pixel detector are vetoed. To reduce other background from misidentified photons, the transverse momentum of the diphoton system ($p_T^{\gamma\gamma}$) is required to be below 2 GeV. To suppress the CEP background, the photon pair with very low acoplanarity $(1-|\Delta\phi/\pi| < 0.01)$ is considered. Since, gg$\rightarrow \gamma\gamma$ process has a large theoretical uncertainty, $\mathcal{O}(50\%)$, mostly related to the modelling of the rapidity gap survival probability, the absolute prediction of this process is estimated by normalizing the MC prediction to data for acoplanarity $(1-|\Delta\phi/\pi|) > 0.02$.

Result

After applying all cuts, we expect ten LbyL events on top of the CEP and QED background [6] (Fig. 2). The analysis with PbPb collisions collected by the CMS experiment is ongoing.

References

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