Study of light-by-light scattering with PbPb collisions at 5.02 TeV with CMS

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Introduction

The elastic scattering of two photons in vaccum, $\gamma\gamma \to \gamma\gamma$, is a pure quantum mechanical process that proceeds at leading order in the fine structure constant, $o(\alpha^4)$, 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, light-by-light (LbyL) scattering remains still unobserved today because of its tiny cross section $\sigma_{\gamma\gamma} \propto o(\alpha^4) \approx 3.10^{-9}$. It was demonstrated in Ref [1] that the large (quasi) real photon fluxes of the protons and ions accelerated at TeV energies at the CERN Large Hadron Collider (LHC) can be used to detect the elastic $\gamma\gamma$ scattering. Since, the photon fluxes scales as Z^2, $\gamma\gamma$ luminosities are extremely enhanced for ion beams, up to $Z^4 = 5.10^7$ in the case of Pb-Pb collisions.

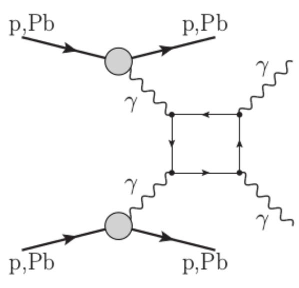

FIG. 1: Diagrams representing elastic $\gamma\gamma \to \gamma\gamma$ scattering in UPC Pb-Pb collisions.

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Data/MC Sample

The final-state of interest here is the exclusive production of two photons, where the diphoton final-state is measured in the central detector. The dataset used in this analysis correspond to 0.4 nb^{-1} of PbPb collisions recorded by the CMS experiment in 2015 at $\sqrt{s}$ = 5.02 TeV. We used MADGRAPH v.5 Monte Carlo (MC) [2] event generator to simulate the leading-order exclusive diphoton cross section including all quark and lepton loops. The background processes, central-exclusive diphoton production gg$\to \gamma\gamma$ and QED $\gamma\gamma \to e^+e^-$, with both $e^{\pm}$ misidentified as photons, were simulated using SUPERCHIC 2.0 [3] and STARLIGHT [4] event generator, respectively. The simulated events were passed through the GEANT 4-based detector simulation and the event reconstruction chain of CMS.

Photon reconstruction

Photon reconstruction is done by using two different algorithm as described below. By default, photons are reconstructed with $E_T >$ 10 GeV, while photons produced in diphoton signal events are with E_T between 2-10 GeV. Therefore, the thresholds of photon and supercluster E_T were reduced to 1 GeV from default 10 GeV for reconstructing low E_T photons.

Island Algorithm

The algorithm [5] begins by searching for seeds (reconstructed hits) with a transverse energy above a threshold. Starting from the seed position, adjacent crystals are examined, scanning first in the ϕ and then in the η direction. Crystals are added to the cluster until either a rise in energy or a crystal that has already been assigned to a different cluster (or

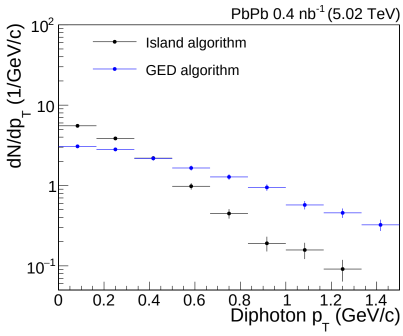

FIG. 2: Yield as a function of diphoton transverse momentum for exclusive $\gamma\gamma \rightarrow \gamma\gamma$

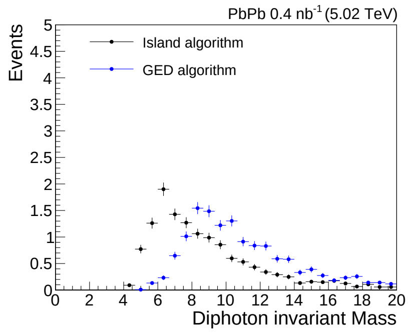

FIG. 3: Yield as a function of diphoton invariant mass for exclusive $\gamma\gamma \rightarrow \gamma\gamma$

that has not been hit) is encountered. The basic clusters are clustered into super clusters.

GED Algorithm

The GED algorithm [6] uses Hybrid algorithm in ECAL barrel and multi-5×5 algorithm in ECAL endcaps, where crystals are not arranged in an $\eta \times \phi$ geometry. The hybrid algorithm begins by searching for seed crystal with transverse energy above a threshold. Arrays of 5×1 crystals in $\eta \times \phi$ are added around the seed crystal in a range of few steps in both directions of ϕ, if their energies exceed a minimum threshold of array. The contiguous arrays are grouped into clusters, with each distinct cluster with energy above threshold then clusters are collected in supercluster. The multi-5×5 algorithm begins by searching for seed crystal with transverse energy above a threshold. Around the seeds, the energy is collected in clusters of 5×5 crystals, that can partly overlap and then grouped to form supercluster.

Event Selection

The diphoton candidates were selected by applying dedicated trigger which require the presence of two electromagnetic showers with $E_T > 2$ GeV. At the offline level, additional selection criteria are applied. Exclusivity criteria are applied by selecting exactly two photons and no extra charged particles or other activity in the detector. In order to minimize the uncertainties related to the knowledge of low-E_T photon efficiencies, photons with $E_T >$ 2 GeV are selected in the pseudorapidity region $\eta < 2.4$. To reduce the background due to misidentified photons, photons are selected with zero pixel hit. By imposing very tight cut on acoplanarity, $\Delta\phi > 3.1$, CEP background can be reduced by very large factor.

Results

Fig. 2 and Fig. 3 shows the diphoton p_T and diphoton invariant mass distribution with GED and Island algorithm after cuts for elastic $\gamma\gamma \rightarrow \gamma\gamma$, respectively. The CEP and QED background processes do not pass the event selection criteria. We expect ≈ 13 signal counts with both algorithm for PbPb collisions at 5.02 TeV. We have shown that light-by-light scattering, a rare fundamental process that has escaped experimental observation so far, can be measured at the LHC, exploiting the large quasireal photon fluxes in electromagnetic interactions of protons and ions accelerated at TeV energies. The measurement of this process with PbPb 5.02 TeV data is under progress.

References

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