Study of exclusive quarkonia production in ultra-peripheral collisions with CMS experiment

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Introduction

Ultra-peripheral Collisions (UPC) are collision of highly accelerated protons or nuclei mediated by strong electromagnetic fields, allowing us to study interactions of photons with hadrons at high energies using proton or nuclei beams. When two nuclei collide, two types of photon-induced electromagnetic processes can occur. i) Photonuclear interaction: A photon from one nucleus interact with the other nucleus and ii) Photon-photon interaction: Photon from each nucleus interacts with each other. The photon-nuclear interactions provide an opportunity to directly probe the gluon density inside the proton/nucleus, by studying the exclusive photoproduction of heavy vector mesons. Photon-photon (or "two photon") fusion processes provide a wide range of opportunities from testing fundamental Quantum Electro Dynamics (QED) to search for physics beyond Standard Model (SM). The measurements presented in this thesis are based on the data collected by the CMS experiment [1].

Exclusive Y photoproduction off protons in ultra-peripheral pPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV

In exclusive quarkonia photoproduction processes, the photon emitted by one of the accelerated charges fluctuates into $q\bar{q}$ bound pair (vector meson) and interacts with the other "target" proton or ion through a colour-singlet gluon exchange. The corresponding photoproduction cross-section is thereby proportional to the square of the gluon density inside the "target". Exclusive Υ photoproduction was first observed at HERA [2] and has recently been studied at the LHC by the LHCb experiment [3] in pp UPCs at $\sqrt{s} = 7$ and 8 TeV. This thesis presents first such measurement in p-Pb UPC[4], including the Υ(1S) cross section as a function of photon-proton center-of-mass energy, $W_{\gamma p}$, in the interval $91 < W_{\gamma p} < 826$ GeV, corresponsing to the Υ rapidity, y $< |2.2|$ and Bjorken-x values are of the order $x \sim 10^{-4}$ to $x \sim 1.3 \times 10^{-2}$. The differential cross-section for Υ(nS) states as a function of transverse momentum squared, p_{T}^2 has been measured, where $p_{\mathrm{T}}^2 \approx |t|$ is the four-momentum transfer at the proton vertex. At low values of $|t|$, the cross-section can be parameterized as $e^{-b|t|}$, where b provides also information on the transverse density profile of the proton. The measurement is carried out in ultra-peripheral pPb collisions at $\sqrt{s_{NN}} =$ 5.02 TeV, collected by the CMS experiment, corresponding to an integrated luminosity of $L_{\mathrm{int}} = 32.6$ nb^{-1}. The Υ(nS) states are studied in their dimuon decay channel. The UPC events were selected with a dedicated trigger, further, exclusive candidates were selected by applying exclusivity criteria. The dominant background contribution from QED, $\gamma\gamma \rightarrow \mu^+\mu^-$, was estimated with STARLIGHT. The contribution of non-exclusive background (inclusive Υ, Drell-Yan and proton dissociation) was estimated by a data-driven method by loosening the exclusivity criteria. The background subtracted p_{T}^2 and y distributions were used to measure the b parameter and estimate the exclusive Υ photoproduction cross-section as a function of $W_{\gamma p}$, respectively. The differential $\mathrm{d}\sigma/\mathrm{d}p_{\mathrm{T}}^2$ cross section was extracted for the three Υ(nS) states combined and fitted with an exponential function $N\ \exp(-bp_{\mathrm{T}}^2)$ in the region $0.01 < p_{\mathrm{T}}^2 < 1.0$ GeV^2. A value of $b = 5.8 \pm 2.1$ (stat) $\pm$ 0.6 (syst) GeV^{-2} is extracted (Fig.1). The data presented in this analysis provide new constraints on the proton structure at low values of x. The exclusive Υ(1S) photoproduction cross section as a function of $W_{\gamma p}$ is compared with the previous experimental measurements and theoretical predictions. A fit with of the CMS data to a function of the form $A \times (W/400)^{\delta}$ gives $\delta = 0.99 \pm 0.40$ and $A = 664 \pm 165$, in agreement with ZEUS [5]. Our data are compatible with a power-law dependence of $\sigma(W_{\gamma p})$ and

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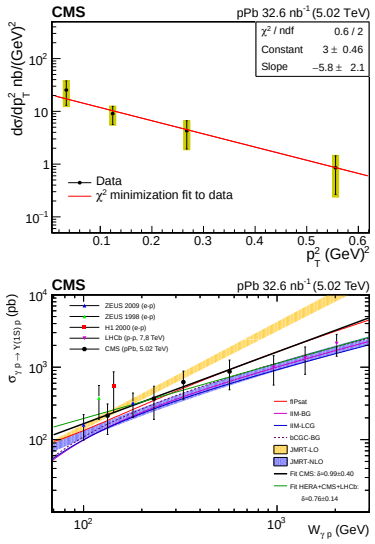

FIG. 1: photoproduction cross section as a function of p_{T}^2 and $W_{\gamma \mathrm{p}}$[4].

disfavor a faster increase with energy as predicted by LO pQCD approaches(Fig.1).

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

The elastic light-by-light (LbyL) scattering, $\gamma\gamma \to \gamma\gamma$, 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. 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.[6] and evidence for its observation has been claimed by the ATLAS collaboration [7] 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 $\to$ Pb$\gamma\gamma$ Pb where the diphoton final-state is measured in the central detector. This thesis presents an evidence for LbyL scattering, $\gamma\gamma \to \gamma\gamma$ in Pb-Pb UPC, 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 [8], modified as discussed in [6], was used to simulate the leading-order exclusive diphoton cross section including all

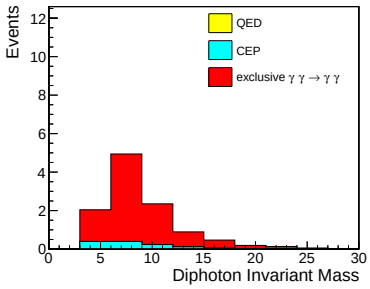

FIG. 2: Diphoton p_{T} MC expectations for LbyL, QED and CEP processes [11].

quark and lepton loops. The exclusive QED, $\gamma\gamma \to e^+e^-$, background where electrons can be misidentified as photons, was generated with STARLIGHT [9]. The central-exclusive diphoton production gg$\to \gamma\gamma$ (CEP) is simulated using SUPERCHIC 2.0 [10], in which the proton-proton cross section has been scaled by $\mathrm{A}^2\mathrm{R}_g^4$, where A = 208 and $\mathrm{R}_g \approx 0.7$ is a gluon shadowing correction, and further normalized in a region of the PbPb data where such background is dominant. The UPC events were selected by applying a dedicated trigger, which requires at least two Egamma object with $\mathrm{E_T} > 2$ GeV and at least one HF empty of hadronic activity. The exclusive LbyL candidate events were selected by applying different exclusivity conditions. After applying all cuts, we expect ten LbyL events on top of the CEP and QED background [11] (Fig. 2) and measure nine events on top of the background. The significance on the observed number of signal candidates events assuming the background-only hypothesis is presented.

References

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