ULTRA-PERIPHERAL VECTOR MESON PRODUCTION IN CMS*

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In this document, a brief introduction to the ultra-peripheral collisions (UPCs) and two analyses performed with the use of these events will be shown. First analysis is a measurement of the UPC Υ photoproduction in the pPb collisions and the second one is the current status of the analysis of Υ photoproduction in the PbPb data, which is still in progress and will be the main part of my Ph.D. Thesis.

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1. Introduction

In the physics of heavy-ion collisions, one of the most pressing problems is to distinguish between the particles produced directly by the nuclei themselves from those originating from the quark–gluon plasma (QGP). Therefore, there is an essential need to study the nature of the initial state forming during these collisions. The initial state can be understood as the parton distribution functions (PDFs), which describe the probability of finding a parton (quark or gluon) carrying a longitudinal momentum fraction of the hadron, x, at a squared energy transfer to the hadron, Q^2. The most recent results obtained by [1] show that nuclear gluon PDFs are still poorly known. This is especially true at low Q^2 and small x, $x < 10^{-2}$ (see Fig. 1).

The Large Hadron Collider (LHC) is a very powerful source of γ–γ and γ–hadron interactions. Since accelerated protons and ions carry an electric charge, they generate high-energy photons which can interact with another photon or with a parton inside a second hadron (photoproduction). A wide variety of particles can be produced in these processes. The ultra-peripheral

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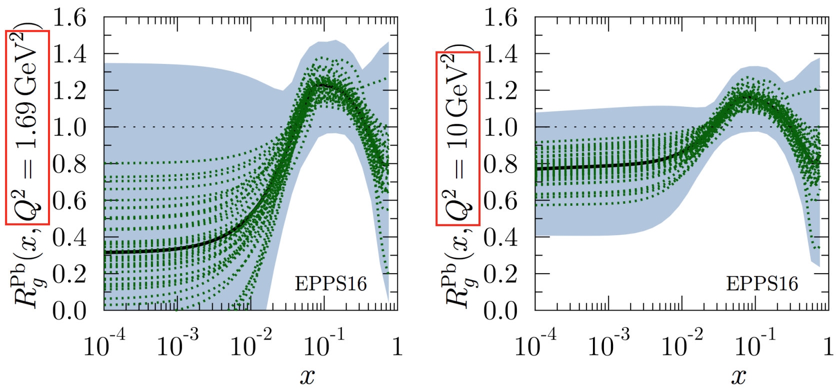


Fig. 1. The EPPS16 nuclear modifications for lead. Largest uncertainty for gluon distributions is for $x < 10^{-2}$ and low Q^2. This is because of lack of data in this region. Dotted lines show different contributions to the uncertainties [1].

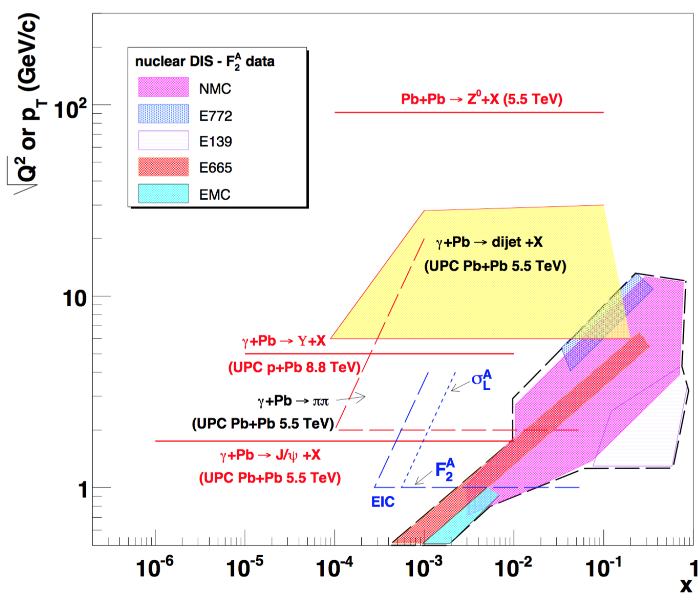


Fig. 2. The kinematic range in which UPCs at the LHC can probe gluons in protons and nuclei in quarkonium production, dijet and dihadron production. The Q^2 value for typical gluon virtuality in exclusive quarkonium photoproduction is shown for J/ψ and Υ. For comparison, the kinematic ranges for J/ψ at RHIC, structure function F_2^A and cross section $\sigma_{\rm L}^A$ at eRHIC, and Z^0 hadron production at the LHC are also shown [2].

collisions (UPC) are the ones, where two hadrons do not collide head-on, but instead they pass close to one another and exchange a very energetic photon. As can be seen in Fig. 2, the studies of UPCs allow to set constrains on the theoretical models, in particular the UPC photoproduction of vector mesons (*e.g.* $\Upsilon(nS)$) probes the previously mentioned kinematic range of $x < 10^{-2}$. The photon-induced processes provide also a great opportunity to study fundamental aspects of quantum electrodynamics (QED) and quantum chromodynamics (QCD) [2].

2. Exclusive Υ photoproduction in Run 1 pPb data

In this analysis [3], Run 1 data from 2013 pPb collisions has been used. The center-of-mass energy per nucleon pair is $\sqrt{s_{NN}} = 5.02$ TeV and the integrated luminosity of the analysed dataset is 32.6 nb^{-1}. The studied process is the exclusive photoproduction of the Υ meson, $\gamma p \to \Upsilon(nS)p$ (with $n = 1, 2, 3$) as shown in Fig. 3. This analysis uses the $\mu^+\mu^-$ decay channel of

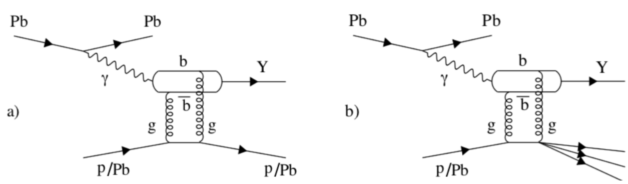
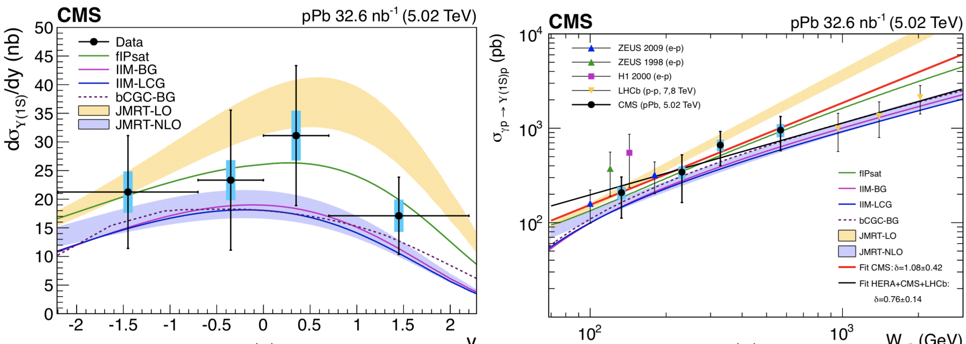


Fig. 3. Feynman diagrams for the signal and two background processes. Panel (a) shows the exclusive Υ photoproduction (signal), panel (b) hadron dissociative Υ photoproduction, and panel (c) the exclusive dimuon QED continuum production.

the $\Upsilon(nS)$ meson. The event selection is the following: at the trigger level, it is requested that there is at least one muon and 1–6 tracks in the event. Only muon pairs with p_{T} between 0.1 and 1 GeV are considered[1]. The two muons must be of the opposite charge, have $p_{\mathrm{T}}^{\mu} > 3.3$ GeV, have a single vertex and no extra charged particles with $p_{\mathrm{T}} > 0.1$ GeV associated with it. To ensure the exclusivity of the event, there is an additional requirement on the largest Hadronic Forward subdetector tower energy deposit to be smaller than 5 GeV. For more details on the CMS experiment and its subdetectors, see [4]. This analysis uses also the STARlight Monte Carlo generator [5] for simulation of the signal and background processes. In Fig. 4 (a), the $\Upsilon(1S)$ cross section is given for the rapidity range $|y| < 2.2$ which corresponds to photon–proton centre-of-mass energies in the range of $91 < W_{\gamma p} < 826$ GeV. In Fig. 4 (a) it can be seen, that the differential cross section, $\mathrm{d}\sigma/\mathrm{d}y$, is sensitive to differences in theoretical modeling. Nevertheless, in this analysis, the results are consistent with most theoretical predictions with JMRT-LO

[1] In this document, $c = 1$.



(a) (b)

Fig. 4. Panel (a): differential $\Upsilon(1S)$ photoproduction cross section as a function of rapidity y. Panel (b): cross section for exclusive $\Upsilon(1S)$ photoproduction as a function of photon–proton centre-of-mass energy W.

giving systematically higher values. With more data, the statistical precision will increase and this measurement will be able to clearly distinguish between the models. In 2016 pPb run, the CMS experiment collected about 180 nb^{-1} (36 nb^{-1} in 2013 pPb run) at $\sqrt{s_{NN}} = 8.16$ TeV. In Fig. 4 (b), the cross section is shown as a function of $W_{\gamma p}$. The results are presented in comparison to the ones from H1, ZEUS and LHCb together with theoretical models. As can bee seen, the CMS results bridge the W previously unexplored region between the LHCb and HERA. Again, the JMRT-LO results show steeper increase of the cross section then other models and data points from the CMS and LHCb.

3. Exclusive Υ photoproduction in Run 2 PbPb data

This analysis, which will be the main part of my Ph.D. Thesis, is still in progress and as such, not finally approved by the CMS Collaboration. It is focused on the same process as the previously described one, except that the meson is produced in γPb collisions instead of γp, $\gamma p\mathrm{Pb} \to \Upsilon(1S) p\mathrm{Pb}$ (see Fig. 3) and 2015 PbPb data are used. The center-of-mass energy is $\sqrt{s_{NN}} = 5.02$ TeV and the luminosity corresponding to the analysed data is 450 μb^{-1}.

The interesting events were selected at the dedicated hardware level, requiring that there is at least one muon reconstructed in the event without p_{T} threshold. In addition, there is a veto on energy deposition in at least one of the HF detectors. At the software trigger level, only events with at least one track in pixel detector are selected. In the offline selection, it is required that there are exactly two muons of the opposite charge and with the reconstructed dimuon mass between 9.3 and 9.6 GeV. Figure 5 (a) shows the rapidity distribution for the dimuon object. As expected, it is relatively flat in the central region and at the edges of acceptance of the muon system, it starts to decrease as one of the two produced muons is outside of the detector acceptance. In Fig. 5 (b), the p_{T} distribution of the dimuon pairs is presented. As can be seen, most of the events have very low p_{T} (below 0.1 GeV). Figure 6 presents an event display of one of the events passing the selection criteria. For those events, the detector is empty apart from the two muons coming from the Υ decay.

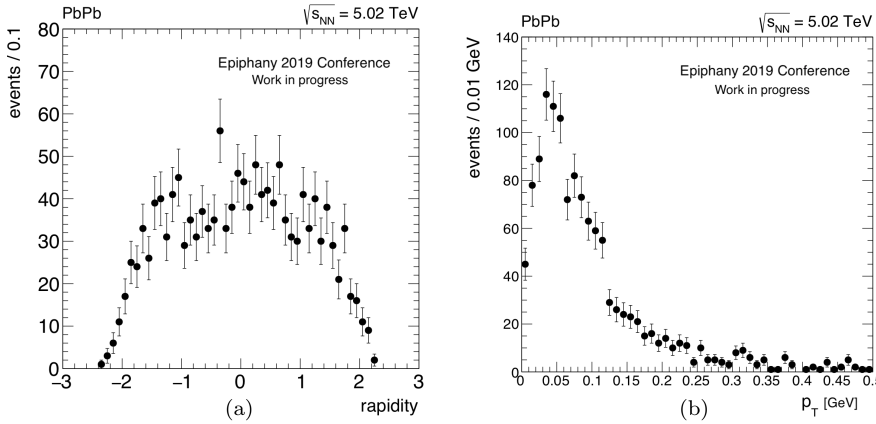


Fig. 5. Figure shows the distributions for the dimuon objects: panel (a) — the y of the dimuon objects and panel (b) — the p_{T} distribution.

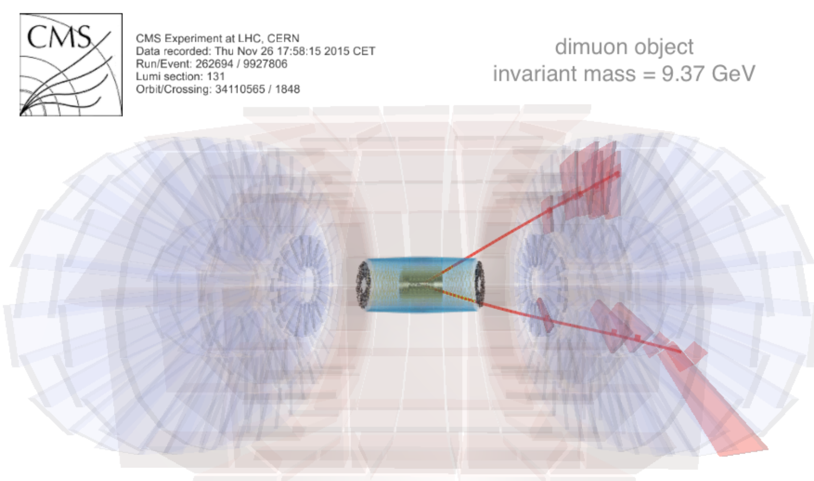


Fig. 6. The event display shows one of the selected events, the visualisation of the CMS detector can be seen, together with two trajectories of muons going into forward direction. The reconstructed invariant mass of the two leptons is consistent with the Υ mass.

4. Conclusions

The UPCs are a very useful tool for measuring the gluon distributions in protons and nuclei. With more data, the theoretical predictions can be verified with analyses described in this paper. The described, ongoing analysis of the PbPb data will be the first measurement of such a process at such high-energy collisions and will be used to further constrain theoretical predictions, leading to better understanding of the QCD processes.

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