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Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland

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Results (and future prospects) of the CMS experiment in photon-induced interactions in p-Pb collisions

Alexandr Bylinkin for the CMS Collaboration

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Exclusive vector meson photoproduction is studied in ultra-peripheral pPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV with the CMS experiment at the LHC. The cross sections are measured as a function of the photon-proton centre-of-mass energy, extending the energy range explored by H1 and ZEUS Experiments at HERA. In addition, the differential cross sections ($d\sigma/dItI$), where $ItI \approx p_T^2$ is the squared transverse momentum of produced vector mesons, are measured and the slope parameters are obtained. The results are compared to previous measurements and to theoretical predictions. Finally, prospect for further measurements of vector meson production that can be performed using the 2016 pPb collision data at 8 TeV to be collected at the end of the year are presented.

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Results (And Future Prospects) Of The CMS Experiment In Photon-Induced Interactions In p-Pb Collisions

Alexander Bylinkin (for the CMS Collaboration)^{1,2,a)}

¹*Moscow Institute of Physics and Technology, MIPT, Moscow, Russia*

²*Moscow Engineering Physics Institute, MEPhI, Moscow, Russia*

^{a)}alexander.bylinkin@gmail.com

Abstract. Exclusive vector meson photoproduction is studied in ultra-peripheral pPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV with the CMS experiment at the LHC. The cross sections are measured as a function of the photon-proton centre-of-mass energy, extending the energy range explored by H1 and ZEUS Experiments at HERA. In addition, the differential cross sections ($d\sigma/d|t|$), where $|t| \approx p_T^2$ is the squared transverse momentum of produced vector mesons, are measured and the slope parameters are obtained. The results are compared to previous measurements and to theoretical predictions. Finally, prospect for further measurements of vector meson production that can be performed using the 2016 pPb collision data at 8 TeV to be collected at the end of the year are presented.

INTRODUCTION

The CMS detector provides a very wide range of opportunities to study high-energy photon-induced interactions with proton and/or ion beams, due to the high energy and large integrated luminosities available at the LHC. Different exclusive particle production processes at high energies have been studied [1, 2, 3]. With the exclusive production of vector meson, nuclear gluon shadowing and parton distribution function at very low- x can be studied.

Exclusive upsilon photoproduction in pPb collisions at 5.02 TeV

Exclusive photoproduction of heavy vector mesons (Fig. 1, left) at very high photon-proton center-of-mass energies ($W_{\gamma p}$) can be studied in ultraperipheral collisions (UPC) of protons (ions). Recently, CMS, ALICE [4] and LHCb [5] presented their measurements of exclusive heavy vector meson photoproduction at the LHC. Since the process occurs through γp or γPb interaction via the exchange of two-gluons with no net color transfer and thus, at leading order (LO), the cross-section is proportional to the square of the gluon density in the target proton or ion. It provides a valuable probe of the gluon density at the small momentum fraction x which is kinematically related to $W_{\gamma p}$ ($x = (M_V/W_{\gamma p})^2$).

FIGURE 1. Diagrams representing exclusive Υ photoproduction (left), and exclusive dimuon QED continuum (right) in pPb collisions.

The exclusive photoproduction of $\Upsilon(1S, 2S, 3S)$ has been measured in their dimuon decay channel in ultraperipheral collisions of protons and heavy ions (pPb) with the CMS experiment at $\sqrt{s_{NN}} = 5.02$ TeV for an integrated luminosity of $L_{int} = 33 \text{ nb}^{-1}$. The photoproduction cross section for $\Upsilon(nS)$ was measured as a function of $W_{\gamma p}$ in the range $91 < W_{\gamma p} < 826$ GeV which corresponds to the rapidity of the Υ meson in the range $|y| < 2.2$ and x values are of the order $x \approx 10^4$ to $x \approx 1.3 \cdot 10^2$. The dependence of the elastic Υ photoproduction cross section on the squared Υ transverse momentum approximating the four-momentum transfer at the proton vertex ($|t| \approx p_T^2$), can be parametrized with an exponential function $e^{b|t|}$ at low values of $|t|$. The differential cross-section $d\sigma/dt$, has been measured in the range $|t| < 1.0$ (GeV/c)² and the b -slope parameter was estimated.

The UPC events were selected by applying dedicated HLT trigger which selects at least one muon in each event and at least one to six tracks. To select the exclusive $\Upsilon(nS)$ events offline, two muon tracks originating from the same primary vertex in each event were used. The muons were selected with $p_T > 3.3$ GeV and pseudorapidity $|\eta| < 2.2$, in order to have high muon nding efficiency. The p_T of the muon pair was selected between 0.1 to 1 GeV. The lower cut on muon pair reduces the contamination from elastic QED background (Fig. 1, right) and higher cut on muon pair reduces the contamination from inelastic background (proton dissociation, inclusive Υ , Drell-Yan). The rapidity of muon pair is restricted to $|y| < 2.2$. The invariant mass distribution for the selected dimuon pairs in the range $8 < M_{\mu^+\mu^-} < 12$ GeV is shown in Fig.2 together with the Gaussian fit.

FIGURE 2. Invariant mass distribution for the $\mu^+\mu^-$ pairs in the range $8 < M_{\mu^+\mu^-} < 12$ GeV. The three peaks correspond to the $\Upsilon(1S)$, $\Upsilon(2S)$ and $\Upsilon(3S)$ mesons. The fit to the data is performed with RooFit. The blue line corresponds to the polynomial fit to the two-photon QED continuum, the red dashed line to the Gaussian fit of the resonances. The corresponding number of events are indicated in the legend.

The dominant background contribution to exclusive Υ signal comes from QED, $\gamma\gamma \rightarrow \mu^+\mu^-$, which was estimated by STARLIGHT. The absolute prediction of QED was checked by comparing the data between invariant mass region 8.912 and 10.6412 GeV for dimuon $p_T < 0.15$ GeV to the simulation. The contribution of non-exclusive background (inclusive Υ , Drell-Yan and proton dissociation) was estimated by a data-driven method by selecting events with more than 2 tracks. This template was normalized to two muon track sample in the region of dimuon $p_T > 1.5$ GeV. Additional background in this analysis originates from a small contribution of exclusive $\gamma Pb \rightarrow \Upsilon Pb$ events. The fraction of these events in the total number of exclusive Υ events was estimated using the reweighted STARLIGHT Υ MC sample. Distributions of the transverse momentum squared p_T^2 and rapidity y of the muon pairs with invariant mass $9.12 < m_{\mu^+\mu^-} < 10.64$ GeV are shown in Fig. 3a)-b) both for reconstructed data and various signal and background contributions.

These backgrounds were subtracted from data to get the exclusive signal. The background subtracted $|t|$ and y

FIGURE 3. Distributions of the transverse momentum squared p_T^2 and rapidity y of the muon pairs with invariant mass $9.12 < m_{\mu^+\mu^-} < 10.64$ GeV in the combined pPb and PbPb samples.

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 distributions were first unfolded to the region $0.01 < |t| < 1$ GeV², $|y| < 2.2$, and muon $p_T^\mu > 3.3$ GeV, using the iterative Bayesian unfolding technique and its further extrapolated to zero transverse momenta by acceptance correction factor.

The differential $d\sigma/dt$ cross section is extracted for the combined three $\Upsilon(nS)$ states as shown in Fig. 4, according to

$$\frac{d\sigma_\Upsilon}{d|t|} = \frac{N^{\Upsilon(nS)}}{L \cdot \Delta|t|} \quad (1)$$

where $|t|$ is approximated by the dimuon transverse momentum squared p_T^2 , $N^{\Upsilon(nS)}$ denotes the background-subtracted, unfolded and acceptance-corrected number of signal events in each $|t|$ bin, L is the integrated luminosity, and $\Delta|t|$ is the width of each $|t|$ bin. The cross section is fitted with an exponential function $Ne^{b|t|}$ in the region $0.01 < |t| < 1.0$ GeV², using an unbinned χ^2 minimization method. A value of $b = 4.5 \pm 1.7(stat) \pm 0.6(syst)$ GeV² is extracted from the fit. This result is in agreement with the value $b = 4.3^{+2.0}_{-1.3}(stat)$ measured by the ZEUS experiment [6] for the photon-proton center-of-mass energy $60 < W_{\gamma p} < 220$ GeV. The measured value of b is also consistent with the predictions based on pQCD models [7].

The differential $\Upsilon(1S)$ photoproduction cross section $d\sigma/dy$ is extracted in four bins of dimuon rapidity according to

$$\frac{d\sigma_{\Upsilon(1S)}}{dy} = \frac{f_{\Upsilon(1S)}}{BR(1 + f_{FD})} \frac{N^{\Upsilon(nS)}}{L \cdot \Delta|t|} \quad (2)$$

where $N^{\Upsilon(nS)}$ denotes the background-subtracted, unfolded and acceptance-corrected number of signal events in each rapidity bin. The factor $f_{\Upsilon(1S)}$ describes the ratio of $\Upsilon(1S)$ to $\Upsilon(nS)$ events, f_{FD} is the feed-down contribution to the $\Upsilon(1S)$ events originating from the $\Upsilon(2S) \rightarrow \Upsilon(1S) + X$ decays (where $X = \pi^+\pi^-$ or $\pi^0\pi^0$), $BR = (2.480.05)$ is the branching ratio for muonic $\Upsilon(1S)$ decays, and Δy is the width of the y bin.

The $f_{\Upsilon(1S)}$ fraction is used from the results of the inclusive Υ analysis [8]. The feed-down contribution of $\Upsilon(2S)$ decaying to $\Upsilon(1S) + \pi^+\pi^-$ and $\Upsilon(1S) + \pi^0\pi^0$ was estimated as 15% from the STARLIGHT. The contribution from feed-down of exclusive χ_b states was neglected, as these double-pomeron processes are expected to be comparatively much suppressed in proton-nucleus collisions [9, 10].

The exclusive $\Upsilon(1S)$ photoproduction cross section as a function of $W_{\gamma p}$ as shown in Figure 5, is obtained by using,

$$\sigma_{\gamma p \rightarrow \Upsilon(1S)p}(W_{\gamma p}^2) = \frac{1}{\Phi} \frac{d\sigma_{\Upsilon(1S)}}{dy} \quad (3)$$

FIGURE 4. Differential Υ photoproduction cross section as a function of $|t|$ measured in pPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV in the dimuon rapidity region $|y| < 2.2$. The solid line represents the result of a fit with an exponential function $N \cdot e^{b|t|}$.

where Φ is the photon flux evaluated at the mean of the rapidity bin, estimated from STARLIGHT. The CMS data are plotted together with the previous measurements from H1 [11], ZEUS [12] and LHC [5] data. It is also compared with different theoretical predictions of the JMRT model [7], factorized IPsat model [13], IIM [14, 15] and bCGC model [16]. As $\sigma(W_{\gamma p})$ is proportional to the square of the gluon PDF of the proton and the gluon distribution at low Bjorken x is well described by a power law, the cross section will also follow a power law. Any deviation from such trend would indicate different behavior of gluon density function. We fit a power-law $A \cdot (W/400)^\delta$ with CMS data alone which gives $\delta = 0.96 \pm 0.43$ and $A = 655 \pm 196$ and is shown by the black solid line. The extracted δ value is comparable to the value $\delta = 1.2 \pm 0.8$, obtained by ZEUS [12].

Summary and prospects for further measurements

We reported the first measurement of the exclusive photoproduction of $\Upsilon(1S, 2S, 3S)$ mesons in the $\mu^+\mu^-$ decay modes in ultraperipheral pPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV, corresponding to an integrated luminosity of 33 nb⁻¹. The exclusive photoproduction cross sections have been measured as a function of the photon-proton center of mass energy, bridging a previously unexplored region between HERA and LHCb measurements. Our data are compatible with a powerlaw dependence of $\sigma(W_{\gamma p})$, disfavouring faster rising predictions of LO pQCD. The spectral slope b has been extracted, in agreement with earlier measurements.

Further measurements of other vector meson species such as J/Ψ and ρ - mesons in ultraperipheral pPb collisions will also give a possibility to extend the energy ranges of the measurements performed by the H1 and ZEUS Experiments at the HERA electron-proton collider. Thus, it should make possible to test the theoretical predictions of various pQCD models.

FIGURE 5. Cross section for exclusive $\Upsilon(1S)$ photoproduction, $\gamma p \rightarrow \Upsilon(1S)p$ as a function of photon-proton center-of-mass energy, $W_{\gamma p}$

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