Results and future prospects of exclusive vector meson production with pPb collisions at CMS

Ruchi Chudasama for the CMS Collaboration

Abstract

Exclusive photoproduction of vector mesons (Upsilon and Rho0) is studied with the large photon flux available in ultra-peripheral pPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV with CMS experiment. It provides a clean probe of the gluon distribution at small values of parton fractional momenta $x$ at central rapidities ($y < 2.5$). 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 ($d\sigma/dt$), 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, prospects 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 exclusive vector meson production with pPb collisions at CMS

Ruchi Chudasama
on behalf of CMS collaboration

Nuclear Physics Division,
Bhabha Atomic Research Center,
Mumbai, India
ruchi.chudasama@cern.ch

Abstract. Exclusive photoproduction of vector mesons (Upsilon and $\rho^0$) is studied with the large photon flux available in ultra-peripheral pPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV with the CMS experiment. It provides a clean probe of the gluon distribution at small values of parton fractional momenta $x$ at central rapidities ($|y| < 2.5$). 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 ($d\sigma/dt$), where $|t| \approx p_T^2$, 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, prospects for further measurements of vector meson production that can be performed using pPb collision data at 8 TeV collected at the end of 2016 are presented.

Keywords: UPC, Upsilon, CMS

1 Introduction

Exclusive vector meson (VM) photoproduction is defined by the reaction $\gamma + p \rightarrow VM + p$, with the characteristic features that, apart from the vector meson in the final state, no other particles are produced and the vector meson has a low transverse momentum. This process can be studied at the Large Hadron Collider in ultra-peripheral collisions (UPCs) of ions and protons occurring at impact parameters much larger than the sum of their radii. Recently, CMS[1], ALICE[2] and LHCb[3] presented their measurements of exclusive heavy vector meson photoproduction at the LHC. Since the process occurs through $\gamma p$ or $\gamma Pb$ interactions via the exchange of two-gluons with no net color transfer, the cross section at leading order (LO) 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 a small momentum fraction $x$, which is kinematically related to $W_{\gamma p}$ ($x = (M_T/W_{\gamma p})^2$). 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 \[5\] at $\sqrt{s_{NN}} = 5.02$ TeV for an integrated luminosity of $L_{int} = 33 \text{ nb}^{-1}$. The photoproduction cross section for $\Upsilon(nS)$ is measured as a function of $W_{\gamma p}$ in the range $91 < W_{\gamma p} < 826$ GeV, which corresponds to the rapidity of the $\Upsilon$ meson in the range $|y| < 2.2$, and $x$ values are of the order $x \sim 10^{-4}$ to $x \sim 1.3 \cdot 10^{-2}$. The differential cross section $d\sigma/dt$, has been measured in the range $|t| < 1.0 (\text{GeV}/c)^2$ and the b-slope parameter is estimated.

2 Event selection and background estimation

The UPC events are selected by applying a dedicated trigger, which selects at least one muon in each event and at least one to six tracks. Two muon tracks originating from the same primary vertex with $p_T > 3.3$ GeV, and pseudorapidity $|\eta| < 2.2$ are used to select exclusive events. The $p_T$ of the muon pair is restricted from 0.1 to 1 GeV to reduce the contamination from elastic QED and inelastic background. The dominant background contribution to exclusive $\Upsilon$ signal comes from QED, $\gamma\gamma \rightarrow \mu^+\mu^-$, which is estimated by STARLIGHT. The contribution of non-exclusive background is estimated by a data-driven method by selecting events with more than 2 tracks. This template was normalized to a two muon track sample in the region of dimuon $p_T > 1.5$ GeV. Additional small background contributions of exclusive $\gamma\text{Pb} \rightarrow \Upsilon\text{Pb}$ events is estimated using a reweighted STARLIGHT $\Upsilon$ MC sample. These backgrounds were subtracted from data to obtain the exclusive signal. The background subtracted $|t|$ and $y$ distributions were used to measure the b parameter, and estimate the exclusive $\Upsilon$ photoproduction cross-section as a function of $W_{\gamma p}$, respectively. The distributions were first unfolded to the region $0.01 < |t| < 1.0$ GeV$^2$, $|y| < 2.2$, and muon $p_T^\mu > 3.3$ GeV, using the D’Agostini method for unfolding and it’s further extrapolated to transverse momenta of 0 GeV by acceptance correction factors.

3 Results and future prospects

The differential $d\sigma/dt$ cross section is extracted for the combined three $\Upsilon(nS)$ states as shown in Fig. 1. The cross section is fitted with an exponential function $N e^{-b|t|}$ in the region $0.01 < |t| < 1.0$ GeV$^2$, using an unbinned $\chi^2$ minimization method. A value of $b = 4.5 \pm 1.7$ (stat) $\pm 0.6$ (syst) GeV$^{-2}$ is extracted from the fit. This result is in agreement with the value $b = 4.3^{+2.0}_{-1.3}$ (stat) $^{+0.5}_{-0.6}$ (syst.) measured by the ZEUS experiment[4] for the photon-proton centre-of-mass energy $60 < W_{\gamma p} < 220$ GeV. The differential $\Upsilon(1S)$ photoproduction cross section $d\sigma/dy$ is extracted in four bins of dimuon rapidity using the background-subtracted, unfolded, and acceptance-corrected number of signal events in each rapidity bin. Due to very limited statistics, the number of $\Upsilon(1S)$ events can not be extracted separately in each rapidity bin. Therefore, they are estimated for three states together, and corrected for the fraction of $\Upsilon(1S)$ to $\Upsilon(nS)$ events and the feed-down contribution of $\Upsilon(2S)$ decaying to $\Upsilon(1S)\pi^+\pi^-$ and $\Upsilon(1S)\pi^0\pi^0$. 
Fig. 1. Differential $\Upsilon$ photoproduction cross section as a function of $|t|$ [14].

Fig. 2 shows the CMS data together with the previous measurements from H1[6], ZEUS[7] and LHCb[2] data. It is also compared with different theoretical predictions of the JMRT model[8], factorized IPsat model[9, 10], IIM[11, 12] and bCGC model[13]. 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 a different behavior of the gluon density function. We fit a power law $A \times (W/400)^{\delta}$ 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 $\delta$ value is comparable to the value $\delta = 1.2 \pm 0.8$, obtained by ZEUS [4]. Our data are compatible with a power law dependence of $\sigma(W_{\gamma p})$, disfavouring faster rising predictions of LO pQCD. Using pPb collisions at 5.02 TeV, we could probe $x \sim 10^{-4}$ to $x \sim 1.3 \cdot 10^{-2}$ values. It would be possible to probe higher values of $W_{\gamma p}$, and lower $x \sim 10^{-6}$ with new pPb data at 8.16 TeV. The increase of statistics will allow us to perform differential studies in $p_{T}$ and $y$ for coherent and incoherent $J/\psi$ and $\psi(2S)$. The $t$ distribution is expected to present a pronounced diffractive peak which can then be used to clearly discriminate between saturation and nonsaturation models[15, 16].

References

Fig. 2. Cross section for exclusive $\Upsilon(1S)$ photoproduction, $\gamma p \rightarrow \Upsilon(1S)p$ as a function of photon-proton center-of-mass energy, $W_{\gamma p}$ [14].

14. CMS Collaboration, FSQ-13-009