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Measurement of exclusive vector meson photoproduction in pPb collisions with the CMS experiment

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Abstract. The exclusive photoproduction of vector mesons provides a unique opportunity to constrain the gluon distribution function within protons and nuclei. Measuring vector mesons of various masses over a wide range of rapidity and as a function of transverse momentum provides important information on the evolution of the gluon distribution within nuclei. A variety of measurements, including the exclusive J/ψ, ρ, and Υ meson production in pPb (at nucleon-nucleon center of mass energies of 5.02 and 8.16 TeV) and PbPb (5.02 TeV) collisions, are presented as a function of squared transverse momentum and the photon-proton center of mass energy. Finally, compilations of these data and previous measurements are compared to various theoretical predictions.

1 Introduction

This article presents the measurement of the exclusive photoproduction of Υ and ρ^0 mesons in pPb collisions at nucleon-nucleon centre-of-mass energy of $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV with the CMS detector [1]. Ultraperipheral collisions (UPCs) of proton-lead ions or lead-lead ions happen when the collision impact parameter is larger than the sum of their radii. Therefore the hadronic interaction is largely suppressed [2]. In UPCs, a boosted ion is the source of a quasi-real photon, which converts into a vector meson state through the interaction with two gluons of no net color emitted from the other ion. In this process, the incoming hadrons remain intact. Such a process is called "exclusive". The study of exclusive quarkonia photoproduction can provide a unique probe that targets the hadron structure, with the large mass of the J/ψ and Υ mesons providing a hard scale for calculations based on perturbative quantum chromodynamics (pQCD) [3]. The study of the photoproduction of Υ and ρ^0 mesons from a proton is sensitive to generalized parton distributions (GPDs), which can be approximated by the square of the gluon density in the proton. Exclusive vector meson photoproduction is interesting because the Fourier transform of the t distribution is related to the two-dimensional distribution of the partons in the transverse plane. Here, t represents the squared four-momentum transfer at the proton vertex. This note presents the $|t| \approx p_{\mathrm{T}}^2$ dependence for the Υ and ρ^0.

In this article we discuss the exclusive photoproduction of ρ^0 meson [4] that decay to $\pi^+\pi^-$ and Υ [5] decay to $\mu^+\mu^-$ process in ultra-peripheral pPb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV. The cross section is measured as a function of $W_{\gamma p}$ and t. This discussion is organized as

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follows. In section 2 we discuss the invariant mass of the vector meson. Section 3 presents the differential cross section as a function of rapidity, $|t|$ and the photon–proton centre-of-mass energy $W_{\gamma p}$. Finally, in section 4 we discuss the summary of this measurement.

2 Invariant mass

Figure 1 shows the invariant mass distribution for dimuons in the range between 8 and 12 GeV that satisfies the selection criteria described in Ref. [5]. To fit the spectrum, an unbinned likelihood fit is performed using RooFIT [52] with a linear function to describe the QED $\gamma + \gamma \rightarrow \mu^{+}\mu^{-}$ continuum background, where the background exponential slope parameter is fixed to the value obtained from a STARLIGHT [6] $\gamma + \gamma \rightarrow \mu^{+}\mu^{-}$ simulation, with three Gaussian functions for the three Υ signal slope parameter of peaks.

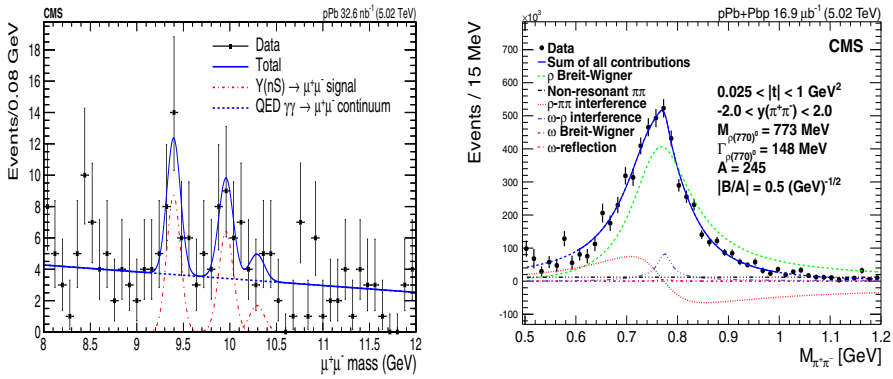

Figure 1. The left-side figure shows the invariant mass distribution of the exclusive dimuon candidates in the range $8 < m_{\mu^+\mu^-} < 12$ GeV that satisfy all the selection criteria, fitted to a linear function for the two-photon QED continuum (blue dashed line) plus three Gaussian distributions corresponding to the $\Upsilon(1S), \Upsilon(2S), \Upsilon(3S)$ mesons (dashed-dotted-red curves). The right-side figure shows the unfolded $\pi^+\pi^-$ invariant mass distribution [4] in the pion pair rapidity interval $|y_{\pi^+\pi^-}| < 2$ fitted with the Söding model [7]. The green dashed line indicates resonant $\rho(770)^0$ production, the red dotted line represents the interference term, the magenta dash-dotted line corresponds to the background from $\omega \rightarrow \pi^+\pi^-\pi^0$, the black dash-dotted line represents the non-resonant contribution, and the blue solid line represents the sum of all these contributions.

The right plot of Figure 1 presents the fit of the unfolded distribution with the modified Söding modell [7]. A least squares fit is performed for the interval $0.6 < M_{\pi^+\pi^-} < 1.1$ GeV, with the quantities, $M_{\rho(770)^0}$, $M_{\omega(783)}$, $\Gamma\rho(770)^0$, $\Gamma_{\omega(783)}$, A, B, C, $\phi_{\omega(783)}$ treated as free parameters.

3 Differential cross section measurement

The differential cross-section of the exclusive $\Upsilon(1S)$ is measured as a function of $W_{\gamma p}$ and y over $|y| < 2.2$, are shown in Figure 2. The p_{T}^2-differential cross section is fitted with an exponential function in the region $0.01 < p_{\mathrm{T}}^2 < 1.0$ GeV^2, using a χ^2 goodness-of-fit minimization technique. The slope parameter $b = 6.0 \pm 2.1$ (stat) ± 0.3 (syst) GeV^{-2} is extracted, and in agreement with $b = 4.3^{+2.0}_{-1.3}$ (stat) $^{+0.5}_{-0.6}$ (syst) GeV^{-2}, which is measured by the ZEUS Collaboration in the photon–proton centre-of-mass energy in the range $60 < W_{yp} < 220$ GeV. The measured results are consistent with the predictions of pQCD-based models.

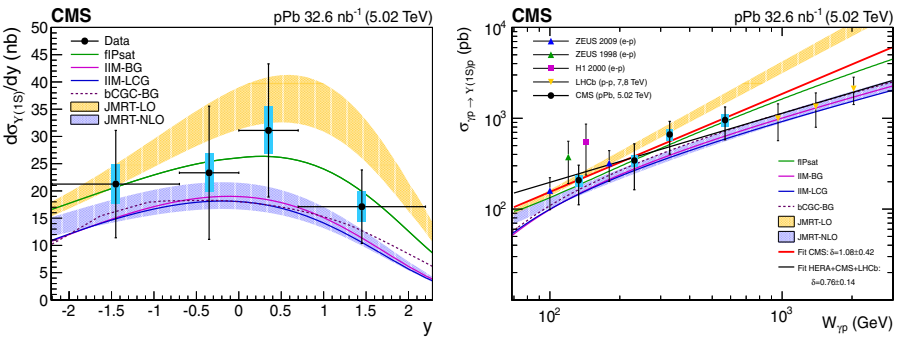

Figure 2. Left plot is the background substracted differential cross section as a function of rapidity measured in pPb collisions. Right plot is the $W_{\gamma p}$ dependence of cross section for the exclusive photo production [5].

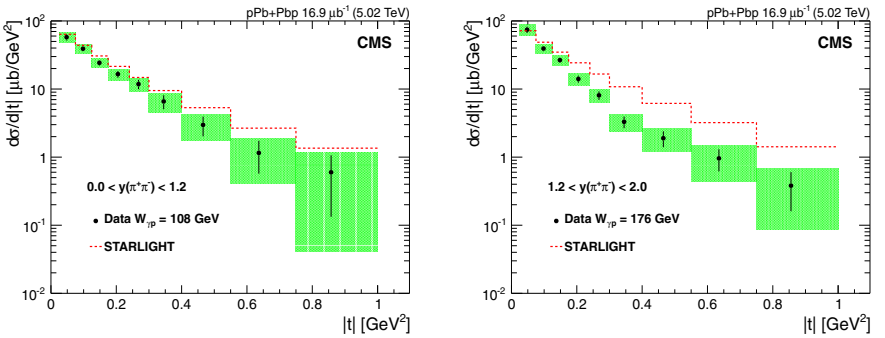

Figure 3. Differential cross section (dσ/dt) is measured for ρ^0 as a function of rapidity bin [4]. The dashed dotted line indicates the predictions from STARLIGHT. The error bars show the statistical uncertainty, and the shaded green areas represent the systematic uncertainties of that bin.

Figure 2 (left plot) shows the rapidity distribution of the Υ(1S). Our results are compared with the various theoretical predictions, consistent with the data within the relatively large experimental uncertainties. The JMRT-LO [8] results are systematically above the data points and all the other calculations. The data are compared to the various theoretical predictions. A fit with the power-law function in the entire $W_{\gamma p}$ range of data yields $\delta = 1.30$ and $\delta = 0.84$ for the LO and NLO calculations, respectively. We significantly reduced the uncertainty compared to ZEUS [9] and cover a wide range of $W_{\gamma p}$.

The differential cross section of ρ^0 is measured as a function of $|t|$ for different rapidity range as shown in figure 3. The $|t|$ distribution is fitted in the region $0.025 < |t| < 0.5$ GeV^2. The data results are compared with the STARLIGHT prediction and it is observed that the STARLIGHT prediction is comparatively higher than the data in the high t region, an effect that becomes more significant as $W_{\gamma p}$ increases [4].

The cross-section measured as a function of $W_{\gamma p}$ is shown in figure 4. The data results are fitted with $\sigma = \alpha_1 W_{\gamma p}^{\delta_1} + \alpha_2 W_{\gamma p}^{\delta_2}$. δ_1 and δ_2 parameters are extracted from the fit and yields the values $\delta_1 = -0.81 \pm 0.04$ (stat) ± 0.09 (syst) and $\delta_2 = 0.36 \pm 0.07$ (stat) ± 0.05 (syst). Both

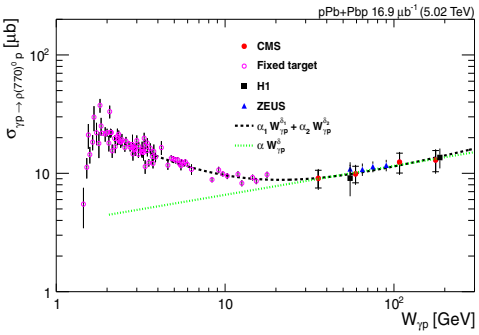

Figure 4. Exclusive ρ meson cross sections measured as a function of $W_{\gamma p}$ [4]. The inner and outer error bars show the statistical uncertainty and systematic uncertainty. The dashed black line shows the result of the Regge fit [10].

the CMS and HERA data together fitted with $\alpha W_{\gamma p}^{\delta}$ and yields $\delta = 0.24 \pm 0.13$ (stat) ± 0.04 (syst).

4 Summary

The cross section of exclusive photoproduction of the Υ and $\rho(770)^0$ is measured in UPC pPb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV with the CMS experiment. The differential cross section as a function of rapidity, p_T^2, and $W_{\gamma p}$ are calculated and compared with previous experimental results from H1, LHCb, and ZEUS. Our results are compared with the previous measurements and are qualitatively consistent within uncertainties. The results discussed in this article provide a wider range of $W_{\gamma p}$ than previous experiments and comparable uncertainties to that of ZEUS. The data is consistent with various pQCD approaches that model the behaviour of the low-x gluon density.

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