Probing small x gluon shadowing from Υ photoproduction in PbPb ultraperipehral collisions at LHC energies

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Introduction

Recent results of exclusive photoproduction of heavy vector mesons at LHC energies by CMS, ALICE and LHCb [1] in ultraperipheral collisions (UPC) confirmed the expectations that UPCs are a very promising probe to study the gluon distributions in nucleons and in nuclei at small x [2, 3]. In this work, we estimate the photoproduction of Υ in the framework of perturbative two-gluon exchange formalism employing various parametrization of gluon distribution functions and compare with the experimental results of HERA [4] and LHCb. The study predicts the rapidity distributions of exclusive Υ photoproduction in PbPb UPC collisions at $\sqrt{s_{NN}} = 5.12$ TeV, the future heavy ion collision scenario at LHC in Run2.

The cross-section of Υ production in the ion-ion (AA) UPC interaction, is given by the sum of two terms, each term is the product of photon flux emitted by one of the colliding participants and the cross-section of Υ photoproduction on the other [2]:

$$\frac{d\sigma_{AA\to AA\Upsilon}(y)}{dy} = [N_{\gamma/A}(\omega)\sigma_{\gamma A\to\Upsilon A}(\omega)]_{\omega=\omega_l} + [N_{\gamma/A}(\omega)\sigma_{\gamma A\to\Upsilon A}(\omega)]_{\omega=\omega_r}$$

Here, ω_l and ω_r denoting photons from the nucleus incident from the left and right respectively; $y = \ln(2\omega/M_\Upsilon)$ is the rapidity of Υ, M_Υ is the mass of Υ. The cross-sections and the left/right fluxes are identical in the above expression, the first term yield a distribution which is just mirror image of the second one.

Photonuclear cross-sections

The photonuclear cross-section of Υ on H ($H \equiv p, A$) can be written as

$$\sigma_{\gamma H\to\Upsilon H}(y) = \frac{d\sigma_{\gamma H\to\Upsilon H}}{dt}|_{t=0} \int dt |F_H(t)|^2 \quad (1)$$

where $d\sigma_{\gamma H\to\Upsilon H} dt|_{t=0}$ is the forward scattering amplitude and $F_H(t)$ is the form factor. Using leading order (LO) approximation, the scattering amplitude for elastic photoproduction of Υ from a proton target reads [2]:

$$\frac{d\sigma_{\gamma p\to\Upsilon p}(W_{\gamma p}, t=0)}{dt} = \frac{16\pi^3\Gamma_{ee}}{3\alpha_{e.m.}M_\Upsilon^5} (1+\eta^2) R_g^2 F^2(Q^2) [\alpha_s(Q^2) x G_p(x, Q^2)]^2 \quad (2)$$

where Γ_{ee} is the width of Υ electronic decay; α_{em} is the fine structure constant; $\alpha_s(Q^2)$ is the running strong coupling constant; $x = M_\Upsilon^2/W_{\gamma p}^2$, is the fraction of nucleon momentum carried by nucleons, $W_{\gamma p}$ is the γp center of mass energy; $G_p(x, Q^2)$ is the gluon distribution in the proton evaluated at momentum transfer $Q^2 = (M_\Upsilon/2)^2$. The relevant x region in CMS@LHC is $\approx 10^{-2} - 10^{-4}$ at central rapidities ($|y| < 2.5$). The factors $(1+\eta^2)$, R_g^2 and $F^2(Q^2)$ corresponds to correction due to real part, skewness and next-to leading (NLO), respectively.

The t dependence of the cross-section for proton (in Eq. 1), is usually parametrized with slope parameter $B_\Upsilon(W_{\gamma p}) = 4.63 + 0.4\alpha' \ln(W_{\gamma p}/90GeV)$, where $\alpha' = 0.06$ [3] and the photoproduction reads, $\sigma_{\gamma p\to\Upsilon p}(W_{\gamma p}) = 1/B(W_{\gamma p})[d\sigma_{\gamma p\to\Upsilon p}/dt|_{t=0}]$. We employed the form $xG_p(x, \mu^2) \propto 1/x^\lambda$ to estimate the factors of $\eta(\lambda)$ and $R_g(\lambda)$ where λ was determined from fit to different gluon PDF and given in Table I. We do not evaluate the $F^2(Q^2)$, but phenomenologically determine it from the normalization of the theoretical predictions of PQCD cross-section from

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leading order (LO) gluon parton distributions in proton, MSTW08, CTEQ6L, CTEQ6L1, JMRT13 using Eq. 3.

$$\frac{1}{\zeta} = \frac{\sigma_{\gamma p\to\Upsilon p}(W_{\gamma p} = 150\text{ GeV})|_{Eq.\ 2}}{286\text{ pb}} \quad (3)$$

LO predictions could well describe the $W_{\gamma p}$

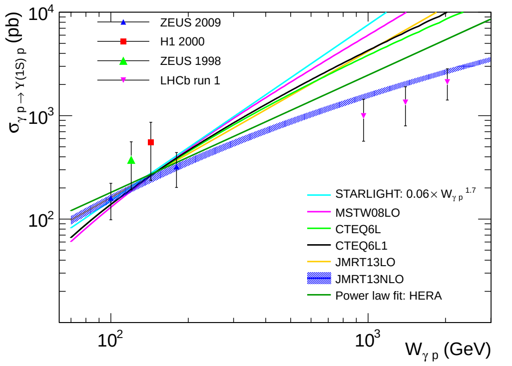

FIG. 1: Photoproduction cross-section of Υ (1S), $\sigma_{\gamma p\to\Upsilon(1S)p}$ with photon-proton center of mass energy $W_{\gamma p}$ compared with the experimental data from HERA [4] and LHCb [1].

dependence of the cross-section $\sigma(\gamma p \to \Upsilon p)$ from HERA, after normalization, but fail to describe the LHCb results as shown in Fig. 1. The NLO parametrization of gluon PDF, JMRT13NLO, is being normalized with $F(Q^2) = 1.87$ which describe both HERA and LHCb data quite well.

TABLE I: The parameter of fit λ of the studied gluon distribution functions, the normalization factor ζ and total photoproduction cross-section in CMS acceptance.

Parame-trization	λ	ζ	σ (μb) (w/o supp.)	σ (μb) (w supp.)
MSTW08	0.411	0.78	96	47
CTEQ6L	0.364	0.67	87	42
CTEQ6L1	0.376	0.74	89	44
JMRT13LO		0.83	73	32
JMRT13NLO		1.87	53	22

In case of nuclear target, the photoproduction is given by,

$$\sigma_{\gamma A\to\Upsilon A}(W_{\gamma p}) = S_A^2(W_{\gamma p})\frac{d\sigma_{\gamma p\to\Upsilon p}}{dt}|_{t=0} \times\Phi_A(t_{\min}) \quad (4)$$

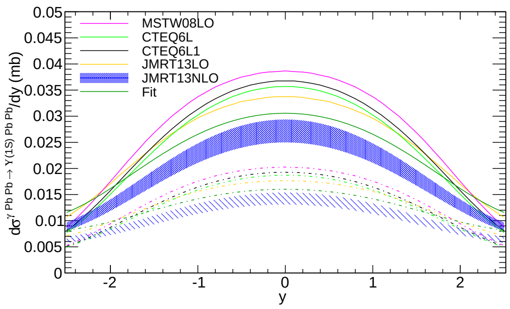

FIG. 2: The rapidity distribution of Υ (1S) photoproduction cross-section for PbPb collisions at $\sqrt{s} = 5.12$ TeV. Solid curves without nuclear effect and dashed are with nuclear gluon shadowing.

where $\Phi_A(t_{\min}) = \int_{t_{\min}}^{\infty} dt|F_A(t)|^2$ and $t_{\min} = -M_\Upsilon^4 m_N^2/W_{\gamma p}^4$ is the minimal momentum transfer to the nucleus; $F_A(t)$ is the nuclear form factor; $S_A(W_{\gamma p})$ is the nuclear suppression factor:

$$S_A(W_{\gamma p}) = \kappa_{A/N}\frac{G_A(x,Q^2)}{A\ G_N(x,Q^2)} = \kappa_{A/N}R(x,Q^2)$$

where $R(x,Q^2)$ is the nuclear gluon modification factor for EPS09 and $\kappa_{A/N}$ accounts the fact that η and R_g in nucleus is small compared to proton.

Results

Fig. 2 shows the predicted rapidity distribution of the cross-section of Υ photoproduction in Pb-Pb UPC collisions integrated over momentum transfer t for the CMS kinematic region. The solid curves are the cross-section without nuclear gluon shadowing, whereas dashed curves are the results with EPS09 nuclear gluon shadowing parameters. Table I (4, 5 col.) gives Υ photoproduction cross-section, without and with nuclear gluon shadowing.

References

[1] ALICE Coll., Phys. Lett.**B 718**, 1273 (2013); LHCb Coll. J. Phys. G 41, 055002 (2014).
[2] V. Guzey *et al.* JHEP **1402**, 046 (2014).
[3] S. P. Jones *et al.* JHEP **11** 085 (2013).
[4] H1 Coll., Phys. Lett **B 483**, 23 (2000); ZEUS Coll., Phys. Lett. **B 680**, 4 (2009).