Onset of Perturbative Color Opacity at Small x and Υ Coherent Photoproduction off heavy nuclei at LHC

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Abstract

We study photon-induced coherent production of Υ in ultraperipheral heavy ion collisions at LHC and demonstrate that the counting rates will be sufficient to measure nuclear shadowing of generalized gluon distributions. This will establish the transition from the regime of color transparency to the regime of perturbative color opacity in an unambiguous way. We argue that such measurements will provide the possibility to investigate the interaction of ultra-small color dipoles with nuclei in QCD at large energies, which are beyond the reach of the electron-nucleon (nucleus) colliders, and will unambiguously discriminate between the leading twist and higher twist scenarios of gluon nuclear shadowing.

1 Introduction

High energy coherent vector meson photo- and electroproduction provides new tools for understanding of many exciting phenomena in the QCD physics of the hadron-nucleus interactions. The photon wave function comprises a variety of hadronic components as well as a direct contribution of the quark-antiquark pairs. In the high energy regime, the photon transforms into a $q\bar{q}$ pair long before the nuclear target. The transverse size of the produced $q\bar{q}$ pair is controlled by the mass of the quark ($r \propto m_q^{-1}$, provided $m_q \gg \Lambda_{QCD}$). Correspondingly, the scale of virtuality in the considered processes is $Q^2 \geq m_q^2$. The strength of the high-energy interaction of small dipoles in QCD depends on the size of the area occupied by the color field within the interacting objects: the smaller the size, the weaker the interaction [1, 2]. Probably the most sensitive indicator of the size of the interacting objects is the t-dependence of exclusive vector meson electro- and photoproduction. The current HERA data on the vector meson electroproduction on the proton target, see e.g. [3], are consistent with the prediction of [4] that the t-slopes of the ρ and J/ψ production production cross sections should converge to the same value with the rate of convergence consistent with the estimate of [5]. This indicates that at small x, $x = (M_V^2 + Q^2)/s$ (x is related to the momentum fractions of the exchanged gluons – see the discussion of Eq. (4); s is the invariant energy for $\gamma - N$ scattering), the configurations of much smaller size than the average

light meson size dominate J/ψ production for all Q^2 and ρ production for $Q^2 \geq 5$ GeV^2. In the kinematics of small x and large Q^2, the QCD factorization theorem predicts that the cross sections of coherent production of vector mesons off nuclei are proportional to the square of the nuclear gluon parton density [1] $G_A(x, Q^2)$ [4, 6, 7]. It is reasonably well known from various data analyses that $G_A(x, Q^2)$ is not shadowed and even may be enhanced at $0.02 \div 0.03 \leq x \leq 0.2$: $G_A(x, Q^2) \geq AG_N(x, Q^2)$. One should note that the small-x behavior of nuclear parton distributions is crucial for various aspects of small-x dynamics with nuclei. The nuclear parton distributions have been analyzed both phenomenologically, by fitting to the available data [8, 9] (which for $Q^2 \geq 2$ GeV^2 are available only for $x \geq 10^{-2}$), and theoretically, by using various models, see Ref. [10] for the review. These analyses suggest a rather significant nuclear shadowing assuming that the leading twist effects dominate. However, the F_{2A}/F_{2D} data are restricted to rather moderate Q^2, where higher twist effects due to e.g. diffractive vector meson production are not negligible.

On the theoretical end, there are two types of models. One class focuses on sufficiently large virtualities, where leading twist dominates. It assumes that the soft physics (aligned jet model) which dominates at the starting scale of evolution for quark shadowing should be present in the gluon sector as well, so that the gluon shadowing effects at the initial evolution scale of a few GeV^2 should be comparable to that of quarks [11, 8]. More recently a more quantitative approach became possible. It is based on the combination of the Gribov theorem connecting diffraction and shadowing [12], and the Collins factorization theorem for hard diffraction in DIS [13]. As a result, this approach effectively takes into account the nonconservation of the number of particles in QCD evolution and the restoration of the gluon fields by the small color singlets. When combined with the HERA hard diffractive data and quasieikonal modeling of the multiple rescattering terms, it leads to the prediction that the gluon shadowing is significantly larger than that for quarks at the starting scale of QCD evolution of $Q^2 \sim 4$ GeV^2.

Another group of the models [14] aims to model the effects of the modification of nuclear gluon field both in the regime of high gluon densities, where the decomposition over the twists is not applicable and at large Q^2 where the leading twist dominates. It assumes that parton densities are saturated at $Q^2 \leq Q_s^2$ ($Q_s^2(x)$ is the saturation scale). An important feature of these models is that they do not lead to the leading twist shadowing at $Q^2 \gg Q_s^2$, see e.g. discussion in [15, 16]. In particular, in these models the effect of nuclear shadowing for the interaction of a small dipole is modeled in the frozen impact parameter eikonal approximation with the dipole coupled to the unscreened nucleon gluon field, leading to the shadowing $\propto xG_N(x, Q^2)/Q^2$.

A large leading twist gluon shadowing would significantly slow down the increase of the cross section of the small dipole-nucleus interaction with energy (which is proportional to the gluon density) and, hence, would significantly extend the x range, where unitarity for the interaction of small dipoles with nuclei is not violated in the DGLAP approximation. As a result, this may strongly affect the pattern of the possible onset of the regime of the black body limit (BBL).

In the x-range, where nuclear gluons are not shadowed, one expects the regime of color

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[1]Note that the corrections due to the skewedness effects at large Q^2 and small x are calculable in terms of the QCD evolution equation for the generalized parton distributions.

transparency for coherent production of onium states. A leading twist shadowing would lead to the onset of the perturbative color opacity with the decrease of x. However, this shadowing merely slows down the increase of the gluon density with the decrease of x. Hence, at sufficiently small x, the perturbative color opacity regime will be also violated. This may lead to the onset of BBL or another nonlinear regime of QCD.

The crucial questions for understanding the interplay among the above mentioned phenomena are the following. What is the kinematical region where the squeezing of the $q\bar{q}$ dipole takes place, which justifies the application of perturbative QCD? What are the leading mechanisms of nuclear shadowing at very small x, where the small size dipole-nucleon interaction become large? Can the gluon saturation effect at small x stop the increase of the cross section before reaching the BBL.

In order to establish the effect of nuclear opacity and clarify the role of the leading and higher twist mechanisms of nuclear shadowing in an unambiguous way, it is necessary to investigate the interaction of a small dipole with the nuclear medium and check whether the amplitude of the interaction is reduced as compared to the color transparency expectation of the amplitude being proportional to the atomic number. Production of light vector mesons at small x in DIS by the longitudinally polarized photons and photoproduction of onium states seem to be optimal for these purposes. The studies of the dipole model in Ref. [17] suggest that one is safely into the perturbative domain at $x \leq 10^{-3}$ only if the transverse distances are below $d \sim 0.3$ fm. For the light mesons this requires $Q^2 \geq 15$ GeV^2 and, hence, an eA collider with energies of HERA and large luminosity. The photoproduction of J/ψ appears to be the borderline case – the amplitude seems to be getting a significant contribution from the transitional region between perturbative and nonperturbative QCD. Although J/ψ photoproduction suits well the studies of the onset of color opacity, in general it may be rather problematic to distinguish the perturbative regime, where the amplitude is proportional to the gluon density, from the regime, where the fast increase of the gluon density results in the violation of the leading twist approximation and the transition to the black body limit (BBL) takes place. In Ref. [18] it was suggested to study the onset of BBL in the coherent photoproduction of dijets from heavy nuclei since in this case the role of the leading twist shadowing is negligible. On the contrary, the coherent Υ photoproduction off heavy nuclei seems to be essentially unique for the investigation of the onset of the perturbative color opacity in the leading twist (LT) shadowing regime. In this case, the interaction is dominated by such small transverse interquark distances d_t, $d_t \sim 0.1$ fm, that physics of interactions is definitely perturbative up to very large energies. For example, the cross section of the interaction of a dipole with $d_t \sim 0.1$ fm is $\sigma(d_t = 0.1\,\text{fm}, x = 10^{-4}) = 3.5$ mb and is even smaller for larger x.

In order to probe the onset of perturbative color opacity in the Υ production, one would need to reach $x \ll 10^{-2}$. This would require an electron-nucleus collider in the HERA energy range with a luminosity per nucleon comparable to the luminosity in the electron-proton collisions, which appears to be rather problematic for HERA. At the same time there are plans for studying the photoproduction off nuclei at LHC using ultraperipheral heavy ion collisions, including the studies of the coherent onium photoproduction. For the review and extended list of references, see Ref. [19].

Recently it was demonstrated [20] that the yield of J/ψ in the coherent production in the kinematics of the ultraperipheral ion collisions at LHC is suppressed at the central rapidities

by a factor of 6 compared to that in the impulse approximation. Such a significant effect of the suppression would clearly signal the revealing of the color opacity phenomena. However, as mentioned above, the gluon virtualities in this case are on the borderline between the perturbative and nonperturbative QCD regimes ($Q_{eff}^2 \sim 3 \div 4$ GeV^2) and the leading twist approximation might not be accurate enough for the evaluation of the scattering amplitude, especially since the nonperturbative region could probably give a significant correction [21].

In summary, Υ photoproduction stands out as the simplest probe of the propagation of small color dipoles, $d_t = 0.1$ fm, at LHC energies, which will allow to investigate the nuclear gluon fields at the effective scale $Q^2 \sim 40$ GeV^2. In this case, the estimates of nuclear shadowing via the leading twist mechanism based on perturbative QCD used in Ref. [20], will be much better justified. The main objective of this work is to present the results of a study of the coherent production of Υ in the ultraperipheral collisions of heavy ions in the kinematics of LHC.

2   Production of Υ in ultraperipheral collisions

The cross section of the coherent Υ production integrated over the transverse momenta of the nucleus, which emitted a photon, can be written using the standard Weizsacker-Williams approximation [22] in the form:

$$\frac{d\sigma(AA \to \Upsilon AA)}{dy} = N_\gamma(y)\sigma_{\gamma A \to \Upsilon A}(y) + N_\gamma(-y)\sigma_{\gamma A \to \Upsilon A}(-y)\,. \tag{1}$$

Here $y = ln\frac{2\gamma m_N M_V}{s}$ is the c.m. rapidity of the produced Υ; γ is Lorentz factor; $\sigma(y)$ is the cross section for the photoproduction of Υ; $N_\gamma(y)$ is the flux of the equivalent photons [23]:

$$N(y) = \frac{Z^2\alpha}{\pi^2} \int d^2b \Gamma_{AA}(\vec{b})\frac{1}{b^2}X^2[K_1^2(X) + \frac{1}{\gamma}K_0^2(X)]\,, \tag{2}$$

where $K_0(X)$ and $K_1(X)$ are modified Bessel functions of the argument $X = bm_V e^y/(2\gamma)$; $\vec{b}$ is the transverse distance between the centers of the colliding nuclei. The standard Glauber profile factor,

$$\Gamma_{AA}(\vec{b}) = \exp\left(-\sigma_{NN}\int\limits_{-\infty}^{\infty} dz \int d^2b_1 \rho_A(z,\vec{b_1})\rho_A(z,\vec{b}-\vec{b_1})\right)\,, \tag{3}$$

accounts for the inelastic strong interactions of the nuclei at impact parameters $b \le 2R_A$ and, hence, suppresses the corresponding contribution to the Υ photoproduction. In our calculations we use the nuclear matter density $\rho_A(z,\vec{b})$ obtained from the mean field Hartree-Fock-Skyrme (HFS) model, which describes many global properties of nuclei [24] as well as many single-particle nuclear structure characteristics extracted from the high energy $A(e, e\prime p)$ reactions [25].

The amplitude of the Υ photoproduction (necessary for the calculation of $\sigma_{\gamma A \to \Upsilon A}$ in Eq. (1)) in the leading twist approximation is described by the series of the Feynman diagrams in Fig. 2. The QCD factorization theorem for exclusive meson photoproduction [6, 7, 4]
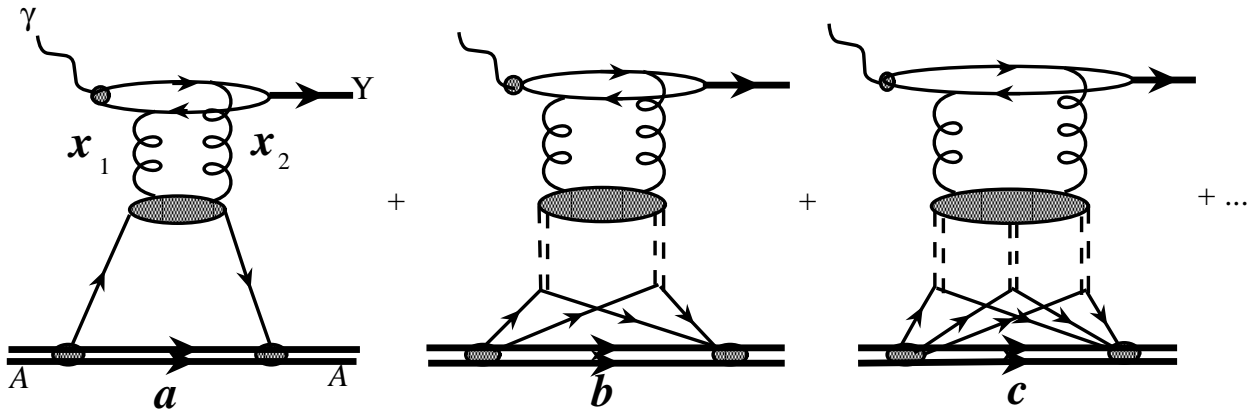
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Figure 1: High energy quarkonium photoproduction in the leading twist approximation.

allows one to express the imaginary part of the forward amplitude for the production of a heavy vector meson by a photon, $\gamma + T \to V + T$, through the convolution of the wave function of the meson at the zero transverse separation between the quark and antiquark, the hard interaction block and the generalized parton distribution (GPD) of the target, $G_T(x_1, x_2, Q^2, t_{min})$, at $t_{min} \approx -x^2 m_N^2$. The gluon light cone fractions x_i for the gluons attached to the quark loop satisfy the relation:

$$x_1 - x_2 = \frac{m_\Upsilon^2}{s} \equiv x, \tag{4}$$

where $s = 4 E_N \omega = 4 \gamma \omega m_N$ is the invariant energy for $\gamma - N$ scattering ($E_N = \gamma m_N$ is the energy per nucleon in the c.m. of the nucleus-nucleus collisions). If the quark Fermi motion and binding effects were negligible, $x_2 \ll x_1$. Numerical estimates using realistic potential model wave functions indicate that for J/ψ, $x_1 \sim 1.5x, x_2 \sim x/2$ [21], and that for Υ, $x_2/x_1 \sim 0.1$ [26]. Modeling of the GPDs at moderate Q^2 suggests that, to a good approximation, $G_T(x_1, x_2)$ can be approximated by the gluon density at $x = (x_1 + x_2)/2$ [4, 27]. For large Q^2 and small x, GPDs are dominated by the evolution from $x_i(init) \gg x_i$. Since the evolution conserves $x_1 - x_2$, the effect of skewedness is determined primarily by the evolution from nearly diagonal distributions.

Hence, we can approximate the amplitude of the Υ photoproduction off nucleus at $k_t^2 = 0$, presented by a series of diagrams in Fig. 2, as

$$M(\gamma + A \to \Upsilon + A) = M(\gamma + N \to \Upsilon + A) \frac{G_A(x, Q_{eff}^2)}{A G_N(x, Q_{eff}^2)} F_A(t_{min}), \tag{5}$$

where F_A is nuclear form factor normalized so that $F_A(0) = A$; $Q_{eff}^2(\Upsilon) \sim 40 \, \text{GeV}^2$ according to the estimates of [5]. It is worth noting that really we are not sensitive here to the precise value of Q_{eff}^2 since for large Q^2, the gluon shadowing decreases slowly with Q^2. Note that the skewedness effects, which are expected to be small at $Q^2 \sim$ a few GeV^2, become important in the Υ case. They appear to increase the cross section of the reaction $\gamma + p \to \Upsilon + p$ by a factor ~ 2, see Refs. [26, 28]. Potentially, this could obscure the connection between the

perturbative color opacity effect and shadowing of the nuclear gluon densities. However, the analysis of [29] shows that the ratio of GPD on nucleus and on a nucleon for $t = t_{min}$ is a weak function of x_2, slowly dropping from its diagonal value ($x_2 = x_1$) with the decrease of x_2. Overall this observation is in a agreement with the general trend mentioned above that it is more appropriate to do a comparison of the diagonal and non-diagonal cases at $x = (x_1 + x_2)/2$.

The effect of leading twist nuclear shadowing can be quantified by considering the diagram (b) in Fig. 2. All possible unitary cuts of the diagram lead to inelastic shadowing in hadron-nucleus total cross sections [12]. Applying these ideas to DIS on nuclei and using the factorization theorem for hard diffraction [6], coupled with the QCD analysis of the HERA data on diffractive DIS [30], nuclear parton distributions can be predicted [13, 10]. In general, the theory of leading twist nuclear shadowing should be applied in two steps. Firstly, the nuclear gluon density distribution is calculated at the starting evolution scale of the effective momentum transfer $Q_0^2 = 4$ GeV^2

$$G_A(x, Q_0^2) = AG_N(x, Q_0^2) - 8\pi\Re e\Big[\frac{(1-i\eta)^2}{1+\eta^2}\int d^2b \int\limits_{-\infty}^{\infty} dz_1 \int\limits_{z_1}^{\infty} dz_2 \int\limits_{x}^{x_{I\!P}^0} dx_{I\!P}$$

$$\times g_N^D(\frac{x}{x_{I\!P}}, x_{I\!P}, Q_0^2, t_{min})\rho_A(\vec{b}, z_1)\rho_A(\vec{b}, z_2)e^{ix_{I\!P}m_N(z_1-z_2)}\, e^{-\frac{1}{2}\sigma_{eff}(x,Q_0^2)(1-i\eta)\int\limits_{z_1}^{z_2} dz\rho_A(\vec{b},z)}\Big]. \quad (6)$$

Here $g_N^D(\frac{x}{x_{I\!P}}, x_{I\!P}, Q_0^2, t_{min})$ is the diffractive gluon density distribution of the nucleon; $x_{I\!P}$ is the Pomeron momentum fraction; η is the ratio of the real to imaginary parts of the elementary diffractive amplitude; $x_{I\!P}^0 = 0.03$ is the cut-off parameter of the theory. As an input, we used the H1 parameterization [30] of $g_N^D(\frac{x}{x_{I\!P}}, x_{I\!P}, Q_0^2, t_{min})$. The effect of the interactions with three and more nucleons of the target (graph (c) in Fig. 2) is included in the attenuation factor $T = \exp(-\sigma_{eff}(x, Q_0^2)(1-i\eta)/2 \int\limits_{z_1}^{z_2} dz\rho_A(\vec{b}, z))$. The effective cross section $\sigma_{eff}(x, Q_0^2)$ accounts for the elastic rescattering of the produced diffractive state off the nuclear nucleon in the series of the rescattering diagram (graphs (b) and (c) in Fig. 2) and is defined by the equation

$$\sigma_{eff}(x, Q_0^2) = \frac{16\pi}{(1+\eta^2)G_N(x, Q_0^2)} \int\limits_{x}^{x_{I\!P}^0} dx_{I\!P} g_N^D(\frac{x}{x_{I\!P}}, x_{I\!P}, Q_0^2, t_{min})\,. \quad (7)$$

Secondly, since the photoproduction of Υ corresponds to larger Q^2 scales ≈ 40 GeV^2, the gluon density distributions were evolved up to this scale using the NLO QCD evolution equations. In the limit of low nuclear density, when the effect of the attenuation factor T can be neglected, Eq. (6) can be applied to evaluate G_A at any scale Q^2 and not only at Q_0^2. In the general case, Eq. (6) should be used only at rather moderate Q_0^2 and should serve as an input for QCD evolution: The modelling of multiple rescattering by the attenuation factor T ignores the fluctuations in the strength of the interaction around the average value σ_{eff}, which is a good approximation only at moderate Q_0^2. Indeed, at $Q_0^2 \approx 3 \div 4$ GeV^2, the interactions are predominantly soft with small cross section fluctuations. The effect of cross

section fluctuations is automatically included in QCD evolution, which leads to violation of the Glauber - like structure of the expression for the shadowing for $Q^2 > Q_0^2$.

One can also address the question of the accuracy of the substitution of the ratio of the generalized gluon densities by the ratio of the diagonal parton densities at the normalization scale. In the case of scattering off two nucleons (only graph (b) in Fig. 2), one can express the leading twist screening via the nondiagonal matrix element of the diffractive distribution function, $\tilde{g}^D$ (an analog of generalized PDF). It depends on the light-cone fraction, which the nucleon lost in the $|in\rangle$ and $\langle out|$ states: $x_{I\!P}$ $x_{I\!P} - x$ respectively, $\beta_{in} = x_1/x_{I\!P}, \beta_{out} = (x_1 - x)/(x_{I\!P} - x)$, and t, Q^2. If we make a natural assumption that

$$\tilde{g}^D(x_1, x, x_{I\!P}, Q_0^2, t) = \sqrt{g^D(\beta_{in}, Q_0^2, x_{I\!P}, t)g^D(\beta_{out}, Q_0^2, x_{I\!P} - x, t)}, \tag{8}$$

we find that in the kinematics we discuss, the resulting skewedness effects are small numerically. They are smaller than the uncertainties in the input gluon diagonal diffractive PDFs.

The discussion of the nuclear gluon distribution culminates in the fact that the cross section of the process $\gamma A \to \Upsilon A$ can be readily obtained by squaring the amplitude in Eq. (5)

$$\sigma_{\gamma A \to \Upsilon A}(s) = \frac{d\sigma_{\gamma N \to \Upsilon N}(s, t_{min})}{dt} \left[\frac{G_A(\frac{M_\Upsilon^2}{s}, Q_{eff}^2)}{AG_N(\frac{M_\Upsilon^2}{s}, Q_{eff}^2)} \right]^2 \int\limits_{-\infty}^{t_{min}} dt \left| \int d^2b dz e^{i\vec{q}_t \cdot \vec{b}} e^{-iq_l z} \rho_A(\vec{b}, z) \right|^2, \tag{9}$$

where $-t = |\vec{q}_t|^2 + |q_l|^2$ is the square of the vector meson transverse momentum and $q_l = m_N M_\Upsilon^2/s$ is the minimal longitudinal momentum transfer in the photoproduction vertex.

The elementary cross section of forward Υ photoproduction in the energy range of interest is not known well experimentally. In our calculation, we used a simple parametrized form

$$\frac{d\sigma_{\gamma N \to \Upsilon N}(s, t)}{dt} = 10^{-4} B_\Upsilon \left[\frac{s}{s_0} \right]^{0.85} \exp(B_\Upsilon t) \tag{10}$$

with the reference scale $s_0 = 6400$ GeV^2; the slope parameter $B_\Upsilon = 3.5\,GeV^{-2}$ and the energy dependence, which follows from the calculations [26] of the photoproduction of Υ in the leading $\log Q^2$ approximation with an account for the skewedness of the partonic density distributions. The cross section is normalized so that the total cross section is in μb.

The results of the calculations using Eq. (9) are presented in Fig. 2. The figure depicts the ratio of $\sigma_{\gamma A \to \Upsilon A}$ calculated with Eq. (9) to that calculated ignoring the effect of nuclear shadowing (setting $G_A = AG_N$). We find a rather strong suppression of the coherent Υ photoproduction cross section off nuclei. Note that UPC collisions at LHC are sensitive to the x-range of $3 \times 10^{-4} \leq x \leq 5 \times 10^{-3}$.

Since the significant effect of shadowing is far beyond the energies available in the fixed target experiments with the photon beams, the only opportunity to study this phenomenon is coherent production in UPC at LHC[2]. In this kinematics, the coherent events can be selected

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[2]In principle, HERA can reach into the necessary kinematics. However, this would require both the approval of HERAIII program and development of the system necessary for high luminosity runs with heavy nuclei.
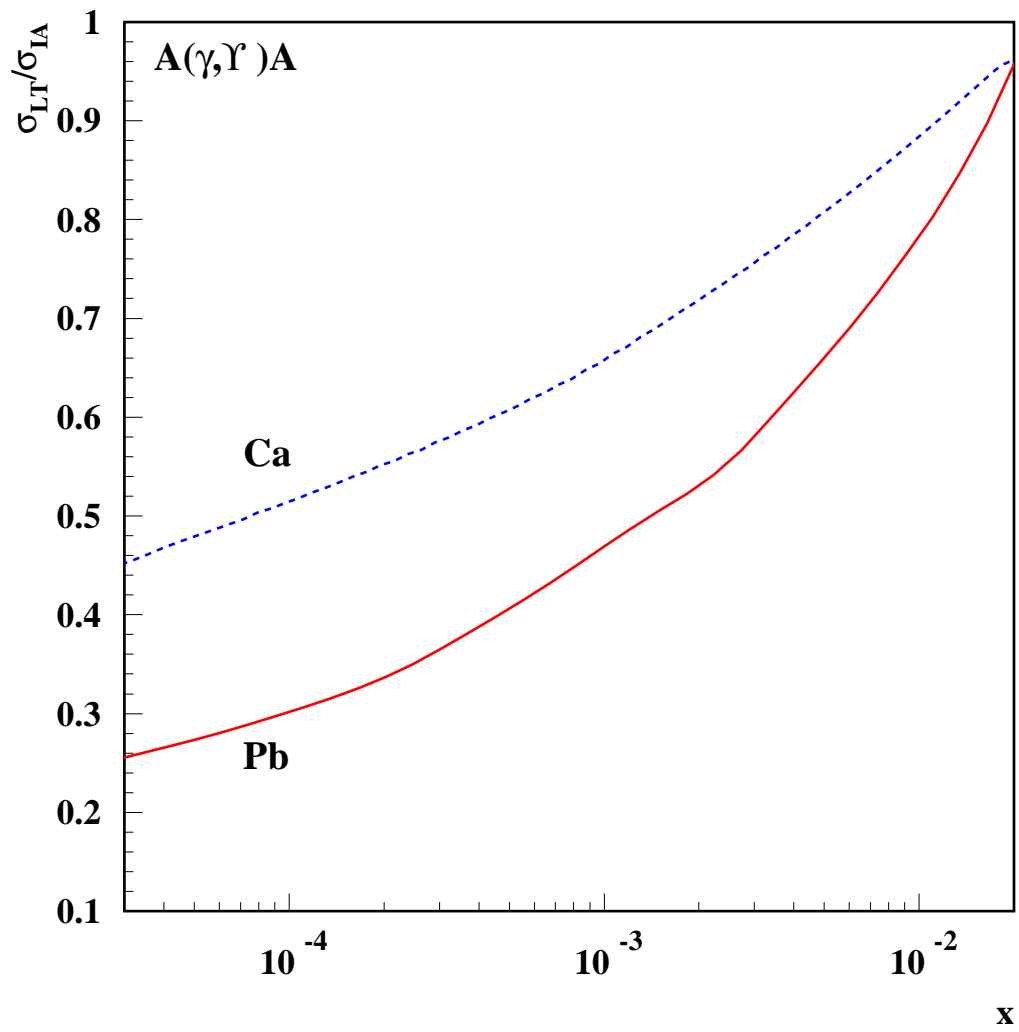
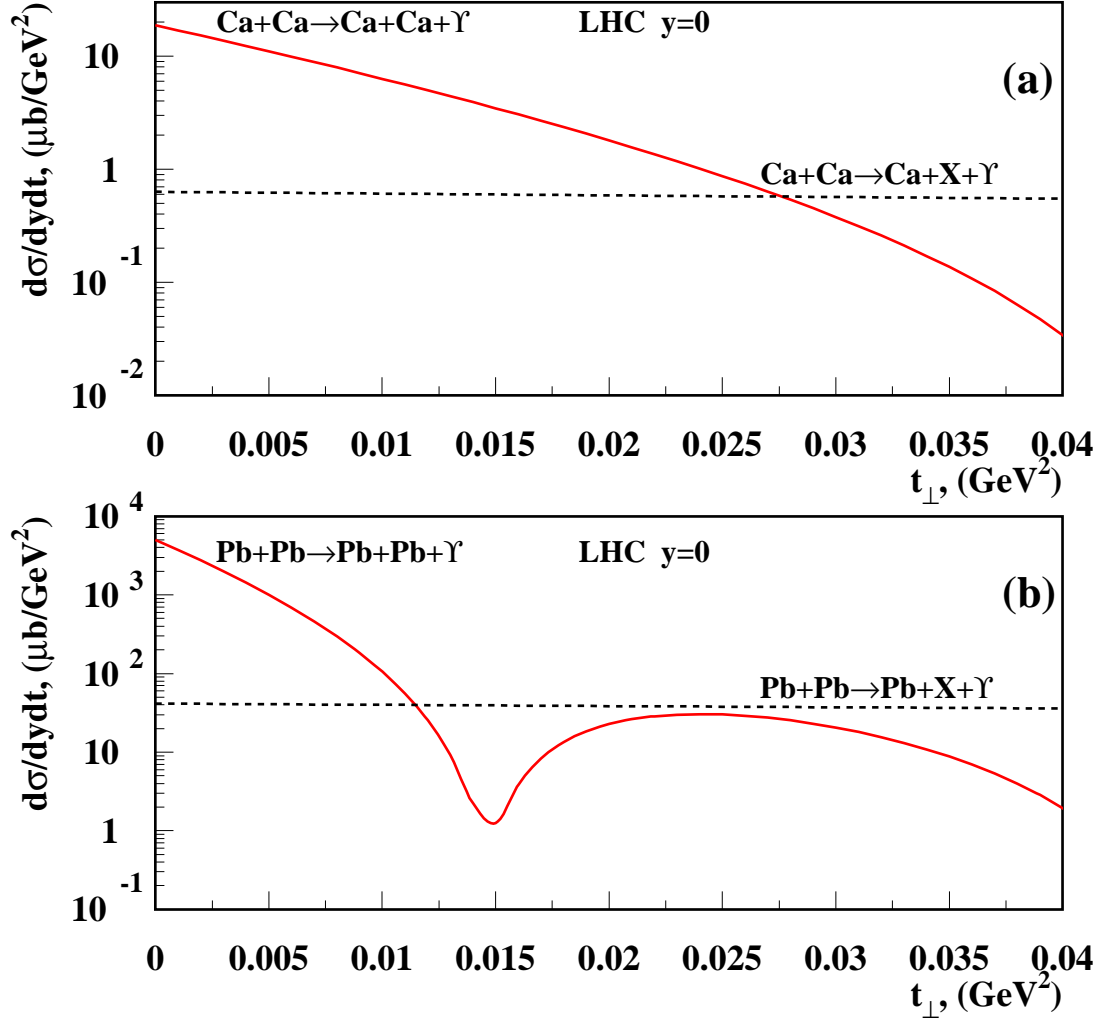Figure 2: The shadowing effect in the Υ photoproduction off Pb and Ca.

Figure 3: The momentum transfer dependence in the coherent Υ production in the UPC at LHC. The solid curve corresponds to the coherent cross section with accounting for nuclear shadowing; the dashed curve corresponds to incoherent Υ production.
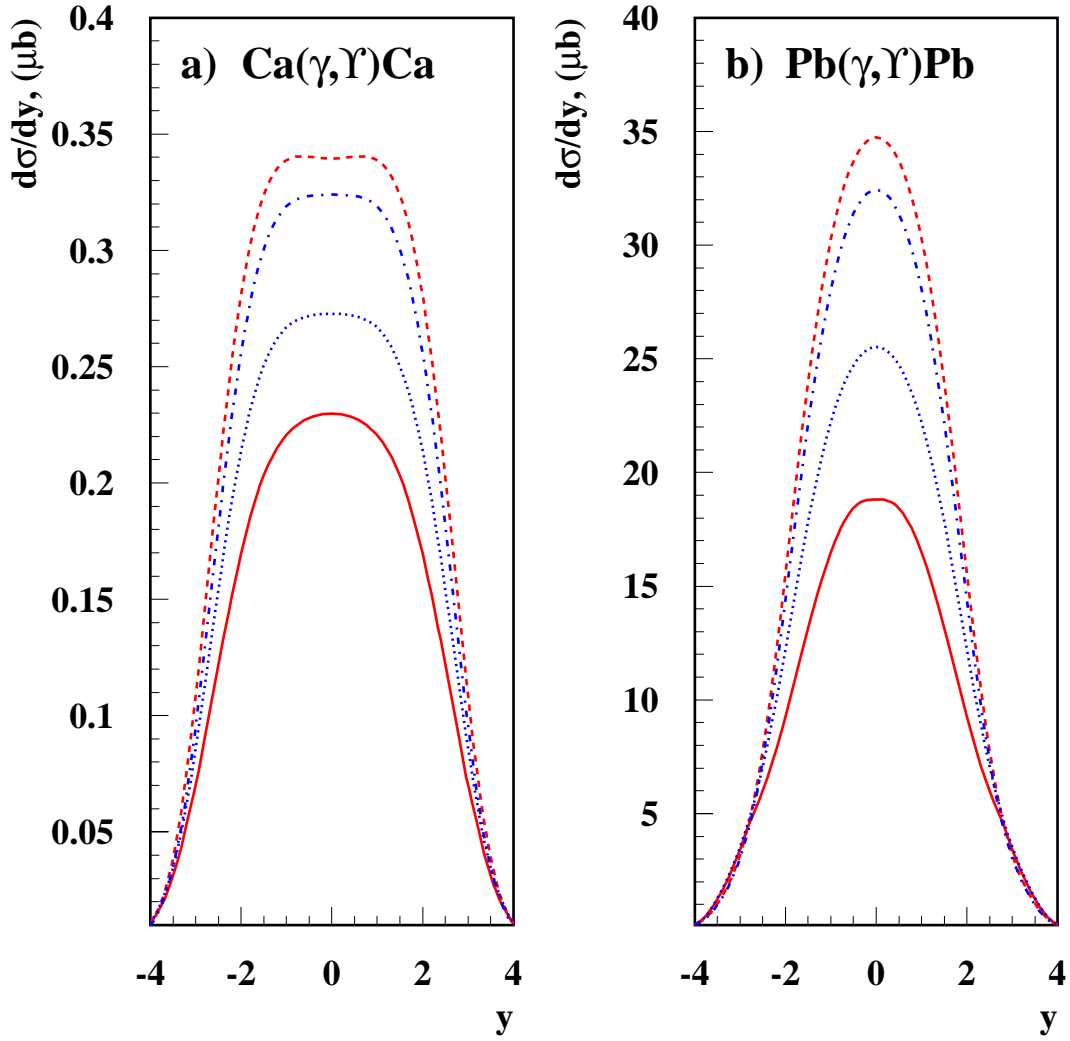
Figure 4: The rapidity distribution for the coherent Υ production in Ca-Ca and Pb-Pb in UPC at LHC. The solid curve corresponds to the calculation including leading twist nuclear shadowing; the dotted curve corresponds to the calculation with the model of shadowing of Eskola *et al.*; the dot-dashed curve is the calculation in the eikonal dipole rescattering model; the dashed curve corresponds to the impulse approximation.

Approximation	CaCa at LHC($\gamma = 3500$)	PbPb at LHC($\gamma = 2760$)
Impulse	1.8 μb	133 μb
Glauber+Leading twist shadowing	1.2 μb	78 μb

Table 1: Total cross sections of Υ production in UPC at LHC.

by the requirement of anticoincidence with the signal in the Zero Degree Calorimeter(the requirement is that there are no neutrons in the final state) and by selecting the produced Υ with the small transverse momentum, which strongly suppresses the contribution of the incoherent diffraction. The specific transverse momentum distributions for both coherent and incoherent production are shown in Fig. 3. The cross section of the incoherent Υ photoproduction was estimated in the impulse approximation as

$$\frac{d\sigma_{\gamma A \to \Upsilon X}(s,t)}{dt} = A \frac{d\sigma_{\gamma N \to \Upsilon N}(s,t)}{dt} \ . \tag{11}$$

This constitutes the upper limit for incoherent contribution.

The rapidity distributions for coherent Υ production in the UPC with Ca and Pb beams are shown in Fig. 4 and the corresponding total cross sections are given in Table 1. For comparison in Fig. 4 we also present results (the dotted curve) of the calculation using the model of Eskola *et al.* [8] for the gluon shadowing, which predicts somewhat smaller suppresion of the Υ yield. In order to illustrate that that eikonal dipole models of rescatterings give a much smaller suppression, we present also the result of the eikonal calculation (the dot-dashed curve) using the analysis of the value of $\sigma(d,x)$ from [17](the result of [31] for $d \sim 0.1$ fm are very similar, see comparison in [17]). It appears that a detector with good acceptance for Υ production for the currently discussed luminosities for heavy ion runs of LHC will collect enough statistics to measure the cross section of the discussed process with good precision. As seen from comparison to the calculations in the Impulse Approximation (Fig. 4), the yield of Υ is expected to be suppressed by a factor of two at central rapidities due to leading twist shadowing. Practically, the only opportunity to draw the conclusion about the onset of the color opacity from the measurement of the Υ yield in the ultraperiph-eral ion collisions at LHC, which we see at the moment, is the comparison of the calculations with the data. Obviously until the rather large uncertainty in the absolute value of the $\gamma + N \to \Upsilon + N$ cross section exists, such a conclusion cannot be considered as decisive. However, in the coming couple of years it is expected that this elementary cross section will be measured at HERA with much better accuracy. Besides, the energy dependence of the elementary cross section can be considered as well established theoretically. Hence, a mea-surement of the Υ yield at the edge of the rapidity distribution, where the effect of shadowing is still insignificant, could help to fix the uncertainty and verify the calculation of the cross section in the impulse approximation in all ranges of rapidities. Therefore, a comparison with the data at the central rapidities would provides us with an estimate of the shadowing effect. Note that there exists a procedure [32] to separate the production of mesons at small and large impact parameters through the study of the nucleus break up, which would allow to determine the ratio of the cross section of Υ production by left and right moving photons for a given rapidity. Another possibility will be to measure the elementary cross section

at LHC in UPC collisions of protons with nuclei. Though this cross section is a factor of $\propto A^{4/3}$ smaller, the expected luminosity in pA collisions is a factor of 100 larger than in AA collisions.

3   Conclusion

We found that the UPC program at LHC will provide a practical way to search for the onset of the perturbative color opacity via the study of the coherent Υ production at LHC and will decisively discriminate between the leading twist and higher twist scenarios of gluon shadowing at large Q^2.

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