

Diffractive J/Ψ photoproduction at large momentum transfer in coherent hadron-hadron interactions at CERN LHC

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The vector meson production in coherent hadron-hadron interactions at LHC energies is studied assuming that the color singlet t -channel exchange carries large momentum transfer. We consider the nonforward solution of the Balitsky, Fadin, Kuraev, and Lipatov equation at high energy and large momentum transfer and estimate the rapidity distribution and total cross section for the process $h_1 h_2 \rightarrow h_1 J/\Psi X$, where h_i can be a proton or a nucleus. We predict large rates, which implies that the experimental identification can be feasible at the LHC.

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I. INTRODUCTION

Understanding the behavior of high energy hadron reactions from a fundamental perspective within quantum chromodynamics (QCD) is an important goal of particle physics (for recent reviews see e.g. Refs. [1–3]). Attempts to test experimentally this sector of QCD started some years ago with the first experimental results from ep collisions at HERA and $pp(\bar{p})$ collisions at Tevatron. Currently, there is a great expectation with respect to the first experimental results from hadron-hadron collisions at CERN LHC [4]. The central papers concerning the knowledge of the Regge limit (high energy limit) of QCD were presented in the late 1970s by Lipatov and collaborators [5]. The physical effect that they describe is often referred to as the QCD pomeron, with the evolution described by the Balitsky, Fadin, Kuraev, and Lipatov (BFKL) equation. One of main features of the BFKL evolution is the strong growth predicted for the cross sections, which implies that at very high energies the BFKL equation should be modified in order to include unitarization corrections [1,3]. However, it is expected that the BFKL prediction should provide a good description of the experimental data in a kinematical window of the current and future high energy colliders (see e.g. [6]).

In recent years our group has proposed the analysis of coherent interactions in hadronic collisions as an alternative way to study the QCD dynamics at high energies [7–17] (for related studies see [18–23]). The basic idea in coherent hadronic collisions is that the total cross section for a given process can be factorized in terms of the equivalent flux of photons into the hadron projectile and the photon-photon or photon-target production cross section. The main advantage of using colliding hadrons and nuclear beams for studying photon induced interactions is the high equivalent photon energies and luminosities that

can be obtained at existing and future accelerators (for a review see Ref. [24]). Consequently, studies of $\gamma p(A)$ interactions at the LHC could provide valuable information on the QCD dynamics.

The photon-hadron interactions in hadron-hadron collisions can be divided into exclusive and inclusive reactions. In the former, one given particle is produced while the target remains in the ground state (or has only internal excitations), and, in the latter, the particle is produced together with one or more particles resulting from the dissociation of the target. The typical examples of these processes are the exclusive vector meson production and the inclusive heavy quark production, described by the reactions $\gamma h \rightarrow Vh$ ($V = \rho, J/\Psi, Y$) and $\gamma h \rightarrow XY$ ($X = c\bar{c}, b\bar{b}$), respectively. Recently, both processes have been discussed considering pp [11,12,15,16], pA [13], and AA [10,11,15,17] collisions as an alternative to constrain the QCD dynamics at high energies (for reviews see Refs. [25,26]), and the results demonstrate that their detection is feasible at the LHC.

In this paper we extend the previous studies to the diffractive vector meson photoproduction with hadron dissociation in the case of large momentum transfer (see Fig. 1) and estimate, for the first time, the corresponding cross section for pp collisions at LHC (for related studies see Ref. [27]). In this process the t -channel color singlet carries large momentum transfer, which means that the square of the four momentum transferred across the associated rapidity gap, $-t$, is large. Different from the diffractive processes studied in Refs. [11,12,15,17–23], which are characterized by two rapidity gaps with the two hadrons remaining intact, now we still have two large rapidity gaps in the detector but one of the hadrons dissociates. One expects a rapidity gap between the proton, which emits the photon and remains intact, and the vector meson. Concerning the other gap, we expect a vector meson on one side and a jet on the other, which balances the transverse momentum. The present study is motivated by the fact that the experimental data for the J/Ψ vector meson

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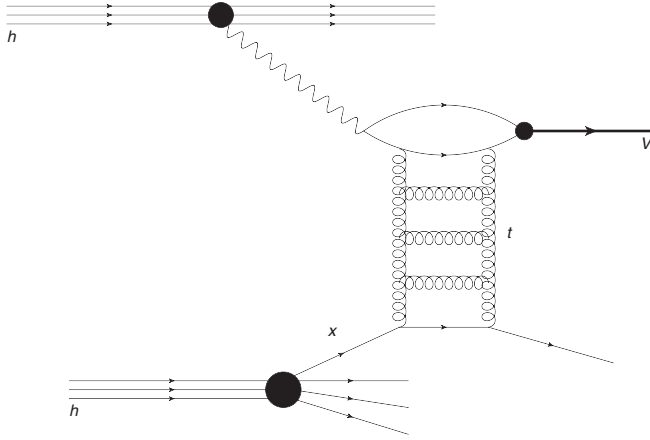


FIG. 1. High- t vector meson photoproduction in coherent hadron-hadron collisions.

photoproduction at high t in electron-proton collisions at HERA can be quite well described using the impact factor representation and the nonforward BFKL solution [28,29].

This paper is organized as follows. In the next section we present a brief review of the formalism necessary for calculate the vector meson production at high- t in photon-hadron and hadron-hadron collisions. In Sec. III we present a comparison between our predictions with the ep HERA data for J/Ψ production. Moreover, we present our predictions considering pp and AA collisions for LHC energies. Finally, in Sec. IV we present a summary of our main conclusions.

II. FORMALISM

Let us consider the hadron-hadron interaction at large impact parameter ($b > R_{h_1}R_{h_2}$) and ultrarelativistic energies. In this regime we expect dominance of the electromagnetic interaction. In heavy ion colliders, the heavy nuclei give rise to strong electromagnetic fields due to the coherent action of all protons in the nucleus, which can interact with each other. Similarly, this also occurs when considering ultrarelativistic protons in $pp(\bar{p})$ colliders. The photon emitted from the electromagnetic field of one of the two colliding hadrons can interact with one photon of the other hadron (two-photon process) or directly with the other hadron (photon-hadron process). The total cross section for a given process can be factorized in terms of the equivalent flux of photons of the hadron projectile and the photon-photon or photon-target production cross section [24]. In general, the cross sections for γh interactions are 2 (or 3) orders of magnitude larger than for $\gamma\gamma$ interactions (see e.g. Refs. [7,30]). In what follows we will focus on photon-hadron processes. For a discussion of the double vector meson production at high t in $\gamma\gamma$ and ultra-peripheral heavy ion collisions see Refs. [9,31,32]. Considering the requirement that in photoproduction there is no hadronic interaction (ultra-peripheral collision), an

analytical approximation for the equivalent photon flux of a nucleus can be calculated and is given by [24]

$$\frac{dN_\gamma(\omega)}{d\omega} = \frac{2Z^2\alpha_{\text{em}}}{\pi\omega} \left[\bar{\eta}K_0(\bar{\eta})K_1(\bar{\eta}) - \frac{\bar{\eta}^2}{2}\mathcal{U}(\bar{\eta}) \right], \quad (1)$$

where ω is the photon energy, γ_L is the Lorentz boost of a single beam, and $K_0(\bar{\eta})$ and $K_1(\bar{\eta})$ are the modified Bessel functions. Moreover, $\bar{\eta} = \omega(R_{h_1} + R_{h_2})/\gamma_L$ and $\mathcal{U}(\bar{\eta}) = K_1^2(\bar{\eta}) - K_0^2(\bar{\eta})$. Equation (1) will be used in our calculations of J/Ψ photoproduction in AA collisions. For proton-proton interactions we assume that the photon spectrum is given by [33]

$$\frac{dN_\gamma(\omega)}{d\omega} = \frac{\alpha_{\text{em}}}{2\pi\omega} \left[1 + \left(1 - \frac{2\omega}{\sqrt{S_{\text{NN}}}} \right)^2 \right] \times \left(\ln\Omega - \frac{11}{6} + \frac{3}{\Omega} - \frac{3}{2\Omega^2} + \frac{1}{3\Omega^3} \right), \quad (2)$$

with the notation $\Omega = 1 + [(0.71 \text{ GeV}^2)/Q_{\text{min}}^2]$ and $Q_{\text{min}}^2 = \omega^2/[\gamma_L^2(1 - 2\omega/\sqrt{S_{\text{NN}}})] \approx (\omega/\gamma_L)^2$.

The cross section for the diffractive J/Ψ photoproduction at large momentum transfer in a coherent hadron-hadron collision is given by

$$\frac{d\sigma[h_1 + h_2 \rightarrow h_1 \otimes J/\Psi \otimes X]}{dydt} = \omega \frac{dN_\gamma(\omega)}{d\omega} \frac{d\sigma_{\gamma h \rightarrow J/\Psi X}(\omega)}{dt}, \quad (3)$$

where \otimes means the presence of a rapidity gap and the rapidity y of the vector meson produced is directly related to the photon energy ω , i.e. $y \propto \ln(2\omega/m_{J/\Psi})$. Moreover, $\frac{d\sigma}{dt}$ is the differential cross section for the process $\gamma h \rightarrow J/\Psi X$. Equation (3) implies that, given the photon flux, the double differential cross section is a direct measure of the photoproduction cross section for a given energy and squared momentum transfer. Some comments are in order here. First, the coherence condition restricts the photon virtuality to very low values, which implies that for most purposes, the photons can be considered as real. Moreover, if we consider $pp/PbPb$ collisions at LHC, the Lorentz factor is $\gamma_L = 7455/2930$, which gives the maximum c.m. γN energy $W_{\gamma p} \approx 8390/950 \text{ GeV}$. Therefore, while studies of photoproduction at HERA are limited to photon-proton center-of-mass energies of about 200 GeV, photon-hadron interactions at LHC can reach 1 order of magnitude higher on energy. Consequently, studies of coherent interactions at LHC could provide valuable information on the QCD dynamics at high energies.

The differential cross section $d\sigma/dt$ for the diffractive J/Ψ photoproduction at large momentum transfer can be obtained using the impact factor representation, proposed by Cheng and Wu [34] many years ago (for a review see Ref. [35]). In this representation, the amplitude for a large- s hard collision process can be factorized in three parts: the impact factors of the colliding particles and the

Green's function of two interacting Reggeized gluons, which is determined by the BFKL equation and is represented by $\mathcal{K}_{\text{BFKL}}$ in what follows. The amplitude for the generic high energy process $AB \rightarrow CD$ can be expressed on the form

$$\begin{aligned} \mathcal{A}^{AB \rightarrow CD}(\mathbf{q}) &= \int d^2\mathbf{k} d^2\mathbf{k}' I^{A \rightarrow C}(\mathbf{k}, \mathbf{q}) \\ &\times \frac{\mathcal{K}_{\text{BFKL}}(\mathbf{k}, \mathbf{k}', \mathbf{q})}{k^2(\mathbf{q} - \mathbf{k})^2} I^{B \rightarrow D}(\mathbf{k}', \mathbf{q}), \end{aligned} \quad (4)$$

where $I^{A \rightarrow C}$ and $I^{B \rightarrow D}$ are the impact factors for the upper and lower parts of the diagram, respectively. That is, they are the impact factors for the processes $A \rightarrow C$ and $B \rightarrow D$ with two gluons carrying transverse momenta \mathbf{k} and $\mathbf{q} - \mathbf{k}$ attached. These gluons are in an overall color singlet state. At lowest order the process is described by two gluon exchange, which implies $\mathcal{K}_{\text{BFKL}} \propto \delta^{(2)}(\mathbf{k} - \mathbf{k}')$ and an energy independent cross section. At higher order, the dominant contribution is given by the QCD pomeron singularity, which is generated by the ladder diagrams with the (Reggeized) gluon exchange along the ladder. The QCD pomeron is described by the BFKL equation [5], with the exchange of a gluon ladder with interacting gluons generating a cross section that increases with the energy. As our goal is the analysis of the vector meson production at large $-t$, we will use in our calculations the nonforward solution of the BFKL equation in the leading logarithmic approximation (LLA), obtained by Lipatov in Ref. [36].

As discussed in detail in Refs. [37,38], at large momentum transfer the pomeron couples predominantly to individual partons in the hadron. This implies that the cross section for the photon-hadron interaction can be expressed by the product of the parton level cross section and the parton distribution of the hadron,

$$\begin{aligned} \frac{d\sigma(\gamma h \rightarrow VX)}{dtdx_j} &= \left[\frac{81}{16} G(x_j, |t|) + \sum_j (q_j(x_j, |t|) \right. \\ &\left. + \bar{q}_j(x_j, |t|)) \right] \frac{d\sigma}{dt}(\gamma q \rightarrow Vq), \end{aligned} \quad (5)$$

where $G(x_j, |t|)$ and $q_j(x_j, |t|)$ are the gluon and quark distribution functions, respectively. The struck parton initiates a jet and carries a fraction x_j of the longitudinal momentum of the incoming hadron, which is given by $x_j = -t/(-t + M_X^2 - m^2)$, where M_X is the mass of the products of the target dissociation and m is the mass of the target. The minimum value of x_j is calculated considering the experimental cuts on M_X . Following Refs. [28,29] we calculate $d\sigma/dt$ for the process $\gamma h \rightarrow VX$ by integrating Eq. (5) over x_j in the region $0.01 < x_j < 1$. The differential cross section for the $\gamma q \rightarrow J/\Psi q$ process, characterized by the invariant collision energy squared s of the photon-hadron system, is expressed in terms of the amplitude $\mathcal{A}(s, t)$ as follows:

$$\frac{d\sigma}{dt}(\gamma q \rightarrow Vq) = \frac{1}{16\pi} |\mathcal{A}(s, t)|^2. \quad (6)$$

The amplitude is dominated by its imaginary part, which we shall parametrize, as in [28,37], through a dimensionless quantity \mathcal{F}

$$\text{Im} \mathcal{A}(s, t) = \frac{16\pi}{9t^2} \mathcal{F}(z, \tau), \quad (7)$$

where z and τ are defined by

$$z = \frac{3\alpha_s}{2\pi} \ln\left(\frac{s}{\Lambda^2}\right), \quad (8)$$

$$\tau = \frac{|t|}{M_V^2 + Q_\gamma^2}, \quad (9)$$

where M_V is the mass of the vector meson, Q_γ is the photon virtuality, and Λ^2 is a characteristic scale related to M_V^2 and $|t|$. In this paper we only consider $Q_\gamma = 0$. In LLA, Λ is arbitrary (but must depend on the scale in the problem; see discussion below) and α_s is a constant. For completeness, we give the cross section expressed in terms of $\mathcal{F}(z, \tau)$, where the real part of the amplitude is neglected,

$$\frac{d\sigma(\gamma q \rightarrow J/\Psi q)}{dt} = \frac{16\pi}{81t^4} |\mathcal{F}(z, \tau)|^2. \quad (10)$$

This representation is rather convenient for the calculations performed below.

The BFKL amplitude, in the LLA and lowest conformal spin ($n = 0$), is given by [36]

$$\begin{aligned} \mathcal{F}_{\text{BFKL}}(z, \tau) &= \frac{t^2}{(2\pi)^3} \int d\nu \frac{\nu^2}{(\nu^2 + 1/4)^2} e^{\chi(\nu)z} I_\nu^{\gamma J/\Psi}(\mathbf{Q}_\perp) \\ &\times I_\nu^{qq}(\mathbf{Q}_\perp)^*, \end{aligned} \quad (11)$$

where \mathbf{Q}_\perp is the momentum transferred, $t = -Q_\perp^2$ (the subscript denotes two-dimensional transverse vectors), and

$$\chi(\nu) = 4\mathcal{R}e(\psi(1) - \psi(\frac{1}{2} + i\nu)) \quad (12)$$

is proportional to the BFKL kernel eigenvalues [39] with $\psi(x)$ being the digamma function.

The quantities $I_\nu^{\gamma J/\Psi}$ and I_ν^{qq} are given in terms of the impact factors $I_{\gamma J/\Psi}$ and I_{qq} , respectively, and the BFKL eigenfunctions as follows [37]:

$$\begin{aligned} I_\nu^{ab}(\mathbf{Q}_\perp) &= \int \frac{d^2\mathbf{k}_\perp}{(2\pi)^2} I_{ab}(\mathbf{k}_\perp, \mathbf{Q}_\perp) \int d^2\rho_1 d^2\rho_2 \\ &\times \left[\left(\frac{(\rho_1 - \rho_2)^2}{\rho_1^2 \rho_2^2} \right)^{1/2+i\nu} - \left(\frac{1}{\rho_1^2} \right)^{1/2+i\nu} \right. \\ &\left. - \left(\frac{1}{\rho_2^2} \right)^{1/2+i\nu} \right] e^{ik_{1\cdot}\rho_1 + i(\mathbf{Q}_\perp - \mathbf{k}_\perp)\cdot\rho_2}. \end{aligned} \quad (13)$$

In the case of coupling to a colorless state only the first

term in the square bracket remains since $I_{ab}(k_{\perp}, Q_{\perp} = k_{\perp}) = I_{ab}(k_{\perp} = 0, Q_{\perp}) = 0$. The impact factor $I_{\gamma J/\Psi}$ describes, in the high energy limit, the couplings of the external particle pair to the color singlet gluonic ladder. It is obtained in the perturbative QCD framework, and we approximate them by the leading terms in the perturbative expansion [40]:

$$I_{\gamma J/\Psi} = \frac{C\alpha_s}{2} \left(\frac{1}{\bar{q}^2} - \frac{1}{q_{\parallel}^2 + k_{\perp}^2} \right). \quad (14)$$

In this formula, it is assumed the factorization of the scattering process and the meson formation, and the non-relativistic approximation of the meson wave function, is used. In this approximation the quarks of the meson have

collinear four-momenta and $M_{J/\Psi} = 2M_c$, where M_c is the mass of the charm. To leading order accuracy, the constant C can be related to the vector meson leptonic decay width

$$C^2 = \frac{3\Gamma_{ee}^{J/\Psi} M_{J/\Psi}^3}{\alpha_{\text{em}}}. \quad (15)$$

Moreover, we have

$$\bar{q}^2 = q_{\parallel}^2 + Q_{\perp}^2/4, \quad (16)$$

$$q_{\parallel}^2 = (Q_{\gamma}^2 + M_{J/\Psi}^2)/4. \quad (17)$$

Using Eq. (14) into (13), one obtains [37,38]

$$I_{\nu}^{\gamma V_i}(Q_{\perp}) = -C_i \alpha_s \frac{16\pi}{Q_{\perp}^3} \frac{\Gamma(1/2 - i\nu)}{\Gamma(1/2 + i\nu)} \left(\frac{Q_{\perp}^2}{4} \right)^{i\nu} \int_{1/2 - i\nu}^{1/2 + i\nu} \frac{du}{2\pi i} \left(\frac{Q_{\perp}^2}{4M_V^2} \right)^{1/2 + u} \times \frac{\Gamma^2(1/2 + u)\Gamma(1/2 - u/2 - i\nu/2)\Gamma(1/2 - u/2 + i\nu/2)}{\Gamma(1/2 + u/2 - i\nu/2)\Gamma(1/2 + u/2 + i\nu/2)}. \quad (18)$$

The quark impact factor is given by $I_{qq} = \alpha_s$, which implies [38]

$$I_{\nu}^{qq}(Q_{\perp}) = -\frac{4\pi\alpha_s}{Q_{\perp}} \left(\frac{Q_{\perp}^2}{4} \right)^{i\nu} \frac{\Gamma(\frac{1}{2} - i\nu)}{\Gamma(\frac{1}{2} + i\nu)}. \quad (19)$$

The differential cross section can be directly calculated substituting the above expressions in Eq. (11) and evaluating numerically the integrals.

III. RESULTS

Let us start the analysis of our results discussing the diffractive J/Ψ photoproduction in ep collisions at HERA. In particular, it is important to clarify our choice for the parameters α_s and Λ . The strong coupling appears in two pieces of calculations: in the impact factors, coming from their couplings to the two gluons, and in the definition of the variable z [Eq. (8)], being generated by the gluon coupling inside the gluon ladder (for details see Ref [29]). In this paper we will treat these strong couplings as being identical, and we will assume a fixed α_s , which is appropriate to the leading logarithmic accuracy. Furthermore, as the cross section is proportional to α_s^4 , our results are strongly dependent on the choice of α_s . Following Refs. [28,29], we assume $\alpha_s = 0.21$, with this value determined from a fit to the HERA data (for a detailed discussion see Ref. [28]). Similarly, in the LLA, Λ is arbitrary but must depend on the scale in the problem. In our case we have that in general Λ will be a function of M_V and/or t . Following Ref. [28] we assume that Λ can be expressed by $\Lambda^2 = \beta M_V^2 + \gamma|t|$, with β and γ being free parameters to be fitted by data. In Fig. 2(a) we compare our predictions for the differential cross section for J/Ψ pro-

duction with the HERA data [41,42]. The curves were obtained using the CTEQ6L parton distributions [43] and considering distinct values for β and γ . A very good agreement with the data is obtained for $\beta = 1.0$ and $\gamma = 0.25$, which are the values that we will use in what follows. In Fig. 2(b) we compare our predictions for the total cross section, obtained by integrating the differential cross sections over distinct t ranges, with the HERA data. We can observe that the experimental data are quite well described, especially at larger values of the center-of-mass energy. Very recently, the ZEUS Collaboration has reported results [44] for the J/Ψ photoproduction at large t in the kinematical range $30 < W < 160$ GeV and $2 < |t| < 20$ GeV², which is larger than that in previous ZEUS measurements [42]. In Fig. 3 we compare our predictions with these new data. We have that our predictions describe the data at large t and/or large values of energy but underestimate the data at small values of t and W .

Let us now calculate the rapidity distribution and total cross sections for diffractive J/Ψ photoproduction in coherent hadron-hadron collisions. The distribution in rapidity y of the produced final state can be directly computed from Eq. (3), by integrating over the squared transverse momentum and using the corresponding photon spectrum. We consider three different choices for the limits of integration. Basically, we assume the same values used in Ref. [42] by ZEUS Collaboration. This choice is directly associated with the fact that the associated γp data are quite well described by our formalism (see Fig. 2). Moreover, we integrate over x_j in the range $10^{-2} < x_j < 1$, which means that we assume that the upper limit on the mass of the target dissociation products at LHC is similar to that considered at HERA. Our predictions for the rapid-

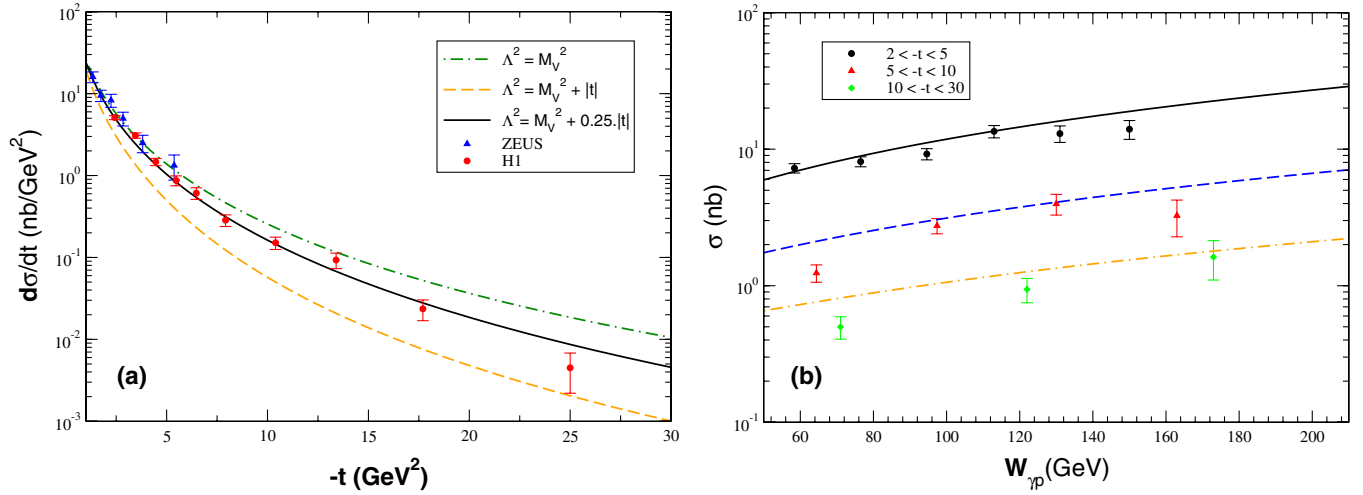


FIG. 2 (color online). (a) Differential cross section for J/Ψ production: theory compared to HERA data ($\langle W \rangle = 100$ GeV). (b) Energy dependence of the total cross section for distinct t ranges. Data are from H1 [41] and ZEUS [42] Collaborations.

ity distribution increase by 20% if the minimum value of x_j is assumed to be 10^{-3} . In Figs. 4(a) and 4(b) we present our results for the rapidity distribution considering pp collisions at $\sqrt{s} = 7.0$ TeV and $\sqrt{s} = 14.0$ TeV, respectively. In this case we consider that the photon spectrum is described by Eq. (2). As expected from Figure 2(a), the rapidity distribution decreases when we select a range with larger values of t . Furthermore, it increases with the energy, which is directly associated with the LL BFKL dynamics that predicts a strong growth with the energy for the cross sections ($\sigma_{\gamma h} \propto W^\lambda$ with $\lambda \approx 1.4$). In Fig. 5 we present our results for $PbPb$ collisions and $\sqrt{s} = 5.5$ TeV. In this case we assume that the photon spectrum is described by Eq. (1) and that the nuclear parton distributions are given by the Eskola, Kolhinen, and Salgado param-

etrization [45]. In comparison to the pp collisions, for heavy ion interactions we predict much larger values for the rapidity distribution with a similar t dependence. Moreover, we predict a plateau in the range $|y| < 2$.

In Table I we present our predictions for the total cross section for some values of center-of-mass energy considering pp and $PbPb$ collisions. The BFKL dynamics implies that the cross sections strongly increase with the energy, resulting in an enhancement by a factor of about 3 when the energy is increased from 7 to 14 TeV. Moreover, since the photon flux is proportional to Z^2 , because the electromagnetic field surrounding the ion is much larger than the proton one due to the coherent action of all protons in the nucleus, the nuclear cross sections are amplified by a factor Z^4 , which implies very large cross sections for the diffractive J/Ψ photoproduction at large- t in $PbPb$ collisions at LHC. Considering the design luminosities at LHC for pp collisions ($\mathcal{L}_{pp} = 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$) and $PbPb$ collisions ($\mathcal{L}_{PbPb} = 4.2 \times 10^{26} \text{ cm}^{-2} \text{ s}^{-1}$), we can calculate the production rates (See Table I). Although the cross section for the diffractive J/Ψ photoproduction at large t in AA collisions is much larger than in pp collisions, the event rates are higher in the pp mode due to its larger luminosity. In particular, we predict approximately 970 events per second in the range $2.0 < |t| < 5.0$ for pp collisions at $\sqrt{s} = 14$ TeV. In contrast, 13 events per second are predicted for $PbPb$ collisions at $\sqrt{s} = 5.5$ TeV in the same t range. However, for a luminosity above $\mathcal{L} \geq 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$, multiple hadron-hadron collisions per bunch crossing are very likely, which leads to a relatively large occupancy of the detector channels even at low luminosities. This drastically reduces the possibility of measurement of coherent processes at these luminosities. In contrast, at lower luminosities the event pileup is negligible. Consequently, an estimate considering $\mathcal{L}_{pp} = 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$ should be more realistic. It reduces our

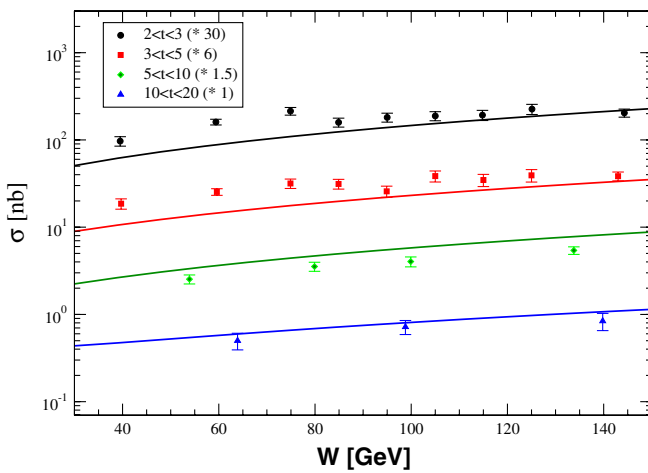


FIG. 3 (color online). Energy dependence of the total cross section for distinct t ranges. Data are from ZEUS Collaboration [44].

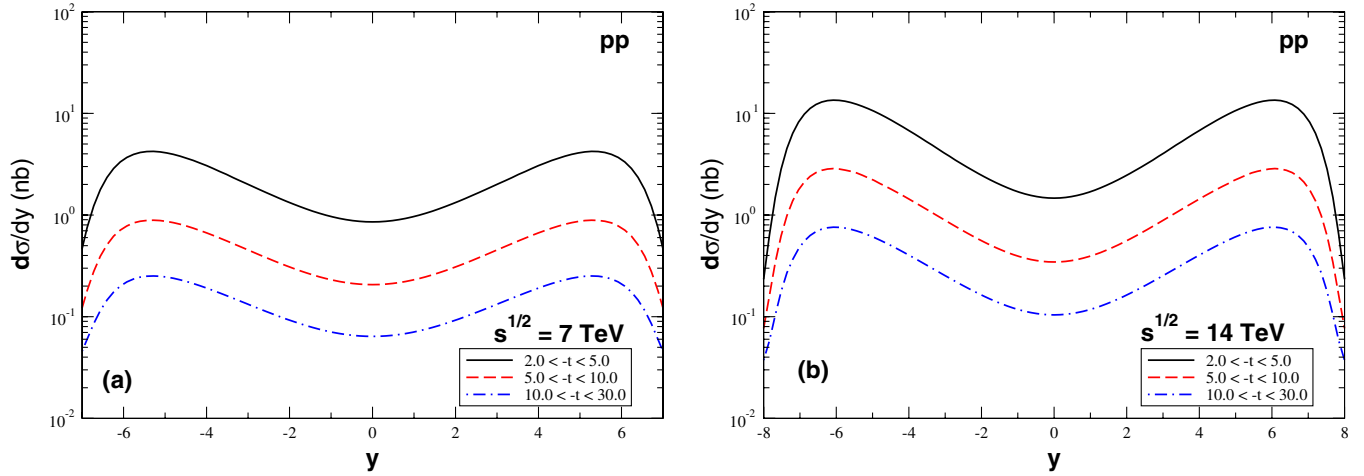


FIG. 4 (color online). Rapidity distribution for the diffractive J/Ψ photoproduction in pp collisions at LHC for distinct t ranges and different values of the center-of-mass energy: (a) $\sqrt{s} = 7.0$ TeV, and (b) $\sqrt{s} = 14.0$ TeV.

predictions for the event rates in pp collisions by a factor of 10^2 .

We predict very large cross sections, which implies that it would be possible to collect an impressive statistics provided one can devise an effective trigger for the two low transverse momentum leptons not accompanied by hadron production. This is a current experimental challenge. Simulations indicate that these events can be identified with good signal to background ratios when the entire event is reconstructed and a cut is applied on the summed transverse momentum of the event [46]. Another important aspect that restricts the experimental separation of coherent processes are the basic features of the LHC detectors [47–50]. The coherent condition leads to the result that the final state has a very low transverse momentum. Consequently, the decay electrons or muons from J/Ψ are produced basically at rest and have energies of the order of $m_{J/\Psi}/2$. Such energies are in a range close to the lower

limits of detector acceptance and trigger selection thresholds. In particular, the energy of the decay products of J/Ψ is lower than those needed to reach the electromagnetic calorimeter or muon chambers at Compact Muon Solenoid (CMS) and ATLAS without significant energy losses in the intermediate material. Probably, the detection of the J/Ψ produced in coherent processes will be not possible in the CMS and ATLAS detectors, and only the Υ states could be observed [47]. In Ref. [23] the authors have estimated the effect of detector acceptances and the impact of measuring one of the protons in the diffractive Υ photoproduction in pp collisions. In particular, they have estimated the effect of the inclusion of a cut in the angle of emission and in the transverse momentum of the decay dileptons. Moreover, the possibility to detect one of the protons in region 420 m from the interaction point was analyzed. This study concludes that these cuts diminish the cross section for Υ production. However, it is still feasible to constrain the QCD dynamics using this process. The implication of these cuts for J/Ψ production, taking into account the characteristics of the CMS and ATLAS detectors, is a subject that deserves a more detailed study. We postpone this analysis for a future publication. However, it is important to emphasize that in ALICE, which is designed to handle multiplicities of several thousand particles in a single event, the reconstruction of the low multiplicity events associated with coherent processes should not be a problem [49]. In particular, the muon arm, which covers the pseudorapidity range $-2.5 > \eta > -4.0$, should be capable of reconstructing J/Ψ and Υ vector mesons through their dilepton decay channel.

Let us compare our results with those presented in Ref. [15] where the diffractive J/Ψ photoproduction at $t = 0$ in coherent interactions was calculated considering the color glass condensate formalism [1]. Both processes predict the presence of two rapidity gaps. Our predictions are smaller than those shown in [15] at least by a factor of 1.5.

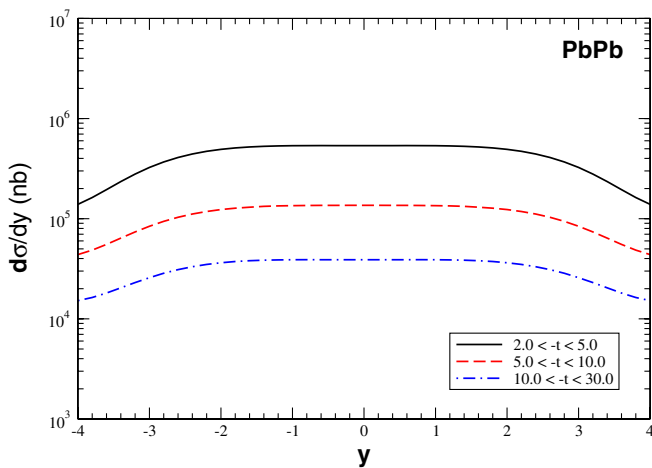


FIG. 5 (color online). Rapidity distribution for the diffractive J/Ψ photoproduction in $PbPb$ collisions at LHC for distinct t ranges and $\sqrt{s} = 5.5$ TeV.

TABLE I. The integrated cross section (event rates/second) for the diffractive J/Ψ photoproduction at large momentum transfer in pp and AA collisions at LHC.

	pp ($\sqrt{s} = 7$ TeV)	pp ($\sqrt{s} = 14$ TeV)	$PbPb$ ($\sqrt{s} = 5.5$ TeV)
$2.0 < t < 5.0$	320 nb (320.0)	970 nb (970.0)	30 mb (13.0)
$5.0 < t < 10.0$	70 nb (70.0)	210 nb (210.0)	09 mb (0.38)
$10.0 < t < 30.0$	20 nb (20.0)	60 nb (60.0)	03 mb (0.12)

Another background that is characterized by two rapidity gaps in the final state are diffractive hadron-hadron interactions: $h_1 + h_2 \rightarrow h_1 \otimes V \otimes h_2$. Recently, the exclusive J/Ψ and Y hadroproduction in $pp/p\bar{p}$ collisions was estimated in Ref. [51] considering the pomeron-odderon fusion (see also [52]). Although there is a large uncertainty in the predictions for pomeron-odderon fusion, it can be of the order of our predictions for the photoproduction of vector mesons. As pointed out in Ref. [51], the separation of odderon and photon contributions should be feasible by the analysis of the outgoing momenta distribution. Furthermore, it is important to emphasize that the experimental separation from the process studied in this paper should be possible, since different from the processes discussed above, at large momentum transfer one of the projectiles dissociates. Therefore, this process could be separated using the forward detectors proposed to be installed at LHC [53].

Finally, we would like to emphasize that several points in the present calculation deserve more detailed studies: the contribution of all conformal spins [29,38,54], the helicity flip of quarks [29], the next-to-leading order (NLO) corrections to the BFKL dynamics [55] and the corrections associated with the saturation effects [1,3]. From previous studies [29], one expects the contribution of higher conformal spins to be small. However, the NLO corrections should modify the energy dependence of the γh cross section and consequently our predictions for the rapidity distributions and total cross sections. In order to

estimate these modifications, it is necessary to include the corrections to the BFKL pomeron, as it was done e.g. in [56], and for the $\gamma \rightarrow V$ impact transition factor [57]. We intend to take into account these contributions in future publications.

IV. SUMMARY

The LHC offers a unique possibility to probe QCD in a new and hitherto unexplored regime. In particular, it will allow the study of coherent processes that are characterized by photon-hadron and photon-photon interactions. In this paper we have restricted our study to γh interactions and extended previous analysis to the diffractive J/Ψ photoproduction together with hadron dissociation with large momentum transfer. The rapidity distribution and total cross sections were estimated considering distinct center-of-mass energies and projectiles using the nonforward solution of the BFKL equation at high energy and large momentum transfer. Our main conclusion is that the LHC can experimentally check our predictions. Besides, we believe that this process can be used to constrain the QCD dynamics at high energies.

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