

Diffractive photoproduction of J/ψ at LHC energies

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Abstract. In this work we calculate the rapidity distribution and the total cross section for the diffractive photoproduction of J/ψ in $PbPb$ collisions in LHC energies. We use the color dipole formalism and different models for the forward dipole-proton scattering amplitude (\mathcal{N}) which take into account nonlinear effects. Using always the same model for the wave function of the vector meson, we estimate the theoretical uncertainty related to the choice of the model for \mathcal{N} . We compare our results with available data from ALICE [1, 2] and present our prediction for higher energies.

1. Introduction

With the advent of modern colliders like RHIC and specially LHC, a deeper study of high energy physics became possible. One of the most interesting topics of high energy hadron physics is the study of QCD in the low x regime. Our knowledge of the parton distributions inside the hadrons is still far from complete. In lepton-hadron and hadron-hadron collisions with fixed virtualities and low x , we expect a fast growth of gluon distributions inside the hadron, as described by the BFKL equation, making it a dense system. However an indefinite growth of gluons inside the hadron would violate the unitarity bound in a given hadronic process. In order to avoid this violation, there is a mechanism to tame the growth of the gluon distribution. This mechanism is called gluon saturation and is associated to effects of gluon recombination. The investigation of saturation effects can be best made through the study of photon-hadron collisions in the color dipole picture. In this formalism, one photon produces a $q\bar{q}$ pair (a color dipole) which scatters off the hadron, producing a given final state. The cross section of dipole-hadron interaction is obtained from the forward scattering amplitude for which there are some models that take into account saturation effects. A way to study photon-hadron collisions is through the diffractive production of vector mesons in ultraperipheral collisions, where one of the hadrons acts as a photon source that interacts with the other hadron.

Here we present our results for the diffractive photoproduction of J/ψ in $PbPb$ collisions for three different saturation models. This work is organized in the following way: in the next section we present the basic formulae of the equivalent photon approximation, the dipole formalism applied to dipole-nucleus interaction is presented in section 3, our results are showed in section 4 and, finally, we present our conclusions.



2. Equivalent photon approximation

Let us consider an ultraperipheral collision between two fast nuclei. In an ultraperipheral collision we must take $b > R_{h_1} + R_{h_2}$, where b is the impact parameter of the collision and R_{h_i} is the radius of the nucleus i . In this regime we can factorize the J/ψ production in nucleus-nucleus collisions in terms of the equivalent flux of photons of the projectile and the photon-nucleus cross section [3, 4]. This method is called equivalent photon approximation. The cross section for diffractive J/ψ photoproduction in a nucleus-nucleus collision is given by

$$\begin{aligned} \sigma(h_1 h_2 \rightarrow h_1 \otimes J/\psi \otimes h_2) &= \int_{\omega_{min}}^{\infty} d\omega \frac{dN_{\gamma/h_1}}{d\omega}(\omega) \sigma_{\gamma h_2 \rightarrow J/\psi h_2}(\omega) \\ &+ \int_{\omega_{min}}^{\infty} d\omega \frac{dN_{\gamma/h_2}}{d\omega}(\omega) \sigma_{\gamma h_1 \rightarrow J/\psi h_1}(\omega) , \end{aligned} \quad (1)$$

where $dN/d\omega$ is the photon spectrum associated to the nucleus, given by

$$\frac{dN_{\gamma/A}(\omega)}{d\omega} = \frac{2Z^2\alpha_{em}}{\pi\omega} \left[\bar{\eta} K_0(\bar{\eta}) K_1(\bar{\eta}) + \frac{\bar{\eta}^2}{2} (K_1^2(\bar{\eta}) - K_0^2(\bar{\eta})) \right] . \quad (2)$$

Here, $\bar{\eta} = \omega(R_{h_1} + R_{h_2})/\gamma_L$, ω is the photon energy in the center-of-mass frame (c.m.s), $\omega_{min} = M_{J/\psi}^2/(4\gamma_L m_p)$, and γ_L is the Lorentz factor. Equation (1) allows us to study the photon-nucleus scattering, which will be addressed below.

3. Diffractive J/ψ photoproduction at high energies

To compute the cross section $\sigma(h_1 h_2 \rightarrow h_1 \otimes J/\psi \otimes h_2)$ from Eq.(1), we need to know the photon-nucleus cross section. In high energy collisions we can do this in the dipole picture, where a virtual photon fluctuates into a quark pair (a color dipole) which scatters off the nucleus (Fig.1). For high energy photon-nucleus coherent scattering we have [4] :

$$\sigma_{\gamma A \rightarrow J/\psi A}^{coh} = \int d^2\mathbf{b} \left[\int d^2\mathbf{r} \int dz \left(\psi_{J/\psi}^* \psi \right) \mathcal{N}_A(x, \mathbf{r}, \mathbf{b}) \right]^2 , \quad (3)$$

where $(\psi_{J/\psi}^* \psi)$ describe the overlap between the J/ψ wave function and the virtual photon wave function. For the meson wave function, we have used the Gaus-LC model [5]. The $\mathcal{N}_A(x, \mathbf{r}, \mathbf{b})$ is the forward dipole-nucleus scattering amplitude, which contains all information about the target and the strong interaction physics.

In our calculations, we use for $\mathcal{N}_A(x, \mathbf{r}, \mathbf{b})$ [6]

$$\mathcal{N}_A(x, \mathbf{r}, \mathbf{b}) = 1 - \exp \left[-\frac{1}{2} \sigma_{dip}(x, r^2) T_A(\mathbf{b}) \right] , \quad (4)$$

where $T_A(\mathbf{b})$ is the nuclear profile function, which is obtained from a three-parameter Fermi distribution for the nuclear density normalized to A , and σ_{dip} is the dipole-proton cross section given by

$$\sigma_{dip}(x, r^2) = 2 \int d^2\mathbf{b} \mathcal{N}_p(x, \mathbf{r}, \mathbf{b}) . \quad (5)$$

Here, \mathcal{N}_p is the forward dipole-proton scattering amplitude.

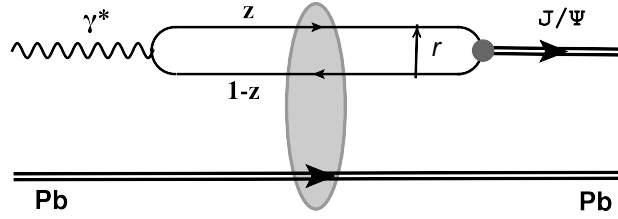


Figure 1. Production of J/ψ in the scattering γ^*Pb in the color dipole picture.

We use three different models for \mathcal{N}_p , which include saturation effects. They are **rcBK** [7], which is based on the solution of the Balitsky-Kovchegov equation, and the phenomenological models **GBW** [8] and **bCGC** [5]. In the bCGC model we present a comparison between the older version and the updated version [9], in which the recently released high precision combined HERA data were included in the analysis. This last model is called **bCGC NEW**.

In the next section, we present our results for the diffractive photoproduction of J/ψ in ultraperipheral ($PbPb$) collisions. For this, we use the different models for \mathcal{N}_p mentioned above.

4. Results

In this section, we present our results for the rapidity distribution and total cross section for the J/ψ production. The distribution on rapidity Y of the produced final state can be directly computed from Eq.(1), by using its relation with the photon energy ω , i.e. $Y \propto \ln(2\omega/m_p)$. Explicitly, the rapidity distribution is given by:

$$\frac{d\sigma(h_1 + h_2 \rightarrow h_1 \otimes J/\psi \otimes h_2)}{dY} = \left[\omega \frac{dN}{d\omega} \Big|_{h_1} \sigma_{\gamma h_2 \rightarrow J/\psi \otimes h_2}(\omega) \right]_{\omega_L} + \left[\omega \frac{dN}{d\omega} \Big|_{h_2} \sigma_{\gamma h_1 \rightarrow J/\psi \otimes h_1}(\omega) \right]_{\omega_R}, \quad (6)$$

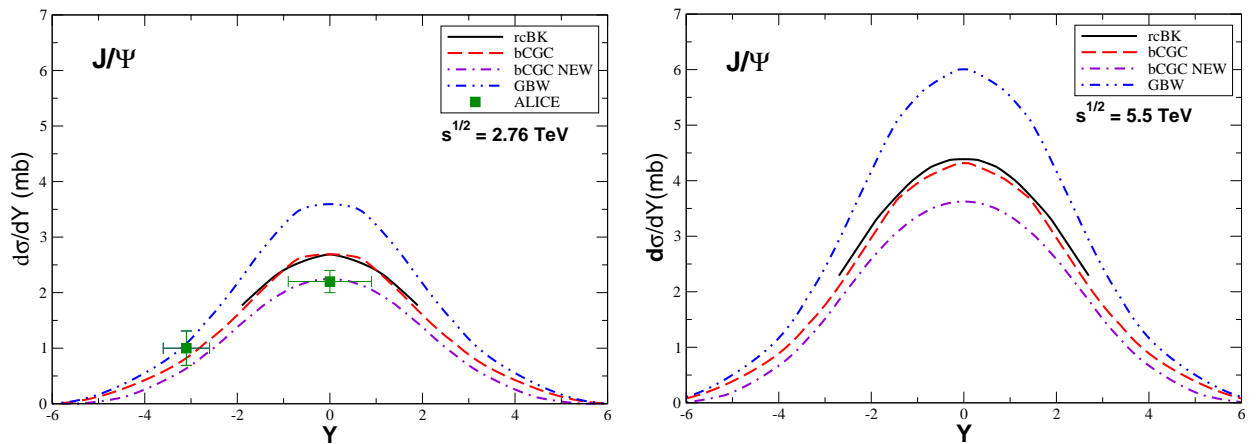


Figure 2. Rapidity distribution for the diffractive photoproduction of J/ψ in $PbPb$ collisions at $\sqrt{s} = 2.76$ TeV (left panel) and $\sqrt{s} = 5.5$ TeV (right panel). Data from ALICE Collaboration [1, 2].

where $\omega_L \propto e^{-Y}$ and $\omega_R \propto e^Y$ denote photons from h_1 and h_2 , respectively. Consequently, given the photon flux, the rapidity distribution is thus a direct measure of the photoproduction cross section for a given energy.

In Fig.2 we present our predictions for the rapidity distribution for the diffractive photoproduction of J/ψ in $PbPb$ collisions. For $\sqrt{s} = 2.76$ TeV (left panel of Fig.2), we compare our results with the ALICE data [1, 2]. For forward rapidity, all the models agree among themselves, and they are in a good agreement with the experimental data. On the other hand, in the central rapidity region, the models are quite different and only the bCGC NEW model is able to describe the data. In the right panel of Fig.2, we present our predictions for the rapidity distribution of J/ψ in $PbPb$ collisions at $\sqrt{s} = 5.5$ TeV. We can see that all the models still have similar predictions at forward rapidities, but with the growth of the energy, the difference between the models increases in the central rapidity region. In these two plots, we can observe that the rcBK model is limited because of its range of validity ($x < 0.01$).

In Table 1 we present our predictions for the total cross sections for the diffractive photoproduction of J/ψ in $PbPb$ collisions at $\sqrt{s} = 2.76$ and 5.5 TeV. Due to the discrepancies in the central rapidity region observed in Fig.2, there are large differences in the value of the total cross sections.

	GBW	bCGC	bCGC NEW
$PbPb$ ($\sqrt{s} = 2.76$ TeV)	18.2 mb	13.6 mb	11.0 mb
$PbPb$ ($\sqrt{s} = 5.5$ TeV)	33.8 mb	24.4 mb	20.3 mb

Table 1. The total cross section for diffractive photoproduction of J/Ψ in pp , pPb and $PbPb$ collisions at LHC energies.

5. Conclusions

In this work, we have calculated the rapidity distribution and total cross section of diffractive photoproduction of J/ψ in ultraperipheral $PbPb$ collisions at LHC energies. With the purpose of studying the theoretical uncertainty in the choice of models of the forward dipole-proton scattering amplitude, we have used only one model for the vector meson wave function and we have used three different models for \mathcal{N}_p . Among the considered models, we have found that the GBW model can be taken as a upper limit while the bCGC NEW can be taken as a lower limit. Moreover, the bCGC NEW model is able to describe the available ALICE data. Our final conclusion, is that the ultraperipheral collisions can be used to constrain the QCD dynamics at high energies.

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