

# Nuclear suppression in diffractive vector meson production within the color glass condensate framework

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**Abstract.** We perform a global Bayesian analysis of diffractive  $J/\psi$  production in  $\gamma + p$  and  $\gamma + \text{Pb}$  collisions within a Color Glass Condensate based framework. Using data from HERA and the LHC, we find that a simultaneous description of  $\gamma + p$  and  $\gamma + \text{Pb}$  observables is challenging. Introducing a global  $K$ -factor to account for theoretical uncertainties improves the agreement with data and enhances the framework's predictive power. We present predictions for integrated  $J/\psi$  cross sections at different photon–nucleus energies and study their  $A$ -dependence relative to a no-saturation baseline, quantifying nuclear suppression and providing insights into the onset of saturation effects.

## 1 Introduction

At small parton momentum fractions  $x$ , gluon densities predicted by linear QCD evolution grow rapidly until non-linear recombination effects set in [1], leading to the high-occupancy Color Glass Condensate (CGC) regime [2, 3]. Diffractive vector meson production is a clean probe of small- $x$  gluons: its cross section scales (at leading order) with the square of the gluon density [4] and is sensitive to the target's spatial structure [5]. Comparing proton and nuclear targets reveals nuclear shadowing [6] or gluon saturation [7, 8].

CGC-based calculations constrained by  $\gamma + p$  data describe both coherent and incoherent diffractive  $J/\psi$  production at HERA [9], where the incoherent channel revealed the importance of a fluctuating proton substructure [10]. Extending the same framework to nuclei in ultraperipheral heavy-ion collisions, experiments have measured  $W$ -dependent coherent  $J/\psi$  cross sections for  $\gamma + \text{Pb}$  [11, 12]. These data show stronger nuclear suppression than expected, as CGC predictions constrained by HERA data typically rise more rapidly with  $W$ .

Here, we analyze the  $A$ -dependence of coherent  $J/\psi$  production with a Bayesian framework that confronts both  $\gamma + p$  and  $\gamma + \text{Pb}$  data. To absorb model uncertainties — such as

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those from the vector meson wave function or higher-order effects — we introduce an overall  $K$ -factor, determined alongside the other parameters. Comparing to the no-saturation limit, we quantify the nuclear suppression and assess its connection to saturation dynamics.

## 2 Model

To compute the diffractive  $J/\psi$  production cross section, we employ the CGC framework including the JIMWLK energy evolution used in Ref. [13]. In this work, we focus on coherent cross-section which, as a function of Mandelstam  $t$ , reads

$$\frac{d\sigma^{\gamma+A \rightarrow J/\psi+A}}{dt} = \frac{K}{16\pi} \left| \langle \mathcal{A}^{\gamma+p \rightarrow V+p} \rangle_{\Omega} \right|^2. \quad (1)$$

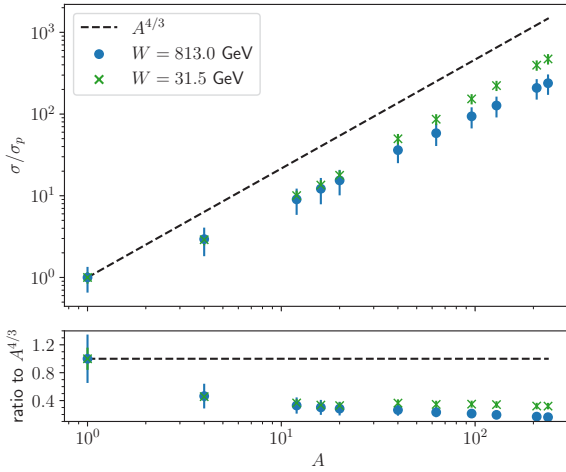
Here  $\langle \mathcal{O} \rangle_{\Omega}$  refers to an average over target configurations  $\Omega$ , and  $\mathcal{A}$  is the amplitude computed from the wave function overlap of the photon and the vector meson, together with the dipole-target amplitude obtained from the Wilson lines in the McLerran-Venugopalan model. The energy evolution of the Wilson lines going into this expression is computed using the JIMWLK evolution on an event-by-event basis [14]. In Ref. [13], it was explored whether additional parameters, such as an additional proton shape parameter or an additional high-frequency regulator for the Wilson lines, should extend the model. It turns out that the combined data from a Bayesian fit to the  $\gamma + p$  and  $\gamma + \text{Pb}$  data disfavors most extensions of the model with additional parameters, but we find that the addition of a  $K$ -factor – scaling all cross sections by a constant – is favored. We make use of this minimally extended model and the generated posterior distribution from Ref. [13] to make predictions using 25 parameter samples from the posterior distribution, allowing us to propagate the variation of the parameters in the posterior distribution to the final predictions. In Ref. [13], the preferred value of the overall  $K$ -factor was found to be  $\sim 0.33$ , implying a strong rescaling of the cross-section normalization. A value  $K < 1$  is compensated in the fits by a larger color charge density, which corresponds to denser nucleons and, in turn, stronger nuclear suppression.

## 3 Results

We make predictions using the same computational setup as in Ref. [13] for nuclei ranging from the proton up to Uranium at two center-of-mass energies,  $W = 31.5$  and  $813$  GeV, corresponding to momentum fractions  $x = 0.01$  and  $1.5 \times 10^{-5}$  respectively. This allows us to study how the nuclear suppression of the coherent cross section develops relative to the  $\gamma + p$  case. Figure 1 shows the ratio of the integrated cross section to that for  $\gamma + p$  as a function of  $A$ . The results deviate significantly from the  $A^{4/3}$  scaling expected without saturation [15], with the suppression increasing monotonically with  $A$ . For the heaviest nuclei, the ratio is reduced to  $\sim 0.3$  at  $W = 31.5$  GeV and to  $\sim 0.15$  at  $W = 813$  GeV. The comparison highlights the stronger suppression at higher energies (smaller  $x$ ), leading to about a factor of two difference between the two  $W$  values for large  $A$ , while the two curves approach each other at small  $A$ .

## 4 Conclusion

We have performed a Bayesian analysis of diffractive  $J/\psi$  production in  $\gamma + p$  and  $\gamma + \text{Pb}$  collisions within the CGC framework. While the approach provides a successful description of HERA data, a simultaneous description of proton and nuclear data remains challenging. Introducing an overall  $K$ -factor significantly improves the agreement with experiment by absorbing uncertainties related to the vector meson wave function and higher-order corrections.



**Figure 1.** Ratio of the integrated coherent  $J/\Psi$  cross section to the  $\gamma + p$  case as a function of the nuclear mass number  $A$  for  $W = 31.5$  and  $813$  GeV. The dashed line shows the expected  $A^{4/3}$  scaling in the absence of saturation effects. Error bars indicate the  $2\sigma$  interval from 25 posterior samples.

Using this framework, we presented predictions for the  $A$ -dependence of the coherent  $J/\psi$  cross section at two photon-nucleus center-of-mass energies. The results show a clear departure from the  $A^{4/3}$  scaling expected without saturation, with nuclear suppression increasing both with  $A$  and with energy. For heavy nuclei, the cross section is suppressed by factors of  $\sim 0.3$  ( $W = 31.5$  GeV) and  $\sim 0.15$  ( $W = 813$  GeV) relative to the no-saturation limit. In the future, a more quantitative assessment of the actual saturation effect will require taking into account the nuclear form factors. Measuring this  $A$  dependence of exclusive vector meson production at the future electron-ion collider (EIC) provides a clean opportunity to investigate the onset of gluon saturation. While the energy coverage is modest at the EIC, one can on the other hand explore the dependence of this observable on the photon virtuality  $Q^2$ .

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