DIFFRACTIVE HEAVY VECTOR MESON PLUS ASSOCIATED JET PRODUCTION IN Pbp COLLISIONS USING THE NLO-BFKL APPROACH

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1. INTRODUCTION

The diffractive photoproduction of vector mesons with large momentum transfer squared t at the proton vertex is a powerful method for studying parton dynamics in the high-energy limit (SCHOEFFEL, 2010). In general, diffractive processes involve the exchange of a color-singlet system between the scattered quarks and gluons. Such processes provide a very clean experimental signature, characterized by the presence of a large rapidity gap between the particles produced in the final state, as illustrated in Fig. 1.

The variable t provides the hard scale needed to apply perturbative Quantum Chromodynamics (pQCD) calculations to describe hard color-singlet exchanges at high-energy limits by means of the Balitsky-Fadin-Kuraev-Lipatov (BFKL) equation (KURAEV, 1976; BALITSKY, 1978). Since energy and rapidity are directly correlated, the evolution of the BFKL equation with energy allows for the study of how the rapidity distribution of the scattering amplitude depends on energy.

Thus, the main goal of this work is to apply the BFKL approach to study the diffractive heavy meson production in semi-exclusive processes induced by photons in Pbp collisions (GONCALVES; SAUTER, 2011), utilizing the enhanced availability of the equivalent photon spectrum from lead. The rapidity distribution of the vector meson cross-section will be evaluated, considering the interval to be covered by FoCal in the ALICE experiment of $3.4 < y < 5.8$ for data-taking from 2027 to 2029 at the LHC (KHATUN, 2024).

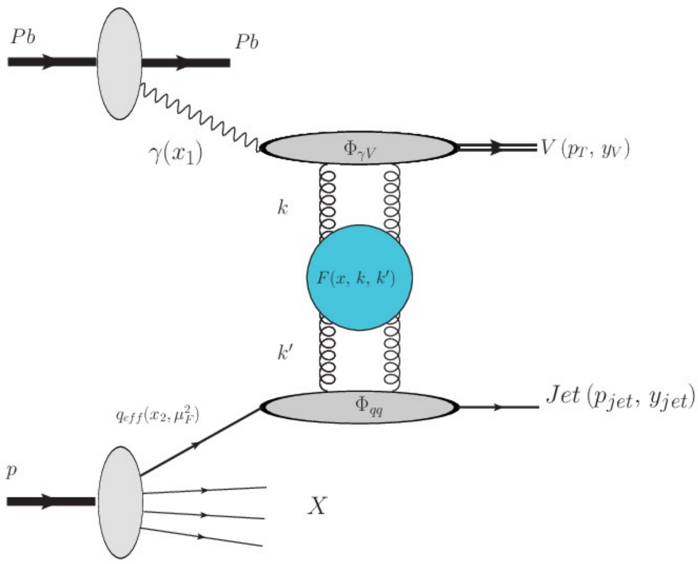

Figure 1: Diffractive Production of Heavy Vector Meson With Large-t Exchange.

2. DIFFRACTIVE MESON PRODUCTION CROSS-SECTION

The cross-section for the photoproduction of vector mesons at large momentum transfer (t) has been studied at HERA (CHEKANOV, 2002) over the last few decades. The J/ψ production process is one of the signals that can be observed in diffractive reactions, where the final state exhibits a large transverse momentum, and a rapidity gap is present between the vector meson and the jet. The differential cross-section for the production process in Pbp collisions, for observables similar to those measured at HERA, can be described as:

$$\frac{d\sigma_{Pbp\to Pb\otimes J/\psi\otimes jet+X}}{dy_{J/\psi}\,dy_{jet}\,dp_t^2}=x_1\,\gamma(x_1)\,x_2 q_{eff}(x_2,\mu_F^2)\frac{d\sigma_{\gamma p\to J/\psi\otimes jet+X}}{dt} \qquad (1)$$

where $\mu_F^2=m_{J/\psi}^2+t$ is the scale resolution, $q_{eff}(x_1,\mu_F^2)$ is the quark and gluons distribution function, $\gamma(x_2)$ represents the equivalent photon flux of the lead and the fractions of the longitudinal momentum are written as:

$$x_1=\sqrt{m_{J/\psi}^2+p_t^2}/\sqrt{s}\,(e^{y_{J/\psi}}+e^{y_{jet}}),x_2=\sqrt{m_{J/\psi}^2+p_t^2}/\sqrt{s}\,(e^{-y_{J/\psi}}+e^{-y_{jet}}). \qquad (2)$$

The pomeron couples predominantly to individual partons in the proton. As a consequence, the cross-section for the photon-proton interaction can be expressed by the product of the parton level cross-section and the Parton Function Distribution (PDF) of the proton,

$$\frac{d\sigma_{\gamma p\to J/\psi\otimes jet+X}}{dt}=\int dx_j\left[\frac{81}{16}G(x_j,|t|)+\sum_i\left(q(x_j,|t|)+\overline{q}_i(x_j,|t|)\right)\right]\frac{d\sigma_{\gamma q\to J/\psi\otimes q}}{dt}, \qquad (3)$$

where the parton level cross-section for the process $\gamma q\to J/\psi\otimes q$, expressed in terms of the BFKL amplitude as follows:

$$\frac{d\sigma_{\gamma q\to J/\psi\otimes q}}{dt}=\frac{16\pi}{81t^4}|\mathscr{F}(z,\tau)|^2, \qquad (4)$$

with

$$\mathscr{F}(z,\tau)=\frac{t^2}{(2\pi)^2}\int d\nu\frac{\nu^2}{(\nu^2+1/4)^2}e^{\omega(\nu)z}I_\nu^{\gamma J/\psi}(Q_\perp)I_\nu^{qq}(Q_\perp), \qquad (5)$$

where $\omega(\nu)=\overline{\alpha}_s\chi^{LO}(\nu)=4\Re(\psi(1)-\psi(1/2+i\nu))$ is the eigenvalue of the next-to-leading order (LO) BFKL kernel, $Q_\perp^2=-t$ is the momentum transfer squared and $\psi(x)$ being is the digamma function. After several efforts, the next-to-leading order (NLO) corrections for the BFKL kernel were resolved (CIAFALONI, 1998). Additionally, issues related to the choice of energy scale, which result in ambiguities in the values of observables, and the application of renormalization schemes (BRODSKY, 1999) were considered. Straightforwardly, these corrections give rise to the NLO-BFKL eigenvalue:

$$\omega_{BLM}^{MOM}(\nu)=\chi^{LO}(\gamma)\frac{\alpha_{MOM}(\hat{Q}^2)N_c}{\pi}\left[1+\hat{r}(\nu)\frac{\alpha_{MOM}(\hat{Q}^2)}{\pi}\right]. \qquad (6)$$

3. RESULTS

As shown in Fig. 2, we calculate $d\sigma/dt$ for the process $\gamma p\to J/\psi\otimes jet+X$ by integrating the Eq. (3) over x_j in the region $0.01<x_j<1$, using MSTW2008LO parametrization for the parton function distributions (PDF). Through this we are able to compare the theoretical approach with the experimental data for J/ψ production for collisions at HERA.

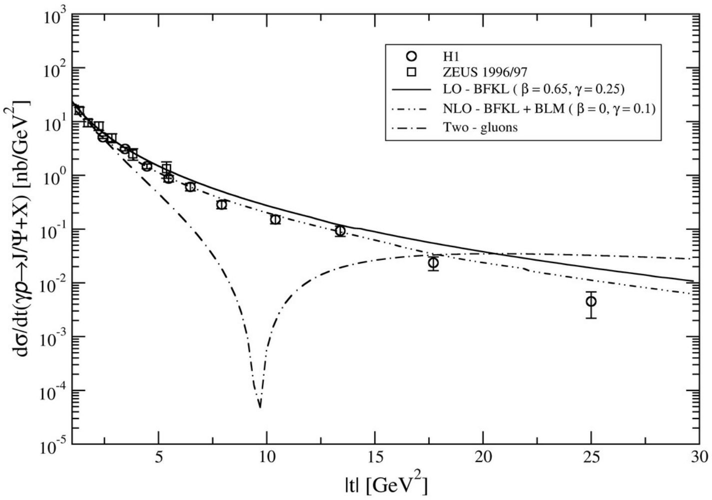

Figure 2: Differential Cross-Section for Diffractive J/ψ Production at Large Momentum Transfer, Considering Different Approaches for the Scattering Amplitude.

According to Eq. (1), we were able to calculate the predictions for the rapidity distributions for the diffractive J/ψ production, in Pbp collisions with center-of-mass (CM) energy of $\sqrt{s}=8.16$ TeV, as presented in Fig. 3.

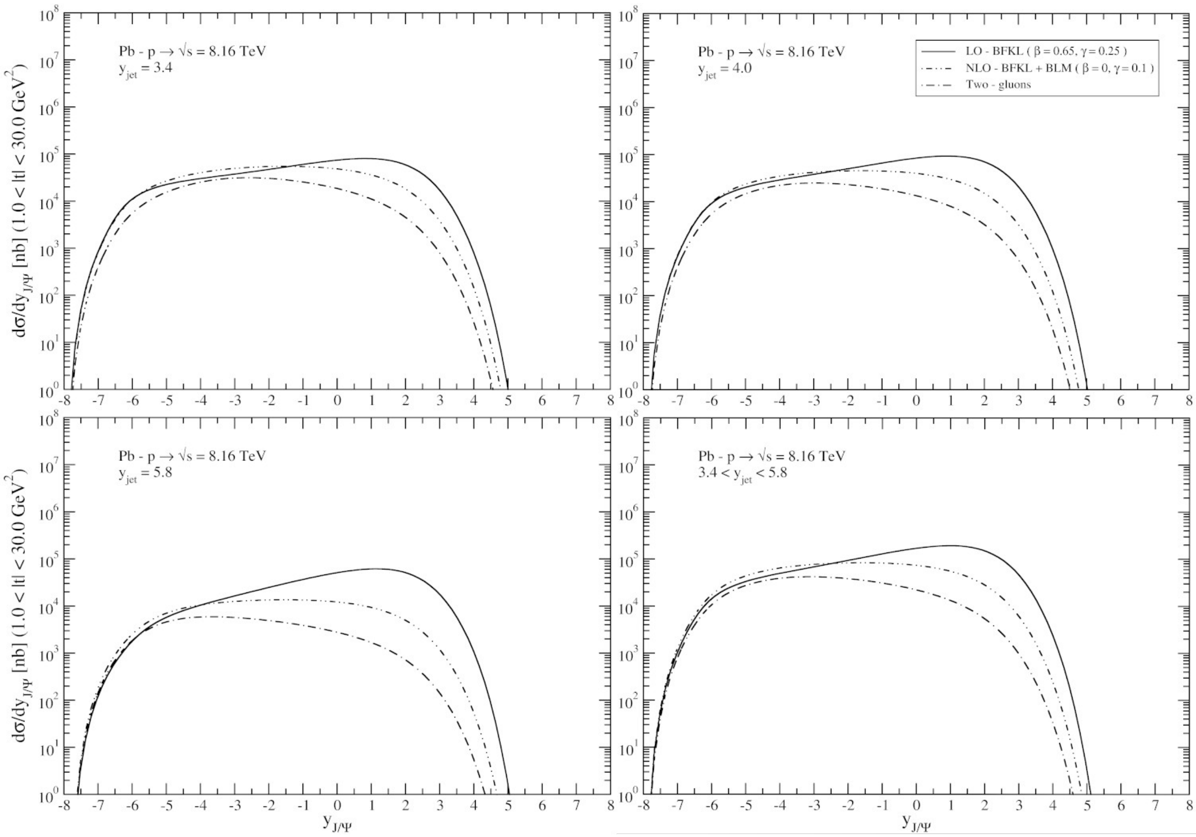

Figure 3: Rapidity Distribution for the Differential Cross-Section in Diffractive J/ψ Plus Jet Production in Pbp Collisions at the LHC.

The jet rapidity value was fixed at different points in order to estimate the rapidity distribution for J/ψ. Moreover, the jet rapidity distributions were integrated over the entire interval to be covered by FoCal. Our analysis shows that the cross-section value for J/ψ vector meson plus associated jet production is sufficient to expect the detection of an experimental signal for this state at ALICE.

As observed, next-to-leading order (NLO) BFKL corrections results in a slower energy dependence of the differential cross-sections production at the LHC. Within HERA kinematical range, both leading-order (LO) and NLO approaches produce similar cross-sections. However, as the energy increases—especially in the regime of large momentum transfer—the predictions start to differ. This makes the NLO-BFKL more suitable for process at higher energies, such as those encountered at the LHC.

4. CONCLUSION

In this study, we explored the potential to investigate BFKL dynamics through the photoproduction of J/ψ vector mesons at large- t in Pbp collisions at the LHC. The focus on Pbp collisions is due to the dominance of γp interactions of photons coming from the lead. As a consequence, the analysis of the rapidity distribution gives direct access to the energy dependence of the γp cross-section. We predict significant differential cross-sections and an enhancement in rapidity distributions due to BFKL evolution, particularly within the kinematic range to be accessible by ALICE Collaboration. Our findings suggest that future experimental analysis at the LHC is feasible and could help constrain aspects of QCD dynamics at high energies.

5. REFERENCES

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