

Exclusive photoproduction of J/Ψ and Ψ' mesons in proton-proton collisions

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Abstract. We present results based on our new paper [1]. The amplitude for the $\gamma p \rightarrow Vp$ reaction is calculated in a pQCD k_t -factorization approach. The corresponding total cross section for different unintegrated gluon distributions is calculated and compared with new HERA data for photon-proton collisions. We also compare the total cross section for $\gamma p \rightarrow Vp$ reaction with recent data extracted by the LHCb collaboration. The amplitude for $\gamma p \rightarrow Vp$ is used to predict cross section for exclusive photoproduction of J/ψ and ψ' mesons in proton-proton collisions. Both Dirac and Pauli electromagnetic form factors are included in the calculation and results are compared with results when only Dirac form factor is included. The effect of Pauli form factor is quantified. Absorption effects are included and their uncertainties are discussed. Different differential distributions e.g. in $J/\psi(\psi')$ rapidity and transverse momentum are presented and compared with existing experimental data for the Tevatron and LHC energy.

1 Introduction

Several years ago in Ref.[2] the exclusive production of J/ψ meson in pp and $p\bar{p}$ collisions was discussed including absorptive corrections and using a $\gamma p \rightarrow J/\psi p$ amplitude extracted from HERA data. Later, in [3] we discussed the exclusive production of Υ mesons, where now a microscopic calculation of the $\gamma p \rightarrow \Upsilon p$ amplitude was performed within a k_t -factorization approach. In the microscopic picture the t -channel exchange in the $\gamma p \rightarrow Vp$ amplitude is modelled by an exchange of two interacting gluons, and k_t -factorization amounts to taking into account the transverse momenta of gluons. The formalism exposed in detail in [4] allows to test unintegrated gluons distributions (UGDF's). Besides the unintegrated gluon distribution, the second ingredient for the calculation is the light-cone wave function of the meson. Here we will present our calculations for exclusive J/ψ and $\psi'(2S)$ production in pp collisions at the LHC, using a microscopic k_t -factorization approach. In our calculation we used two different wave functions of the vector meson: Gaussian and Coulombic. The experimental data at HERA for the production of different vector mesons prefer the Gaussian light-cone wave function [3, 4]. The first measurement of exclusive J/ψ production in hadronic collisions at high energies was made by the CDF collaboration at the Tevatron [5]. Recently also the LHCb collaboration measured rapidity distribution of the J/ψ [6] and ψ' [7] mesons and we will compare our calculation to their results.

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2 Photoproduction $\gamma p \rightarrow Vp$ at HERA

The amplitude for the reaction is shown schematically in Fig.1. The full amplitude for this process can be written as:

$$M(W, \Delta^2) = (i + \rho) \Im M(W, \Delta^2 = 0, Q^2 = 0) \exp\left(\frac{-B(W)\Delta^2}{2}\right), \quad (1)$$

where ρ is the ratio of real to imaginary part of the amplitude and $B(W)$ is slope parameter which depends on energy: $B(W) = B_0 + 2\alpha'_{eff} \log\left(\frac{W^2}{W_0^2}\right)$ [1, 4]. The imaginary part of the amplitude depends on the unintegrated gluon distribution function (UGDF) $F(x_{eff}, \kappa^2)$ and on the wave function of the vector meson $\psi_V(z, k^2)$ and for $\Delta = 0$ and $Q^2 = 0$ is given by the formula [3]:

$$\begin{aligned} \Im M(W, \Delta^2 = 0, Q^2 = 0) = & W^2 \frac{c_v \sqrt{4\pi\alpha_{em}}}{4\pi^2} 2 \int_0^1 \frac{dz}{z(1-z)} \int_0^\infty \pi dk^2 \psi_V(z, k^2) \\ & \int_0^\infty \frac{\pi d\kappa^2}{\kappa^4} \alpha_S(q^2) F(x_{eff}, \kappa^2) (A_0(z, k^2) W_0(k^2, \kappa^2) + A_1(z, k^2) W_1(k^2, \kappa^2)). \end{aligned} \quad (2)$$

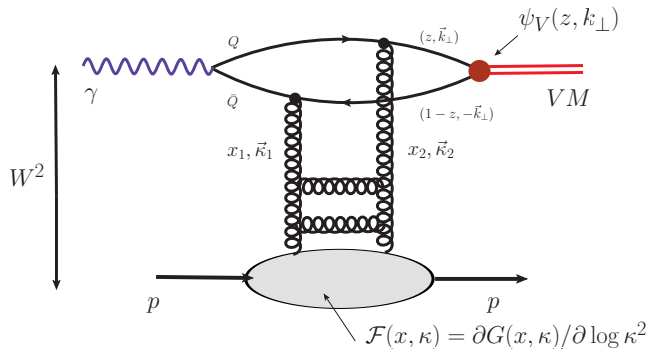


Figure 1. A sketch of the amplitude for exclusive photoproduction $\gamma p \rightarrow Vp$.

Total cross section can be calculated as:

$$\sigma(\gamma p \rightarrow J/\psi p) = \frac{1 + \rho^2}{16\pi B(W)} \left| \frac{\Im M(W, \Delta^2 = 0, Q^2 = 0)}{W^2} \right|^2. \quad (3)$$

In our calculation we used two types of the wave functions: Gaussian and Coulombic [3]. The parameters of the wave function are obtained from fitting the decay width into $e^+ e^-$.

In the left panel of Fig. 2 we show the ratio of the cross section for the first radial excitation ψ' to the cross section for the ground state J/ψ . The ratio of the 2S/1S is strongly dependent on the model of the wave function. For the following calculations we used Gaussian wave function. In the middle panel we present the total cross section for $\gamma p \rightarrow J/\psi p$ and in the right panel for $\gamma p \rightarrow \psi' p$. The total cross section is shown as a function of collision energy for different UGDFs models: Ivanov-Nikolaev (solid), Kutak-Stasto linear (dashed) and Kutak-Stasto nonlinear (dash-dotted). The dotted line (only for J/ψ) represents a calculation with a simple power-like parametrization of the old HERA data [8]. The HERA data points [9] and the LHCb data points [6] are shown for comparison.

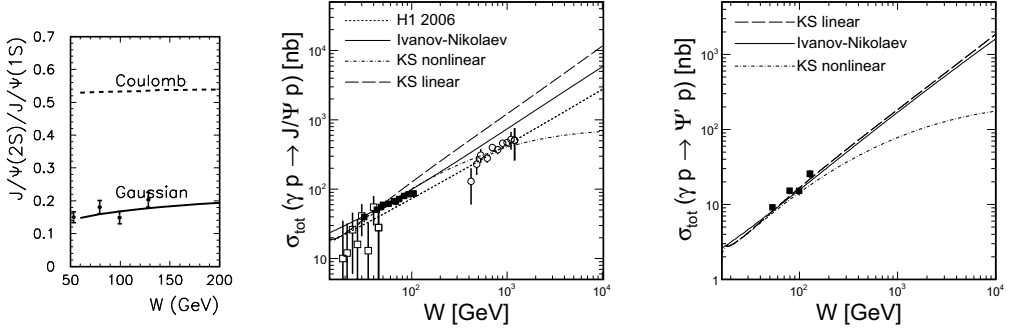


Figure 2. Left panel: ratio of the cross section for first radial excitation to that for the ground state as a function of energy. Middle panel: total cross section for the J/ψ meson photoproduction as a function of collision energy. Right panel: total cross section for the $\gamma p \rightarrow \psi' p$ as a function of collision energy.

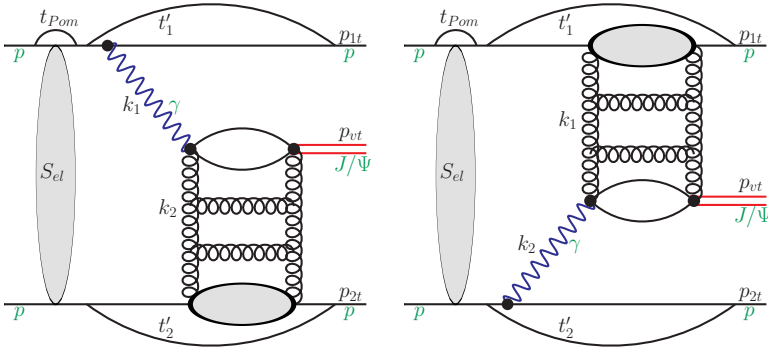


Figure 3. Diagrams representing the amplitude for the $pp \rightarrow pJ/\psi p$ process.

3 Exclusive photoproduction of J/ψ and ψ' meson in pp and $p\bar{p}$ collisions.

The full amplitude for the $pp \rightarrow pJ/\psi p$ is calculated as:

$$M_{h_1 h_2 \rightarrow h_1' h_2' V}^{\lambda_1 \lambda_2 \rightarrow \lambda_1' \lambda_2' \lambda_V}(p_1, p_2) = M_{h_1 h_2 \rightarrow h_1' h_2' V}^{(0)\lambda_1 \lambda_2 \rightarrow \lambda_1' \lambda_2' \lambda_V}(s, s_1, s_2, t_1, t_2) - \delta M_{h_1 h_2 \rightarrow h_1' h_2' V}^{\lambda_1 \lambda_2 \rightarrow \lambda_1' \lambda_2' \lambda_V}(p_1, p_2), \quad (4)$$

where $M_{h_1 h_2 \rightarrow h_1' h_2' V}^{(0)\lambda_1 \lambda_2 \rightarrow \lambda_1' \lambda_2' \lambda_V}(s, s_1, s_2, t_1, t_2)$ is the Born amplitude and $\delta M_{h_1 h_2 \rightarrow h_1' h_2' V}^{\lambda_1 \lambda_2 \rightarrow \lambda_1' \lambda_2' \lambda_V}(p_1, p_2)$ is the absorptive correction to the amplitude (see Ref. [1]).

Distribution in the transverse momentum of J/ψ meson is presented in Fig.4. The role of Pauli electromagnetic form factor was quantified in [1]. Large effect of the tensor coupling is observed for large transverse momenta.

In Fig.5 we shown rapidity distribution for J/ψ (upper plots) and ψ' (lower plots) mesons for three different UGDFs models. The absorption damps rapidity distribution by about 30%. We present results with the standard absorption (elastic rescattering) as well as with the absorption increased by a

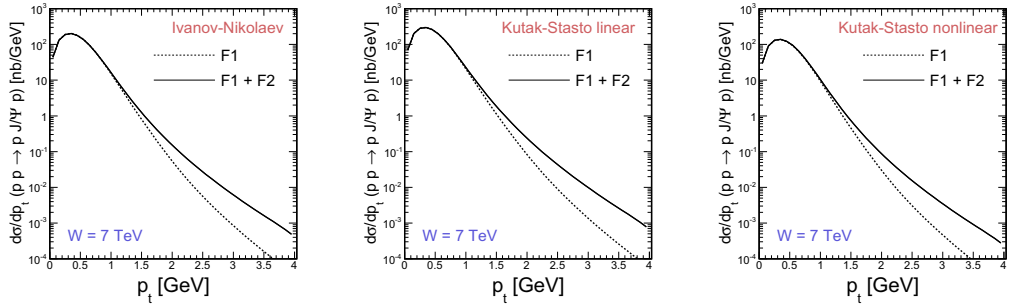


Figure 4. J/ψ transverse momentum distribution calculated with the Born amplitudes for three different UGDFs. The dashed lines include contributions with the Dirac F_1 electromagnetic form factor and the solid lines include in addition Pauli F_2 electromagnetic form factor.

factor of 1.4 to simulate inelastic terms. The results with the Kutak-Stasto nonlinear UGDF are almost consistent with the recent LHCb data [7].

4 Conclusions

Based on the photoproduction $\gamma p \rightarrow J/\psi(\psi')p$ amplitudes, we have calculated cross sections for exclusive J/ψ and ψ' meson photoproduction in proton-proton collisions. We have compared our results with the recent HERA[9] and LHCb data [6, 7]. It turns out that the best description of the data is achieved with the Kutak-Stasto unintegrated glue which includes saturation effects. In our calculation for hadronic reaction we have included the absorption effects. This effect depends on rapidity and transverse momentum of vector mesons. We have taken into account both the coupling of photons via spin-conserving vector coupling with F_1 Dirac electromagnetic form factor as well as spin-flipping tensor coupling with F_2 Pauli electromagnetic form factor. More details on the formalism as well as more results for J/ψ and ψ' production can be found in Ref. [1].

Acknowledgements

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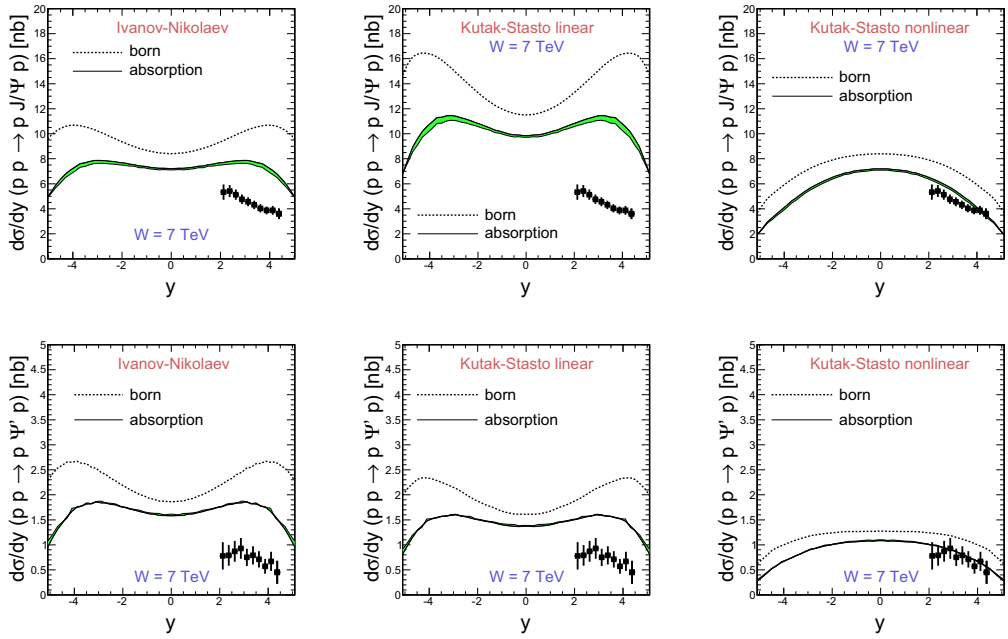


Figure 5. Rapidity distribution of J/ψ (upper plots) and ψ' (lower plots) mesons calculated with inclusion of absorption effects (solid lines), compared with the Born result (dashed lines). The new LHCb data points [7] are shown for comparison.