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A model for high energy rho meson leptoproduction based on collinear factorization and dipole models

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We present a phenomenological model for the helicity amplitudes T_{11} and T_{00} of the rho meson exclusive diffractive leptoproduction in the forward limit. This model leads to a very good description of the polarized cross-sections σ_T and σ_L when compared to HERA data. This model is based on the impact factor representation of the helicity amplitudes. The $\gamma^* \to \rho$ impact factor is computed within the light-cone collinear factorization scheme, the impact parameter space representation allowing to factorize out the dipole-target amplitude. Finally our description combines a model for the dipole-target amplitude that includes the saturation effects with the results for the impact factor where the twist 2 and twist 3 distribution amplitudes of the rho meson are involved.

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1. Introduction

We present a phenomenological model for the longitudinal and transverse polarized cross-sections of the exclusive diffractive leptoproduction of the rho meson in the high energy limit. The polarized cross-sections are obtained from the helicity amplitudes T_{00} and T_{11} in the forward limit $t \to 0$ where we denote $T_{\lambda_\rho \lambda_\gamma}$ the amplitude associated to the process

$$\gamma^*(\lambda_\gamma, q) N(p) \to \rho(\lambda_\rho, p_\rho) N(p') \tag{1.1}$$

for a nucleon target N, and where λ_γ and λ_ρ denote the polarizations of the virtual photon and of the rho meson. Our approach is based on the following kinematical assumptions:

- the center of mass $\gamma^* N$ energy is asymptotically large and one can define two light-cone momenta p_1 and p_2 such that,

$$p_\rho \sim p_1\,, \quad p \sim p_2\,, \quad q \sim p_1 - \frac{Q^2}{s} p_2\,, \quad s = (q+p)^2 \sim 2 p_1 \cdot p_2 \gg Q^2\,,\, m_\rho^2\,, \tag{1.2}$$

- the virtuality of the photon Q is much larger than the QCD scale Λ_{QCD} in order to compute the photon vertex using pQCD techniques.

The first assumption allows to factorize helicity amplitudes $T_{\lambda_\rho \lambda_\gamma}$ into the $\gamma^*_{\lambda_\gamma} \to \rho_{\lambda_\rho}$ impact factor

$$\Phi^{\gamma^*_{\lambda_\gamma} \to \rho_{\lambda_\rho}} = \frac{1}{2s} \int \frac{d\kappa}{2\pi} i\mathscr{M}(\gamma^*(\lambda_\gamma, q) + g(k_1) \to \rho(\lambda_\rho, p_1) + g(k_2))\,, \tag{1.3}$$

where $\mathscr{M}$ is the amplitude of the sub-process $\gamma^*(\lambda_\gamma, q) + g(k_1) \to \rho(\lambda_\rho, p_1) + g(k_2)$, $\mathscr{F}(x, \underline{k})$ is the unintegrated gluon density and $\kappa = (q+k_1)^2$. The helicity amplitude $T_{\lambda_\rho \lambda_\gamma}$ then reads[1]

$$T_{\lambda_\rho \lambda_\gamma} = is \int \frac{d^2\underline{k}}{(\underline{k}^2)^2} \Phi^{\gamma^*_{\lambda_\gamma} \to \rho_{\lambda_\rho}}(\underline{k})\, \mathscr{F}(x, \underline{k})\,, \tag{1.4}$$

where $k_1 = \frac{\kappa + Q^2 + \underline{k}^2}{s} p_2 + k_\perp$ and $k_2 = \frac{\kappa + \underline{k}^2}{s} p_2 + k_\perp$ are the $t-$channel gluon momenta (fig. 1).

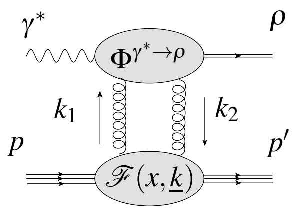

Figure 1: Impact factor representation of the helicity amplitudes.

The second assumption $Q^2 \gg \Lambda^2_{QCD}$ allows to compute the $\gamma^*_{\lambda_\gamma} \to \rho_{\lambda_\rho}$ impact factor within the light-cone collinear factorization scheme. The leading twist $\gamma^*_L \to \rho_L$ impact factor has been computed in [1] by Ginzburg, Panfil and Serbo in 1987 while an approach to derive the $\gamma^*_T \to$

[1] We denote $\underline{x}$ the 2-dimension euclidean vector associated to the Minkowskian space vector $x_\perp$ in the transverse plane, $\underline{x}^2 = -x^2_\perp$.

ρ_T impact factor, which involves the twist 3 light-cone operators of the rho meson, have been performed in 2010 in [2, 3] by Anikin, Ivanov, Pire, Szymanowski and Wallon. The results obtained from this first principle approach are parameterized by the rho meson twist 2 and twist 3 distribution amplitudes (DAs). Using the model of ref. [4] from Ball, Braun, Koike and Tanaka for the DAs, we built a first model in ref. [5], using a phenomenological model for the nucleon impact factor that was proposed in ref. [6] by Gunion and Soper in 1977. The sizable contribution from soft gluons of $\underline{k}^2 < 1$ GeV^2 motivates the present model where saturation effects are taken into account.

In ref. [7] we have shown that the impact factor in the impact parameter representation reads,

$$\Phi^{\gamma_L^*\to\rho_L}(\underline{k},Q,\mu^2) = \left(\frac{\delta^{ab}}{2}\right)\int dy \int d\underline{r}\, \psi_{(q\bar{q})}^{\gamma_L^*\to\rho_L}(y,\underline{r};Q,\mu^2)\,\mathscr{A}(\underline{r},\underline{k})\,, \tag{1.5}$$

$$\begin{aligned}\Phi^{\gamma_T^*\to\rho_T}(\underline{k},Q,\mu^2) &= \left(\frac{\delta^{ab}}{2}\right)\int dy \int d\underline{r}\, \psi_{(q\bar{q})}^{\gamma_T^*\to\rho_T}(y,\underline{r};Q,\mu^2)\,\mathscr{A}(\underline{r},\underline{k}) \\ &+ \left(\frac{\delta^{ab}}{2}\right)\int dy_2 \int dy_1 \int d\underline{r}\, \psi_{(q\bar{q}g)}^{\gamma_T^*\to\rho_T}(y_1,y_2,\underline{r};Q,\mu^2)\mathscr{A}(\underline{r},\underline{k})\,,\end{aligned} \tag{1.6}$$

where the functions $\psi^{\gamma_{L(T)}^*\to\rho_{L(T)}}$ are the results for the overlaps of the wave functions of the virtual photon and the rho meson, computed in the collinear factorization approach up to twist 3 and $\mathscr{A}$ is the dipole-target amplitude. The computation of the $\gamma_T^* \to \rho_T$ transition involves the quark antiquark contribution and the quark antiquark gluon contribution as represented in the fig. 2.

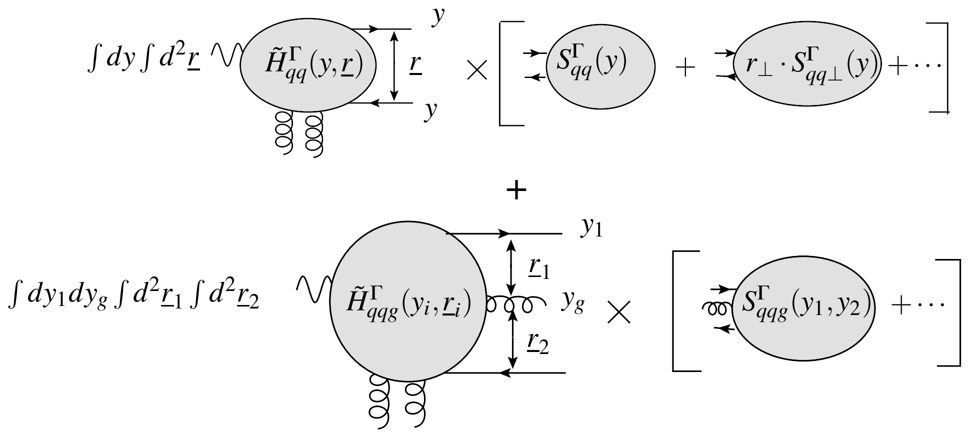

Figure 2: Contributions to the twist 3 impact factor. The $\tilde{H}^\Gamma$'s are Fourier transforms in the transverse coordinate space of hard parts and the S^Γ's functions are soft parts that are parameterized by the DAs up to twist 3. The y's stand for the longitudinal fractions of rho meson momentum of the partons and $\underline{r}$'s stand for the transverse sizes between the partons. The label Γ indicates the Fierz structure on which are projected the different contributions in order to factorize hard and soft parts in spinor space.

Soft parts $S_{q\bar{q}}^{\Gamma}$ and $S_{q\bar{q}g}^{\Gamma}$ are parameterized by a set of six twist 3 and one twist 2 DAs which are not independent. This set can be reduced to a set of three independent DAs for which the model in ref. [4] gives explicit expressions depending on the renormalization scale μ^2. The result in the limit $\mu^2 \to \infty$ is called "asymptotic" (AS) result. The full twist 3 result (Total), where we put $\mu^2 = \frac{Q^2+m_\rho^2}{4}$, can be also separated into two contributions, the Wandzura-Wilczek (WW) contribution that only depends on the twist 2 DA and the genuine contribution which only depends on the quark antiquark gluon (twist 3) DAs.

The factorization of the dipole-target scattering amplitude in eqs. (1.5, 1.6) allows to implement arbitrary models for this dipole-target amplitude. Neglecting the skewness effects in the dipole-target scattering amplitude, the helicity amplitudes can be expressed in terms of the dipole cross-section $\hat{\sigma}(x,r)$,

$$\frac{T_{00}}{s} = \int dy \int d\underline{r}\, \psi_{(q\bar{q})}^{\gamma_L^* \to \rho_L}(y,\underline{r};Q,\mu^2)\, \hat{\sigma}(x,\underline{r}), \tag{1.7}$$

$$\frac{T_{11}}{s} = \int d\underline{r} \left[\int dy \psi_{(q\bar{q})}^{\gamma_T^* \to \rho_T}(y,\underline{r};Q,\mu^2) + \int dy_2 \int dy_1 \psi_{(q\bar{q}g)}^{\gamma_T^* \to \rho_T}(y_1,y_2,\underline{r};Q,\mu^2) \right] \hat{\sigma}(x,\underline{r}). \tag{1.8}$$

Assuming the phenomenological $t-$dependence of the differential cross-sections,

$$\frac{d\sigma_{L,T}}{dt}(t) = e^{-b(Q^2)t}\, \frac{d\sigma_{L,T}}{dt}(t=0), \tag{1.9}$$

where $b(Q^2)$ has been extracted from the H1 data [8], the polarized cross-sections σ_L and σ_T can be expressed in terms of the forward helicity amplitudes T_{00} and T_{11},

$$\sigma_L = \frac{1}{b(Q^2)} \frac{|T_{00}(s,t=0)|^2}{16\pi s^2}, \qquad \sigma_T = \frac{1}{b(Q^2)} \frac{|T_{11}(s,t=0)|^2}{16\pi s^2}. \tag{1.10}$$

2. Results

In figs. 3 are shown the predictions of our model, from ref. [9], obtained using the dipole cross-section model of ref. [10], compared with H1 [8] and ZEUS [11] data. For $Q^2 \gtrsim 5$ GeV^2,

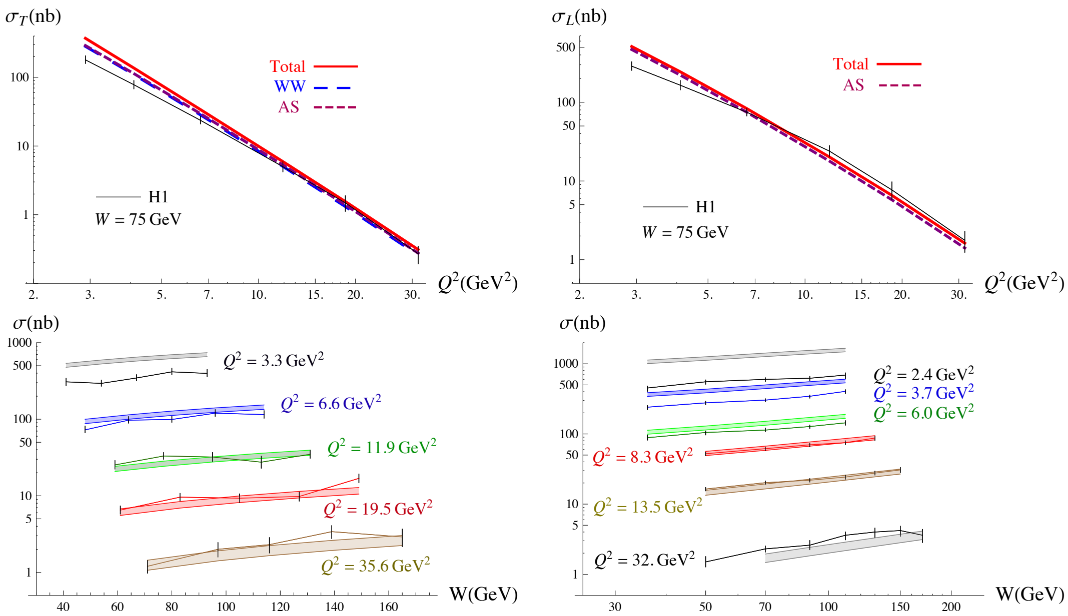

Figure 3: Top left: Total, WW and AS contributions to σ_T vs Q^2, compared to H1 [8] data. Top right: Total and AS twist 2 contributions to σ_L vs Q^2 compared to H1 data. Bottom line: Predictions for the total cross-section σ vs W compared to H1 (left) and ZEUS [11] (right) data.

the predictions we obtain, without any free parameter to adjust, are in very good agreement with

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the Q^2- and the $W-$dependence of the polarized cross-sections. The success of this model to describe these dependence and the normalizations of the cross-sections indicates that the factorization scheme which is chosen in this study works for large Q^2. The discrepancy for small $Q^2 \lesssim 5$ GeV^2 could be due to higher twist corrections of the $\gamma^*_{\lambda_\gamma} \to \rho_{\lambda_\rho}$ impact factors. Note that the cross-sections have a weak dependence in the choice of the renormalization scale μ.

3. Conclusion

We have presented a model based on first principle calculations to factorize the helicity amplitudes. The non-perturbative parts of the process are encoded in the DAs of the rho meson and the dipole scattering amplitude. We use the universality of these non-pertubative objects to get a model without free parameter. The predictions obtained for the polarized cross-sections of the rho meson diffractive leptoproduction works successfully for large Q^2. Higher twist corrections would be desirable in order to get a better control for lower Q^2 values and thus to get closer to the genuine saturation regime in the HERA kinematics. The extension of this treatment in the non-forward limit would allow to get the dipole-target impact parameter dependence, which would be a good probe to determine the gluon density profile of the proton in the high energy limit.

4. Acknowledgment

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