Exclusive diffractive vector meson production in high-energy hadron-induced reactions

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Abstract

Following recent studies of vector meson production (VMP) at HERA, we calculate and predict cross sections for exclusive diffractive VMP production in hadron-induced reactions, in particular those (to be) measured at RHIC and the LHC.

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0.1 Introduction

Exclusive vector meson production (VMP) and deeply virtual Compton scattering (DVCS) was intensively studied - both experimentally and theoretically - at HARA (for a review see, e.g. [1]). From the theoretical and phenomenological point of view the two main problems here are: 1) How to combine the known (from pQCD, DGLAP evolution) Q^2 dependence with the t dependence not known from QCD, but famiinar in the Regge-pole theory. Possible solutions will be presented below.

The available data [3] and those to be collected offer a new insight in the dynamics of VMP. There is much common between the VMP amplitude in ep and pp collisions.

Ar HERA, see [2] the differential cross section $\frac{d\sigma}{dt}$ for the reaction $\gamma^* p \to J/\psi p$ was parameterized as

$$\frac{d\sigma}{dt}(W,t,Q^2) = \frac{d\sigma}{dt}\Big|_{t=0,W=W_0} \left(\frac{W}{W_0}\right)^{4(\alpha(t)-1)} \exp(B_0 t) \left(\frac{m_{J/\psi}^2}{m_{J/\psi}^2 + Q^2}\right)^n , \tag{1}$$

where $\alpha(t) = \alpha_0 + \alpha' t$. The values of parameters found from the fit to the data are: $\frac{d\sigma}{dt}|_{t=0,W=W_0} = 326$ nb/GeV^2, $W_0 = 95$ GeV, $B_0 = 4.63$ GeV^{-2}, $\alpha_0 = 1.224$, $\alpha' = 0.164$ GeV^{-2} , $n = 2.486$.

Assuming the dominance of the helicity-conserving transitions, and neglecting the real part, one can write

$$\mathcal{M}(s,t,Q^2) = \delta_{\lambda_\gamma \lambda_V} \delta_{\lambda_p \lambda_{p'}} is \sqrt{16\pi \frac{d\sigma}{dt}\Big|_{t=0,W=W_0}} \left(\frac{s}{W_0^2}\right)^{\alpha(t)-1} \exp(B_0 t/2) \left(\frac{m_{J/\psi}^2}{m_{J/\psi}^2 + Q^2}\right)^{n/2} , \tag{2}$$

identical for each combination of particle helicities. In our case of hadroproduction the amplitude is a function of either (s_1, t_1, Q_2^2) or (s_2, t_2, Q_1^2).

0.2 Model "Capua"

Neglecting spin, the invariant scattering amplitude with a simple Regge pole exchange, as shown in Fig.1 from Ref. [4], can be written as

$$A(s,t,\tilde{Q}^2)_{\gamma^* p\to\gamma(V)p} = -A_0 V_1(t,\tilde{Q}^2) V_2(t)(-is/s_0)^{\alpha(t)}. \quad (3)$$

Here A_0 is a normalization factor, $V_1(t,\tilde{Q}^2) = \exp[b_2\beta(z)]$ is the $\gamma^* I\!P\gamma$ vertex, $V_2(t) = \exp[b_1\alpha(t)]$ is the $pI\!Pp$ vertex, being $\beta(z)$ and $\alpha(t)$ the exchanged Pomeron trajectory in the photon vertex and in the proton vertex, respectively.

In Ref. [4] for DVCS only the helicity conserving amplitude was considered. For not too large Q^2 the contribution from longitudinal photons is small (it vanishes for $Q^2 = 0$). Moreover, at high energies, typical of the HERA collider, the amplitude is dominated by the helicity conserving Pomeron exchange and, since the final photon is real and transverse, the initial one is also transverse. Electroproduction of vector mesons, discussed in the present paper, requires to take into account both the longitudinal and transverse cross sections. For convenience, and following the arguments based on duality (see Ref. [4] and references therein), the t dependence of the $pI\!Pp$ vertex V_2 is introduced via the trajectory and a generalization of this concept is applied also to the $\gamma^* I\!P\gamma$ vertex V_1, which however, apart from t, depends also on Q^2 through the trajectory

$$\beta(z) = \beta_0 - \beta_1 \ln(1-\beta_2 z), \quad (4)$$

where $\beta_i,\ \ i = 0-2$, are the $\beta(z)$-trajectory parameters, and $\beta_1\beta_2 = \beta'$ is the forward slope of this trajectory.

Hence the scattering amplitude in Eq. (3) can be written in the form

$$A(s,t,\tilde{Q}^2)_{\gamma^* p\to\gamma(V)p} = -A_0 e^{b_2\beta(z)} e^{b_1\alpha(t)} (-is/s_0)^{\alpha(t)}. \quad (5)$$

Although the model has many parameters, most of them are constrained by plausible assumptions. First, we fix the intercepts of both $\alpha(t)$ and $\beta(z)$ to the value of 1.09. The *Hardening* of the dynamics with increasing $\tilde{Q}^2$ may be accounting for either by letting the intercept to be $\tilde{Q}^2$-dependent, unacceptable by Regge-factorization, or by introducing one more, *hard* component in the Pomeron (still unique!) with a $\tilde{Q}^2$-dependent residue, as suggested e.g. in Refs. [11] and [**?**]. In any case, the trajectories and their parameters are the same for DVCS and for VMP. The other two parameters of the trajectories, α_1 and α_2 (β_1 and β_2) are fixed in the following way: their product $\alpha' = \alpha_1\alpha_2$ ($\beta' = \beta_1\beta_2$) is their forward slope, that we set equal to the value $\alpha' = 0.25$ GeV^{-2}. Furthermore, since $\alpha_1 \approx 2$ from the quark counting rules (see Ref. [4]), we get $\alpha_2 = \alpha'/\alpha_1 = 0.125$ GeV^{-2}. The same values are used also for the correspondent β_1 β_2 parameters of the $\beta(z)$-trajectory.

The parameter s_0 is not fixed by the Regge-pole theory. The nice and plausible relation $s_0 = 1/\alpha' \approx (1/4)m_p^2$ follows from the hadronic string model [**?**], other values, however, cannot be excluded. We set, for sake of simplicity, $s_0 = m_p^2 \approx 1$ GeV^2.

Finally, we set the parameter b_1 entering the proton vertex (lower vertex of Fig. **??**(c)) to $b_1 = 2.0$. In fact, this (p$I\!P$p) vertex is know from the analysis of the pp and $\bar{p}p$ scattering to be of the form $\exp(bt)$, and an estimate of b is $b \approx 2$ GeV^{-2} (see for this Ref. [**?**] and references therein).

0.3 Amplitude with hard and soft components

We would like to introduse the amplitude with two components. The "soft" one should dominate at low $\widetilde{Q}^2$ and the "hard" one at large $\widetilde{Q}^2$.

$$H_s = \frac{A_s}{\left(1+\frac{\widetilde{Q}^2}{Q_s^2}\right)^{n_s}}, \quad H_h = \frac{A_h\left(\frac{\widetilde{Q}^2}{Q_h^2}\right)}{\left(1+\frac{\widetilde{Q}^2}{Q_h^2}\right)^{n_h+1}}. \tag{6}$$

Each component has its own Regge trajectory: $\alpha_s(t) = \alpha_{0s} + \alpha'_s t, \quad \alpha_h(t) = \alpha_{0h} + \alpha'_h t.$

As input values for pomeron trajectories we can use parameters proposed by Donnachie and Landshoff [11, 10]: $\alpha_s(t) = 1.08 + 0.25t, \quad \alpha_h(t) = 1.44 + 0.01t.$

Thus the scattering amplitude will assume the form:

$$A(s,t,Q^2,M_V^2) = \frac{s_0}{\sqrt{\pi}}\left[H_s\, e^{-i\frac{\pi}{2}\alpha_s(t)}\left(\frac{s}{s_0}\right)^{\alpha_s(t)} e^{b_s t} + H_h\, e^{-i\frac{\pi}{2}\alpha_h(t)}\left(\frac{s}{s_0}\right)^{\alpha_h(t)} e^{b_h t}\right]. \tag{7}$$

The factor $\frac{s_0}{\sqrt{\pi}}$ in front of the amplitude is just the convenient constant for defining the parameters in $A_{s,h}$. In the previous work [6] (and also in Eq. (**??**)) we used the amplitude in the form where $b_{s,or\,h}$ was substituted by the combination

$$2\left(\frac{a_{s,h}}{\widetilde{Q}^2} + \frac{b_{s,h}}{2m_p^2}\right). \tag{$*$}$$

Fitting the data we have found that parameters assume large errors, and that the $a_{s,h}$ parameters are close to 0, thus to reduce number of free parameters, we simplified the previous model by $2\left(\frac{a_{s,h}}{\widetilde{Q}^2} + \frac{b_{s,h}}{2m_p^2}\right) \to b_{s,h}$. Such a combination (*) was important for the description of $B(Q^2)$ when we used a model with only one term (see previous section), but in the case of two terms the Q^2-dependence of the slope B can be reproduced without extra (*) combination, since each term in the amplitude has its own Q^2-dependent factor $H_{s,h}(Q^2)$.

Eq. (7) can also be rewritten in form:

$$A(s,t,Q^2,{M_v}^2) = \frac{s_0}{\sqrt{\pi}}\left[A_s e^{-i\frac{\pi}{2}\alpha_s(t)}\left(\frac{s}{s_0}\right)^{\alpha_s(t)} e^{b_s t - n_s \ln\left(1+\frac{\widetilde{Q}^2}{Q_s^2}\right)} \right. \tag{8}$$

$$\left. + A_h e^{-i\frac{\pi}{2}\alpha_h(t)}\left(\frac{s}{s_0}\right)^{\alpha_h(t)} e^{b_h t - (n_h+1)\ln\left(1+\frac{\widetilde{Q}^2}{Q_h^2}\right) + \ln\left(\frac{\widetilde{Q}^2}{Q_h^2}\right)}\right],$$

where the terms $e^{b_s t - n_s \ln\left(1+\frac{\widetilde{Q}^2}{Q_s^2}\right)}$ and $e^{b_h t - (n_h+1)\ln\left(1+\frac{\widetilde{Q}^2}{Q_h^2}\right) + \ln\left(\frac{\widetilde{Q}^2}{Q_h^2}\right)}$ can be interpreted as a product of the form factors of upper and lower vertices.

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