THE POMERON IN EXCLUSIVE VECTOR MESON PRODUCTION

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Abstract

An earlier developed model for vector meson photoproduction, based on a dipole Pomeron exchange, is extended to electroproduction. Universality of the non linear Pomeron trajectory is tested by fitting the model to ZEUS and H1 data as well as to CDF data on $\bar{p}p$ elastic scattering.

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1 Introduction

Elastic production of vector mesons in electron-proton interaction has provided a deeper understanding of the diffraction phenomenon and finds a sensible description in a variety of models. The first attempts to describe diffractive photoproduction were based on Regge theory [1] and vector dominance model [2]. Since various aspects of the deep inelastic scattering and of elastic processes are both present in photoproduction it is quite natural that perturbative QCD can help to understand many features of the HERA experimental results. Examples where perturbative QCD has been applied to this process can be found in Ref. [3].

In these perturbative calculations regarding diffractive processes, that in this case have characteristic features of the elastic ones, non perturbative contributions are present and their description becomes an important ingredient of the theoretical model while lying outside perturbation theory. Hence, models based on Regge pole phenomenology maintain their important task in helping to construct a representation of non perturbative aspects of the scattering amplitude. For the processes under consideration many papers based on Regge poles exchange successfully reproduced [4, 5] new experimental HERA data. A different approach to asymptotic behavior was advocated recently in Ref. [6].

The aim of this paper is to expound the properties of the most important and intricate Regge exchange: the vacuum, or Pomeron exchange. $J/\psi$ photoproduction and, apart from small subleading contributions, $\Phi$ photoproduction are genuine Pomeron filters that, together with very high energies reactions, permit a careful study of the non perturbative features of diffraction.

After a short description of the model, that has been already introduced in Ref. [5], in Section 2, an analysis of the HERA data for $J/\psi$ and $\Phi$ photoproduction and electroproduction will be presented in Sections 3 and 4. A test of the Pomeron universality where the model is applied to proton-antiproton elastic scattering at very high energy will be considered in Section 5. The Conclusions in Section 6 will complete the paper.

2 The model

A convenient way to obtain rising cross sections with the Pomeron intercept equal to one assumes that the Pomeron is a double Regge pole. This means that the $t$-channel partial wave, corresponding to the Pomeron exchange, has a double pole for $\ell = \alpha(t)$. In this choice we are comforted by the numerous successes of this model in its applications to hadronic reactions [1, 5, 7]. The total cross section will then increase logarithmically with $s$ at large energies.

The reason why non asymptotic contributions are more important for the dipole
than for the Regge pole can be easily seen. The asymptotic behavior of $P_\alpha(z)$, where $z = -1 - 2s/(t - 4m^2)$, is $P_\alpha(z) \sim z^\alpha(1 + O(1/z^2))$. In the case of a dipole, the corrections are of the order $1/z$ since a simple calculation gives, in the limit $\alpha \to 1$ and $z \to \infty$,

$$\frac{\partial P_\alpha(z)}{\partial \alpha} \bigg|_{\alpha=1} \sim z \left[ \ln z - 4\pi + \frac{8\pi}{z} + O \left( \frac{1}{z^2} \right) \right].$$

To this correction, that could influence the low energy behavior of the amplitude, we must add the contribution of a Pomeron daughter, that is difficult to estimate, and the possibility that also quarks be present in the Pomeron. All these arguments suggest that it is better to apply the model as far as possible from the low energy region, choosing the invariant scattering amplitude in the form

$$A(s, t) = i f(t) \left( -i \frac{s}{s_0} \right)^{\alpha_P(t)} \left[ \ln \left( -i \frac{s}{s_0} \right) - g(t) \right],$$

where $g(t)$ and $f(t)$ are functions, for the moment undetermined, of the momentum transfer. $\alpha_P(t)$ is the Pomeron trajectory with $\alpha_P(0) = 1$.

The choice of the function $f(t)$, that represents the product of the vertices $\gamma$-Pomeron-meson and proton-Pomeron-proton, will be made by imposing the condition that the Pomeron exchange is pure spin $\alpha_P$ exchange. It has been shown in [8] that this constraint leads to a vertex of the form $[(\alpha_P(t) - 1)f_1(t) + (\alpha_P(t) + 1)f_2(t)]$ and, in the neighborhood of $t = 0$, to a term vanishing with $t$ whatever the form of the trajectory could be. The presence of this term, that is usually neglected, makes the determination of the slope independent of the value of the differential cross section in the forward direction and can help in explaining non trivial properties of the forward cone.

It has been shown in Ref. [5] that the simple form for the elastic differential cross section of vector meson photoproduction

$$\frac{d\sigma}{dt} = \left[ a e^{bt} + c t e^{dt} \right]^2 \left( \frac{s}{s_0} \right)^{2\alpha_P(t) - 2} \left[ \left( \ln \frac{s}{s_0} + g \right)^2 + \frac{\pi^2}{4} \right],$$

where $g$ is a constant, gives a good quality fit to the experimental data [9, 10]. We notice that the form [2] satisfies also the aforesaid conditions and will be adopted in this paper.

Since the amplitude, in the Regge form, should have no essential singularity at infinity in the cut plane, $\Re \alpha(s)$ is bounded by a constant, for $s \to \infty$, and this leads to the bound

$$|\alpha(s)| < M s^q,$$

with $q < 1$ and $M$ an arbitrary constant. The choice [11, 5]

$$\alpha_P(t) = 1 + \gamma (\sqrt{t_0} - \sqrt{t_0 - t}),$$

(3)
where $t_0 = 4m_x^2$ and $\gamma = m_x/1 GeV^2$, satisfies the above conditions and reproduces the standard Pomeron slope at $t = 0$, $\alpha'_P(0) \simeq 0.25 GeV^{-2}$. Eq. (3) for the trajectory defines uniquely the model for photoproduction.

Consider now electroproduction of a vector meson. As noticed in Refs. [12, 13] a commonly adopted form for the $Q^2$ dependence of the $J/\Psi$ cross section is

$$
\sigma_{\gamma^* p \rightarrow J/\Psi p}^{\text{tot}} \propto \frac{1}{(1 + Q^2/M_{J/\Psi}^2)^n},
$$

where $n \sim 1.75$, according to the ZEUS Collaboration [12], and $n \sim 2.38$ according to the H1 Collaboration [10].

For large $Q^2$ all the amplitudes but the double flip one, for diffractive vector meson electroproduction, can be evaluated in perturbative QCD [14]. In the longitudinal photon amplitudes, a factor $Q/M_{J/\Psi}$ is a consequence of gauge invariance irrespective of the detailed production dynamics. If we consider only the dominant twist s-channel helicity conserving amplitudes, the factor in Eq. (4) thus finds a natural explanation. The $Q^2$ dependence, however, will appear also in the strong coupling and in the gluon structure function through the hard scale of perturbative QCD [14].

In our approach, based on Regge pole theory, the factor (4) will be certainly present in electroproduction, multiplying the differential cross section (2), but this will not complete all the possible corrections. Since, in the dipole Pomeron formalism, the product of the vertices can affect the parameter $g$, all the parameters can acquire a weak $Q^2$ dependence. We neglect this dependence in $a, b, c, d$ and assume that $g$ varies as $g \times [1 + Q^2/(Q^2 + M_{\Psi}^2)]^\gamma$ where $\gamma$, if this assumption is correct, is small. One can interpret this functional dependence of $g$ as coming from a $Q^2$ dependence of $s_0$ in $\ln(s/s_0)$.

The final form of the differential cross section is:

$$
\frac{d\sigma}{dt} = \left(1 + \frac{Q^2}{M_{J/\Psi}^2}\right)^{-\beta} \left[e^{bt} + ct e^{dt}\right]^2 \left(\frac{s}{s_0}\right)^{2\alpha_P(t) - 2} \times \left(\ln\left(\frac{s}{s_0}\right) + g \left[1 + Q^2/(Q^2 + M_{\Psi}^2)\right]\right)^2 + \frac{\pi^2}{4},
$$

where, for $Q^2 = 0$, all the parameters have the same value as for photoproduction. We notice that the value of $\beta$ includes a factor $(1 + Q^2/M_{J/\Psi}^2)$ that comes from the contribution of the longitudinal amplitude, relevant at $Q^2 \neq 0$, which leads to $|A|^2 = |A_T|^2 + |A_L|^2$. The approximate relation $A_L \sim Q A_T/M_{J/\Psi}$ can be applied in this phenomenological approach.

In the following Sections the parameterizations (2) and (5) will be applied to $J/\Psi$ and $\Phi$ photoproduction and electroproduction. Only for these processes, in
fact, the dominant exchange is due to the Pomeron and we do not need to introduce non-leading trajectories. We can thus avoid contributions that can interfere with the object of our study and that, at intermediate energies where data are available, can be large.

3 $J/\Psi$ photoproduction and electroproduction

Following the analysis of Ref. [5] we apply Eq. (2) to the new dataset of $J/\Psi$ photoproduction [9]. This dataset represents measurements of $J/\Psi$ photoproduction in two channels: $J/\Psi \rightarrow e^+e^-$ and $J/\Psi \rightarrow \mu^+\mu^-$ which may possibly have different normalizations especially for differential cross sections. To test if it is so we limit our fit to the region $W \leq 160$ GeV and check the predictions of the model for the differential cross section and the total integrated cross section.

As noticed in the previous paper [5], the parameter $d$ varies little in the fit, so that we keep the same value $d = 0.851$ GeV$^{-2}$ fixed, thus leaving only four parameters free. In order to avoid the region of inelastic background we limit the $t$ region to $|t| < 1$ GeV$^2$. In the fit we use differential cross sections only. For the electron channel we have obtained the results shown in Column 2 of Table 1 with $\chi^2$/d.o.f. = 1.5. For the muon channel the results are presented in Column 3 of Table 1 with $\chi^2$/d.o.f. = 1.0.

| Photoproduction | $J/\Psi \rightarrow e^+e^-$ | $J/\Psi \rightarrow \mu^+\mu^-$ | $J/\Psi \rightarrow e^+e^-$ |
|-----------------|----------------------------|----------------------------|----------------------------|
| $W < 160$ GeV   | (1.8 ± 0.1) · 10$^{-3}$    | (1.83 ± 0.09) · 10$^{-3}$   | (1.97 ± 0.13) · 10$^{-3}$   |
| $W < 300$ GeV   | 2.25 ± 0.24                | (−0.97 ± 0.19) · 10$^{-3}$  | (−0.35 ± 0.67) · 10$^{-3}$  |
| $a$ [GeV$^{-1}$]| 1.55 ± 0.49                | 1.40 ± 0.51                 | 0.851                      |
| $b$ [GeV$^{-2}$]| (−0.48 ± 0.54) · 10$^{-3}$ | (−0.35 ± 0.67) · 10$^{-3}$  | 0.851                      |
| $c$ [GeV$^{-3}$]| 0.851                     | 0.851                      | −4.58 ± 0.29               |
| $d$ [GeV$^{-2}$]| −4.23 ± 0.37              | −4.25 ± 0.22               | 0.851                      |
| $g$              | −4.23 ± 0.37              | −4.25 ± 0.22               | −4.58 ± 0.29               |

Table 1: Values of parameters obtained by fitting $J/\Psi$ photoproduction data.

The different channels give us different values of parameters $b$ and $c$ and as can be seen in Figs. 1, 2, 3, 4 the resulting high energy predictions for elastic and differential cross sections of exclusive $J/\Psi$ photoproduction are quite different. We notice that the electron channel predictions are in a very good agreement with the data for $W > 160$ GeV, while the muon channel provides somewhat lower estimate of cross sections for higher energies. It will be interesting to see if the experimental data on $J/\Psi \rightarrow \mu^+\mu^-$ channel would support such a trend or the conclusion is only a

1The data are available from [15].
statistical fluctuation. If we use all the two channel data altogether we obtain a very high \( \chi^2 / \text{d.o.f.} = 1.9 \). To implement a better analysis one needs a more complete set of data on differential cross sections in both channels.

We proceed by choosing the electron channel without limiting the value of \( W \). The result is presented in Column 4 of Table II with \( \chi^2 / \text{d.o.f.} = 1.2 \).

The behavior of the local slope \( B(W) = \frac{d}{dt}(\ln \frac{d\sigma}{dt}) \) as a function of \( W \) for various fixed values of \(|t|\) is presented in Fig. 5. As expected from the differential cross section and the curvature of the Pomeron trajectory (3), the local slope decreases with \(|t|\). Its value at \( t \approx -(0.2 \pm 0.5) \) GeV\(^2\) meets the experimental measurements (see Fig. 5). This is quite understandable, since the experimental value is the average over a wide interval in \( t \) covering the measurements. The rise of the slope toward \( t = 0 \) is a well-known phenomenon in hadronic physics; its appearance in photoproduction was emphasized e.g. in Ref. [17].

Without any fitting we achieve a good agreement with the data on integrated elastic cross section, \( \chi^2 / \text{point} = 0.95 \). The high error of \( c \) is due to the scarcity of the data on the differential cross section in the region \( 0 < |t| < 1 \) GeV\(^2\). A more complete set of high accurate data will allow us to arrive at a definite conclusion about the values of parameters.

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Figure 1: Elastic cross section of \( J/\Psi \) photoproduction. The dashed line corresponds to \( J/\Psi \rightarrow e^+e^- \) channel fit (Column 2 of Table II). The dotted line corresponds to \( J/\Psi \rightarrow \mu^+\mu^- \) channel fit (Column 3 of Table II). The solid line corresponds to \( J/\Psi \rightarrow e^+e^- \) channel fit (Column 4 of Table II).
Figure 2: Differential cross section of exclusive $J/\Psi$ photoproduction for $35 \leq W \leq 80$ GeV. Line aliases and symbols are the same as in Fig. 1.

Figure 3: Differential cross section of exclusive $J/\Psi$ photoproduction for $100 \leq W \leq 140$ GeV. Line aliases and symbols are the same as in Fig. 1.

Figure 4: Differential cross section of exclusive $J/\Psi$ meson photoproduction for $147.5 \leq W \leq 260$ GeV. Line aliases and symbols are the same as in Fig. 1.

Figure 5: The slope of differential cross section of exclusive $J/\Psi$ photoproduction.

Now we use Eq. (5) in order to describe electroproduction of $J/\Psi$. We fix all the parameters obtained by fitting the photoproduction data (see Column 4 of Table 1.)
and fit two parameters $\beta$ and $\gamma$ to the dataset $^2$. The values of the parameters are the following: $\beta = 1.94 \pm 0.42, \gamma = 0.69 \pm 0.24$ and $\chi^2$/d.o.f. = 0.81.

The factor $[1 + Q^2/(Q^2 + M^2_V)]^\gamma$ grows up to 1.5 in the available region of photon virtuality $0 < Q^2 < 50 \text{ GeV}^2$.

In the case of $\gamma = 0$ we obtain $\beta = 2.86 \pm 0.09$ and $\chi^2$/d.o.f. = 1.07. We proved that the fit is rather insensible to the value of $0 < \gamma < 1$.

Figure 6: Cross section of exclusive $J/\Psi$ electroproduction as a function of $W$.

Figure 7: Cross section of exclusive $J/\Psi$ electroproduction as a function of $Q^2$.

4 $\Phi$ meson photoproduction and electroproduction

The major part of the data on $\Phi$ photoproduction is concentrated in the low energy region $^2$, we thus would not expect the asymptotic contribution $^2$ to work as well as in the case of $J/\Psi$ photoproduction. As we have only four experimental points of the differential cross section at the energy 94 GeV which are in the region of intermediate $t$, we do not expect to obtain quantitative, but rather qualitative description of the process (as can be seen in Figs. 8, 9 where exclusive elastic and differential cross sections are presented). It turns out that the scarce data do not allow us to determine the parameters $c$ and $g$ with a reasonable error. The result of the fit is presented in Table $^2$ and the $\chi^2$/d.o.f. = 0.34.

$^2$The data are available from [13], [16].
\[ a = (0.46 \pm 0.12) \cdot 10^{-2} \text{ [GeV}^{-1}] , \]
\[ b = 2.26 \pm 0.12 \text{ [GeV}^{-2}] , \]
\[ c = 0.0 \pm 0.68 \cdot 10^{-2} \text{ [GeV}^{-3}] , \]
\[ d = 0.851 \text{ [GeV}^{-2}] , \]
\[ g = -0.08 \pm 1.5 . \]

Table 2: Values of parameters obtained by fitting \( \Phi \) photoproduction data. ( \(|t| < 1 \text{ GeV}^2\)).

As expected, the asymptotic formula (2) does not reproduce the data near threshold (see Fig. 8).

To reproduce electroproduction of \( \Phi \) we go along the same lines as in the previous section and use Eq. (5). Relying on our experience of \( J/\Psi \) electroproduction, we restrict our consideration to the case \( \gamma = 0 \) and obtain \( \beta = 2.12 \pm 0.03 \), \( \chi^2 / \text{d.o.f.} = 0.3 \). The results can be seen in Figs. 10, 11 where elastic and differential cross sections of \( \Phi \) exclusive electroproduction are shown.

Figure 8: Elastic cross section of exclusive \( \Phi \) photoproduction.

Figure 9: Differential cross section of exclusive \( \Phi \) photoproduction.
Figure 10: Elastic cross section of exclusive $\Phi$ electroproduction as function of $W$.

Figure 11: Elastic cross section of exclusive $\Phi$ electroproduction as function of $Q^2$.

5 Pomeron universality

The model we consider is consistent with s-channel unitarity and asymptotic factorizability. Universality, in this context, refers to the choice (3) for the Pomeron trajectory that provides a reliable description of exclusive vector meson production. The conjecture that the trajectory in Eq. (3) is universal is supported by the following example.

We consider the proton-antiproton scattering at sufficiently high energies, where only the Pomeron presumably contributes. Following tradition [18], it is a customary practice to adopt a linear Pomeron trajectory in order to describe hadronic interactions. In a different approach [7, 19] that provides a satisfactory fit to $pp$ and $\bar{p}p$ data a square root trajectory similar to that of Eq. (3) has been preferred. It is interesting to update this last fit using Eq. (3) and the same parameters adopted for photoproduction: $t_0 = 4m_\pi^2$ and $\gamma = m_\pi/1$GeV$^2$.

In order to use the asymptotic formula, we choose the data on the differential cross section at energies $\sqrt{s} = 546$ GeV and 1.8 TeV [20]. As we take into account neither Pomeron daughters nor possible odderon contributions, we concentrate on the region of low $|t|$, $0 < |t| < 0.2$ GeV$^2$. The result is presented in Table 3 with $\chi^2$/d.o.f. = 1.04.
\[ a = 0.41 \pm 0.01 \, [\text{GeV}^{-1}], \]
\[ b = 7.61 \pm 3.36 \, [\text{GeV}^{-2}], \]
\[ c = -1.12 \pm 1.40 \, [\text{GeV}^{-3}], \]
\[ d = 7.72 \pm 0.52 \, [\text{GeV}^{-2}], \]
\[ g = 2.86 \pm 0.41. \]

Table 3: Values of parameters obtained by fitting \( p\bar{p} \) data.

In Figs. 12, 13 we depict respectively the results of the fit for the differential cross section and the predicted total and elastic cross sections of \( \bar{p}p \) scattering.

The non linear trajectory of Eq. (3) provides a satisfactory agreement with the data also for this hadronic process. We consider the obtained result as an argument in support of the Pomeron universality.

![Figure 12: Differential cross section of elastic \( \bar{p}p \) scattering at the energies \( \sqrt{s} = 546 \, \text{GeV} \) and \( 1.8 \, \text{TeV} \).](image1)

![Figure 13: Elastic and total cross sections of \( \bar{p}p \) scattering.](image2)

6 Conclusions

The aim of this paper was to study the Pomeron exchange in reactions where non leading contributions are absent or negligible. We have chosen \( J/\Psi \) and \( \Phi \) photoproduction and electroproduction as Pomeron filters.

Our analysis is based on the dipole Pomeron model assuming a Pomeron trajectory with intercept equal to one and a non linear \( t \)-dependence. The choice of the vertices is based on covariant Reggeization as explained in Section 2 of Ref. [8]. To reduce the number of free parameters we have used an approximate form of the vertex. As a result, we have obtained a good description of the data on \( J/\Psi \) and \( \Phi \)
photoproduction and electroproduction.

To demonstrate the universality of the chosen trajectory we applied the model to \( \bar{p}p \) scattering at sufficiently high energies where only the Pomeron contributes. The good agreement with the experimental data is an argument in favor of the chosen Pomeron trajectory.

We are convinced to have reached a deeper understanding of the properties of the dipole Pomeron.

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References

[1] A. Donnachie and P.V. Landshoff, Phys. Lett. B185 (1987) 403.

[2] H. Fraas and M. Kuroda, Phys. Rev. D16 (1977) 2778

[3] M. Ryskin, Z. Phys. C 57 (1993) 89.
   J. Bartels, et al., Phys. Lett. B 375 (1996) 301.
   S.J. Brodsky, et al., Phys. Rev. D 59 (1994) 3134.
   J. C. Collins, L. Frankfurt and M. Strikman, Phys. Rev. D 56 (1997) 2982.
   J.R. Cudell and I. Royen, Phys. Lett. B 397 (1997) 317; Nucl. Phys. B 545 (1999) 505.

[4] L.L. Jenkovszky, E.S. Martynov, F. Paccanoni, ”Regge Pole Model for Vector Photoproduction at HERA”, hep-ph/9608384 and proceedings of “HADRON-96”, Novii Svet, 1996.
   R. Fiore, L.L. Jenkovszky, F. Paccanoni, Eur. Phys. J. C 10 (1999) 461.
   E. Martynov, E. Predazzi , A. Prokudin, Eur. Phys. J. C 26 (2002) 271.
   E. Martynov, E. Predazzi , A. Prokudin, hep-ph/0211430, ”Vector meson photoproduction in the soft dipole Pomeron model framework”, to be published in Phys. Rev. D.

[5] R. Fiore, L.L. Jenkovszky, F. Paccanoni, A. Papa, Phys. Rev. D 65 (2002) 077505.
[6] S.M. Troshin, N.E. Tyurin, “Regularities of vector-meson electroproduction: transitory effect or early asymptotic?” [hep-ph/0301112]

[7] L.L. Jenkovszky, Fortschr. Phys. 34 (1986) 791.
    P. Desgrolard et al., Nuovo Cimento 107 (1994) 637.

[8] F. Paccanoni, EPJdirect C 4 (2002) 1.

[9] ZEUS Collaboration, S. Chekanov et al. Eur. Phys. J. C24 (2002) 345.

[10] H1 Collaboration, C. Adloff et al., Phys. Lett. B483 (2001) 63.

[11] R. Fiore et al., Eur. Phys. J. A10 (2001) 217.

[12] ZEUS Collaboration, J. Breitweg et al., Eur. Phys. J. C 6, 603 (1999).

[13] H1 Collaboration, S. Aid et al., Eur. Phys. J. C 10, 373 (1999); Nucl. Phys. B 468, 3 (1996).

[14] E.V. Kuraev, N.N. Nikolaev and B.G. Zakharov, JEPT Lett. 68, 696 (1998),[Pisma Zh. Eksp. Teor. Fiz. 68, 667 (1998)].

[15] REACTION DATA Database [http://durpdg.dur.ac.uk/hepdata/reac.html]

[16] CROSS SECTIONS PPDS database [http://wwwppds.ihep.sw:8001/c1-5A.html]

[17] J. Nemchik, Phys. Lett. B497 (2001) 235.

[18] A. Donnachie, P.V. Landshoff, Nucl. Phys. B 231 (1984) 189.

[19] L.L. Jenkovszky, B.V. Struminskii and A.N. Shelkovenko, Yad. Fiz. 46 (1987) 1200 [Sov. J. Nucl. Phys. 46 (1987) 700].

[20] CDF Collaboration, F. Abe et al., Phys. Rev. D 50, 5518 (1994).