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The Role of Screening Corrections in High Energy Photoproduction

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ABSTRACT

The role of screening corrections, calculated using the eikonal model, is discussed in the context of soft photoproduction. We present a comprehensive calculation considering the total, elastic and diffractive cross sections jointly. We examine the differences between our results and those obtained from the supercritical Pomeron-Reggeon model with no unitary corrections.

Key-words: Pomeron eikonal approach; Screening corrections; Diffractive dissociation; HERA data.

1 Introduction

The second generation of HERA results on total, elastic and diffractive cross sections have recently become available [1, 2]. In this note we explore the possibility of a comprehensive description of these data which are considered to be soft processes. Both H1 and ZEUS report that in the HERA energy domain $(\sigma_{el} + \sigma_{diff})$ is about 35-40% of the total cross section. This is similar to the ratio observed in $\bar{p}p$ scattering in the ISR-Tevatron energy range, where the need for screening corrections has been established [3]. In the present analysis we apply the methods used in hadronic processes [4, 5] to photon initiated processes, and attempt to formulate a comprehensive description of total, elastic and diffractive photoproduction reactions, in a Regge model with screening corrections.

Our amplitude is normalised so that

$$\frac{d\sigma}{dt} = \pi |f(s,t)|^2 \tag{1}$$

$$\sigma_{tot} = 4\pi Im f(s,0) \tag{2}$$

The scattering amplitude in b-space is defined as

$$a(s,b) = \frac{1}{2\pi} \int d\mathbf{q} \;\; e^{-i\mathbf{q}\cdot\mathbf{b}} f(s,t) \tag{3}$$

where $t = -q^2$.
In this representation

$$\sigma_{tot} = 2 \int d\mathbf{b} \;\; Im a(s,b) \tag{4}$$

$$\sigma_{el} = \int d\mathbf{b} \;\; |a(s,b)|^2 \tag{5}$$

The introduction of screening rescattering corrections is greatly simplified in the eikonal approximation where at high energy $a(s,b)$ is assumed to be pure imaginary, and can be written in the simple form

$$a(s,b) = i(1 - e^{-\Omega(s,b)}) \tag{6}$$

where the opacity $\Omega(s,b)$ is a real function. As we shall utilize Regge parametrizations, analyticity and crossing symmetry are easily restored by substituting $s^{\alpha} \rightarrow s^{\alpha} e^{-i\pi\alpha/2}$, where α denotes the exchanged Regge trajectory.

In previous publications [4, 5] we have shown that the eikonal approximation can be summed analytically for a Gaussian input

$$\Omega(s,b) = \nu(s) e^{-\frac{b^2}{R^2(s)}} \tag{7}$$

Eq. (7) provides a good approximation for Regge type amplitudes, where

$$Im f(s,t) = C e^{R_0^2 t} (\frac{s}{s_0})^{\alpha(t)-1} sin[\frac{\pi\alpha(t)}{2}] \tag{8}$$

with $\alpha(t) = \alpha(0) + \alpha' t$. On transforming to b-space we obtain

$$\nu(s) = \frac{C R_1^2(s)}{2 \mid \beta \mid^2} (\frac{s}{s_0})^{\alpha(0)-1} = \frac{\sigma_0}{2\pi R^2(s)} (\frac{s}{s_0})^{\alpha(0)-1} \simeq \frac{\sigma_{tot}}{4\pi B_{el}} \tag{9}$$

$$R^2(s) = \frac{4 \mid \beta \mid^2}{R_1^2(s)} \simeq 4 R_1^2(s) \tag{10}$$

$$R_1^2(s) = R_0^2 + \alpha' ln(\frac{s}{s_0}) \tag{11}$$

$$\mid \beta \mid^2 = R_1^4 + \frac{\pi^4 \alpha'^2}{4} \tag{12}$$

where $\sigma_0 = \sigma(s_0)$ and B_{el} denotes the elastic slope $[B_{el} = \frac{1}{2} R^2(s)$]. With this input, we obtain in the eikonal approximation

$$\sigma_{tot} = 2\pi R^2(s)[ln\nu(s) + C - Ei(-\nu(s))] \tag{13}$$

$$\sigma_{in} = \pi R^2(s)[ln 2\nu(s) + C - Ei(-2\nu(s))] \tag{14}$$

$$\sigma_{el} = \sigma_{tot} - \sigma_{in} \tag{15}$$

where $Ei(x) = \int_{-\infty}^{x} \frac{e^t}{t} dt$, and C = 0.5773 is the Euler constant. In the following we take $\alpha_P(t) = 1 + \Delta + \alpha' t$ and $\alpha_R(t) = 0.5 + t$.

The above parametrization also allows one to obtain a closed expression for single diffraction dissociation , where in the triple Regge limit with no screening corrections we have

$$\frac{M^2 d\sigma_{sd}}{dM^2 dt} = \sigma_0^2 (\frac{s}{M^2})^{2\Delta + \alpha' t} [G_{PPP} (\frac{M^2}{s_0})^{\Delta} + G_{PPR} (\frac{M^2}{s_0})^{-\frac{1}{2}}] \tag{16}$$

With the introduction of screening corrections [5] we obtain

$$\frac{M^2 d\sigma_{sd}}{dM^2} = \frac{\sigma_0^2}{2\pi \bar{R}_1^2(\frac{s}{M^2})} (\frac{s}{M^2})^{2\Delta} \cdot [G_{PPP} (\frac{M^2}{s_0})^{\Delta} a_1 \frac{1}{(2\nu(s))^{a_1}} \gamma(a_1, 2\nu(s))$$
$$+ G_{PPR} (\frac{M^2}{s_0})^{-\frac{1}{2}} a_2 \frac{1}{(2\nu(s))^{a_2}} \gamma(a_2, 2\nu(s))] \tag{17}$$

where G_{PPP} and G_{PPR} are the triple Regge couplings corresponding to single diffraction dissociation,

$$\bar{R}_i^2(\frac{s}{M^2}) = 2R_{0i}^2 + r_{0i}^2 + 4\alpha' ln(\frac{s}{M^2}) \tag{18}$$

$r_{0i} \leq 1GeV^{-2}$ denotes the radius of the triple vertex and can safely be neglected.

$$a_i = \frac{2R^2(s)}{\bar{R}_1^2(\frac{s}{M^2}) + 2\bar{R}_i^2(\frac{M^2}{s_0})} \tag{19}$$

The indices i =1,2 corresponds to P (Pomeron) and R (Reggeon) exchanges. $\gamma(a, 2\nu)$ denotes the incomplete Euler gamma function $\gamma(a, 2\nu) = \int_0^{2\nu} z^{a-1} e^{-z} dz$.

The formalism presented above needs to be modified when applied to photoproduction. To this end we make the following two assumptions:
1) The photoproduction cross section can be estimated using the diagonal vector dominance model (VDM) relation

$$\sigma_{tot}(\gamma, p) = \sigma_{VDM}(\gamma p) = \sum_{V=\rho,\omega,\phi} \frac{4\pi\alpha}{f_V^2} \sigma(Vp) \tag{20}$$

where $\frac{4\pi\alpha}{f_\rho^2} \simeq \frac{1}{300}$, and we assume the standard U-spin SU(3) relation $\rho : \omega : \phi$ = 9:1:2.
2) In addition, we assume the validity of the additive quark model, where

$$\sigma_{tot}(\rho p) \simeq \sigma_{tot}(\omega p) \simeq \frac{1}{2}[\sigma_{tot}(\pi^+ p) + \sigma_{tot}(\pi^- p)] \tag{21}$$

$$\sigma_{tot}(\phi p) \simeq \sigma_{tot}(K^+ p) + \sigma_{tot}(K^- p) - \sigma_{tot}(\pi^- p) \tag{22}$$

Using the Donnachie-Landshoff (DL) parametrization of the total cross sections [6] we have [7]

$$\sigma_{tot}(\rho p) \simeq \sigma_{tot}(\omega p) \simeq 13.36 s^{\Delta} + 31.79 s^{-\eta} \tag{23}$$

$$\sigma_{tot}(\phi p) \simeq 10.01 s^{\Delta} + 1.51 s^{-\eta} \tag{24}$$

where $\Delta = 0.0808$ and $\eta = 0.4525$. With these numbers we deduce that in the HERA energy range the direct $\gamma - \rho$ coupling is responsible for 78% of the corresponding photoproduction cross section. At lower energies the percentage of rho is slightly higher. In our calculations we have used an overall average of $C_\rho = 0.785$, $C_\omega = 0.090$ and $C_\phi = 0.125$.

2 Total cross sections

To facilitate a numerical calculation, we need to specify our input to Eq. (9) and (10). To this end, and in accordance with our basic assumption that the photoproduction processes under consideration are soft, we utilize a DL type parametrization, where we take as our input

$$\sigma_{tot} = X(\frac{s}{s_0})^{\Delta} + Y(\frac{s}{s_0})^{-\eta} \tag{25}$$

with $\Delta = 0.0808$ and $\eta = 0.4525$ [6]. Our choice X = 73.5 μb and Y = 175 μb (with $s_0 = 1\ GeV^2$) are bigger than those used by DL, so as to compensate for the absorption initiated by the eikonalization. For Eq.(10) we chose $R_0^2 = 4.6\ GeV^{-2}$ and $\alpha'_P = 0.25\ GeV^{-2}$. With this input we are able to reproduce the low energy ($\sqrt{s} \leq 15$ GeV) data well. Our results (denoted as GLM) for the entire energy range $\sqrt{s} \geq 5$ GeV are shown in Fig.1 together with the relevant experimental points for σ_{tot} [1,2,8]. In general, the contribution of the Regge term in the HERA energy range is negligible, so that these data points actually fix the Pomeron term. We did not attempt a " best fit" by fine tuning our parameters, as considerable ambiguity still exists for the measurement of σ_{tot} at HERA, where the reported experimental errors are larger than 10%, mostly due to systematic uncertainties.

A very important feature of our calculation is that σ_{tot} in the energy range discussed, behaves effectively like $s^{0.066}$. This is lower than our input value of $\Delta = 0.0808$ suggested by DL. Our result is a direct consequence of the eikonalization summation, where the input Δ changes slowly with increasing s, towards an asymptotic ln^2s behaviour, as implied by Eq. (13). Our value of $\Delta_{eff} = 0.066$ should be compared with ALLM [9] who have $\Delta = 0.045$ and Capella et al. [10] who find $\Delta = 0.077$. The exact value of Δ_{eff} in photoproduction processes is of considerable interest. DL suggest a universal value of $\Delta = 0.0808$. This is supported mainly by the $\bar{p}p$ data where σ_{tot} values are available up to $\sqrt{s} = 1800$ GeV. As we have noted previously, the HERA data presently available is not sufficiently accurate to distinguish between the various choices of Δ_{eff}. To be able to do this, the experimental error has to be reduced by about a factor of three. This requires a radical reduction of the present systematic error at HERA, which is not an easy task.

3 Elastic cross sections

The photoproduction reaction γ + p $\rightarrow$ V + p (where V = ρ, ω, ϕ) and the total cross section are related by

$$\frac{4\pi\alpha}{f_V^2}\sigma(\gamma p \rightarrow Vp) = (1+\rho^2)\frac{[C_V\sigma_{tot}(\gamma p)]^2}{16\pi B_{el}} \tag{26}$$

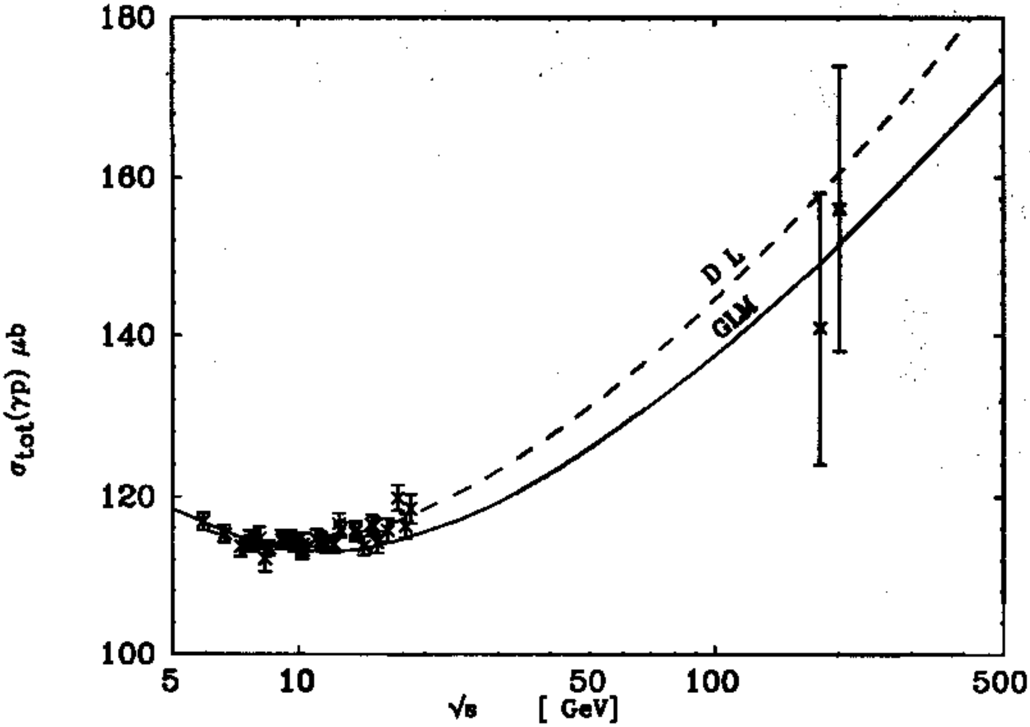

Figure 1: Total photoproduction cross section as a function of the γp center of mass energy.
The solid line is the prediction of the DL model, while the dashed line is that of GLM.

At HERA energies, $\rho^2 \ll 1$ and can safely be neglected. At lower energies for the reaction $\gamma p \to \rho p$, we find that $\rho^2 \simeq 0.1$ for $\sqrt{s} = 5$ GeV, with increasing energy it reduces rapidly, so that at $\sqrt{s} = 20$ GeV $\rho^2 \simeq 0.01$.

With our input Eqs.(20-24), and assuming the same elastic slope B_{el} for ρ, ω, and ϕ photoproduction we obtain,

$$\sigma(\rho)\ : \sigma(\omega)\ : \sigma(\phi) = 0.81\ : 0.09 : 0.10 \tag{27}$$

Clearly, the best procedure to analyze the elastic data we are discussing, is to make a combined analysis of σ_{tot} ,σ_{el} and B_{el} . This is not practical as for $\gamma p \to \rho p$ at low energies we have only one measurement [11] of $B_{el} = 10.6 \pm 1.0\ GeV^{-2}$ (at $\sqrt{s}$ =14 GeV) , which covers sufficiently low values of $| t |$. From the ZEUS data on σ_{tot} and σ_{el} quoted in Table I, we deduce that $B_{el} = 13.2\ GeV^{-2}$ at $\sqrt{s}$ =180 GeV. These values suggest $R_0^2 = 4.0$ GeV^{-2}. We have found that a better overall reproduction of σ_{tot} and σ_{el} is achieved with $R_0^2 = 4.6\ GeV^{-2}$, which is the value used throughout the present analysis.

The assumption that all vector mesons have a common slope B_{el}, is an oversimplification. From the analysis of purely hadronic reactions we know that B_{el} becomes smaller with increasing m_V^2. For $\gamma p \to \phi p$ we have a measured value [12] of $B_{el} = 6.0 \pm 0.3\ GeV^{-2}$ at $\sqrt{s} = 2.5$ -3.7 GeV . This corresponds to a choice of $R_0^2 \simeq 2.3\ GeV^{-2}$ and changes the ratio given in Eq.(27) to

$$\sigma(\rho)\ : \sigma(\omega)\ : \sigma(\phi) = 0.79\ : 0.08\ : 0.12 \tag{28}$$

due to the different values of R_0^2 chosen for ρ, ω and ϕ. We note that in the DL model $B_{el} = \frac{1}{2} R^2(s)$. As a consequence of eikonalization we expect that $B_{el}^{GLM} > B_{el}^{DL}$. This difference which is small at HERA energies, increases significantly with energy.

Our predictions for $\sigma(\gamma p \to \rho p)$ together with the relevant data [2, 8] are illustrated in Fig.2. We also show the predictions of the DL model taking $R_0^2 = 4.6\ GeV^{-2}$. Once again, we observe a systematic difference between the DL predictions and ours. These differences are listed in Table I for $\sqrt{s} = 180$ GeV together with the reported ZEUS data [2]. As in the analysis of σ_{tot}, the error on the reported data point for $\sigma(\gamma p \to \rho p) =$ $18 \pm 7\ \mu$b (at $\sqrt{s}$ =180 GeV) is too large to allow one to dicriminate between the two models.

Table I also contains the predictions of the DL and GLM models for ω and ϕ photoproduction. We have denoted by DL1 and GLM1 the models evaluated with a common B_{el} , e.g. Eq.(27). By DL2 and GLM2 we denote the results where a different value of the slope has been used for ϕ photoproduction, e.g. Eq.(28). The results for $\gamma p \to \phi p$ should be compared with the parametrization suggested by DL, where [6]

$$\sigma(\gamma p \to \phi p) = 0.275\ s^{0.1616}\ (\mu b) \tag{29}$$

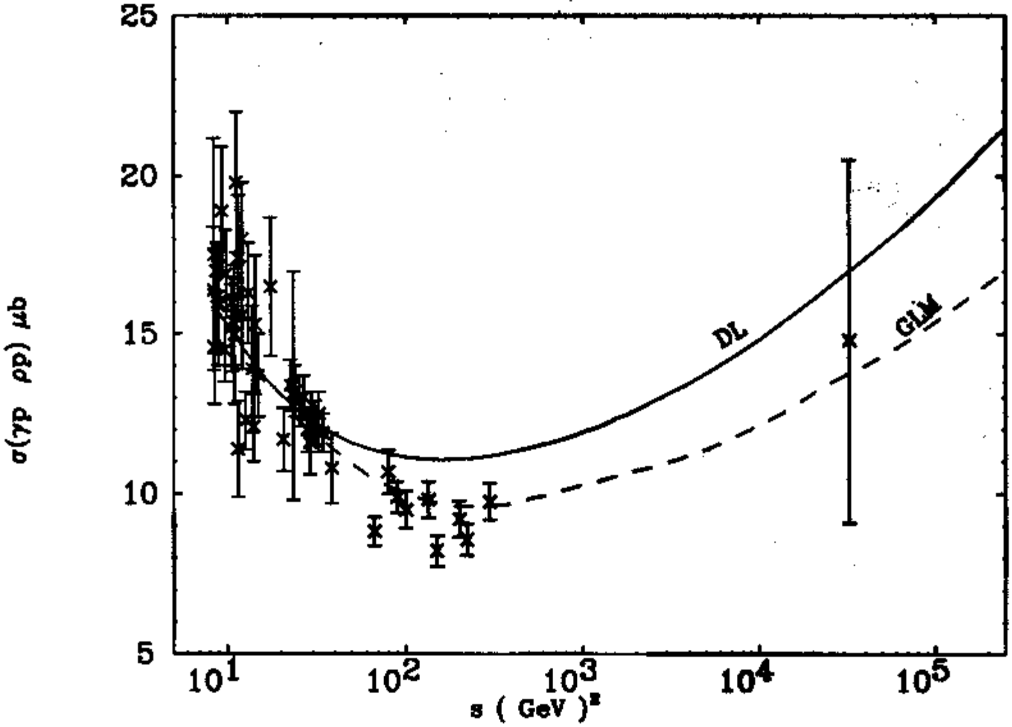

Figure 2: Cross section for $\sigma(\gamma p \to \rho p)$ as a function of the γ p center of mass energy squared. Curves as in Fig. 1

The above parametrization leads to a value $\sigma(\phi) = 1.5\ \mu$b at $\sqrt{s} = 180$ GeV. The problem is that the above fit when compared to the DL parametrization for σ_{tot} implies that B_{el} $= 18.0\ GeV^{-2}$ with no energy dependence. This value is a factor of more than two larger than the reported data point of Ref. 12.

In Table I we also show the results of our attempt to evaluate $\sigma(\gamma p \to \psi p)$ at $\sqrt{s} =$ 180 GeV. The data [13] shows a rapid increase of $\sigma(\psi)$ from threshold to a local plateau of 25 nb at $\sqrt{s} = 15$ GeV. In our interpretation, this is the energy value where the Pomeron contribution is larger than the Reggeon one, safely enabling us to extrapolate to $\sqrt{s} =$ 180 GeV. We use the same notation as previously, i.e. DL1 and GLM1 correspond to a common B_{el}, which is not a realistic assumption due to the relatively large mass of the ψ. For a more realistic estimate we use $R_0^2 = 0.5\ GeV^{-2}$ for DL2 and GLM2. Due to the small cross sections, the differnce between the predictions for DL and GLM models are insignificant. This is not suprising, as for small Ω, $(1 - e^{-\Omega}) \simeq \Omega$.

Table I. ZEUS data and the DL and GLM predictions at $\sqrt{s} = 180$ GeV

	ZEUS data	DL1	DL2	GLM1	GLM2
σ_{tot} (μb)	143 ± 4 ± 17	157.9	157.9	149.8	149.8
$\sigma(\gamma p \to \rho p)$ (μb)	14.8 ± 5.7	17.1	17.1	13.7	13.7
$\sigma(\gamma p \to \omega p)$ (μb)		1.9	1.9	1.5	1.6
$\sigma(\gamma p \to \phi p)$ (μb)		2.1	2.6	1.7	2.1
$\sigma(\gamma p \to V p)$ (μb)	18.0 ±7.0	21.1	21.6	16.9	17.4
$\sigma(\gamma p \to X_1 p)$ (μb)		14.4	14.4	12.2	12.2
$\sigma(\gamma p \to V X_2)$ (μb)		12.0	12.2	10.2	10.3
$\sigma(\gamma p \to X_1 X_2)$ (μb)		8.1	8.2	7.3	7.4
σ_{diff} (μb)	33.0 ± 8.0	34.5	34.8	29.7	29.9
$\sigma(\gamma p \to \psi p)$ (nb)		46.2	31.5	45.0	30.5
$\sigma(\gamma p \to \psi X)$ (nb)		36.8	33.1	22.1	20.6

4 Diffractive cross sections

There are three diffractive photoproduction channels to consider

$$\gamma p \to X_1 p \tag{30}$$

$$\gamma p \to V X_2 \tag{31}$$

$$\gamma p \to X_1 X_2 \tag{32}$$

The single diffractive channels given in Eqs.(30) and (31) can be calculated using the triple Regge formalism, e.g. Eq. (16-17). To perform such a calculation we need values for the parameters G_{PPP} and G_{PPR}, in addition to those parameters fixed from the analysis of the total and elastic cross sections. Unfortunately, we do not have sufficient data to support such an analysis. The only experimental data available [11], for reaction Eq.(30) is at $\sqrt{s} = 14$ GeV, where a very simple triple critical Pomeron ($\Delta = 0$) type behaviour was assumed, and the PPR contribution was neglected. With these assumptions one has

$$\frac{d\sigma_{sd}}{dt dx} = \frac{A}{1-x} \cdot e^{b(t+0.05)} \tag{33}$$

where the given fits for A and b enable us to evaluate $\sigma_{sd}(\gamma p \to X_1 p) = 7.5$ μb at this energy with the diffractive mass $2\ GeV^2 \leq M^2 \leq 0.05s$.

If we assume a simple supercritical Pomeron model, such as the DL model, then Eq.(16) implies that

$$\frac{\sigma_{sd}(s_1)}{\sigma_{sd}(s_2)} = (\frac{s_1}{s_2})^{2\Delta} \frac{\bar{R}_1^2(\frac{s_2}{<M_2^2>})}{\bar{R}_1^2(\frac{s_1}{<M_1^2>})} \tag{34}$$

where $< M_i^2 >$ denotes the weighted average of the M^2 distribution.

The above expression for σ_{sd} grows much faster than σ_{tot}, so the need for screening corrections is apparent. The energy scale at which these corrections become important is not known. Assuming Eq. (17), we expect

$$\frac{\sigma_{sd}(s_1)}{\sigma_{sd}(s_2)} = (\frac{s_1}{s_2})^{2\Delta} \cdot \frac{\bar{R}_1^2(\frac{s_2}{<M_2^2>})}{\bar{R}_1^2(\frac{s_1}{<M_1^2>})} \cdot \frac{[2\nu(s_2)]^{a(s_2)}}{[2\nu(s_1)]^{a(s_1)}} \frac{\gamma[a(s_1), 2\nu(s_1)]}{\gamma[a(s_2), 2\nu(s_2)]} \tag{35}$$

The energy dependence suggested by Eq.(35) is much milder than that of the non-corrected formula in Eq.(34). We note that in the high energy limit $B_{sd}^{DL} = \frac{1}{2}\bar{R}_1^2$, while B_{sd}^{GLM} is slightly larger, however even at HERA energies the difference is not significant.

To calculate the cross section for the reactions listed in Eqs. (31) and (32), we assume the non-relativistic quark model and approximate factorization, from which we derive the equalities

$$\sigma_{sd}(\gamma p \to \rho X_2) = \frac{2}{3} \sigma_{sd}(\gamma p \to X_1 p) \tag{36}$$

$$\sigma_{sd}(\gamma p \to X_1 X_2) = \frac{\sigma_{sd}(\gamma p \to X_1 p) \sigma_{sd}(\gamma p \to \rho X_2)}{\sigma_{el}(\gamma p \to \rho p)} \tag{37}$$

Two sets of results depending on the choice of R_0^2 for DL and for the unitarity corrected GLM diffractive cross sections at $\sqrt{s}$ = 180 GeV are summarized in Table I. Both the DL and our calculation (GLM) yield a very reasonable diffractive cross section of 29-35 μb. These results should be compared with the experimental value of 33 $\pm 8\mu$b given by ZEUS.

We have also calculated the inclusive cross section for $\gamma + p \rightarrow \psi + X$. As in our previous calculations we start with an average $\sigma(\gamma + p \rightarrow \psi + X) = 18$ nb at $\sqrt{s} = 15$ GeV [14], and obtain the results given in Table I for $\sqrt{s}$ = 180 GeV. Unfortunately, due to the lack of uniformity associated with the definition of diffractive events, our results are somewhat uncertain.

5 Discussion

The two models discussed in this paper differ greatly in their physical content. The DL model has a most attractive feature in that all Pomeron exchange reactions have the same predicted energy dependence, i.e. $s^{0.0808}$ for σ_{tot} and $s^{0.1616}$ modulated by a lns term for σ_{el} and σ_{diff}. One of the deficiencies of the model is that there is no hint at what energy scale this simple parametrization will fail to describe the data, in addition it has no provision for incorporating unitarity corrections, which become important at higher energies. Hence, the predictive power of the DL model at exceedingly high energies is limited.

In contrast the GLM eikonal model is unitarized by construction, and as such predicts that the effective energy dependence differs in different energy domains, changing gradually from a powerlike behaviour in energy to ln^2s. In addition, the energy dependence, which is universal in the DL model, evolves differently for the different channels in the GLM eikonal model.

For this reason it is important to study photoproduction processes and examine their energy dependence. At present this is not a decisive test, as both the DL model with Δ = 0.0808 and ALLM with Δ = 0.045 are compatible with the HERA data points. Our present treatment suggests an effective $\Delta_{eff} = 0.066$. We await improvement of the data points measured at HERA, to discriminate between the different models.

In this paper we have studied photoproduction processes initiated by a quasi real photon. The problem of how to extrapolate these cross sections as a function of the photon's virtuality Q^2, has been discussed recently in several papers [9,10,15]. A conclusion common to all of these investigations is, that whereas Δ is relatively small ($\Delta \leq 0.1$) for

$Q^2 \leq 5\ GeV^2$, it becomes considerably larger $\Delta \simeq 0.35$ for $Q^2 > 10\ GeV^2$. This has interesting consequences for the case of high mass diffraction in real photoproduction and DIS. Both H1 and ZEUS assume that $\frac{d\sigma_{sd}}{dM^2}$ has a M^{-2} dependence on the diffractive mass. Actually, in the triple Regge limit, with or without screening corrections, we expect the dependence to be $M^{-2\alpha_P(0)}$, where $\alpha_P(0)\ = 1 + \Delta$. This was observed in $\bar{p}p$ interactions at the Tevatron [16]. For real photoproduction, where $Q^2 = 0$, this is an insignificant correction as Δ is small, however, for $Q^2 > 10\ GeV^2$ where $\alpha_P(0) = 1.35$, we expect a dramatic change in the behaviour of $\frac{d\sigma_{sd}}{dM^2}$.

We would like to mention that the GLM eikonal model enables one to describe the matching between deep inelastic data with $\Delta\ \sim 0.35$ and the photoproduction data with $\Delta\ \sim\ 0.08$ incorporating sufficiently strong shadowing correction, as well as non-Regge like power behaviour of the Pomeron contribution (see Ref. [3] for the first attempt in this direction). Since in QCD the Pomeron structure is not a simple Regge pole, we can incorporate the Q^2 behaviour both in the scale of the shadowing correction, and in the effective power of of ν on s. We postpone futher discussions of this interesting question to further publications.

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