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Predicting $F_2^{D(3)}$ from the dipole cross-section

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We employ a parameterisation of the proton dipole cross section previously extracted from electroproduction and photoproduction data to predict the diffractive structure function $F_2^{D(3)}(Q^2, \beta, x_{I\!P})$. Comparison with HERA H1 data yields good agreement.

1. Introduction

The proton dipole cross section σ_d is a universal quantity in singly dissociative diffractive γ p processes. [1,2] It is simply the total cross section for scattering a $q\bar{q}$ pair of a given size and energy in the photonic fluctuation off the proton target. We make use of a parameterisation used to extract σ_d from a fit to electroproduction and photoproduction γ p total cross-section data [3] to predict the diffractive structure function $F_2^{D(3)}(Q^2, \beta, x_{I\!P})$.

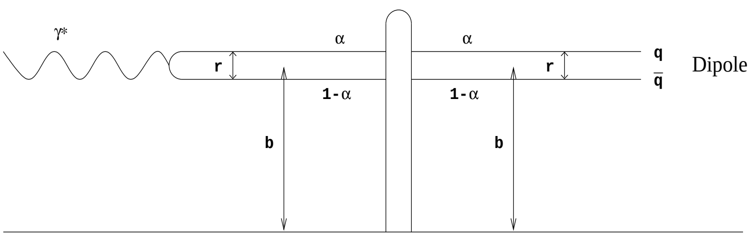

Figure 1. The dipole fluctuation of the incoming photon.

2. Functional forms

The dipole cross-section is in general a function of three variables (Figure 1): $s = W^2$, the CMS energy squared of the photon proton system; r, the transverse separation averaged over all orientations of the $q\bar{q}$ pair; and α, the fraction of the incoming photon light cone energy possessed by one member of the $q\bar{q}$ pair. We assumed a form with two

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terms, each with a Regge type s dependence and no dependence on α. Specifically, we assumed

$$\sigma_d(s,r) = a_0^S \left(1 - \frac{1}{1+(a_1^S r + a_2^S r^2)^2}\right)(r^2 s)^{\lambda_S} + (a_1^H r + a_2^H r^2 + a_3^H r^3)^2 \exp(-\nu_H^2 r)(r^2 s)^{\lambda_H}. \quad (1)$$

The dipole cross section is related to the photon proton cross section via

$$\sigma^{L,T}_{\gamma^*,p} = \int \mathrm{d}\alpha \mathrm{d}^2 r \, |\psi^{L,T}_\gamma(\alpha,r)|^2 \sigma_d(s,r,\alpha) \quad (2)$$

where $\psi^{L,T}_\gamma(\alpha,r)$ are the longitudinal and transverse components of the light cone photon wave function. For the photon wave function itself, we used the tree level QED expression [1,4] modified by a factor $f(r)$ to represent confinement effects:

$$|\psi_L(\alpha,r)|^2 = \frac{6}{\pi^2}\alpha_{em}\sum_{q=1}^{3} e_q^2 Q^2 \alpha^2 (1-\alpha)^2 K_0^2(\epsilon r) \times f(r) \quad (3)$$

$$|\psi_T(\alpha,r)|^2 = \frac{3}{2\pi^2}\alpha_{em}\sum_{q=1}^{3} e_q^2 \left\{[\alpha^2 + (1-\alpha)^2]\epsilon^2 K_1^2(\epsilon r) + m_f^2 K_0^2(\epsilon r)\right\} \times f(r) \quad (4)$$

and

$$f(r) = \frac{1 + B\exp(-c^2(r-R)^2)}{1 + B\exp(-c^2 R^2)}. \quad (5)$$

Here $\epsilon^2 = \alpha(1-\alpha)Q^2 + m_f^2$, K_0 and K_1 are modified Bessel functions and the sum is over 3 light quark flavours, with a generic mass of assumed value $m_f^2 = 0.08$ GeV^2. The values of the constants B, c^2, and R were generated by the fit.

3. Calculating $F_2^{D(3)}$

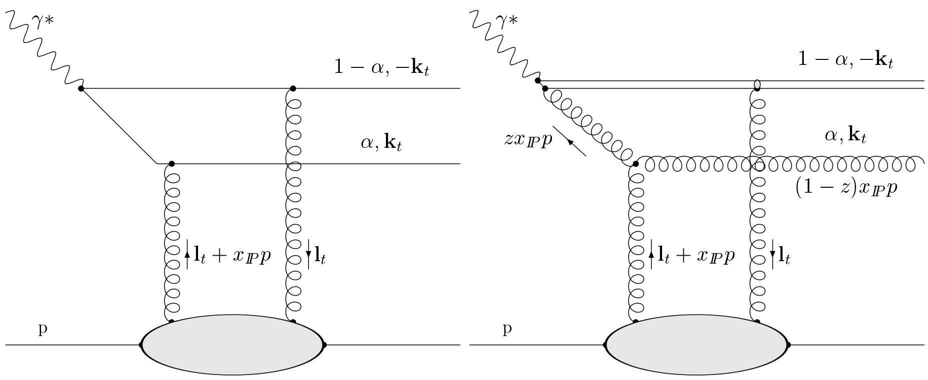

Figure 2. The q$\bar{\text{q}}$ and q$\bar{\text{q}}$g contributions to $F_2^{D(3)}$.

To calculate the contribution of the quark antiquark dipole to $F_2^{D(3)}$ we made use of expressions derived from a momentum space treatment [5,6]. Also, we calculated the contribution of the higher q$\bar{\text{q}}$g Fock state using an effective two gluon dipole description from the same source. Typical Feynman diagrams are shown in Figure 2. For compatibility with this approach, we must replace s by $\tilde{s}$, where $\tilde{s} = Q^2(1/x_{I\!P} - 1)$. First defining

$$\Phi_{0,1} \equiv \int_0^\infty r\mathrm{d}r K_{0,1}(\epsilon r)\sigma_d(r,\tilde{s})J_{0,1}(kr) \int_0^\infty r\mathrm{d}r f(r) K_{0,1}(\epsilon r)\sigma_d(r,\tilde{s})J_{0,1}(kr), \tag{6}$$

we have for the longitudinal and transverse q$\bar{\text{q}}$ components respectively

$$x_{I\!P} F^D_{q\bar{q},L}(Q^2,\beta,x_{I\!P}) = \frac{3Q^6}{32\pi^4\beta b} \cdot \sum_{f=1}^{3} e_f^2 \cdot 2\int_{\alpha_0}^{1/2} \mathrm{d}\alpha\alpha^3(1-\alpha)^3\Phi_0 \tag{7}$$

$$x_{I\!P} F^D_{q\bar{q},T}(Q^2,\beta,x_{I\!P}) = \frac{3Q^4}{128\pi^4\beta b} \cdot \sum_{f=1}^{3} e_f^2 \cdot 2\int_{\alpha_0}^{1/2} \mathrm{d}\alpha\alpha(1-\alpha) \left\{\epsilon^2[\alpha^2 + (1-\alpha)^2]\Phi_1 + m^2\Phi_0\right\} \tag{8}$$

where the lower limit of the integral over α is given by $\alpha_0 = (1/2)\left(1 - \sqrt{1 - 4m_f^2/M_X^2}\right)$ and b is the slope parameter, which we have taken as 7.2 [7]. For the q$\bar{\text{q}}$g term we have

$$x_{I\!P} F^D_{q\bar{q}g}(Q^2,\beta,x_{I\!P}) = \frac{81\beta\alpha_S}{512\pi^5 b} \sum_f e_f^2 \int_\beta^1 \frac{\mathrm{d}z}{(1-z)^3} \left[\left(1-\frac{\beta}{z}\right)^2 + \left(\frac{\beta}{z}\right)^2\right] \tag{9}$$

$$\times \int_0^{(1-z)Q^2} \mathrm{d}k_t^2 \ln\left(\frac{(1-z)Q^2}{k_t^2}\right) \left[\int_0^\infty u\mathrm{d}u\, \sigma_d(u/k_t,\tilde{s}) K_2\left(\sqrt{\frac{z}{1-z}u^2}\right) J_2(u)\right]^2 \tag{10}$$

with $\alpha_S = 0.2$. (We have inserted a missing factor of 1/2 compared with the expression in [6].) This expression diverges if our parameterisation is used as it stands. However, this is due solely to the mild divergence after σ_d saturates in r of the factor $(r^2 s)^{\lambda_S}$ as $r \to \infty$. This behaviour at large r is not determined by data and is an artefact of the parameterisation. Hence we have imposed a saturation value for σ_d of its value at $r = 2$ fm for all higher r. Plots of the contributions to $x_{I\!P} F_2^{D(3)}$ calculated from these expressions are compared with H1 1994 data [8] in Figure 3. Agreement is good, even at low β where the q$\bar{\text{q}}$g term dominates. Comparison with ZEUS 1994 data [9] also gives good agreement overall but with deviations at larger Q^2 values for small and moderate β.

4. Conclusions

We have successfully predicted the diffractive structure function $F_2^{D(3)}$ using a parameterised dipole cross section obtained from electro- and photoproduction data. Unlike the model proposed in [6,10], the parameterisation exhibits effective saturation in r only, with no saturation in the energy variable $s = W^2$. Agreement with data is reasonable, leading to the conclusion that the HERA data do not necessarily indicate such saturation at present energies.

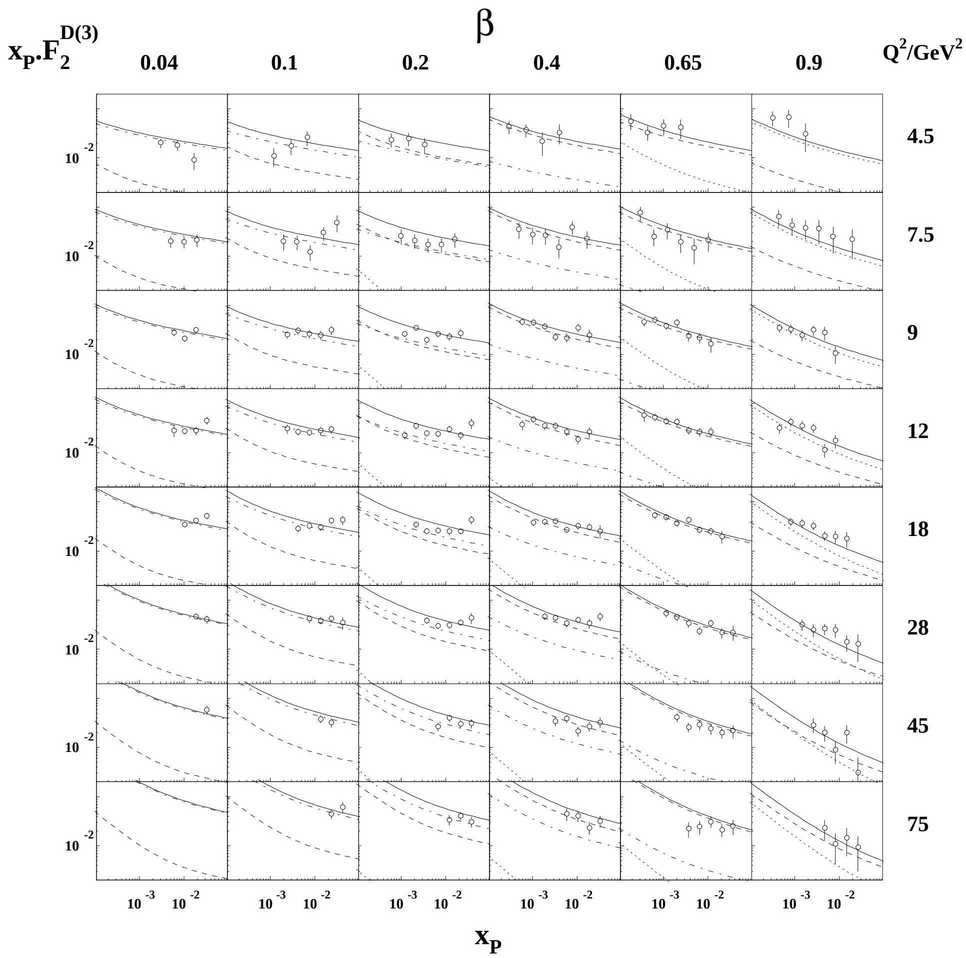

Figure 3. Contributions to $x_{I\!P} F_2^{D(3)}$ compared with H1 1994 data. Full, dotted, dashed and dot dashed lines are the total, longitudinal $q\bar{q}$, transverse $q\bar{q}$ and $q\bar{q}g$ contributions respectively.

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