Inclusive Diffraction at HERA

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Abstract. Results from the HERA collaborations H1 and ZEUS on the diffractive structure function are presented. Intermediate Q^2 data are successfully described by a two-component Regge-motivated model, and QCD analysis reveals the pomeron to have a large gluonic content. Recent low Q^2 data confirm the rise of the effective pomeron intercept with Q^2, which is unexpected for a simple Regge pole. The qualitative features of the data are successfully described by the "saturation" model.

INTRODUCTION

The diffraction of virtual photons in e^+p collisions has been a subject of great interest. The H1 and ZEUS collaborations study the diffractive process $ep \to eXY$, as shown in figure 1, which is mediated by the exchange of a net colour singlet state with vacuum quantum numbers, the pomeron ($I\!P$). X and Y are hadronic systems produced at the $\gamma^* I\!P$ and $pI\!P$ vertices respectively separated by a large gap in rapidity, a characteristic signature of diffractive deep-inelastic scattering (DIS) interactions. Taking the 4-vectors of the incoming(outgoing) lepton, proton and virtual photon to be $e(e')$, $p(p')$ and q respectively, the DIS kinematic variables are,

$$s = (e+p)^2 \qquad W^2 = (q+p)^2 \qquad Q^2 = -q^2 = (e-e')^2, \tag{1}$$

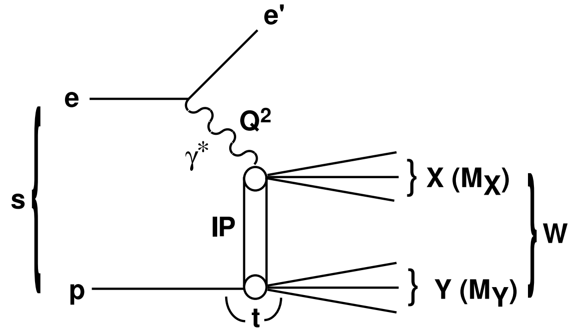


FIGURE 1. Kinematics of inclusive diffractive DIS at HERA.

where s is the ep centre of mass energy squared, W^2 the $\gamma^* p$ centre of mass energy squared and Q^2 the photon virtuality. The scaling variables are $x = (-q^2)/(2p \cdot q)$ and $y = (p \cdot q)/(p \cdot e)$. The diffractive variables are,

$$t = (p - p')^2 \qquad x_{I\!P} = \frac{q \cdot (p - p')}{q \cdot p} \qquad \beta = \frac{-q^2}{2q \cdot (p - p')}, \tag{2}$$

where t is the 4-momentum transfer squared at the proton vertex and $x_{I\!P}$ and β may be interpreted as the fraction of the proton's 4-momentum transferred to the pomeron and the fraction of the 4-momentum of the pomeron carried by the struck quark respectively. Note that $x = x_{I\!P}\beta$.

The process has previously been well measured at medium [1] [2] and high [3] Q^2. New data have been released by ZEUS [4] in the transition region between photoproduction and DIS, which previously was neither well measured nor understood.

Soft hadron-hadron and photoproduction experiments showed diffraction to be universally well described in terms of a pomeron trajectory [5],

$$\alpha_{\mathrm{I\!P}}(t) = \alpha_{\mathrm{I\!P}}(0) + \alpha'_{\mathrm{I\!P}} t, \tag{3}$$

where $\alpha_{\mathrm{I\!P}}(0) = 1.08$ and $\alpha'_{\mathrm{I\!P}} = 0.25$ GeV^{-2}. In comparison DIS is well described by the hard processes of QCD. There therefore exists a region of transition where the interplay of soft and hard processes can be studied.

INTERMEDIATE Q^2 MEASUREMENTS

The diffractive structure function $F_2^{D(3)}$ is defined as,

$$\frac{d^3\sigma(ep \to epX)}{dx d\beta dQ^2} = \frac{4\pi\alpha_{em}^2}{\beta^2 Q^4}\left(1 - y + \frac{y^2}{2}\right) F_2^{D(3)}(\beta, Q^2, x_{I\!P}), \tag{4}$$

where the longitudinal photon contribution F_L^D is neglected. A measurement of the inclusive diffractive proton structure function was extracted from H1 1994 data [1] via detection of large rapidity gap events. The kinematic region covered was $4.5 < Q^2 < 75$ GeV^2, $0.0002 < x_{I\!P} < 0.04$ and $0.04 < \beta < 0.9$. The measurement was also constrained to the region $M_Y < 1.6$ GeV and $|t| < 1$ GeV^2. The measured $x_{I\!P}$ dependence of $x_{I\!P} F_2^{D(3)}$ is shown in bins of β and Q^2 in figure 2.

The data show an overall trend for $x_{I\!P} F_2^{D(3)}$ to fall with increasing $x_{I\!P}$. However at low values of β, the data rise at the highest values of $x_{I\!P}$. These features of the data are successfully described by a two component Regge model comprising a leading pomeron and a subleading meson component. Assuming Regge factorisation, the diffractive structure function can be represented as,

$$F_2^{D(3)}(x_{I\!P}.\beta, Q^2) = f_{\mathrm{I\!P/p}}(x_{I\!P}) F_2^{\mathrm{I\!P}}(\beta, Q^2) + f_{\mathrm{I\!R/p}}(x_{I\!P}) F_2^{\mathrm{I\!R}}(\beta, Q^2), \tag{5}$$

where,

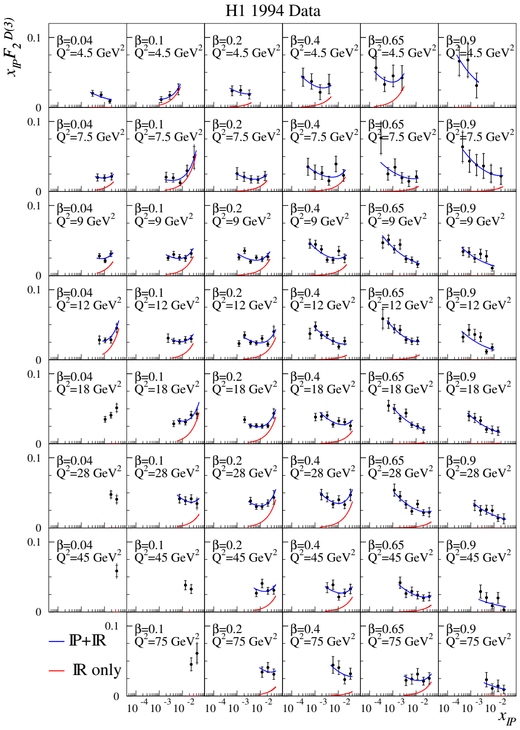


FIGURE 2. Measurement of the diffractive structure function, $x_{I\!P}F_2^{D(3)}$ as a function of $x_{I\!P}$.

$$f_{\mathrm{I\!P}/\mathrm{p}} = \int_{t_{cut}}^{t_{min}} \frac{e^{B_{\mathrm{I\!P}}t}}{x_{I\!P}^{2\alpha_{\mathrm{I\!P}}(t)-1}} dt \qquad f_{\mathrm{I\!R}/\mathrm{p}} = \int_{t_{cut}}^{t_{min}} \frac{e^{B_{\mathrm{I\!R}}t}}{x_{I\!P}^{2\alpha_{\mathrm{I\!R}}(t)-1}} dt, \tag{6}$$

where $B_{\mathrm{I\!P}}$ and $B_{\mathrm{I\!R}}$ are slope parameters. Regge fits to the data yield values of,

$$\alpha_{\mathrm{I\!P}}(0) = 1.203 \pm 0.020 \text{ (stat.)} \pm 0.013 \text{ (syst.)} \,{}^{+0.030}_{-0.035} \text{ (model)}, \tag{7}$$

$$\alpha_{\mathrm{I\!R}}(0) = 0.50 \pm 0.11 \text{ (stat.)} \pm 0.11 \text{ (syst.)} \,{}^{+0.09}_{-0.10} \text{ (model)}. \tag{8}$$

Hence although the value of $\alpha_{\mathrm{I\!R}}(0)$ agrees with that from total hadron cross section analyses (for f_2 exchange for example), the measured value of $\alpha_{\mathrm{I\!P}}(0)$ is larger than that of the soft pomeron, indicating that the physics processes differ in the photoproduction and DIS regimes.

Scaling Violations

The Q^2 dependence of $F_2^{D(3)}$ as measured from 1994-1995 data [3] is shown in figure 3(a). The low value of $x_{I\!P}(= 0.005)$ at which the study is performed implies that subleading contributions are negligible, hence the dependence on Q^2 of the pomeron structure function is directly visible. Figure 3(a) shows $x_{I\!P}F_2^{D(3)}$ as a function of Q^2 and positive scaling violations are visible, persisting to high β values, implying a large gluonic component in the pomeron.

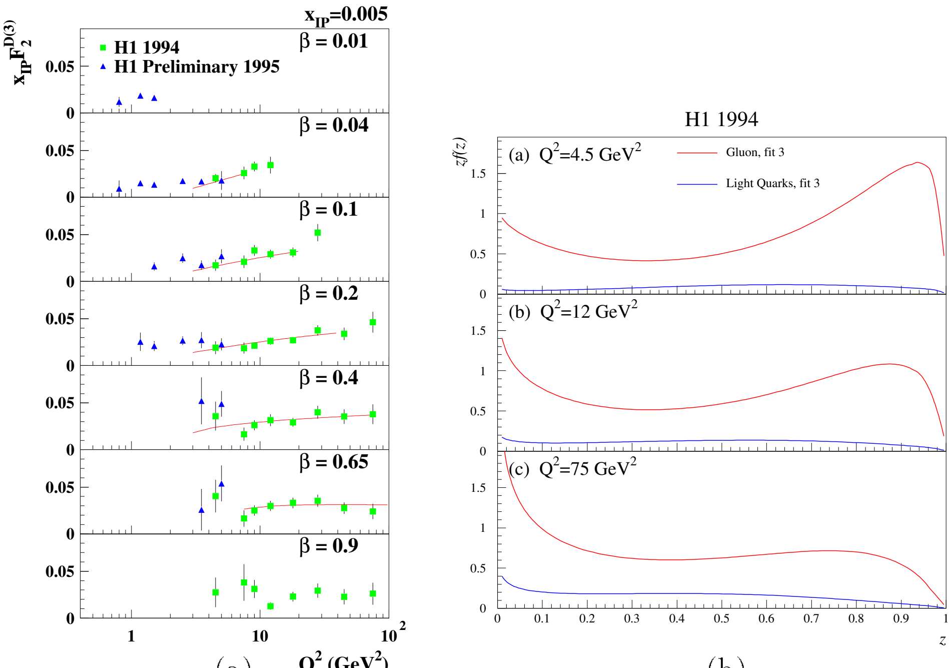
Assuming Regge factorisation, the structure functions $F_2^{I\!P}(\beta, Q^2)$ and $F_2^{I\!R}(\beta, Q^2)$ describe the structure of the pomeron and meson exchanges respectively. Assuming a parameterisation of the parton distributions of the pomeron and meson exchanges at a starting scale Q_0^2, fits have been performed to the data assuming DGLAP evolution.

Parton Distributions

Figure 3(b) shows the parton distributions which result from a QCD fit involving both light quarks and gluons with $Q_0^2 = 3.0$ GeV^2, where $f(z)$ is the parton distribution function and z is the fraction of the momentum of the pomeron carried by the parton [1]. The momentum fraction carried by gluons decreases with increasing Q^2, from approximately 90% at $Q^2 = 4.5$ GeV^2 to about 80% at $Q^2 = 75$ GeV^2. Hence the data favour a large gluonic component in the pomeron and boson-gluon fusion to be the dominant mechanism in diffractive DIS.

LOW Q^2 $F_2^{D(3)}$

Recently ZEUS measured $F_2^{D(3)}$ (1997 data) [4] using their Beampipe Calorimeter in the region $0.22 \lesssim Q^2 \lesssim 0.7$ GeV^2, a previously unexplored region of phase space. Diffractive events were selected by two different methods, the "ln M_X^2" method,



(a) (b)

FIGURE 3. (a) $x_{I\!P} F_2^{D(3)}$ as a function of Q^2 showing the rising scaling violations and (b) Pomeron parton distributions in bins of Q^2.

where the uncorrected ln M_X^2 distribution is separated into diffractive and non-diffractive parts, and the "LPS" method, in which diffractive events are identified via the diffractive peak near unity in the x_L distribution where $x_L = E_p/E_{p'}$ and E_p and $E_{p'}$ are the energies of the proton before and after scattering respectively.

For the former sample the diffractive differential cross section was measured as a function of W in bins of Q^2 and M_X. The cross section is parameterised at fixed M_X and Q^2 as,

$$\frac{d\sigma^{diff}}{dM_X} \propto (W^2)^{2(\bar{\alpha}_{\mathbb{P}}-1)}, \tag{9}$$

in Regge theory where,

$$\bar{\alpha}_{\mathbb{P}} = \alpha_{\mathbb{P}}(0) - \alpha'_{\mathbb{P}} \cdot |\bar{t}|. \tag{10}$$

A fit of the form of equation 9 was performed, yielding the value of $\bar{\alpha}_{\mathbb{P}}$ to be,

$$\bar{\alpha}_{\mathbb{P}} = 1.126 \pm 0.012\ (\text{stat.})\ {}^{+0.027}_{-0.032}\ (\text{syst.}). \tag{11}$$

Assuming $\alpha'_{\mathbb{P}} = 0.25$ GeV^{-2} and using $|\bar{t}| = 0.13$ GeV^{-2}, $\alpha_{\mathbb{P}}(0)$ was extracted via equation 10. The result is shown in figure 4 where the effective $\alpha_{\mathbb{P}}(0)$ is shown as a function of Q^2, with other results from diffractive and total cross section measurements. There is evidence for a rise of $\alpha_{\mathbb{P}}(0)$ with Q^2 in the diffractive case, unexpected from simple Regge pole theory. The diffractive and inclusive results are observed to be compatible at low Q^2 but inconsistent at higher values.

The differential cross section $d\sigma/dM_X$ has been measured as a function of Q^2 at fixed M_X and W. A turnover is observed near $Q^2 = 1$ GeV^2. The relation between the differential cross section and the diffractive structure function is given by,

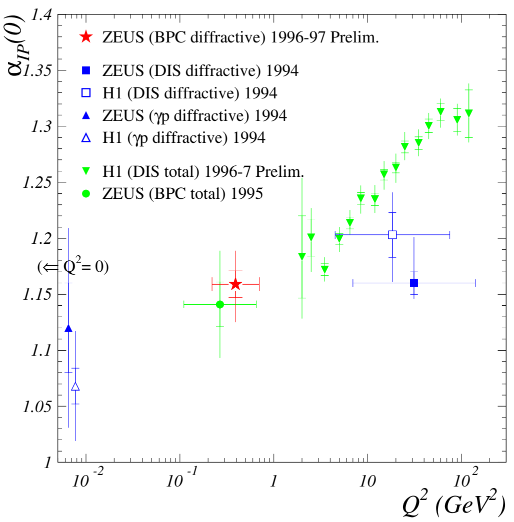


FIGURE 4. Q^2 dependence of the effective $\alpha_{\mathbb{P}}(0)$ for inclusive and diffractive ep processes.

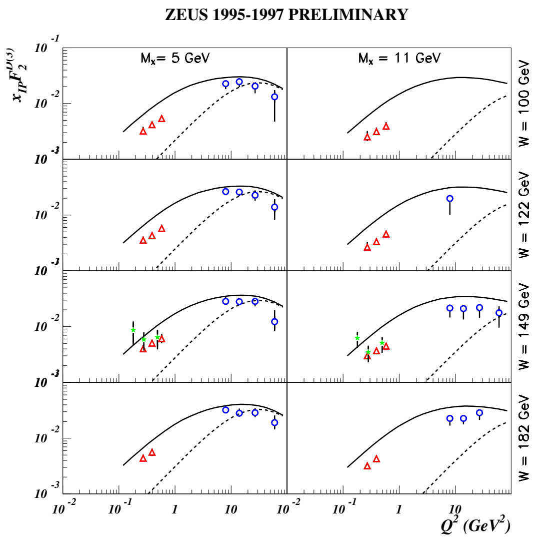


FIGURE 5. Q^2 dependence of $F_2^{D(3)}$ showing the transition at low Q^2. The triangles are from the ln M_X^2 analysis, the stars are LPS data and the circles are from a higher Q^2 analysis [2]. The dashed and solid curves show the saturation model predictions with $q\bar{q}$ and $q\bar{q}g$ terms respectively.

$$\frac{d\sigma^{diff}}{dM_X} \sim 4\pi^2\alpha \frac{2M_X}{Q^2+M_X^2} \frac{x_{\mathbb{P}} F_2^{D(3)}}{Q^2}, \qquad (12)$$

so at low values of Q^2 and fixed M_X, $x_{\mathbb{P}} F_2^{D(3)}$ is proportional to Q^2. Figure 5 shows $x_{\mathbb{P}} F_2^{D(3)}$ plotted against Q^2 in bins of M_X and W. The predictions in figure 5 are from the "saturation" model [6] [7] which assumes the virtual photon fluctuates into $q\bar{q}$ and $q\bar{q}g$ states before an interaction with the proton via a two gluon exchange. The dipole cross section for this interaction increases as Q^2 decreases and "saturates" at low Q^2. Figure 5 shows that the qualitative features (although not the normalisation) of the low Q^2 data are well reproduced. The "saturation" model is however successful at describing data at higher values of Q^2.

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