COMPARISON OF DIFFRACTIVE AND NON-DIFFRACTIVE DEEP INELASTIC SCATTERING

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ABSTRACT

A comparison is made of recent deep–inelastic scattering measurements, using data taken with the H1 detector at HERA, with Regge theory predictions based on the assumption of a universal 'soft' pomeron. It is shown that whereas the diffractive deep–inelastic scattering cross-section can be well described by such a model, the variation of the inclusive deep–inelastic scattering cross section with Bjorken x cannot. These observations are confirmed by a measurement of the ratio of the diffractive deep–inelastic cross section $\frac{\mathrm{d}^3\sigma^D_{ep}}{\mathrm{d}x\mathrm{d}Q^2\mathrm{d}\beta}$ to the inclusive deep–inelastic ep cross section $\frac{\mathrm{d}^2\sigma_{ep}}{\mathrm{d}x\mathrm{d}Q^2}$. A measurement is presented of $F_2^D(x,Q^2)$, the diffractive contribution to $F_2(x,Q^2)$ and of the ratio $r^D(x,Q^2) = F_2^D(x,Q^2)/F_2(x,Q^2)$ for $x_{I\!P} < 0.05$. It is shown that approximately 10 % of events, arise from single diffraction. The ratio is found to be rather independent of x and Q^2.

1. Introduction

The high energy ($>\simeq$10 GeV) behaviour of the elastic and total cross sections for all soft hadronic interactions (including real photon proton interactions) can be described using Regge theory in terms of t channel exchange of a universal 'soft' pomeron. Recent measurements of deep–inelastic scattering at HERA have reached the values of low Bjorken x where comparisons with the Regge model may be made. In this paper measurements of the inclusive and diffractive deep–inelastic cross sections are compared both with each other and with the predictions for a universal soft pomeron.

Regge theory predicts that the elastic ($pp \to pp$, $\pi^+p \to \pi^+p$ etc.) or quasi-elastic ($pp \to pX$, $\gamma p \to Xp$, $\pi p \to \pi X$ etc.) scattering cross section for any hadronic process to have a W^2 dependence of the form:

$$\frac{\mathrm{d}\sigma^{ELAS}(W^2,t)}{\mathrm{d}t} \propto (W^2)^{2[\alpha(t)-1]} \tag{1}$$

where W is the centre of mass collision energy, t is the 4-momentum transfer and $\alpha(t) = 1 + \alpha' t + \varepsilon$ is the Regge trajectory with intercept $\alpha(0) = 1 + \varepsilon$. The total cross section can be treated similarly by means of the optical theorem. This states that the inclusive cross section is proportional to the imaginary part of the forward ($t = 0$) elastic scattering amplitude, so:

$$\sigma^{TOT}(W^2) \propto \sqrt{\frac{\mathrm{d}\sigma^{ELAS}}{\mathrm{d}t}}\Bigg|_{t=0} \propto (W^2)^{\alpha(t=0)-1}. \tag{2}$$

At high energy ($W >\simeq 10$ GeV) it is observed that a single trajectory describes the energy behaviour of all elastic, quasi-elastic and total cross sections for hadron-hadron or photon-hadron processes. This trajectory is called the Pomeranchuk trajectory or 'soft pomeron' and has parameters $\varepsilon = 0.085$ and $\alpha' = 0.25$ [1].

Regge theory may also be applied to virtual photon proton scattering (i.e. deep–inelastic scattering) provided the condition[a] $W^2 >> Q^2$, or equivalently Bjorken $x << 1$, is fulfilled. The total virtual photon proton cross section, $\sigma^{TOT}_{\gamma^* p}$, is predicted to have a dependence (at fixed Q^2):

$$\sigma^{TOT}_{\gamma^* p}(W^2, Q^2) \propto (W^2)^{\alpha(t=0)-1} \propto \frac{1}{x^{\epsilon}} \tag{3}$$

since $x \approx Q^2/W^2$. The diffractive cross section would follow:

$$\frac{\mathrm{d}\sigma^{D}_{\gamma^* p}(W^2, Q^2, t)}{\mathrm{d}t} \propto (W^2)^{2[\alpha(t)-1]} \propto \frac{1}{x^{2[\epsilon+\alpha' t]}}. \tag{4}$$

2. Comparison of the Manifestation of the Pomeron in the Inclusive and Diffractive Virtual Photon-Proton Cross Sections.

The total and diffractive cross sections have been measured at H1 with the results expressed as the structure functions $F_2(x, Q^2)$ for the inclusive measurement and $F_2^{D(3)}(\beta, Q^2, x)$ for the diffractive contribution[b]. The structure functions are simply related to the γ^*-proton cross sections via:

$$F_2(x, Q^2) \approx \frac{Q^2}{4\pi^2\alpha}\sigma^{TOT}_{\gamma^* p}(W^2, Q^2), \qquad F_2^{D(3)}(\beta, Q^2, x) \approx \frac{Q^2}{4\pi^2\alpha}\frac{\mathrm{d}\sigma^{D}_{\gamma^* p}}{\mathrm{d}x_{I\!P}}, \tag{5}$$

where the approximation has been made assuming x is small and that both F_L (the longitudinal structure function) and F_3 can be neglected. The Regge prediction for

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[a] in deep–inelastic scattering W is the centre of mass energy of the γ^*-proton system.

[b] The variables used in diffractive deep–inelastic scattering, $x_{I\!P} = \frac{q\cdot(P-P')}{q\cdot P}$ and $\beta = \frac{x}{x_{I\!P/p}}$ are as specified in [2]. In the infinite momentum frame of the incident proton, $x_{I\!P}$ is the fraction $x_{I\!P/p}$ of the 4–momentum P of the incident proton carried by the exchange in the diffractive interaction, leaving a colourless remnant of the proton with 4–momentum P'. Similarly β is the fraction $x_{q/I\!P}$ of the 4–momentum $P - P'$ of this exchange, usually taken to be the $I\!P$, carried by the quark which interacts with the virtual photon. $t = (P - P')^2$ is the 4–momentum transfer at the incident proton vertex.

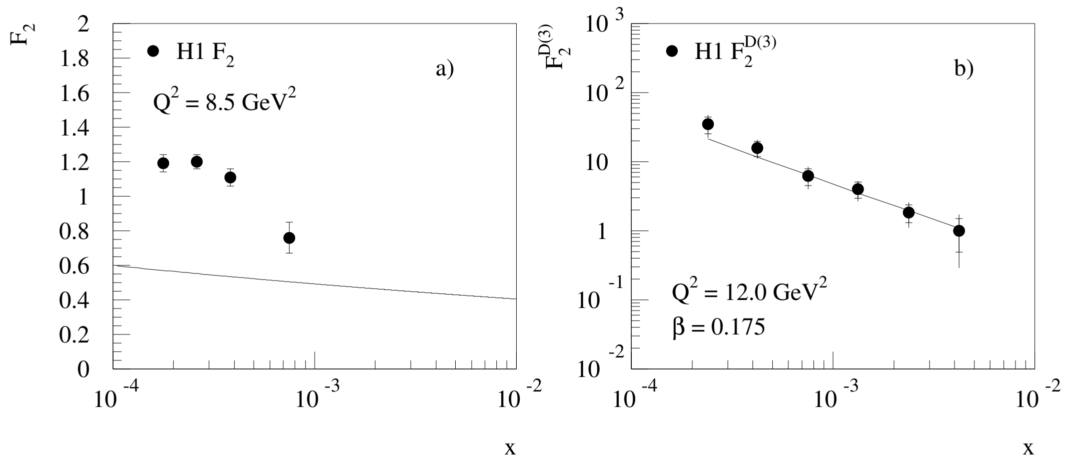

Figure 1: Comparison of a) $F_2(x,Q^2)$ and b) $F_2^{D(3)}(\beta,\, Q^2,\, x)$ with the predictions of the soft pomeron model of Donnachie and Landshoff.

fixed Q^2 and fixed β then becomes:

$$F_2(x,Q^2) \propto (W^2)^{\alpha_{I\!P}(t=0)-1} \propto \frac{1}{x^{\varepsilon_I}}, \tag{6}$$

$$xF_2^{D(3)}(\beta,\, Q^2,\, x) \propto (W^2)^{\alpha(t\approx 0)-1} \propto \frac{1}{x^{2\varepsilon_D}}, \tag{7}$$

where ε_I and ε_D denote the intercept of the manifestation of the pomeron in the inclusive and diffractive cross sections respectively.[c]

Figures 1.a and 1.b show a comparison of $F_2(x,Q^2)$ and $F_2^{D(3)}(\beta,\, Q^2,\, x)$ as measured at H1 [3, 2] with a Regge model prediction where ε is set to the soft pomeron value of 0.085 [4, 5].

It can be seen that the rise of $F_2(x,Q^2)$ with decreasing x is much faster than that predicted, indeed a fit to the measured structure function yields a value of $\varepsilon_I \simeq 0.19$ [3]. This value is, however, in closer agreement with perturbative calculations of the hard or BFKL pomeron [6].

Conversely the data for $F_2^{D(3)}(\beta,\, Q^2,\, x)$ agree well with the soft pomeron expectation giving a value of $\varepsilon_D = 0.10 \pm 0.03 \pm 0.04$ [2].

[c] In the measurement of $F_2^{D(3)}(\beta,\, Q^2,\, x)$ we perforce integrate over t. To good approximation, $\alpha(t)$ may be replaced by $\alpha(t=0)$ because the t distribution of the soft hadronic proton interaction is likely to be "peripheral" and the t dependence of $\alpha(t)$ is likely to be slight. If the t distribution of proton diffraction is here like that in soft pp collisions, namely peripheral with a dependence e^{bt} with $b > 1$, then the systematic error, which arises by ignoring any t dependence of $\alpha(t)$ of size given by the slope $\alpha' = 0.25\,\mathrm{GeV}^{-2}$ of the $I\!P$ trajectory, is 4%.

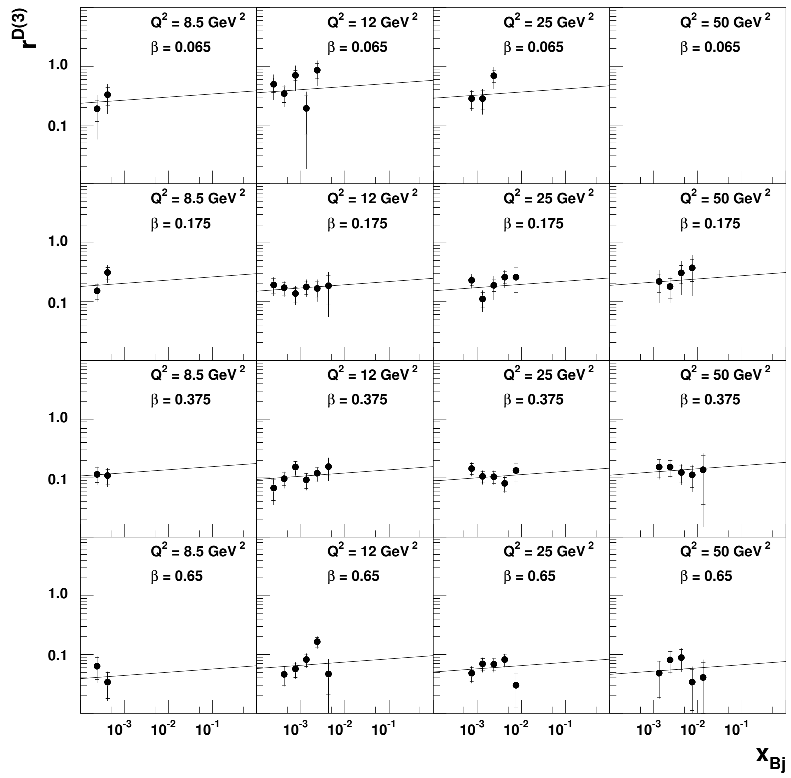

Fig. 2. The ratio $r^D(3)$ of the diffractive to the inclusive γ^*-proton cross sections. The solid line represents a fit of the form x^n with $n = 0.05 \pm 0.06 \pm 0.08$.

A complementary way of viewing the data may be had by taking a ratio of the two cross sections:

$$r^{D(3)} = \frac{\mathrm{d}^3\sigma^D_{ep}}{\mathrm{d}x\mathrm{d}Q^2\mathrm{d}\beta} \Bigg/ \frac{\mathrm{d}^2\sigma_{ep\to eX}}{\mathrm{d}x\mathrm{d}Q^2} = \frac{x}{\beta^2} \cdot \frac{F_2^{D(3)}(\beta,\, Q^2,\, x)}{F_2(x, Q^2)}. \tag{8}$$

From equations 6 and 7 it follows that (at fixed Q^2 and β):

$$r^{D(3)} \propto x^{\varepsilon_I - 2\varepsilon_D}. \tag{9}$$

$r^{D(3)}$ is plotted in figure 2. Included in figure 2 is a fit of the form x^n which yields:

$$\varepsilon_I - 2\varepsilon_D = 0.05 \pm 0.06 \pm 0.08, \tag{10}$$

and is within errors the same for all β and Q^2.

This result is indicative of a constant or slightly rising dependence on x and not the fall expected with a universal soft pomeron for which $\varepsilon_I = \varepsilon_D$ so $r^D(3) \propto x^{-\varepsilon}$.

3. Measurement of $F_2^D(x, Q^2)$ – the Diffractive Contribution to $F_2(x, Q^2)$

A first measurement of $F_2^D(x, Q^2)$, the diffractive contribution to $F_2(x, Q^2)$ has

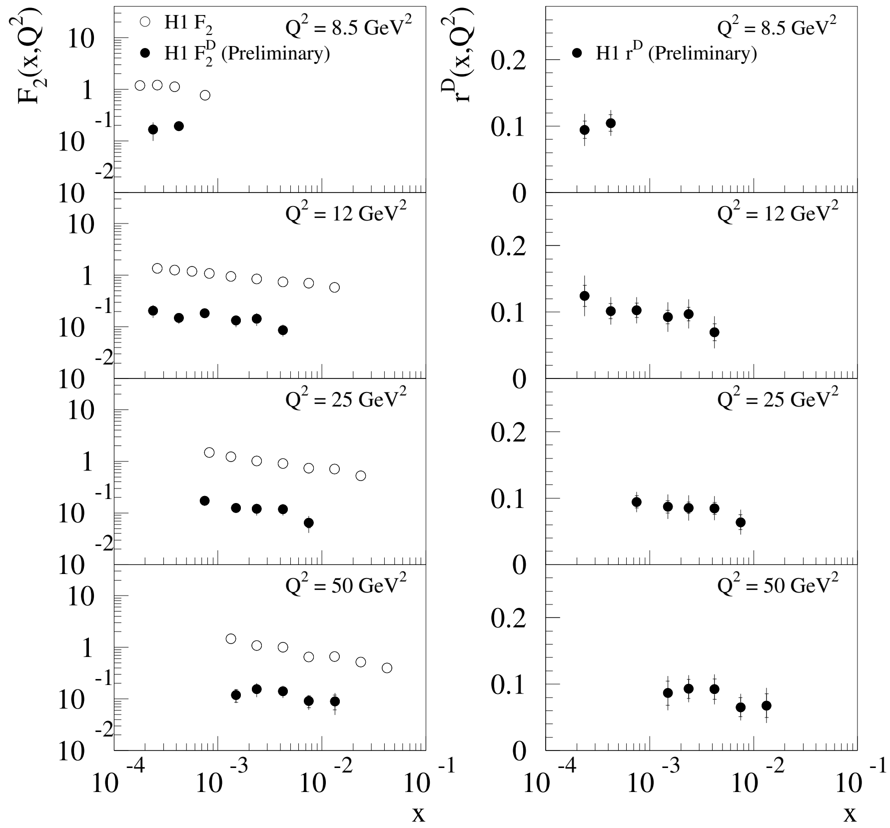

Fig. 3. The structure function $F_2^D(x,Q^2)$ and the ratio $r^D = F_2^D(x,Q^2)/F_2(x,Q^2)$ for $x_{I\!P} < 0.05$.

been made in [3]. The measurement presented here differs in that it accesses a wider kinematic domain ($x_{I\!P} < 0.05$ rather than the previous limit of $x_{I\!P} < 0.01$) and it is for the single diffractive case where the proton scatters elastically. A measurement has also been made of the ratio $r^D(x,Q^2) = F_2^D(x,Q^2)/F_2(x,Q^2)$, for which the errors are smaller since certain systematics cancel.

The measurement was made along similar lines to the procedure described in [2]. Diffractive deep–inelastic scattering events were selected by requiring a well measured electron in the backward electromagnetic calorimeter and and absence of activity in any of the subdetectors that reach $\eta > 3.2$ where $\eta = -\ln(\tan(\theta/2))$ and $\theta = 0°$ is the proton beam direction. The sample of events were found to be relatively uncontaminated with $\approx 18\%$ non diffractive background and $\approx 1\%$ each of photoproduction and beam–gas background. The data were corrected for losses and other detector effects using the Monte Carlos RAPGAP [7] and DIFFVM [8]. The results are shown in figure 3. It should be noted that this ratio has no Regge model prediction of the form of equation 9, since $F_2^D(x,Q^2)$ requires an integration over an a priori unknown β dependence. It can be seen that the ratio is roughly 10 % for all x and Q^2 apart from values of x approaching the kinematic limit of $x = 0.05$ where $r^D \to 0$

because of the constraint $x_{I\!P} < 0.05$. There is nowhere in the kinematic region where the diffractive events dominate and so the diffractive events cannot be responsible for the observed rise of $F_2(x, Q^2)$ with decreasing x.

4. Conclusions

It has been shown that the diffractive deep–inelastic cross section is consistent with a Regge model based upon a universal soft pomeron. Such a model cannot explain the form of the inclusive deep–inelastic cross section, for which perturbative calculations give better agreement.

A measurement has been made of $F_2^D(x, Q^2)$, the diffractive contribution to $F_2(x, Q^2)$, and of $r^D(x, Q^2) = F_2^D(x, Q^2)/F_2(x, Q^2)$. The results show that ≈ 10 % of deep–inelastic events over the accessed kinematic range can be attributed to single diffraction. The variation of this fraction is rather independent of x and Q^2.

5. References

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