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Inclusive diffractive deep inelastic scattering at ZEUS

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Abstract. We present new results from ZEUS on diffractive deep inelastic scattering, $\gamma^* p \to Xp, XN$, for a wide range in $Q^2, W, M_X, x_{I\!P}, \beta$. The diffractive cross section shows a steep decrease with t, dominant higher twist at low M_X and predominant leading twist at large M_X. For $M_X > 2$ GeV, the diffractive structure function of the proton rises steeply as $x_{I\!P} \to 0$. The structure function of the Pomeron has a maximum near $\beta = 0.5$ suggesting that the lowest state of the Pomeron is a $q\bar{q}$ state. For $\beta < 0.1$, the pomeron structure function is rising as $\beta \to 0$, and as Q^2 increases, similar to the proton structure function.

1 Introduction

Quantum Chromodynamics in the perturbative DGLAP expansion permits a precise description of the proton structure functions measured in inclusive deep-inelastic lepton-nucleon scattering (DIS) in terms of quark (q) and gluon (g) densities of the proton. For the diffractive component of DIS, $ep \to e'XN$, (N = proton or low-mass excited nucleonic state) QCD is still far from achieving such success. The observation of events with a large rapidity gap at HERA [2] has paved the way for the study of diffraction in DIS over a large range in spatial resolution (Q^2), center-of-mass energy of the hadronic system (W) and mass of the system X (M_X), see Fig. 1. In a t-channel picture, where t is the four-momentum transfer squared between incoming proton and outgoing N, diffraction is mediated by the exchange of a colourless object carrying the quantum numbers of the vacuum, called the Pomeron, which in lowest order could be a $q\bar{q}$ or a gg system (see Fig. 1). The analogue of the proton structure function F_2, the diffractive structure $F_2^{D(3)}$ [5], is parametrized in terms of Q^2, the momentum fraction $x_{I\!P} = (M_X^2 + Q^2)/(W^2 + Q^2)$ of the proton carried by the Pomeron, and the momentum fraction $\beta = Q^2/(M_X^2 + Q^2)$ of the Pomeron carried by the struck quark.

New results on diffraction have been obtained from two different analyses [1]. One of them uses data taken in 1998/9 with the fine-grained Forward Plug Calorimeter

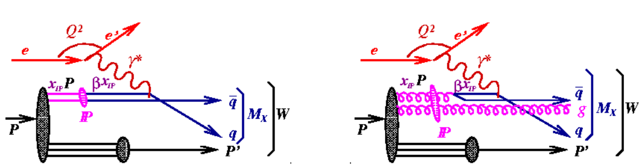

Fig. 1. Low order diagrams for deep inelastic diffractive scattering via $ep \to eXN$

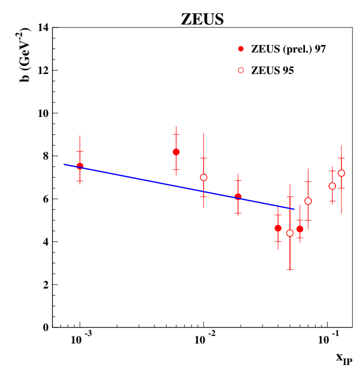

Fig. 2. The slope b of the diffractive cross section (LPS)

(FPC) installed in the 20×20 cm^2 beam hole of the forward uranium calorimeter. The FPC increases the calorimetric coverage by about one unit in pseudorapidity and the range in M_X by about a factor of 1.7. The diffractive component is isolated by the M_X method [3]. Results are presented for $\gamma^* p \to XN, M_N < 2.3$ GeV with $2.2 < Q^2 < 80$ GeV^2, $37 < W < 245$ GeV and $M_X < 35$ GeV. The other analysis uses the Leading Proton Spectrometer (LPS) to select events with forward scattered protons carrying at least 90% of the incoming proton momentum. Based on data taken in 1997, results are presented for $\gamma^* p \to Xp$ with $0.03 < Q^2 < 100$ GeV^2, $25 < W < 240$ GeV and $1.5 < M_X < 70$ GeV.

The LPS analysis shows that the diffractive cross section is steeply falling with t. Parametrization of the diffractive cross section by $d\sigma(\gamma^* p \to Xp)/dt \propto e^{-b|t|}$ yields $b = 7.9 \pm 0.5(stat.)^{+0.8}_{-0.5}(syst.)GeV^{-2}$ for $2 < Q^2 < 100$ GeV^2, $M_X > 1.5$ GeV, $0.075 < |t| < 0.35$ GeV^2. Assuming b to be independent of t, the measured LPS diffractive cross sections have been extrapolated to the full kinematically allowed t-range.

Figure 3 presents the diffractive cross section $d\sigma/dM_X$ as a function of Q^2 for different M_X and W bins. For $Q^2 >$

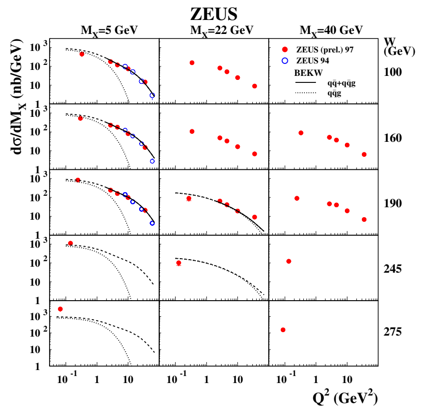

Fig. 3. The diffractive cross section (LPS)

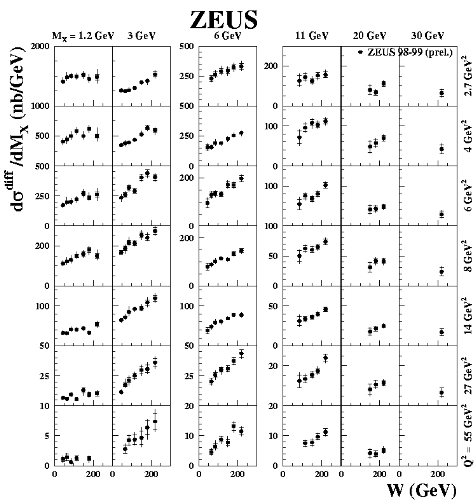

Fig. 4. The diffractive cross section (FPC)

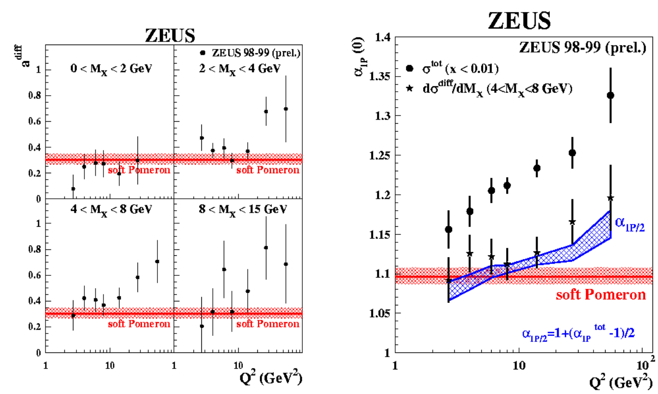

Fig. 5. The power a^{diff} (*left*) and the intercepts of the Pomeron trajectory from the total $\gamma^* P$ cross section and the diffractive cross section (*right*) (FPC)

3 GeV^2 the cross section is approximately $\propto (1/Q^2)^n$ where for $M_X = 5$ GeV $n > 1$ showing a substantial higher twist component, while for $M_X \geq 22$ GeV: $n \approx 1$, compatible with a dominant leading twist behaviour.

The diffractive cross section $d\sigma^{diff}/dM_X$ measured in the FPC analysis is shown in Fig. 4 as a function of W for different Q^2 and M_X. Comparison with the LPS data shows that about 30% of the FPC cross section is due to nucleon dissociation with $M_N < 2.3$ GeV. For $M_X < 2$ GeV, the diffractive cross section is rather constant with W while at higher M_X, a strong rise with W is observed for all values of Q^2. Fits of $d\sigma^{diff}/dM_X$ to the form $d\sigma^{diff}/dM_X = h \cdot W^{a^{diff}}$ resulted in the a^{diff} values shown in Fig. 5 (left) as a function of Q^2. For $M_X > 2$ GeV, there is a clear tendency for a^{diff} to rise with Q^2. In Regge models, a^{diff} is related to the t-averaged intercept of the Pomeron trajectory, $\overline{\alpha_{I\!P}} = 1 + a^{\rm diff}/4$. Hadron-hadron scattering leads to $\alpha_{I\!P}^{\rm soft}(0) = 1.096^{+0.012}_{-0.009}$ and to a t averaged value of $a^{\rm soft} = 0.302^{+0.048}_{-0.036}$ shown by the band in Fig. 5. For $Q^2 > 10$ GeV^2 and $M_X > 2$ GeV, however, $a^{\rm diff}$ lies above $a^{\rm soft}$, the probability for $a^{\rm diff} \leq a^{\rm soft}$ being less than 0.1 %. The data give clear evidence for $a^{\rm diff}$ rising with Q^2.

In Fig. 5 (right) the Q^2-dependence of $\alpha_{I\!P}^{\rm tot}(0)$ obtained in this analysis from the W-dependence of the total $\gamma^* p$-cross section, $\alpha_{I\!P}^{\rm tot}(0) = 1 + \lambda$, is compared with $\alpha_{I\!P}^{\rm diff}(0) = \overline{\alpha_{I\!P}} + 0.02$ obtained from the diffractive cross section for $4 < M_X < 8$ GeV. The diffractive result lies approximately half-way in between the soft Pomeron and the result obtained from $\sigma^{\rm tot}_{\gamma^* p}$. The diffractive data are well described by the shaded band which represents 'half' of the W rise of the total cross section, $\alpha_{I\!P}(0) = 1 + \lambda/2$: for $M_X > 2$ GeV, the diffractive and total cross sections have approximately the same W dependence.

The ratio of the diffractive cross section, integrated over the measured M_X-range, to the total cross section, $\sigma^{\rm diff}_{obs}(M_X < 35\ {\rm GeV}, M_N < 2.3\ {\rm GeV})/\sigma^{\rm tot}$, has been evaluated as a function of Q^2 for the highest W bin (200 - 245 GeV), which provides the highest reach in M_X, $M_X < 35$ GeV. Diffraction contributes a substantial fraction of the total cross section: $\sigma^{\rm diff}_{obs}(M_X < 35\ {\rm GeV}, M_N < 2.3\ {\rm GeV})/\sigma^{\rm tot} = 19.8^{+1.5}_{-1.4}\%$ at $Q^2 = 2.7$ GeV^2 decreasing slowly to $10.1^{+0.6}_{-0.7}\%$ at $Q^2 = 27$ GeV^2.

2 Diffractive structure function of the proton

The diffractive structure function of the proton can be related to the diffractive cross section for $W^2 \gg Q^2$ as follows [5]:

$$x_{I\!P} F_2^{D(3)}(\beta, x_{I\!P}, Q^2) = \frac{Q^2(Q^2 + M_X^2)}{8\pi^2 \alpha M_X} \frac{d\sigma^{\rm diff}_{\gamma^* p \to XN}}{dM_X} \quad (1)$$

If $F_2^{D(3)}$ is interpreted in terms of quark densities, it specifies the probability to find, in a diffractive process, a quark carrying a momentum fraction $x = \beta x_{I\!P}$ of the proton momentum. Figure 6 shows $x_{I\!P} F_2^{D(3)}$ as a function of $x_{I\!P}$ for different values of β and Q^2. For the lowest M_X region which corresponds to high β, little dependence on $x_{I\!P}$ is observed, in contrast to lower β selections where $x_{I\!P} F_2^{D(3)}$ rises strongly as $x_{I\!P} \to 0$, reflecting the rapid increase of the diffractive cross section with rising W. This strong increase is reminiscent of the rise of the proton structure

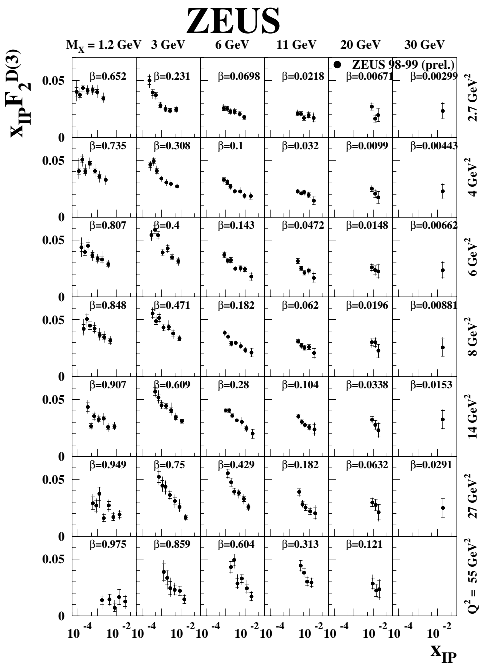

Fig. 6. The diffractive structure function of the proton, $x_{I\!P} F_2^{D(3)}$ (FPC)

function $F_2(x, Q^2)$ as $x \to 0$ which can be attributed to the rapid increase of the gluon density in the proton as $x \to 0$.

3 The structure function of the Pomeron

It has been suggested [5] that $F_2^{D(3)}(x_{I\!P}, \beta, Q^2)$ should factorize into a term which depends on the probability of finding a Pomeron carrying a fraction $x_{I\!P}$ of the proton momentum, and the structure function of the Pomeron, $F_2^{D(2)}$, given in terms of the quark densities of the Pomeron which depend on β and Q^2:

$$F_2^{D(3)}(x_{I\!P}, \beta, Q^2) = f_{I\!P}(x_{I\!P}, Q^2) \cdot F_2^{(D(2)}(\beta, Q^2) \quad (2)$$

where $f_{I\!P}(x_{I\!P}, Q^2)$ is generically called the Pomeron flux factor. In this model, the flux factor is assumed to be of the form $f_{I\!P}(x_{I\!P}, Q^2) = (C/x_{I\!P}) \cdot (x_0/x_{I\!P})^{n(Q^2)}$. Taking for the arbitrary normalization constant $C = 1$ leads to

$$F_2^{D(2)}(\beta, Q^2) = x_0 \cdot F_2^{D(3)}(x_0, \beta, Q^2). \quad (3)$$

The values of $F_2^{D(2)}(\beta, Q^2)$ were extracted from the data as follows. For a given (Q^2, β) combination, those $x_{I\!P} F_2^{D(3)}$ measurements with $0.5 \cdot x_0 < x_{I\!P} < 1.5 \cdot x_0$ were selected. For each measurement selected, the $x_{I\!P} F_2^{D(3)}$ value measured at $x_{I\!P\,meas}$ was transported to $x_{I\!P} = x_0$ using a global fit to the $x_{I\!P} F_2^{D(3)}$ data. On average, the difference between measured and transported value was of the order of 5%. Finally, for every (Q^2, β) point the weighted average of the selected measurements was determined. The resulting measurements of $F_2^{D(2)}(\beta, Q^2)$ are presented in Fig. 7. Several aspects are noteworthy. Firstly, there is a large contribution from the valence region, $\beta > 0.2$. In fact, $F_2^{D(2)}(\beta, Q^2)$ has a maximum near $\beta = 0.5$ consistent with a $\beta(1-\beta)$ variation. This suggests strongly that the lowest state of the Pomeron in this process is $q\bar{q}$. The data indicate also that the region of high β decreases as Q^2 increases from 14 - 27 GeV^2. For $\beta < 0.1$, $F_2^{D(2)}$ is seen to rise as $\beta \to 0$, and to rise with increasing Q^2. This behaviour is very similar to that of the proton structure function F_2.

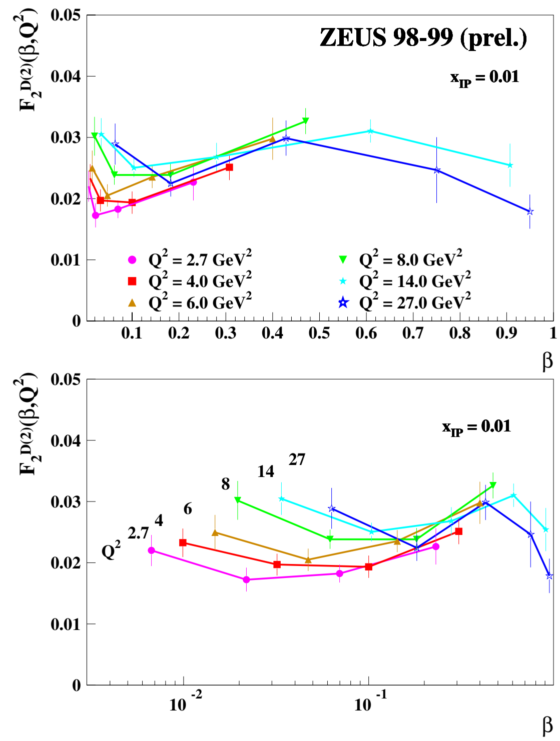

Fig. 7. The diffractive structure function of the pomeron, $F_2^{D(2)}$ (FPC)

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