Diffractive Dissociation in Deep Inelastic Scattering

H1 and ZEUS Collaborations

Talk given by
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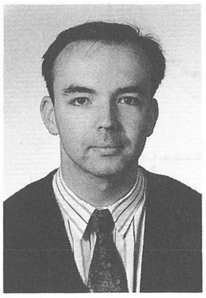

Abstract

We present results of measurements of the diffractive cross section in deep inelastic scattering at HERA performed by the H1 and ZEUS collaborations. The results are presented in terms of the diffractive structure function as a function of $x_{I\!P}$, the momentum fraction lost by the proton, of β, the momentum fraction of the struck quark with respect to $x_{I\!P}$, and of Q^2. The dependence of this structure function on $x_{I\!P}$ is measured to be independent of both β and Q^2, and is consistent with both a diffractive interpretation and a factorisable *ep* diffractive cross section. In the measured Q^2 range, the diffractive structure function approximately scales with Q^2 at fixed β. The observed cross section is compared to several model predictions for diffractive dissociation.

1 Introduction

The analysis of deep-inelastic electron-proton scattering (DIS) at HERA ($Q^2 > 8$ GeV^2) has demonstrated the existence of events at low Bjorken-x ($10^{-4} < x_{Bj} < 10^{-2}$) with a large rapidity gap between the outgoing proton system and the hadronic system seen in the detector [1, 2]. The number of those events is exceeding expectations from standard DIS. In particular it is not exponentially suppressed with increasing rapidity gap, as would be expected if the exchanged photon interacts with a single colour-charged parton inside the proton. Fig. 1 shows the η_{max} distribution for the DIS events taken with the H1 detector during the 1993 running period, where η_{max} is defined as the pseudorapidity of the first calorimeter object above 400 MeV closest to the proton direction. The distribution is compared with expectations from standard DIS Monte Carlo models (CDM [3] and MEPS [4]), which assume that the photon couples to a single quark inside the proton. Such models can obviously not describe the flat η_{max}-distribution in the range $(-2; 2)$.

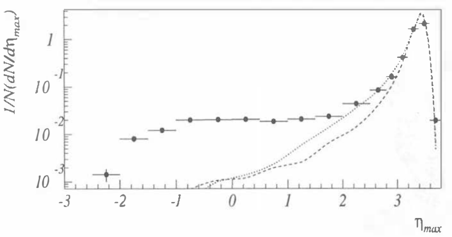

Figure 1: *The η_{max}-distribution for the 1993 H1 DIS data. The data are compared with the expectations of "standard" DIS Monte Carlos (dashed CDM, dotted MEPS).*

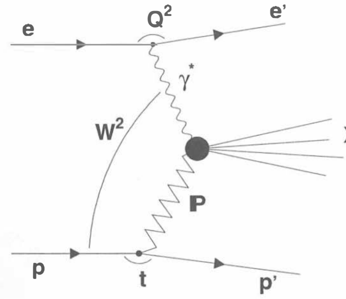

Figure 2: *Diagram of the diffractive reaction mechanism*

The flat η_{max} distribution, the weak dependence on the center-of-mass energy of the $\gamma - p$ system (W) and the shape of the M_x distribution (M_x is the mass of the observed hadronic system inside the main detector) suggest that the underlying production mechanism is a diffractive interaction between a highly virtual photon and the proton. Diffractive processes are generally understood to proceed through the exchange of a colourless object with the quantum numbers of the vacuum, generically called the pomeron. The true nature of this exchanged "object" remains unclear. The diagram of such a process is shown in Fig. 2.

Different approaches exist to model diffractive processes in DIS. Monte Carlo implementations of those models are available [5, 6, 7], and it has been demonstrated that a combination of diffractive and "standard" DIS Monte Carlo events reproduces most features of the data in a satisfactory way [8, 9, 10].

A fit to the η_{max} distribution has been used to estimate the percentage of diffractive events in bins of W, Q^2 and x_{Bj}. The result is shown in Fig. 3. Note that the fraction of diffractive events is about 10-15% of the total DIS sample and does not depend strongly on W, Q^2 and x_{Bj}.

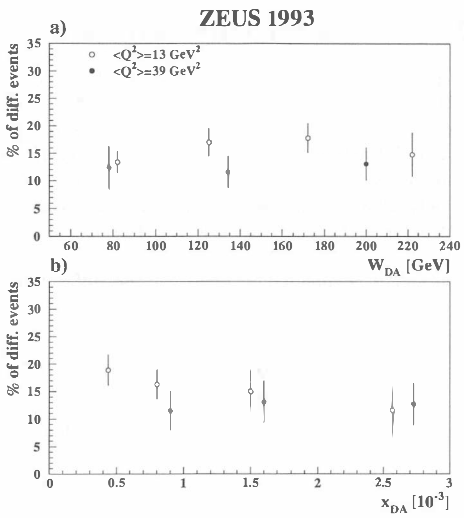

Figure 3: *Fraction of diffractive events as function of (a) W and (b) x_{Bj} in two Q^2 intervals. The relative contributions of the NZ diffractive model and the non-diffractive CDM model are determined by a fit to the ZEUS data.*

It is convenient to express the cross section for diffractive events in terms of a diffractive structure function. Here we report on measurements of the diffractive structure function as function of $x_{\mathbb{P}}$, the momentum fraction lost by the proton, of β, the momentum fraction of the struck quark with respect to $x_{\mathbb{P}}$, and of Q^2, by the two HERA experiments H1 and ZEUS. In the present analyses, an integral is performed over the (undetected) momentum transfer squared (t) to the outgoing proton system.

2 Kinematics

The kinematic variables used to describe DIS events $e\,(k) + p\,(P) \to e'\,(k') + \textit{anything}$ are: the negative of the squared four-momentum transfer carried by the virtual photon[1]: $Q^2 = -q^2 = -(k - k')^2$ and the Bjorken variable: $x_{Bj} = \frac{Q^2}{2P\cdot q}$.

In the diffractive DIS process shown in Fig. 2: $e\,(k) + p\,(P) \to e'\,(k') + p'(P') + X$, the hadronic system X (excluding the proton) and the scattered electron e' are detected in the main detector. Since the system X is fully contained, its invariant mass M_X can be determined from the calorimeter information. To describe the pomeron structure, the final-state distributions of the following diffractive variables are used:

$$x_{\mathbb{P}} = \frac{(P-P')\cdot q}{P\cdot q} = \frac{M_X^2 + Q^2 - t}{W^2 + Q^2 - M_p^2} \simeq \frac{M_X^2 + Q^2}{W^2 + Q^2},$$

the momentum fraction of the pomeron within the proton; and

$$\beta = \frac{Q^2}{2(P-P')\cdot q} = \frac{x_{Bj}}{x_{\mathbb{P}}} = \frac{Q^2}{M_X^2 + Q^2 - t} \simeq \frac{Q^2}{M_X^2 + Q^2},$$

the momentum fraction of the (struck) quark which interacts with the virtual photon with respect to $x_{\mathbb{P}}$. In the above formulae, $t = (P - P')^2$ is the squared momentum transfer at the proton vertex, whose absolute magnitude is small compared to $Q^2 + M_X^2$ in diffractive processes for the kinematic region studied here.

In models where diffraction is described by the exchange of a particle-like pomeron, β is the momentum fraction of the struck quark within the pomeron. For the structure of the pomeron in DIS, this variable plays a role analogous to that of x_{Bj} for the structure of the proton.

[1]In the Q^2 range used for this analysis, ep interactions are described to sufficient accuracy by the exchange of a virtual photon.

3 Measurement of the diffractive structure function

The data were taken during the 1993 running period at the HERA ep collider at DESY. The integrated luminosity is 271 ± 14 nb^{-1} for H1 and 540 nb^{-1}($\pm3.5\%$) for ZEUS. Diffractive events are selected by a rapidity gap requirement between the outgoing proton system and the hadronic system detected in the calorimeter. The diffractive cross section has been measured in bins of Q^2, β and $x_{I\!P}$. To unfold the effects of acceptance and event migration Monte Carlo implementations of models for diffractive dissociation have been used [5, 6, 7]. The background due to "standard" DIS processes has been subtracted statistically in each bin. Details can be found in [11, 12].

The results for the diffractive cross section can be expressed in terms of the diffractive structure function $F_2^{D(3)}(\beta, Q^2, x_{I\!P})$:

$$\frac{d^3\sigma_{diff}}{d\beta dQ^2 dx_{I\!P}} = \frac{2\pi\alpha^2}{\beta Q^4}\left(1 + (1-y)^2\right) F_2^{D(3)}(\beta, Q^2, x_{I\!P}),$$

following the procedure of [13]. The results for $F_2^{D(3)}$ of the H1 analysis are presented in Fig. 4.

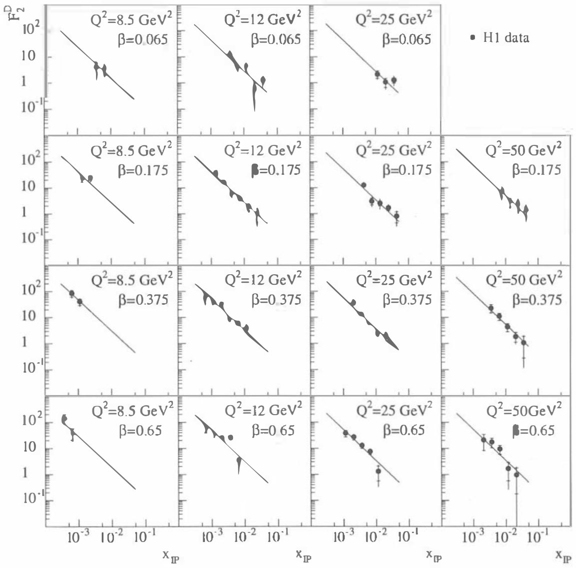

Figure 4: *The diffractive structure function $F_2^{D(3)}$ as measured by the H1 collaboration in bins of β, Q^2 and $x_{I\!P}$. The inner error bar is the statistical error; the full error shows the statistical and systematic error added in quadrature; superimposed is the result of the fit establishing a factorisable dependence of the form $\propto x_{I\!P}{}^{-n}$ (see text). Note that an overall normalisation uncertainty of 8% is not included.*

In all (β, Q^2) bins $F_2^{D(3)}$ is observed to decrease monotonically with increasing $x_{I\!P}$ in the measured range. A good fit to all H1 data points, irrespective of β and Q^2, is obtained assuming a dependence like $x_{I\!P}{}^{-n}$ with a single exponent $n = 1.19 \pm 0.06(stat.) \pm 0.07(syst.)$, χ^2/d.f. $= 32.0/46$ (χ^2/d.f. $= 64.5/46$ assuming only statistical errors). The observed universal dependence on $x_{I\!P}$ is thus a feature of the data at the present level of statistical accuracy. There is no evidence for any systematic trend in the contributions to χ^2 as a function of β and Q^2.

Following the same procedure ZEUS obtains: $n = 1.30 \pm 0.08\ (stat)\ {}^{+\,0.08}_{-\,0.14}\ (sys)$, which is slightly higher than, but compatible with the H1 value.

Such a universal dependence on $x_{I\!P}$, independent of β and Q^2, is expected if the deep-inelastic reaction mechanism responsible for rapidity gap events involves a (colourless) target $I\!P$ in the incident proton whose characteristics do not depend on $x_{I\!P}$, and which carries only a small fraction of the proton's momentum. The dependence of $F_2^{D(3)}(\beta, Q^2, x_{I\!P})$ then factorises into the product of a universal term $f_{I\!P/p}(x_{I\!P}, t)$, which describes the "flux" of $I\!P$ "in" the proton, and a term which describes any structure of $I\!P$ and which is a function of only β and Q^2.

Following the ideas of Regge theory the expected $x_{I\!P}$ dependence in diffractive dissociation is related to the pomeron trajectory:

$$F_2^{D(3)} \propto x_{I\!P}^{-(2\alpha_{I\!P}(t)-1)},$$

where the conventional parametrisation of $\alpha_{I\!P}(t) = 1.085 + 0.25 \cdot t$ is extracted from "soft hadronic" diffractive interactions. Integrated over t, it is expected that $F_2^{D(3)} \propto x_{I\!P}^{-n}$ with $n \approx 1.1$. The observed values are slightly higher but still compatible within the quoted errors.

In order to illustrate the β and Q^2 dependence of $F_2^{D(3)}(\beta, Q^2, x_{I\!P})$, $F_2^{D(3)}$ was integrated over the measured range of $x_{I\!P}$, using the fitted $x_{I\!P}$ dependence. The resulting values of $\tilde{F}_2^D(\beta, Q^2)$ are shown in Fig. 3 as a function of β and Q^2.

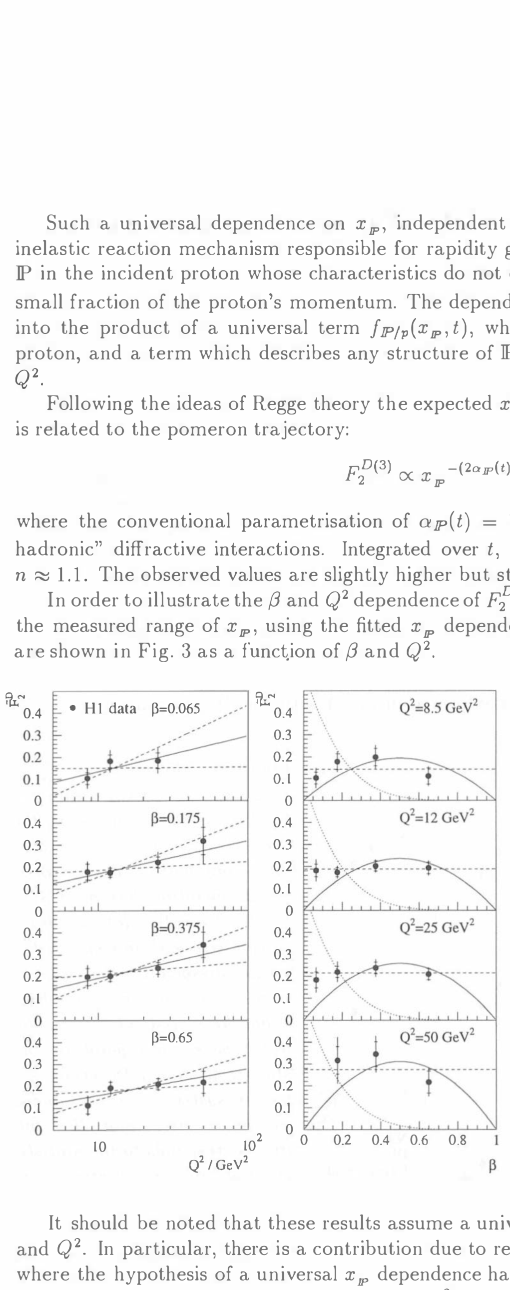

Figure 5: *Dependence of $\tilde{F}_2^D(\beta, Q^2)$ on Q^2 and β for the H1 data; superimposed on the Q^2 dependence are the results of fits at each β which assume leading logarithmic scaling violations; the best fit (solid lines) and the curves corresponding to variation of ± 1 standard deviation of the slope (dashed lines) are shown. Superimposed on the β dependence are the simplest $q\bar{q}$ expectation for $I\!P$ structure - $[\beta(1-\beta)]$ (solid lines) - , and a constant dependence (dashed lines), for which the overall normalisations are determined from fits to the data; also displayed is a dependence of the form $[(1-\beta)^5]$ (dotted lines) with arbitrary normalisation. Note that an overall normalisation uncertainty of 8% is not included.*

It should be noted that these results assume a universal $x_{I\!P}$ dependence in *all* regions of β and Q^2. In particular, there is a contribution due to regions of $x_{I\!P}$ which are not measured and where the hypothesis of a universal $x_{I\!P}$ dependence has not been tested experimentally.

There is no evidence for any substantial Q^2 dependence of $\tilde{F}_2^D$. This is consistent with a picture where the underlying interaction is the scattering of a virtual photon with a point-like quark within the pomeron. Note the slow rise of $\tilde{F}_2^D$ with Q^2 even at the highest β value of about 0.65. The $\tilde{F}_2^D(\beta, Q^2)$ values as a function of β for fixed Q^2 are consistent with a flat β dependence. The ansatz of a soft dependence $(1-\beta)^5$ is clearly ruled out.

4 Comparison with models of diffractive dissociation

Different approaches exist to model diffractive processes.

In the Donnachie-Landshoff (DL) model diffraction in DIS is described through pomeron exchange between the virtual photon and the proton, with the pomeron coupling predominantly to quarks [14]. The authors calculate the cross section in the framework of Regge theory. The result can be interpreted in terms of a pomeron structure function with a resulting hard β dependence like $\beta \cdot (1 - \beta)$. The authors also predict an additional soft contribution to the pomeron structure function which is expected to become important only for $\beta < 0.1$.

Capella et al. calculate the diffractive structure function also in the framework of conventional Regge theory [15]. Using Regge factorisation, they relate the pomeron structure function to the deuteron structure function using parameters which are determined from soft hadronic diffraction data with an appropriate change for the disappearance of screening corrections with increasing Q^2.

In the model of Nikolaev and Zakharov (NZ) diffractive dissociation is described as a fluctuation of the photon into a $q\bar{q}$ or $q\bar{q}g$ Fock state [16, 17]. The result for the cross section can be approximated by a two-component structure function of the pomeron, each component having its own flux factor. This corresponds to factorisation breaking which is caused by BFKL evolution effects.

The predictions of these models are confronted in Fig. 4 with the ZEUS data.

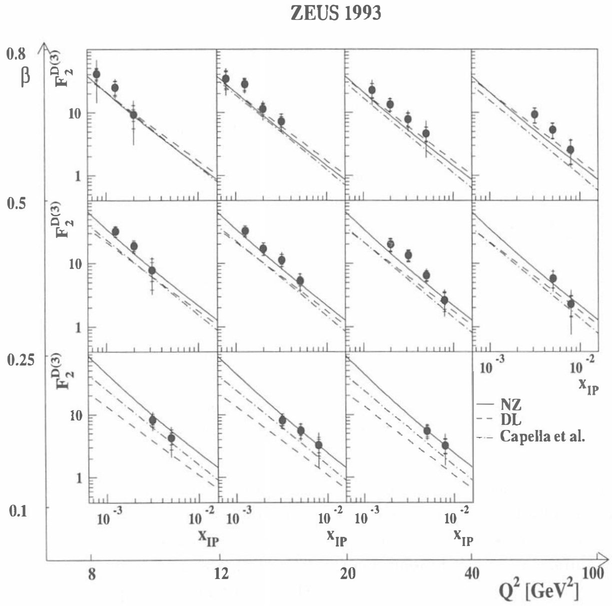

Figure 6: *The results of $F_2^{D(3)}$ measured by ZEUS compared to the models discussed in the text. Note that the estimated 15% contribution due to double dissociation has been subtracted from the data in order to compare with models for the single dissociation cross section. The inner error bars show the statistical errors, the outer bars correspond to the statistical and DIS event selection systematic errors added in quadrature, and the full line corresponds to the statistical and total systematic errors added in quadrature. The overall normalisation uncertainty of 3.5% due to the luminosity and 10% due to the subtraction of the double dissociation background is not included.*

At high β-values the predictions of Nikolaev-Zakharov, Donnachie-Landshoff and Capella et al. underestimate the data slightly, but are generally in reasonable agreement. At smaller β-values, the Donnachie-Landshoff parametrisation, which includes only a hard component of the pomeron structure function, underestimates the observed $F_2^{D(3)}$. The Capella et al.

and Nikolaev-Zakharov predictions, which include an additional soft component, give a fair description at smaller β-values. The factorisation-breaking effects in the model of Nikolaev-Zakharov, which occur at small β values, are too small to be observable in this analysis.

5 Summary

The properties of events in deep inelastic e–p scattering at HERA with a large rapidity gap between the outgoing proton system and the observed hadronic system are consistent with the process of diffractive dissociation of a highly virtual photon in the field of the proton.

The cross section for diffractive interactions has been measured by the two HERA experiments H1 and ZEUS in bins of $x_{I\!P}$, the momentum fraction lost of the proton, β, the momentum fraction of the struck quark with respect to $x_{I\!P}$, and of Q^2. The results are presented in terms of the diffractive structure function $F_2^{D(3)}$. The $x_{I\!P}$ dependence of $F_2^{D(3)}$ is consistent with the form $(1/x_{I\!P})^n$ in all bins of β and Q^2, with $n = 1.19 \pm 0.06\ (stat) \pm 0.07\ (sys)$ [H1] and $n = 1.30 \pm 0.08\ (stat)\ ^{+\ 0.08}_{-\ 0.14}\ (sys)$ [ZEUS]. This is compatible with models where $F_2^{D(3)}$ factorises into a pomeron flux $f_{I\!P/p}(x_{I\!P}, t)$ and a pomeron structure function $F_2^{I\!P}(\beta, Q^2)$. The value of n is slightly higher but compatible with that obtained from hadron-hadron interactions. In the measured Q^2 range, the pomeron structure function is approximately independent of Q^2 at fixed β consistent with an underlying interaction where the virtual photon scatters off point-like quarks within the pomeron. The observed β-dependence of the pomeron structure function requires both a hard and a soft component. The observed cross section is in agreement with the predictions for diffractive dissociation of several models like those of Donnachie-Landshoff, Nikolaev-Zakharov and Capella et al. .

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