DIFFRACTION AT HERA

Jörn Grosse-Knetter, DESY, Notkestr. 85, D-22603 Hamburg, Germany

Abstract

Recent results on diffraction at HERA based on analyses of the H1 and ZEUS Collaborations were presented. The dissociation of the photon as well as the production of dijets both in photoproduction and deep inelastic scattering in *ep* interactions were considered. Properties of the Pomeron, namely its intercept $\alpha_{\mathbb{P}}(0)$ and its partonic structure, were investigated.

In photoproduction the Pomeron intercept was measured to be in agreement with results from fits to hadronic cross sections. Larger values were found in deep inelastic scattering. In addition, H1 observed a breaking of the factorisation of the diffractive structure function, consistent with a contribution from a meson exchange. No dependence on the photon virtuality Q^2 was found. ZEUS observed a tendency of $\alpha_{\mathbb{P}}(0)$ to grow with Q^2, but more data are needed to draw final conclusions. The distribution of the squared four-momentum at the proton vertex, t, was measured to fall exponentially.

An analysis of the diffractive structure function in deep inelastic scattering and of dijet cross sections in deep inelastic scattering and photoproduction yielded a dominant hard gluon content of the Pomeron.

1 Introduction

A new class of events with properties indicating a diffractive production mechanism was observed in ep scattering at HERA. In these diffractive reactions the photon emitted by the positron is assumed to interact with the proton via the exchange of an object carrying the vacuum quantum numbers called the Pomeron $\mathbb{P}$. Experimentally, the diffractive reaction:

$$e(k)p(P) \rightarrow e(k')XN(P') \tag{1}$$

can be characterised by a gap in rapidity between the photon dissociative state X and the system N, where N can be either a proton or a higher mass state. Contributions in addition to Pomeron exchange, for example meson exchange, have to be dealt with before the diffractive contribution can be extracted.

In 1994, HERA provided positrons of energy 27.5 GeV and protons of energy 820 GeV. Two classes of events were distinguished by the scattered positron being in the central detector or not: deep inelastic scattering (DIS) and photoproduction, corresponding to virtual and almost real exchanged photons, respectively. The following variables were used – the symbols representing the particles four-momenta refer to those given in equation (1): the squared four-momentum transferred at the electron vertex: $Q^2 = -q^2 = (k-k')^2$; the photon-proton centre-of-mass energy: $W^2 = (q+P)^2$; and the squared four-momentum transferred at the proton vertex: $t = (P-P')^2$. Two further variables are used to describe the diffractive behaviour, where M_X is the mass of the system X: $x_{\mathbb{P}} = \frac{(P-P')\cdot q}{P\cdot q} \approx \frac{M_X^2+Q^2}{W^2+Q^2}$ and $\beta = \frac{Q^2}{2x_{\mathbb{P}}\, P\cdot q} \approx \frac{Q^2}{M_X^2+Q^2}$. In the case of Pomeron exchange they represent the fraction of the beam proton momentum carried by the Pomeron and the fraction of the Pomeron momentum carried by the struck parton, respectively.

2 Photon Diffractive Dissociation

2.1 Photon Diffractive Dissociation in Photoproduction

The photon dissociation in photoproduction is studied in terms of triple-Regge amplitudes[1]. Assuming a pure $\mathbb{P}\mathbb{P}\mathbb{P}$ amplitude, this description yields for fixed W:

$$\frac{\mathrm{d}\sigma_{\mathrm{diff}}}{\mathrm{d}M_X^2} \sim \left(\frac{1}{M_X^2}\right)^{\alpha_{\mathbb{P}}(0)} \frac{1}{b_0 + 2\alpha'_{\mathbb{P}} \ln(W^2/M_X^2)}\,, \tag{2}$$

where $\alpha_{\mathbb{P}}(0)$ is the intercept of the Pomeron trajectory, $\alpha'_{\mathbb{P}}$ its slope, and b_0 is the t-slope at $W = M_X$. Fits to hadronic data[2] gave $\alpha_{\mathbb{P}}(0) = 1.08$ and $\alpha'_{\mathbb{P}} = 0.25\,\mathrm{GeV}^{-2}$.

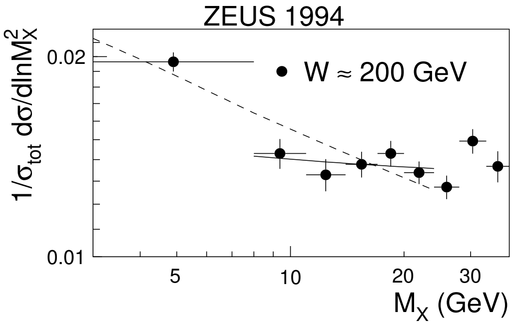

Figure 1: $\mathrm{d}\sigma_{\mathrm{diff}}/\mathrm{d}\ln M_X^2$ as measured by ZEUS in the reaction $\gamma p \to XN(M_N < 2\,\mathrm{GeV})$. The lines are explained in the text.

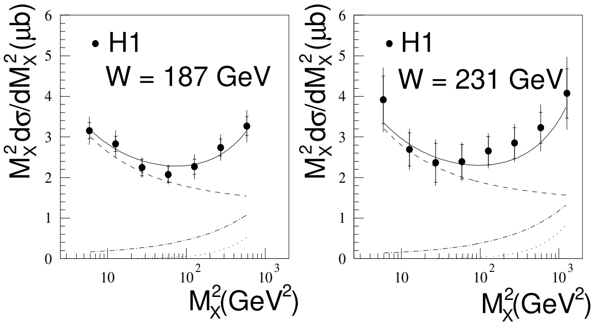

Figure 2: $M_X^2\mathrm{d}\sigma/\mathrm{d}M_X^2$ as measured by H1 in the reaction $\gamma p \to XN(M_N < 1.6\,\mathrm{GeV})$. The lines are explained in the text.

Photoproduction events were selected requiring a hit in an electron tagger restricting the kinematical range to $Q^2 < 0.02\,\mathrm{GeV}^2$ (ZEUS) or $0.01\,\mathrm{GeV}^2$ (H1). The diffractive events were selected requiring a pseudorapidity* gap in the range $4.3 < \eta < 5.8$ (ZEUS) or $3.2 < \eta < 7.0$ (H1) corresponding to $M_N < 2\,\mathrm{GeV}$ or $M_N < 1.6\,\mathrm{GeV}$, respectively. M_X is determined using the information from the central detector.

The $\mathrm{d}\sigma_{\mathrm{diff}}/\mathrm{d}\ln M_X^2$ as measured by ZEUS[3)], after subtracting remaining non-diffractive contributions using Monte Carlo simulations, is shown in Figure 1. A fit according to a pure $\mathbb{P}\mathbb{P}\mathbb{P}$ amplitude in the range $8\,\mathrm{GeV} < M_X < 24\,\mathrm{GeV}$ (solid line) yielded:

$$\alpha_{\mathbb{P}}(0) = 1.12 \pm 0.04(\mathrm{stat.}) \pm 0.08(\mathrm{syst.})$$

in good agreement with fits to hadronic data[2)]. Inclusion of the range $3\,\mathrm{GeV} < M_X < 8\,\mathrm{GeV}$ in the fit reveals the contribution from the $\mathbb{P}\mathbb{P}\mathbb{R}$ amplitude at small M_X (dashed line).

The $M_X^2\mathrm{d}\sigma/\mathrm{d}M_X^2$ as measured by H1[4)] for $|t| < 1\,\mathrm{GeV}^2$ is shown in Figure 2. To obtain a large lever arm in both W and M_X, a fit was performed (solid line) using the H1 data at two W values and measurements from fixed target experiments[5)], combining diffractive (dashed line), non-diffractive (dotted line) and interference (dot-dashed line) contributions. It yielded:

$$\alpha_{\mathbb{P}}(0) = 1.068 \pm 0.016(\mathrm{stat.}) \pm 0.022(\mathrm{syst.}) \pm 0.041(\mathrm{model})$$

again in good agreement with fits to hadronic data[2)].

2.2 Photon Diffractive Dissociation in DIS

The two HERA Collaborations used three different methods to study diffractive photon dissociation in DIS.

---

*The pseudorapidity η is defined as $\eta = -\ln(\tan(\frac{\theta}{2}))$, where θ is the polar angle in the laboratory frame taken with respect to the proton direction.

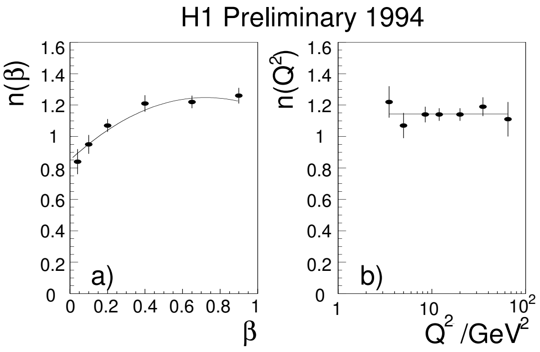

Figure 3: Values of n determined by fits to the structure function $F_2^{D(3)}$ according to equation (4) as measured by H1. n is shown as a function of β and Q^2.

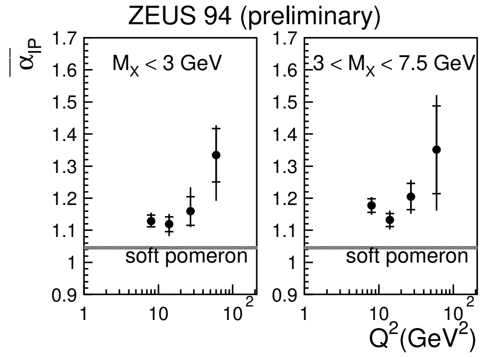

Figure 4: Values of $\overline{\alpha_{\mathbb{P}}}$ as a function of Q^2 determined by fits to $\mathrm{d}\sigma_{\text{diff}}/\mathrm{d}M_X$ according to equation (5) as measured by ZEUS. The horizontal lines indicate the $\overline{\alpha_{\mathbb{P}}}$ determined from hadronic soft interactions[2)].

Method 1: The diffractive differential cross section can be written in terms of the diffractive structure function[6)] $\mathrm{F}_2^{\mathrm{D}(3)}$:

$$\frac{\mathrm{d}^3\sigma_{\text{diff}}}{\mathrm{d}Q^2\mathrm{d}\beta\mathrm{d}x_{\mathbb{P}}} = \frac{2\pi\alpha^2}{\beta Q^2}(1+(1-y)^2)\mathrm{F}_2^{\mathrm{D}(3)}(Q^2,\beta,x_{\mathbb{P}})\,. \tag{3}$$

Assuming universal and pure Pomeron exchange yields factorisation into a flux proportional to $x_{\mathbb{P}}$ and a Pomeron structure function:

$$\mathrm{F}_2^{\mathrm{D}(3)}(Q^2,\beta,x_{\mathbb{P}}) \to \left(\frac{1}{x_{\mathbb{P}}}\right)^n \ \mathrm{F}_2^{\mathbb{P}}(Q^2,\beta)\,, \tag{4}$$

where the power of the flux is related to the Pomeron intercept by $n = 2\overline{\alpha_{\mathbb{P}}} - 1$ (the bar indicates the average over t).

An analysis of the structure function $F_2^{D(3)}$ in the range $x_{\mathbb{P}} < 0.05$ (effectively selecting the diffractive sample), $2.5 < Q^2 < 65\,\mathrm{GeV}^2$, $M_N < 1.6\,\mathrm{GeV}$, and $|t| < 1\,\mathrm{GeV}^2$ was performed by H1[7)]. The analysed data sample corresponds to an integrated luminosity of $2\,\mathrm{pb}^{-1}$. A fit according to equation (4) was performed, yielding the power n as a function of β and Q^2 as shown in Figure 3. The observed dependence of n on β, implying a breaking of factorisation, can be explained by a contribution from meson exchange with intercept in the region of 0.5. The data were thus fitted using the sum of two contributions: $\left(\frac{1}{x_{\mathbb{P}}}\right)^a F_2^{\mathbb{P}} + \left(\frac{1}{x_{\mathbb{P}}}\right)^b F_2^M$, the latter term representing the meson exchange. The pion structure function was assumed for F_2^M. The data are consistent with a constant value of a. The resulting power a yielded a Pomeron intercept of (for the transition $\overline{\alpha_{\mathbb{P}}} \to \alpha_{\mathbb{P}}(0)$, $\alpha'_{\mathbb{P}} = 0.3\,\mathrm{GeV}^{-2}$ and $b_0 = 6\,\mathrm{GeV}^{-2}$ was assumed):

$$\alpha_{\mathbb{P}}(0) = 1.18 \pm 0.02(\text{stat.}) \pm 0.04(\text{syst.})\,,$$

which is larger than the value observed in soft interactions.

Method 2: For universal and pure Pomeron exchange the diffractive cross section can be written as[1)]:

$$\frac{\mathrm{d}\sigma_{\mathrm{diff}}}{\mathrm{d}M_X} \sim (W^2)^{(2\overline{\alpha_{\mathbb{P}}}-2)} . \tag{5}$$

The W-dependence of $\mathrm{d}\sigma_{\mathrm{diff}}/\mathrm{d}M_X$ was studied by ZEUS using the complete DIS sample ($8 < Q^2 < 60\,\mathrm{GeV}^2$). The analysed data sample corresponds to an integrated luminosity of $2.6\,\mathrm{pb}^{-1}$. The non-diffractive part was subtracted by a fit to the $\ln M_X^2$ spectrum assuming an exponential falling at low M_X. The resulting $\overline{\alpha_{\mathbb{P}}}$ is shown in Figure 4 as a function of Q^2. Again, the value obtained is larger than the intercept measured in soft interactions indicated by the solid line. In addition, ZEUS finds a tendency for $\overline{\alpha_{\mathbb{P}}}$ to grow with Q^2, though more data are needed to draw final conclusions.

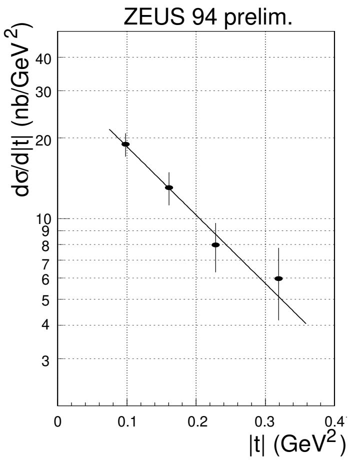

Figure 5: $\mathrm{d}\sigma_{\mathrm{diff}}/\mathrm{d}|t|$ as measured via the leading proton by ZEUS in diffractive photon dissociation in DIS. The line corresponds to a fit according to $\mathrm{d}\sigma_{\mathrm{diff}}/\mathrm{d}|t| = A\mathrm{e}^{-b|t|}$.

Method 3: In another analysis by ZEUS[8)], the outgoing proton was tagged in a leading proton spectrometer. The fraction of the beam momentum carried by the scattered proton, x_L, and t were measured. The requirement $0.97 < x_L < 1.02$ selected diffractive events. The differential cross section $d\sigma_{\mathrm{diff}}/d|t|$ shown in Figure 5 was measured in the range $0.07 < |t| < 0.36\,\mathrm{GeV}^2$ and $4 < Q^2 < 30\,\mathrm{GeV}^2$. A fit assuming the exponential form $d\sigma_{\mathrm{diff}}/d|t| = A\mathrm{e}^{-b|t|}$ yielded:

$$b = 5.9 \pm 1.3(\mathrm{stat.})^{+1.1}_{-0.7}(\mathrm{syst.})\ \mathrm{GeV}^{-2} .$$

$F_2^{D(3)}$ was also measured in the same range. A fit to $F_2^{D(3)}$ according to equation (4) yielded:

$$\overline{\alpha_{\mathbb{P}}} = 1.14 \pm 0.04(\mathrm{stat.}) \pm 0.08(\mathrm{syst.}) .$$

3 Partonic Structure of the Pomeron

3.1 Analysing the Diffractive Structure Function

The integral of $F_2^{D(3)}$ over $x_{\mathbb{P}}$ describes the partonic structure of the diffractive exchange similar to F_2 in the case of the proton, thus providing information about the partonic structure of the Pomeron; the variable β corresponds to the Bjorken-x in the case of the proton. The integral

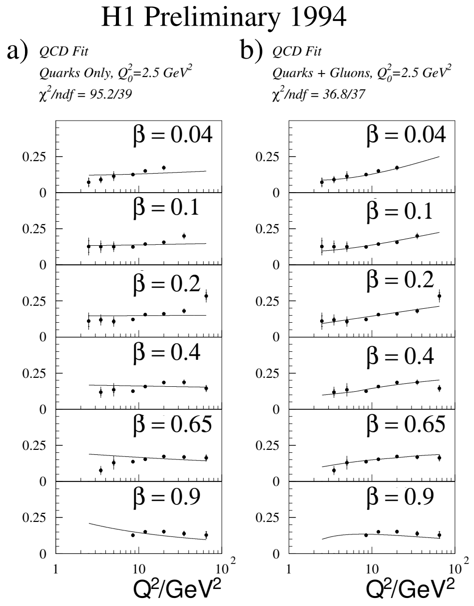

Figure 6: $\tilde{F}_2^D$ as a function of Q^2 for different values of β as determined by H1. The lines correspond to QCD fits to the data.

$\tilde{F}_2^D = \int_{3\cdot 10^{-4}}^{0.05} F_2^{D(3)} \mathrm{d}x_{\mathbb{P}}$ in the range $|t| < 1\,\mathrm{GeV}^2$ as derived by H1 is shown in Figure 6. A violation of the scale invariance, i.e. the rise of $\tilde{F}_2^D$ with $\ln Q^2$, persists to quite large values of β indicating a substantial gluon content in the Pomeron. This was confirmed by QCD fits to $\tilde{F}_2^D$ in the framework of DGLAP evolution shown by the lines in Figure 6. Figure 6a shows that assuming a pure quark content only yielded no good fit, while assuming both quark and gluon content gave a good fit as shown in Figure 6b. The gluon distribution obtained is very strongly peaked as the fraction of the exchanged momentum carried by the gluon tends to 1. Throughout the Q^2 range, more than 80% of the momentum of the exchange was found to be carried by gluons.

3.2 Diffractive Dijet Production

In factorisable models of the Pomeron, the diffractive production of dijets in *ep* scattering is described by a parton of the Pomeron taking part in the hard scattering. Dijet production thus gives access to the partonic structure of the Pomeron. The dijet cross section in DIS was analysed in terms of $\xi_{\mathbb{P}} = \frac{Q^2+M_{jj}^2}{Q^2+M_X^2}$, the fractional momentum of the diffractive exchange entering the hard scattering. A comparison with the prediction derived from the above analysis of $\tilde{F}_2^D$demonstrates again the necessity of a hard gluon content[9)]. A comparison of the photoproduction dijet cross section with predictions from the POMPYT Monte Carlo led to the same conclusion[9,10)].

References:

1) A.H. Mueller, Phys. Rev. **D2** (1970) 2963.
2) A. Donnachie and P.V. Landshoff, Nucl. Phys. **B231** (1984) 189.
3) ZEUS Collaboration, J. Breitweg et al., DESY 97-061 (1997).
4) H1 Collaboration, C. Adloff et al., DESY 97-009 (1997).
5) T. Chapin et al., Phys. Rev. **D31** (1985) 17.
6) G. Ingelmann and P. Schlein, Phys. Lett. **B152** (1985) 256.
7) H1 Collaboration, Paper pa02-061 submitted to ICHEP'96, Warsaw, Poland, July 1996.
8) ZEUS Collaboration, Paper pa02-026 submitted to ICHEP'96, Warsaw, Poland, July 1996.
9) H1 Collaboration, Paper pa02-062 submitted to ICHEP'96, Warsaw, Poland, July 1996.
10) ZEUS Collaboration, Paper pa02-039 submitted to ICHEP'96, Warsaw, Poland, July 1996.