MEASUREMENT AND INTERPRETATION OF $F_2^{D(3)}$

M. Dirkmann for the H1-Collaboration

Lehrstuhl Exp. Phys. 5, Universität Dortmund, Germany

Abstract. An analysis of diffractive deep-inelastic ep scattering at HERA is presented using data taken in 1994 with the H1 detector corresponding to an integrated luminosity of $\sim 2\,\mathrm{pb}^{-1}$. The cross section is measured in terms of a diffractive structure function $F_2^{D(3)}(\beta, Q^2, x_{I\!P})$ of the proton over the kinematic range $2.5 < Q^2 < 65$ GeV^2, $0.01 < \beta < 0.9$ and $0.0001 < x_{I\!P} < 0.05$. The dependence of $F_2^{D(3)}$ on $x_{I\!P}$ is found not to depend on Q^2 but to depend on β, demonstrating that the factorisation of the $\gamma^* p$ cross section into a universal diffractive flux (depending only on $x_{I\!P}$ and t) and a single structure function (depending only on β and Q^2) is not tenable. The data are consistent with an interpretation in which two individually factorisable components contribute to $F_2^{D(3)}$. They may be identified with the exchange of pomeron ($I\!P$) and meson (M) Regge trajectories with $x_{I\!P}$ dependencies $\propto x_{I\!P}^{-(2\alpha_{I\!P}-1)}$, $x_{I\!P}^{-(2\alpha_M-1)}$ with $\alpha_{I\!P}(0) = 1.18 \pm 0.02(\mathrm{stat})\pm0.04(\mathrm{syst})$ and $\alpha_M(0) = 0.6 \pm 0.1(\mathrm{stat})\pm0.3(\mathrm{syst})$. The Q^2 and β dependences of $F_2^{D(3)}$ are examined by integrating $F_2^{D(3)}$ over $x_{I\!P}$. For different β, violations of scale invariance are observed which are consistent with a substantial gluon component in diffractive exchange. When confronted with the leading order DGLAP evolution equations in perturbative QCD, the data yield first estimates of the partonic content of diffractive exchange which is dominated by a leading gluon at the starting scale of $Q_0^2 = 2.5\,\mathrm{GeV}^2$.

I THE CROSS SECTION FOR DIFFRACTIVE DEEP–INELASTIC SCATTERING

The measured cross-section is defined in [1] and will only be shortly reviewed here. The hadronic final state of an event is decomposed into two distinct systems X and Y which are separated by the largest gap in the rapidity distribution of the final state. In addition to the well know kinematic variables of "standard" DIS (Q^2, x_{Bj}, y) new variables are defined in terms of the systems X and Y, where Y is the system closest to the incoming proton direction:

$$t = (P - Y)^2, \;\; x_{I\!P} = \frac{Q^2 + M_X^2}{Q^2 + W^2}, \;\; \beta = \frac{Q^2}{Q^2 + M_X^2};$$

β is analogous to the Bjorken-x variable for scattering off the exchanged system with 4-momentum $(P - Y)$.

The experimental selection of events is based on an absence of hadron production in regions of the H1 detector covering a laboratory pseudorapidity interval $3.4 < \eta < 7.5$ [1]. The system X is then taken to be composed of all particles produced backward of this gap. The limit of 7.5 on the pseudorapidity reached by particles in the leading system, Y, restricts its mass to $M_Y < 1.6$ GeV and the squared 4-momentum transfer to $|t| < 1.0\,\mathrm{GeV}^2$.

The data are used to measure a cross-section for the process, $ep \to e'XY$, differential in $x_{I\!P}$, β and Q^2, in the kinematic range $2.5 < Q^2 < 65$ GeV^2, $0.01 < \beta < 0.9$ and $0.0001 < x_{I\!P} < 0.05$. Following the procedure proposed in [2], the results are presented in terms of a diffractive structure function $F_2^{D(3)}(\beta, Q^2, x_{I\!P})$ [2] which is related to the differential $ep \to e'XY$ cross section by

$$\frac{\mathrm{d}^3\sigma^D_{ep\to eXY}}{\mathrm{d}x_{I\!P}\,\mathrm{d}\beta\,\mathrm{d}Q^2} = \frac{4\pi\alpha^2}{\beta Q^4}(1 - y + \frac{y^2}{2})F_2^{D(3)}(\beta, Q^2, x_{I\!P}).$$

The quantity $x_{I\!P} \cdot F_2^{D(3)}(\beta, Q^2, x_{I\!P})$ is shown as a function of $x_{I\!P}$ in figure 1 for different values of β and Q^2. In a Regge interpretation [3], in which the $x_{I\!P}$ dependence is assumed to describe a reggeon flux associated with the proton, one expects a behaviour of the form $F_2^{D(3)} \propto 1/x_{I\!P}^n$ with $n \approx 2\alpha(0) - 1$, where $\alpha(t) = \alpha(0) + \alpha' t$ is the effective Regge trajectory[3].

The improved precision and extended kinematic range of these new data reveal clear deviations from the universal factorisation observed in our previous measurement [4].

One possible explanation for the absence of a universal factorisation is that there is a contribution from sub-leading trajectories to the measured cross section which may be identified with the exchange of quantum numbers corresponding to physical meson states. After the pomeron, the next–leading exchanges are the approximately degenerate trajectories with the quantum numbers of the f_2, ρ, ω and a_2 mesons, for which one would expect a contribution to $x_{I\!P} \cdot F_2^{D(3)}$ that rises with $x_{I\!P}$.

Superimposed in figure 1 is the result of a fit to the data in which both a pomeron component $A(\beta, Q^2) \cdot x_{I\!P}^{-n_{I\!P}}$ and meson component $C_M \cdot F_2^M(\beta, Q^2) \cdot$

---

[1] The H1 coordinate system is defined such that positive rapidity corresponds to the proton beam direction.

[2] Since t is not measured $F_2^{D(3)}(\beta, Q^2, x_{I\!P})$ is implicitly integrated over t in the given kinematic range

[3] In practice, the finite values of t at which the measurement takes place are expected to reduce n relative to $2\alpha(0) - 1$ by a few percent.

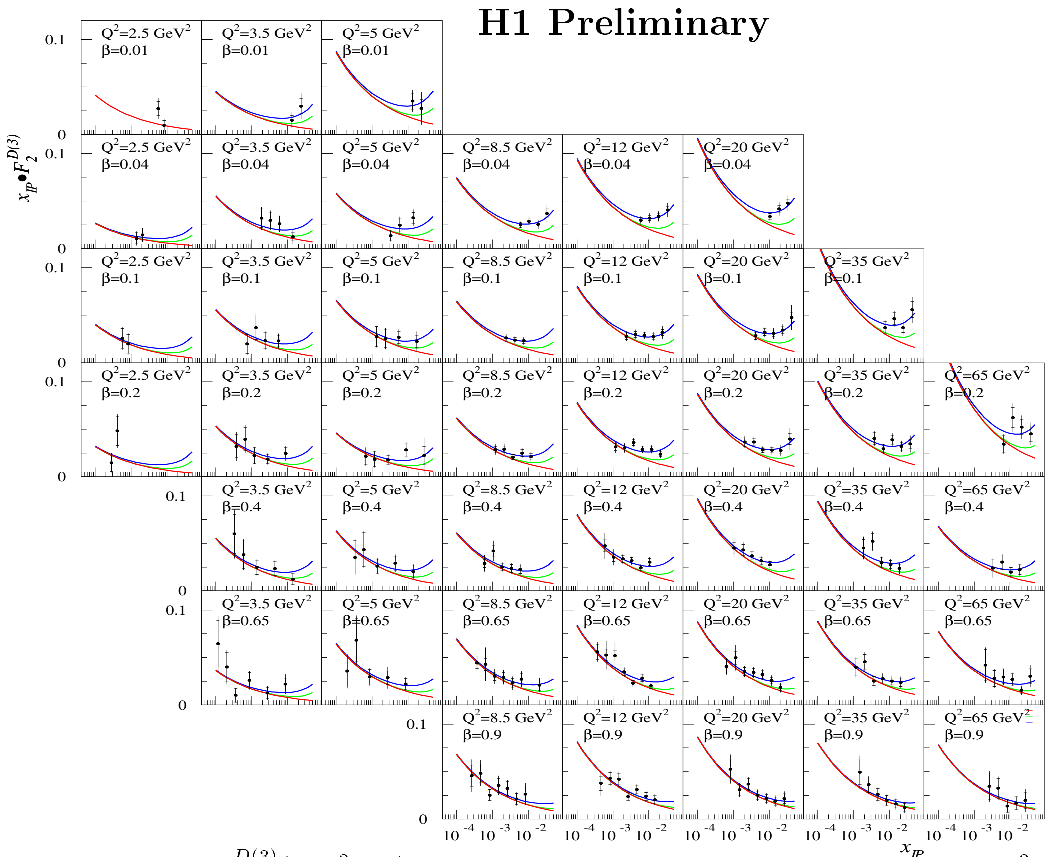

FIGURE 1. $x_{I\!P} \cdot F_2^{D(3)}(\beta, Q^2, x_{I\!P})$ as a function of $x_{I\!P}$ for different values of β and Q^2. Also shown is the result of a phenomenological fit in which two separately factorisable components contribute to the measured cross section. The lowest line is the contribution of the pomeron alone, the middle line the sum of pomeron and meson contribution and the upper line the total sum including the interference.

$x_{I\!P}^{-n_M}$ contribute to $F_2^{D(3)}$. The two amplitudes are assumed to maximally interfere with a phase angle of 45°, as expected from the signature factors. The parameters C_M, $n_{I\!P}$ and n_M are free parameters in the fit along with the value of $A(\beta, Q^2)$ at each separate value of β and Q^2. Since no measurements of the structure function of the mesons in question exist, the function $F_2^M(\beta, Q^2)$ is taken from a GRV parameterisation of the pion structure function [5]. The systematic effect on the values of the parameters extracted from the fit procedure is found to be small for any choice of $F_2^M(\beta, Q^2)$ which falls with increasing β (see [6] for details).

A good description of the data is obtained for fits with ($\chi^2/ndf = 165/156$) and without ($\chi^2/ndf = 170/156$) interference. Correcting for the integration over t yields $\alpha_{I\!P}(0) = 1.18 \pm 0.02(\text{stat}) \pm 0.04(\text{syst})$ and $\alpha_M(0) = 0.6 \pm 0.1(\text{stat}) \pm 0.3(\text{syst})$ for the intercepts of the pomeron and meson trajectories respectively. Here the systematic errors include those associated with the treatment of the meson structure function and the inclusion or exclusion of interference. The value of α_M is entirely consistent with that expected for the exchange of the f_2, ρ, ω and a_2 trajectories. The value of $\alpha_{I\!P}(0)$ is somewhat larger than that obtained in some parameterisations of soft hadronic interactions [7].

II QCD ANALYSIS

In the factorisable prescription proposed in [2], $\int \mathrm{d}x_{I\!P} F_2^{D(3)}(\beta, Q^2, x_{I\!P})$ describes the partonic structure of the diffractive exchange in an analogous way to $F_2(x, Q^2)$ in the case of the proton. Despite the observation of non-factorisation of the measured cross-section, performing the integration over $x_{I\!P}$ provides a measurement of the average deep-inelastic structure of whatever colourless exchanges contribute in the kinematic domain accessed.

We define

$$\tilde{F}_2^D(\beta, Q^2) = \int_{x_{I\!P}=0.0003}^{x_{I\!P}=0.05} F_2^{D(3)}(\beta, Q^2, x_{I\!P})\mathrm{d}x_{I\!P}$$

which is proportional to the structure function for the exchange averaged over the range, $1\,\mathrm{GeV}^2 < |t| \leq |t_{min}(x_{I\!P})|$ and $0.0003 \leq x_{I\!P} \leq 0.05$. Fig. 2 shows $\tilde{F}_2^D(\beta, Q^2)$ as a function of Q^2 for fixed β. The most striking feature is that a rise with $\ln Q^2$ persists to values of β far in excess of the point ($x \sim 0.15$) at which the structure of the nucleon becomes dominated by valence quarks rather than gluons, and $\mathrm{d}F_2(x, Q^2)/\mathrm{d}\ln Q^2$ correspondingly becomes negative. The nature of the scaling violations of $\tilde{F}_2^D(\beta, Q^2)$ are thus in qualitative accord with the hypothesis of a substantial gluon component in the structure of the diffractive exchange. No significant changes of this behaviour are observed when lowering the upper limit of the integration.

A QCD analysis of $\tilde{F}_2^D(\beta, Q^2)$ confirms this qualitative picture. A $u+d+s$ flavour singlet quark distribution and a gluon distribution are parameterised at a starting scale, $Q_0^2 = 2.5\ \mathrm{GeV}^2$, as

$$x_{i/I\!P} \cdot f_i(x_{i/I\!P}) = A_i\, x_{i/I\!P}^{B_i}\, (1 - x_{i/I\!P})^{C_i}$$

where $i = q, g$ and $x_{i/I\!P}$ is the fraction of the exchange momentum carried by parton i. These parton distributions are then evolved using DGLAP [8] evolution to $Q^2 > Q_0^2$, with the values of $A_{q,g}$, $B_{q,g}$ and $C_{q,g}$ as fit parameters (see [6] for details).

Figure 2a shows the best fit obtained for $\tilde{F}_2^D$ when A_g is constrained to be zero, and only quarks contribute at the starting scale. Because of the persistence of rising $\ln Q^2$ scaling violations to high values of β, no such parameterisation is acceptable (confidence level CL = 0.00013%). An excellent (CL = 47.8%) fit, shown in figure 2b, can be obtained when gluons are also

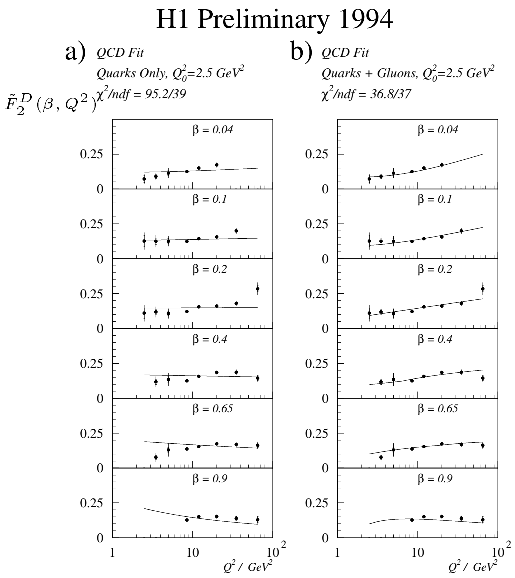

FIGURE 2. Result of the QCD-fit described in the text. a) only using quarks at the starting scale Q_0^2 and b) using quarks and gluons.

introduced at the starting scale. The fit then leads to a dominant gluon contribution concentrated at $x_{i/\mathbb{P}} \approx 1$ at the starting scale, carrying about 80% of the momentum.

Excluding the data at $\beta = 0.9$, which correspond to the resonance region of $M_X \sim m_{\rho,\omega,\phi,\rho',...}$ from the QCD analysis does not affect in any way the conclusions drawn.

III ACKNOWLEDGEMENTS

I would like to thank my colleagues in H1 whose efforts made possible the results presented here. It is a pleasure to thank the organisers.

REFERENCES

1. P. R. Newman, Contribution to this conference.
2. G. Ingelman abd P. Schlein, Phys. Lett. **B152** (1985) 256
3. See for example P.Collins, "An Introduction to Regge Theory & High Energy Physics", CUP, Cambridge (1977).
4. H1 Collaboration, T. Ahmed et. al. Phys. Lett. **B348** (1995) 681.
5. M. Glück, E. Reya, A. Vogt, Z. Phys. **C53** (1992) 651-656.
6. J. P. Phillips, Proceedings to the 28^{th} International Conf. on HEP (pa02-061)
7. A. Donnachie and P. Landshoff, Nucl. Phys. **B303** (1988) 634.
8. Yu. L. Dokshitzer, JETP **46** (1977) 641.
   V. N. Gribov and L. N. Lipatov, Sov. Journ. Nucl. Phys. **15** (1972) 78.
   G. Altarelli and G. Parisi, Nucl. Phys. **B126** 1977 298.