Submitted to the International Europhysics Conference on High Energy Physics,
HEP97, Jerusalem, Israel, August 1997

Observation of Deep Inelastic *ep* Scattering with a Leading Proton

H1 Collaboration

Abstract

The H1 detector at HERA, upgraded with a forward proton spectrometer, has been used to measure the cross section for deep inelastic scattering in the kinematic range $2.6\,\mathrm{GeV}^2 \leq Q^2 \leq 28.6\,\mathrm{GeV}^2$ and $10^{-3} \leq x \leq 10^{-2}$ with a leading proton in the energy range $580\,\mathrm{GeV} \leq E'_p \leq 740\,\mathrm{GeV}$ for $p_\perp < 200\,\mathrm{MeV}$. This class of events is described by a structure function $F_2^{LP(3)}$ very similar to that for diffractive *ep* scattering. The shape of $F_2^{LP(3)}$ is well described by models based on meson exchange.

Abstract 379
Parallel Sessions 2, 3
Plenary Sessions 2, 3

In 1995, H1 installed a forward proton spectrometer (FPS) to detect leading protons with energies between 500 and 760 GeV and scattering angles below 1 mrad. The FPS has been used to measure the cross section for the process $ep \to e'p'X$, where the scattered proton has a transverse momentum $p_\perp < 200\,\mathrm{MeV}$, in the deep–inelastic (DIS) regime. This cross section is parametrized by a structure function $F_2^{LP\,(3)}$ in analogy to the diffractive structure function $F_2^{D\,(3)}$ [1, 2].

The present analysis uses the kinematic variables x, Q^2, and ξ, or equivalently β, Q^2, and ξ that have been introduced for describing rapidity gap events. They are defined as follows:

$$Q^2 = -q^2 \qquad x = \frac{Q^2}{2P\cdot q} \qquad \xi = \frac{q\cdot(P-P')}{q\cdot P} \qquad \beta = \frac{Q^2}{2q\cdot(P-P')} = \frac{x}{\xi}.$$

Here q, P and P' are the 4-momenta of the virtual boson, the incident and the final state proton respectively. In the infinite momentum frame of the proton ξ may be interpreted as the fraction $x_{\pi/p}$ of the proton's four momentum carried by the exchanged object (here denoted as π), and β as the four momentum fraction $x_{q/\pi}$ of the pion carried by the struck quark. The definition of ξ in terms of four–vectors is identical to that of the quantity $x_{I\!P}$ used in the diffractive analysis for events where the proton stays intact. It is measured by the FPS via the relation $\xi = 1 - E'_p/E_p$, where E_p and E'_p are the energy of the beam and the scattered proton. The momentum transfer t is given by (m_p is the proton mass)

$$t = (P-P')^2 = -\frac{\xi^2 m_\mathrm{p}^2 + p_\perp^2}{1-\xi}.$$

The structure function $F_2^{LP\,(4)}$ for processes with a leading proton of transverse momentum $p_\perp < 200\,\mathrm{MeV}$ is defined as follows:

$$\frac{\mathrm{d}^4\sigma}{\mathrm{d}x\,\mathrm{d}Q^2\,\mathrm{d}\xi\,\mathrm{d}t} = \frac{4\pi\alpha^2}{x\,Q^4}\left(1-y+\frac{y^2}{2R}\right)F_2^{LP\,(4)}\,(x,\,Q^2,\,\xi,\,t).$$

Then $F_2^{LP\,(3)}$ is related to a fourfold differential cross section integrated over t:

$$\begin{aligned}\frac{\mathrm{d}^3\sigma}{\mathrm{d}x\,\mathrm{d}Q^2\,\mathrm{d}\xi} &= \int_{t_0}^{t_\mathrm{min}} \frac{4\pi\alpha^2}{x\,Q^4}\left(1-y+\frac{y^2}{2R}\right)F_2^{LP\,(4)}(x,\,Q^2,\,\xi,t)\,\mathrm{d}t \\ &= \frac{4\pi\alpha^2}{x\,Q^4}\left(1-y+\frac{y^2}{2R}\right)F_2^{LP\,(3)}(x,\,Q^2,\,\xi),\end{aligned}$$

where y is given by $y = Q^2/xs$, with s being the ep collision centre of mass energy squared, and the integration bounds are

$$t_\mathrm{min} = -\frac{\xi^2 m_\mathrm{p}^2}{1-\xi}, \qquad t_0 = t_\mathrm{min} - \frac{(200\,\mathrm{MeV})^2}{1-\xi}.$$

This definition is analogous to the introduction of $F_2^{D\,(3)}$, where, however, the t-integration extends over a different range and $F_2^{D\,(3)}$ includes cases where the proton is excited to low mass states.

For the measurement presented here, the ratio R of the cross sections for longitudinal and transverse photons is assumed to be 0. The biggest shift in any bin introduced by assuming $R = \infty$ instead is 9 %, and smaller than 1.8 % for 9 of the 12 $(x,\,Q^2)$ bins.

The structure function $F_2^{LP\,(3)}$ was determined from data taken with the H1 detector upgraded with the FPS [4, 5] in 1995, when HERA operated with 27.5 GeV positrons and 820 GeV

protons. The integrated luminosity was $L = 1.44\,\mathrm{pb}^{-1}$. The acceptance and migration corrections were performed using the Monte Carlo generator RAPGAP [6] implementing a pion–exchange model and using the GRV–LO pion parton densities [7]. LEPTO 6.5 [8], a model based on DIS with soft color interactions in the final state, was used as a cross-check. The data are grouped in 12 $(x,\, Q^2)$–bins in the range $6 \cdot 10^{-5} < x < 6 \cdot 10^{-3}$ and $2\,\mathrm{GeV}^2 < Q^2 < 50\,\mathrm{GeV}^2$, and 4 bins of ξ in the range $0.098 < \xi < 0.244$, corresponding to a β range of $2.5 \cdot 10^{-4} < \beta < 6 \cdot 10^{-2}$. The result of the measurement is shown in Figure 1.

The data show a weak ξ dependence at fixed Q^2 and x. They also show a logarithmic rise of $F_2^{LP\,(3)}$ with Q^2 and a weak x dependence with a tendency to rise with falling x. The ξ dependence is different from the pomeron contribution to the diffractive structure function $F_2^{D(3)}\,(x,\, Q^2,\, x_{I\!P})$ [1], which at fixed β and at fixed t varies like $x_{I\!P}^{-n}$ with $n = 2\alpha_{I\!P}\,(t) - 1$ and $\alpha_{I\!P}\,(0) = 1.20$ [3]. This difference cannot be explained by the different t-ranges covered in the two measurements. The observed features are incompatible with the assumption that pomeron exchange is the origin of events with a leading proton in the kinematic range of this measurement. The observations are, however, in accord with a pion exchange model implemented in RAPGAP, although the overall normalization is too low by a factor of about 2. This could be due to contributions from additional Regge trajectories, or to an underestimate of the sea quark content in the pion parton densities, which have only been determined from data for $\beta > 0.2$ [7].

The LEPTO model describes the cross section in the lowest Q^2 bin including the absolute normalisation, but fails to reproduce the rise of $F_2^{LP\,(3)}$ with Q^2. The ξ spectrum is in broad agreement with the data.

A key feature of meson exchange models is a factorization of the form

$$F_2^{LP\,(3)}\,(\beta,\, Q^2,\, \xi) = f_{\pi/p}\,(\xi) \cdot F_2^{\pi}\,(\beta,\, Q^2),$$

where $f_{\pi/p}\,(\xi)$ is the pion flux integrated over the appropriate t range and F_2^{π} is the pion structure function. To test this hypothesis independently of assumptions about the pion flux, to which contributions from other meson exchanges may have to be added, and about the pion structure, a fit to the data was performed of the form

$$F_2^{LP\,(3)}\,(\beta,\, Q^2,\, \xi) = r\,(\xi) \cdot (a \cdot \beta^b + c \cdot \beta^d \cdot \log Q^2) = r\,(\xi) \cdot \tilde{F}_2^{LP}\,(\beta,\, Q^2), \qquad (1)$$

with free parameters a, b, c, and d. The ansatz $\tilde{F}_2^{LP}\,(\beta,\, Q^2) = (a \cdot \beta^b + c \cdot \beta^d \cdot \log Q^2)$ is expected to describe a hadron structure function in the β range relevant here. The flux $r\,(\xi)$ was normalized at $\xi = 0.171$ to be 1, and fitted for the other three ξ bins, introducing three additional degrees of freedom. The χ^2/df of this fit is $52.9/41$, corresponding to a confidence level of 10 % for the factorization hypothesis with this parametrization assuming statistical and bin dependent systematic errors.

The fits are displayed in Figure 2 with a clear signature for the structure function $\tilde{F}_2^{LP}$ rising logarithmically with Q^2 falling with β as expected for a hadron. In a model where pion exchange is assumed, $\tilde{F}_2^{LP}$ would be expected to be proportional to the pion structure function F_2^{π}.

In models not based on the exchange of an intermediate object the meaning of β is not clear, and one might expect a factorization—if any—in terms of the variables x, Q^2, and ξ, if the behavior of the proton remnant is essentially independent of what happens in the current fragmentation region. To test this hypothesis, a fit of $F_2^{LP\,(3)}\,(x,\, Q^2,\, \xi)$ to the functional form (1) was performed, where β was replaced by x. The resulting $\chi^2/df = 53.1/41$ is similar to that for a factorization in β, Q^2, and ξ, so one cannot distinguish between these two hypotheses with the present precision of the data. An interpretation in which the incident proton interacts via meson exchange, in particular pion exchange, and in which the incident positron probes the deep–inelastic structure of this exchange is found to describe well the dependences of $F_2^{LP\,(3)}$.

Acknowledgements

We are grateful to the HERA machine group whose outstanding efforts have made and continue to make this experiment possible. We thank the engineers and technicians for their work in constructing and now maintaining the H1 detector, our funding agencies for financial support, the DESY technical staff for continual assistance, and the DESY directorate for the hospitality which they extend to the non-DESY members of the collaboration.

The H1 Forward Proton Spectrometer was supported by INTAS contract 93-43.

References

[1] H1 Collaboration, T. Ahmed et al., *Phys. Lett.* **B348**, 681 (1995).

[2] ZEUS Collaboration, M. Derrick et al., *Z. Phys.* **C68**, 569 (1995).

[3] H1 Collaboration, *Paper* **377** submitted to this conference.

[4] H1 Collaboration, I. Abt et al., *Nucl. Instr. Meth.* **A386**, 310 (1997), *ibid.* 348.

[5] H1 SPACAL Group, R.–D. Appuhn et al., *Nucl. Instr. Meth.* **A386**, 397 (1997).

[6] H. Jung, *Comp. Phys. Comm.* **86**, 147 (1995).

[7] M. Glück, W. Reya, and A. Vogt, *Z. Phys.* **C53**, 651 (1992).

[8] G. Ingelman, A. Edin, and J. Rathsman, *Comp. Phys. Comm.* **101**, 108 (1997).

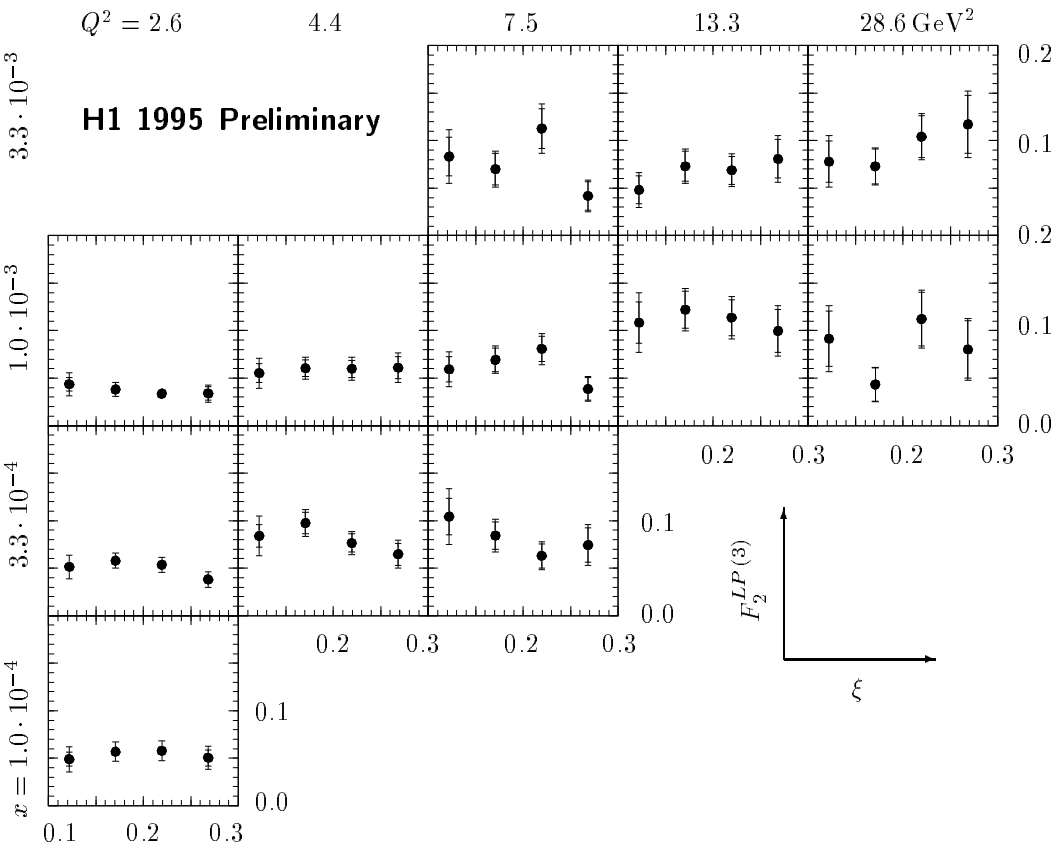

Figure 1: $F_2^{LP(3)}(x, Q^2, \xi)$ in bins of x and Q^2 as function of ξ. The inner error bars denote the statistical error, the outer error bar show statistical and full systematic errors added in quadrature. An overall normalization uncertainty of 5.2% is not shown.

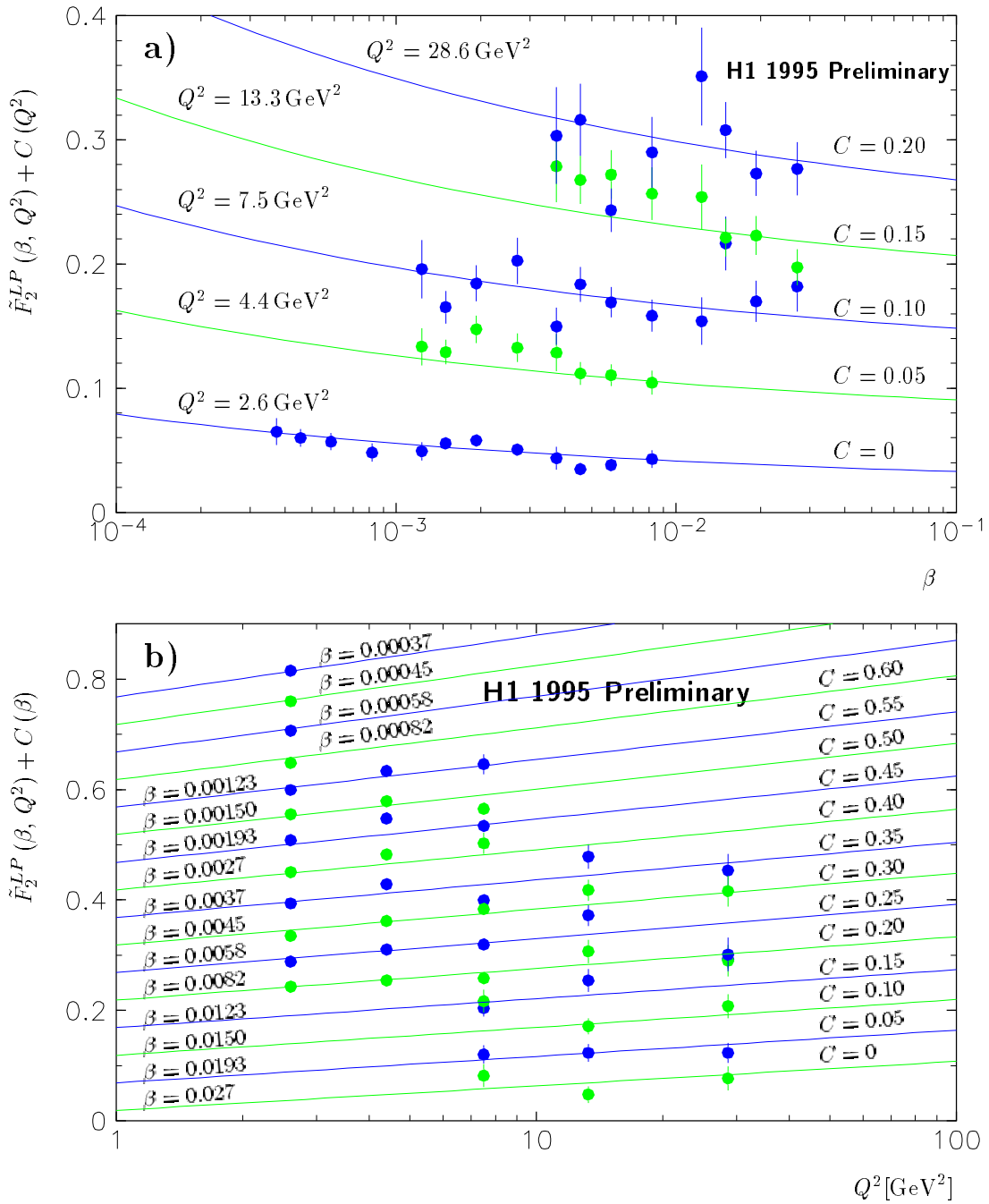

Figure 2: Fits to $F_2^{LP\,(3)} = r(\xi) \cdot \tilde{F}_2^{LP}(\beta, Q^2)$ (see text for details). For easier visualisation data points are marked differently to distinguish between different ranges of Q^2 and β.
a) $\tilde{F}_2^{LP}(\beta, Q^2)$ for constant Q^2, b) $\tilde{F}_2^{LP}(\beta, Q^2)$ for constant β.