DEEP INELASTIC SCATTERING AT HIGH Q^2

J. GROSSE-KNETTER
on behalf of the H1 and ZEUS Collaborations

*University of Oxford, Particle & Nuclear Physics, Keble Road,
Oxford OX1 3RH, U.K.
E-mail: J.Grosse-Knetter1@physics.ox.ac.uk*

Neutral- and charged-current deep inelastic scattering have been studied in e^+p and e^-p collisions at HERA at centre-of-mass energies of 300 GeV or 320 GeV, respectively. Single differential cross-sections are presented in the kinematic region $Q^2 > 200\,\mathrm{GeV}^2$; good agreement with the Standard Model predictions is found. The neutral-current cross-sections provide direct evidence for the presence of Z^0 exchange in the space-like region explored by deep inelastic scattering. Fits to the charged-current cross-sections yield values of the W mass in good agreement with the directly measured value.

1 Introduction

The deep inelastic scattering (DIS) of leptons by nucleons has proved to be an important tool both in the development of the current understanding of proton structure and in the determination of the form of the Standard Model (SM). Lepton-proton collisions at HERA give access to DIS reactions at high momentum transfer squared, Q^2. At high Q^2 neutral-current (NC) DIS is sensitive to the influence of the weak sector via exchange of Z^0 bosons, while charged-current (CC) DIS is mediated by W exchange only. In addition, NC and CC DIS is sensitive to different combinations of parton distribution functions (PDFs).

Presented here is the measurement of CC and NC cross-sections for $Q^2 > 200\,\mathrm{GeV}^2$ and their comparison to SM predictions. H1 and ZEUS each collected approximately $40\,\mathrm{pb}^{-1}$ of positron-proton data from 1994 to 1997, and a part (approximately $5\,\mathrm{pb}^{-1}$) of the electron-proton data collected from 1998 to 1999 is shown. During this time HERA collided 27.5 GeV positrons (electrons) with 820 (920) GeV protons, corresponding to centre-of-mass energies of $\sqrt{s} = 300$ (320) GeV.

2 Standard Model Cross-Sections

The Born-level cross-section for the NC process $e^{\pm}p \rightarrow e^{\pm}X$ can be expressed as[1]:

$$\frac{d^2\sigma^{\rm NC}(e^{\pm})}{dx dQ^2} = \frac{2\pi\alpha^2}{xQ^4}\left[Y_+\, F_2^{\rm NC}(x,Q^2) \mp Y_-\, xF_3^{\rm NC}(x,Q^2) - y^2\, F_L^{\rm NC}(x,Q^2)\right]$$

where x is the Bjorken scaling variable, $\alpha = 1/137$ the QED coupling constant and $Y_{\pm} = 1 \pm (1-y)^2$, with $y = Q^2/sx$. In leading order (LO) QCD the structure functions are:

$$\begin{aligned} F_2^{\rm NC} &= \frac{1}{2}\sum_f (xq_f + x\bar{q}_f)\left[(V_f^L)^2 + (V_f^R)^2 + (A_f^L)^2 + (A_f^R)^2\right], \\ xF_3^{\rm NC} &= \sum_f (xq_f - x\bar{q}_f)\left[V_f^L A_f^L - V_f^R A_f^R\right], \end{aligned}$$

where xq_f ($x\bar{q}_f$) are the quark (anti-quark) momentum distributions. In LO QCD, we have $F_L^{\rm NC} = 0$. The functions V_f and A_f can be written as $V_f^{L,R} = e_f - (v_e \pm a_e)\, v_f P_{\rm Z}(Q^2)$ and $A_f^{L,R} = -(v_e \pm a_e)\, a_f P_{\rm Z}(Q^2)$, where e_i is the electric charge in units of the positron charge and the weak couplings, $a_i = T_i^3/\sin 2\theta_{\rm W}$ and $v_i = (T_i^3 - 2e_i \sin^2\theta_{\rm W})/\sin 2\theta_{\rm W}$, are functions of the weak isospin, T_i^3, and the weak mixing angle, $\theta_{\rm W}$. $P_{\rm Z}$ is the ratio of Z^0 boson and photon propagators, $P_{\rm Z} = Q^2/(Q^2 + M_Z^2)$, where M_Z is the mass of the Z^0 boson.

The Born level cross-section for the CC process $e^{\pm}p \rightarrow \overset{(-)}{\nu}_e X$ can be expressed as:

$$\frac{d^2\sigma^{\rm CC}(e^{\pm})}{dx dQ^2} = \frac{G_F^2}{4\pi x}\left(\frac{M_W^2}{M_W^2 + Q^2}\right)^2 \cdot \left[Y_+\, F_2^{\rm CC}(x,Q^2) \mp Y_-\, xF_3^{\rm CC}(x,Q^2) - y^2\, F_L^{\rm CC}(x,Q^2)\right]$$

where M_W is the mass of the W boson and G_F the Fermi constant. In LO QCD the term in square brackets is $2[\bar{u} + \bar{c} + (1-y)^2(d+s)]$ for e^+p scattering, ie dominated by sea quarks at high y, and $2[u + c + (1-y)^2(\bar{d} + \bar{s})]$ for e^-p scattering[1], ie dominated by valence quarks.

3 Results

Details of the analyses presented here and the complete results from the e^+p sample are available elsewhere[2]. Electroweak effects on the DIS cross sections can be observed as function of Q^2. Therefore we restrict ourselves to discussing the cross-section $d\sigma/dQ^2$ only. For example, the cross-section $d\sigma/dQ^2$ from the H1 NC analysis is shown in figure 1 and the cross-section $d\sigma/dQ^2$ from the ZEUS CC analysis is shown in figure 2. Both the e^+p and preliminary e^-p results are shown. All points agree with the SM predictions within errors over several orders of magnitude.

Whereas the e^+p and e^-p NC data are approximately equal at low Q^2, the e^- data is larger than e^+ at large Q^2. The difference at high Q^2 is caused by the different sign with which the structure function enters the cross section (see section 2). The CC data indicate that electrons yield a larger cross-section than positrons. Most of the effect comes from the different selection of quark flavours in the coupling to the exchanged W boson when changing the charge of the lepton beam (see section 2). An additional small increase is caused by the higher centre-of-mass energy for the e^-p sample as indicated by the dotted line in figure 2.

Both the CC and the NC cross-sections are sensitive to electroweak parameters. The propagator ratio $P_{\rm Z}$ reduces the e^+p cross-section for $Q^2 > 10000\,{\rm GeV}^2$ by about 25% compared to pure photon-exchange. This prediction is in good agreement with the data while absence of Z^0 exchange is ruled out.

The absolute magnitude of the CC cross-section at low Q^2 is proportional to the Fermi constant G_F and the PDFs, while the Q^2 dependence of the CC cross-section is dominated by

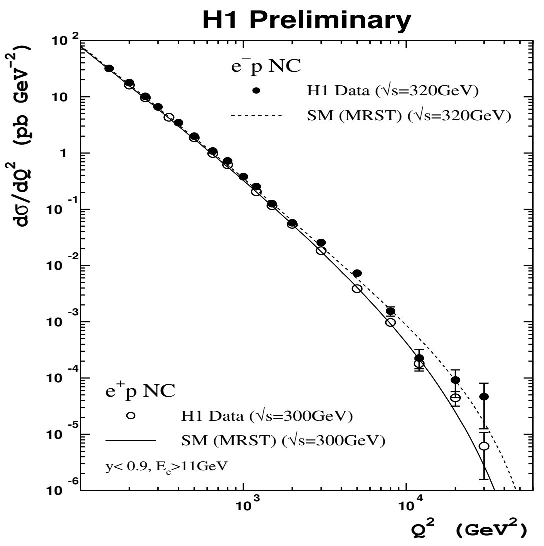

Figure 1: The NC DIS cross-section $d\sigma/dQ^2$ for data (symbols) and the SM prediction (curves). The errors contain statistical and uncorrelated systematic errors; the overall luminosity uncertainty is not shown. The open circles and the solid line are for e^+p data, the dots and the dashed line for e^-p data.

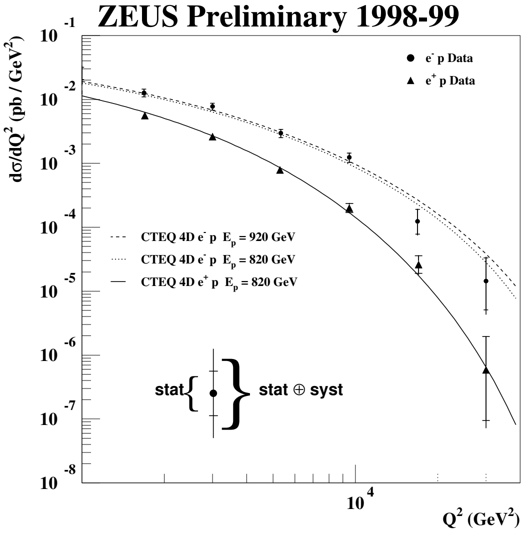

Figure 2: The CC DIS cross-section $d\sigma/dQ^2$ for data (symbols) and the SM prediction (curves). The inner error bars indicate the statistical errors. The triangles and the solid line are for e^+p data, the dots and the dashed line for e^-p data, the dotted line for e^-p data assuming a proton beam energy of 820 GeV.

the propagator term $[M_W^2/(M_W^2+Q^2)]^2$, which produces substantial damping of the cross-section at high Q^2. By evaluating a χ^2 function with fixed G_F, the 'propagator-mass' of the exchanged W boson is fitted. A fit to the single differential cross-section $d\sigma(e^+p)/dQ^2$ (ZEUS) yields:

$$M_W = 81.4^{+2.7}_{-2.6}(\text{stat.})\pm 2.0(\text{syst.})^{+3.3}_{-3.0}(\text{PDF})\ \text{GeV},$$

where the last error (PDF) is determined from PDF uncertainties obtained from a QCD fit [2]. A fit to the double-differential cross-section $d^2\sigma(e^+p)/dxdQ^2$ (H1) yields:

$$M_W = 80.9 \pm 3.3(\text{stat.}) \pm 1.7(\text{sys.}) \pm 3.7(\text{theo.})\ \text{GeV},$$

where the last error (theo.) is determined from PDF uncertainties obtained from varying a QCD fit [2]. Both results are in good agreement with the value obtained by direct measurement[3], $M_W = 80.41 \pm 0.10\,\text{GeV}$. This shows that the SM gives a consistent description of charged-current induced time-like and space-like processes over a wide range of virtualities.

Acknowledgments

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