ELECTROWEAK PHYSICS IN $\mathbf{e^{\pm}p}$ SCATTERING AT HERA

Stefan Rieß
Universität Hamburg
II. Institut für Experimentalphysik
Luruper Chausse 149; 22761 Hamburg; Germany
For the H1 and ZEUS collaborations

Abstract:

The Q^2 and x dependence of cross sections for charged and neutral current deep inelastic processes are measured in $e^{\pm}p$ reactions. Good agreement with Standard Model expectations is found. Comparable size of cross sections for the neutral current process and for the weak charged current process are observed above $Q^2 \approx m_W^2$. From the charged current cross section a propagator mass of $m_W = 81\ ^{+6}_{-7}\ ^{+7}_{-5}$ GeV is determined. A preliminary upper limit for the W–production cross section of $\sigma(e+p \rightarrow e+X+W) < 7pb$ at 95 % CL is reported.

1 Introduction

The unification of weak and electromagnetic forces is an important ingredient of the Standard Model. As a consequence, the cross sections for neutral current (NC) and charged current (CC) processes

$$e^{\pm}p \rightarrow e^{\pm} + X \quad \text{and} \quad e^{\pm}p \rightarrow \overset{(-)}{\nu}_e + X \tag{1}$$

(X denotes the hadronic system recoiling against the lepton) are predicted to be of comparable size when probing small distances (e.g. at $Q^2 \simeq m_W^2$). Q^2 is the four momentum transfer and the HERA experiments H1 and ZEUS at the unique electron–proton collider HERA permit the study of these processes in a new kinematic regime at large Q^2.

For CC processes the lowest order cross section can be written as:

$$\frac{\mathrm{d}^2\sigma_{\mathrm{CC}}^{e^-}}{\mathrm{d}x\mathrm{d}Q^2} = \frac{G_\mu^2}{2\pi}\left(\frac{1}{(1+Q^2/m_W^2)^2}\right)\left[u + c + (1-y)^2(\bar{d}+\bar{s})\right] \tag{2}$$

$$\frac{\mathrm{d}^2\sigma_{\mathrm{CC}}^{e^+}}{\mathrm{d}x\mathrm{d}Q^2} = \frac{G_\mu^2}{2\pi}\left(\frac{1}{(1+Q^2/m_W^2)^2}\right)\left[\bar{u} + \bar{c} + (1-y)^2(d+s)\right], \tag{3}$$

where G_μ is the Fermi constant known from the measurement of the muon lifetime. Here x and y are the Bjorken scaling variables which are related by $Q^2 = sxy$. The center of mass energy squared s is given by the product of the electron and proton beam energies $s = 4E_eE_p$. The quark and anti-quark densities (u,d,s,c) all depend on x and Q^2. In the propagator term m_W denotes the mass of the W bosons which mediate the weak force.

The NC cross section is governed by the photon propagator, the Z^0 exchange contribution grows with Q^2 but is still small for $Q^2 \approx m_{Z^0}^2$. Therefore electroweak effects in NC processes are experimentally not significant for present statistics.

In this report the dependence of the charged current cross section on Q^2 and on x is presented. Results are based on publications by the ZEUS[1),2)] and by the H1 Collaboration.[3)–5)] From the Q^2 differential cross section of CC data m_W is derived .

The coupling strengths (κ, λ) for the triple Boson vertex $WW\gamma$ are predicted by the standard model.[6),7)] At HERA deviations from these predictions are accessible in different reaction channels and are called anomalous couplings. Preliminary results from the ZEUS Collaboration are presented for the production of W bosons being radiated off the virtual photon in NC events.

2 Experimental conditions

In HERA electron or positron beams (27.5 GeV in 1994) collide with 820 GeV protons. This report is based on data taken in 1993 to 1995 using the H1 and ZEUS detectors. The total integrated luminosities are in the order of 4 pb^{-1} per experiment.[2),5)]

H1 and ZEUS are multi–purpose, almost hermetic detectors optimized to measure large Q^2 events in deep inelastic scattering. A detailed description of the detectors and their performance can be found elsewhere.[8),9)] The basic design of both detectors is rather similar. Both experiments use drift chambers in a longitudinal magnetic field to measure tracks and to determine the interaction vertex of an event. H1 uses a finely segmented Liquid argon (LAr) calorimeter[10)] and ZEUS a compensating Uranium-Scintillator calorimeter. The response of each calorimeter to single pions and electrons was measured in test beams. The hadron energy scale has been verified within 4% (H1) and 5% (ZEUS) with data taken at HERA. Fast multi level triggers allow to trigger efficiently on missing transverse momenta (CC trigger) or on large electromagnetic energy deposition (NC trigger). Muon systems surround each calorimeter and are used for background rejection due to incoming muons. Luminosity systems measure the rate of the small angle Bremsstrahlung process $ep \rightarrow ep\gamma$[12)13)] and allow the determination of the luminosity with a precision in the order of 1.5%.

3 Results for CC and NC differential cross sections

The event selection for the CC analyses is based on information of the hadronic final state. H1 also selects NC events on the same basis. Energies and directions are measured by the calorimeters. The hadronic transverse momentum sum $p_{T,h}$ measures the missing transverse momentum in each event and $E_{T,h}$ is the total transverse energy. These quantities provide the main cuts for event selection. H1 requires $p_{T,h} > 25\mathrm{GeV}$ and ZEUS cuts at $p_{T,h} > 11\mathrm{GeV}$ and $p_{T,h}/E_{T,h} > 0.45$.

Possible background consists of ep related processes like photoproduction. Incoming muons like halo muons from the proton beam or comic muons are identified by dedicated pattern recognition algorithms and timing of calorimeter and trackers with respect to the HERA clock. The detection efficiencies for CC events are determined with the hadronic final state of the NC data where the scattered electron is discarded from the analysis. H1 relies solely on this approach, whereas ZEUS uses Monte Carlo simulations in connection with their NC data. For all details of background estimation and efficiency calculation please refer to ref.[1)–5)] Final CC event samples consist of 25 events in e^-p and 49 events in e^+p for H1 and 30 events in e^-p and 56 events in e^+p for ZEUS ($Q^2 > 200\mathrm{GeV}^2$ at ZEUS).

The final state kinematics is fully specified by two independent variables. Following the method proposed in[14)] the transverse momentum sum $p_{T,h}$ and the energy transfer y_h (also calculable with the hadronic final state) are used. Q^2 and the fraction of the proton momentum carried by the interacting quark x are given by

$$Q_h^2 = \frac{p_{T,h}^2}{1-y_h}; \qquad x = \frac{Q_h^2}{sy_h}. \tag{4}$$

For comparison to data and for studies of migration effects and unfolding a detailed detector simulation is used by each experiment. The electroweak processes are generated by the DJANGO Monte Carlo program that includes QED radiative effects of order $\mathcal{O}(\alpha)$[15)] with proton parton densities of the MRSH (H1) and MRSA (ZEUS) parameterizations.[16)] The program makes use of the color dipole model as implemented in ARIADNE[17)] for hadronization. Unfolding techniques[18)] are applied to determine the true x and Q^2 distribution from the measured distributions.

In Fig. 1 the Q^2-differential cross sections for the $e^{\pm}p$ data for NC and CC for $p_T >$ 25 GeV are presented.[2),5)] p_T is the transverse momentum of the scattered lepton. The theoretical prediction was obtained with the HERACLES[20)] generator using the MRSA′[16)] proton parton densities. Corrections for acceptance and for detector resolution are applied, radiative effects are not corrected for. The preliminary ZEUS data are rescaled to take the $p_T > 25$ GeV cut into account. The NC cross section decreases over six orders of magnitude with increasing Q^2. Above $Q^2 \succeq m_W^2 \approx 5000$ GeV^2 the cross sections for NC and CC processes are of comparable size. For the e^+p data the charged current cross section stays below the neutral current cross section over the whole Q^2 range, due to the different quark densities of the u and d quark in the proton. In addition the contribution to the cross section by the d quark is felicity suppressed (cf. eq. (2,3),[4)]). Sources of systematic errors are the uncertainty in the hadronic energy scale, uncertainties in the determination of the trigger and selection efficiencies as well as the luminosity measurement.

For the neutral current cross section in Fig. 1 shows the Standard Model expectation for γ, Z^0 exchange and assumed photon exchange only. The comparison shows that the present integrated luminosity does not yet allow the distinction between the pure photon exchange and the total electroweak cross section in NC reactions.

From the CC sample ZEUS fits a common propagator mass simultanuosly to the electron and positron induced cross sections, yielding $m_W = 79\ ^{+8}_{-7}\ ^{+6}_{-3}$ GeV. The first errors are of

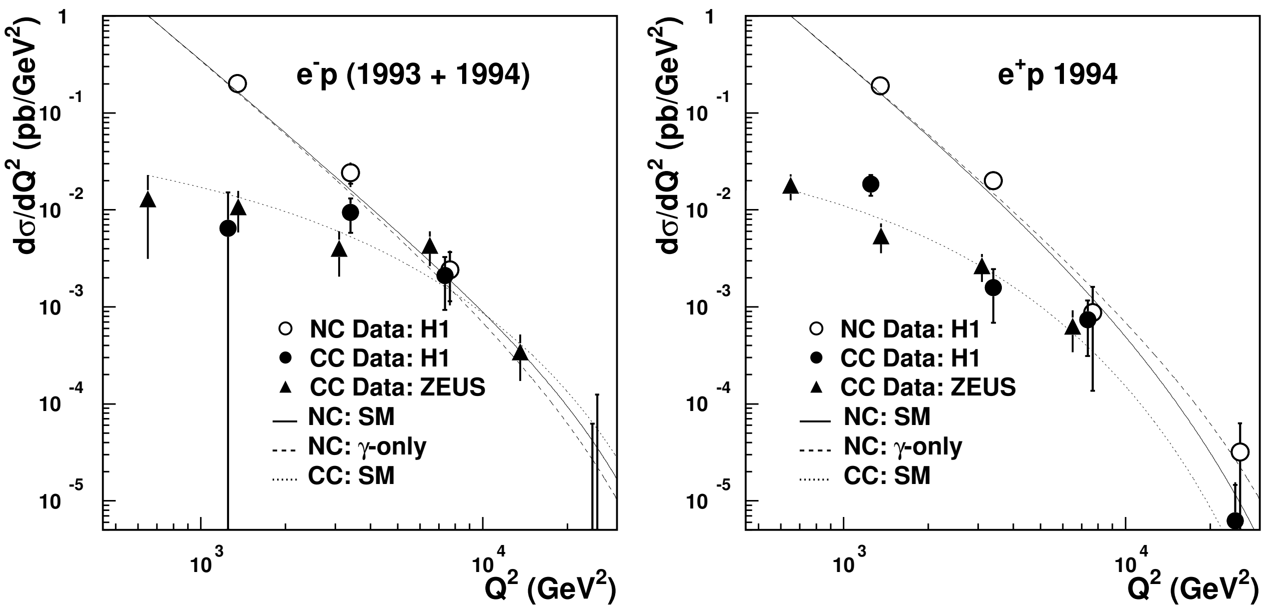

Figure 1: *The differential cross sections $d\sigma/dQ^2$ are shown for charged and neutral current interactions with $p_T > 25$ GeV for e^-p collisions in a) and for e^+p collisions in b). The error bars correspond to statistical and the systematic errors added in quadrature. The solid lines indicate the Standard Model predictions for neutral current interactions and the dotted lines for charged current interactions. Dashed lines show the prediction for NC from photon exchange alone. The ZEUS data are corrected to correspond to $p_T > 25$ GeV.*

statistical and the second of systematic origin. H1 obtains propagator masses of $m_W(e^-p) = 78\ ^{+11}_{-9}\ ^{+4}_{-3}$ GeV and $m_W(e^+p) = 97\ ^{+18}_{-15}\ ^{+5}_{-10}$ GeV using extended maximum likelihood[19] fits. This exhibits that both charged current processes are consistent with the exchange of a W boson which has equal mass for both charge states. Therefore a combined fit results in $m_W = 84\ ^{+9}_{-6}\ ^{+5}_{-4}$ GeV. The size of the statistical uncertainties reflect the different sensitivities of the e^+p and e^-p cross sections to the propagator mass. For both experiments the systematic error is dominated by the uncertainty of the hadronic energy scale. The averaged propagator mass from both experiments yields a smaller statistical error, systematic errors are added in quadrature.

$$m_W = 82\ ^{+6}_{-5}\ ^{+7}_{-5}\ \text{GeV}.$$

This confirms previous results from HERA on the W-mass[1,3,4] with improved precision. In addition the mass of the intermediate W boson is in agreement with the mass determined from direct production of W bosons at $p\bar{p}$-colliders.[21]

The differential x distributions for CC measured by ZEUS in $e^{\pm}$ induced reactions are shown in Fig 2a. The measured cross sections fall with increasing x. At low x, where both

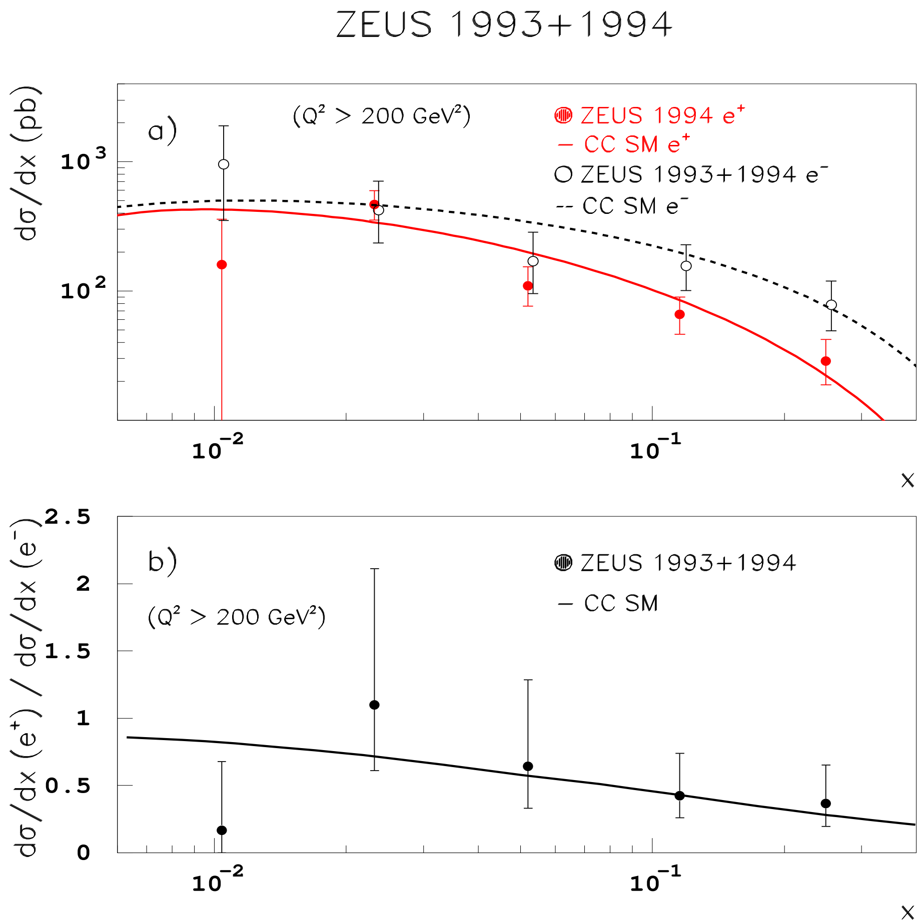

Figure 2: *The differential cross sections $d\sigma/dx$ are shown in a) for charged current interactions with $Q^2 > 200$ GeV^2 for $e^{\pm}p$ collisions . The error bars correspond to statistical and systematic errors added in quadrature. The solid and the dashed lines indicate the Standard Model predictions for charged current interactions. The ratio of the two cross sections is shown in b) where data is given by the dots and the curve represents the Standard Model expectation.*

cross sections are of almost equal size the cross section is dominated by sea quarks. At larger $x > 0.2$ scattering on valence quarks contributes mostly to the cross section. The x dependent ratio of u to d quark density causes the e^+p induced cross section to drop more rapidly with increasing x than the e^-p induced one (cf. Fig. 2b). With increased luminosity future data will allow to constrain parton densities at large Q^2. Their knowledge is vital for precision measurements of electroweak parameters at HERA.

4 W Production

The ZEUS collaboration searched for candidates for the process $e+p \rightarrow e+X+W(\rightarrow e+\nu_e)$ in a data volume corresponding to $9pb^{-1}$ in $e^{\pm}p$ data. The selection of event candidates in this channel consists of the requirement of a total missing $p_{T,h} > 20GeV$, an identified electron and the azimuthal angle between electron and hadronic system has to be smaller than 3.04. No candidates are found. With a total selection efficiency of 47% for this channel an upper limit on the total W production cross section of 7pb (preliminary) is set at 95% confidence level. This result can be converted to constrain the size of the anomalous couplings to $|\Delta\lambda| < 11$ and $|\Delta\kappa| < 7.2$. The H1 Collaboration reported earlier on an event being a candidate for $e+p \rightarrow e+X+W(\rightarrow \mu+\nu_\mu)$[22)]

5 Conclusion

The x and Q^2 dependence of the charged current processes have been measured for e^- and e^+ beams colliding with protons for transverse momenta of the scattered lepton above 25 GeV(H1) and $Q^2 > 200\text{GeV}^2$ (ZEUS). At large momentum transfers $Q^2 \simeq m_W^2 \sim 5000$ GeV^2 the same strength of the weak (CC) and electroweak (NC) forces is observed. The combined propagator mass measured in charged current scattering is $m_W = 82\ ^{+6}_{-7}\ ^{+7}_{-5}$ GeV and is consistent with the direct measurement of the W boson mass. The x dependence of the CC process measured for $Q^2 > 200\text{GeV}^2$ provides information about the quark to anti-quark content of the proton at large Q^2. All differential cross sections are in agreement with the Standard Model expectations. A preliminary result on the total W-production cross section is derived by the ZEUS collaboration: $\sigma(e+p \rightarrow e+X+W) < 7pb$.

Acknowledgment

I am grateful to all members of the H1 and ZEUS collaboration whose work made it possible that this data was taken and analyzed and to U.Katz and B.Straub who introduced the details of the ZEUS analysis to me. Finally for a careful reading of the manuscript and his helpful comments I thank again U.Katz as well as I.Negri and A.B.Fahr for translating the title page to French.

References

1) ZEUS Collaboration, M. Derrick et al., Phys. Rev. Lett. 75(1995)1006.

2) ZEUS Collaboration, M. Derrick et al., in preparation.

3) H1 Collaboration, T. Ahmed et al., Phys. Lett. B324 (1994) 241.

4) H1 Collaboration, S. Aid et al., Z. Phys. C67 (1995) 565.

5) H1 Collaboration, S. Aid et al., Phys. Lett. B, in press.

6) T. Helbig and H.Spiessberger, Nucl. Phys. B 373 (1992) 73.

7) U. Baur, J. Vermaseren and D. Zeppenfeld, Nucl. Phys. B 375 (1992) 3.

8) H1 Collaboration, I. Abt et al., *The H1 detector at HERA*, DESY Preprint 93-103 (1993).

9) ZEUS Collaboration, ed. U.Holm Status Report *The ZEUS detector*, DESY 993.

10) H1 Calorimeter Group: B. Andrieu et al., Nucl. Instr. and Meth. A336 (1993), 460.

11) H1 Calorimeter Group, B. Andrieu et al., Nucl. Instr. and Meth. A336 (1993), 499 ; ibid. A350 (1994) 57.

12) H1 Collaboration, T. Ahmed et al., Z. Phys. C66 (1995) 529.

13) M. Derrick et al., Phys. Lett. B293 (1992) 465.

14) F. Jacquet and A. Blondel, Proceedings of the "Study for an ep Facility in Europe" (1979) 391.

15) G.A. Schuler and H. Spiesberger, DJANGO: Proceedings of the Workshop "Physics at HERA", Hamburg, Vol. 3 (1991) 1419.

16) A.D. Martin, W.J. Stirling and R.G. Roberts, Phys. Rev. D50 (1994) 6734, Phys. Rev. D51 (1995) 4756.

17) L. Lönnblad, Comm. Phys. Comm. 71 (1992) 433.

18) G. Zech, *Comparing Statistical Data to Monte Carlo Simulation: Parameter Fitting and Unfolding,* DESY-95-113.

19) R. Barlow, Nucl. Inst. and Meth. A297 (1990) 496.

20) A. Kwiatkowski, H. Spiesberger and H.-J. Möhring, Comp. Phys. Comm. 69 (1992) 155.

21) Particle Data Group, Phys. Rev. D50 (1994) 1191.

22) H1 Collaboration, T.Ahmed et al., DESY Preprint 94-248 (1994).