Journal of Physics: Conference Series

OPEN ACCESS

Charged and neutral current cross sections from HERA

To cite this article: R Ciesielski 2008 *J. Phys.: Conf. Ser.* **110** 042007

Charged and neutral current cross sections from HERA

Robert Ciesielski[1], **on behalf of the H1 and ZEUS Collaborations**

[1] Deutsches Elektronen-Synchrotron, DESY, Notkestr. 85, 22607 Hamburg, Germany

E-mail: robert.ciesielski@desy.de

Abstract. The cross sections for inclusive neutral and charged current deep inelastic $e^{\pm}$p scattering at high Q^2 with polarised lepton beams at HERA-II are presented. The electroweak effects in spacelike scattering are highlighted and compared to the Standard Model prediction.

1. Introduction

The operation of the HERA ep collider came to an end in June 2007. A good understanding of QCD and the precise measurements of the proton parton density functions (PDFs) were made possible by intensive studies of two deep inelastic $e^{\pm}p$ scattering (DIS) processes: neutral current (NC) interactions, $e^{\pm}p \rightarrow e^{\pm}X$, and charged current (CC) interactions, $e^{\pm}p \rightarrow \bar{\nu}_e(\nu_e)X$. The NC (CC) processes are mediated by the exchange of a photon or Z^0 boson ($W^{\mp}$ boson) and they can be described by three invariant variables: the virtuality of the exchanged boson, Q^2, the Bjorken scaling variable, x, and the inelasticity, y ($Q^2 = sxy$). In 2002, the collider was upgraded (HERA-II) to provide higher instantaneous luminosities and longitudinal polarisation of the lepton beam. This significantly improved the precision in the high-Q^2 region where Z^0 and $W^{\pm}$ exchange becomes significant and allowed tests to be made of the electroweak sector of the Standard Model (SM) in the spacelike scattering, complementary to LEP and Tevatron precision measurements. This paper reviews the recent electroweak measurements of the inclusive NC and CC cross sections at high Q^2 and high x, performed by H1 and ZEUS collaborations using part of the HERA-II data.

2. Unpolarised NC and CC cross sections and xF_3 structure function

The double differential cross section for $e^{\pm}p$ NC DIS may be written in terms of proton structure functions, F_2, xF_3 and F_L:

$$\frac{d\sigma^{e^{\pm}p}}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}[Y_+F_2 \mp Y_-xF_3 - y^2F_L], \tag{1}$$

where α is the fine-structure constant and $Y_{\pm} = 1 \pm (1-y)^2$. The structure functions F_2 and xF_3 contain the sum and the difference of the quark and antiquark PDFs, the longitudinal structure function, F_L, is sizable only at high y and can be neglected at high Q^2 and high x. The double differential cross section for e^-p and e^+p CC DIS may be written as:

$$\frac{d\sigma^{e^-p}}{dxdQ^2} = \frac{G_F^2}{2\pi}\frac{M_W^4}{(Q^2+M_W^2)^2}[(u+c)+(1-y)^2(\bar{d}+\bar{s})] \tag{2}$$

$$\frac{d\sigma^{e^+p}}{dxdQ^2} = \frac{G_F^2}{2\pi}\frac{M_W^4}{(Q^2+M_W^2)^2}[(\bar{u}+\bar{c})+(1-y)^2(d+s)], \tag{3}$$

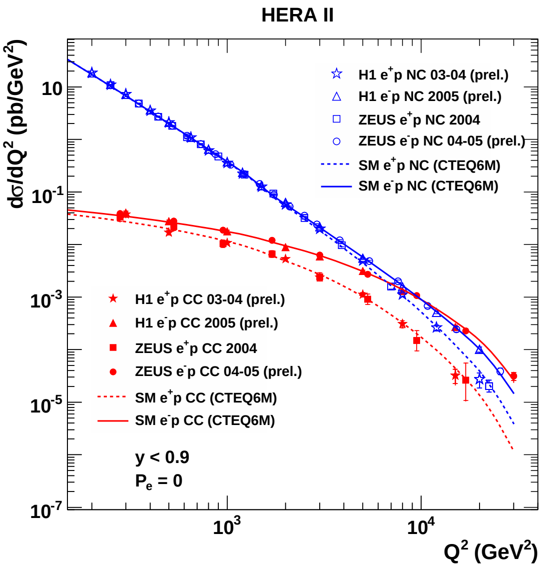

Figure 1. Unpolarised $e^{\pm}p$ NC and CC single differential cross sections, $d\sigma/dQ^2$.

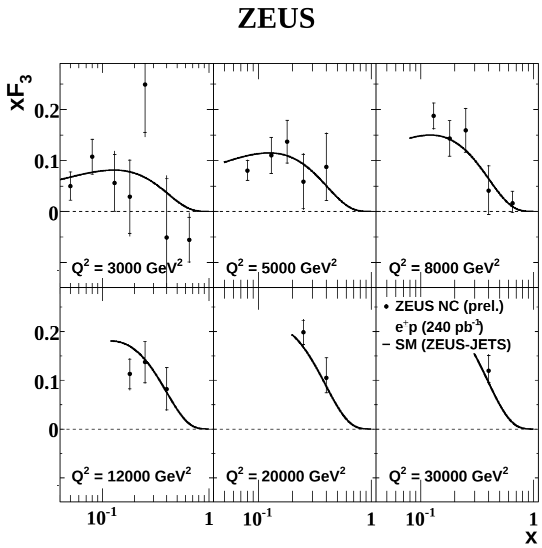

Figure 2. The structure function xF^3, as a function of x in bins of Q^2.

where G_F is the Fermi constant, M_W is the mass of the $W^{\pm}$ boson and terms in brackets describe the composition of quarks in the proton probed by the W^+ or W^- boson. Figure 1 shows the unpolarised $e^{\pm}p$ NC and CC cross sections as a function of Q^2. They were measured using separate samples of HERA II data with the positive and negative beam polarisation, combined and corrected for the small residual polarisation[1, 2, 3, 4]. At lower Q^2, the NC cross sections are identical for e^-p and e^+p scattering, as they proceed by the exchange of the photon. At higher Q^2, the e^-p cross section can be seen to be significantly above the e^+p cross section, due to the Z^0 exchange and the contribution from $\gamma - Z^0$ interference which changes its sign with the lepton charge. At lower Q^2, the CC cross section is smaller than the NC cross section because of the $W^{\pm}$ propagator mass term. In the region where $Q^2 \sim M_W^2, M_Z^2$ the CC and NC cross sections become similar, which can be considered as a manifestation of electroweak unification in spacelike scattering. The difference in CC cross section magnitude for e^-p and e^+p scattering arises from the fact that the u-quark density in the proton is larger than the d-quark density, additionally suppressed by the helicity factor $(1-y)^2$. Both the shape and the magnitude of the NC and CC cross sections are well described by the SM expectation.

In the case of unpolarised beams, the difference in magnitude of the NC cross section for e^-p and e^+p scattering is described by the interference structure function xF_3, sensitive to the valence quark distribution in the proton. It can be measured from the lepton charge asymmetry: $xF_3 = Y_+/2Y_-[\tilde{\sigma}^{NC}(e^-p) - \tilde{\sigma}^{NC}(e^+p)]$, where $\tilde{\sigma}^{NC} = (xQ^4/2\pi\alpha^2 Y_+)d\sigma^{NC}/dxdQ^2$ is the reduced cross section. Both H1 and ZEUS have performed measurements of xF_3[5, 6]. Figure 2 shows xF_3 extracted by the ZEUS experiment using unpolarised e^+p HERA-I sample and the full set of polarised e^-p HERA-II data, combined to give effective e^-p unpolarised sample[6].

3. Polarised CC cross sections

The longitudinal polarisation has a particularly strong effect on the CC cross sections, as they are predicted to be linearly dependent on the polarisation, independently of kinematic variables:

$$\sigma_{CC}^{e^{\pm}p}(P_e) = (1 \pm P_e)\sigma_{CC}^{e^{\pm}p}(P_e = 0). \tag{4}$$

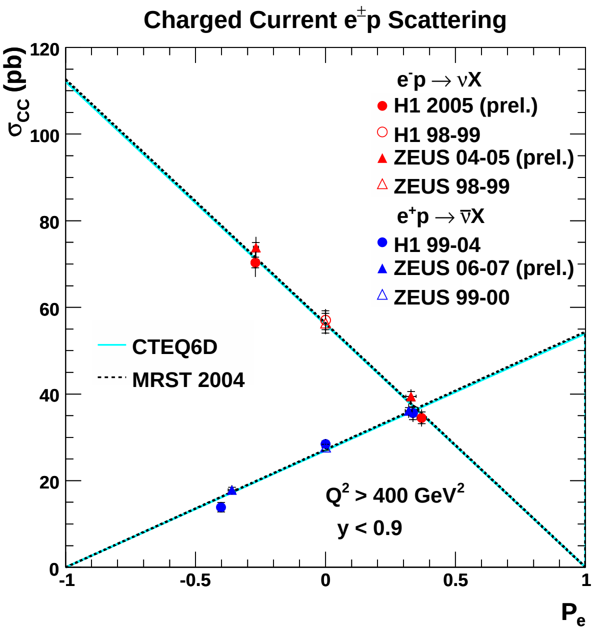

Figure 3. Total $e^{\pm}p$ CC cross sections as a function of the lepton beam polarisation, P_e.

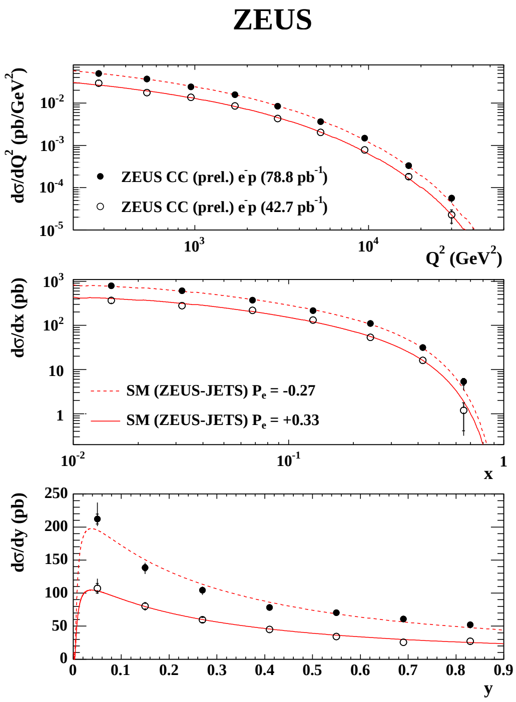

Figure 4. Single differential CC e^-p cross sections as a function of Q^2 (top), x (middle) and y (bottom) for two lepton polarisations.

Here, P_e is defined as $P_e = (N_R - N_L)/(N_R + N_L)$, where N_R and N_L are the numbers of right and left-handed leptons in the beam. In the Standard Model only left-handed fermions and right-handed antifermions take part in weak interactions, hence the CC cross sections are expected to vanish at $P_e = 1(-1)$ for $e^-p(e^+p)$ scattering. Both H1[4, 7] and ZEUS[8, 9] have measured the total CC cross sections at different values of lepton polarisation, in the kinematic range $Q^2 > 200$ GeV^2 and $Q^2 > 400$ GeV^2 and $y < 0.9$, respectively. Figure 3 shows the total cross sections in the kinematic range of H1 data, together with unpolarised cross sections[11, 12, 13] and SM predictions. The linear dependence on P_e is clearly observed, in agreement with the chiral structure of the SM. The cross sections were fitted with the linear functions and from the extrapolation of fits to $P_e = 1(-1)$ for $e^-p(e^+p)$ scattering the limits on the mass of the right-handed $W_R^{\pm}$ have been set by both experiments[10]. The ZEUS experiment has measured the e^-p single differential cross sections, $d\sigma/dQ^2$, $d\sigma/dx$ and $d\sigma/dy$, for two values of electron polarisation[8], shown in Figure 4. The results agree with the SM prediction and, as expected, the cross section dependence on the polarisation is independent of kinematic variables.

4. Polarised NC cross sections

Since the contribution from Z^0 exchange becomes significant only at higher Q^2, the effect of the polarisation on the NC cross section is expected to depend on Q^2. This dependence can be seen by decomposing the generalised structure functions for $e^{\pm}p$ scattering as follows:

$$F_2^{\pm} = F_2^{\gamma} - (v_e \pm P_e a_e)\chi_Z F_2^{\gamma-Z} + (v_e^2 + a_e^2 \pm v_e a_e P_e)\chi_Z^2 F_2^Z \quad (5)$$

$$xF_3^{\pm} = -(a_e \pm P_e v_e)\chi_Z xF_3^{\gamma-Z} + (2v_e a_e \pm P_e(v_e^2 + a_e^2))\chi_Z^2 xF_3^Z, \quad (6)$$

where F_2^{γ} is associated with the pure photon exchange, $F_{2,3}^{\gamma-Z}$ correspond to the $\gamma - Z^0$ interference and $F_{2,3}^Z$ describe the pure Z^0 contribution. Here, $\chi_Z = 1/\sin^2(2\theta_W)Q^2/(Q^2 + M_Z^2)$

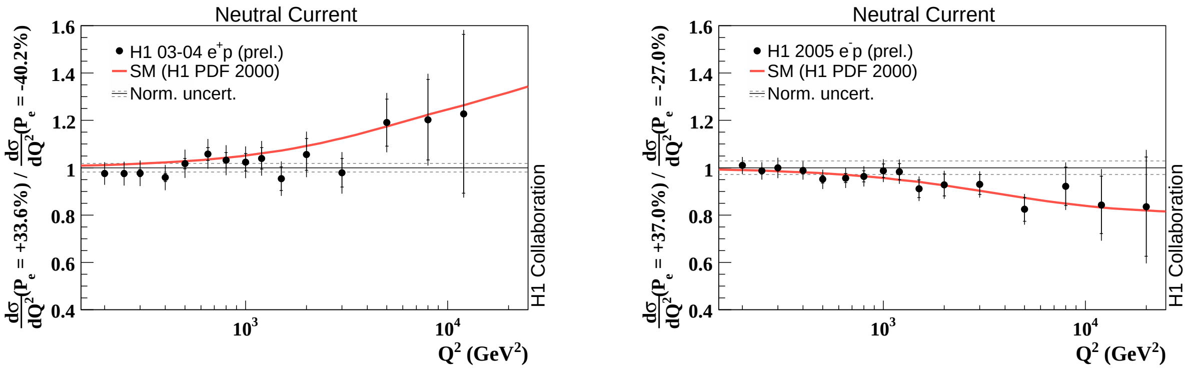

Figure 5. The ratio of the NC $d\sigma/dQ^2$ cross sections for the positive over negative lepton beam polarisation, for e^+p (left) and e^-p (right) scattering.

is the ratio of the Z^0 and photon propagators, $v_e \simeq 0$ and $a_e = -1/2$ are the vector and axial couplings of Z^0 to electron. Both collaborations have studied the polarisation effects on the NC cross sections [10]. Figure 5 shows the ratio of the differential $d\sigma/dQ^2$ cross sections for the positive over negative polarisation, measured by H1 for e^+p and e^-p scattering[5]. The observed polarisation asymmetry increases with Q^2, driven by the propagator ratio, χ_Z, and it is positive (negative) for e^+p (e^-p) data, due to the parity violating $F_2^{\gamma-Z}$ contribution to the cross section, which changes its sign with the lepton charge. This behaviour is in agreement with the SM expectation.

5. Summary

The high luminosities and polarised lepton beam available at HERA-II have allowed tests to be made of the electroweak sector of the SM in spacelike scattering at high Q^2. The dependence of the inclusive CC cross sections on the polarisation is in agreement with the chiral structure of the SM. The effect of the parity violation is seen in the NC cross sections at high Q^2. The high precision polarised inclusive CC and NC data also provide an important input to the combined NLO QCD and electroweak fits. The results presented here are based on part of HERA-II data and will be improved in the near future. In order to further increase precision, both H1 and ZEUS collaborations will combine the results, which will correspond to a total luminosity of about 1 fb^{-1}.

References

[1] Chekanov S *et al* [ZEUS Coll.] 2006 *Phys. Lett.* B **638** 210
[2] ZEUS Coll. 2004 *CC and NC DIS with longitudinally polarised positron beams* ZEUS-prel-04-030
[3] H1 Coll. 2006 *High Q^2 CC in ep collisions* H1-prel-06-041
[4] H1 Coll. 2006 *High Q^2 NC in ep collisions* H1-prel-06-042
[5] H1 Coll. 2006 *NC Interactions in $e^{\pm}p$ Scattering with Longitudinally Polarised Leptons* cont. to ICHEP 2006
[6] ZEUS Coll. 2007 *Measurement of high-Q^2 NC DIS cross sections with a longitudinally polarised electron beam at HERA* Cont. to DIS 2007
[7] Adolf C *et al* [H1 Coll.] 2003 *Eur. Phys. J.* C **30** 1
[8] ZEUS Coll. 2006 *Measurement of high-Q^2 CC DIS cross sections with a longitudinally polarised electron beam at HERA* Cont. to ICHEP 2006
[9] ZEUS Coll. 2007 *Measurement of high-Q^2 CC DIS cross sections with a longitudinally polarised positron beam at HERA* Cont. to EPS 2007
[10] Zhang Z *Electroweak results from HERA* These proceedings.
[11] Adolf C *et al* [H1 Coll.] 2000 *Eur. Phys. J.* C **19** 269
[12] Chekanov S *et al* [ZEUS Coll.] 2002 *Phys. Lett.* B **539** 197
[13] Chekanov S *et al* [ZEUS Coll.] 2003 *Eur. Phys. J.* C **32** 1