Neutral and Charged Currents at High Q^2 in ep Interactions

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The inclusive single and double differential cross-sections for neutral and charged current processes with four-momentum transfer squared Q^2 between 150 and and 30000 GeV^2 are measured with the H1 and ZEUS detectors at HERA. Data on e^+p interactions have been collected from 1994 to 1997 and correspond to an integrated luminosity of about 40 pb^{-1}. Preliminary e^-p results presented by H1 are based on data collected in 1998 and beginning of 1999 with an integrated luminosity of 5.6 pb^{-1}. No significant deviation from the Standard Model has been found. Predictions of the electroweak theory are confronted with the data. Their consistency is expressed by the measured mass of the W boson obtained from the Q^2 dependence of the charged current cross-section and by the observed difference in e^-p and e^+p neutral current cross-sections at high Q^2 due to γZ° interference.

1 Introduction

Measurements of the inclusive deep inelastic charged lepton-nucleon scattering cross sections have always been of great importance for the development of high energy physics. Two main questions have been addressed in such studies. First, tests of the theory of strong interactions (QCD) and second, the determination of the momentum distributions of the partons within the nucleon. This report concentrates on a third aspect, namely on purely electroweak effects which become observable at HERA, where 27.5 GeV positrons were colliding with 820 GeV protons (27.5 GeV electrons with 920 GeV protons in 1998/1999), in a region of very high four-momentum transfer squared Q^2 comparable with the masses squared of the vector bosons Z^o and W. Especially interesting in this respect is the comparison of e^+p and e^-p neutral (NC) and charged (CC) current cross-sections at high Q^2.

The results of the H1 and ZEUS experiments presented here are obtained from e^+p data collected from 1994 to 1997 with an integrated luminosity of about 40 pb^{-1} [1,2], and from e^-p data collected in 1998 and beginning of 1999 with an integrated luminosity of 5.6 pb^{-1}. The preliminary e^-p results by H1 and the final results on single differential e^+p NC cross sections by ZEUS are presented on this conference for the first time.

2 Neutral Current Cross Sections

The differential cross-section for NC deep inelastic ep scattering is related to the three structure functions F_2, F_L and xF_3 according to

$$\frac{d^2\sigma^{e^\pm p->e^\pm X}}{dxdQ^2} = \frac{2\pi\alpha^2}{Q^4x}\left[Y_+F_2(x,Q^2) - y^2F_L(x,Q^2) \mp Y_-xF_3(x,Q^2)\right] \quad (1)$$

where x denotes the Bjorken variable, $y = Q^2/xs$ is the inelasticity, s is the center of mass energy squared, α is the fine structure constant and $Y_\pm = 1\pm(1-y)^2$. The dominant contribution in eq. 1 is due to the proton structure function F_2 which is related in the frame of the quark-parton model to the sum of the proton momentum fractions carried by the quarks and antiquarks in the proton. The contribution of the longitudinal structure function F_L to the presented cross-sections is $< 5\%$ at highest y values and negligible for $y < 0.4$. The parity violating structure function xF_3 is appearing due to γZ^o interference and contributes with different sign to the e^+p and e^-p cross-sections.

The measurement of the double differential cross-section is presented in the form of a reduced cross-section defined as $\tilde{\sigma}_{NC} \equiv \frac{Q^4x}{2\pi\alpha^2}\frac{1}{Y_+}\frac{d^2\sigma}{dxdQ^2}$ which coincides with F_2 in the region where F_L and xF_3 can be neglected. The results on the reduced NC cross-section for high x ($x \geq 0.07$) are shown in Figure 1. The measurements are in agreement with the expectation of the Standard Model (SM). Only at very high Q^2 >15000 GeV^2 and x=0.45 there is a slight excess in the data which is also visible at Q^2 >15000 GeV^2 in the single differential cross-section $d\sigma/dQ^2$ given in Figure 2. The sensitivity to pure electroweak effects in e^+p NC interactions is shown in Figure 3 where single differential cross-sections $d\sigma/dQ^2$ and $d\sigma/dx$ are compared with the SM expectation and theoretical predictions where M_Z is put to 40 GeV or to infinity. In the latter case the γZ^o interference contribution is suppressed. At Q^2 >10000 GeV^2 the predictions are significantly different and the data are in favour of the SM which predicts a reduction of the e^+p NC cross-section. The effect of the γZ^o interference is directly visible in the comparison of the e^-p and e^+p NC single differential cross-sections $d\sigma/dQ^2$ shown in Figure 4. In agreement with the SM prediction the e^-p cross-section is above that of e^+p for Q^2 ≥3000 GeV^2. The increase of the center of mass energy in e^-p interactions does not influence this conclusion.

3 Charged Current Cross Section

The CC differential cross-sections for ep interactions in leading order QCD are given by

$$\frac{d^2\sigma^{e^+p->\bar{\nu}X}}{dxdQ^2} = \frac{G_F^2}{2\pi x}\left(\frac{M_W^2}{M_W^2+Q^2}\right)^2\left[x\bar{u}(x,Q^2) + x\bar{c}(x,Q^2) + (1-y)^2(xd(x,Q^2) + xs(x,Q^2))\right] \quad (2)$$

$$\frac{d^2\sigma^{e^-p->\nu X}}{dxdQ^2} = \frac{G_F^2}{2\pi x}\left(\frac{M_W^2}{M_W^2+Q^2}\right)^2 \left[xu(x,Q^2)+xc(x,Q^2)+(1-y)^2(x\bar{d}(x,Q^2)+x\bar{s}(x,Q^2))\right] \qquad (3)$$

where G_F is the Fermi constant and $q(x,Q^2)$ and $\bar{q}(x,Q^2)$ are the densities of the different quark and antiquark flavours in the proton. The reduced CC cross-section is defined in analogy to the NC case as $\tilde{\sigma}_{CC} \equiv \frac{2\pi x}{G_F^2}\left(\frac{M_W^2+Q^2}{M_W^2}\right)^2 \frac{d^2\sigma}{dxdQ^2}$. Results on the double differential e^+p CC cross-section are given in Figure 5 in comparison with the SM expectation. At low x the cross-section is dominated by the antiquark density, while at $x > 0.2$ the cross-section is almost entirely determined by d quark (dashed line on the right plot). The single differential CC and NC cross-sections $d\sigma/dQ^2$ for e^+p and e^-p interactions are shown in Figure 6. The CC cross-sections are suppressed by the propagator at low Q^2 and approach the NC cross-sections at high Q^2. The e^-p CC cross-section exceeds that of e^+p by almost a factor of 10 at large Q^2 due to the coupling to different flavours (u and d quarks respectively) and the helicity factor, eq. 2, 3. The Q^2 dependence of the e^+p CC process has been used to determine the propagator mass with the results M_W=81.2±3.3(stat.)±4.3(syst.) GeV (H1) and M_W=78.6±2.5(stat.)±3.2(syst.) GeV (ZEUS) which are in agreement with the world average for the W boson mass.

4 Summary

The neutral and charged current processes at high Q^2 have been studied at HERA. Double differential e^+p and single differential $e^{\pm}p$ cross-sections have been measured up to Q^2=30000 GeV^2. The results are in agreement with the Standard Model expectations. Only at very high Q^2 >15000 GeV^2 there is a slight excess in the NC e^+p data, which has become less significant when adding the 1997 data to the 1994-1996 event sample.

Comparison of e^-p and e^+p NC cross sections $d\sigma/dQ^2$ shows, that starting from Q^2 ≈3000 GeV^2 the e^-p cross section exceeds that of e^+p, demonstrating the positive (negative) contribution of the γZ^o interference to the e^-p (e^+p) cross-sections.

The CC cross-section measurements in e^+p and e^-p interactions constrain valence d and u quark densities at high x. Due to the coupling to different flavours the e^-p CC cross-section exceeds that of e^+p by almost a factor of 10 at large Q^2.

The Q^2 dependence of the e^+p CC process has been used to determine the W mass. The values obtained agree well with the mass of the W boson as measured in time-like processes, thereby confirming the electroweak sector of the Standard Model in space like region.

The HERA experiments start to probe electroweak effects and, as the measurements are still limited by statistics, we are looking forward to the upgrade of the HERA collider in the year 2000 which will bring an increase of luminosity by a factor of 5 and yield an integrated luminosity of about 1 fb^{-1} until 2006.

Acknowledgments

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References

1. H1 collaboration, "Measurement of Neutral and Charged Current Cross-Sections at High Q^2", contributed paper 533, ICHEP 98, Vancouver.
2. ZEUS collaboration, "Measurements of High-Q^2 Neutral-Current DIS Cross Sections at HERA", "Measurements of High-Q^2 Charged-Current DIS Cross Sections at HERA", contributed papers 752 and 751, ICHEP 98, Vancouver.

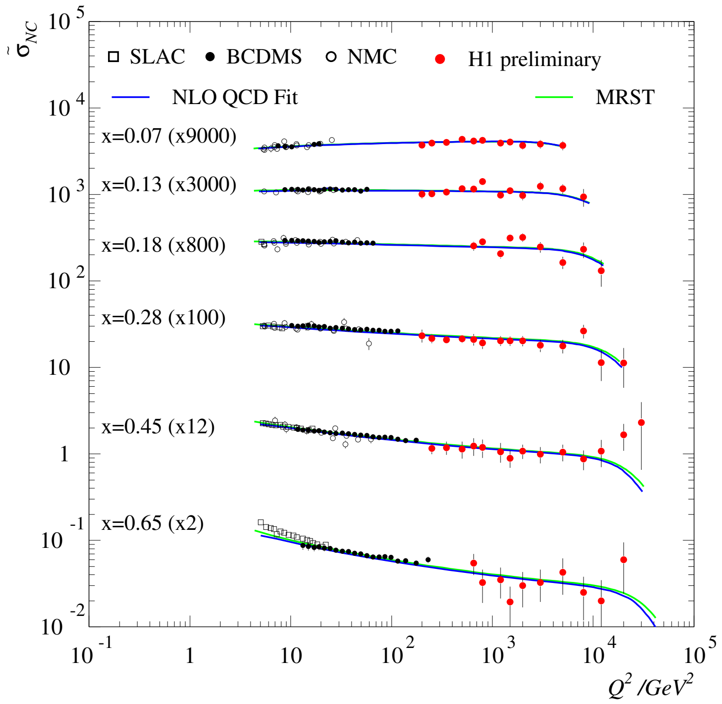

Figure 1: Reduced NC cross-section at high x compared with the Standard Model expectation.

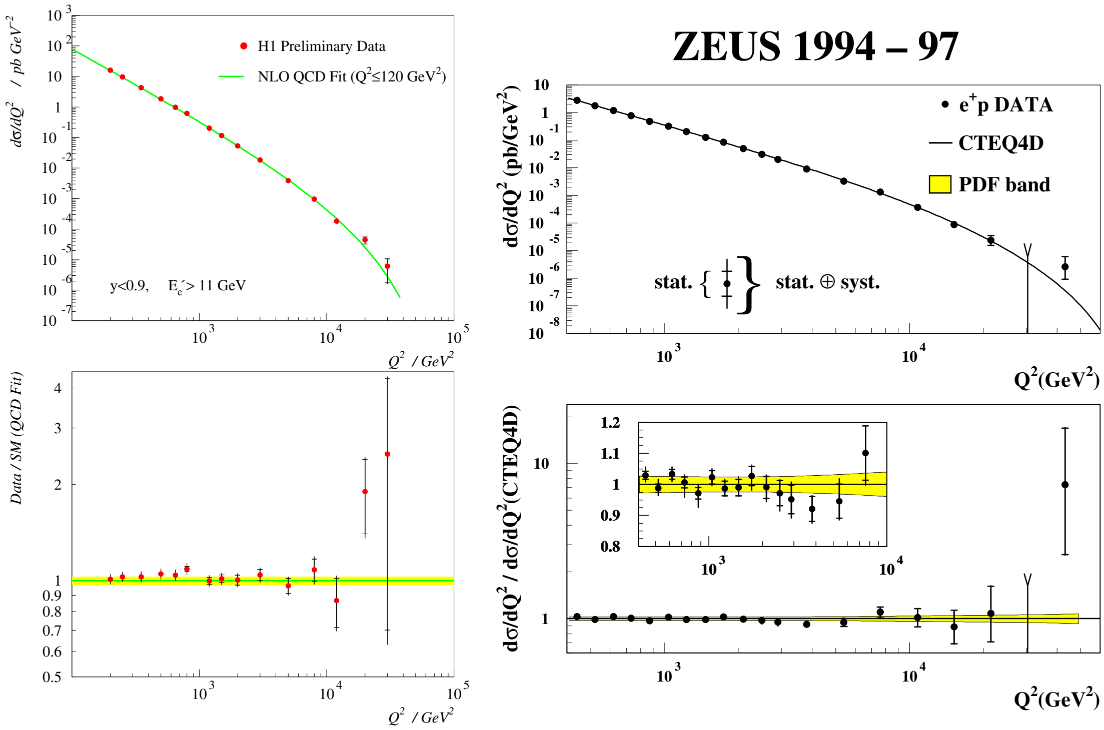

Figure 2: Single differential NC cross-section $d\sigma/dQ^2$ compared with the Standard Model expectation. Ratios of the cross-sections to the SM expectations are shown in the bottom plots. The grey band shows in case of H1 the experimental normalization uncertainty and in case of ZEUS it represents the estimated uncertainty of the SM expectation.

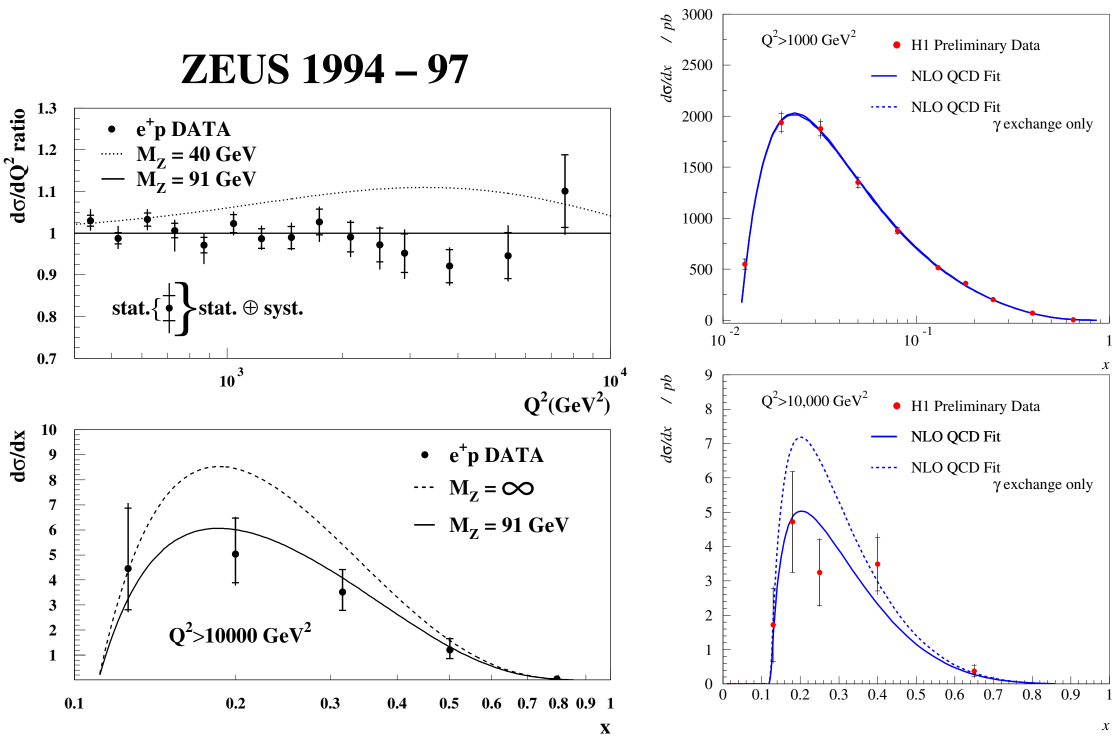

Figure 3: Single differential cross-sections $d\sigma/dQ^2$ and $d\sigma/dx$ compared with the Standard Model expectation and theoretical predictions where M_Z is put to 40 GeV or to infinity. In the latter case Z° contribution is neglected.

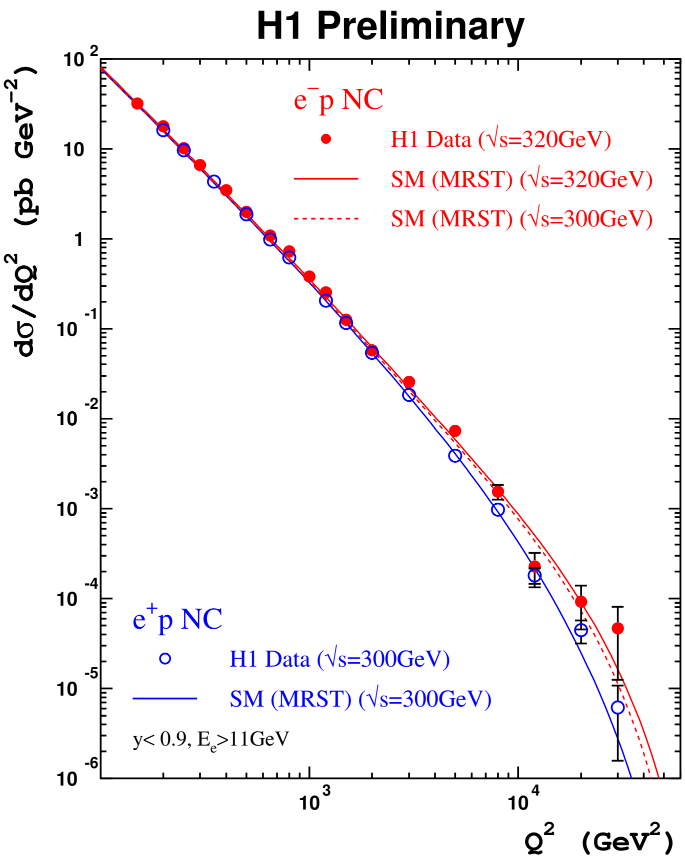

Figure 4: Single differential NC cross section $d\sigma/dQ^2$ for e^-p and e^+p interactions compared with the Standard Model expectation. The dashed line presents the SM expectation for e^-p interactions with the center of mass energy decreased to 300 GeV corresponding to the e^+p data.

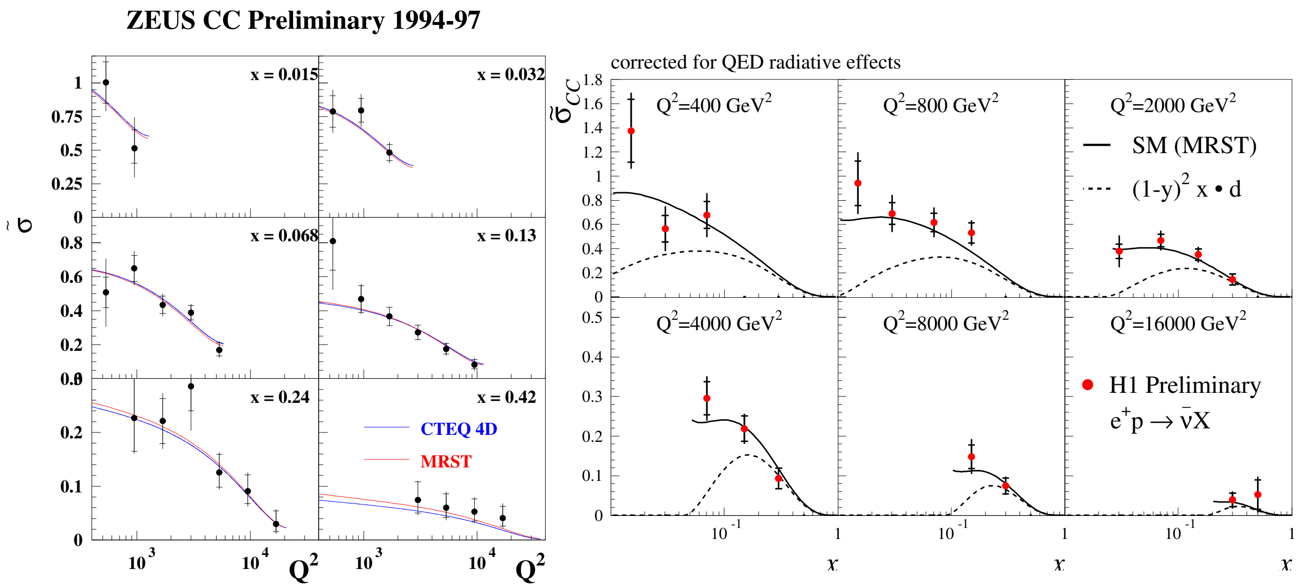

Figure 5: The reduced charged current double differential cross section is shown as function of Q^2 for different x values and as function of x for different Q^2 values compared with the Standard Model expectation for different parton density paratemerizations. Also shown is the expected d quark contribution (right hand plot).

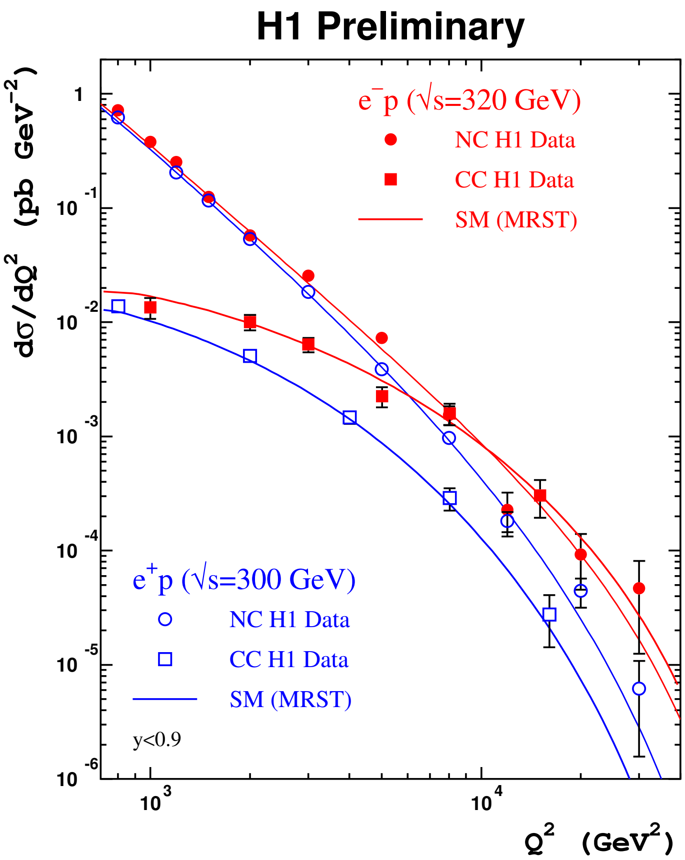

Figure 6: Single differential NC and CC cross sections $d\sigma/dQ^2$ for e^-p and e^+p interactions compared with the Standard Model expectations.