HIGH Q^2 CHARGED AND NEUTRAL CURRENT CROSS SECTIONS

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Inclusive cross-section measurements of electron-proton and positron proton interactions at high momentum transfer Q^2 are shown. The data were recorded with the H1 and ZEUS detectors at HERA in the years 1994-2000 (HERA I) and 2003-2004 (HERA II). During the HERA II data-taking period the positron beam was longitudinally polarised.

1 Introduction

At the HERA machine at DESY/Hamburg positrons or electrons collide with protons at a centre-of-mass energy of 319 GeV. Since 2002 HERA is operated at higher specific luminosity. Furthermore, it now provides longitudinally polarised leptons for the collider experiments H1 and ZEUS.

The H1 and ZEUS experiments are multi-purpose detectors with full solid angle coverage for tracking, calorimetry and muon detectors. In the neutral current channel electrons with high transverse momentum are detected in the calorimeter. In the charged current channel a massless neutrino escapes the detector, and it is reconstructed from the hadronic final state by constraining the energy and momentum sum. In the HERA I data-taking period an integrated luminosity of $\mathcal{O}(100)\,\mathrm{pb}^{-1}$ and $\mathcal{O}(15)\,\mathrm{pb}^{-1}$ has been collected per experiment in e^+p and e^-p collisions, respectively. In the HERA II data-taking period $\mathcal{O}(50)\,\mathrm{pb}^{-1}$ were recorded, about equally shared between left- and right-handed positrons with an average polarisation of $\langle P_R\rangle = 32\%$ and $\langle P_L\rangle = -40\%$.

The cross-section are given as a function of the kinematic variables $Q^2 = -q^2$, $x = Q^2/(pq)$, and $y = Q^2/sx$. Here s is the centre-of mass energy squared, q is the four-vector of the exchanged boson, and p is the four-vector of the incoming proton.

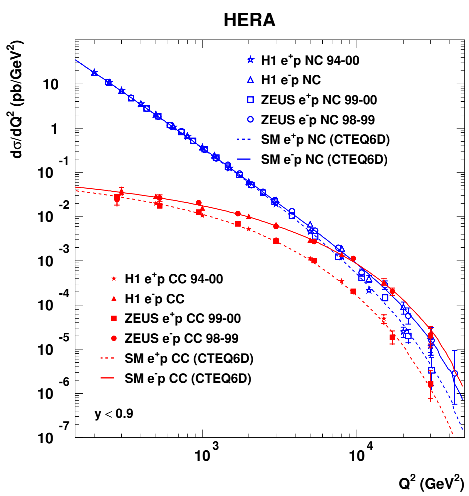

Figure 1. The single-differential neutral current and charged current cross-section $\frac{d\sigma}{dQ^2}$, as measured by H1 and ZEUS in e^+p and e^-p collisions with $Q^2 > 200\,\mathrm{GeV}^2$.

2 HERA I cross-sections

2.1 Single differential Neutral Current and Charged Current cross-sections

The cross-section $\frac{d\sigma}{dQ^2}$, as measured by ZEUS [1,2,3,4,5,6] and H1 [7,8,9], is depicted in figure 1, for both Neutral Current (NC) and Charged Current (CC) reactions recorded in both e^+p and e^-p collisions. The NC cross-section is large at low Q^2 and decreases over several orders of magnitude as Q^2 is increased from $200\,\mathrm{GeV}^2$ to $30000\,\mathrm{GeV}^2$. The e^+p and e^-p data overlay at low Q^2. At high Q^2

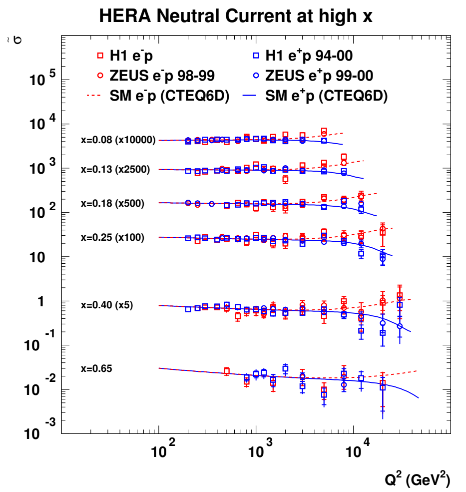

Figure 2. The reduced neutral current cross-section $\tilde{\sigma}$, measured by H1 and ZEUS in e^+p and e^-p collisions at high x.

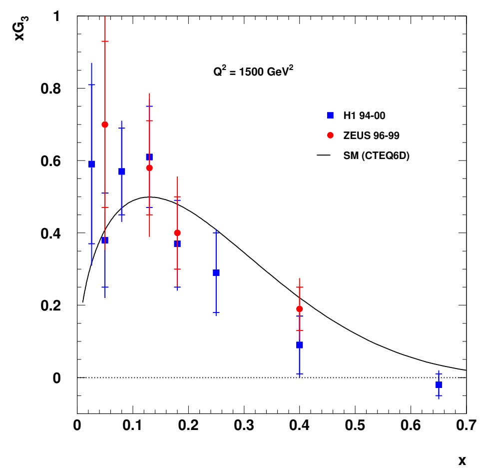

Figure 3. The structure function $x\tilde{G}_3$, measured by H1 and ZEUS.

the e^+p cross-section is smaller. The CC cross-section is almost constant at low Q^2 but falls off rapidly at high Q^2. The e^+p cross-section is significantly lower than the e^-p cross-section at high momentum transfer. For $Q^2 > 3000\,\mathrm{GeV}^2$ the NC and CC cross-sections are of similar size. The data are well described by NLO QCD calculations. The Q^2 dependence is driven by the propagator of the photon $\frac{1}{Q^4}$ for NC and by the propagator of the W-boson $\frac{1}{(Q^2+M_W^2)^2}$ for CC. The difference between e^+p and e^-p data is due to the $Z^0\gamma$ interference in NC reactions. For CC interactions this difference is attributed to the valence quark densities and the relevant helicity factors.

2.2 *Double differential Neutral Current cross sections*

Double differential NC cross-sections for $e^{\pm}p$ scattering are shown in terms of the reduced cross-section $\tilde{\sigma}^{\pm}_{\mathrm{NC}}$:

$$\tilde{\sigma}^{\pm}_{\mathrm{NC}} = \frac{d^2\sigma_{\mathrm{NC}}}{dxdQ^2} / \left(\frac{2\pi\alpha^2 Y_+}{(Q^2)^2 x}\right) \approx F_2 \mp \frac{Y_-}{Y_+} xF_3.$$

The helicity factors are $Y_{\pm} = 1 \pm (1-y)^2$. The reduced cross-sections are shown in figure 2, measured for various values of x as a function of Q^2. The Q^2 dependence is not very strong. These scaling violations are well described by the DGLAP evolution. The main contribution to the cross-section is the photon exchange F_2. The difference between e^+p and e^-p data at highest Q^2 is attributed to the Z/γ interference. After subtracting the e^+p data from the e^-p data, xF_3 may be measured at high Q^2. The structure function xF_3 is sensitive to the valence quarks alone. Figure 3 shows the HERA measurements of $x\tilde{G}_3$, where propagator terms have been removed from xF_3. They compare well to NLO QCD calculations.

2.3 *Double differential Charged Current cross sections*

Double differential CC cross-sections are shown in terms of the reduced cross-section$\tilde{\sigma}_{\mathrm{CC}^{\pm}}$:

$$\tilde{\sigma}_{\mathrm{CC}^{\pm}} = \frac{d^2\sigma^{\pm}_{\mathrm{CC}}}{dxdQ^2} / \left(\frac{G_F^2 M_W^2}{(Q^2+M_W^2)^2 2\pi x}\right).$$

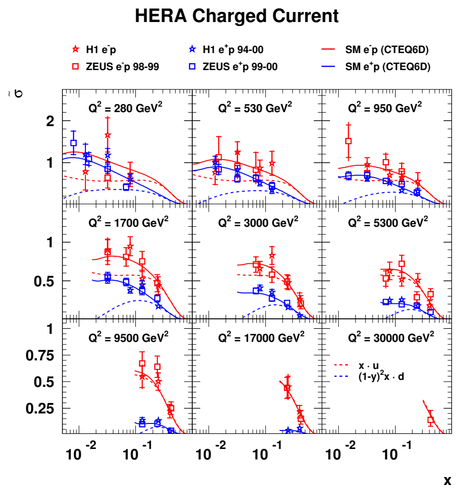

Figure 4. The reduced charged current cross-section $\tilde{\sigma}$, measured by H1 and ZEUS in e^+p and e^-p collisions at high x.

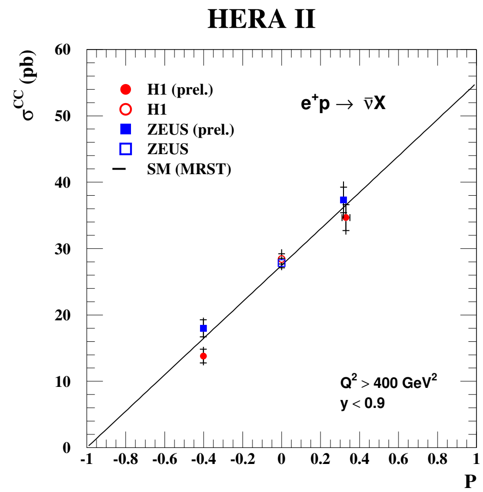

Figure 5. The charged current cross-section for e^+p collisions as a function of the e^+-beam polarisation, measured by H1 and ZEUS.

These reduced cross-sections are related to the quark densities,

$$\tilde{\sigma}^-_{\rm CC} \approx (xu + +uc + x\bar{d} + x\bar{s}),$$

$$\tilde{\sigma}^+_{\rm CC} \approx (1-y)^2(xd + xs + x\bar{u} + x\bar{c})$$

The HERA results are shown in figure 4. The data are shown as a function of x for nine values of Q^2. The NLO QCD calculation based on low energy data is able to describe the data. Also shown are the contributions from u and d valence quarks. The CC data may be used to extract the u (d) quark at high x from e^-p (e^+p data. For the e^+p cross-sections the d quark is suppressed by a helicity factor $(1-y)^2$. A precise determination of the valence quarks at highest x requires a still larger datasets, mostly in e^+p collisions.

3 First HERA II results with longitudinally polarised leptons

3.1 Lepton polarisation at HERA II

Leptons with transverse polarisation are routinely produced at HERA since 1993. However, for most experiments longitudinally polarised leptons are required. During the HERA II upgrade spin-rotators were installed around the H1 and ZEUS experiment. A polarisation of up to 50% has been observed. The average polarisation achieved in 2003 and 2004 was $\langle P_R \rangle = 32\%$ ($\langle P_L \rangle = -40\%$) for the right-handed (left-handed) spin configuration.

3.2 Charged Current cross-sections at HERA II

In the Standard Model of electroweak interactions, only left-handed electrons (right-handed positrons) are taking part in CC interactions, and the CC cross-section depends linearly on the polarisation P. This hypothesis is tested in figure 5, where CC cross-sections are shown for three different polarisation values of the e^+ beam. The cross-section measurements are well compatible with a linear dependence on P. A straight-line fit to the data available at present is compatible to non-existing right-handed charged currents:

$$\sigma^{+}_{CC}(P=-1) = 0.2 \pm 1.8(\text{stat}) \pm 1.6(\text{sys}).$$

3.3 Neutral Current cross-sections at HERA II

NC cross-sections are sensitive to polarisation at high Q^2, where the Z-boson exchange contributes. First measurements of polarised NC cross-section as a function of Q^2 are shown in figure 6. The effect of polarisation is expected to show up as a difference at very high Q^2. However, given the integrated luminosity and average polarisation available at present, these effects turn out to be rather small.

4 Summary

The unpolarised high Q^2 data collected at HERA I provides valuable information to constrain the proton over a wide kinematic range. Only the measurements at highest x and highest Q^2 are still statistically limited. In particular, an even larger sample of $e{+}p$ data is necessary to further constrain the d quark at high x.

The HERA II data-taking with polarised lepton beams period has started. It is planned to collect $\mathcal{O}(1\,\text{fb}^{-1}$ in the coming years. First analyses of $\mathcal{O}(50)\,\text{pb}^{-1}$ have been shown. In the CC sector, the cross-section is enhanced or suppressed, depending on the sign of polarisation. More data is required to set stringent limits on right-handed charged Currents. In the NC sector the data is still statistically limited. New methods of disentangling the quark flavours in the proton may become available in the future by combining large datasets from lepton beams with different charge and polarisation.

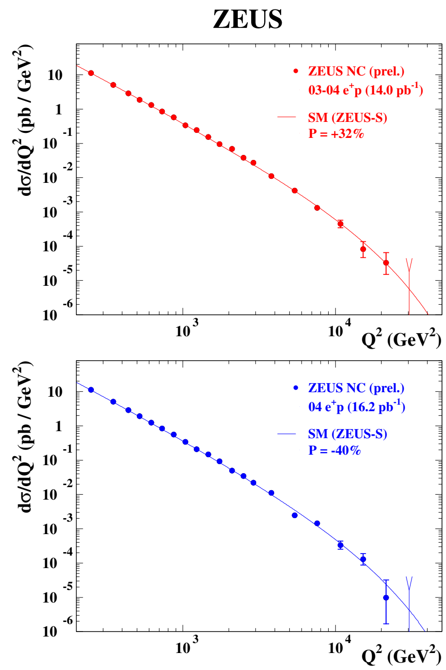

Figure 6. The neutral current cross-section for right-handed e^+ beams ($\langle P_R \rangle = 32\%$) and left-handed e^+ beams ($\langle P_L \rangle = -40\%$ as a function of Q^2, measured by ZEUS.

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