HIGH Q^2 STRUCTURE FUNCTIONS AT HERA

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The latest results of H1 and ZEUS on the electroweak cross sections using polarised lepton beams are presented with the improvements in the parton density functions that result from them. The asymmetry of the neutral current cross sections between e^-p and e^+p was measured and shows parity violation in agreement with the Standard Model. The dependence of the charged current cross section on the beam polarisation has been obtained and its extrapolation to full polarisation implies the absence of right-handed charged currents. Constraints on the vector and axial vector couplings of the u and d quarks to the Z boson from a combined QCD and electroweak fit are shown and the results from the combination of H1 and ZEUS data are reviewed.

1 Introduction

The experiments H1 and ZEUS at the electron-proton collider HERA at DESY collected data during the period 1992-2007 and have probed the structure of the proton over a large kinematic region. The kinematic scope of these experiments can be described in terms of the four-momentum transfer squared, Q^2, between the colliding lepton and the proton and the momentum carried by the struck quark, Bjorken-x, and spans $0 < Q^2 < 10^5$ GeV^2 and $10^{-6} < x < 1$.

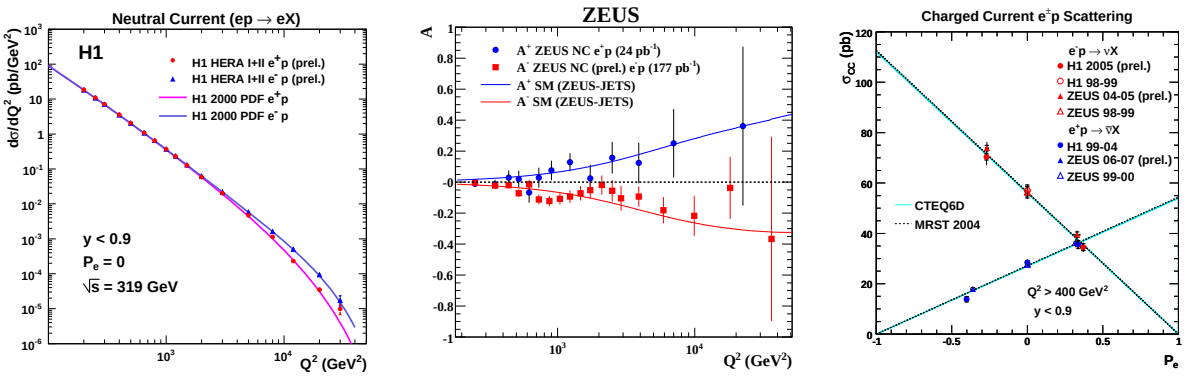
In the HERA-I running phase the collider provided unpolarised beams until the luminosity upgrade in 2000, which marked the beginning of the HERA-II running phase in which the lepton beam was longitudinally polarised around the two experiments. H1 and ZEUS measured the cross sections for neutral (NC) and charged current (CC) processes, from which parton density functions (PDFs) were determined in global fits at next-to-leading order in QCD. For an understanding of the structure of the proton a precise measurement of the PDFs is crucial. With the beginning of beam operation at the Large Hadron Collider (LHC) imminent, the results from HERA are particularly important as the constraints on the PDFs from this data are relevant in a significant part of the LHC kinematic region.

2 Electroweak cross sections and structure functions

The cross section for the NC process is given by [1]

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

where α is the fine structure constant, $Y_\pm = 1\pm(1-y)^2$ and y can be obtained from the expression $Q^2 = sxy$ using the centre of mass energy, $\sqrt{s}$. The above equation shows the relation between



(a) (b) (c)

Figure 1: (a) NC single differential cross sections versus Q^2 as measured by H1. (b) NC asymmetry in e^+p and e^-p measured by ZEUS. (c) Polarisation dependence of the CC cross sections measured by H1 and ZEUS.

the cross section and the structure functions of the proton. These are F_2, which dominates the cross section and is related to the sum of the quark and antiquark distributions, xF_3, which becomes significant at high Q^2 and is proportional to the difference of the quark and antiquark distributions and F_L, the longitudinal structure function, which contributes at high y and gives a measure of the gluon density in the proton. However, in the kinematic range relevant here F_L is small and can be neglected.

H1 results on the NC single differential cross sections $d\sigma/dQ^2$ using 270 pb^{-1} e^+p and 165 pb^{-1} e^-p data from the HERA-I and II running periods are shown in Fig. 1a. The measurements were obtained in the kinematic regime of $200 < Q^2 < 30\,000$ GeV^2 and $y < 0.9$. At high Q^2 the e^-p cross sections are larger than the e^+p cross sections as expected from the positive contribution of xF_3 in the former case. H1 used these cross sections to perform a form factor analysis from which an upper limit on the quark radius was obtained of $0.74 \cdot 10^{-18}$ m at 95% CL [2].

The NC cross section contains a dependence on the lepton polarisation, P_e, which enters through the structure functions. This polarisation dependence can be expressed in terms of the asymmetry, A, which is defined at full polarisation as

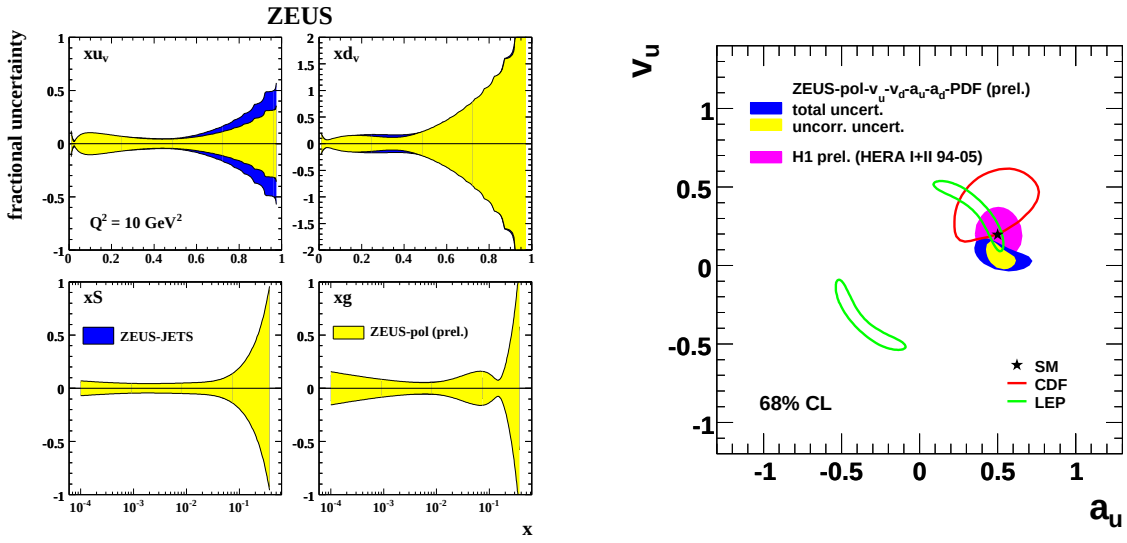
$$A = \frac{\sigma(P_e = +1) - \sigma(P_e = -1)}{\sigma(P_e = +1) + \sigma(P_e = -1)}. \tag{2}$$

The asymmetry as measured by ZEUS using 24 pb^{-1} of e^+p and 177 pb^{-1} of e^-p data is presented in Fig. 1b and compared to the SM predictions using the ZEUS-JETS PDFs [4]. The divergence between the asymmetry of e^+p and e^-p at high Q^2 is a clear indication of parity violation in the NC processes.

The leading order CC cross section, neglecting weak radiative corrections can be expressed as:

$$\frac{d^2\sigma_{CC}(e^\pm p)}{dxdQ^2} = (1 \pm P_e)\frac{G_F^2}{2\pi}\left(\frac{M_W^2}{M_W^2 + Q^2}\right)^2[u' + c' + (1-y)^2(d' + s' + b')], \tag{3}$$

where G_F is the Fermi coupling constant and u', c', d', s' represent the quark densities of the respective flavour and stand for $u, c, \bar{d}, \bar{s}, \bar{b}$, in the case of e^-p scattering and for $\bar{u}, \bar{c}, d, s, b$ in the case of e^+p. These expressions reveal that the dominant PDFs at high x, u and d, are best probed by deep inelastic scattering in e^-p and e^+p, respectively. The expected linear dependence of the CC cross section on the polarisation has been measured by H1 and ZEUS and can be seen in Fig.1c. The extrapolation of the cross sections to full polarisation indicates the absence of right-handed CC processes. The upper limit on the mass of a right-handed W boson was obtained by H1 to be 186 GeV/c^2 at 95% CL [3].



(a) (b)

Figure 2: (a) Fractional uncertainties of the up-valence, down-valence, sea and gluon PDFs using ZEUS-JETS and ZEUS-pol., (b) Axial and vector couplings of the u-quark obtained from a combined QCD and electroweak fit.

3 Electroweak and QCD fits using polarised data

Utilising the measurements of the electroweak cross sections H1 and ZEUS obtained PDFs as well as quark couplings from a simultaneous QCD and electroweak fit. In addition to the data sets used in previous fits the polarised data from HERA-II was also taken into account. Figure 2a compares the fractional uncertainties on individual PDFs between the old ZEUS-JETS based on HERA-I ZEUS data only and the new ZEUS-pol PDFs [5] which also uses HERA-II ZEUS e^-p data. The u valence-quark PDF benefits the most from the addition of the new e^-p data, which leads to a significant improvement of the fractional uncertainties in the high x region.

Limits on the axial (a) and vector (v) couplings of the u and d quark were obtained from a fit in which a_u, a_d, v_u, v_d were all treated as free parameters. The results for the couplings of the u-quark are shown in Fig. 2b. Compared to previous H1 and ZEUS constraints the axial couplings improved under the addition of an order of magnitude more e^-p data, whereas the vector couplings benefited the most from the polarisation of that new data set. The limits set by H1 and ZEUS are competitive with limits obtained by CDF and LEP.

4 Combination of H1 and ZEUS data

To exploit the full potential of HERA the results of H1 and ZEUS have to be combined in a model independent way. The published HERA-I deep inelastic cross sections from these experiments have thus been merged for $Q^2 > 1.5$ GeV^2. The method used is described in detail elsewhere [6]. The combination procedure, in which systematic correlations are taken into account, leads to a significant reduction of the overall uncertainty. The results for the combined H1 and ZEUS NC cross sections are shown in Fig. 3. The strength of the method lies in the reduction of the uncertainty both in the region of low Q^2, where systematic uncertainties dominate, as well as at high Q^2, where the combined measurement benefits from improved statistics. Systematic uncertainties are reduced by allowing the correlated uncertainties to vary coherently in the averaging procedure. The uncertainties are largely uncorrelated between H1 and ZEUS, thus, a cross calibration between the experiments is achieved resulting in an overall reduction of the

systematic errors. This is highlighted in Fig. 3b, which shows an enlarged version of the plot on the left. The overall uncertainty on the combined data points labelled 'HERA I', shown in black, is smaller than the uncertainty on individual H1 and ZEUS data points across the whole range of Q^2 [7].

Further work needs to be done to combine the HERA-II data from H1 and ZEUS. But upon completion of that project the 'final word' from HERA will comprise 1 fb^{-1} and will significantly contribute to the precise knowledge of the proton PDFs for the upcoming experiments at the Large Hadron Collider.

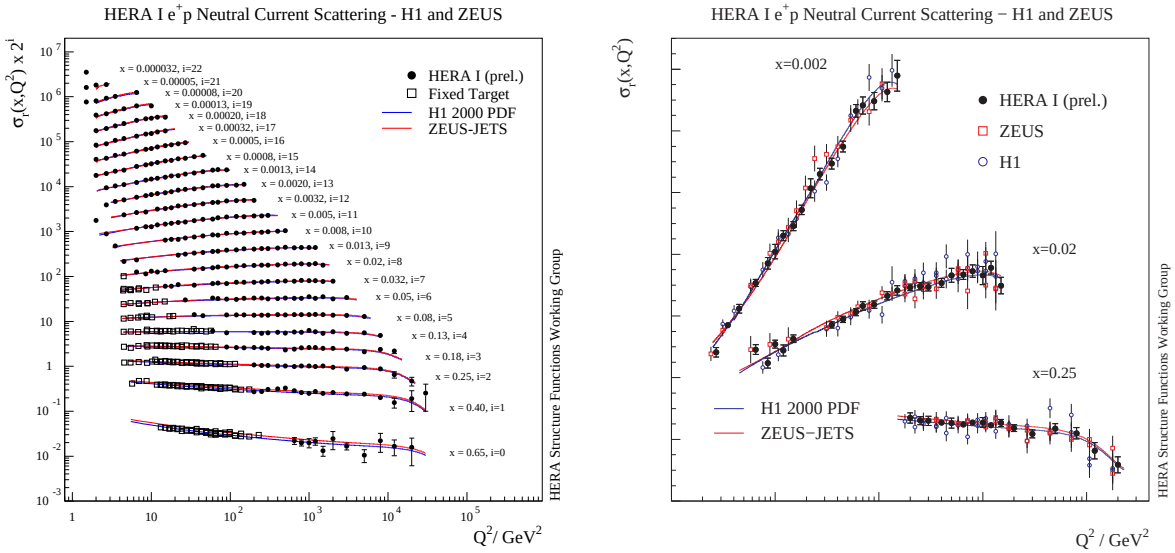


Figure 3: (a) H1 and ZEUS combined NC cross sections compared to results from fixed target experiments and SM predictions using the ZEUS-JETS and H1 2000 PDFs. (b) Enlarged plot for x=0.002, 0.02, 0.25 highlighting the reduced uncertainty on the combined results (black) compared to individual H1 (blue) and ZEUS (red) results.

References

1. R. Devenish and A. Cooper-Sarkar, *Deep Inelastic Scattering*, Oxford University Press, 2003.
2. H1 Coll., *High Q^2 Neutral Currents using the Complete HERA Data*, Proceedings to the *23rd International Symposium on Lepton-Photon Interactions at High Energy*, Daegu, Korea (LP2007).
3. H1 Coll., *Charged current interactions in ep scattering at HERA with longitudinally polarised electrons*, Proceedings to the *33rd International Conference on High Energy Physics*, Moscow, Russia (ICHEP06).
4. ZEUS Coll., S. Chekanov *et. al.*, *Eur, Phys. J.* C **42**, 1 (2005)
5. ZEUS Coll., preliminary result ZEUS-prel-07-027, 2007, available from http://www-zeus.desy.de/public_results/publicsearch.html
6. S. Glazov, Proceedings to the *XIII International Workshop on Deep Inelastic Scattering*, Madison, USA (DIS2005).
7. H1 and ZEUS Coll., *Combination of H1 and ZEUS Deep Inelastic $e^{\pm}p$ Scattering Cross Section Measurements*, Proceedings to the *23rd International Symposium on Lepton-Photon Interactions at High Energy*, Daegu, Korea (LP2007).