34^{th} International Conference on High Energy Physics, Philadelphia, 2008

Inclusive high Q^2 cross sections and QCD and EW fits at HERA

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The latest measurements of the cross sections for neutral and charged current deep inelastic scattering in $e^{\pm}p$ collisions at HERA with longitudinally polarised lepton beams are presented. The measured cross sections are compared with the predictions of the Standard Model. Next-to-leading-order QCD analyses of HERA data are also presented. The analyses yield the parton distribution functions of the proton and are extended to also extract electroweak parameters. The determinations from HERA are compared with those from LEP and the Tevatron.

1. INTRODUCTION

Deep inelastic scattering (DIS) of leptons off nucleons probes the structure of matter at small distance scales. Two types of DIS interactions are possible at HERA: neutral current (NC) reactions $e^-p \to e^-X$ and $e^+p \to e^+X$, where a photon or Z^0 boson is exchanged and charged current (CC) interactions $e^-p \to \nu X$ and $e^+p \to \bar{\nu}X$, where a $W^{\pm}$ boson is exchanged.

The kinematics of charged current and neutral current deep inelastic scattering processes are defined by the four-momenta of the incoming lepton (k), the incoming proton (P), the outgoing lepton (k') and the hadronic final state (P'). The four-momentum transfer between the electron and the proton is given by $q = k - k' = P' - P$. The square of the centre-of-mass energy is given by $s = (k + P)^2$. The description of DIS is usually given in terms of three Lorentz invariant quantities, which may be defined in terms of the four-momenta k, P and q:

- $Q^2 = -q^2$, the negative square of the four-momentum transfer,
- $x = \frac{Q^2}{2P\cdot q}$, the Bjorken scaling variable,
- $y = \frac{q\cdot P}{k\cdot P}$, the fraction of the energy transferred to the proton in its rest frame.

These variables are related by $Q^2 = xys$, when the masses of the incoming particles can be neglected.

This paper presents the most recent measurements of the cross sections for $e^{\pm}p$ NC and CC DIS with longitudinally polarised lepton beams. The measurements are based on around 300 pb^{-1} of data collected at a centre-of-mass energy of 318 GeV. The measured cross sections are compared to the Standard Model predictions. Next-to-leading-order QCD analyses of HERA data are also presented. The analyses are used to extract the parton distribution functions (PDFs) of the proton and are extended to also extract electroweak parameters.

2. CROSS SECTIONS

The longitudinal polarisation of the lepton beam is defined as $P_e = (N_R - N_L)/(N_R + N_L)$, where $N_R(N_L)$ are the numbers of right(left)-handed leptons in the beam. The double-differential cross section for the neutral current process with polarised lepton beams is given by

$$\frac{d^2\sigma^{\mathrm{NC}}(e^{\pm}p)}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}[H_0^{\pm} + P_e H_{P_e}^{\pm}], \tag{1}$$

where α is the QED coupling constant and $H_0^{\pm}$ and $H_{P_e}^{\pm}$ contain the unpolarised and polarised structure functions, respectively, such that at leading order in QCD

$$H_{0,P_e}^{\pm} = Y_+ F_2^{0,P_e} \mp Y_- xF_3^{0,P_e}, \qquad F_2^{0,P_e} = \sum_q x(q+\bar{q})A_q^{0,P_e}, \qquad xF_3^{0,P_e} = \sum_q x(q-\bar{q})B_q^{0,P_e}, \tag{2}$$

where $Y_\pm = 1 \pm (1-y)^2$ and $q(x,Q^2)$ and $\bar{q}(x,Q^2)$ are the quark and antiquark PDFs, respectively, and the sums run over the five active quark flavours. The A and B coefficients contain the quark and lepton couplings to the photon and Z^0 boson and are given by

$$A_q^0 = e_q^2 - 2e_q v_q v_e \chi_Z + (v_q^2 + a_q^2)(v_e^2 + a_e^2)\chi_Z^2, \qquad B_q^0 = -2e_q a_q a_e \chi_Z + 4v_q a_q v_e a_e \chi_Z^2, \tag{3}$$

$$A_q^{P_e} = 2e_q v_q a_e \chi_Z - 2(v_q^2 + a_q^2) v_e a_e \chi_Z^2, \qquad B_q^{P_e} = 2e_q a_q v_e \chi_Z - 2v_q a_q (v_e^2 + a_e^2)\chi_Z^2, \tag{4}$$

where e_f is the electric charge in units of the positron charge and a_f and v_f are the axial and vector couplings of the fermion f. The quantity χ_Z is proportional to the ratio of the Z^0 and photon propagators

$$\chi_Z = \frac{1}{\sin^2 2\theta_W}\left(\frac{Q^2}{M_Z^2 + Q^2}\right), \tag{5}$$

where M_Z is the mass of the Z^0 boson and θ_W is the Weinberg angle.

The cross section for CC DIS with a longitudinally polarised lepton beam, can be expressed as

$$\frac{d^2\sigma^{\text{CC}}(e^\pm p)}{dxdQ^2} = (1 \pm P_e)\frac{G_F^2}{4\pi x}\left(\frac{M_W^2}{M_W^2 + Q^2}\right)^2 \left[Y_+ F_2^\pm - Y_- xF_3^\pm - y^2 F_L^\pm\right], \tag{6}$$

where G_F is the Fermi constant and M_W is the mass of the $W^\pm$ boson. The structure functions $F_2^\pm$ and $xF_3^\pm$ contain sums and differences of the quark and anti-quark PDFs and $F_L^\pm$ is the longitudinal structure function.

3. RESULTS

In order to study the polarisation dependence of the NC DIS cross sections the polarisation asymmetry may be formed by

$$A^\pm = \frac{2}{P_e^+ - P_e^-}\frac{\sigma^\pm(P_e^+) - \sigma^\pm(P_e^-)}{\sigma^\pm(P_e^+) + \sigma^\pm(P_e^-)}, \tag{7}$$

where $P_e^\pm$ are the mean polarisation values of the positively and negatively polarised data samples and $\sigma^\pm$ are the measured $e^\pm p$ cross sections. The asymmetry is shown in Fig. 1 (left) as a function of Q^2. It can be seen that the values are non-zero and are well described by the Standard Model prediction evaluated using the ZEUS-JETS [1] PDFs, confirming the expected polarisation dependence. The asymmetry is proportional to $a_e v_q$ and therefore a direct measurement of parity violation at high Q^2.

The cross sections for $e^\pm p$ CC DIS are shown as a function of the longitudinal polarisation of the lepton beam in Fig. 1 (right) including the unpolarised ZEUS measurements from the 1998-2000 data [2, 3]. The data are compared to the Standard Model prediction evaluated using the ZEUS-JETS, CTEQ6 [4] and MRST04 [5] PDFs. The Standard Model predicts a linear dependence on P_e with the cross section becoming zero for right-handed (left-handed) electron (positron) beams, due to the chiral nature of the Standard Model. The predictions describe the data well.

4. COMBINED ELECTROWEAK AND QCD FIT

The neutral current cross sections give information on the quark couplings to the Z^0 boson which appear in the coefficients A and B in Sect. 2. One can see that since v_e is small and $\chi_Z \gg \chi_Z^2$ for the HERA kinematic regime, the axial and vector couplings are dominant in the unpolarised xF_3 and polarised F_2 terms, respectively. These electroweak parameters can be fitted simultaneously with the PDF parameters to perform a model-independent extraction [6]. The details of the fits for the PDFs follow the procedures in previous H1 and ZEUS publications [1, 7] closely. The H1 fit includes inclusive NC and CC DIS data over a large range in Q^2 and x. The ZEUS fit also includes

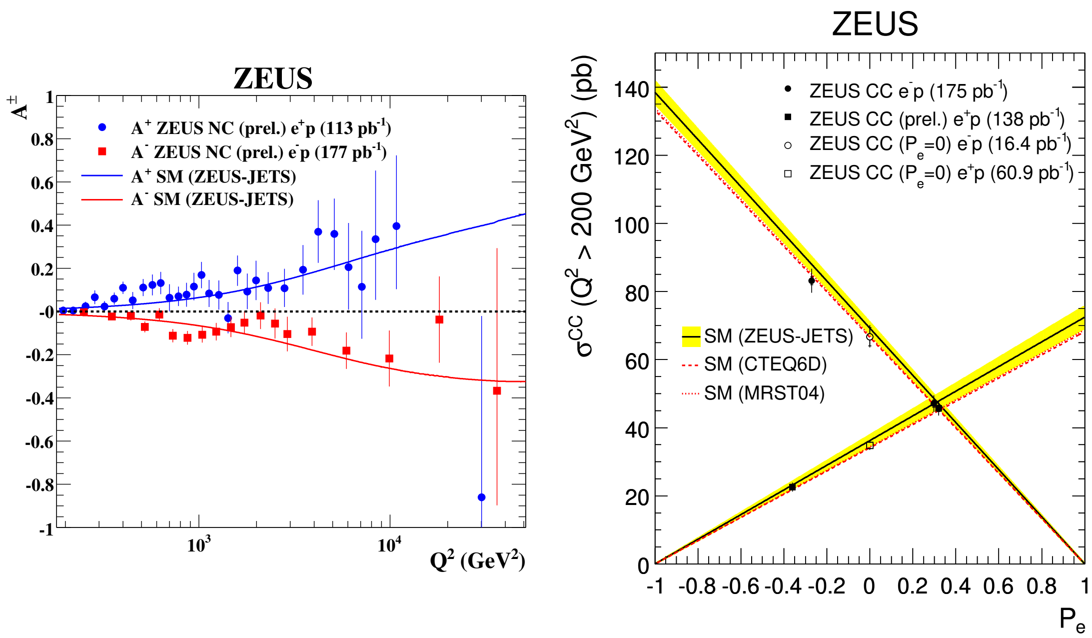

Figure 1: The neutral current asymmetry $A^{\pm}$ as a function of Q^2 (left) and the cross section for charged current DIS as a function of the polarisation of the lepton beam (right).

jet cross-section data. These fits are extended to extract the quark couplings to the Z^0 boson from the high-Q^2 NC DIS data.

Figure 2 shows the extracted PDF parameters compared to those from the ZEUS-JETS fit.The PDFs are not significantly altered by the inclusion of electroweak parameters in the fit. Figure 3 shows the results of the determination of a_q and v_q for u and d type quarks, together with results from other experiments. The HERA data are more sensitive to light quarks and thus the extracted couplings are compared with the corresponding light-quark extractions from LEP [8] and CDF [9]. The extracted values of the couplings are in agreement with the Standard Model predictions and the precision is competitive with measurements from other colliders.

5. SUMMARY

The cross sections for neutral and charged current deep inelastic scattering in $e^{\pm}p$ collisions with longitudinally polarised lepton beams have been measured. The latest measurements, based on around 300 pb^{-1} of data are well described by the Standard Model. Combined QCD and electroweak fits to HERA data yield determinations the parton distribution functions and simultaneously allow the extraction of the light-quark couplings to the Z^0 boson from the high-Q^2 NC DIS data. The extracted values of the couplings are in agreement with the Standard Model predictions and the precision is competitive with measurements from other colliders.

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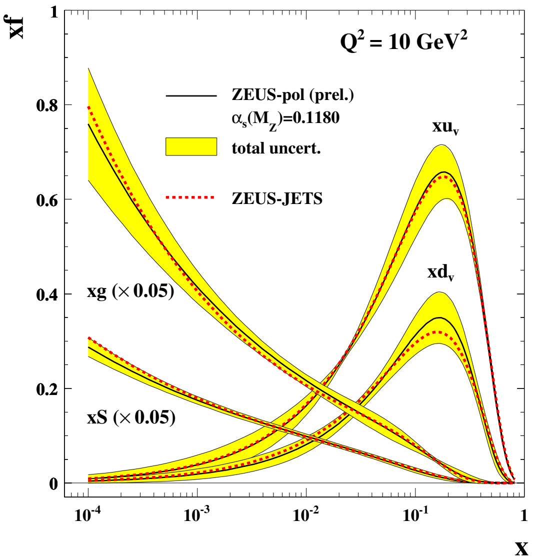

Figure 2: The extracted parton density functions of the proton at $Q^2 = 10$ GeV^2.

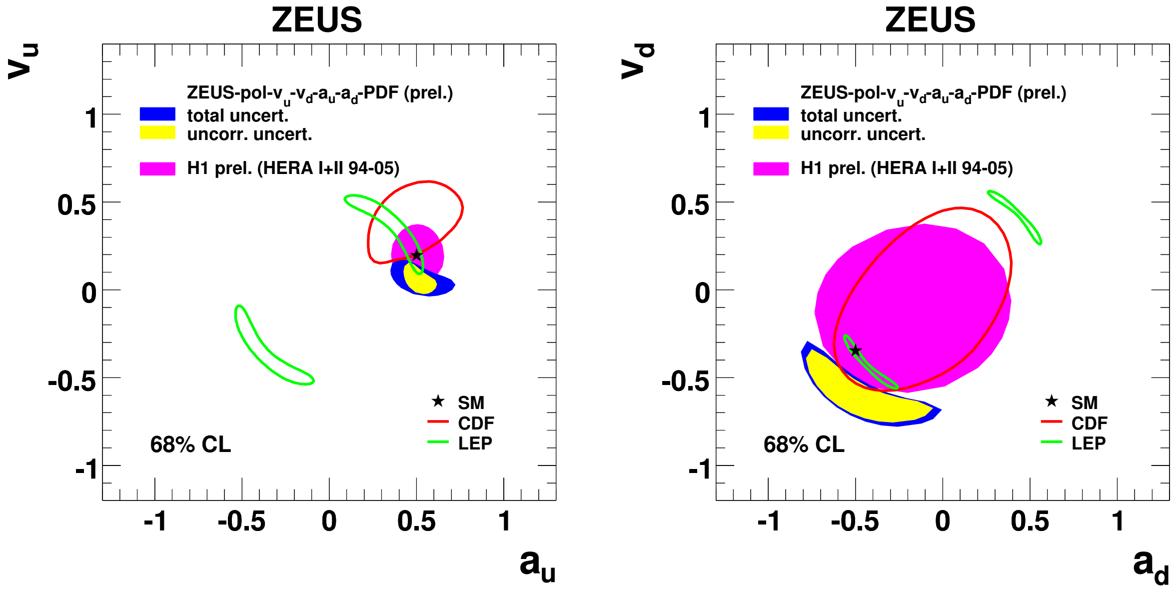

Figure 3: The extracted values of the axial and vector couplings of the Z^0 boson to the up (left) and down (right) quarks. The contours represent 68% confidence limits.

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