CHARGED CURRENT DEEP INELASTIC SCATTERING WITH POLARISED $e^{\pm}$ BEAMS AT HERA†

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Measurements by the H1 and ZEUS collaborations of the cross sections for charged current deep inelastic scattering in $e^{\pm}p$ collisions with longitudinally polarised lepton beams are presented. The total cross sections for $e^{\pm}p$ charged current deep inelastic scattering are presented at positive and negative values of the longitudinal polarisation of the lepton beam. In addition, single and double-differential cross sections are presented for the kinematic region $Q^2 > 200$ GeV^2. The measured cross sections are compared with the predictions of the Standard Model.

Keywords: HERA; H1; ZEUS; charged current; polarised.

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 $e^-p \rightarrow e^-X$ and $e^+p \rightarrow e^+X$, where a photon or Z^0 boson is exchanged and charged current (CC) interactions $e^-p \rightarrow \nu X$ and $e^+p \rightarrow \bar{\nu} X$, where a $W^{\pm}$ boson is exchanged.

The Standard Model (SM) predicts that the cross section for charged current DIS should exhibit dependence on the longitudinal polarisation of the incoming lepton beam. The dependence is predicted to be linear with the cross section becoming zero for right-handed (left-handed) electron (positron) beams, due to the chiral nature of the Standard Model.

The kinematics of the charged 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 lepton 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 measurements from the H1[1] and ZEUS[2] collaborations of the cross sections for $e^{\pm}p$ CC DIS with longitudinally polarised lepton beams. The measurements are based on the data samples given in Table 1 collected between 2003 and 2005 at a centre-of-mass energy of 318 GeV. The measured cross sections are compared to the Standard Model predictions.

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Table 1. Integrated luminosities and average polarisations for the data samples.

	$P_e < 0$		$P_e > 0$	
	$\mathcal{L}(\mathrm{pb}^{-1})$	P_e	$\mathcal{L}(\mathrm{pb}^{-1})$	P_e
H1 e^+p	20.7	-0.40	26.9	$+0.34$
H1 e^-p	68.6	-0.27	29.6	$+0.37$
ZEUS e^+p	11.5	-0.41	12.3	$+0.32$
ZEUS e^-p	78.8	-0.27	42.7	$+0.33$

2. Cross sections

The electroweak Born-level cross-section for the CC reactions, $e^-p \to \nu X$ and $e^+p \to \bar{\nu} X$, with longitudinally polarised lepton beams (defined in Eqn. (1)), can be expressed as

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

where G_F is the Fermi constant, M_W is the mass of the W boson and $Y_\pm = 1 \pm (1-y)^2$. The structure functions F_2 and xF_3 contain sums and differences of the quark and anti-quark parton density functions (PDFs) and F_L is the longitudinal structure function. The longitudinal polarisation of the positron beam is defined as

$$P_e = \frac{N_R - N_L}{N_R + N_L}, \qquad (1)$$

where N_R and N_L are the numbers of right and left-handed leptons in the beam.

3. Results

The total cross sections are shown as a function of the longitudinal polarisation of the lepton beam in Fig. 1 including earlier measurements with unpolarised beams[3,4,5,6]. The data are compared to the Standard Model prediction evaluated using the H1 2000 PDFs[4]. The SM prediction describes the data well. Linear fits to the $e^\pm p$ data yield the values given in Table 2 for the right-handed charged current cross section. Assuming the coupling strength of the right-handed charged current is the same as the left-handed case, these measurements can be expressed as lower limits on the mass of a right-handed W boson. The best limit, given by the H1 e^+p data sample, is 208 GeV at 95% CL.

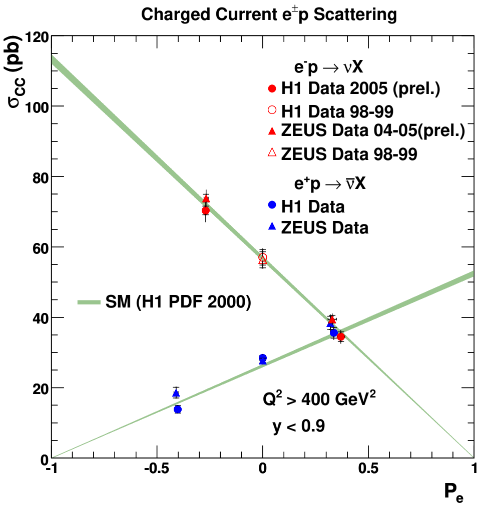

Fig. 1. The total cross section for $e^\pm p$ CC DIS as a function of the longitudinal polarisation of the lepton beam.

Table 2. Estimates of the cross section for right-handed CC DIS from the different data samples.

	σ (pb)	$\delta_{\mathrm{stat.}}$ (pb)	$\delta_{\mathrm{syst.}}$ (pb)
H1 e^+p	-3.9	2.3	1.1
H1 e^-p	-0.9	2.9	3.5
ZEUS e^+p	7.4	3.9	1.2
ZEUS e^-p	0.8	3.1	5.0

The single-differential cross-sections $d\sigma/dQ^2$, $d\sigma/dx$ and $d\sigma/dy$ for e^-p charged current DIS are shown in Fig. 2. A clear difference is observed between the measurements for positive and negative longitudinal polarisation, which is independent of the kinematic variables. The effects are well described by the SM evaluated using the ZEUS-JETS PDFs[7].

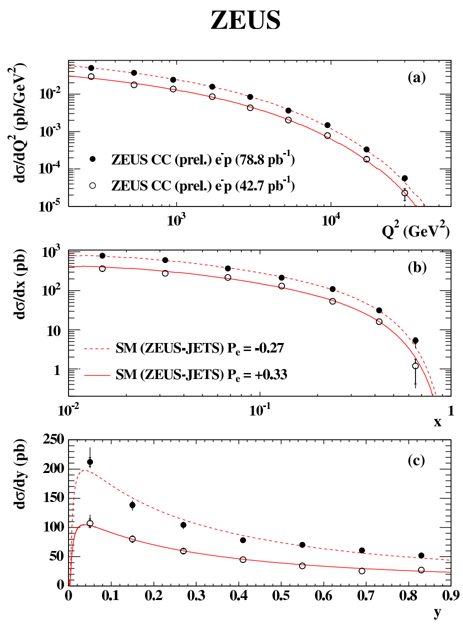

Fig. 2. The differential cross-sections (a) $d\sigma/dQ^2$, (b) $d\sigma/dx$ and (c) $d\sigma/dy$ are shown. The curves show the SM predictions evaluated using the ZEUS-JETS PDFs.

The reduced double-differential cross section, $\tilde{\sigma}$, is defined by

$$\tilde{\sigma} = \left[\frac{G_F^2}{2\pi x} \left(\frac{M_W^2}{M_W^2 + Q^2} \right)^2 \right]^{-1} \frac{d^2\sigma}{dx\, dQ^2}.$$

At leading order in QCD, $\tilde{\sigma}(e^- p \to \nu_e X)$ depends on the quark momentum distributions as follows:

$$\tilde{\sigma}(e^- p \to \nu_e X) = x\left[u + c + (1-y)^2(\bar{d} + \bar{s})\right].$$

The reduced cross section is shown in Fig. 3 as a function of x, at fixed values of Q^2. The predictions of the SM, evaluated using the ZEUS-JETS fit give a good description of the data.

4. Summary

The cross sections for charged current deep inelastic scattering in $e^{\pm}p$ collisions with longitudinally polarised lepton beams have been measured. The total cross sections for $e^{\pm}p$ charged current deep inelastic scattering are presented at positive and negative values of the longitudinal polarisation of the lepton beam. In addition, single and double-differential cross sections are presented for the kinematic region $Q^2 > 200$ GeV^2. The measured cross sections are well described by the predictions of the Standard Model.

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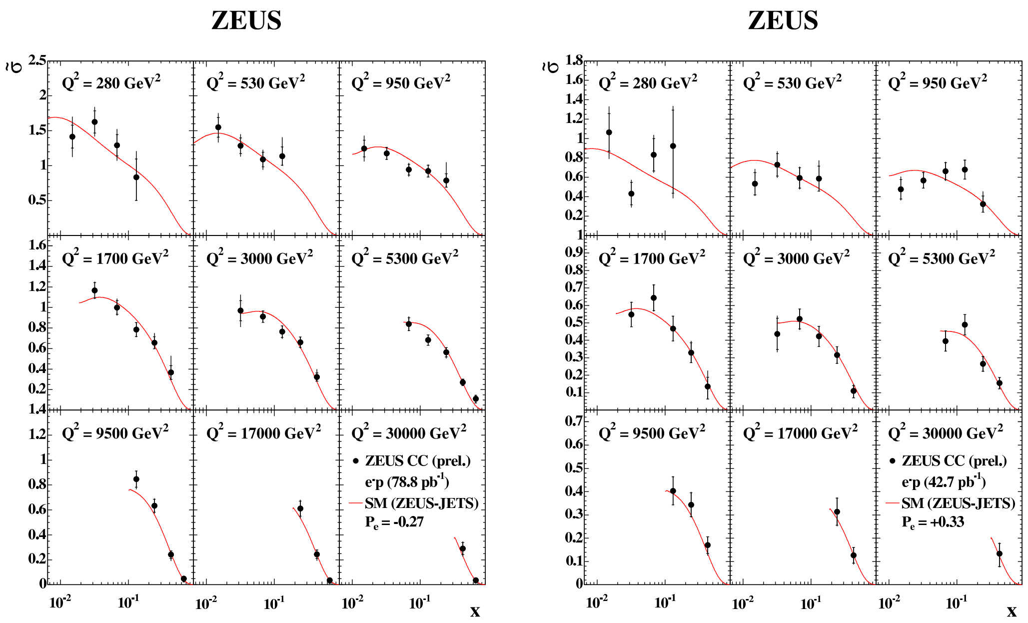

Fig. 3. The reduced cross section is shown for negatively polarised $e^{-}p$ data (left) and positively polarised $e^{-}p$ (right). The curves show the SM predictions evaluated using the ZEUS-JETS PDFs.