Measurement of high-Q^2 e^+p neutral current cross sections at HERA and determination of the structure function $x\tilde{F}_3$

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The cross sections for neutral current deep inelastic scattering in e^+p collisions with a longitudinally polarised positron beam were measured using the ZEUS detector at HERA. The single-differential cross-sections $d\sigma/dQ^2$, $d\sigma/dx$ and $d\sigma/dy$ and the double-differential cross sections in Q^2 and x are presented in the kinematic region $Q^2 > 185$ GeV^2 and $y < 0.9$ for both positively and negatively polarised positron beams and for each polarisation state separately. The measurements are based on an integrated luminosity of 135.5 pb^{-1} taken in 2006 and 2007 at a centre-of-mass energy of 318 GeV. The structure function $x\tilde{F}_3$ is determined by combining these e^+p results with previously measured e^-p neutral current data. The measured cross sections are compared to the predictions.

1 Introduction

At the *ep* collider HERA electrons and positrons with an energy of 27.5 GeV collided with protons of an energy of predominantly 920 GeV, leading to a centre-of-mass energy of about 320 GeV. During the HERA II running period (2002-2007), the instantaneous luminosity was higher and the lepton beam was longitudinally polarised. This made it possible to study the polarisation dependence of deep inelastic scattering (DIS) in $e^\pm p$ neutral current (NC) and charged current (CC) interactions. The higher integrated luminosity of the HERA II data also improves the precision of measurements of the proton structure functions and makes these measurements a key input to the fits of the parton distribution functions (PDFs).

The NC DIS measurement presented here [1] is from e^+p data collected in 2006–2007. The sample corresponds to an integrated luminosity of 135.5 pb^{-1}, where 78.8 pb^{-1} were collected with a positive polarisation of the positron beam, while for the remaining 56.7 pb^{-1} the polarisation of the beam was negative. The mean polarisation of the two data sets is 0.32 and -0.36, leading to a mean polarisation of 0.03 for the combined set.

2 Neutral Current cross sections with longitudinally polarised leptons

The electroweak Born-level cross section of the NC process $e^{\pm}p \rightarrow e^{\pm}X$ can be written as

$$\frac{d^2\sigma(e^{\pm}p)}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}\left[Y_+\tilde{F}_2(x,Q^2) \mp Y_- x\tilde{F}_3(x,Q^2)\ -y^2\tilde{F}_L(x,Q^2)\right] = \frac{2\pi\alpha^2}{xQ^4}\tilde{\sigma}\ .$$

At HERA, of the (generalised) proton structure functions, $\tilde{F}_2$ is dominant in most of the phase space and $x\tilde{F}_3$ is sizable at high Q^2. $\tilde{F}_L$ gives a sizable contribution only at high y. Taking into account the lepton-beam polarisation, P_e, $\tilde{F}_2$ and $x\tilde{F}_3$ can be expressed as:

$$\tilde{F_2}^{\pm} = F_2^{\gamma} - (v_e \pm P_e a_e)\chi_Z F_2^{\gamma Z} + (v_e^2 + a_e^2 \pm 2P_e v_e a_e)\chi_Z^2 F_2^Z$$

and

$$x\tilde{F_3}^{\pm} = -(a_e \pm P_e v_e)\chi_Z xF_3^{\gamma Z} + (2v_e a_e \pm P_e(v_e^2 + a_e^2))\chi_Z^2 xF_3^Z\ ,$$

where $\chi_Z = \frac{1}{\sin^2\theta_W}\frac{Q^2}{M_Z^2+Q^2}$, v_e and a_e being the vector and axial-vector couplings of the electron to the Z boson and θ_W is the electroweak mixing angle.

At leading order in QCD, F_2^{γ}, $F_2^{\gamma Z}$ and F_2^Z can be written as linear combinations of the sum and $F_3^{\gamma Z}$ and F_3^Z as linear combinations of the difference of quarks and anti-quarks distributions in the proton:

$$[F_2^{\gamma}, F_2^{\gamma Z}, F_2^Z] = \sum_q [e_q^2, 2e_q v_q, v_q^2 + a_q^2] x(q + \bar{q})$$

and

$$[xF_3^{\gamma Z}, xF_3^Z] = \sum_q [e_q a_q, v_q a_q] x(q - \bar{q})\ .$$

The difference of the e^+p and e^-p cross sections at zero polarisation of the lepton beam can be used to extract the structure function $x\tilde{F}_3$.

If the NC cross sections is measured separately for positive and negative lepton-beam polarisation, the polarisation asymmetry

$$A^{\pm} = \frac{2}{P_e^+ - P_e^-}\frac{\sigma^{\pm}(P_e^+) - \sigma^{\pm}(P_e^-)}{\sigma^{\pm}(P_e^+) + \sigma^{\pm}(P_e^-)}$$
$$= \mp 2\chi_Z a_e v_q e_q / e_q^2 \propto a_e v_q$$

can be extracted. The asymmetry is proportional to the products $a_e v_q$ of the axial-vector coupling of the electron and the vector coupling of the quarks to the Z boson. Thus a measurement of A^+ can give direct evidence of parity violation with minimal assumptions on the proton structure.

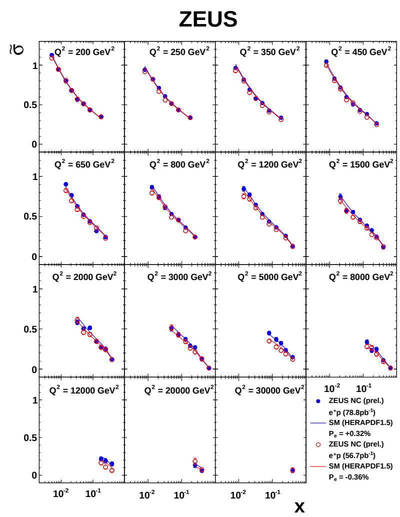

Figure 1: The NC reduced cross sections $\tilde{\sigma}_{NC}$ as a function of x at fixed Q^2 values: shown are e^+p ZEUS data with positive polarisation (closed circles) and the corresponding SM predictions obtained using the HERAPDF1.5 PDFs (solid lines) as well as the data with negative polarisation (open circles) and the corresponding SM predictions obtained using the HERAPDF1.5 PDFs (dashed lines).

3 Results

3.1 Polarised cross sections and polarisation asymmetry

The single-differential and the reduced cross sections (shown in Figure 1) were measured for negative and positive polarisation and agree with the Standard Model (SM) expectation evaluated using the HERAPDF1.5 [2, 3] PDFs. At high Q^2, the cross sections for the two polarisations differ, as expected, and from this difference the polarisation asymmetry A^+ was extracted showing parity violation (see Figure 2).

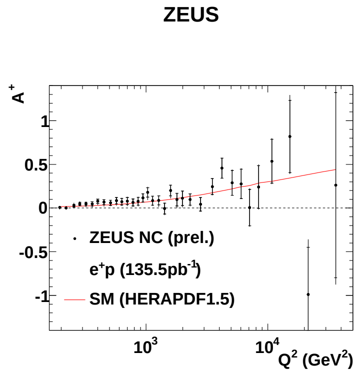

Figure 2: The Q^2 dependence of the polarisation asymmetry A^+, from e^+p scattering. The ZEUS data points are compared to the SM expectation obtained using the HERAPDF1.5 PDFs (solid red line).

3.2 Unpolarised cross sections and $x\tilde{F}_3$

The complete data set was also analysed and the single-differential cross sections $d\sigma/dQ^2$, $d\sigma/dx$ and $d\sigma/dy$ were measured and corrected to $P_e = 0$ for the residual polarisation. They are presented in Figure 3. From the reduced cross sections at zero polarisation in combination with the previously published results of e^-p data [4] the structure function $x\tilde{F}_3$ was extracted and is shown in Figure 4. These e^-p and e^+p data sets are the largest from ZEUS giving the most precise ZEUS $x\tilde{F}_3$ measurement to date.

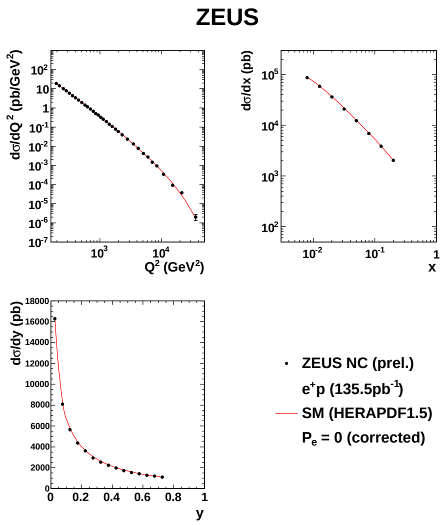

Figure 3: The single-differential NC e^+p cross sections $d\sigma/dQ^2$ (top left), $d\sigma/dx$ (top right) and $d\sigma/dy$ (bottom left) for $Q^2 > 185$ GeV^2 and $y < 0.9$.

4 Summary

The e^+p NC cross sections were measured with a longitudinally polarised lepton beam using the HERA II 2006–2007 data sample. The polarisation asymmetry of the NC cross section was measured showing parity violation directly with minimal dependence on the PDFs. Exploiting the dependence of the NC cross section on the charge of the lepton beam, the structure function $x\tilde{F}_3$, sensitive to the valence quark distributions, was extracted. The measurements are in agreement with the SM and have the potential to constrain the PDFs.

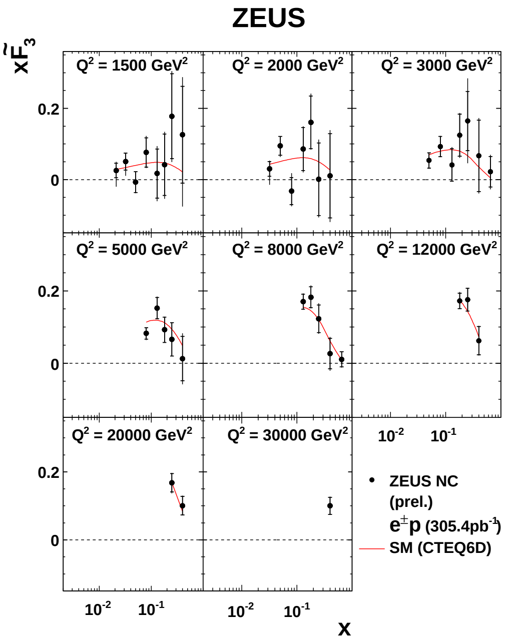

Figure 4: The structure function $x\tilde{F}_3$ evaluated using e^+p and e^-p data (solid points) compared to the SM expectations obtained using the CTEQ6D PDF set (solid line).

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