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# Neutral and charged current cross sections and measurements of $F_2, xF_3$ and $F_L$ at high $Q^2$ at HERA

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**Abstract.** Inclusive $e^+p$ cross sections for neutral and charged current deep inelastic scattering have been determined by the H1 and ZEUS collaborations at HERA. The data were recorded in 1999 and 2000 at a center of mass energy of 318 GeV with an integrated luminosity of 65.2 $\text{pb}^{-1}$ and 60.9 $\text{pb}^{-1}$, respectively. Taking into account previously published $e^{\pm}p$ neutral current data the structure functions $F_2$ and $xF_3$ were extracted. $F_L$ was determined by extending the measurement to small scattered positron energies. The quark singlet distribution $F_2^{CC}$ was extracted for the first time at HERA by combining $e^+p$ and $e^-p$ charged current cross sections. All results are well described by Standard Model expectations.

**PACS.** 13.60.Hb Total and inclusive cross sections (including deep-inelastic processes) – 14.20.Dh Protons and neutrons

## 1 Introduction

Deep inelastic lepton proton scattering (DIS) plays a key role in the investigation of the structure of the proton. The H1 and ZEUS detectors at the HERA collider offer the possibility to determine the proton structure at small distance scales, a previously unexplored kinematic domain.

This paper presents the HERA measurements of high $Q^2$ neutral (NC) and charged current (CC) cross sections with the H1 and ZEUS detectors. The integrated luminosity of the $e^+p$ data collected in the years 1999-2000 corresponds to 65 $\text{pb}^{-1}$ and 61 $\text{pb}^{-1}$ for H1 and ZEUS, respectively [1,2]. Combining the measurements with 16 $\text{pb}^{-1}$ $e^-p$ data [3,4] and previous $e^+p$ data more than 100 $\text{pb}^{-1}$ were recorded with each experiment.

The neutral current data is used to extract the structure functions $F_2, xF_3$ and $F_L$. The structure function $F_2^{CC}$ is extracted from the charged current data which was also used to investigate the chiral structure of the Standard Model (SM) in terms of its $(1-y)^2$ dependence.

## 2 High-$Q^2$ DIS NC and CC cross sections

The double differential NC cross section for $e^{\pm}p \rightarrow e^{\pm}X$ can be written as:

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

where $Y_{\pm} = 1 \pm (1-y)^2$ and $\alpha$ is the fine-structure constant. All structure functions depend on both $x$ and $Q^2$. For convenience the reduced cross section is used which is defined as follows:

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

The double differential CC cross section is given by:

$$\frac{d^2\sigma_{CC}^{e^{\pm}p}}{dxdQ^2} = \frac{G_F^2}{4\pi x}\frac{M_W^4}{(Q^2+M_W^2)^2}[Y_+F_2^{CC} \mp Y_-xF_3^{CC} - y^2F_L^{CC}], \quad (3)$$

where $G_F$ is the Fermi constant $G_F$ and $M_W$ is the mass of the $W$-boson. The reduced CC cross section is defined as:

$$\tilde{\sigma}_{CC}^{e^{\pm}p} = \frac{2\pi x}{G_F^2}\frac{(Q^2+M_W^2)^2}{M_W^4}\frac{d^2\sigma_{CC}^{e^{\pm}p}}{dxdQ^2} \,. \quad (4)$$

The precise determination of the NC and CC cross sections integrated over x can be seen in Fig. 1. The single differential cross sections $d\sigma/dQ^2$ span several orders of magnitude in agreement with the SM expectation. At low values of $Q^2$ the neutral current cross section is dominated by photon exchange and therefore much larger than the CC cross section as can be seen from the propagator terms in 1 and 3. At high values of $Q^2$ where the $Z$-boson exchange is a significant contribution to the NC process, the CC and NC cross sections are of similar magnitude.

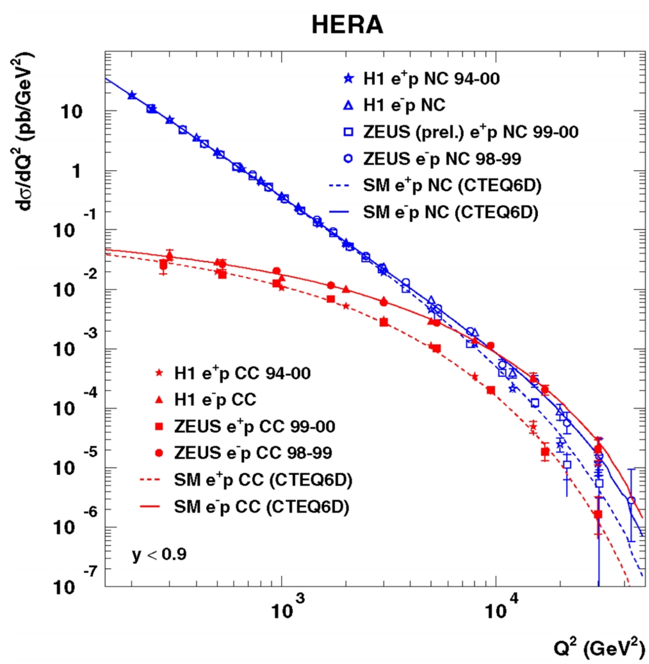


**Fig. 1.** Single differential cross section $d\sigma/dQ^2$ as a function of $Q^2$ in NC and CC measured with the H1 and ZEUS detectors

### 2.1 The structure function $F_2$

The structure function $F_2$ is the dominant structure function over the majority of the accessible phase space. It can be expressed as a combination of the parton and antiparton densities inside the proton, in leading order QCD $F_2$ is given:

$$F_2(x, Q^2) = \sum_f x(q_f + \bar{q}_f)A_f \, ; \tag{5}$$

where the summation runs over all quark flavours $f$ and $A_f$ and denotes the electroweak couplings. $F_2$ was extracted up to $Q^2$ values of 30000 GeV$^2$ and found in good agreement with the SM expectation as determined by the QCD evolution of the parton density functions (PDFs) extracted at lower values of $Q^2$.

### 2.2 The structure function $F_L$

The structure function $F_L$ was extracted by the H1 collaboration at high values of $Q^2$. Neglecting small electro-weak effects in the region of the extraction $F_L$ can be expressed in the following way:

$$F_L(x, Q^2) = \frac{1}{y^2}(Y_+ F_2^{em} - Y_+ \tilde{\sigma}_{NC}) \, . \tag{6}$$

By extrapolating the electro-magnetical part of the stucture function $F_2$ into the high $y$ region $F_L$ can be extracted. The result is shown in Fig. 2. The results from $e^-p$ and $e^+p$ data sets are mutually consistent and in agreement with the expectation.

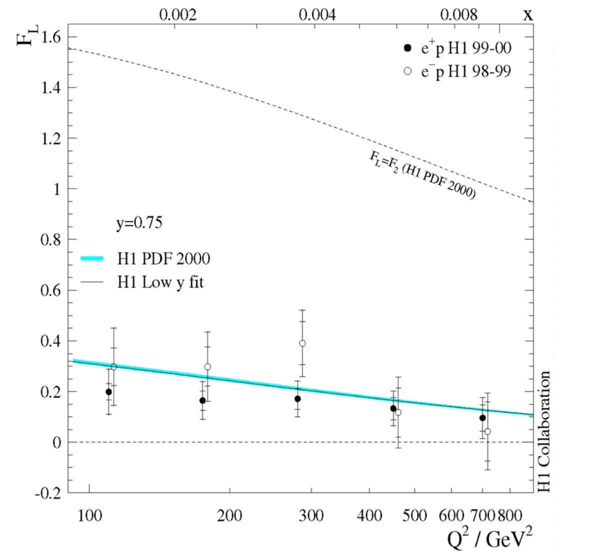


**Fig. 2.** The Structure Function $F_L$ extracted by the H1 collaboration at high values of $Q^2$. The extraction was performed in both $e^-p$ and $e^+p$ data

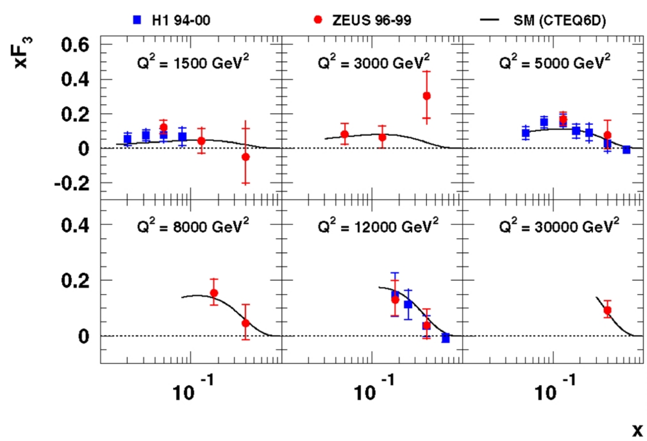


**Fig. 3.** The determination of the structure function $xF_3$ in bins of $Q^2$ as a function of $x$

### 2.3 The structure function $xF_3$

Cross sections of NC $e^-p$ and $e^+p$ scattering differ due to the different contribution of the structure function $xF_3$ as can be seen in 1. By combining $e^-p$ and $e^+p$ data sets $xF_3$ can be determined. $xF_3$ is dominated by the interference between photon and $Z$ boson, in leading order QCD it can be written as:

$$xF_3(x, Q^2) = \sum_f x(q_f - \bar{q}_f)B_f \, , \tag{7}$$

where $B_f$ denotes the electroweak couplings. The valence quark dependent $xF_3$ was extracted by both collaborations as can be seen in Fig. 3. Both results are consistent and in agreement with the SM expectations however, the measurement is statistically limited due to the relative small $e^-p$ data sample.

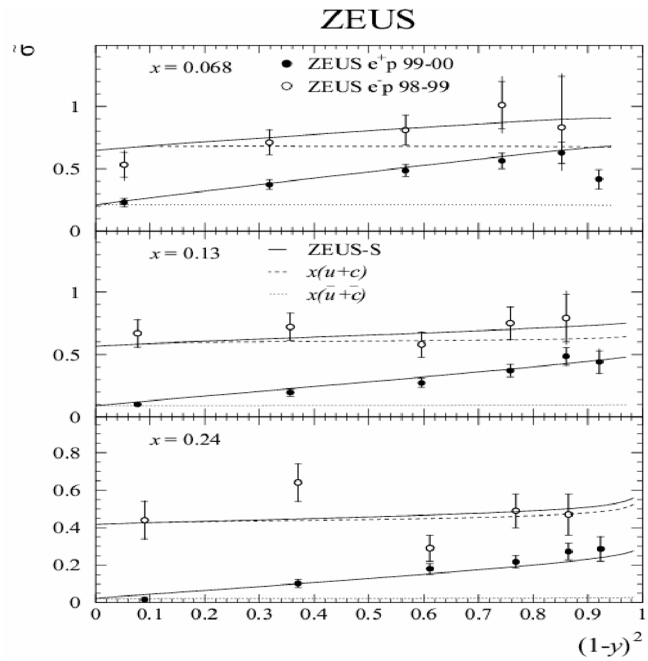


**Fig. 4.** The CC reduced cross section as a function of $(1-y)^2$ in $e^+p$ and $e^-p$ data measured by the ZEUS collaboration

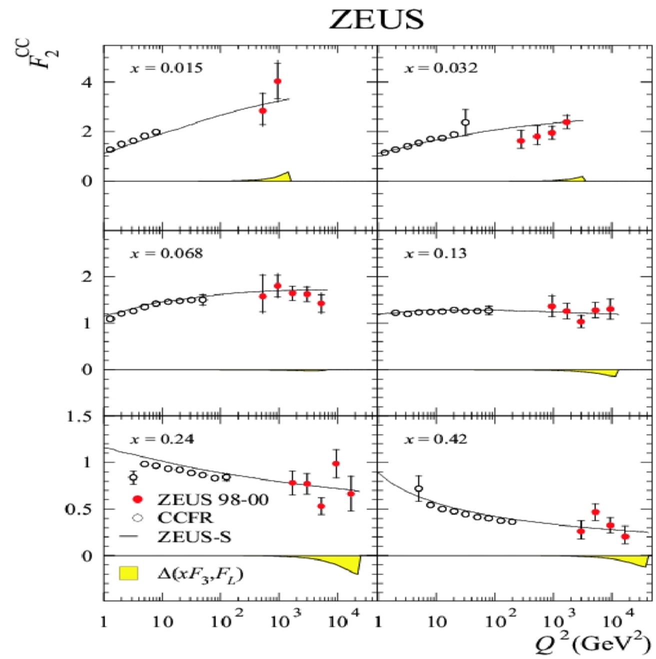


**Fig. 5.** The extraction of the structure function $F_2^{CC}$ in bins of $x$ as a function of $Q^2$

## 3 Reduced CC cross section

In leading order QCD the CC reduced cross section can be expressed as a function of quark momentum distributions. The $e^-p$ reduced CC cross section is given by:

$$\tilde{\sigma}_{CC}^{e^-p} = x(u + c + (1-y)^2(\bar{d} + \bar{s}))\,, \tag{8}$$

whereas the $e^+p$ reduced CC cross section can be expressed in the following form:

$$\tilde{\sigma}_{CC}^{e^+p} = x(\bar{u} + \bar{c} + (1-y)^2(d + s))\,. \tag{9}$$

Since the $W$ boson couples only to left-handed fermions and right-handed antifermions the angular distribution of the scattered quark in $e^+\bar{q}$ and $e^-q$ CC DIS will be flat in the lepton-quark centre-of-mass scattering angle $\theta^*$ whereas it will be distributed as $(1+\cos\theta^*)$ in $e^+q$ and $e^-\bar{q}$ scattering. Since $(1-y)^2 \propto (1+\cos\theta^*)$, the helicity structure of CC interactions is illustrated by plotting $\tilde{\sigma}_{CC}^{e^\pm p}$ as a function $(1-y)^2$. In Fig. 4 the intercept reflects the $(\bar{u}+\bar{c})$ $[(u+c)]$ contribution for $e^+p$ $[e^-p]$ CC whereas the slope displays the $(d+s)$ $[(\bar{d}+\bar{s})]$ contribution.

## 4 The structure function $F_2^{CC}$

For the first time at HERA the quark singlet distribution $F_2^{CC}$ was determined combining the $e^+p$ and $e^-p$ data sets. In leading order QCD $F_{2e^+p}^{CC}$ can be written as sum of $d$-type and $\bar{u}$-type PDFs whereas $F_{2e^-p}^{CC}$ can be expressed as sum of $u$-type and $\bar{d}$-type PDFs. The sum of both structure functions represents therefore the contribution from all quark and antiquark flavours. $F_2^{CC}$ was determined by adding $e^+p$ and $e^-p$ CC cross sections and correcting for contributions from $xF_3^{CC}$ and $F_L^{CC}$ $(\Delta(xF_3^{CC}, F_L^{CC}))$. Figure 5 shows the extracted $F_2^{CC}$ and the size of the correction $\Delta(xF_3^{CC}, F_L^{CC})$ in bins of $x$ as a function of $Q^2$ in addition to CCFR measurements corrected for heavy-target effects. Both results, spanning more than four orders of magnitude in $Q^2$ are well described by the SM prediction.

## 5 Conclusion

NC and CC cross sections in deep inelastic $e^+p$ scattering were measured by the H1 and ZEUS collaborations at HERA using an integrated luminosity corresponding to 65 pb$^{-1}$ and 61 pb$^{-1}$, respectively. In combination with previous data sets the structure functions $F_2$, $F_L$, $xF_3$ and $F_2^{CC}$ were determined at high momentum transfers. The Standard Model gives a very good description of all the data confirming the evolution of parton distributions to values of $Q^2$ exceeding the squared mass of the $Z$ boson.

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