PROCEEDINGS OF SCIENCE

Inclusive ep cross sections at HERA and determinations of F_L

Vladimir Chekelian (Shekelyan)[*†]
MPI for Physics, Munich
E-mail: shekeln@mpp.mpg.de

The inclusive *ep* neutral and charged current deep-inelastic scattering cross sections are measured in the H1 and ZEUS experiments at HERA, with an electron beam energy of 27.5 GeV and a nominal proton beam energy of 920 GeV (820 GeV till 1997) and reduced proton beam energies of 575 and 460 GeV. The data span six orders of magnitude in negative four-momentum-transfer squared, Q^2, and in Bjorken x. A combination of the data at nominal proton beam energy from unpolarised *ep* scattering taken during the HERA I phase as well as measurements with longitudinally polarised electron and positron beams from the HERA II running period is performed. The combination method takes correlations of systematic uncertainties into account, resulting in an improved accuracy. The longitudinal structure function F_L is measured using the neutral current cross section data at the reduced and nominal proton beam energies.

The 2011 Europhysics Conference on High Energy Physics-HEP 2011,
July 21-27, 2011
Grenoble, Rhône-Alpes France

[*]Speaker.
[†]on behalf of the H1 and ZEUS collaborations

© Copyright owned by the author(s) under the terms of the Creative Commons Attribution-NonCommercial-ShareAlike Licence.

PoS(EPS-HEP2011)288

1. Introduction

The inclusive neutral current (NC) and charged current (CC) deep-inelastic scattering (DIS) at the *ep* collider HERA (1992-2007) has been central to the exploration of proton structure and quark-gluon interaction dynamics as prescribed in perturbative Quantum Chromodynamics (QCD). At HERA electrons and positrons of 27.5 GeV collided with protons of 920 GeV (820 GeV until 1997). This corresponds to an *ep* center of mass energy of 320 GeV. Operation of HERA proceeded in two phases, HERA I (1992-2000) with unpolarised and HERA II (2003-2007) with longitudinally polarised lepton beam. The two *ep* interaction regions were instrumented with the multi-purpose detectors of the H1 and ZEUS collider experiments. Each of the two experiments collected a total integrated luminosity of $\approx 0.5\,fb^{-1}$, about equally shared between positive and negative polarities and positive and negative longitudinal polarizations of the lepton beam. At the end of the HERA data taking, special runs were performed with reduced energies of the proton beam of 460 and 575 GeV.

An ultimate goal of the inclusive NC and CC cross section measurements is to obtain a unique HERA data set, which provides averages of the H1 and ZEUS results produced in different years benefiting from the different features of the respective apparatus. A combination of the H1 and ZEUS measurements is performed for the HERA I as well as HERA II running periods. These combined data are analyzed in the QCD framework, and the parton distribution functions (PDFs) in the proton are determined.

The inclusive NC cross section data at the reduced and nominal proton beam energies are used to measure the longitudinal structure function F_L in a model independent way.

2. Combined H1 and ZEUS inclusive cross sections

The deep-inelastic $e^{\pm}p$ NC scattering cross section with unpolarised beams can be expressed in a reduced form as

$$\tilde{\sigma}^{\pm}_{NC}(x,Q^2) = \frac{\mathrm{d}^2\sigma^{e^{\pm}p}_{NC}}{\mathrm{d}x\mathrm{d}Q^2}\frac{xQ^4}{2\pi\alpha^2}\frac{1}{Y_+} = F_2(x,Q^2) \mp \frac{Y_-}{Y_+}xF_3(x,Q^2) - \frac{y^2}{Y_+}F_L(x,Q^2), \tag{2.1}$$

where α is the fine structure constant, x is the Bjorken scaling variable, Q^2 is the negative four-momentum-transfer squared, y characterises the inelasticity of the interaction and $Y_{\pm} = 1 \pm (1-y^2)$. The NC cross section is dominated by the contribution of the proton structure function F_2. At leading order in QCD, F_2 is related to a linear combination of sums of the quark and anti-quark momentum distributions in the proton, and the structure function xF_3 is related to a linear combination of their differences. The longitudinal structure function F_L is equal to zero in the leading order due to the spin one half nature of the quarks. Non-zero values of the longitudinal structure function appear in QCD due to gluon radiation.

The deep-inelastic $e^{\pm}p$ CC scattering cross section can be expressed in a similar manner. The $W^{\pm}$-boson exchange in the charged current process distinguishes between the charges of the constituent quarks. Thus, for the electron (positron) beam the cross section depends on the $u,\bar{d}$ $(d,\bar{u})$ quark content of the proton.

The H1 and ZEUS measurements on inclusive NC and CC reactions cover a wide range of x and Q^2. For NC the kinematic range is $6\cdot 10^{-7} \leq x \leq 0.65$ and $0.045 \leq Q^2 \leq 30000\,\mathrm{GeV}^2$, and for

PoS(EPS-HEP2011)288

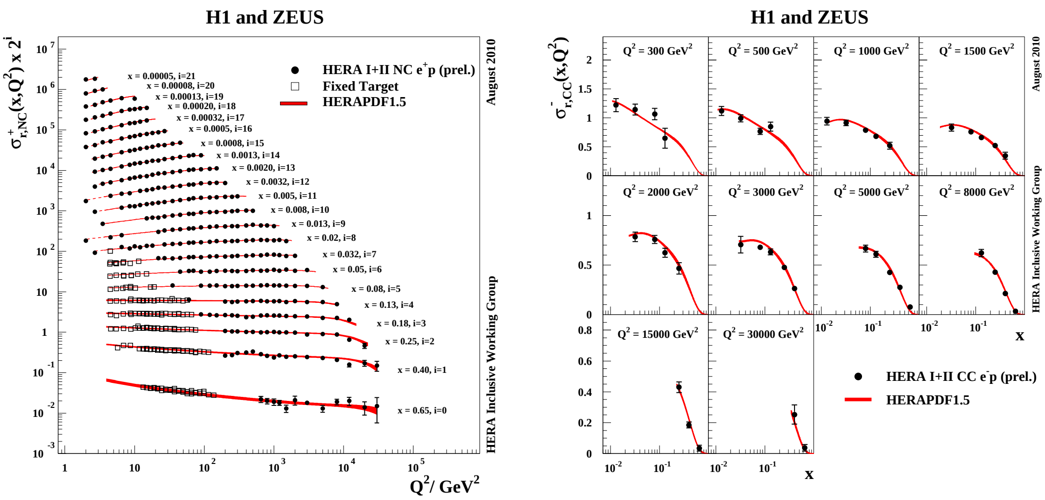

Figure 1: The combined HERA e^+p NC (left plot) and e^-p CC (right plot) unpolarized reduced cross sections as a function of Q^2 and x, correspondingly, compared to the Standard Model predictions based on HERAPDF1.5 [5].

CC it is $1.3 \cdot 10^{-2} \leq x \leq 0.65$ and $300 \leq Q^2 \leq 30000$ GeV^2. All published NC and CC cross section measurements from H1 and ZEUS obtained using data collected during the HERA I phase, are combined in one simultaneous minimization [1]. The resulting shifts of the correlated systematic uncertainties are propagated to both NC and CC data such that one coherent data set is obtained. The data sets considered for the combination were taken with proton beam energies of 820 and 920 GeV. Therefore, the data are corrected to a common center of mass energy corresponding to $E_p = 920$ GeV and then averaged. The NC data for $y \geq 0.35$ are kept separate for the two proton beam energies. Since H1 and ZEUS have employed different experimental techniques, different detectors and methods of kinematic reconstruction, the averaging leads to a significantly reduced correlated systematic uncertainty. This reduction propagates to all average points, including also those which are based solely on the measurement from one experiment.

This averaging is extended to include the H1 and ZEUS measurements [2, 3] from the HERA II running period. The input H1 and ZEUS data show a good consistency with $\chi^2/n_{\rm dof} = 967.5/1032$. The inclusion of the large HERA II data set leads to an improved uncertainty especially at large Q^2. This combined data set [4] contains complete information on inclusive DIS cross sections measured by H1 and ZEUS at HERA. There are in total 134 sources of correlated systematic uncertainty. None of these systematic sources shifts by more than 2σ of the nominal value in the averaging procedure. The total uncertainty of the combined data set reaches 1% for NC scattering in the best measured region, $20 < Q^2 < 100$ GeV^2.

A next-to-leading order (NLO) QCD analysis is performed based exclusively on these combined cross section data. New sets of parton distribution functions, HERAPDF1.0 [1] (HERA I data) and HERAPDF1.5 [5] (HERA I and HERA II data), are obtained using a variable-flavour-number scheme. They have total uncertainties at the level of a few percent at low x, which include experimental as well as model and parametrisation uncertainties.

PoS(EPS-HEP2011)288

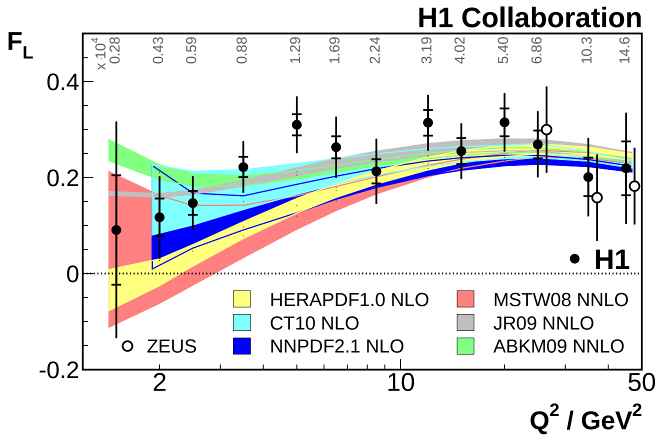

Figure 2: The H1 and ZEUS measurement of $F_L(Q^2)$ averaged over x at fixed values of Q^2. The resulting x values of the averaged F_L are given in the figure for each point in Q^2. The bands represent predictions based on HERAPDF1.0 [1], CTEQ6.6 [8], and NNPDF2.1 [9] NLO as well as MSTW08 [10], JR09 [11] and ABKM09 [12] NNLO calculations.

In Figure 1 the averaged e^+p NC (left plot) and e^-p CC (right plot) reduced cross sections, obtained using the entire HERA data, are shown together with the Standard Model predictions based on the PDFs from the HERAPDF1.5 QCD fit [5].

3. The longitudinal structure function F_L

A model independent measurement of the longitudinal structure function $F_L(x,Q^2)$ requires several sets of NC cross sections at fixed x and Q^2 but different y. This was achieved at HERA by variation of the proton beam energy. The F_L measurements are performed using e^+p data with three proton beam energies: the reduced energies of 460 GeV and 575 GeV and the nominal energy of 920 GeV.

According to Eq. (2.1), the $F_L(x,Q^2)$ contribution to the reduced cross section is proportional to $f(y) = y^2/[1+(1-y)^2]$. Therefore, the F_L values can be determined as slopes of straight-line fits of the measured $\tilde{\sigma}_{NC}(x,Q^2,y)$ values as a function of the y-dependent factor $f(y)$. More sophisticated procedures to determine F_L and F_2 are applied by H1 and ZEUS to take into account correlations of data points due to systematic uncertainties. The H1 and ZEUS measurements of $F_L(x,Q^2)$ [6, 7] are averaged over x at fixed Q^2, and the resulting $F_L(Q^2)$ is shown in Figure 2. The data are reasonably well reproduced by predictions based on NLO and NNLO QCD. The measurements of F_L are used to determine the ratio $R = F_L/(F_2 - F_L)$. For $Q^2 \geq 3.5\,\mathrm{GeV}^2$ the ratio R shows constant behaviour with $R = 0.26 \pm 0.05$.

4. Summary

Inclusive cross sections of $e^{\pm}p$ NC and CC scattering, measured by H1 and ZEUS at HERA, are combined providing the most accurate data set with a total uncertainty which reaches 1% for

PoS(EPS-HEP2011)288

NC in the bulk of the phase space. The inclusion of the large HERA II data set leads to a reduction of the errors especially at large Q^2. The combined data are the sole input to NLO QCD analyses which provide the HERAPDF1.0 and HERAPDF1.5 sets of parton distributions. With the data at the reduced proton beam energies of 460 GeV and 575 GeV and at the nominal proton beam energy of 920 GeV the measurement of the longitudinal structure function of the proton is performed without any model assumptions. It is found that the ratio $R = F_L/(F_2 - F_L)$ is consistent with being constant with $R = 0.26 \pm 0.05$.

References

[1] H1 and ZEUS Collab., F. D. Aaron *et al.*, *JHEP01*, 109 (2010).

[2] H1 Collab., H1prelim-09-042, H1prelim-09-043.

[3] ZEUS Collab., S. Chekanov *et al.*, *Eur. Phys. J.*, C**61**, 223 (2009);
ZEUS Collab., S. Chekanov *et al.*, *Eur. Phys. J.*, C**62**, 625 (2009);
ZEUS Collab., H. Abramowicz *et al.*, *Eur. Phys. J.*, C**70**, 945 (2010).

[4] H1 and ZEUS Collab., H1prelim-10-141 or ZEUS-prel-10-017.

[5] H1 and ZEUS Collab., H1prelim-10-142 or ZEUS-prel-10-018.

[6] H1 Collab., F. D. Aaron *et al.*, *Phys. Lett.*, B**665**, 139 (2008);
H1 Collab., H1prelim-08-042;
H1 Collab., F. D. Aaron *et al.*, *Eur. Phys. J.*, C**71**, 1579 (2011).

[7] ZEUS Collab., S. Chekanov *et al.*, *Phys. Lett.*, B**682**, 8 (2009).

[8] H.-L. Lai *et al.*, *Phys. Rev.*, D**82**, 074024 (2010).

[9] R. D. Ball *et al.*, *Nucl. Phys.*, B**838**, 136 (2010);
S. Forte *et al.*, *Nucl. Phys.*, B**834**, 116 (2010).

[10] A. D. Martin *et al.*, *Eur. Phys. J.*, C**63**, 189 (2009).

[11] M. Glück *et al.*, *Eur. Phys. J.*, C**53**, 355 (2008);
P. Jimenez-Delgado and E. Reya, *Phys. Rev.*, D**79**, 074023 (2009).

[12] S. Alekhin *et al.*, *Phys. Rev.*, D**81**, 014032 (2010).

PoS(EPS-HEP2011)288