MEASUREMENTS OF PROTON STRUCTURE FUNCTIONS, α_s AND PARTON DISTRUBUTION FUNCTIONS AT HERA

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The measurement and QCD analysis of neutral and charged current cross sections at HERA are presented. For the kinematic range of four-momentum transfer Q^2 between ≈ 1 GeV^2 and 30000 GeV^2 and Bjorken x between 0.0013 and 0.65 the data are compared to NLO QCD predictions. In dedicated NLO QCD analyses the extraction of the parton distribution functions of the proton is performed. Results for the measurement of the strong coupling constant α_s are presented.

1 Introduction

Deep inelastic scattering (DIS) experiments have played a major role in the understanding of the partonic structure of matter. In the past decade proton structure has been studied in *ep* collisions by the two HERA experiments H1 and ZEUS.
Both experiments have been delivering increasingly precise structure function measurements leading to improved knowledge of the parton distribution functions (PDFs) inside the proton. Measurements of the proton structure are a good testing ground for QCD predictions. The precise knowledge of the PDFs is also important for reliable predictions of cross sections of the standard model and for new physics searches at future hadron colliders such as the LHC.

2 The Neutral and Charged Current Cross Sections

In deep inelastic *ep* scattering the structure of the proton can be probed by γ and Z^0 or by $W^\pm$ exchange. The first are referred to as neutral current (NC) processes ($ep \rightarrow eX$) whereas the latter are charged current (CC) interactions ($ep \rightarrow \overset{(-)}{\nu} X$).

The NC cross section can be expressed in terms of three structure functions F_2, xF_3 and F_L:

$$\frac{d^2\sigma_{NC}^{e^\pm p}}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4} \cdot \Phi_{NC}^{e^\pm p}, \quad with \quad \Phi_{NC}^{e^\pm p} = Y_+ F_2 \mp Y_- xF_3 - y^2 F_L. \tag{1}$$

$Y_\pm = 1 \pm (1-y)^2$ contains the helicity dependences of the electro-weak interactions where $y = Q^2/xs$. The negative four-momentum transfer squared Q^2, carried by the exchanged gauge boson, represents its resolution power with respect to the proton. The fraction of the proton momentum carried by the struck parton is given by x-Bjorken and s is the center-of-mass energy squared.
The structure functions are sensitive to the parton distributions. In the quark parton model, F_2 is related to the sum of quark and anti-quark momentum distributions, $xq(x,Q^2)$ and $x\bar{q}(x,Q^2)$, whereas xF_3 is related to their difference. The longitudinal structure function F_L is vanishing in this model. In the bulk of the kinematic region at HERA the dominating contribution to the cross section is due to F_2 related to the pure photon exchange. Only at large values of Q^2 the contribution from Z^0 exchange becomes important. The longitudinal structure function F_L is significant at large y only.

The inclusive CC cross section for ep interactions can be expressed in terms of three structure functions W_2, xW_3 and W_L :

$$\frac{d^2\sigma_{CC}^{e^\pm}}{dxdQ^2} = \frac{G_F^2}{2\pi x}\left(\frac{M_W^2}{Q^2+M_W^2}\right)^2 \phi_{CC}^{e^\pm}, \quad with \quad \phi_{CC}^{e^\pm} = \frac{1}{2}\left(Y_+ W_2^\pm \mp Y_- xW_3^\pm - y^2 W_L^\pm\right), \tag{2}$$

where G_F is the Fermi coupling constant. In leading order (LO) these structure functions are, depending on the charge of the beam lepton, sensitive to certain quark compositions.

The results for the measurements of NC and CC single differential cross sections $\frac{d\sigma}{dQ^2}$ by H1 and ZEUS are summarised in fig. 1.

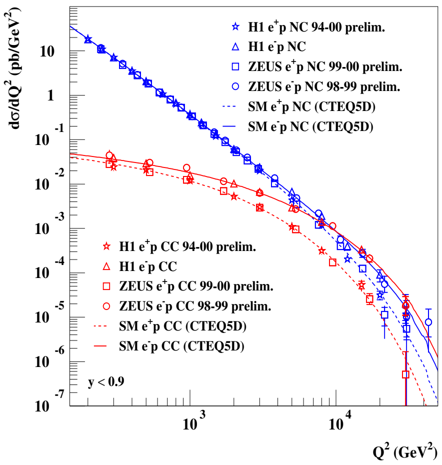

Figure 1: *NC and CC cross sections $d\sigma/dQ^2$ measured by H1 and ZEUS in e^+p and e^-p interactions are compared with the SM predictions based on PDFs from CTEQ5D* [1].

In NC $\frac{d\sigma}{dQ^2} \sim \frac{1}{Q^4}$ due to the dominance of photon exchange. At $Q^2 \approx 100$ GeV^2 the cross section is about a factor of 1000 larger than the CC cross section. However, at $Q^2 \gtrsim M_z^2, M_W^2$ both cross sections are of the same order of magnitude, illustrating electro-weak unification in DIS. In e^-p interactions both cross sections are larger than in the case of e^+p scattering. In NC the positive (negative) γZ interference term in the e^-p (e^+p) interactions is responsible for this effect. It can be employed to measure xF_3 [2]. The difference in the CC cross section is caused

by the different type of valence quark taking part in the interaction.
The measurements of NC and CC $e^{\pm}p$ scattering cross sections provide complementary sensitivity to different quark distributions and the gluon distribution $xg(x, Q^2)$. The accuracy and kinematic coverage of the cross section data enables dedicated QCD analyses.

3 NLO QCD Analysis of HERA data

In most of the kinematic range the NC cross section is dominated by the structure function F_2. Using Eq. 1 F_2 can be extracted from the measurement of the double differential NC cross section. Fig. 2 (left) shows the H1 and ZEUS F_2 data together with data from fixed target experiments. The data are well described by the DGLAP evolution over four orders of magnitude in x and Q^2. The steep rise of F_2 at small x is driven by the gluon.
In the NLO QCD fit the PDFs are parameterised at a fixed starting scale $Q^2 = Q_0^2$ and determined by the fitting procedure. The resulting PDFs at the starting scale obtained by H1 are shown in fig. 2 (right). The present accuracy of the NC and CC HERA data allows to perform a fit to HERA data alone.

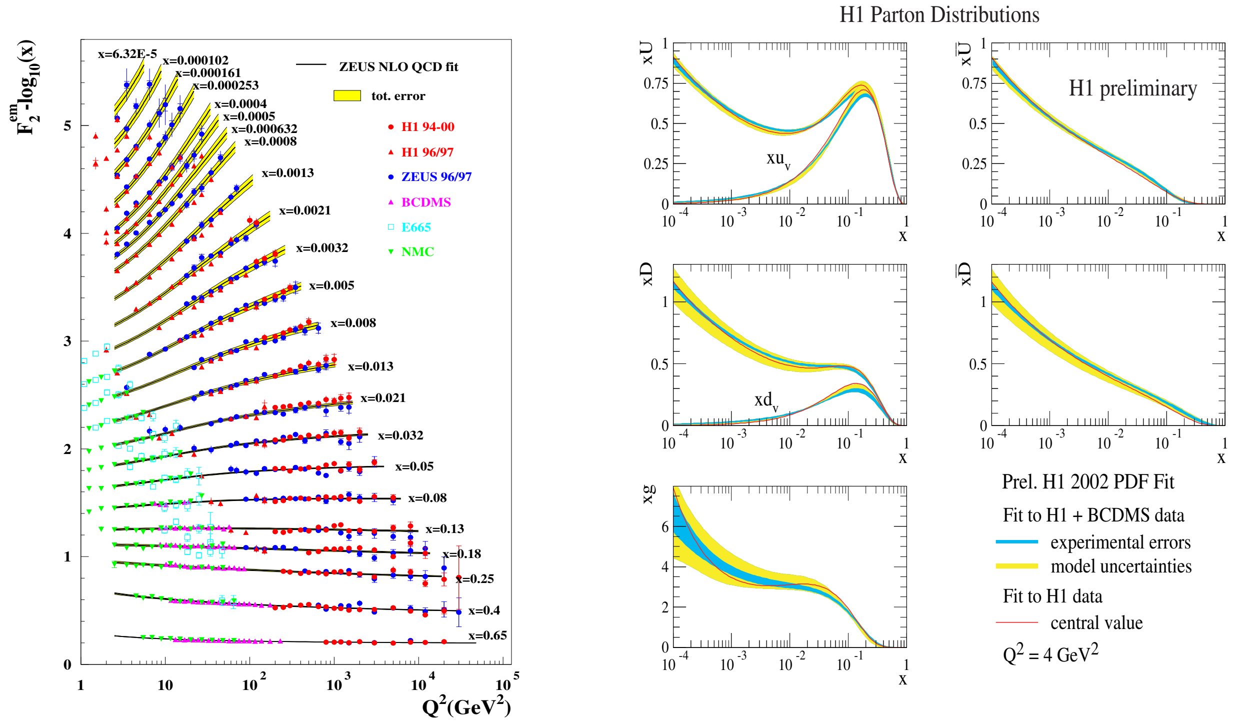

Figure 2: *Left: F_2^{em}, i.e. F_2 from pure γ exchange, from HERA and fixed target experiments compared with ZEUS NLO QCD fit. Right: PDFs $xU = x(u+c)$, $x\bar{U} = x(\bar{u}+\bar{c})$, $xD = x(d+s)$, $x\bar{D} = x(\bar{d}+\bar{s})$ and xg as determined from the H1 fits at the starting scale $Q_0^2 = 4\ GeV^2$.*

The evolution of the PDFs in Q^2 at fixed x is predicted by the NLO DGLAP equations [3]. The PDFs at $Q^2 = 1000$ GeV^2 as determined from the NLO QCD fits are shown for H1 [4] and ZEUS [5] in fig. 3 (left). At $Q^2 = 10$ GeV^2 the ZEUS results are also compared to global fits (right). The results of H1 and ZEUS are consistent with the results of the global analyses MRST2001 [6] and CTEQ6M [7].

In dedicated QCD fits $\alpha_s(M_z)$ has been measured by both experiments. The results obtained by H1 and ZEUS are $\alpha_s(M_z) = 0.1150 \pm 0.0017(exp)^{+0.0009}_{-0.0007}(model)$ [8] and $\alpha_s(M_Z) = 0.1166 \pm 0.0008(uncorr.) \pm 0.0032(corr.) \pm 0.0036(norm.) \pm 0.0018(model)$ [5] respectively. Both results

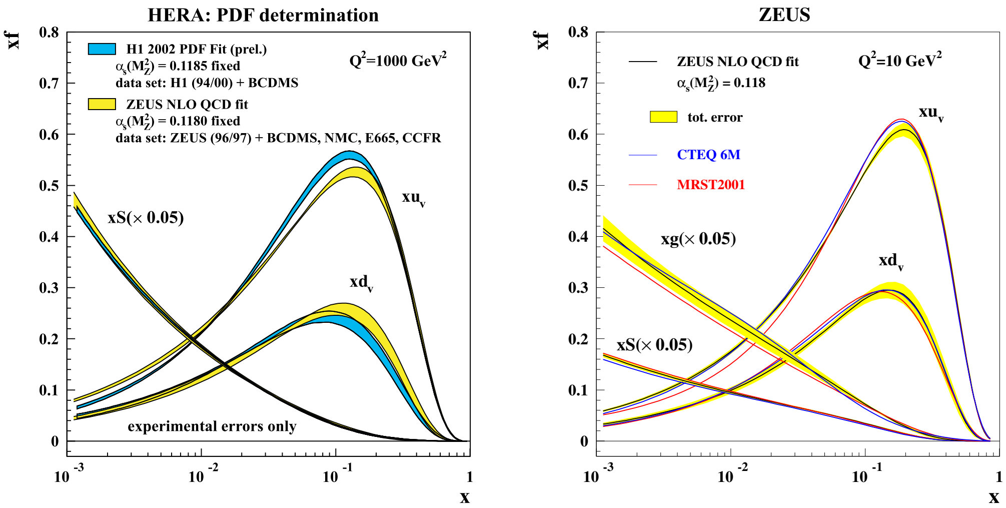

Figure 3: *Left: Comparison of the PDFs extracted by H1*[4] *and ZEUS*[5]*. Right: Comparison of the PDFs from the ZEUS fit to global fits by MRST2001*[6] *and CTEQ6M*[7]

are consistent and competitive with the world average. However, theoretical uncertainties due to higher order effects are estimated to be ± 0.005. For a reduction of these errors NNLO calculations are indispensable.

4 Conclusion

H1 and ZEUS have performed NLO QCD analyses of their data. The data are well described by the predictions. Extractions of the parton densities and a measurement of the strong coupling constant α_s were performed.
In order to improve the theoretical uncertainties of the measurements NNLO calculations are needed.
With the HERA luminosity upgrade the amount of data will increase substantially and polarisation of the lepton beams will be achieved. More precise and new measurements will thus be possible in the future and help to improve the understanding of the structure of the proton.

References

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