

# Proton Structure Measurements and the HERAPDF fit

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**Abstract.** New and previously published measurements on the deep inelastic  $ep$  scattering cross section by the H1 and ZEUS collaborations are presented. The uncertainties can be significantly reduced by a model independent combination procedure, which treats the systematic error correlations in a coherent way. The combined H1 and ZEUS measurements of the inclusive neutral and charged current cross sections are used to perform a common NLO QCD fit, called HERAPDF 0.1. The resulting set of parton density functions (PDFs) have a much improved experimental uncertainty compared to previous extractions using the uncombined H1 or ZEUS data.

## 1. Introduction

The HERA collider facility in Hamburg, Germany, was a unique machine for lepton-proton scattering at highest energies. For the two experiments H1 and ZEUS protons with an energy of up to 920 GeV and electrons or positrons with an energy of 27.6 GeV were collided. This is equivalent to a maximal centre of mass energy of  $\sqrt{s} = 320$  GeV. At the end of June 2007 the data taking finished.

In Deep Inelastic Scattering (DIS) of leptons off nucleons the substructure of the nucleons was discovered. DIS continues to be the tool for exploring the substructure of the nucleons with high precision, i.e. measuring their quark and gluon content in the form of so called parton distribution functions (PDFs). The evolution of PDFs is a sensitive test of our understanding of QCD dynamics, which is expressed in the form of PDF evolution equations. Furthermore a precise knowledge of PDFs is vital for measurements at hadron colliders, such as the LHC.

The kinematics of the scattering are described in terms of the Lorentz invariant quantities: the Bjorken scaling variable  $x$ , the inelasticity  $y$ , and the virtuality  $Q^2$ . The HERA experiments have made measurements of the proton structure for  $Q^2$  values of up to 50000 GeV<sup>2</sup> and  $x$  values down to  $10^{-6}$ .

One of the most fundamental measurements to be performed is that of the neutral current (NC) inclusive cross section for the reaction  $ep \rightarrow e'X$ , which can be expressed in the form

$$\frac{d^2\sigma_{NC}^{e\mp p}}{dx dQ^2} = \frac{2\pi\alpha^2 Y_+}{xQ^4} \left( F_2 - \frac{y^2}{Y_+} F_L \pm \frac{Y_-}{Y_+} xF_3 \right), \quad (1)$$

with  $Y_{\pm} = 1 \pm (1-y)^2$  and the structure functions  $F_2$ ,  $F_L$  and  $xF_3$ . At leading order, the structure functions relate to the PDFs as

$$F_2 = x \sum e_q^2 (q(x) + \bar{q}(x)) \quad \text{and} \quad xF_3 \sim x \sum 2e_q a_q (q(x) - \bar{q}(x)). \quad (2)$$

Additional information can be obtained from charged current (CC) cross section for the reaction  $ep \rightarrow \nu_e X$ :

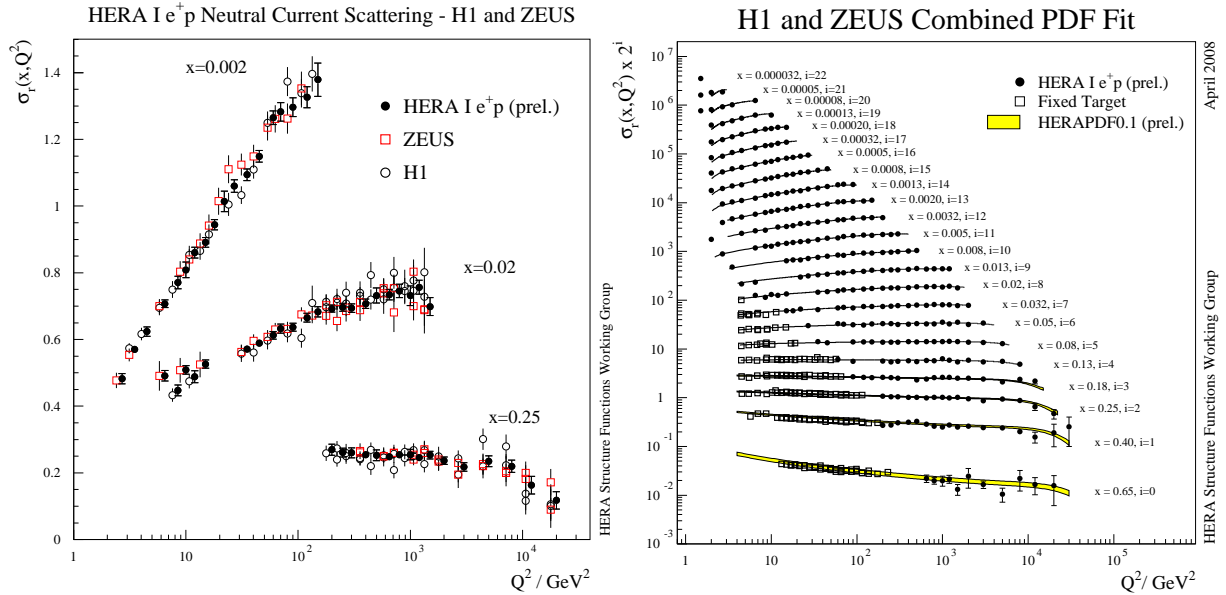
$$\sigma_{e^+p}^{CC} \sim x(\bar{u} + \bar{c}) + x(1-y)^2(d+s) \quad \text{and} \quad \sigma_{e^-p}^{CC} \sim x(u+c) + x(1-y)^2(\bar{d} + \bar{s}). \quad (3)$$

The gluon density  $xg(x, Q^2)$ , which does not enter the inclusive cross section calculations at leading order, is constrained by the  $F_2$  scaling violations, jet cross sections and the measurement of  $F_L$ .

## 2. Combination of HERA cross section data and QCD Fit

Both ZEUS and H1 have performed inclusive cross section measurements with comparable precision and covering a similar kinematic range. Therefore the results of the two experiments may be combined to provide a single set containing all inclusive HERA cross sections and to be used for further QCD analyzes. The averaging procedure, described in detail in [1], is without theoretical assumptions. Only small theoretical corrections are needed for swimming points to a common  $x, Q^2$  grid and for adjusting earlier measurements performed at a proton beam energy of 820 GeV.

The precision cross section data from the HERA experiments are typically reported with three different components of the measurement uncertainty: statistical and systematic uncertainties, where the latter consist of parts uncorrelated or correlated between different kinematic domains. The correlated uncertainties, which are due to effects like the luminosity measurement or shifts in the electron energy calibration need to be treated correctly in the averaging procedure. As a result, not only the uncorrelated and statistical part of the uncertainties are reduced. Because the measurements by the two experiments have different sensitivities to the correlated uncertainties, these can be constrained further and thus reduced.

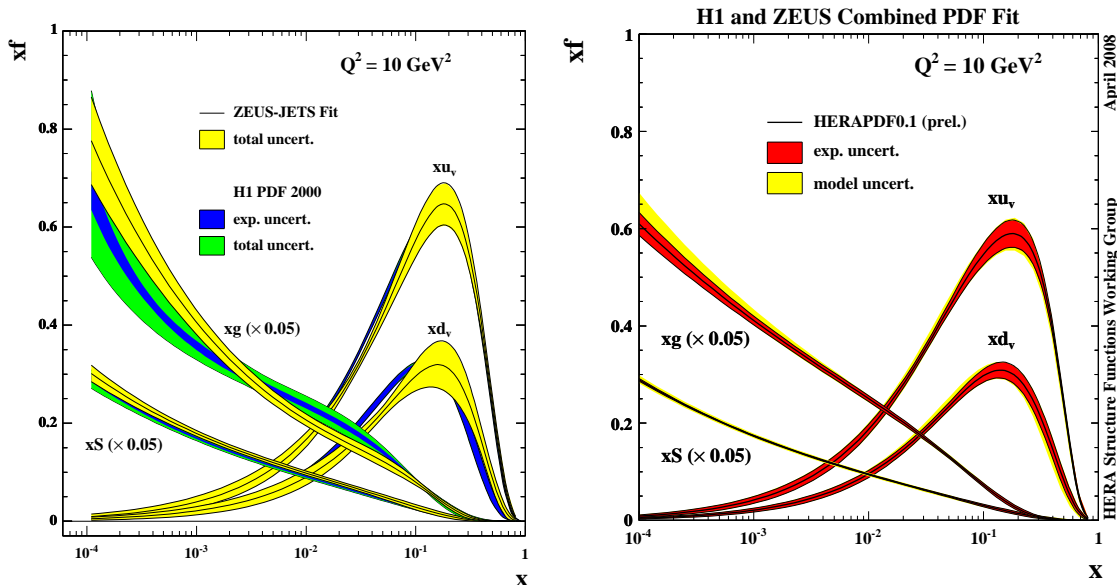


**Figure 1.** Left: Published H1 and ZEUS data and their combination for a set of fixed  $x$  values as a function of  $Q^2$ . Right: The full combined  $e^+p$  data set shown together with the QCD analysis result HERAPDF 0.1 [2]. The HERA data is complemented by fixed target data at lower values of  $Q^2$  and higher  $x$ .

The combination procedure is performed separately for the sets of  $e^+p$  and  $e^-p$  scattering and using both NC and CC data [2]. The original data and the combination are shown for a

few exemplary values of  $x$  of the  $e^+p$  NC data set in figure 1, left. A remarkable reduction of the uncertainties is apparent. Figure 1, right, shows the full  $e^+p$  data set, which is seen to cover four orders of magnitude in  $x$  and  $Q^2$  with very high precision. The compatibility of the two experiments is observed to be very good with a total  $\chi^2 = 510$  for 599 averaged points.

The combined data is in the following used to perform a QCD analysis at NLO using HERA data only. For the analysis, which is called HERAPDF 0.1, the DGLAP evolution equations are used to evolve the PDFs, which are parametrized at the starting scale of  $Q_0^2 = 4 \text{ GeV}^2$ . A full evaluation of experimental and theory model uncertainties is performed. The resulting PDFs are shown in figure 2 at a scale of  $Q^2 = 10 \text{ GeV}^2$  and compared to earlier separate analyzes of the H1 and ZEUS collaborations [3, 4]. A reduction of the uncertainties is seen, which is due to the improved combined data used as input. This is most notable on the gluon density, which dominates all other partons at low  $x$  whose uncertainty is typically also larger than the quark PDFs, which are directly accessed in DIS.



**Figure 2.** Published H1 and ZEUS QCD fits (left) [3, 4] compared to the new analysis using the combined HERA data (right) [2]. For all fits, the valence distributions,  $xu_v$  and  $xd_v$ , the total sea quark distribution  $xS$  and the gluon distribution  $xg$  are shown at a scale of  $Q^2 = 10 \text{ GeV}^2$ .

### 3. New Inclusive Measurements from HERA

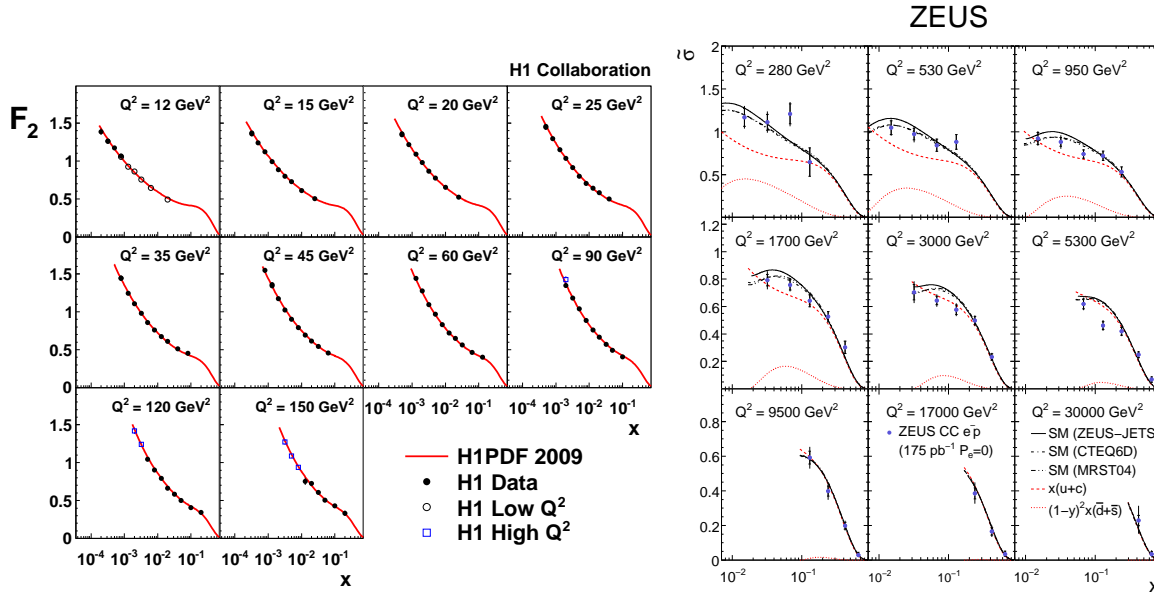
While data taking at HERA has stopped, more precise measurements have become available recently or are expected for the near future.

In general, analyzes at low and intermediate  $Q^2 \leq 150 \text{ GeV}^2$  can be performed using relatively small data sets. Therefore the new high precision analyzes of H1 [1, 5] were performed using data from the HERA-I running period, which ended in the year 2000. The total measurement uncertainties were reduced to as low as 1.5% per point, which is about a factor of two better than previous data covering this kinematic domain [6, 7]. As an example, the new results on the structure function  $F_2$  from [5] are shown in figure 3, left.

The analyzes at higher  $Q^2 \geq 150 \text{ GeV}^2$  are in general more constrained by the available statistics. Therefore improvements are expected from the analysis of the HERA-II data, where nearly  $400 \text{ pb}^{-1}$  were collected per experiment after the HERA luminosity upgrade starting from

the year 2003. The data sample is about balanced between  $e^+p$  and  $e^-p$ . A new feature of the HERA-II data is also beam polarization, where typical average values of 30 – 40% are reached.

ZEUS has recently published new results on the inclusive NC and CC  $e^-p$  cross section [8, 9]. Figure 3, right, shows the CC cross sections and highlights their dependence on different quark flavours in the proton. These are the first double differential inclusive measurements using the polarized electron beam. Also the employed  $e^-p$  HERA-II data samples have an integrated luminosity ten times larger than the previously used HERA-I sample.



**Figure 3.** New results on the inclusive NC cross section at lower  $Q^2$  by H1 (left) [5] and on the inclusive CC cross section at lower  $Q^2$  by ZEUS (right) [9]. The data are compared to different QCD fits.

#### 4. Conclusions

The HERA experiments measure the proton structure in a wide range of  $x$  and  $Q^2$ , thus providing stringent tests of QCD and valuable input for the LHC. A new procedure combines the already published data to obtain one HERA data set with improved uncertainties. A combined QCD fit, HERAPDF 0.1, is performed using this combined data set. It is able to describe the data and provides PDFs with much reduced uncertainties compared to previous fits performed separately by the H1 and ZEUS collaborations. In addition new measurements are available with significantly increased experimental precision.

#### 5. References

- [1] F.D. Aaron *et al.* [H1 Collaboration], arXiv:0904.0929 [hep-ex].
- [2] H1 and ZEUS Collaborations, H1prelim-09-045, ZEUS-prel-09-011.
- [3] C. Adloff *et al.* [H1 Collaboration], Eur. Phys. J. C **30** (2003) 1 [arXiv:hep-ex/0304003].
- [4] S. Chekanov *et al.* [ZEUS Collaboration], Eur. Phys. J. C **42** (2005) 1 [arXiv:hep-ph/0503274].
- [5] F.D. Aaron *et al.* [H1 Collaboration], arXiv:0904.3513 [hep-ex].
- [6] C. Adloff *et al.* [H1 Collaboration], Eur. Phys. J. C **21** (2001) 33 [arXiv:hep-ex/0012053].
- [7] S. Chekanov *et al.* [ZEUS Collaboration], Eur. Phys. J. C **21** (2001) 443 [arXiv:hep-ex/0105090].
- [8] S. Chekanov *et al.* [ZEUS Collaboration], arXiv:0901.2385 [hep-ex].
- [9] S. Chekanov *et al.* [ZEUS Collaboration], arXiv:0812.4620 [hep-ex].