H1 QCD Fit and Extraction of PDFs

Burkard C. Reisert
Fermi National Accelerator Laboratory
Batavia, Illinois 60510, USA
E-mail: reisert@fnal.gov

A next-to-leading order (NLO) QCD analysis of the H1 inclusive neutral and charged current cross section data is performed, using a novel decomposition of cross sections into up and down type quark distributions. The fit parameter space is narrowed using theoretical constraints adapted to the new ansatz.

1 Introduction

The latest H1 inclusive cross section measurements [1, 2], together with the low Q^2 precision data [3] and the high Q^2 $e^\pm p$ data [4, 5] previously published by the H1 Collaboration, cover a huge range in four-momentum transfer squared Q^2 and Bjorken x. The measurements of neutral (NC) and charged current (CC) $e^\pm p$ scattering cross sections provide complementary sensitivity to different quark distributions and the gluon distribution. The improved accuracy now available allows the determination of a set of parton distributions and their uncertainty from H1 data alone.

2 Cross Sections, Structure Functions and Parton Distributions

After correction for QED radiative effects the measured CC cross section for unpolarized ep scattering may be expressed as

$$\frac{\mathrm{d}^2\sigma^\pm_{CC}}{\mathrm{d}x\mathrm{d}Q^2} = \frac{G_F^2}{2\pi x}\left[\frac{M_W^2}{Q^2+M_W^2}\right]^2 (Y_+ W_2^\pm \mp Y_- x W_3^\pm - y^2 W_L^\pm),$$

G_F being the Fermi coupling constant and M_W the mass of the W boson. The helicity dependences of the electroweak interactions are contained in $Y_\pm = 1 \pm (1-y)^2$, y being the inelasticity. In the quark parton model (QPM), where $W_L^\pm = 0$, $W_2^\pm$ and $xW_3^\pm$ may be interpreted as lepton beam-charge dependent sums and differences of up type (xU), down type (xD) and of anti-quark type ($x\overline{U}, x\overline{D}$) distributions and are given by

$$W_2^+ = x(\overline{U}+D),\ W_3^+ = x(D-\overline{U}),\ W_2^- = x(U+\overline{D}),\ W_3^- = x(U-\overline{D}).$$

The unpolarized inclusive NC section is given by

$$\frac{\mathrm{d}^2\sigma^{\pm}_{NC}}{\mathrm{d}x\mathrm{d}Q^2} = \frac{2\pi\alpha^2}{xQ^4}(Y_+\tilde{F}_2 \mp Y_- x\tilde{F}_3 - y^2\tilde{F}_L),$$

where $\alpha \equiv \alpha(Q^2=0)$ is the fine structure constant. $\tilde{F}_2$, $x\tilde{F}_3$ and $\tilde{F}_L$ denote the generalised NC proton structure functions. The dominant contribution to the cross section is $\tilde{F}_2$ and to $\tilde{F}_2$ is the electromagnetic structure function F_2. In the QPM, F_2 can be written as

$$F_2 = \frac{4}{9}(xU + x\overline{U}) + \frac{1}{9}(xD + x\overline{D}).$$

In the high Q^2 neutral current data, complementary sensitivity is obtained from $x\tilde{F}_3$ which is dominated by the photon Z-boson interference term $xF_3^{\gamma Z} = x[2(U-\overline{U})] + (D-\overline{D})]/3$, but still more precise measurements are required to exploit xF_3 for a dedicated determination of the valence quark distributions.

The $e^{\pm}p$ NC and CC cross sections can thus be written completely in terms of (anti-) quark type distributions, which is utilised to define a novel quark distribution decomposition of the NC and CC cross sections in which the valence quark distributions u_v and d_v are obtained from the differences $U-\overline{U}$ and $D-\overline{D}$, respectively.

In the fit to the H1 and BCDMS data the isoscalar nucleon structure function F_2^N is determined by the singlet combination of parton distributions and a small contribution from the difference of strange and charm quark distributions, $F_2^N = \frac{5}{18}x(U+\overline{U}+D+\overline{D}) + \frac{1}{6}x(c+\bar{c}-s-\bar{s})$.

3 Parameterisation of PDFs

The initial parton distributions, $xP = xg$, xU, $x\overline{U}$, xD, $x\overline{D}$, are parameterised at $Q^2 = Q_0^2$ in the following general form:

$$xP(x) = A_P x^{B_P}(1-x)^{C_P}[1 + D_P x + E_P x^2 + F_P x^3 + G_P x^4].$$

A number of relations between parameters can be introduced naturally in this ansatz. At low x the valence quark distributions are expected to vanish and the sea quark and anti-quark distributions can be assumed to be equal. Thus the low x parameters A_q and B_q are constrained to be the same for xU, $x\overline{U}$

and for xD, $x\overline{D}$. Further constraints are the conventional momentum sum rule and the valence quark counting rules. Disentangling the individual quark flavour contributions to the sea is possible only with additional experimental information and/or assumptions. The charm and strange quark distributions may be constrained using experimental data, as provided by H1 and ZEUS on the charm contribution to F_2 [6, 7] and from NuTeV on the strangeness content of the nucleon [8]. Assuming that the strange and charm sea quark distributions xs and xc can be expressed as fractions f_s and f_c of $x\overline{D}$ and $x\overline{U}$ at the starting scale, further constraints are used in the fit: $A_{\overline{U}} = A_{\overline{D}} \cdot (1-f_s)/(1-f_c)$ and $B_U = B_D$, which ensure that $\bar{d}/\bar{u} \to 1$ as $x \to 0$.

4 Fit Procedure

The analysis is performed in the $\overline{\mathrm{MS}}$ renormalisation scheme using the DGLAP evolution equations at NLO. The structure function formulae given here are thus replaced by integral convolutions of coefficient functions and PDFs. An approach is used whereby all quarks are taken to be massless, including the charm and bottom quarks. The bottom distribution, xb, is evolved assuming that $xb(x, Q^2) = 0$ for $Q^2 < m_b^2$, where m_b is the bottom quark mass.

The analysis uses an x space program developed within the H1 collaboration [9]. In the fit procedure a χ^2 function is minimised which is defined in [3]. The minimisation takes into account correlations caused by systematic uncertainties allowing the error parameters, including the relative normalisation of the various data sets, to be determined by the fit. Correlations may occur between data points of one data set as well as across data sets, since they may arise from the same source.

5 Results

Parton distributions obtained by the fit to exclusively H1 data are shown in figure 1 and compared to the fit to H1 and BCDMS data. Excellent agreement of the PDFs between the two fits is observed. The high Q^2 data of H1 allow distinction between up and down type distributions, yielding results compatible with those from BCDMS proton and deuteron data. The PDFs are further compared to recent results from the MRST [10] and CTEQ [11] groups. Given the many differences in terms of the data sets used, the assumptions made and the treatment of heavy flavour the agreement of the H1 PDF 2000 fit with the MRST and CTEQ analyses is remarkable. For further details see [2].

The error bands reflect the size of the measurement uncertainties. However they also depend significantly on the fit assumptions, as demonstrated in figure 2. If, for example, the constraints forcing $\bar{d} - \bar{u} \to 0$ when $x \to 0$ are relaxed, the size of the light quark asymmetry at low x is largely unknown, figure 2b. Collisions of electrons with deuterons at HERA could be used to determine $\bar{d} - \bar{u}$ at low x with a few per cent accuracy [12], see figure 2c.

Acknowledgments
I would like to express my gratitude to the Fermi National Accelerator Laboratory (FNAL), the Deutsches Elektronen Synchrotron (DESY) and the Max-Planck-Institut für Physik (MPI), as well as the local organizers who's combined financial and administrative efforts made my contribution to the DIS 2003 Conference possible.

References

[1] A. Dubak, these proceedings.
[2] H1 Collaboration, submitted to Eur. Phys. J., hep-ex/0304003.
[3] H1 Collaboration, Eur. Phys. J. C **21**, 33 (2001), hep-ex/0012053.
[4] H1 Collaboration, Eur. Phys. J. C **13**, 609 (2000), hep-ex/9908059.
[5] H1 Collaboration, Eur. Phys. J. C **19**, 269 (2001), hep-ex/0012052.
[6] H1 Collaboration, Phys. Lett. B **528**, 199 (2002), hep-ex/0108039.
[7] ZEUS Collaboration, Eur. Phys. J. C **12**, 35 (2000), hep-ex/9908012.
[8] NuTeV Collaboration, Phys. Rev. D **64**, (2001), hep-ex/0102049.
[9] C. Pascaud and F. Zomer, hep-ph/0104013.
[10] A. D. Martin *et al.*, Eur. Phys. J. C **23**, 73 (2002) hep-ph/0110215.
[11] J. Pumplin *et al.*, JHEP. **0207**, 012 (2002) hep-ph/0201195.
[12] T. Alexopoulos *et al.*, Electron-Deuteron Scattering with HERA, a Letter of Intent for an Experimental Program with the H1 Detector, H1-04/03-609, DESY PRC, April 2003.

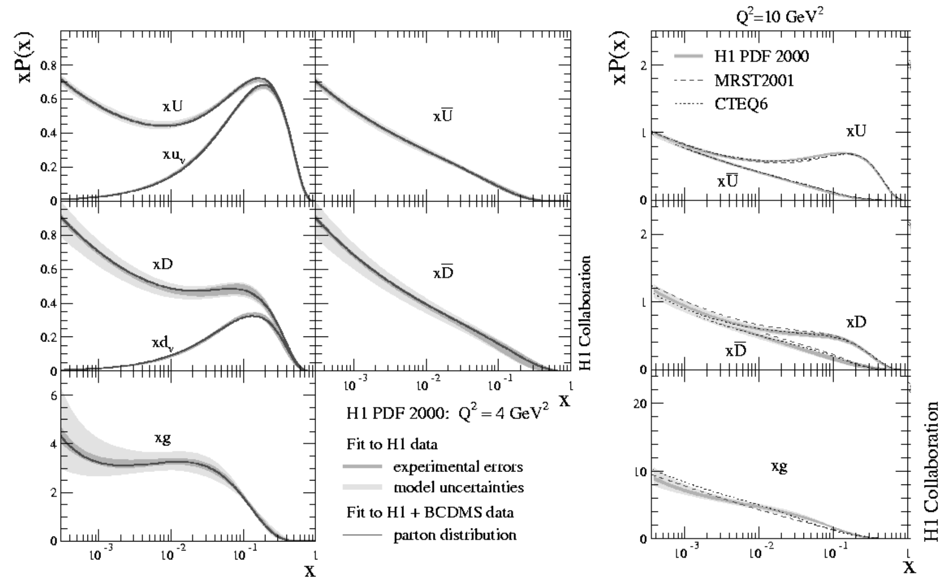

Figure 1: Parton distributions xU, $x\overline{U}$, xD, $x\overline{D}$ and xg as determined from the H1 PDF 2000 fit to H1 data only. The inner error band represents the experimental uncertainty, the outer error band shows the total uncertainty obtained by adding in quadrature the experimental and model uncertainties. For comparison, the parton distributions from the fit to H1 ep and BCDMS μp and μd data are shown as solid line, as are the recent results from the MRST and CTEQ groups, shown in the right column as dashed and dotted lines.

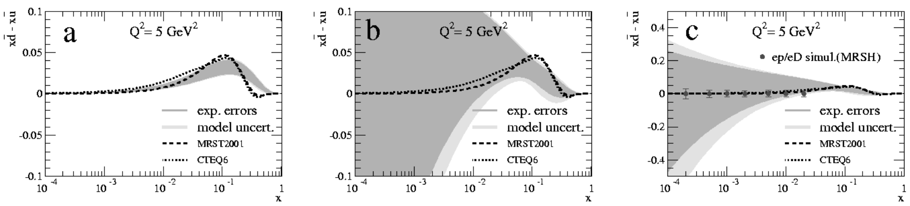

Figure 2: The light sea quark asymmetry as obtained in the fit to H1 ep and BCDMS μp and μd data. The uncertainty at low x depends significantly on the fit assumptions (a, b). DIS ed collisions at HERA could be used to constrain the $\bar{d} - \bar{u}$ asymmetry at low x from data (c).