Fit of EW Parameters using Polarised DIS H1 Data

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on behalf of the H1 Collaboration

Outline

- Introduction
- New constraints from HERA-2 Data with $P_e$
- Results
- Summary
Introduction

ep collider, HERA, used to be the largest electron microscope
Both NC and CC inclusive cross sections were precisely measured

Combined HERA-1 data primary input for all modern PDF sets:
- CTEQ
- MRST
- NNPDFs
- HERAPDF1.0
- ....

- Increased lumi (x10 e-, x2 e+)
- Long. polarized e beam
- Full combination HERA-1 & -2
Neutral and Charged Current DIS Interactions

Event kinematics:
- $Q^2 = -q^2$: Boson virtuality
- $x$: momentum fraction of struck parton
- $y = Q^2 / sx$: inelasticity

NC interactions sensitive to light quark couplings to Z
\[
\frac{d^2\sigma_{\text{NC}}^\pm}{dx dQ^2} \sim Y_+ \tilde{F}_2 + Y_- x \tilde{F}_3 \quad \text{with} \quad Y_\pm = 1 \pm (1 - y)^2
\]

\(v_e \sim 0 \Rightarrow \text{some of the terms are negligible}\)

\[
\tilde{F}_2 = F_2 - v_e \kappa_Z F_2^{\gamma Z} + (v_e^2 + a_e^2) \kappa_Z^2 F_2^Z
\]

\[
x \tilde{F}_3 = -a_e \kappa_Z x F_3^{\gamma Z} + 2v_e a_e \kappa_Z^2 x F_3^Z
\]

\[
F_2^Z = x \sum_q \left( v_q^2 + a_q^2 \right) \{ q + \bar{q} \}
\]

\[
x F_3^{\gamma Z} = 2x \sum_q e_q a_q \{ q - \bar{q} \}
\]

\(\Rightarrow a_q \text{ mainly constrained by } x F_3^{\gamma Z}\)

\(\Rightarrow v_q \text{ constrained by } F_2^Z\)

\[
\kappa_Z^{-1} = \frac{2\sqrt{2\pi}\alpha}{G_F M_Z^2} \frac{Q^2 + M_Z^2}{Q^2}
\]

In on-mass-shell scheme:

\[
G_F = \frac{\pi\alpha}{\sqrt{2} M_W^2} \left( 1 - \frac{M_W^2}{M_Z^2} \right)^{-1} (1 + \Delta r)
\]

\[
\Delta r = \Delta r(\alpha, M_W, M_Z, m_t, m_h, \ldots)
\]

First determination performed by H1 [PLB 632 (2006) 35]
Polarized e beam (P_e) \rightarrow Additional terms

\[ \tilde{F}_2 = F_2 - (v_e - P_e a_e) \kappa_Z F_2^{\gamma Z} + (v_e^2 + a_e^2 - 2P_e v_e a_e) \kappa_Z^2 F_2^Z \]

\[ x\tilde{F}_3 = -(a_e - P_e v_e) \kappa_Z x F_3^{\gamma Z} + [2v_e a_e - P_e (v_e^2 + a_e^2)] \kappa_Z^2 x F_3^Z \]

\[ \begin{bmatrix} F_2^{\gamma Z} & F_2^Z \end{bmatrix} = x \sum_q \begin{bmatrix} 2e_q v_q, v_q^2 + a_q^2 \end{bmatrix} \{q + \bar{q}\} \]

\[ \begin{bmatrix} x F_3^{\gamma Z} & x F_3^Z \end{bmatrix} = 2x \sum_q \begin{bmatrix} e_q a_q, v_q a_q \end{bmatrix} \{q - \bar{q}\} \]

\rightarrow additional constraint on v_q by F_2^{\gamma Z}
## Used Data Sets

<table>
<thead>
<tr>
<th>Data set</th>
<th>$Q^2$-range [GeV$^2$]</th>
<th>$\sqrt{s}$ [GeV]</th>
<th>No. of data points</th>
<th>Polarization [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e^+$ Combined low-$Q^2$</td>
<td>(0.5) 12 – 150</td>
<td>319</td>
<td>81 (262)</td>
<td>–</td>
</tr>
<tr>
<td>$e^+$ Combined low-$E_p$</td>
<td>(1.5) 12 – 90</td>
<td>301</td>
<td>118 (136)</td>
<td>–</td>
</tr>
<tr>
<td>$e^+$ NC 94–97</td>
<td>150 – 30 000</td>
<td>301</td>
<td>130</td>
<td>–</td>
</tr>
<tr>
<td>$e^+$ CC 94–97</td>
<td>300 – 15 000</td>
<td>301</td>
<td>25</td>
<td>–</td>
</tr>
<tr>
<td>$e^-$ NC 98–99</td>
<td>150 – 30 000</td>
<td>319</td>
<td>126</td>
<td>–</td>
</tr>
<tr>
<td>$e^-$ CC 98–99</td>
<td>300 – 15 000</td>
<td>319</td>
<td>28</td>
<td>–</td>
</tr>
<tr>
<td>$e^-$ NC 98–99 high-$y$</td>
<td>100 – 800</td>
<td>319</td>
<td>13</td>
<td>–</td>
</tr>
<tr>
<td>$e^+$ NC 99–00</td>
<td>150 – 30 000</td>
<td>319</td>
<td>147</td>
<td>–</td>
</tr>
<tr>
<td>$e^+$ CC 99–00</td>
<td>300 – 15 000</td>
<td>319</td>
<td>28</td>
<td>–</td>
</tr>
<tr>
<td>$e^+$ NC L HERA-II</td>
<td>120 – 30 000</td>
<td>319</td>
<td>137</td>
<td>$-37.0 \pm 1.0$</td>
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<td>$e^-$ NC L HERA-II</td>
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<td>138</td>
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For the first 2 data sets, only data above 12GeV$^2$ are included.
Fit Strategy

- 5 sets of PDFs parameterised at starting scale $Q_0^2 = 1.9$ GeV$^2$
  \[
  xg(x) = A_g x^{B_g} (1-x)^{C_g} - A'_g x^{B'_g} (1-x)^{C'_g},
  \]
  \[
  xu_{uv}(x) = A_{uv} x^{B_{uv}} (1-x)^{C_{uv}} (1 + E_{uv} x^2),
  \]
  \[
  xd_{dv}(x) = A_{dv} x^{B_{dv}} (1-x)^{C_{dv}},
  \]
  \[
  x\bar{U}(x) = A_{\bar{U}} x^{B_{\bar{U}}} (1-x)^{C_{\bar{U}}},
  \]
  \[
  x\bar{D}(x) = A_{\bar{D}} x^{B_{\bar{D}}} (1-x)^{C_{\bar{D}}},
  \]

Momentum sum rule and quark counting rules applied to constrain
$A_g, A_{uv}, A_{dv}$ ($C'_g$ fixed to 25)

Other constraints applied: $A_{\bar{U}} = A_{\bar{D}}, B_{\bar{U}} = B_{\bar{D}}$

- DGLAP evolution & cross section calculations in NNLO QCD
Fit Strategy

- Fits performed with log-normal based likelihood function

\[
\chi^2 = \sum_{ij} \log \frac{d_i}{\tilde{\sigma}_i} V_{ij}^{-1} \log \frac{d_j}{\tilde{\sigma}_j}
\]

Correlation in data (d) taken into account in covariance matrix (V)

- Fit-1: Quark couplings + PDFs
  - 4 or 2 couplings + 13 PDF parameters
  - chi2 value: 1370.5/(1388-21)=1.0

- Fit-2: \(M_W + \text{PDFs}\) (chi2 value: 1372.3/(1388-18)=1.0)
  - Translate to \(\sin^2 \theta_W\) in on-mass-shell scheme by using known \(M_Z\)
  - Divide data sets in several \(Q^2\) ranges
  - \(\sin^2 \theta_W\) extracted at different scale \(\mu = \sqrt{Q^2}\)
  - chi2 value: 1365.3/(1388-24)=1.0
Fit-1 Results

Fixing $\alpha, M_Z, M_W$ in NC
$G_F, M_W$ in CC

- Significant improvement over HERA-I determination
- 2 coupling fit is more precise due to the reduced correlation
Comparison with LEP and Tevatron Results

- Precision (in particular for $a_u$, $v_u$) competitive with LEP & D0
- LEP determinations have ambiguity in sign
This result comparable with a similar one from ZEUS (previous talk)

ZEUS fit included HERA-I and -II data sets from H1 with $P_e=0$

**SM overconstrained**

➤ at HERA, $W$ boson appears as a virtual boson exchange
➤ Probing space-like momentum transfers
➤ $M_W$ determined in on-mass-shell scheme by fixing $\alpha, M_Z, m_t, m_h$
➤ Correlation with PDFs properly taken into account

$$M_W = 80.407 \pm 0.118 \text{(exp, PDF-fit)} \pm 0.005(M_Z, m_t, m_h) \text{ GeV}$$

to be compared with HERA-I result:

$$M_W = 80.786 \pm 0.205 \text{(exp)} \pm 0.063 \text{(th)} \text{ GeV}$$

⇒ A factor ~2 improvement!

⇒ Extract $\sin^2 \theta_W \text{(on-mass-shell)} = 1 - \frac{M_W^2 \text{(fit)}}{M_Z^2 \text{(input)}}$
Fit-2: Weak Mixing Angle versus $Q^2$

$\sin^2\theta_W$ showing no strong scale dependence as expected

Results consistent with precise Z-pole measurements
(Light) quark couplings determined with much improved precision, thanks to
- the new sensitivity with polarised $e^+/e^-$ beams at HERA-II
- more HERA-II high $Q^2$ cross section measurement

$A M_W$ (and $\sin^2\theta_W$) determination
- A factor of 2 improvement in precision over HERA-I

The final results (including 1-loop EW corrections) will be published soon