High $Q^2$ Neutral Current in Polarised $e^\pm p$ Collisions at HERA II

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On Behalf of the H1 Collaboration

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Longitudinally Polarised Lepton Beam at HERA II

- Sokolov-Ternov effect → lepton beam has transverse polarisation
- Spin rotator before/after the H1/ZEUS/HERMES detectors

Polarisation:

\[ P_e = \frac{N_{RH} - N_{LH}}{N_{RH} + N_{LH}}, \]

\( N_{RH} (N_{LH}) \): number of RH(LH) leptons in the beam

- Polarisation built-up time \( \sim \) 30 minutes
- Monitoring by two independent compton polarimeters
Data Sets

“Right handed” (RH) for $P_e > 0$
“Left handed” (LH) for $P_e < 0$

2003-04 $e^+p$

<table>
<thead>
<tr>
<th></th>
<th>Lumi, pb$^{-1}$</th>
<th>Polarisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>RH</td>
<td>26.9</td>
<td>(+33.6±0.6)$%$</td>
</tr>
<tr>
<td>LH</td>
<td>20.7</td>
<td>(-40.2±1.1)$%$</td>
</tr>
</tbody>
</table>

2005 $e^-p$

<table>
<thead>
<tr>
<th></th>
<th>Lumi, pb$^{-1}$</th>
<th>Polarisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>RH</td>
<td>29.6</td>
<td>(+37.0±1.3)$%$</td>
</tr>
<tr>
<td>LH</td>
<td>68.6</td>
<td>(-27.0±1.8)$%$</td>
</tr>
</tbody>
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- HERA II lumi $\sim 150$ pb$^{-1}$ (HERA I $\sim 120$ pb$^{-1}$)
- HERA II $e^-p$ lumi six times larger than HERA I $e^-p$
**Neutral Current (NC) DIS:** \( e^\pm p \rightarrow e^\pm X \)**

**Kinematics:**
- \( Q^2 = -(k - k')^2 = -q^2 \)
  - virtuality of \( \gamma^*, Z_0 \)
- \( x = Q^2 / 2(Pq) \) momentum fraction of proton carried by struck quark
- \( y = (Pq) / (Pk) \) inelasticity
- \( Q^2 = sxy \)

**DIS is sensitive probe of the proton structure**
- **High \( Q^2 \):** Probe with small spatial resolution \( \lambda \sim 1/\sqrt{(Q^2)} \), resolve 1/1000\(^{th}\) size of proton
- **QCD, PDFs**
- **Probe EW dynamics**
NC Cross Section

- NC DIS cross section:
  \[
  \frac{d^2\sigma_{NC}(e^\pm p)}{dx dQ^2} = \frac{2\pi\alpha^2}{xQ^4} [Y_+ \tilde{F}_2 \mp Y_- x\tilde{F}_3 - y^2 \tilde{F}_L], \quad Y_\pm = 1 \pm (1 - y)^2
  \]

  Dominant contribution
  Contribution only important at high \( Q^2 \)
  Sign changes in \( e^+ / e^- \)
  Sizeable only at high \( y \)

- NC reduced cross section:
  \[
  \tilde{\sigma}_{NC}(e^\pm p) = \frac{xQ^4}{2\pi\alpha^2} \frac{1}{Y_+} \frac{d^2\sigma_{NC}(e^\pm p)}{dx dQ^2} = \tilde{F}_2 \mp \frac{Y_-}{Y_+} x\tilde{F}_3 - \frac{y^2}{Y_+} \tilde{F}_L
  \]

- In QPM:
  \[
  F_2(x, Q^2) = x \sum A_i(q_i + \bar{q}_i) \\
xF_3(x, Q^2) = x \sum B_i(q_i - \bar{q}_i) \\
F_L = F_2 - 2xF_1 = 0 (Callan-Gross relation)
  \]
NC structure functions, $\tilde{F}_2$ and $xF_3$, can be decomposed as:

$$\tilde{F}_2 = F_2 - (v_e \pm Pe a_e) \chi_Z F_2^{\gamma Z} + (v_e^2 + a_e^2 \pm 2Pe v_e a_e) \chi_Z^2 F_2^Z,$$

$$xF_3 = - (a_e \pm Pe v_e) \chi_Z xF_3^{\gamma Z} + (2v_e a_e \pm Pe (v_e^2 + a_e^2)) \chi_Z^2 xF_3^Z,$$

where: “+” for $e^+ p$, “-” for $e^- p$

**Polarisation dependence:**

- **Dominating e/m contribution** is independent of $P_e$
- **Polarised contribution** appears at high $Q^2$, mainly due to $\gamma Z$ interference
Neutral Current Event in the H1 Detector

**LAr calorimeter:**

- High granularity 45000 cells
- $\frac{\sigma(E)}{E} = \frac{12\%}{\sqrt{E/\text{GeV}}}$ e/m energy
- $\frac{\sigma(E)}{E} = \frac{50\%}{\sqrt{E/\text{GeV}}}$ had energy

- Electron produces isolated and compact energy deposition
- Identified using shape and size of e/m shower profile
- Balanced by hadronic final state in $\varphi$
Electron energy ($E'_e$), scattering angle ($\theta_e$), etc are described by MC

Low background level. Main contributions: photoproduction ($\gamma p$), QED compton, lepton-pair production
2003-04 $e^+ p \frac{d\sigma}{dQ^2}$ and RH/LH

Neutral Current

\[ \frac{d\sigma_{NC}}{dQ^2} (pb GeV^{-2}) \]

- $P_e = +33.6\%$
- $y < 0.9$

\[ \frac{d\sigma_{NC}}{dQ^2} (pb GeV^{-2}) \]

- $P_e = -40.2\%$
- $y < 0.9$

- $\frac{d\sigma_{e^+p}}{dQ^2} (RH, LH)$ and RH/LH
- Rise of the ratio RH/LH as function of $Q^2$
- Polarisation asymmetry is not yet significant

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2005 $e^- p \, d\sigma / dQ^2$ and RH/LH

- $d\sigma^{e^- p} / dQ^2$ (RH, LH) and RH/LH
- Drop of the ratio RH/LH as function of $Q^2$
- Indication of the polarisation effect on NC cross sections, although significance is moderate

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Polarisation Asymmetry in NC: Combination of Results

\[ \sigma_{NC}^{e\pm p} \sim \cdots F_2 + \cdots ( -v_e \mp P_e a_e ) F_2^Z \mp \cdots a_e x F_3^Z \]

Neutral Current

\[ R = \frac{\frac{d\sigma}{dQ^2}(e^+ p, P_e = +33.6\%) + \frac{d\sigma}{dQ^2}(e^- p, P_e = -27.0\%)}{\frac{d\sigma}{dQ^2}(e^+ p, P_e = -40.2\%) + \frac{d\sigma}{dQ^2}(e^- p, P_e = +37.0\%)} \]

- H1 Preliminary
- SM (H1 PDF 2000)
- Norm. uncert.
Neutral Current at High $x$ and $xF_3$

- **HERA II unpolarised cross-sections**

$$\tilde{\sigma}_{e^\pm p} = \tilde{F}_2 - \frac{y^2}{y_+} \tilde{F}_L \mp \frac{y_-}{y_+} x \tilde{F}_3$$

- $xF_3$ for HERA I+II:

$$x \tilde{F}_3 = \frac{y_+}{2y_-} (\tilde{\sigma}^{e^+ p} - \tilde{\sigma}^{e^- p})$$

$$xF_3 = -ae \frac{\kappa w Q^2}{Q^2 + M_Z^2} x F_3^Z + (2v_e a_e) \left( \frac{\kappa w Q^2}{Q^2 + M_Z^2} \right) x F_3^Z$$
Structure Function $xF_3^{\gamma Z}$

$$xF_3^{\gamma Z} = x\tilde{F}_3/\left(\frac{-ae\kappa_w}{Q^2 + M_Z^2}\right)$$
Summary

- HERA II NC cross sections for 2003-04 $e^+p$ and 2005 $e^-p$ interactions with longitudinally polarised lepton beams are measured.
- Polarisation effects on NC cross sections are visible but significance is moderate.
- The structure functions $\tilde{x}F_3$ and $xF_3^{\gamma Z}$ are determined using HERA I and HERA II with improved statistical precision.
- Data is well described by Standard Model.