Prospects for a measurement of $F_L$ with the ZEUS detector

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On behalf of ZEUS Collaboration

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\[ F_L \text{ in theory} \]

**ZEUS experiment measures cross-section**

\[
\frac{d^2 \sigma}{d x d Q^2}(x, Q^2) = \frac{2 \pi \alpha^2}{x Q^4} \left[ Y + F_2(x, Q^2) - y^2 F_L(x, Q^2) \right]
\]

\[ Y_+ = 1 + (1 - y)^2 \]

(at low $Q^2 \Rightarrow xF_3$ neglected)

**$F_2$** — dominant contribution to cross section

**$F_L$** — related to cross section of longitudinally polarised photon

– in Quark-Parton Model (QPM): $\sigma_L = 0 \Rightarrow F_L = 0$

– $F_L$ nonzero in pQCD, in LO

\[
F_L = \frac{Q^2}{4 \pi^2 \alpha} \sigma_L
\]

\[
F_L = \frac{\alpha_s}{4 \pi} x^2 \int \frac{d z}{z^3} \left[ \frac{16}{3} F_2 + 8 \sum e_q^2 \left( 1 - \frac{x}{z} \right) zg \right]
\]

At small $x$ the gluon density dominates

$\Rightarrow$ $F_L$ has never been measured at small $x$

$\Rightarrow$ measurement of $F_L$ would provide direct access to gluon densities
Status of $F_L$ and gluon densities

- Relatively large uncertainties in gluon densities at small $x$
- $F_L$ is poorly constrained by present data → different theoretical predictions
- Measurement of $F_L$ → test of our QCD understanding → important input to QCD fits of PDF's

**F_{L} measurement with two beam energies**

\[
\frac{d^2 \sigma}{dx \, dQ^2} = \frac{2 \pi \alpha^2}{xQ^4} \left( F_2 - \frac{y^2}{Y_+} F_L \right) \left( \tilde{\sigma} \rightarrow \text{reduced cross section} \right)
\]

To separate \(F_2\) and \(F_L\) one needs to measure the cross section at the same \(x\) and \(Q^2\) but different values of \(y\) ⇒ different \(s\) (different beam energies)

\[
F_L(x, Q^2) = \frac{\tilde{\sigma}_1(x, Q^2, y_1) - \tilde{\sigma}_2(x, Q^2, y_2)}{y_2^2/Y_{2+} - y_1^2/Y_{1+}}
\]

**larger \(y\) difference**  
more points (beam energies)  
≡ higher accuracy of \(F_L\) measurement
Possible running scenarios

3 months of HERA running at lower proton beam energy:

→ 2 vs. 3 energy points

<table>
<thead>
<tr>
<th>SCENARIO</th>
<th>$E_p = 920$ GeV</th>
<th>$E_p = 460$ GeV</th>
<th>$E_p = 690$ GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30 pb$^{-1}$</td>
<td>10 pb$^{-1}$</td>
<td>0 pb$^{-1}$</td>
</tr>
<tr>
<td>2</td>
<td>30 pb$^{-1}$</td>
<td>5 pb$^{-1}$</td>
<td>5 pb$^{-1}$</td>
</tr>
</tbody>
</table>

→ lower energy ⇒ higher precision on $F_L$ (350 GeV ?)

→ to consider — uncertainties with HERA setup times
  — lower luminosity at lower beam energy

→ we assume two beam energies (scenario 1)

→ if accelerator setup and data taking smooth, could try third point at the end
Coverage of the kinematic space

\[ E_p = 460 \text{ GeV} \]

Low energy run (LER)

\[ E_p = 920 \text{ GeV} \]

Low energy run (LER) + High energy run (HER)

4 – 12 GeV in scattered electron energy in LER \( \Leftrightarrow \) 16 – 20 GeV in scattered electron energy in HER

Best \( F_L \) measurement \( \Rightarrow \) reach highest \( y \) possible
\( \Rightarrow \) lowest possible electron energy in LER
Main issues — Electron finding

Need to reliably recognize the scattered DIS electron down to 4 GeV

- Low $Q^2$ so electrons mostly in backward direction

Components:

RCAL:
- looking at fraction of energy deposited in the EM part

HES + Presampler:
- looking at the shape of the shower

Tracking:
- photon-electron separation
- central tracking using CTD and MVD has acceptance only up to $\approx 168^\circ$
- SRTD could help, however, behind a lot of material
  $\Rightarrow$ increased $\gamma \rightarrow e^+e^-$ probability
Main issues — Photoproduction background

• largest contribution to background ⇐ large cross section at low $Q^2$

**PhP event:**
→ electron irradiates almost a real photon which then interacts with the proton
→ true electron with lower energy goes down the beam pipe
→ one of the particles in the detector recognized as DIS electron

For DIS candidate with valid electron:
→ within acceptance window measure PhP directly
→ normalize PhP Monte Carlo

6m tagger
→ working fine
→ agreement with ZEUS luminosity measurement system within 2%
→ PYTHIA PhP background distribution vs. 6m tagger acceptance (reconstructed as DIS events)

- **positron running advantageous** over electron running
  → lower energy
- for $e^+$ running 6m tagger identifies 25% of php events
- possibly measure php and normalize MC
Details of the study

Use Monte Carlo to estimate the precision of the $F_L$ extraction with the ZEUS detector

➔ in HER select events with electron candidate with
   \( 16 \text{ GeV} < E_e < 20 \text{ GeV}, \ \ 160^{\circ} < \theta_e < 172^{\circ} \)

➔ in LER select events with electron candidate with
   \( 4 \text{ GeV} < E_e < 12 \text{ GeV}, \ \ 150^{\circ} < \theta_e < 168^{\circ} , \ \text{require track} \ \text{for} \ E_e < 10 \text{ GeV} \)

➔ use 6m tagger to reject PhP if within the acceptance

<table>
<thead>
<tr>
<th>Systematic checks:</th>
<th>Varied by:</th>
</tr>
</thead>
<tbody>
<tr>
<td>→ Photoproduction background normalization</td>
<td>10%</td>
</tr>
<tr>
<td>→ Electron finding inefficiency (including trigger)</td>
<td>10%</td>
</tr>
<tr>
<td>→ Energy scale</td>
<td>2% at 4 GeV → 1% at 27.5 GeV</td>
</tr>
<tr>
<td>→ Luminosity uncorrelated</td>
<td>1%</td>
</tr>
<tr>
<td>→ Luminosity correlated</td>
<td>2%</td>
</tr>
</tbody>
</table>
Reconstructed kinematic variables

**High energy run**

- $Q^2_{el}$
- $y_{el}$
- $\log_{10} x_{el}$
- $E - p_z$
- $E_e$
- $\theta_e$

**Low energy run**

- $Q^2_{el}$
- $y_{el}$
- $\log_{10} x_{el}$
- $E - p_z$
- $E_e$
- $\theta_e$

PhP background is a problem for Low energy run (for low energy electrons)

- $4 \text{ GeV} < E_e < 12 \text{ GeV}$
  - $150^\circ < \theta_e < 168^\circ$
- $16 \text{ GeV} < E_e < 20 \text{ GeV}$
  - $160^\circ < \theta_e < 172^\circ$

(normalized to 1 pb$^{-1}$)
Uncertainties of $F_L$ extraction

Low $Q^2$: small stat., big syst.

Note: $F_L$ values set to $0.2 F_2$

Largest systematics from:
PhP background normalization and EF inefficiency

High $Q^2$: big stat., small syst.
Hadron-electron separation using shower size in the calorimeter

**HES:**
- Silicon diodes at $4X_0$ in the EMC
- ~ shower maximum for several GeV electrons
- Small interaction probability for hadrons

**PRESAMPLER:**
- Scintillator tiles covering EMC
- Energy correction for showers developed in the dead material before reaching cal
- Small output for hadrons

Using HES and Presampler to improve electron finding outside the tracking acceptance.

Under study…
Use Bayesian approach to extract \[ R = \frac{F_L}{F_2} \]

→ suppose \( R \) is a constant, i.e. we can combine all bins
→ include all uncertainties
→ MC sample had a value of \( R = 0.2 - 0.3 \)
→ extracted \( R \) uncertainty \( \approx 0.027 \)

Average \( \frac{F_L}{F_2} \) from theoretical predictions:

- CTEQ5D: 0.25
- MRST2002 LO: 0.3
- MRST2004 NLO: 0.18
- MRST2004 NNLO: 0.18

\( R \) in MC = 0.2 - 0.3

\( E_p = 920 \text{ GeV} \quad 30 \text{ pb}^{-1} \)
\( E_p = 460 \text{ GeV} \quad 10 \text{ pb}^{-1} \)

9.5 GeV\(^2 < Q^2 < 45 \text{ GeV}^2\)
Summary

- $F_L$ should be measured
  - basic ingredient in the cross section
  - test of perturbative QCD at small $x$
  - would bring information on gluon density

- kinematic range and precision of $F_L$ measurement with ZEUS is moderate

- however, there is room for improvement
  - extending $Q^2$ and $x$ range
  - better electron finding with HES and Presampler
  - better understanding of the PhP background using 6m tagger
    → reduction of the PhP normalization systematics

ZEUS Collaboration has expressed interest in low energy running to the DESY PRC (will be meeting in May)
BACKUP SLIDES
$Q^2 = 9.5, 12, 14.5, 19, 25, 30, 38, 45 \text{ GeV}^2$

$\rightarrow$ 2-6 $x$ points/$Q^2$ point

$\rightarrow$ Limitation at low $Q^2$ is tracking requirement

$\rightarrow$ Limitation at high $Q^2$ is statistics
→ clearly, **electron finding at low energies is a challenge**

→ the ZEUS detector is not the ideal device
   ⇒ we want to perform a NC cross-section measurement at high $y$
   with current beam energy

→ this will allow to prepare and test detectors and techniques for electron finding and background rejection

**New territory for ZEUS $F_2$ measurement**