Measurement of the Longitudinal Structure Function in Diffraction

$F^D_L$

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Diffractive DIS

• diffractive reduced cross section

\[
\sigma_r^D = F_2^D - \frac{y^2}{Y_+} F_L^D
\]

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

\[
\frac{d^3 \sigma_{ep \to eXY}}{dx_{IP} d\beta dQ^2} = \frac{2\pi\alpha^2}{\beta Q^4} Y_+ \sigma_r^D(x_{IP}, \beta, Q^2)
\]
• diffractive reduced cross section

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\]

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

• this analysis focuses on the diffractive longitudinal proton structure function
QCD Factorisation in Diffraction

- diffractive parton densities
  - extracted from the inclusive measurements
  - $x_{IP}$ dependence factorised

- NLO QCD fit ($\beta$ and $Q^2$ dependence)
- singlet parametrisation:
  $$z\Sigma(z, Q_0^2) = A_q z^B_q (1 - z)^C_q$$

- 2 gluon parametrisations:
  - Fit A
    $$z g(z, Q_0^2) = A_g (1 - z)^C_g$$
  - Fit B
    $$z g(z, Q_0^2) = A_g$$
QCD Factorisation in Diffraction

- inclusive measurements constrain quarks
- gluons are constrained weakly from the scaling violations

\[ \frac{d \sigma_r^D}{d \ln Q^2} \]

- diffractive dijets in DIS
  - compatible with the parton densities from H1 2006 DPDF Fits
  - QCD factorisation holds
  - Fit B preferred
QCD Factorisation in Diffraction

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  - low statistics
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- FLD measurement
  - probes low \( x_{IP} \) and \( \beta \) region inaccessible by dijets and \( D^* \)

\[
F_L^D \sim x \, g(x)
\]
last months of HERA running were dedicated to the measurements of $F_L$ and $F_L^D$

→ low energy runs

- $E_p = 460$ GeV
- $E_p = 575$ GeV

nominal proton beam energy

- $E_p = 820$ GeV
- $E_p = 920$ GeV
Measurement Strategy

- analysis closely follows the measurement of the inclusive $F_L$ by H1 (published as DESY-08-053)

- Rosenbluth plots
  - separate the structure functions $F_L^D$ and $F_2^D$ by combining measurements at different $y$ (for the fixed $x_{IP}$, $\beta$, $Q^2$)

\[
\sigma_r^D = F_2^D - \frac{y^2}{Y_+} F_L^D \quad Y_+ = 1 + (1 - y)^2
\]

\[Q^2 = x_{IP} \beta y s\]

- data at different centre-of-mass energy needed
  - 2 pb$^{-1}$ $E_p = 820$ GeV
  - 21 pb$^{-1}$ $E_p = 920$ GeV
  - 6 pb$^{-1}$ $E_p = 460$ GeV
  - 4 pb$^{-1}$ $E_p = 575$ GeV
Data Selection and H1 Detector

- **Diffractive selection:**
  - large rapidity gap $\to \eta_{\text{max}} < 3.3$

- **$F_L^D$ selection:**
  - $Q^2 > 2.5$ GeV$^2$
  - high $y$ region sensitive to $F_L^D \to y < 0.9$
  - kinematic variables reconstructed from the scattered positron
    \[ Q^2 = 4 E_e E'_e \cos^2 \frac{\theta_e}{2} \quad y = 1 - \frac{E'_e}{E_e} \sin^2 \frac{\theta_e}{2} \approx 1 - \frac{E'_e}{E_e} \]
  - low scattered positron energy $\to E'_e > 3.4$ GeV
  - high level of photoproduction background
  - challenging measurement requiring precise positron identification
    - cluster (Spacal calorimeter)
    - track (central tracker and/or Backward Silicon Tracker)
Background at High $y$

- data at high $y$ contain photoproduction background
  - scattered positron escapes the central detector through the beam-pipe
  - one of the hadronic final state particles is mis-identified as the scattered positron
  - background from hadronic particles is almost charge symmetric
    \[ \frac{N_{bg}^+}{N_{bg}^-} \sim 1 \]

- background subtraction using the charge of the scattered positron candidate

\[
N^+ = \text{signal events} + \text{background from } \pi^+ \\
N^- = \text{background from } \pi^-
\]

\[ N_{signal} = N^+ - N^- \]
data with positive charge
background determined from the data with negative charge
signal Monte Carlo (based on H1 2006 DPDF Fit B) + background from data

- **Monte Carlo does not simulate** $F_L^D \rightarrow$ it overshoots data at high $y$

$$\sigma_r^D (F_L^D = 0) = F_2^D$$
Normalisation of Data Sets

- data cross section is corrected for proton dissociation
  - rapidity gap selection accepts events with dissociated protons up to $M_Y = 1.6$ GeV (acceptance of the forward detectors near the beam pipe)
  - 7% uncertainty → can it be reduced?

- use as constraint that $F_2^D$ is independent of the beam energy
  - no significant contribution from $F_L^D$ at low $y$ (high $\beta$)
  - data cross sections normalised to H1 2006 DPDF Fit B at $Q^2 = 13.5$ GeV$^2$, $0.28 < \beta < 0.42$ in order to give the same $F_2^D$
  - normalisation changed by < 4%
  - uncertainty reduced to 2.5%

\[
\sigma_r^D = F_2^D - \frac{y^2}{Y_+} F_L^D
\]
\[
Q^2 = x_{IP} \beta y s
\]
Diffractive Reduced Cross Sections

- $7 < Q^2 < 32 \text{ GeV}^2$
- $E_p = 920, 575, 460 \text{ GeV}$

- Cross sections agree with H1 2006 DPDF Fit B
- Contribution of non-zero $F_L^D$ observed → fall at low $\beta$
- Prediction for $\sigma_r^D(F_L^D = 0) = F_2^D$ overestimates data
Diffractive Reduced Cross Sections

• $2.5 < Q^2 < 7 \text{ GeV}^2$

• $E_p = 820, 575, 460 \text{ GeV}$

- data at $E_p = 820 \text{ GeV}$ from the publication DESY-06-049
  - cover larger $\beta$ range
  - used to determine H1 2006 DPDF Fit A and Fit B
  - the Fits are known to underestimate data at $Q^2 < 8.5 \text{ GeV}^2$
Sensitivity to $F^D_L$

- data cross sections are sensitive to $F^D_L$

$$\sigma^D_r = F^D_2 - \frac{y^2}{Y^+} F^D_L$$

$$Q^2 = x_{IP} \beta y s$$
**$F_L^D$ Fits**

- Linear fit in the Rosenbluth plots to obtain $F_2^D$ and $F_L^D$

$$\sigma_r^D = F_2^D - \frac{y^2}{Y_+} F_L^D$$

- Highest sensitivity to $F_L^D$ at high $y$ (low $\beta$)
**$F^D_L$ Results**

- $F^D_L$ is measured in the kinematic region:
  \[ 2.5 < Q^2 < 32 \text{ GeV}^2 \]
  \[ 0.001 < x_{IP} < 0.01 \]
- Measurements are corrected to:
  \[ Q^2 = 4 \text{ and } 13.5 \text{ GeV}^2 \]
  \[ x_{IP} = 0.003 \]

- Significantly non-zero results (more than 5\(\sigma\))
- Consistent with the H1 2006 DPDF Fits
  - Based on DPDF's and factorisation
  - Extrapolation of the Fits shown for $Q^2 = 4 \text{ GeV}^2$
$F_L^D \text{ Results}$

- $F_2^D$ prediction gives the upper bound for $F_L^D$ in the range of validity of the Fits.

![Graph showing $F_L^D (x_{ip}, \beta, Q^2)$ for H1 Preliminary results.](graph.png)

$Q^2 = 13.5 \text{ GeV}^2$

$x_{ip} = 0.003$
QCD Fits and Higher Twist Effects

- higher twist longitudinal contribution to diffraction at high $\beta$ implies large $F_L^D$ (e.g. BEKW)
- $F_2^D$ dominated by $F_L^D$ at high $\beta$ and low $Q^2$
  \[ F_2 = F_T + F_L \]
- QCD fits from H1 only consider the leading twist and do not predict large $F_L^D$

- measurement is also consistent with K. Golec-Biernat et al.
- no sensitivity to the twist 4 contribution in the current $\beta$ range
Summary

- the first $F_L^D$ measurement
- significant non-zero value (more than 5σ)
- a new, independent test of the diffractive gluon density
- verification of the QCD factorisation in diffractive DIS
  - dijets
  - $D^*$
  - $F_L^D$

- $F_L^D$ measured at $Q^2 = 13.5 \text{ GeV}^2$, $x_{IP} = 0.003$ and $\beta \sim 0.1$
- $Q^2 = 4 \text{ GeV}^2$, $x_{IP} = 0.003$ and $\beta \sim 0.03$