Measurement of the Inclusive $e^\pm p$ Scattering Cross Section at High Inelasticity $y$ and of the Structure Function $F_L$

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Content

• Deep Inelastic Scattering at HERA
• DIS x-section at low $Q^2$
• x-section measurements at high inelasticity $y$
• Results on the structure function $F_L$
• Combined data for phenomenological analyses
• Conclusions
The $ep$ collider HERA

- Circumference: 6.3 km
- $27.5\times920(820)\text{ GeV, } \sqrt{s_{ep}} = 319\text{ GeV}$
- 2 collider experiments: H1 and ZEUS
- HERA I: 1992-2000
- Luminosity upgrade: mid 2000 – end 2001
- Higher luminosity: HERA II (2003 – 2007)
Inclusive DIS at HERA

Use the scattered electron to reconstruct event kinematics:

\[ Q^2 = 4E_e E'_e \cos^2 \frac{\theta_e}{2} \] - four momentum transfer squared in the reaction

\[ x = \frac{Q^2}{s_y} \] - fraction of the proton momentum carried by the parton

\[ y = 1 - \frac{E'_e}{E_e} \sin^2 \frac{\theta_e}{2} \] - fraction of the lepton’s energy loss

\[ s = 4E_e E_p \] - center-of-mass energy squared
NC cross section and structure functions

NC Reduced cross section: \[ \sigma_r(x, Q^2) \]

\[
\frac{d^2 \sigma_{NC}(e^\pm p)}{dx dQ^2} = \frac{2\pi \alpha^2}{x Q^4} Y_+ \left[ F_2 - \frac{Y^2}{Y_+} F_L \right]
\]

Dominant contribution

Sizeable only at high \( y \) (\( y > \sim 0.6 \))

- The proton structure functions in QPM:
  \[
  F_2(x) = \sum_i e_i^2 x [q_i(x) + \bar{q}_i(x)] - \text{sum of the (anti)quarks density distributions weighted with their electric charge squared}
  \]
  \[
  F_L(x) = 0
  \]

- In QCD: \( F_L(x, Q^2) \sim \text{gluon density} \)
\( \sigma_r \) for \( E_p = 460, 575 \) and 920 GeV

- New cross-section measurements for different \( E_p \) at HERA II
  [H1 Collab., Eur.Phys.J. C71, 2011 1579]

- For \( E_p = 920 \) GeV, these data are combined with previous H1 measurements
  [H1 Collab., Eur.Phys.J. C63, 2009 625],
  [H1 Collab., Eur.Phys.J. C64, 2009 561],
  [H1 Collab., Eur.Phys.J. C21, 2001 33]
  leading to factor of 2 improvement in precision at high \( y \)
$F_L$ determination

- $F_L$ determined from measurements at different CME
- $F_L$ is proportional to the variation of $\sigma_r$ as a function of $y^2/(1+(1-y)^2)$
- Improved determination procedure, taking into account correlations due to systematic uncertainties

[H1 Collab., Eur.Phys.J. C71, 2011 1579]
The measurement spans over 2 decades in $x$ at low $0.00002 < x < 0.002$

- Measured HERA $F_2$ and $F_L$ are consistent with predictions of the NLO DGLAP fit in the ACOT scheme
HERA $F_L$ and different predictions

- New measurement extends to $Q^2 \geq 1.5$ GeV$^2$
- Within the uncertainties all predictions describe the data reasonably well
- Good agreement between H1 and ZEUS measurements
The ratio $R$

HERA data are consistent with const $R = 0.26 \pm 0.05$
Phenomenological analysis settings

- Combined H1 data for $E_p=820–920$ GeV, $0.2 \leq Q^2 \leq 150$ GeV$^2$ [H1 Collab., Eur.Phys.J. C63, 2009 625], [H1 Collab., Eur.Phys.J. C64, 2009 561], [H1 Collab., Eur.Phys.J. C21, 2001 33]

- Combined for $y_{460} \leq 0.35$ low $E_p=460$ and 575 GeV data

- ‘H1fitter’ fitting program, based on NLO DGLAP QCDNUM [arXiv:1005.1481] evolution code. The fitter has been extended to include non-DGLAP models (dipole, $\lambda$-fit)

- See more about HERA fits in talk of Voica Radescu
\( \sigma_r \) and QCD fits

- Two calculation schemes for QCD fits: ACOT and RT with different computation of the heavy quark structure functions and of the structure function \( F_L \).
- Better quality of ACOT fit: \( \chi^2/\text{dof} = 715/781 \) vs RT fit with \( \chi^2/\text{dof} = 765/781 \).
- With increasing of \( Q^2 \) cut:
  - fit quality is improved
  - gluon is increased, sea becomes smaller at low \( x \)

| \( Q^2_{\text{min}} \)/GeV\(^2\) | 1.5 | 2 | 2.5 | 3.5 | 5 | 7.5 |
|----------------------------------|-----|---|----|-----|---|-----|
| \( \chi^2/\text{n_{dof}} \)     | 824.8/834 | 777.9/818 | 748.7/801 | 715.2/781 | 677.6/759 | 626.9/712 |
\( \lambda \text{ fit} \)

- At low \( Q^2 \) and \( x \to 0 \) rise of \( F_2 \) towards low \( x \) may be described by
  \[
  F_2(x, Q^2) = c(Q^2) \cdot x^{-\lambda(Q^2)}
  \]

- Fit \( x \)-dependences of \( \sigma_r \) in \( Q^2 \) bins with two free parameters \( c(Q^2), \lambda(Q^2) \) and fixed \( R=0.26 \)
  \[
  \sigma_r(x, Q^2) = F_2(x, Q^2) \cdot \left[ 1 - \frac{y^2}{1 + (1 - y)^2} \cdot \frac{R}{1 + R} \right]
  \]

- Fit results
  - For \( Q^2 \geq 2 \text{ GeV}^2 \)
    - \( \lambda \) exhibits a linear increase as function of \( \ln Q^2 \)
    - Normalisation \( C \) is constant
  - For \( Q^2 < 2 \text{ GeV}^2 \)
    - \( \lambda \) deviates from that linear dependence
    - Normalisation \( C \) rises with increasing of \( Q^2 \)

With offset method for syst. errors quality of the fit is poor: \( \chi^2/\text{dof}=538/350 \)
Introduce a $\lambda'$ fit

- Parameterisation of the $F_2$ is extended by one parameter to allow for deviations from a simple power law

$$F_2(x, Q^2) = c(Q^2) \cdot x^{-\lambda(Q^2)+\lambda'(Q^2) \ln x}$$

- Fit returns significantly improved $\chi^2$/dof=405/326
  - $\lambda$ exhibits a constant behaviour ($\lambda \sim 0.25$)
  - strong correlations between $\lambda$ and $\lambda'$
- Fix $\lambda=0.25$ and let $C(Q^2)$, $\lambda'(Q^2)$ float which yields $\chi^2$/dof=464/350

Confirms a QCD prediction [A. De Rujula et al., Phys. Rev. D10, 1649 (1974)]:
rise of $F_2$ slower than power $1/x$, faster than power $\ln1/x$
\( \sigma_r \) and Dipole Model fits

- Test DModels with and without DGLAP-based correction for valence contribution
- Fits to data in \( 3.5 \leq Q^2 \leq 150 \text{ GeV}^2 \) and \( x < 0.01 \) where both DM and DGLAP are working
- The addition of valence contribution improves description of the data at high \( x \) but overall fit quality is not better

| Fit Conditions | GBW | HIM | \( \chi^2 / n_{\text{dof}} \) | ACOT | RT |
|----------------|-----|-----|-----------------|------|----|
| Nominal fit    | 718.8/352 | 397.6/352 | 424.9/352 | 715.2/781 | 764.5/781 |
| \( Q^2 \geq 3.5 \text{ GeV}^2 \) | 559.7/252 | 259.4/252 | 261.7/252 | 715.2/781 | 764.5/781 |
| DGLAP_valence  | 739.5/252 | 287.6/252 | 371.4/252 | 248.3/249 | 288.8/249 |

 ⇒ Best fit for DGLAP-ACOT, closely followed by IIM
\( F_L \) vs phenomenological models

- At \( Q^2 > 10 \text{ GeV}^2 \): good agreement between data and all considered models
- At low \( Q^2 \): RT fit falls below data. Other models describe measured \( F_L \) well
Summary

• The new most precise HERA measurement of the inclusive $e^\pm p$ scattering cross section at high inelasticity $y$ and of the structure function $F_L$ is presented
• The analysis is published in EPJC [H1 Collab., Eur. Phys. J. C71, 2011 1579. arXiv:1012.4355 [hep-ex]]
• $F_L$ is measured for the first time at HERA down to $Q^2 = 1.5 \text{ GeV}^2$
• Data are consistent with constant $R \sim 0.26$ and generally well described by the phenomenological models
• From the considered models NLO DGLAP ACOT fit provides the best description of HERA data
Back up
The preliminary combined measurement of $F_L$ cover the range of $2.5 \leq Q^2 \leq 800 \text{ GeV}^2$ and $0.00005 \leq x \leq 0.06$

Data are in a good agreement with HERAPDF1.0 for $Q^2 > 10 \text{ GeV}^2$
Background estimation

- Measure particle charge using curvature of the associated track

- $e^+p$ scattering:
  - Scattered lepton has the beam charge (positive)
  - Background from hadronic particles, $\gamma$ conversions is almost charge symmetric:
    \[ N_{BG}^+ \approx N_{BG}^- \]

- Require positive charge for the signal sample. Estimate remaining background using negative sample
**F$_2$-F$_L$ Fitter: new method**

Instead of $\sigma$-average, extract $F_2/F_L$ directly

$$\chi^2(F_2, F_L, \alpha) = \sum_i \left[ \frac{(F_2^i - f(y^i)F_L^i) - \sum_j \Gamma^j \alpha_j - \mu^i}{\Delta_i^2} \right]^2 + \sum \alpha_j^2 + \sum \left( \frac{F_L^i - \frac{R}{R + 1} F_2^i}{\Delta_{F_L}^i} \right)^2$$

Minimization vs $F_2, F_L$ and syst. sources $\alpha$ leads to a simple system of linear equations:

$$R = \frac{F_L}{F_2 - F_L} \approx 0.25$$

$\mu^i$ – measured x-section

$\Delta_i$ – its uncertainty

$\alpha_j$ – correlated error sources

which can be easily solved numerically.
Dipole model fits

• At low $x$ and $Q^2$ the virtual photon-proton scattering can be described using the color dipole model (CDM):

$$\gamma^*(q) + p(p) \rightarrow \gamma^*(q) + p(p)$$

the initial $\gamma^*$ splitting into a quark-antiquark pair (dipole), this pair scattering on the proton and the $q\bar{q}$ subsequently fusing into the final state $\gamma^*$

• We consider here three CDM as representative for a much larger variety of Dipole models:
  GBW (Golec-Biernat & Wusthoff), IIM (Iancu, Itakura & Munier) and B-SAT (Kowalski, Motyka & Watt)
• CDM are applicable for $x<0.01$ where the gluon and sea dominate. All models neglect valence contributions which are sizeable: 5-15%