Inclusive Measurements of inelastic lepton scattering on unpolarized H and D targets at 27.6 GeV

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For the HERMES COLLABORATION
DIS cross section and structure functions

\[
\frac{d^2 \sigma}{dx \ dQ^2} = \frac{4 \pi \alpha^2_{em}}{Q^4} \frac{F_2(x, Q^2)}{x} \left[ 1 - y - \frac{Q^2}{4E^2} + \frac{y^2 + Q^2/E^2}{2 \left( 1 + R(x, Q^2) \right)} \right]
\]
Why measuring inclusive DIS cross sections at HERMES?

HERMES (1996-2005) \[30\text{M proton} + 28\text{M deuteron}\]
\(~450\text{pb}^{-1}\)
\(~460\text{pb}^{-1}\)

eg. Compared to NMC \[3\text{M proton} + 6\text{M deuteron}\]

\[F_2^p, \ F_2^d, \ \sigma^p, \ \sigma^d, \ \frac{\sigma^p}{\sigma^d}\]

\[\int \frac{dx}{x} \left( F_2^p - F_2^d \right) \]
Gottfried Sum

\[d_v/u_v\]
Valence Quark Ratio

Explore the transition between perturbative and non-perturbative QCD

\[\text{Gottfried Sum}\]
The HERMES Spectrometer

**Reconstruction:** $\delta p/p < 2\%$, $\delta \theta < 1$ mrad

**Internal gas targets:** unpol: H, D, He, N, Ne, Kr, Xe, He, H, D, He

**Particle ID:** TRD, Preshower, Calorimeter, RICH
Kinematic plane

- $0.006 < x < 0.9$
- $0.1 < y < 0.85$
- $0.2 \text{ GeV}^2 < Q^2 < 20 \text{ GeV}^2$
- $W^2 > 5 \text{ GeV}^2$

- 19 x bins
- Up to 6 $Q^2$ bins
- Total: 81 bins

- Traditional DIS region ($Q^2 > 1 \text{ GeV}^2$) can be easily separated
Extraction of cross sections

- DIS YIELDS
- UNFOLDING
- DIS BORN CROSS SECTION

- Particle ID efficiencies
- Trigger efficiencies
- Charge symmetric background subtraction
- Geometric acceptance
- Detector smearing
- Radiative corrections
- Tracking related effects
Luminosity

Elastic reference process: interaction of beam with target shell electrons

• Electron beam: Moller scattering $e^- e^- \rightarrow e^- e^-$
• Positron beam: Bhabha scattering $e^+ e^- \rightarrow e^+ e^-$

annihilation $e^+ e^- \rightarrow 2\gamma$

$$L = \int \mathcal{L} \, dt = (R_{LR} - \Delta t \cdot R_L \cdot R_R) \cdot C_{Lumi} \cdot \frac{A}{Z} \cdot l \cdot \Delta t_{meas}$$

Normalization uncertainty 6.4% (proton) and 6.6% (deuteron)
Particle ID efficiencies

Leptons identified by $PID > PID_{cut}$ with $PID_{cut} = 0$

**Hadron contamination:**
fractional contribution of hadrons above $PID_{cut}$

**Lepton identification efficiency:**
fraction of leptons selected with $PID > PID_{cut}$

$$N_{corr} = N_{uncorr} \cdot \frac{1 - C(PID_{cut})}{\mathcal{E}(PID_{cut})}$$

Correction $\sim 1\%$
Trigger efficiencies

\[ \varepsilon(TR) = \varepsilon(H0) \cdot \varepsilon(H1) \cdot \varepsilon(PRE) \cdot \varepsilon(CALO) \]

**Dependence on time (voltage changes, radiation...), momentum, angle**: Efficiencies are calculated separately for Top and Bottom, data production, bin

**Example: H0 efficiency for 2000 data**

\[ N_{corr} = N_{uncorr} \cdot \frac{1}{\varepsilon(TR)} \]
Charge symmetric background

- meson Dalitz decay $\pi^0 \rightarrow \gamma e^+ e^-$
- photon conversion $\gamma \rightarrow e^+ e^-$

These $e^+$ and $e^-$ originate from secondary processes

- Lower momenta (high $y$) concentration
- Correction applied by counting the number of events with charge opposite of the beam

$$N_{corr}^{+, -} = N_{uncorr}^{+, -} - N_{cs}^{+, -}$$
Experimental cross section

Yields are corrected for

- Trigger efficiencies
- PID efficiencies
- Charge symmetric background

\[ \sigma^{Exp}(j) = \frac{N_{corr}(j)}{L} \]
Unfolding Kinematic bin Migration

\[ S(i, j) = \frac{n(i, j)}{n_{\text{Born}}(j)} \]
Smearing matrix

\[ \sigma_{\text{Born}}(i) = S'^{-1}(i, j) \left[ \sigma^{\text{Exp}}(j) - S(j, 0) \sigma_{\text{Born}}(0) \right] \]
Background term

4π BORN MC
- Simulation of true cross section
- No radiative effects
- No tracking

FULL DETECTOR MC
- Detector material (GEANT4)
- Radiative effects
- Tracking

(Same Luminosity)
Detection efficiencies for high multiplicity radiative events

- The incoming electron can radiate a high energy photon and then scatter elastically with the nucleon.

  - Small scattering angle
  - Large probability of hitting the beam pipe, causing a shower and saturating the wire chambers

- These unreconstructed events are included in the smearing matrix
- Efficiencies extracted from MC

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Main source of systematics: Misalignment

• IDEAL situation: Perfect alignment of beam and spectrometer
• In practice:
  ▪ Top and bottom parts of the detector are displaced
  ▪ Beam position differs from nominal position

• Simulation of misalignment done in MonteCarlo
• Difference between measured and simulated cross section used as systematic uncertainty (~7%)
$F_2^{p,d}$ results


Normalization uncertainty: 6.4% (P), 6.6% (D)

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DIFFRACTION2010
$F_2^{p,d}$ results

✓ Agreement in the region of overlap $0.03 < x < 0.7, 1.1 \text{ GeV}^2 < Q^2 < 13 \text{ GeV}^2$


Normalization uncertainty: 6.4% (P), 6.6% (D)
$F_2^{p,d}$ results

- Agreement in the region of overlap $0.03 < x < 0.7, \ 1.1 \ GeV^2 < Q^2 < 13 \ GeV^2$
- Data in a so far unexplored region $0.007 < x < 0.05, \ 0.3 \ GeV^2 < Q^2 < 0.9 \ GeV^2$


Normalization uncertainty:
6.4% (P), 6.6% (D)
HERMES data agree with previous parameterization from SMC and are included in the fit GD10.
• HERMES data agree with previous data in the same kinematic range
The Parameterization GD10-P,D

\[ \sigma_{L+T}(\gamma^*p) = \frac{4\pi\alpha_{em}}{Q^2(1-x)} \frac{Q^2 + 4M^2x^2}{Q^2} \cdot F_2 \]

• \( \chi^2 \) includes point-by-point statistical and systematic uncertainties
• Consistency with respect to \( R=\sigma_T/\sigma_L \)
• Experimental normalizations are fitted
• Calculation of statistical error bands

With the inclusion of HERMES data:
• Parameter uncertainties decrease by up to 30% (proton) and 40% (deuteron)
• \( \chi^2 \) changes from 0.90 to 0.92(proton) and 0.86 to 0.90 (deuteron)
Cross section $\sigma_{L+T}^{p,d}$
Cross section ratio $\sigma^p / \sigma^d$

- Determined on a year-by-year basis and then averaged
- Reduction of
  - Normalization uncertainty
  - many systematic effects (misalignment, PID...)

The remaining 1.4% normalization uncertainty comes from variations of beam conditions within each data set.

HERMES data agree with data from SLAC (similar $Q^2$) and data at higher $Q^2$ from NMC. BCDMS data are known to disagree with the other data sets.
Conclusions

HERMES has measured the structure functions $F_2^p$ and $F_2^d$. Data points agree with previous data in the data-overlap region and add new data in a previously unexplored region.

Fits to $F_2^{p,d}$ world data are performed, leading to a clear improvement of parameter uncertainties.

Proton and deuteron are combined to obtain $\sigma^p/\sigma^d$, resulting in a large cancellation of systematic uncertainties on the two targets.
PID efficiencies and contaminations

Dependence on momentum (eff.’s decrease at higher $p$), production, bin
Eff $> 94\%$, C $< 2\%$