Measuring the Fifth Structure Function in $D(\vec{e}, e'p)n$

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for the CLAS Collaboration

1. Introduction and Background.
2. Event Selection and Corrections.
3. Extracting the Fifth Structure Function.
4. Preliminary Comparison with Theory
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Scientific Motivation

- Establish a baseline for the hadronic model to meet. The deuteron is an essential testing ground because it is the simplest nucleus. On the theory side see also Deuteron Benchmarking Project.

- Differing mix of relativistic corrections (RC), meson-exchange currents (MEC), final-state interactions (FSI), and isobar configurations (IC) depending on kinematics.

- Learn more about FSI in quasielastic kinematics.
  - The fifth structure function is zero in PWIA and is dominated by FSI.
  - Short-Range Correlations (SRC).
  - Deuteron as neutron target, $N^* N$ interaction ...

\textsuperscript{a}http://hule.fi u.edu/highnp/deubenchmarking.htm
Introduction

- Goal: Measure the imaginary part of the LT interference term (the fifth structure function) of \( D(e', e'p)n \) at \( Q^2 \approx 1 \text{ (GeV/c)}^2 \).

- The cross section is

\[
\frac{d^3\sigma}{d\omega d\Omega_e d\Omega_p} = \sigma^{\pm} = \sigma_L + \sigma_T + \sigma_{LT} \cos(\phi_{pq}) + \sigma_{TT} \cos(2\phi_{pq}) + h\sigma'_{LT} \sin(\phi_{pq})
\]

where \( \pm \) refers to different beam helicities.

- Asymmetry requires polarized beam.

\[
A'_{LT} = \frac{\sigma^{+}_{90} - \sigma^{-}_{90}}{\sigma^{+}_{90} + \sigma^{-}_{90}} = \frac{\sigma'_{LT}}{\sigma_L + \sigma_T - \sigma_{TT}}
\]

\[
\phi_{pq}
\]

This asymmetry is for single angles only!
Existing Measurements of Structure Functions of the Deuteron

- Several results from Bates in the 1990’s for different structure functions and kinematics (i.e. quasielastic, ‘dip’ region) using the Out-Of-Plane Spectrometer. See S. Gilad, *et al.*, NP A631, 276c, (1998) and references therein.

- Existing efforts at JLab to measure deuteron structure functions in quasielastic kinematics.
  - W. Boeglin, Hall A experiment E01-020 - measure $R_{LT}$.
  - This report.
Data Collection with CLAS

- CEBAF is the 7/8-mile-long, racetrack-shaped electron accelerator at JLab that produces continuous electron beams up to 6 GeV.

- CLAS is a 45-ton, six-sector detector covering most of $4\pi$, with drift chambers to measure trajectories, scintillators for TOF, Cerenkov counters to identify electrons, and calorimeters to measure energy. A toroidal magnetic field determines momentum.
The Data Set

- Analyze data from the E5 run period in Hall B.
- Two beam energies, 4.23 GeV and 2.56 GeV, with normal torus polarity (electrons inbending).
- One beam energy 2.56 GeV with reversed torus polarity (electron outbending) to reach lower $Q^2$.
- Recorded about 2.3 billion triggers, $Q^2 = 0.2 - 5.0(GeV/c)^2$.
- Dual target cell with liquid hydrogen and deuterium.
- Beam polarization: 0.736 ± 0.017
Event Selection and Corrections

- Select $e - p$ coincidences in quasi-elastic kinematics using a cut on the energy transfer so $\nu = \frac{Q^2}{2M_N} \pm 0.03$ GeV.

- Use missing mass to select neutrons $0.84 \text{ GeV}^2 \leq \text{MM}^2 \leq 0.92 \text{ GeV}^2$.

- Put fiducial cuts on electrons and protons.$^a$

- Corrections: acceptance,$^b$ momentum, beam charge asymmetry.

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$^a$See Poster 3A.00030 by Kristen Greenholt in CEU session this afternoon.

$^b$See Poster 3A.00012 by Rusty Burrell and Kuri Gill in CEU session this afternoon.
Method for Extracting $A'_{LT}$

To take full advantage of the nearly $4\pi$ coverage of CLAS we extract the $\phi_{pq}$-dependent moments of the data in each bin in $p_m$. Let

$$
\langle \sin \phi_{pq} \rangle_\pm = \frac{\int_{-\pi}^{\pi} \sigma^\pm \sin \phi_{pq} d\phi_{pq}}{\int_{-\pi}^{\pi} \sigma^\pm d\phi_{pq}} = \pm \frac{\sigma'_{LT}}{2\sigma_L + \sigma_T} \approx \pm \frac{A'_{LT}}{2} .
$$

If there is a sinusoidally-varying component to the acceptance, then

$$
\langle \sin \phi_{pq} \rangle_\pm = \pm \frac{A'_{LT}}{2} + \alpha_{acc}
$$

and we can get rid of that background by subtracting the results for the different helicities.

$$
\langle \sin \phi_{pq} \rangle_+ - \langle \sin \phi_{pq} \rangle_- = A'_{LT}
$$
Preliminary $A'_{LT}$ Results for $D(\vec{e}, e'p)n$
Some Consistency Checks

Effect of Fiducial Cuts

$ep \rightarrow e'p\pi^0$ Comparison

$D(\vec{e}, e'p)n$ (Preliminary)

- $E = 2.6$ GeV
  - Reversed torus polarity
  - LT $A'$
  - Normal torus polarity

Run Number:
- 24520
- 24530
- 24540
- 24550
- 24560
- 24570
- 24580

$Q_\pm \geq -0.0127$, $LT < A'$. $Q_\pm \geq -0.0158$, $LT < A'$. K. Joo and C. Smith
Some Consistency Checks

Effect of Fiducial Cuts

$e p \rightarrow e' p \pi^0$ Comparison

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E = 2.6 GeV

Reversed torus polarity

Normal torus polarity

Run Number

24520 24530 24540 24550 24560 24570 24580

LT $A'$

-0.1

-0.08

-0.06

-0.04

-0.02

0

0.02

0.04

0.06

0.08

0.1

0

0.05

0.1

$p_m$ (GeV/c)

0 0.1 0.2 0.3 0.4 0.5 0.6 0.7

Red - electron and proton fiducials on

Blue - fiducials off

K. Joo and C. Smith

This work
Some Consistency Checks

Effect of Fiducial Cuts

$D(\vec{e}, e'p)n$ (Preliminary)

$e_p \rightarrow e'p\pi^0$ Comparison

$<A'_{LT}> = -0.0158 \pm 0.0009, Q^2 = 0.4 - 0.7 \text{ GeV}^2$

$K. Joo and C. Smith$
Preliminary Comparison With Theory

- Hartmuth Arenhövel (black) - Starts with the non-relativistic Schrödinger Equation and adds RC, MEC, IC, and FSI. Averaged over the CLAS acceptance.

![Diagram showing preliminary results for different Q^2 values.](image-url)
Preliminary Comparison With Theory

- Hartmuth Arenhövel (black) - Starts with the non-relativistic Schrödinger Equation and adds RC, MEC, IC, and FSI. Averaged over the CLAS acceptance.

- Jean-Marc Laget (green) - Uses a diagrammatic approach. Calculation is for $Q^2 = 1.1$ GeV$^2$ (lower panel) and $Q^2 = 0.7$ GeV$^2$ (upper panel).

![Graph showing $D(\vec{e}, e'p)n$ Preliminary](image)
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Sabine Jeschonnek (red) - Calculation is for $Q^2 = 1.1$ GeV$^2$.

See Sabine’s talk!
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See Sabine’s talk!
Conclusions

- We observe a 4% dip in $A'_{LT}$ at $p_m \approx 220$ MeV/c in the low $Q^2$ data set and a 6% dip in $A'_{LT}$ at the same $p_m$ in the middle $Q^2$ range. The high-$Q^2$ data has poor statistics for $A'_{LT}$.

- The calculation by Jeschonnek reproduces the data in the middle $Q^2$ range!

- At low $p_m$, the calculations by Arenhövel reproduce the data, but diverge (they’re too negative) above $p_m = 250$ MeV/c.

- At low $p_m$, the Laget calculations reproduce the low-$Q^2$ data, but are too small in magnitude in the middle $Q^2$ range.

- The $\langle \sin \phi_{pq} \rangle$ technique works well including the subtraction of the two different beam helicities to eliminate sinusoidal components of the acceptance.
Asymmetry Background Results

\[ d(\bar{e}, e'p)n (\text{Preliminary}) \]

- **E=2.6 GeV, \( Q^2=0.2-0.5 \text{ (GeV/c)}^2 \)**
  - Reversed torus polarity
  - Red - electron and proton fiducials on
  - Blue - fiducials off

- **E=2.6 GeV, \( Q^2=0.7-1.1 \text{ (GeV/c)}^2 \)**
  - Normal torus polarity

- **E=4.2 GeV, \( Q^2=1.4-2.3 \text{ (GeV/c)}^2 \)**
  - Normal torus polarity

\[ d(\bar{e}, e'p)n \]

- **E=2.6 GeV, Reversed torus polarity**
  - red - efids, pfids on
  - blue - fiducials off

- **2.6 GeV, normal polarity**
  - red - efids, pfids on
  - blue - fiducials off

- **E=4.2 GeV, Normal torus polarity**

\[ p_m \text{ (GeV/c)} \]
$W$ dependence of $A'_{LT}$ at the Quasi-elastic Peak