A Measurement of the $g_2$ Spin Structure Function at Low $Q^2$

Toby Badman
The University of New Hampshire
For the Jlab g2p collaboration
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Inclusive Electron Scattering

\[ p = (E, k) \]
\[ p' = (E', k') \]
\[ q = (\nu, \tilde{q}) \]
\[ W \]
\[ P = (M, 0) \]

Inclusive unpolarized cross section:
\[
\frac{d^2\sigma}{d\Omega dE'} = \sigma_{Mott} \left[ \frac{1}{\nu} F_2(x, Q^2) + \frac{2}{M} F_1(x, Q^2) \tan^2 \left( \frac{\theta}{2} \right) \right]
\]

Inclusive polarized cross section differences:
\[
\frac{d^2\sigma}{d\Omega dE'} (\uparrow \downarrow - \downarrow \uparrow) = \frac{4 \alpha^2}{MQ^2\nu} E' \left[ (E + E' \cos \theta) g_1(x, Q^2) - \frac{Q^2}{\nu} g_2(x, Q^2) \right]
\]
\[
\frac{d^2\sigma}{d\Omega dE'} (\uparrow\Rightarrow - \downarrow\Rightarrow) = \frac{4 \alpha^2 \sin \theta E'^2}{MQ^2\nu^2} \left[ \nu g_1(x, Q^2) - 2E g_2(x, Q^2) \right]
\]

\[ Q^2 = -q^2 = 4EE' \sin^2 \left( \frac{\theta}{2} \right) \]
\[ W^2 = M^2 + 2M\nu - Q^2 \]
\[ x = \frac{Q^2}{2M\nu} \]
Experimental Technique

Measured quantities:

\[ g_1 = \frac{MQ^2}{4\alpha_e^2} \frac{y}{(1-y)(2-y)} \left[ \Delta \sigma_\parallel + \tan^\theta \frac{1}{2} \Delta \sigma_\perp \right] \]

\[ \Delta \sigma_\perp \text{ contributes only } \sim 5\% \text{ to } g_1 \text{ at our kinematics.} \]

\[ g_2 = \frac{MQ^2}{4\alpha_e^2} \frac{y^2}{2(1-y)(2-y)} \left[ -\Delta \sigma_\parallel + \frac{1 + (1-y) \cos \theta}{(1-y) \sin \theta} \Delta \sigma_\perp \right] \]

\[ \Delta \sigma_\perp \text{ measured during } g_2^p \text{ experiment, } \Delta \sigma_\parallel \text{ contributes } \sim 2 - 8\% \text{ to } g_2. \]
Motivation

- Very little data exists for the proton $g_2$ structure function.
- Measurements at Jefferson Lab:
  - RSS ($1 < Q^2 < 2 \text{ GeV}^2$) published
  - SANE ($2 < Q^2 < 6 \text{ GeV}^2$) analysis
  - $g_{2p}$ ($0.02 < Q^2 < 0.2 \text{ GeV}^2$) analysis
- A low $Q^2$ measurement will be a useful tool for testing the validity of $\chi$PT and the studying the moments of $g_2$.

Existing data:

![Graph showing existing data for $g_2$ at SLAC and JLAB SANE.](https://via.placeholder.com/150)
Experimental Setup

Jefferson Lab CEBAF:
- 12 GeV maximum beam energy
- 200 $\mu$A maximum current
- 85% electron polarization

Hall A:
- All new beam diagnostics (BPM, BCM, rasters)
- Chicane installed for transverse target field
- 2.5/5T rotatable target field
- Septum magnet for small scattering angles
Model estimated kinematic coverage
Physics Asymmetry

Preliminary systematics:

- Target Polarization: 2-8%
- Inelastic XS Model: 10%
- Dilution: 2-8%
- Packing Fraction: 5-45%

2.254 GeV 5T Transverse Asymmetry

$g_2^P$ Collaboration, Apr. 12 2016
No radiative corrections
Preliminary systematics
Unpolarized Cross Section

- Acceptance correction study is still underway.
- An acceptance cut is chosen such that the theta/phi distribution is flat within the cut region.

- Proton XS is calculated as:
  \[
  \frac{d\sigma}{d\Omega dE} = \frac{e^{M_{NH3}}}{A\rho_{NH3}Z_{NH3}} f Y_{NH3}
  \]

Preliminary systematics:

<table>
<thead>
<tr>
<th>Packing Fraction</th>
<th>5-45%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dilution</td>
<td>2-8%</td>
</tr>
<tr>
<td>Unpolarized XS model (dilution)</td>
<td>10%</td>
</tr>
<tr>
<td>Acceptance</td>
<td>25%</td>
</tr>
</tbody>
</table>
Radiative Corrections

- Preliminary polarized radiative correction:

\[ R = A_{unrad} - A_{rad} \]

- \( A_{(un)rad} \) is generated from MAID.

- Polarized radiative correction study is still underway, results will be updated when complete.
Proton Spin Structure Functions

Preliminary systematics:

<p>| | |</p>
<table>
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<tr>
<td>Unpolarized XS model</td>
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\[ Q^2 \approx 0.1 \text{GeV}^2 \]
A measurement of the proton spin structure function $g_2$ at low $Q^2$ is an important component in the testing of a number of effective theories of QCD.

The g2p experiment, which measured $g_2$ in a $Q^2$ region of $0.02 - 0.2\,\text{GeV}^2$, successfully ran at Jefferson Lab during the spring of 2012 and analysis is still ongoing.

Preliminary methods for determining the acceptance and radiative effects give promising results for the spin structure at a $Q^2$ of $0.1\,\text{GeV}^2$.

Current efforts are focused on improving these methods and reducing systematics.

More results to come shortly!
Thank You!

g2p Analysis Team:

**Students**
Toby Badman
Melissa Cummings
Chao Gu
Min Huang
Jie Liu
Pengjia Zhu
Ryan Zielinski

**Spokespeople**
Alexandre Camsonne
JP Chen
Don Crabb
Karl Slifer

**Post Docs**
Kalyan Allada
Elena Long
James Maxwell
Vince Sulkosky
Jixie Zhang
The B.C. Sum Rule

- $0^{th}$ moment of $g_2$:
  \[
  \Gamma_2 = \int_0^1 g_2(x, Q^2) \, dx = 0
  \]

- Existing data:
  - Brown: SLAC E155x
  - Red: Hall C RSS
  - Black: Hall A E94-010
  - Green: Hall A E97-110
  - Blue: Hall A E01-012

- $g_2p$ hopes to fill in low $Q^2$ region for the proton.
Spin Polarizabilities

- \( \gamma_o = \frac{16 \alpha M^2}{Q^6} \int_0^x x^2 \left[ g_1(x, Q^2) - \frac{4M^2}{Q^2} x^2 g_2(x, Q^2) \right] dx \)

- \( \delta_{LT} = \frac{16 \alpha M^2}{Q^6} \int_0^x x^2 [g_1(x, Q^2) + g_2(x, Q^2)] dx \)

- Generalized spin polarizabilities \( \gamma_o \) and \( \delta_{LT} \) are benchmark tests of \( \chi \)PT.

- Some disagreement with neutron polarizabilities.

- No proton data yet!

Data from E94010

The physics asymmetry first requires the calculation of two target quantities:

- The length ratio of material in the target cup, called the *packing fraction*.
  \[
P_f = \left( \frac{Y_P}{Y_E} - 1 \right) \left( \frac{\chi_N \sigma_N + \chi_H \sigma_H}{\chi_{He} \sigma_{He}} \right)^{-1}
\]

- The fractional composition of proton material in the target, called the *dilution factor*.
  \[
f = 1 - \frac{Y_{BG}}{Y_P}
\]

- The asymmetry is then calculated as:
  \[
  A_{phy} = \frac{1}{fP_b P_t} \frac{Y_+ - Y_-}{Y_+ + Y_-}
  \]
Cross Section Differences

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Very Preliminary

$\rho_2$ Collaboration, Apr. 12 2016
No radiative corrections
Preliminary systematics