Highest $Q^2$ Polarized Measurement of the Electric Form Factor of the Neutron – E02-013

Presented by
Jonathan Miller
For the Hall A E02-013 Collaboration
6/14/2008
Overview

• Introduction
• Electric Form Factor of the Neutron
• Quasi-elastic Process Selection
• New Techniques
• Asymmetry Calculation and Results
• Conclusions and Future
## Collaborators

<table>
<thead>
<tr>
<th>Name</th>
<th>Institution</th>
<th>Responsibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gordon Cates</td>
<td>University of Virginia</td>
<td>Spokesperson</td>
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<tr>
<td>Nilanga Liyanage</td>
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<td>Spokesperson</td>
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<td>Bogdan Wojtsekhowski</td>
<td>Jefferson Lab</td>
<td>Spokesperson</td>
</tr>
<tr>
<td>Robert Feuerbach</td>
<td>William and Mary</td>
<td>Post Doc and Analysis Coordinator</td>
</tr>
<tr>
<td><strong>Current Students</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sergey Abrahamyan</td>
<td>University of Yerevan</td>
<td>Monte Carlo, Shower and Analysis of $Q^2 = 1.2 \text{ GeV}^2$</td>
</tr>
<tr>
<td>Brandon Craver</td>
<td>University of Virginia</td>
<td>Drift Chambers</td>
</tr>
<tr>
<td>Aidan Kelleher</td>
<td>William and Mary</td>
<td>Target and Analysis of $Q^2 = 1.7$ and $2.5 \text{ GeV}^2$</td>
</tr>
<tr>
<td>Jonathan Miller</td>
<td>University of Maryland</td>
<td>Neutron Arm and Analysis of $Q^2 = 1.7, 2.5, \text{ and } 2.5 \text{ GeV}^2$</td>
</tr>
<tr>
<td><strong>Graduated</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seamus Riordan, PhD</td>
<td>Carnegie Mellon E02-013 Post Doc</td>
<td>Analysis Software and Analysis of $Q^2 = 1.7 \text{ and } 3.5 \text{ GeV}^2$ and Post Doc</td>
</tr>
<tr>
<td>Tim Ngo, MS</td>
<td>University of California</td>
<td>Neutron Arm Geometry</td>
</tr>
<tr>
<td>Ameya Kolarkar, PhD</td>
<td>University of Kentucky</td>
<td>Target</td>
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The Electric Form Factor of the Neutron

\[
\frac{d\sigma}{d\Omega} = \left( \frac{d\sigma}{d\Omega} \right)_{\text{Mott}} \frac{E_f}{E_i} \left[ \frac{G_E^2 + \tau G_M^2}{1 + \tau} + 2\tau G_M^2 \tan^2 \frac{\theta}{2} \right]
\]

\[
\left( \frac{d\sigma}{d\Omega} \right)_{\text{Mott}} = \left( \frac{\alpha \cos \frac{\theta}{2}}{2 E_i \sin^2 \frac{\theta}{2}} \right)^2
\]

\[
\tau = \frac{Q^2}{4M}
\]

\[
G_E^n Q^2 = 0 \implies 0
\]

\[
G_M^n Q^2 = 0 \implies \mu_n
\]
Using GPDs, the ratio of the up and down flavor components of the Dirac form factor are constrained by a measurement of the Sachs electric form factor.

A smaller value of $G_{E \, n}$ relates to a smaller value of the ratio.
What are we using to make the measurement?

- CEBAF provides a polarized (83%) electron beam.
- The Target provides high polarization throughout the experiment (45-50%).
- Big Bite provides the trigger, and selects for scattered electron events.
- The Neutron Arm provides selection of quasi-elastic events (using time of flight and hit location) and charge identification.
How are we measuring $G_E^n$?

$\sigma^{\text{pol}} = \Sigma + h\Delta$

$A = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-}$

$= \frac{\alpha \lambda + \beta}{\gamma \lambda^2 + \delta}$

$\lambda = \frac{G_E}{G_M}$

Coefficients averaged over acceptance.
# Experiment Overview

<table>
<thead>
<tr>
<th>Beam Energy (GeV)</th>
<th>$Q^2$ (GeV$^2$)</th>
<th>Neutron Momentum (GeV/c)</th>
<th>Flight Path (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.519</td>
<td>1.2</td>
<td>1.2</td>
<td>9</td>
</tr>
<tr>
<td>2.079</td>
<td>1.7</td>
<td>1.6</td>
<td>9</td>
</tr>
<tr>
<td>2.638</td>
<td>2.5</td>
<td>2.1</td>
<td>9</td>
</tr>
<tr>
<td>3.290</td>
<td>3.5</td>
<td>2.6</td>
<td>12</td>
</tr>
</tbody>
</table>

- **Challenges:**
  - High $Q^2$
  - High rate in the detectors
  - Determination of charged
  - Due to large fringe magnetic field caused by Big Bite
Experiment Observations

- The time spectrum for quasi-elastics currently has a $\sigma < 500$ ps.
- Even clean events (like the one pictured) still contain many hits not relating to the event. Most events are much messier.

Neutron Arm Event – Shows hits within the neutron arm (veto and neutron detectors).
• Adjust minimum amplitude to remove lower energy hits.
• Removes accidentals in the dead region (up to 110 ns) and in the coincidence region.
• Using a value of 200 safely removes accidentals.
• Veto Rate is accidental rate per paddle (average).
Main selection of Quasi-elastic Events is via

- Time of Flight
- Perpendicular Momentum
- Invariant Mass

For quasi-elastics, $\sigma$ of the Time Spectrum is 500 ps for $Q^2 = 1.7 \text{ GeV}^2$. 

$$p_\perp = p \times \hat{q}$$
Accidental Background Technique

Blue is the region used to determine total background counts.

Green is region to determine the ratio of charged to uncharged.

Red is the region used to select (quasi)elastics.

\[ N_{\text{total}} = N_{\text{QE}} + N_{\text{Back}} \]

To determine the ratio of charged to uncharged events, events far from the quasi-elastic region are used so that they are not effected by the quasi-elastic events.
Large amounts of data need removed at \( Q^2 = 3.5 \text{ GeV}^2 \) to remove pion electroproduction.

These cuts are still necessary at \( Q^2 = 1.7 \text{ GeV}^2 \).

The cuts used are for a missing mass of \( \leq 2 \text{ GeV} \).

\[ \text{He} \left( \vec{e}, e'N \right) X \]

\[ m_{\text{miss}}^2 = \left( p_{He} + q - p_n \right)^2 \]
Asymmetry Calculation

• To determine the physical asymmetry:
  – The accidental background is subtracted from the raw asymmetry.
  – Proton physical asymmetry is calculated from the known proton form factors.
  – Proton to neutron conversion between the target and the detector is accounted.
  – Various other dilution corrections are included in the Table below.

<table>
<thead>
<tr>
<th>Corrections</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam Polarization</td>
<td>83.5% ± 1.1%</td>
</tr>
<tr>
<td>Target Polarization</td>
<td>48.7% ± 2%</td>
</tr>
<tr>
<td>Neutron Polarization</td>
<td>86% ± 2%</td>
</tr>
<tr>
<td>Nitrogen Dilution</td>
<td>94.3% ± 0.9%</td>
</tr>
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## $G_E^n$ Calculation

<table>
<thead>
<tr>
<th>Name</th>
<th>$Q^2 = 1.7 , \text{GeV}^2$ (± Sta ± Sys)</th>
<th>$Q^2 = 3.5 , \text{GeV}^2$ (± Sta ± Sys)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw Asymmetry</td>
<td>-0.058 ± 0.003</td>
<td>-0.026 ± 0.008</td>
</tr>
<tr>
<td>Number of QE</td>
<td>156061</td>
<td>15325</td>
</tr>
<tr>
<td>$Q^2$</td>
<td>1.72</td>
<td>3.47</td>
</tr>
<tr>
<td>Physical Asymmetry</td>
<td>-0.256 ± 0.011 ± 0.02</td>
<td>-0.117 ± 0.036 ± 0.012</td>
</tr>
<tr>
<td>Lambda (form factor ratio)</td>
<td>-0.207 ± 0.029</td>
<td>-0.213 ± 0.057</td>
</tr>
<tr>
<td>$G_E^n$ (not including FSI)</td>
<td>0.0317 ± 0.002 ± 0.0029</td>
<td>0.0109 ± 0.0026 ± 0.0008</td>
</tr>
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</table>
Results
Preliminary
To Do

• Final State Interaction calculations in progress.
• Implement Ole Hansen’s new Big Bite tracking code.
• Finalize Target, Big Bite and Neutron Arm calibrations.
• Results for $Q^2 = 1.2$ and $2.5 \text{ GeV}^2$.
• Improve Monte Carlo to account for Pion Electroproduction.
• Members of the analysis group will be working to have published all kinematics by early 2009.
Preliminary values of $G_E^n$ for $Q^2 = 1.7$ and $3.5$ GeV$^2$ achieved.

The $Q^2 = 3.5$ GeV$^2$ point shows the discriminating power of our results, and suggests a reevaluation of our understanding of GPDs and the orbital momentum of the quarks.