A Measurement of $G_{E^n}$ at High Momentum Transfer in Hall A

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For the E02-013 Collaboration and  
Hall A Collaboration
Elastic EM Form Factors

For an extended spin-1/2 particle, the general vertex term is:

\[ \Gamma^\mu = F_1(q^2) \gamma^\mu + \frac{\kappa}{2M} F_2(q^2) i \sigma^{\mu\nu} q^\nu \]

Elastic cross-section:

\[
\frac{d\sigma}{d\Omega_{\text{finite}}} = \left( \frac{d\sigma}{d\Omega} \right)_M \left[ (F_1^2 + \tau \kappa^2 F_2^2) + 2\tau (F_1 + \kappa F_2)^2 \tan^2 \frac{\theta_e}{2} \right]
\]

Or in terms of the Sachs Form factors:

\[
\frac{d\sigma}{d\Omega} = \left( \frac{d\sigma}{d\Omega} \right)_M \left[ \frac{G_E^2 + \tau G_M^2}{1 + \tau} + 2\tau G_M^2 \tan^2 \frac{\theta_e}{2} \right]
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Dominate at large \( Q^2 \)
Double Polarization Measurement

\[
A_N = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}
\]

\[
A_{phys} = - \left( \frac{G_E}{G_M} \right) \frac{2\sqrt{\tau(\tau + 1)} \tan(\theta_e/2) \sin \theta^* \cos \phi^*}{(G_E/G_M)^2 + \tau(1 + 2(1 + \tau) \tan(\theta_e/2))} \\
- \frac{2\tau \sqrt{1 + \tau + (1 + \tau)^2 \tan(\theta_e/2) \tan(\theta_e/2) \cos \theta^*}}{(G_E/G_M)^2 + \tau(1 + 2(1 + \tau) \tan(\theta_e/2))}
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\[ -2\tau \sqrt{1 + \tau + (1 + \tau)^2 \tan(\theta_e/2) \tan(\theta_e/2) \cos\theta^*} \]

\[ \frac{1}{(G_E/G_M)^2 + \tau(1 + 2(1 + \tau) \tan(\theta_e/2))} \]
Double Polarization Measurement

\[
A_N = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}
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A_{phys} = - \left( \frac{G_E}{G_M} \right) \frac{2 \sqrt{\tau (\tau + 1) \tan (\theta_e/2) \sin \theta^* \cos \phi^*}}{(G_E/G_M)^2 + \tau (1 + 2(1 + \tau) \tan (\theta_e/2))}
\]

\[
2\tau \sqrt{1 + \tau + (1 + \tau)^2 \tan (\theta_e/2) \tan (\theta_e/2) \cos \theta^*}
\]

\[
\left( \frac{G_E}{G_M} \right)^2 + \tau (1 + 2(1 + \tau) \tan (\theta_e/2))
\]
Elastic EM Form factors: the Neutron

- $G_M^n$ behavior well matched by the dipole form up to $Q^2 \sim 4 \text{GeV}^2$
- $G_E^n$ more sensitive than other FF to details of the pion-cloud at low $Q^2$
- $G_E^n$ is not precisely measured above $1.5 \text{GeV}^2$
- Permits disentanglement of $F_2$

\[
F_1^n(t) = \frac{2}{3} F_1^u(t) - \frac{2}{3} F_1^d(t)
\]
\[
F_2^n(t) = \frac{2}{3} F_2^u(t) - \frac{2}{3} F_2^d(t)
\]
\[
F_1^q(t) = \int_{-1}^{+1} dx \ e_q H^q(x, \xi, t)
\]
\[
F_2^q(t) = \int_{-1}^{+1} dx \ e_q E^q(x, \xi, t)
\]
Exclusive QE scattering: $^{3}\text{He}(e,e'n)$

E02-013: Cates, Liyanage, Wojtsekhowski

$Q^2 = 1.3, 1.7, 2.5, 3.5 \text{ GeV}^2$
Exclusive QE scattering: $^3\text{He}(\bar{e},e'n)$

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$Q^2 = 1.3, 1.7, 2.5, 3.5 \text{ GeV}^2$

Neutron Arm (Big HANG)

Compton Polarimeter

Moller Polarimeter

$^3\text{He}$ target

$\sim 9 \text{ m}$

$\sim 2.5 \text{ m}$

BB Dipole

MWDC's

Pre-shower Timing Plane Shower

2 veto planes

7 Iron/scintillator sandwich planes

$e$ $e'$
Exclusive QE scattering: $^3$He($\vec{e},\vec{e}'n$)

Q$^2 = 1.3, 1.7, 2.5, 3.5$ GeV$^2$

Beam polarization 84%

Target polarization $\sim 50$

7 Iron/scintillator sandwich planes

E02-013: Cates, Liyanage, Wojtsekhowski

~9 m

~2.5 m
Data analysis: BigHand and BigBite

- Progress of 1.7 GeV² dataset shown
- $\sigma_{BH} \sim 400$ ps timing resolution achieved
- $\sigma_{P/p} \sim 0.8\%$ for BigBite
QE Event Selection

- Use “W” and missing 3-momentum to select QE events; (here W assumes scattering from stationary nucleon)

For protons from $^3\text{He}(e,e'p)$:
QE Event selection: Neutrons

Accidental Background

Quasi-elastic defined as:

- $0.8 < W < 1.15$ GeV
- $|P_{\text{par}} - q| < 250$ MeV/c
- $P_{\text{perp}} < 150$ MeV/c
A significant fraction of “neutron” background not from accidental coincidences, but are protons.
Observed Asymmetry at 1.7 GeV$^2$

Observed asymmetry is $0.0439 \pm 0.0024$

(5.5% relative statistical uncertainty)

Requires:
- proton→neutron conv.
- finite acceptance corr.
- dilution factors
- polarization factors
Contributions to $G_E^n$ at 1.7 GeV$^2$

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Value</th>
<th>Effective Uncertainty Relative to $G_E^n$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw Asymmetry</td>
<td>0.0439</td>
<td>5.5 %</td>
</tr>
<tr>
<td>Instr. Asymmetry</td>
<td>-0.006</td>
<td>0.1 %</td>
</tr>
<tr>
<td>Accid. Background</td>
<td>0.002</td>
<td>1.5 %</td>
</tr>
<tr>
<td>Beam Polarization $P_e$</td>
<td>0.84</td>
<td>3 %</td>
</tr>
<tr>
<td>Target Polarization $P_{He}$</td>
<td>0.49</td>
<td>4 %</td>
</tr>
<tr>
<td>Neutron Polarization $P_n$</td>
<td>$0.86 \cdot P_e$</td>
<td>2 %</td>
</tr>
<tr>
<td>Dilution factor from N$_2$</td>
<td>0.95</td>
<td>3 %</td>
</tr>
<tr>
<td>Dilution due to $p \rightarrow n$</td>
<td>in process</td>
<td></td>
</tr>
<tr>
<td>Correction for $A_{</td>
<td></td>
<td>}$</td>
</tr>
<tr>
<td>FSI/nuclear correction factor</td>
<td>0.85 to 1</td>
<td>in process</td>
</tr>
<tr>
<td>$G_M^n$</td>
<td>-0.170</td>
<td>1 %</td>
</tr>
</tbody>
</table>
Impact

\[ G_E^n \]

\[ Q^2 \ [\text{GeV}^2] \]

\[ F_2/F_1 \propto \ln^2(Q^2/\Lambda^2)/Q^2 \]

Herberg
Ostrick
Madey
Seimetz
Warren
Becker
Bermuth
E02-013 (proj)

Miller
Miller (q-only)
Galster fit
Summary and Outlook

• We have collected data for the first high-precision measurement of $G_E^n$ up to $Q^2=3.5$ GeV$^2$.

• Analysis of 1.7 GeV$^2$ set is nearing completion, and 3.5 GeV$^2$ is underway.

• The same experiment could be done at 4.5 GeV$^2$, and (with “super-BigBite) up to 7.5 GeV$^2$.

• The precision measurement at high $Q^2$ will determine $F_1$ and $F_2$, and the related GPD’s.