**Update for E12-07-104: Measurement of the Neutron Magnetic Form Factor at High $Q^2$ Using the Ratio Method on Deuterium**

- $G^n_M$: fundamental quantity that describes the neutron magnetization at low $Q^2$ and the quark structure at higher $Q^2$ (DOE Milestone HP4).
- Constraint on generalized parton distributions (GPDs), Guidal *et al*.
- Testing ground for calculations built on QCD: Miller (light-cone), Cloët *et al* (Dyson-Schwinger).
- Early challenge for lattice QCD at high $Q^2$ (DOE Milestone HP9).
- Wide $Q^2$ range needed to separate $u$ and $d$ spatial distributions.

![Graph showing $G^n_M/Q$](image)

Error bars are systematic uncertainty; statistical is less.

Part of NSAC Long Range Plan
Update for E12-07-104: CLAS12 $G_{M}^{n}$ - Experiment Summary

- Measure ratio of quasielastic (QE) $e - n$ to $e - p$ on deuterium.

$$R = \frac{\frac{d\sigma}{d\Omega}(2H(e, e'n)_{QE})}{\frac{d\sigma}{d\Omega}(2H(e, e'p)_{QE})}$$

- Reduces experimental effects (luminosity, Fermi corrections, deuteron wave function, ...) as in CLAS6.

- Extension of CLAS6 measurement (PRL 102, 192001, 2009).

- $Q^2 = 3.5 - 14.0$ GeV$^2$; 56 days.

- Statistical Uncertainty: $< 3\%$ in high-$Q^2$ bins; much better at lower $Q^2$.

- Systematic Uncertainty: $< 3\%$ across the full $Q^2$ range.
**Challenge:** Separate QE events from high-$Q^2$, inelastic background.

1. $\theta_{pq}$ cut: QE neutrons/protons emitted in a narrow cone along $\vec{q}$.
2. Hermiticity cut: No additional particles in the event.

Effect of $\theta_{pq}$ and hermiticity cuts.

Worst-case (high-$Q^2$) simulation.

- Internal consistency check for $e-n$: electromagnetic calorimeter and time-of-flight separately measure neutrons.


Using a proven method, we will significantly expand our understanding of nucleon structure and challenge theory.
1. Recall effect of requiring \( \theta_{pq} < 1.5^\circ \) and hermiticity cut to reduce inelastic background.

Effect of \( \theta_{pq} \) and hermiticity cuts.

2. To reduce inelastic background further, reduce the maximum \( \theta_{pq} \).

\[
f_{IN} = \frac{inelastic}{total} \text{ for } W^2 < 1.2 \text{ GeV}^2.
\]
Quasielastic Scattering, CLAS12, E = 11 GeV

$Q^2 = 15.0 \text{ GeV}^2$

$Q^2 = 3.5 \text{ GeV}^2$

$\theta_e \text{ (deg)}$

$\theta_n \text{ (deg)}$
1. For the CLAS6 data, the hermiticity cut is not needed. Applying it just reduces the already small inelastic background (compare black and red histograms).

2. Without requiring $\theta_{pq} < 3^\circ$, the hermiticity cut still reduces the inelastic background (compare blue and green histograms).

3. Hermiticity cut here includes $ep$ events with additional out-of-time tracks or ones that fall outside the vertex cut (1.5 cm).

4. Effect of hermiticity cut in CLAS12 simulation is qualitatively consistent with CLAS6, E5 data.
Characterize the neutron detection efficiency $\epsilon_n$ with

$$\epsilon_n = S \times \left( 1 - \frac{1}{1 + \exp\left(\frac{p_n - p_0}{a_0}\right)} \right)$$

where $S$ is the height of the plateau for $p_n > 2 \text{ GeV}/c$, $p_0$ is the center of the rising part of $\epsilon_n$, and $a_0$ controls the slope of $\epsilon_n$ in this region.

Fit the $\epsilon_n$ with a third-order polynomial and a flat region.

Use the original $\epsilon_n$ and the fit in reconstructing the neutrons and take the difference.
Systematic uncertainty $(\Delta G^n_M / G^n_M \times 100)$ based on differences in the proton reduced cross section parameterizations of Bosted and Arrington-Melnitchouk.

Systematic uncertainty $(\Delta G^n_M / G^n_M \times 100)$ based on differences in $G^n_E$ parameterizations of Kelly and BBBA05. Future measurements will reduce the uncertainty for $Q^2 < 7.5 \text{ GeV}^2$. 

The neutron electric form factor from Kelly and BBBA05 parameterizations as a function of $Q^{2}$ (J. J. Kelly, PRC 70, 068202 (2004) and R. Bradford et al., hep-ph/0602017.)
Summary of expected systematic uncertainties for CLAS12 $G_M^n$ measurement in percentages ($100 \times \Delta G_M^n/G_M^n = 2.5\% (2.7)$). Red numbers represent the previous upper limits from the CLAS6 measurement.

<table>
<thead>
<tr>
<th>Quantity</th>
<th>$\delta G_M^n/G_M^n \times 100$</th>
<th>Quantity</th>
<th>$\delta G_M^n/G_M^n \times 100$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neutron efficiency</td>
<td>&lt; 0.7(1.5)</td>
<td>$\theta_{pq}$ cut</td>
<td>&lt; 1.0(1.7)</td>
</tr>
<tr>
<td>proton $\sigma$</td>
<td>&lt; 1.5(1.5)</td>
<td>$G_E^n$</td>
<td>&lt; 0.7(0.5)</td>
</tr>
<tr>
<td>Background subtraction</td>
<td>&lt; 1.0</td>
<td>Fermi loss correction</td>
<td>&lt; 0.9</td>
</tr>
<tr>
<td>neutron accidentals</td>
<td>&lt; 0.3</td>
<td>Neutron MM cut</td>
<td>&lt; 0.5</td>
</tr>
<tr>
<td>neutron proximity cut</td>
<td>&lt; 0.2</td>
<td>proton efficiency</td>
<td>&lt; 0.4</td>
</tr>
<tr>
<td>Nuclear Corrections</td>
<td>&lt; 0.2</td>
<td>Radiative corrections</td>
<td>&lt; 0.2</td>
</tr>
</tbody>
</table>
Update for E12-07-104: Comparison of CLAS6 and CLAS12 measurements

- Black Squares - CLAS12 anticipated
- Red Circles - J. Lachniet et al.

Anticipated Statistical uncertainties only

Anticipated Systematic Uncertainty

Red Circles - J. Lachniet et al.
Black Squares - CLAS12 anticipated
Update for E12-07-104: Comparison of CLAS12 and E12-09-019 methods

1. To reduce inelastic background further, reduce the maximum $\theta_{pq}$.

\[
\frac{f_{IN}}{W^2 < 1.2 \text{ GeV}^2} = \frac{\text{inelastic}}{\text{total}}
\]

2. In a similar $Q^2$ range, in E12-09-019 only the $\theta_{pq}$ cut will be used leaving more inelastic background contaminating the the QE peak.

3. At higher $Q^2$ (i.e. in PR10-005), the width of the inelastic component will continue to increase.