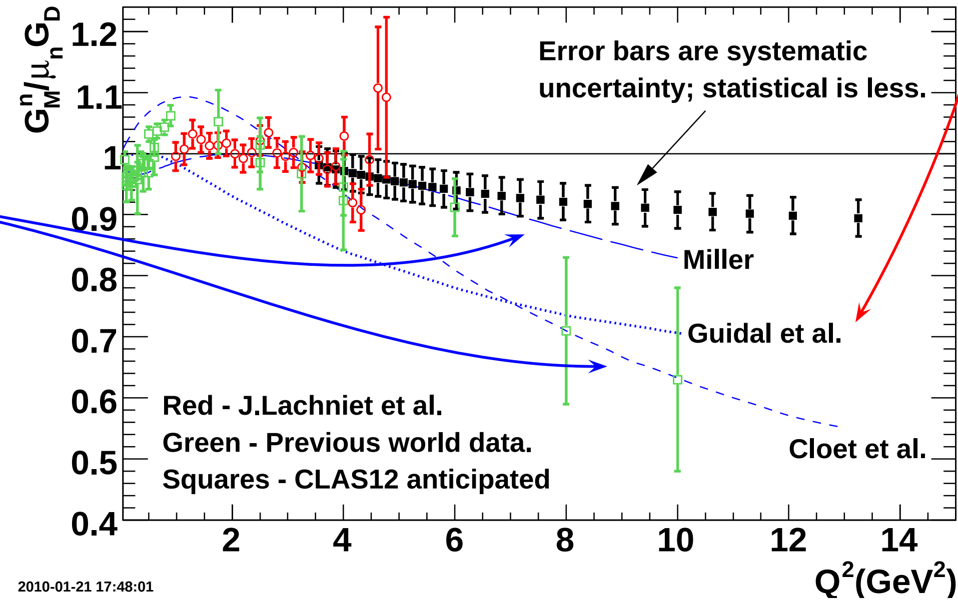
Update for E12-07-104: Measurement of the Neutron Magnetic Form Factor at High Q^2 Using the Ratio Method on Deuterium

- G_M^n: 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.



Part of NSAC Long Range Plan

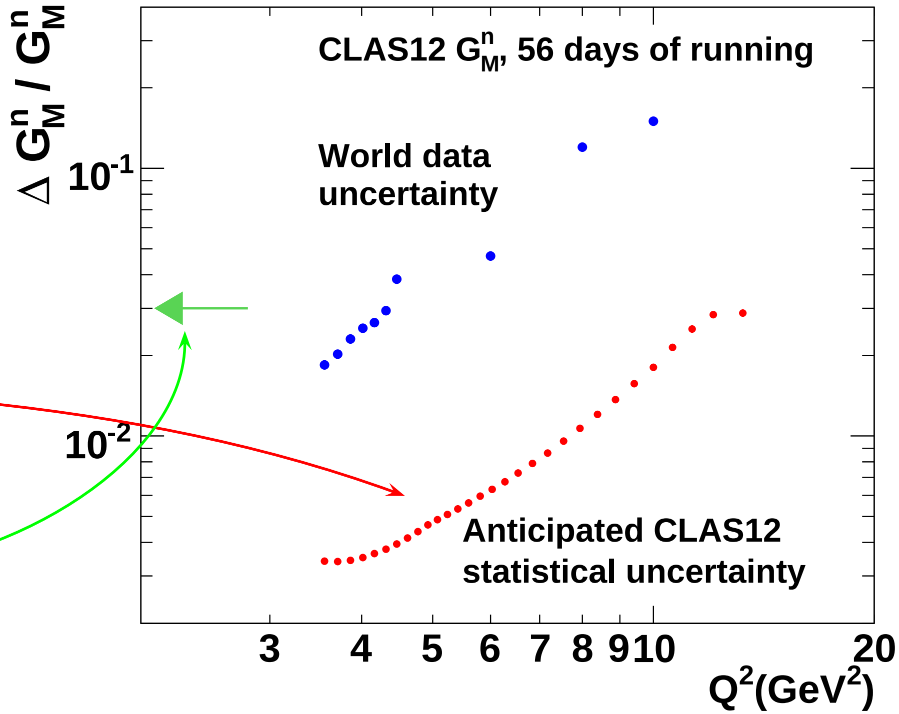
Update for E12-07-104: CLAS12 G_M^n - Experiment Summary

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

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

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

- Extension of CLAS6 measurement (PRL 102, 192001, 2009).
- $Q^2 = 3.5 - 14.0\ \mathrm{GeV}^2$; 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.

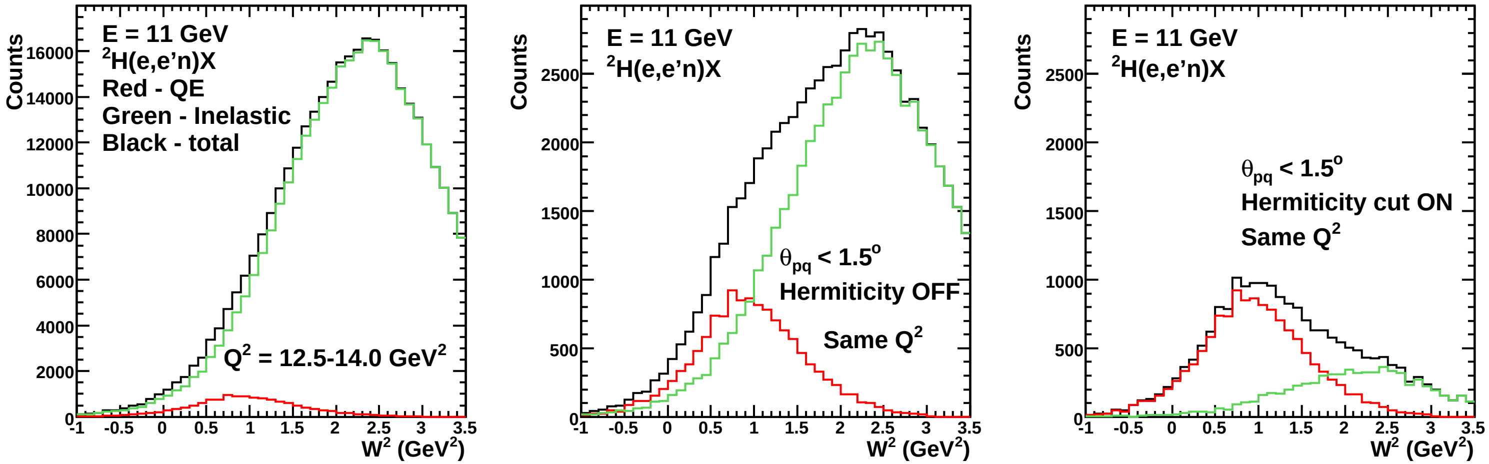


Update for E12-07-104: CLAS12 G_M^n - Analysis Details

- Challenge: Separate QE events from high-Q^2, inelastic background.
  1. θ_{pq} **cut:** QE neutrons/protons emitted in a narrow cone along $\vec{q}$.
  2. **Hermiticity cut:** No additional particles in the event.

Effect of θ_{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.
- Simultaneous, *in situ* calibrations with dual hydrogen-deuterium target.

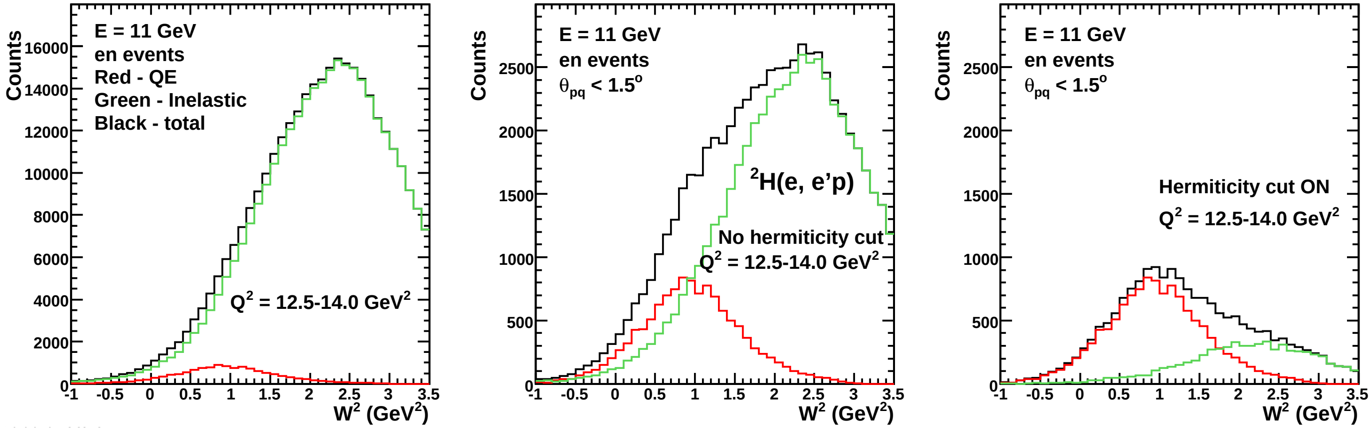
Using a proven method, we will significantly expand our understanding of nucleon structure and challenge theory.

Update for E12-07-104: CLAS12 G_M^n - Additional Slides

Update for E12-07-104: CLAS12 G_M^n - Optimizing θ_{pq} Cut

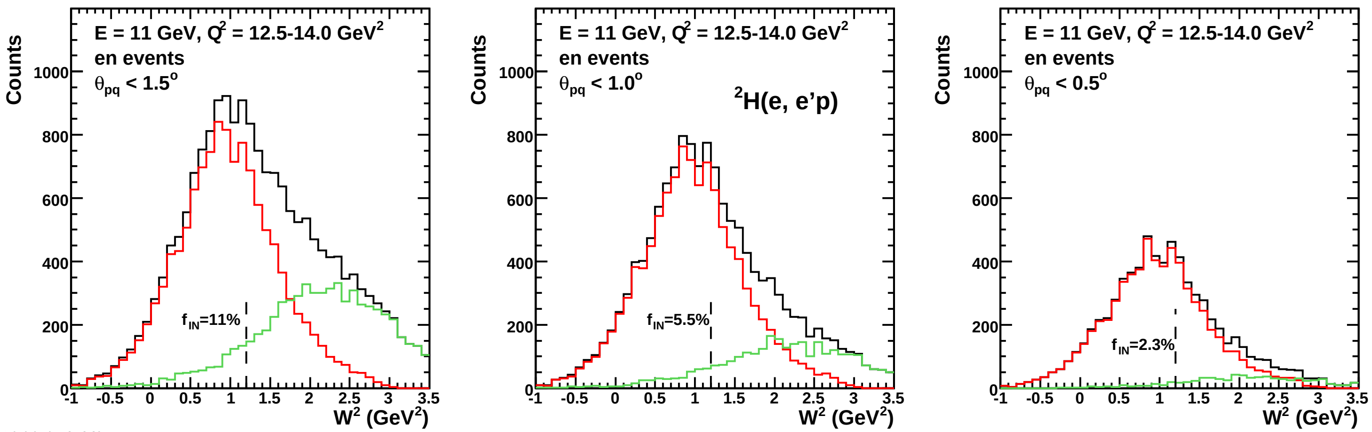
1. Recall effect of requiring $\theta_{pq} < 1.5^\circ$ and hermiticity cut to reduce inelastic background.

Effect of θ_{pq} and hermiticity cuts.

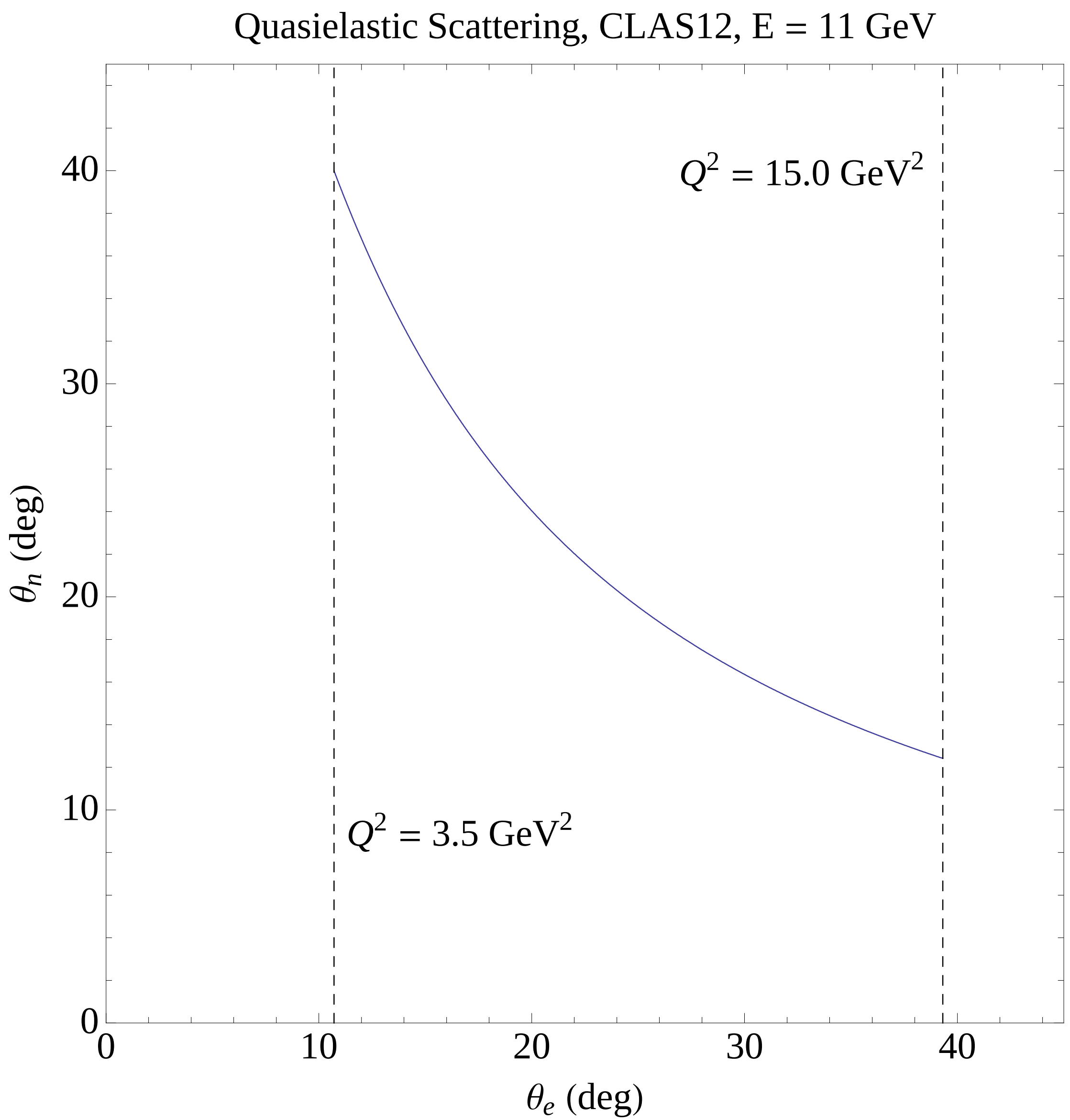


2. To reduce inelastic background further, reduce the maximum θ_{pq}.

$f_{IN} = \frac{inelastic}{total}$ for $W^2 < 1.2\ \mathrm{GeV}^2$.

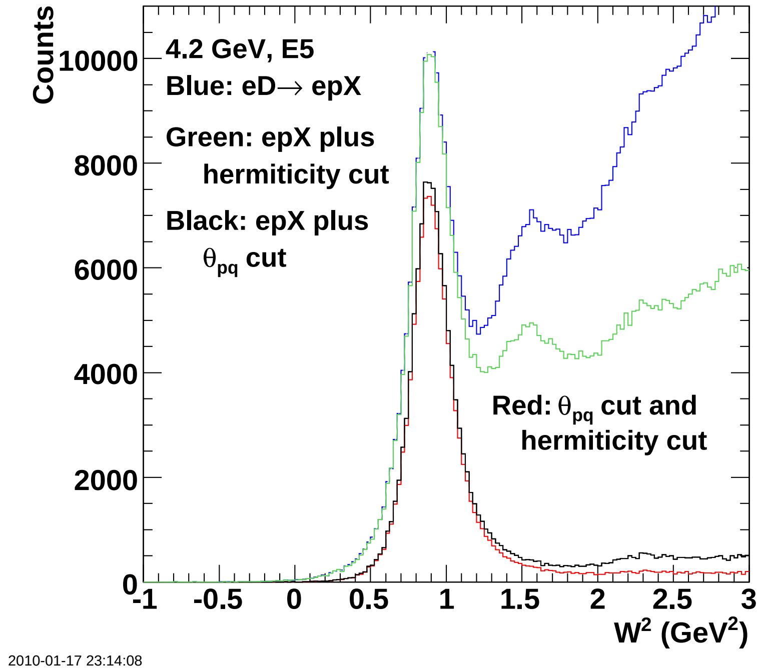


Update for E12-07-104: CLAS12 G_M^n - QE Scattering Angles



Update for E12-07-104: CLAS12 G_M^n - Hermiticity Cut

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.

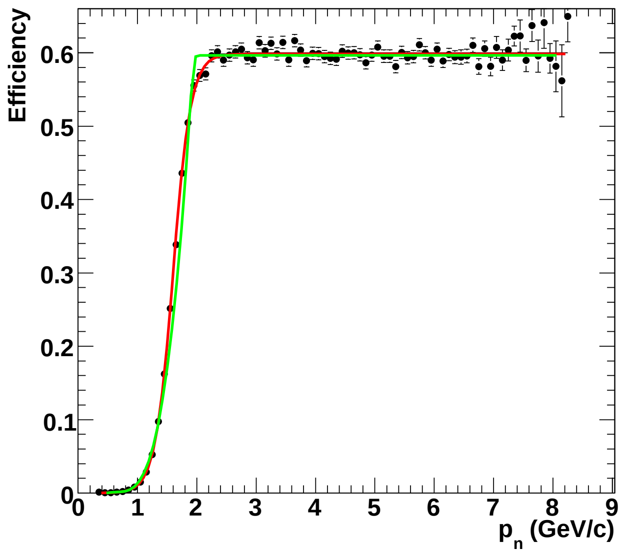
Update for E12-07-104: Neutron Detection Efficiency Uncertainty

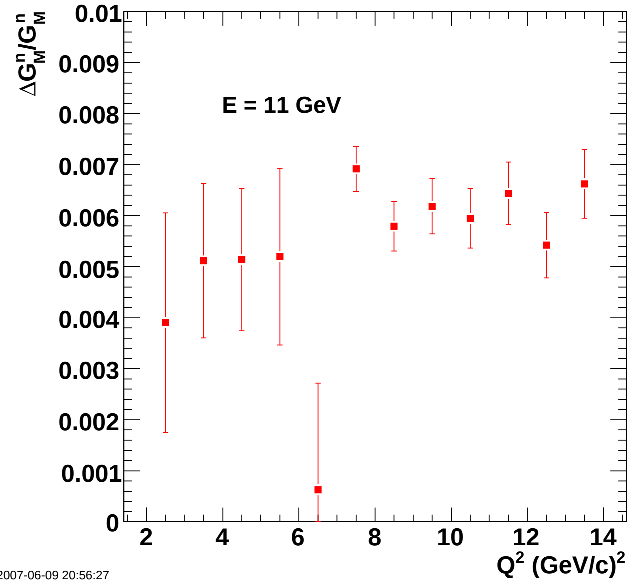
- Characterize the neutron detection efficiency ϵ_n with

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

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

- Fit the ϵ_n with a third-order polynomial and a flat region.
- Use the original ϵ_n and the fit in reconstructing the neutrons and take the difference.





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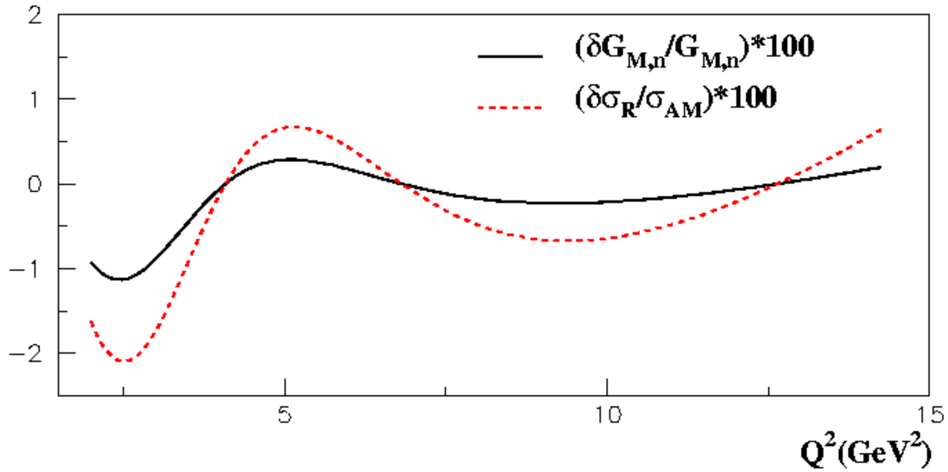
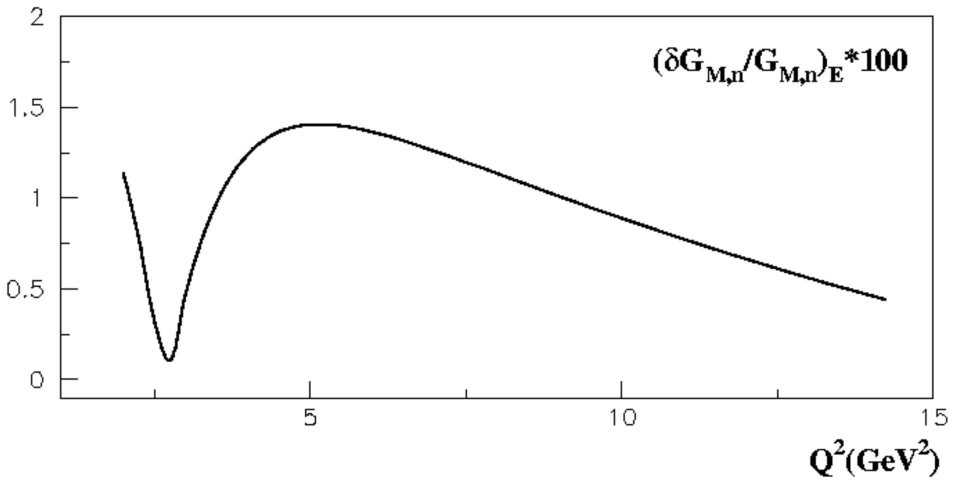
Update for E12-07-104: Other Elastic Form Factors Uncertainties

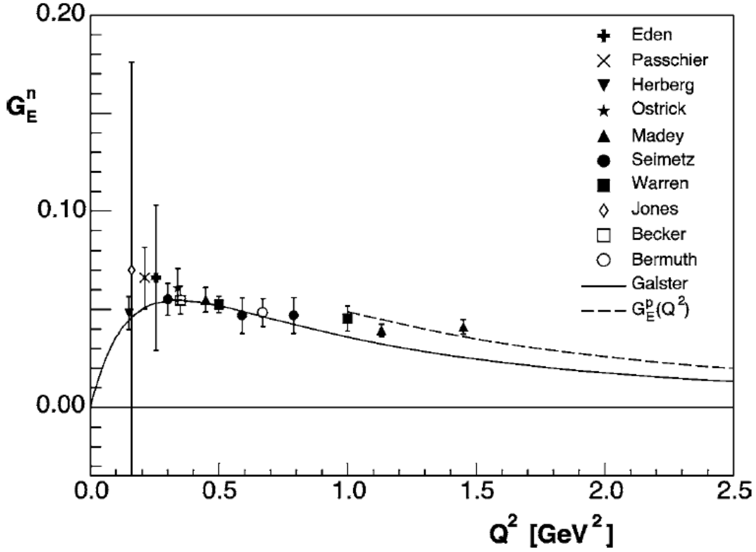
- Systematic uncertainty ($\Delta G_M^n/G_M^n \times 100$) based on differences in the proton reduced cross section parameterizations of Bosted and Arrington-Melnitchouk.

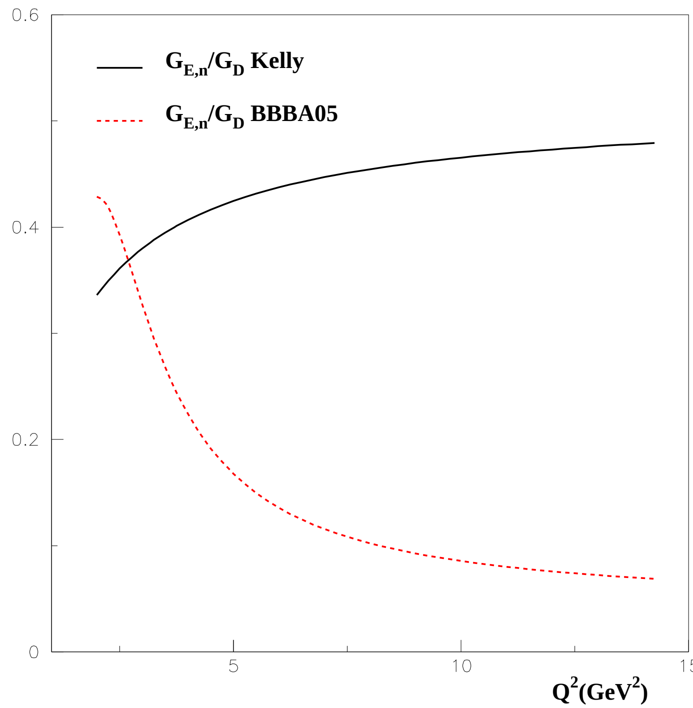


- Systematic uncertainty ($\Delta G_M^n/G_M^n \times 100$) based on differences in G_E^n parameterizations of Kelly and BBBA05. Future measurements will reduce the uncertainty for $Q^2 < 7.5\ \mathrm{GeV}^2$.



Update for E12-07-104: G_E^n Uncertainty





World data on G_E^n. (C.E. Hyde-Wright and K.deJager, Ann. Rev. Nucl. Part. Sci. **54** (2004) 54 and references therein.)

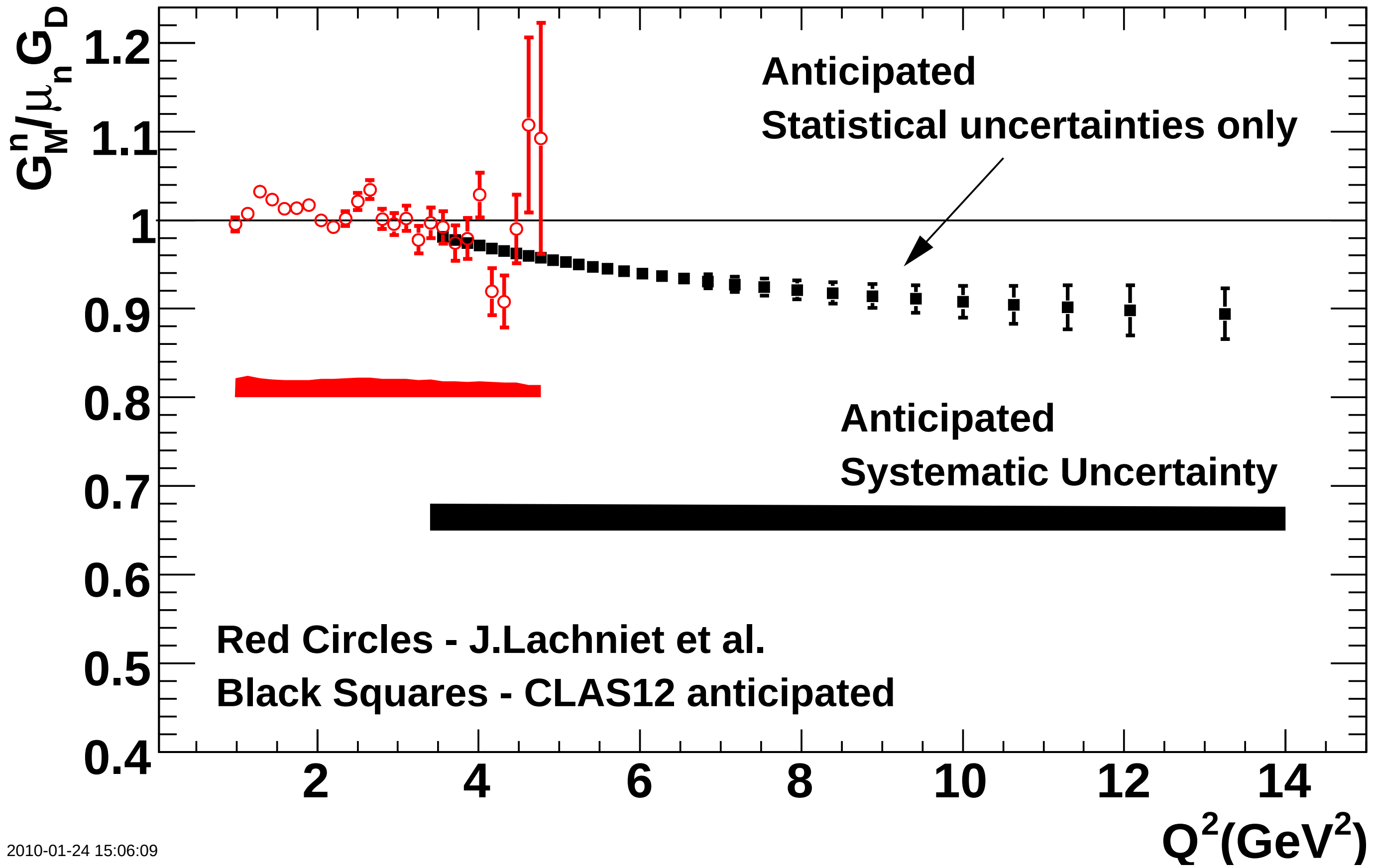
The neutron electric form factor from Kelly and BBBA05 parameterizations as a function of Q^2 (J. J. Kelly, PRC 70, 068202 (2004) and R. Bradford *et al.*, hep-ph/0602017.)

Update for E12-07-104: Systematic Uncertainties

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.

Quantity	$\delta G_M^n / G_M^n \times 100$	Quantity	$\delta G_M^n / G_M^n \times 100$
Neutron efficiency	< 0.7(1.5)	θ_{pq} cut	< 1.0(1.7)
proton σ	< 1.5(1.5)	G_E^n	< 0.7(0.5)
Background subtraction	< 1.0	Fermi loss correction	< 0.9
neutron accidentals	< 0.3	Neutron MM cut	< 0.5
neutron proximity cut	< 0.2	proton efficiency	< 0.4
Nuclear Corrections	< 0.2	Radiative corrections	< 0.2

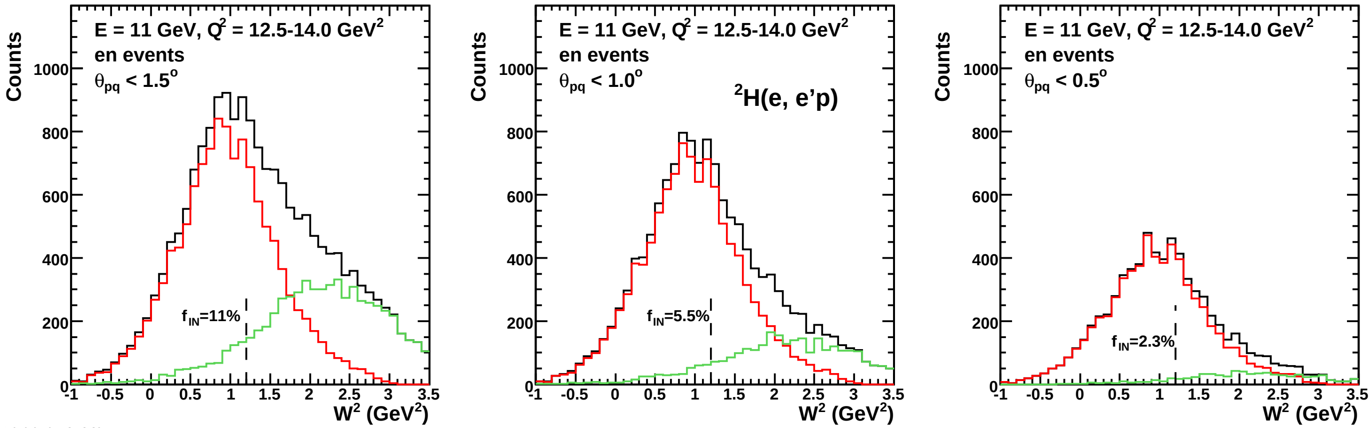
Update for E12-07-104: Comparison of CLAS6 and CLAS12 measurements



Update for E12-07-104: Comparison of CLAS12 and E12-09-019 methods

1. To reduce inelastic background further, reduce the maximum θ_{pq}.

$f_{IN} = \frac{inelastic}{total}$ for $W^2 < 1.2\ \mathrm{GeV}^2$.



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

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