Future Measurements of the Nucleon Elastic Electromagnetic Form Factors at Jefferson Lab

G.P. Gilfoyle

University of Richmond, Richmond, VA 23173

Outline

1. Scientific Motivation
2. Necessary Background
3. What we hope to learn.
4. The Measurements
5. Summary and Conclusions

Iglesia de la Matriz

Scientific Motivation - What We Hope to Learn.

- Nucleon elastic electromagnetic form factors (EEFFs) describe the distribution of charge and magnetization in the nucleon.
- Reveal the internal landscape of the nucleon and nuclei.
- Rigorously test QCD in the non-perturbative regime.
  - Nuclear models, constituent quarks,...
  - lattice QCD.
- Map the transition from the hadronic picture to QCD.

Scientific Motivation - What We Hope to Learn.

- Nucleon elastic electromagnetic form factors (EEFFs) describe the distribution of charge and magnetization in the nucleon.
- Reveal the internal landscape of the nucleon and nuclei.
- Rigorously test QCD in the non-perturbative regime.
  - Nuclear models, constituent quarks,...
  - lattice QCD.
- Map the transition from the hadronic picture to QCD.

EEFFs have played an essential role in nuclear and nucleon structure for more than a half century.

Some Necessary Background

- EEFFs cross section described with Dirac (F_1) and Pauli (F_2) form factors

$$\frac{d\sigma}{d\Omega} = \sigma_{Mott}\left[\left(F_1^2 + \kappa^2\tau F_2^2\right) + 2\tau\left(F_1 + \kappa F_2\right)^2 \tan^2\left(\frac{\theta_e}{2}\right)\right]$$

where

$$\sigma_{Mott} = \frac{\alpha^2 E' \cos^2(\frac{\theta_e}{2})}{4E^3 \sin^4(\frac{\theta_e}{2})}$$

and κ is the anomalous magnetic moment, E (E') is the incoming (outgoing) electron energy, θ is the scattered electron angle and $\tau = Q^2/4M^2$.

- For convenience use the Sachs form factors.

$$\frac{d\sigma}{d\Omega} = \sigma_{Mott}\left(\frac{(G_E^n)^2 + \tau(G_M^n)^2}{1+\tau} + 2\tau\tan^2\frac{\theta_e}{2}(G_M^n)^2\right)$$

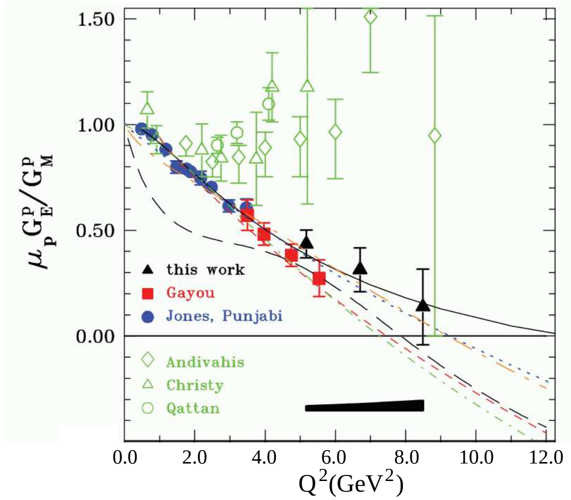
where

$$G_E = F_1 - \tau F_2$$

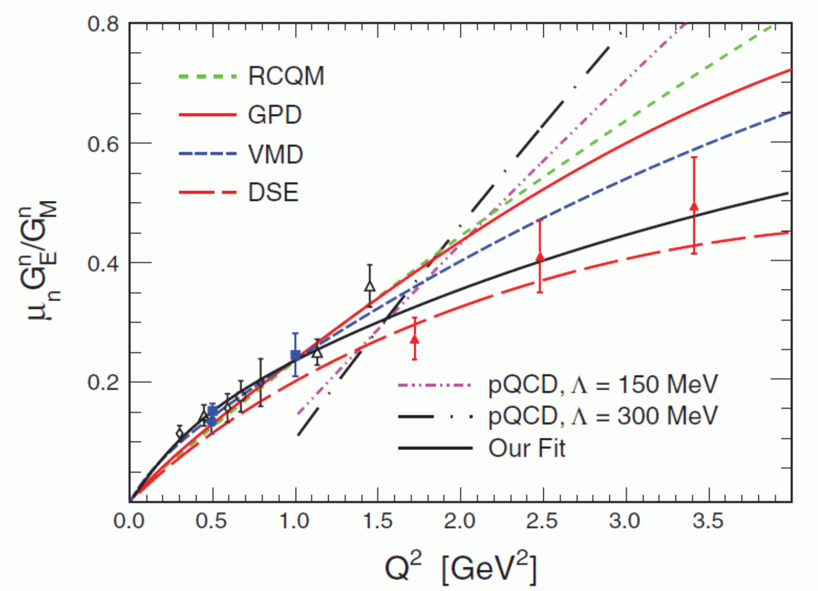
$$G_M = F_1 + F_2$$

Where We Are Now.

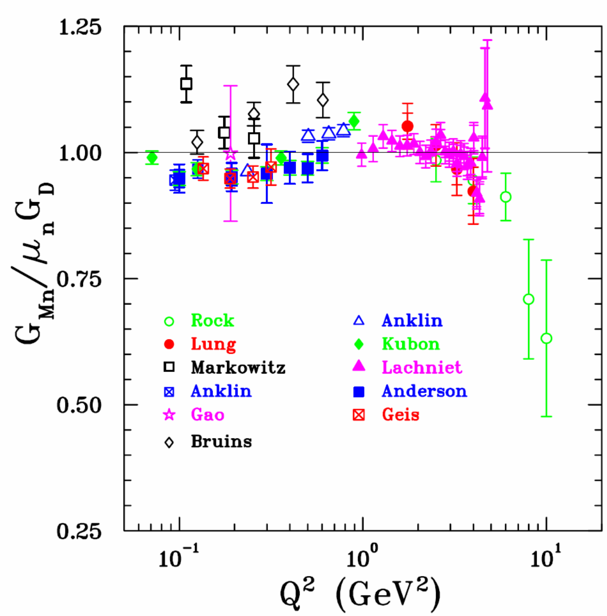
- The ratio G_E^p/G_M^p from recoil polarization measurements diverged from previous Rosenbluth separations.
  - Two-photon exchange (TPE).
  - Effect of quark orbital angular momentum (OAM).
- Neutron magnetic FF G_M^n still follows dipole.
- High-Q^2 G_E^n opens the door to flavor decomposition.



PRL **104**, 242301 (2010)



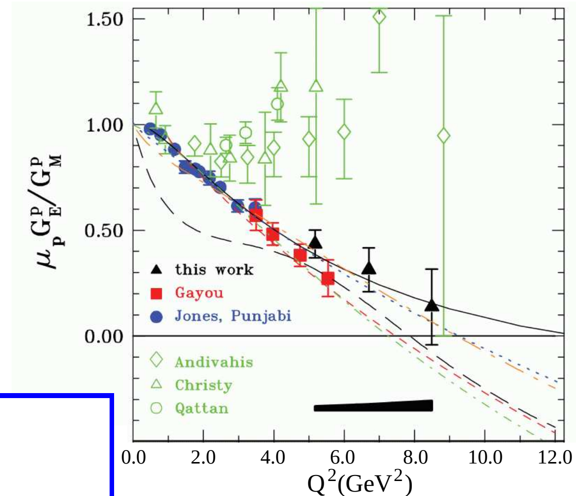
PRL 105, 262302 (2010)



Scholarpedia, 5(8):10204

Where We Are Now.

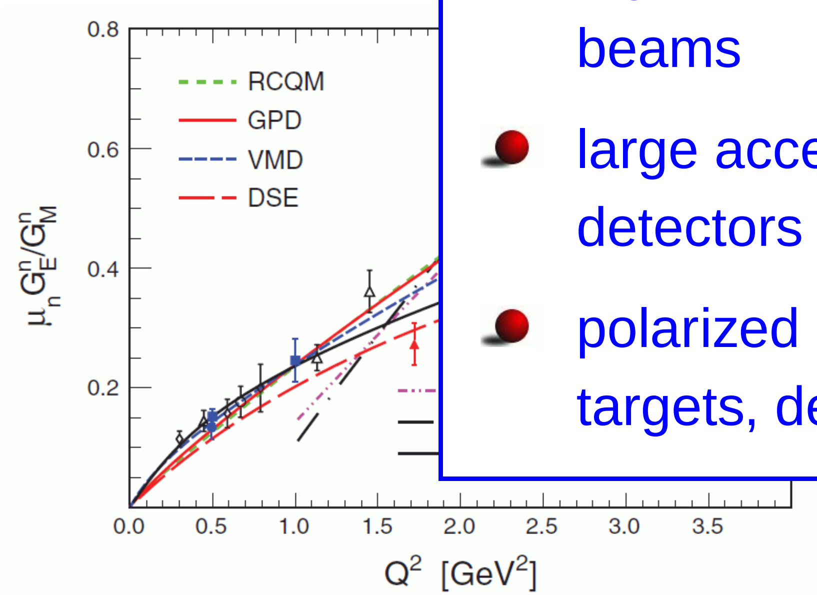
- The ratio G_E^p/G_M^p from recoil polarization measurements diverged from previous Rosenbluth separations.
  - Two-photon exchange (TPE).
  - Effect of quark orbital angular momentum (OAM).
- Neutron magnetic FF G_M^n still follows dipole.
- High-Q^2 G_E^n opens the do



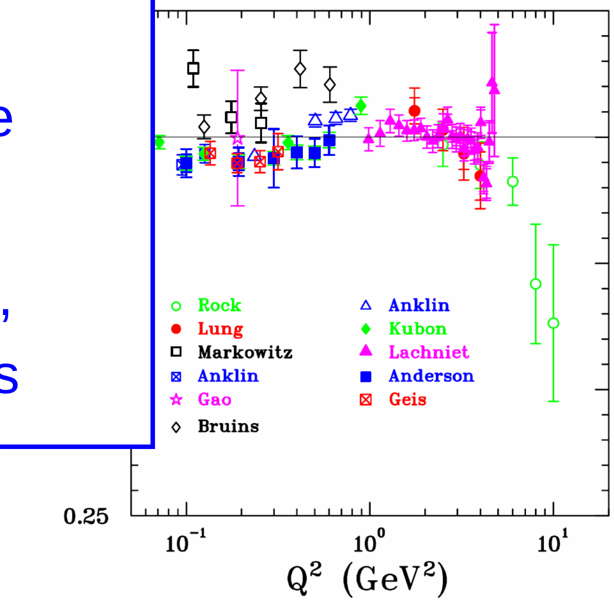
PRL **104**, 242301 (2010)

Advances driven by:

- high luminosity beams
- large acceptance detectors
- polarized beams, targets, detectors



PRL 105, 262302 (2010)

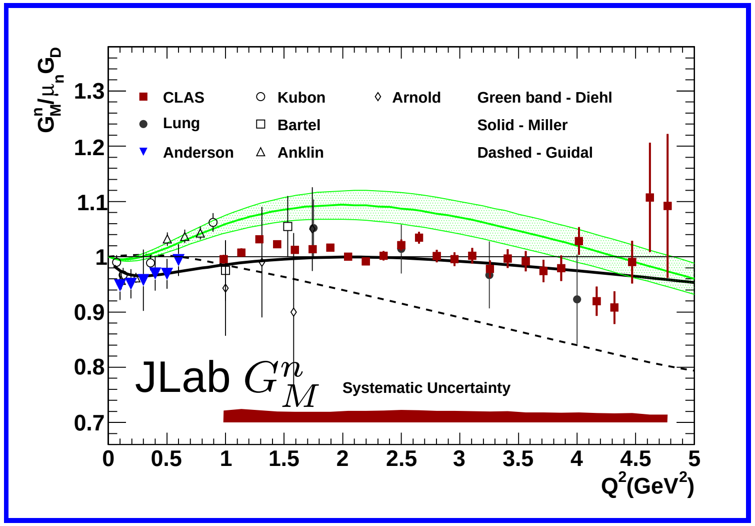


Scholarpedia, 5(8):10204

Where We Are Now.

The EEFFs emerge from Quantum Chromodynamics (QCD), but calculations here require non-perturbative methods.

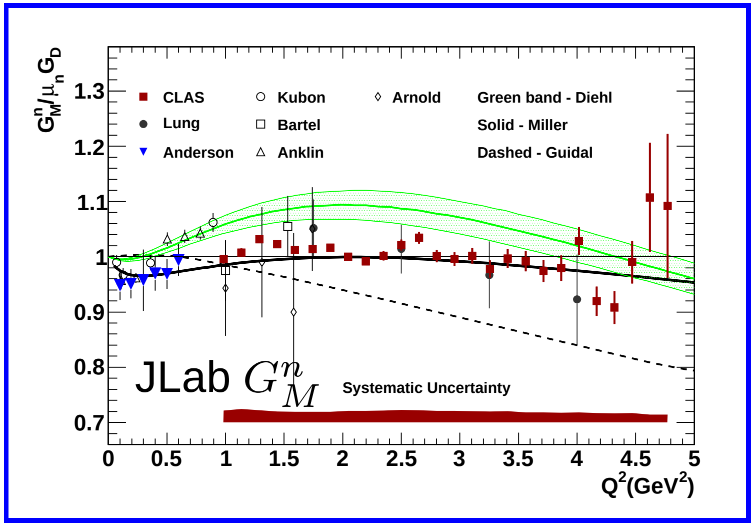
- Vector Meson Dominance and dispersion analyses fit all four EEFFs, but use many parameters.
- Constituent Quark Models highlight relativity, but don't capture all of QCD.
- Generalized Parton Distributions (GPDs) connect valence quarks in transverse space and longitudinal momentum.
- EEFFs are the first moments of the GPDs.

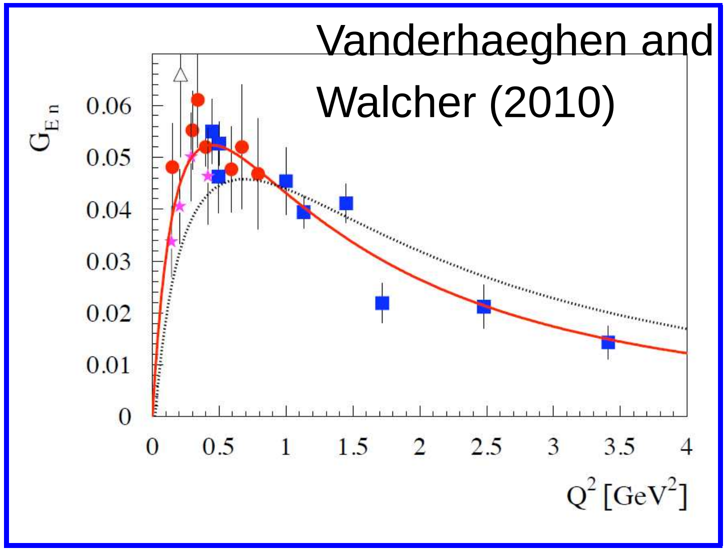


Where We Are Now.

The EEFFs emerge from Quantum Chromodynamics (QCD), but calculations here require non-perturbative methods.

- Vector Meson Dominance and dispersion analyses fit all four EEFFs, but use many parameters.
- Constituent Quark Models highlight relativity, but don't capture all of QCD.
- Generalized Parton Distributions (GPDs) connect valence quarks in transverse space and longitudinal momentum.
- EEFFs are the first moments of the GPDs.





Where We Are Now - Lattice QCD

- Lattice gauge theory is the only means of *ab initio* QCD calculations in the non-perturbative regime.
- Computationally challenging.
- EEFFs are an early test of lQCD.
  - The isovector form of the EEFFs is

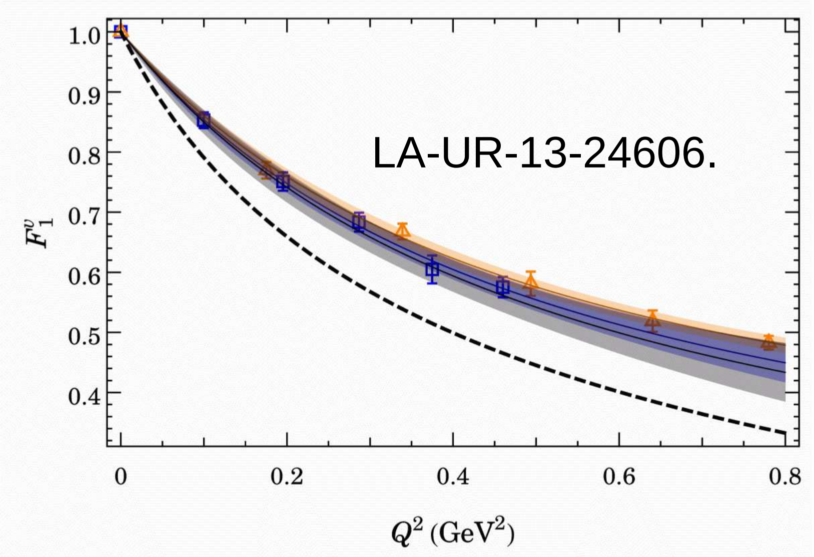
$$F^V_{1,2} = \frac{F^p_{1,2} - F^n_{1,2}}{2}$$

where

$$F_1 = \frac{\tau G_M + G_E}{1+\tau} \qquad F_2 = \frac{G_M - G_E}{1+\tau}$$

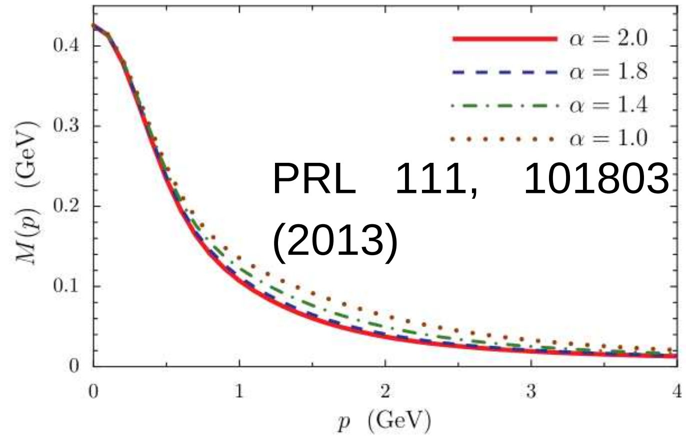
where $\tau = Q^2/4M^2$.

  - This form of the EEFFs does not have disconnected diagrams which are computationally intensive.
- Expect EEFF calculation in the next decade.



Where We Are Going - Dyson-Schwinger Eqs

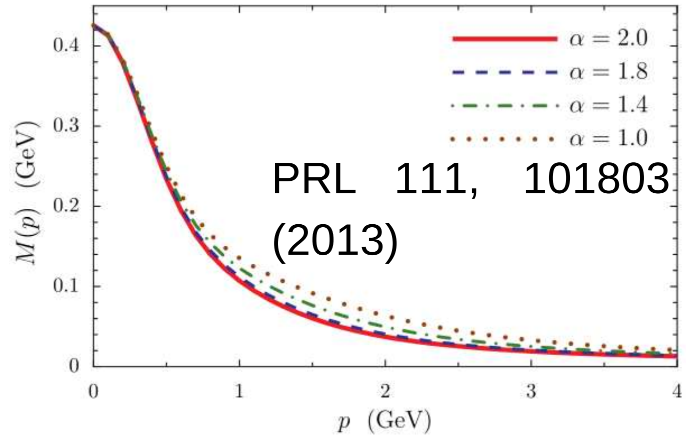
- Equations of motion of quantum field theory.
  - Infinite set of coupled integral equations.
  - Inherently relativistic, non-perturbative, connected to QCD.
  - Deep connection to confinement, dynamical chiral symmetry breaking.
  - Infinitely many equations, gauge dependent $\rightarrow$ Choose well!



- Recent results (Cloët et al).
  - Model the nucleon dressed quark propagator as a quark-diquark.
  - Damp the shape of the mass function $M(p)$.

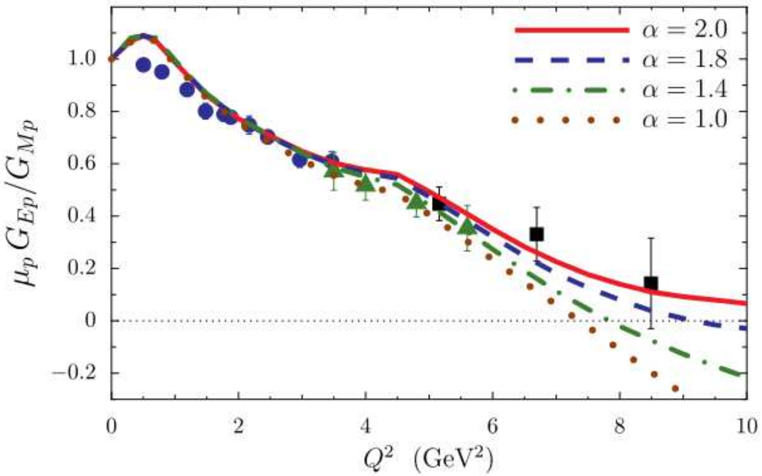
Where We Are Going - Dyson-Schwinger Eqs

- Equations of motion of quantum field theory.
  - Infinite set of coupled integral equations.
  - Inherently relativistic, non-perturbative, connected to QCD.
  - Deep connection to confinement, dynamical chiral symmetry breaking.
  - Infinitely many equations, gauge dependent $\rightarrow$ Choose well!



- Recent results (Cloët et al).
  - Model the nucleon dressed quark propagator as a quark-diquark.
  - Damp the shape of the mass function $M(p)$.

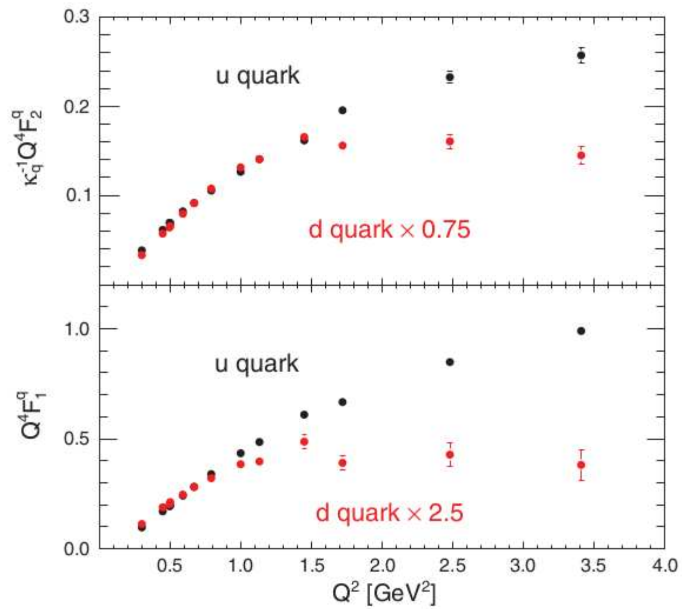
Position of zero in $\mu_p G_E^p / G_M^p$ sensitive to shape of $M(p)$!



Where We Are Going - Flavor Decomposition

- With all four EEFFs we can unravel the contributions of the u and d quarks.
- Assume charge symmetry, no s quarks and use (Miller *et al.* Phys. Rep. **194**, 1 (1990))

$$F^u_{1(2)} = 2F^p_{1(2)} + F^n_{1(2)} \qquad F^d_{1(2)} = 2F^n_{1(2)} + F^p_{1(2)}$$



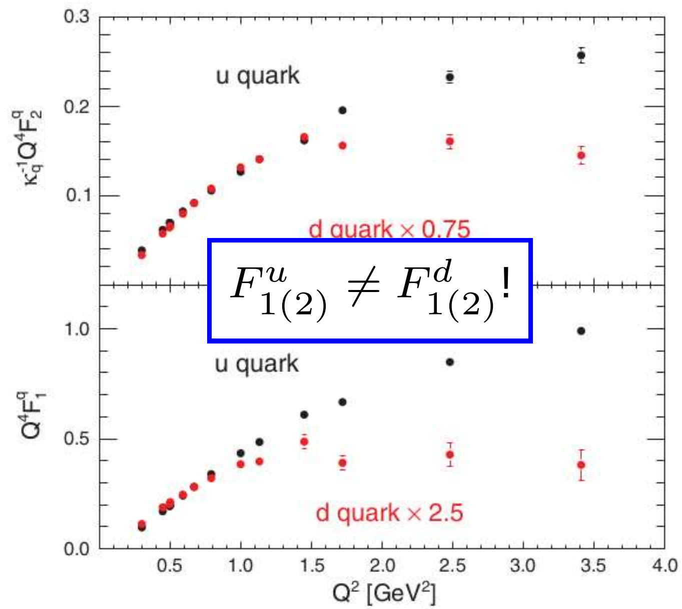
PRL **106**, 252003 (2011).

Where We Are Going - Flavor Decomposition

- With all four EEFFs we can unravel the contributions of the u and d quarks.
- Assume charge symmetry, no s quarks and use (Miller *et al.* Phys. Rep. **194**, 1 (1990))

$$F^u_{1(2)} = 2F^p_{1(2)} + F^n_{1(2)} \qquad F^d_{1(2)} = 2F^n_{1(2)} + F^p_{1(2)}$$

- Evidence of di-quarks? d-quark scattering probes the diquark.



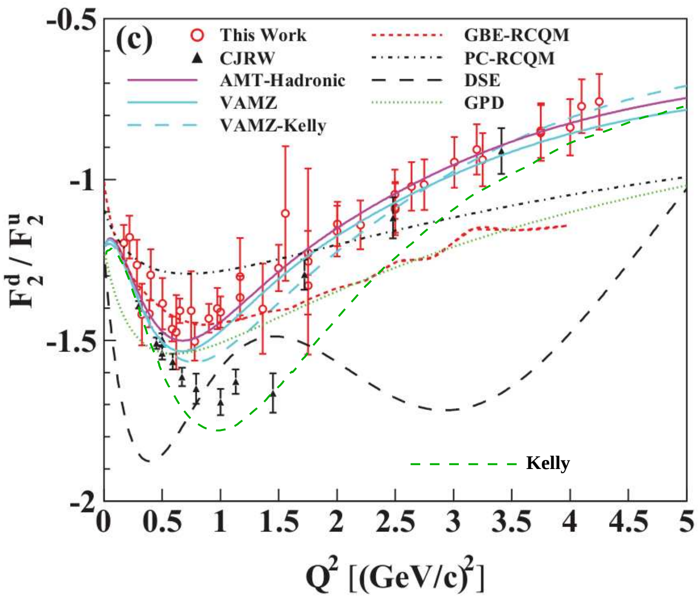
PRL **106**, 252003 (2011).

Where We Are Going - Flavor Decomposition

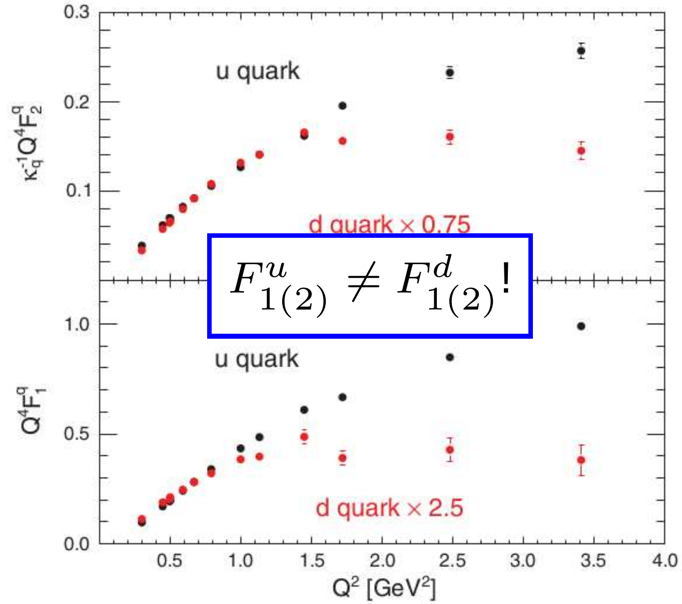
- With all four EEFFs we can unravel the contributions of the u and d quarks.
- Assume charge symmetry, no s quarks and use (Miller *et al.* Phys. Rep. **194**, 1 (1990))

$$F^u_{1(2)} = 2F^p_{1(2)} + F^n_{1(2)} \qquad F^d_{1(2)} = 2F^n_{1(2)} + F^p_{1(2)}$$

- Evidence of di-quarks? d-quark scattering probes the diquark.



PRC, 86 065210



PRL **106**, 252003 (2011).

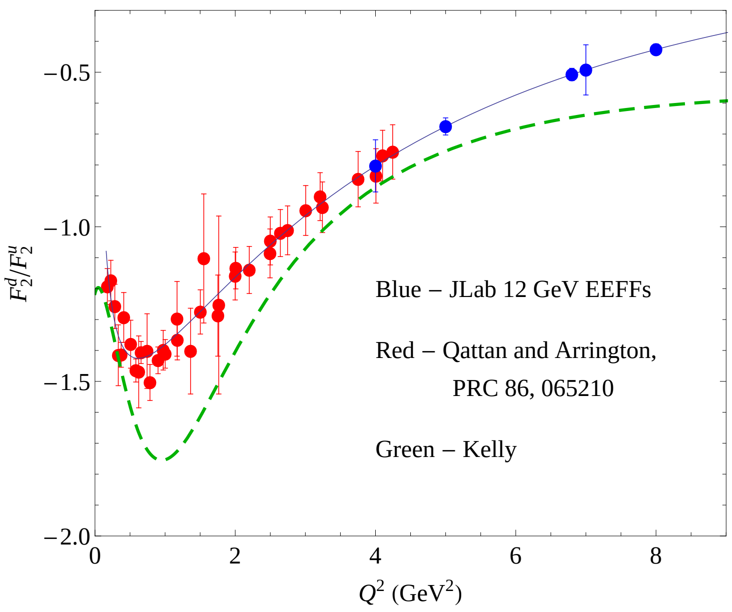
- F_2^f / F_2^u ratio not well reproduced by any models $\rightarrow$ good test bench.

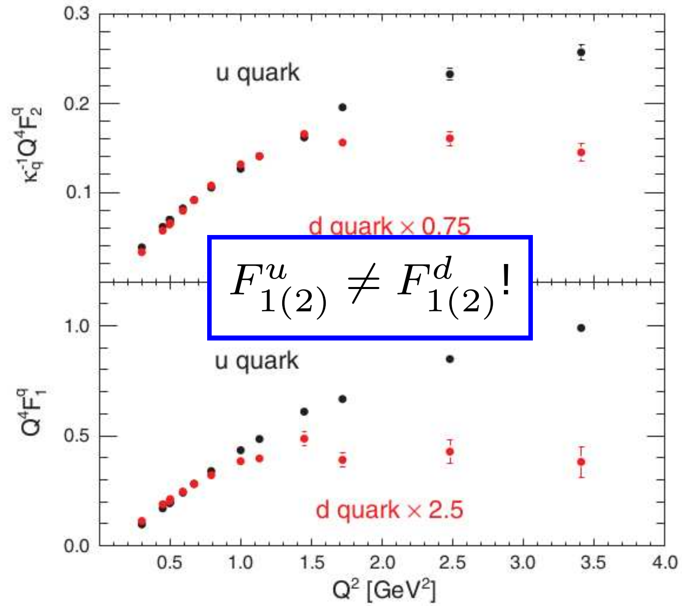
Where We Are Going - Flavor Decomposition

- With all four EEFFs we can unravel the contributions of the u and d quarks.
- Assume charge symmetry, no s quarks and use (Miller *et al.* Phys. Rep. **194**, 1 (1990))

$$F^u_{1(2)} = 2F^p_{1(2)} + F^n_{1(2)} \qquad F^d_{1(2)} = 2F^n_{1(2)} + F^p_{1(2)}$$

- Evidence of di-quarks? d-quark scattering probes the diquark.





PRL **106**, 252003 (2011).

- F_2^f/F_2^u ratio not well reproduced by any models $\rightarrow$ good test bench.

The JLab program will double our reach in Q^2 here.

Where We Are Going - New Experiments.

The JLab Lineup

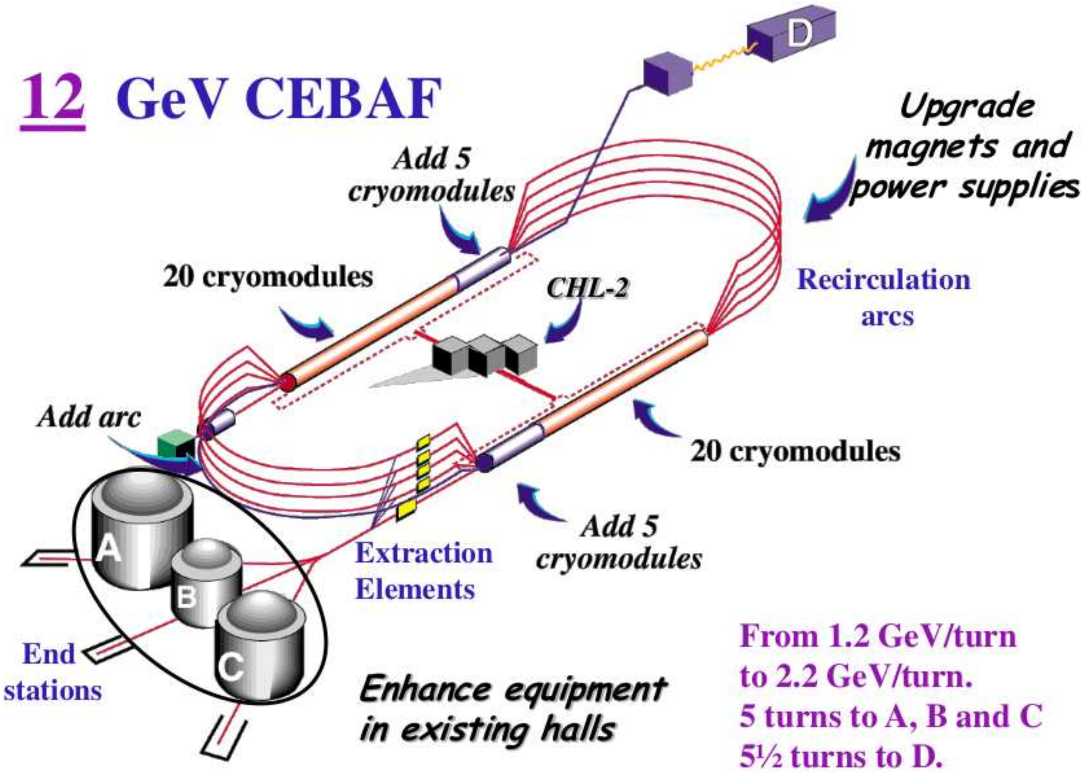
Quantity	Method	Target	$Q^2 (GeV^2)$	Hall	Beam Days
G_M^p	Elastic scattering	LH_2	$7 - 15.5$	A	24
G_E^p/G_M^p	Polarization transfer	LH_2	$5 - 12$	A	45
G_M^n	$E - p/e - n$ ratio	$LD_2 - LH_2$	$3.5 - 13.0$	B	30
G_M^n	$E - p/e - n$ ratio	LD_2, LH_2	$3.5 - 13.5$	A	25
G_E^n/G_M^n	Double polarization asymmetry	polarized ^3He	$5 - 8$	A	50
G_E^n/G_M^n	Polarization transfer	LD_2	$4 - 7$	C	50

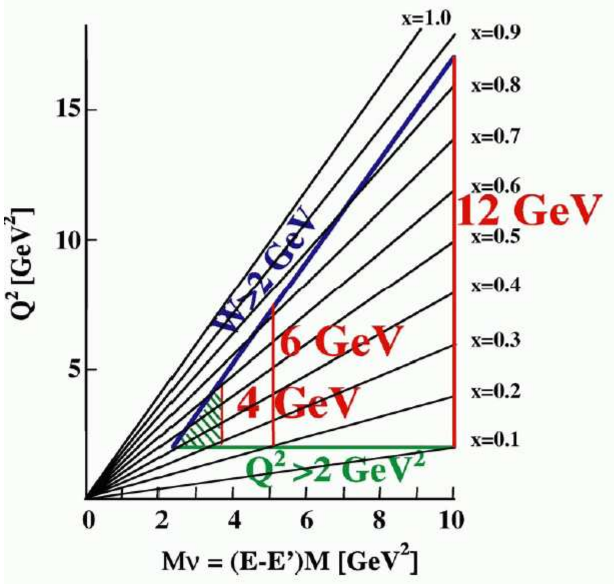
All are extensions of 6 GeV era experiments.

PAC approval for 224 days of running in the first five years.

Jefferson Lab

How We Will Get There: Jefferson Lab.

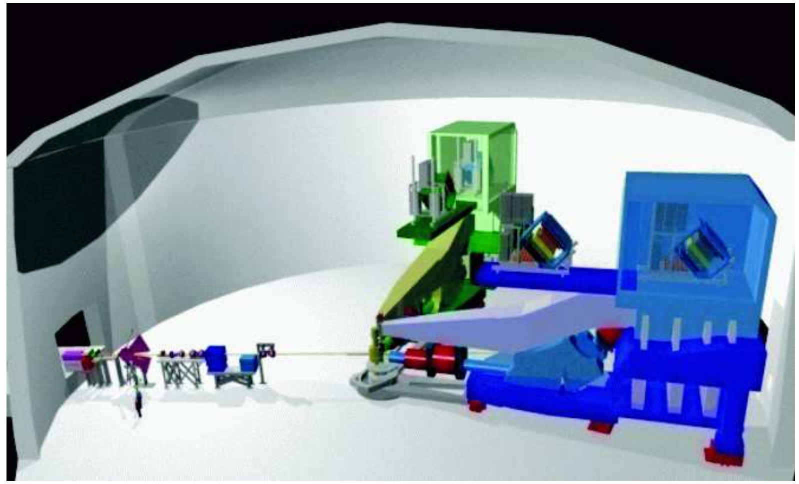




Continuous Electron Beam Accelerator Facility (CEBAF)

- Superconducting Electron Accelerator, 100% duty cycle.
- $E_{max} = 11\ \mathrm{GeV}$ (Halls A, B, and C) and $12\ \mathrm{GeV}$ (Hall D), $\Delta E/E \approx 2 \times 10^{-4}$, $I_{summed} \approx 90\ \mu A$, $P_e \geq 80\%$.

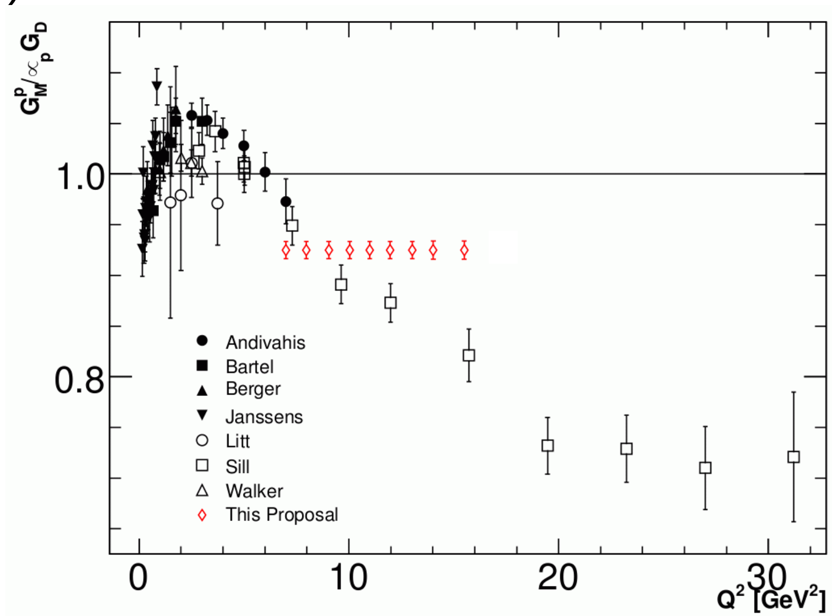
Proton Magnetic Form Factor - G_M^p



- E12-07-108 in Hall A (Gilad, Moffitt, Wojtsekhowski, Arrington).
- Precise measurement of ep elastic cross section and extract G_M^p.
- Both HRSs in electron mode.
- Beamtime: 24 days.
- $\mathrm{Q}^2 = 7.0 - 15.5\,\mathrm{GeV}^2$ ($1.0,\ 1.5\,\mathrm{GeV}^2$ steps).
- Significant reduction in uncertainties:

	$d\sigma/d\Omega$	G_M^p
Point-to-Point	1.0-1.3	0.5-0.6
Normalization	1.0-1.3	0.5-0.6
Theory	1.0-2.0	0.5-1.0

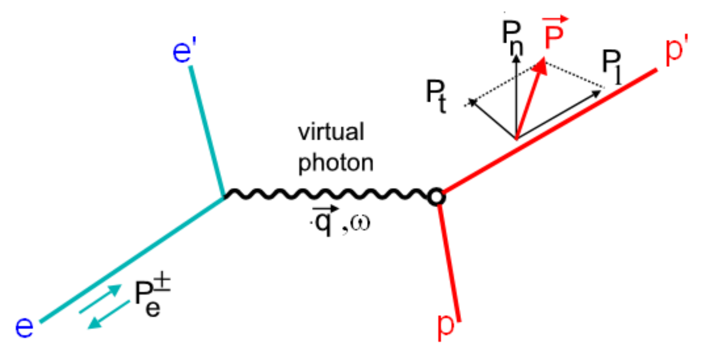
- Two-Photon Exchange is a major source of uncertainty $\rightarrow$ vary ϵ to constrain.
- Sets the scale of other EEFFs.



Proton Form Factor Ratio G_E^p/G_M^p

- E12-07-109 (GEp(5)) in Hall A (Brash, Jones, Perdrisat, Pentchev, Cisbani, Punjabi, Khandaker, Wojtsekhowski).
- Polarization transfer using $\mathrm{H}(\vec{e}, e'\vec{p})$:

$$\frac{G_E^p}{G_M^p} = -\frac{P_t}{P_l}\frac{E+E'}{2M}\tan\left(\frac{\theta_e}{2}\right)$$



- Electron arm: EM calorimeter (BigCal).
- Proton arm: new, large-acceptance magnetic spectrometer (SBS) with double polarimeter, and hadron calorimeter.
- Beamtime: 45 days.
- Kinematics and Uncertainties:

Q^2 (GeV^2)	5.0	8.0	12.0
$\Delta[\mu G_E/G_m]$	0.025	0.031	0.069

- Combined with GEp(4).

Proton Form Factor Ratio G_E^p/G_M^p

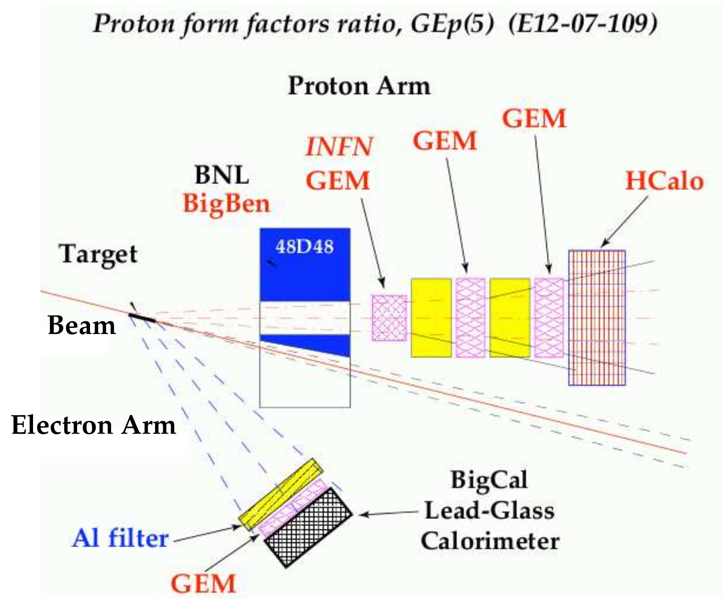
- E12-07-109 (GEp(5)) in Hall A (Brash, Jones, Perdrisat, Pentchev, Cisbani, Punjabi, Khandaker, Wojtsekhowski).
- Polarization transfer using $\mathrm{H}(\vec{e}, e'\vec{p})$:

$$\frac{G_E^p}{G_M^p} = -\frac{P_t}{P_l}\frac{E+E'}{2M}\tan\left(\frac{\theta_e}{2}\right)$$

- Electron arm: EM calorimeter (BigCal).
- Proton arm: new, large-acceptance magnetic spectrometer (SBS) with double polarimeter, and hadron calorimeter.
- Beamtime: 45 days.
- Kinematics and Uncertainties:

Q^2 (GeV^2)	5.0	8.0	12.0
$\Delta[\mu G_E/G_m]$	0.025	0.031	0.069

- Combined with GEp(4).



Proton Form Factor Ratio G_E^p/G_M^p

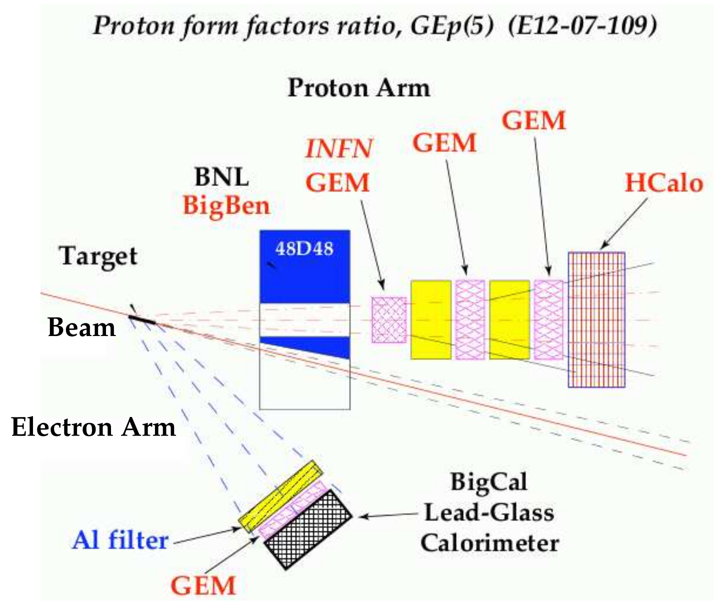
- E12-07-109 (GEp(5)) in Hall A (Brash, Jones, Perdrisat, Pentchev, Cisbani, Punjabi, Khandaker, Wojtsekhowski).
- Polarization transfer using $\mathrm{H}(\vec{e}, e'\vec{p})$:

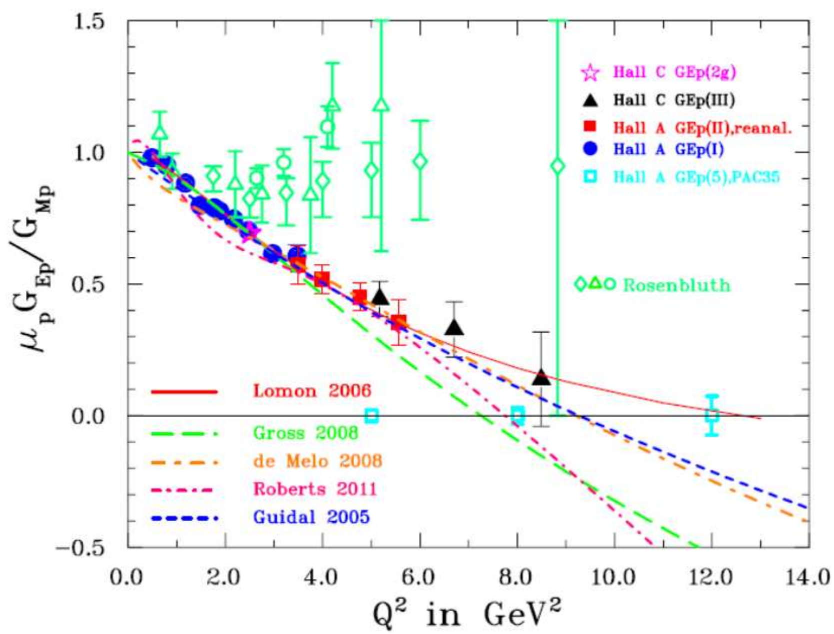
$$\frac{G_E^p}{G_M^p} = -\frac{P_t}{P_l}\frac{E+E'}{2M}\tan\left(\frac{\theta_e}{2}\right)$$

- Electron arm: EM calorimeter (BigCal).
- Proton arm: new, large-acceptance magnetic spectrometer (SBS) with double polarimeter, and hadron calorimeter.
- Beamtime: 45 days.
- Kinematics and Uncertainties:

Q^2 (GeV^2)	5.0	8.0	12.0
$\Delta[\mu G_E/G_m]$	0.025	0.031	0.069

- Combined with GEp(4).





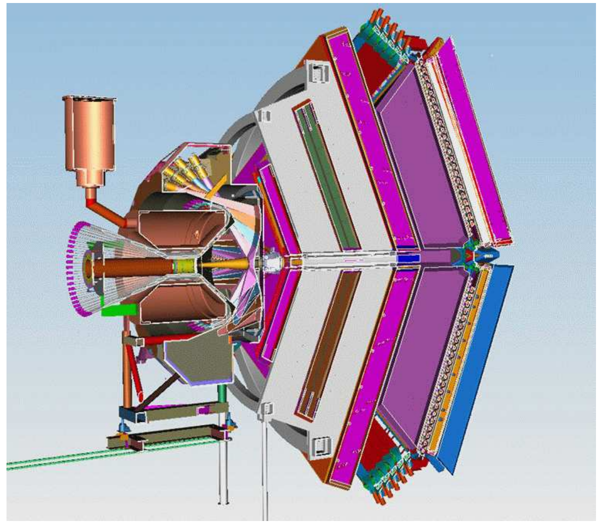
Neutron Magnetic Form Factor G_M^n - 1

- E12-07-104 in Hall B (Gilfoyle, Hafidi, Brooks).
- Ratio Method on Deuterium ($^2\mathrm{H}(e,e'p)n$ and $^2\mathrm{H}(e,e'n)p$):

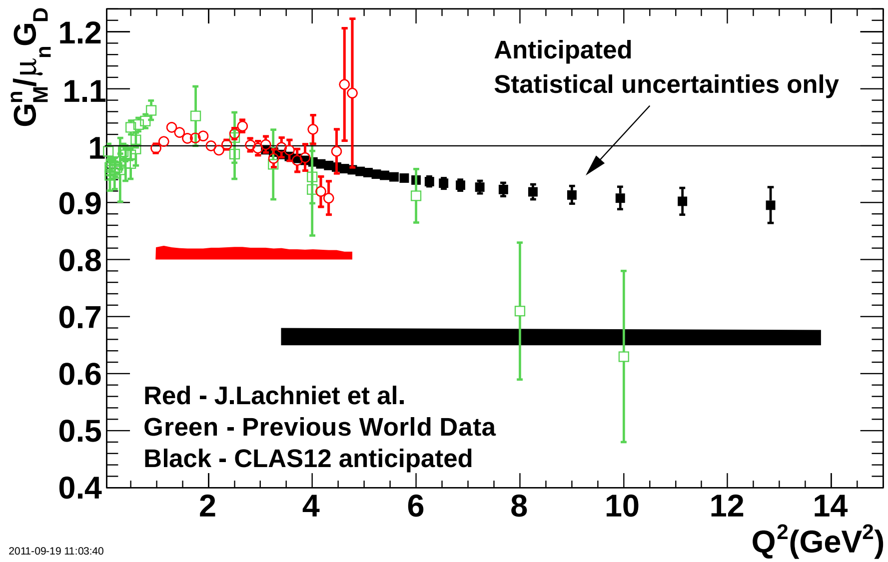
$$R = \frac{\frac{d\sigma}{d\Omega}[^2\mathrm{H}(e,e'n)_{QE}]}{\frac{d\sigma}{d\Omega}[^2\mathrm{H}(e,e'p)_{QE}]}$$

$$= a \times \frac{\sigma_{Mott}\left(\frac{(G_E^n)^2+\tau(G_M^n)^2}{1+\tau}+2\tau\tan^2\frac{\theta_e}{2}(G_M^n)^2\right)}{\frac{d\sigma}{d\Omega}[^1\mathrm{H}(e,e')p]}$$

where a is nuclear correction.



- Precise neutron detection efficiency needed to keep systematics low.
  - tagged neutrons from $p(e,e'\pi^+n)$.
  - Dual $LD_2 - LH_2$ target for *in situ* calibrations.
- Kinematics: $\mathrm{Q}^2 = 3.5 - 13.0\ (\mathrm{GeV/c})^2$.
- Beamtime: 30 days.

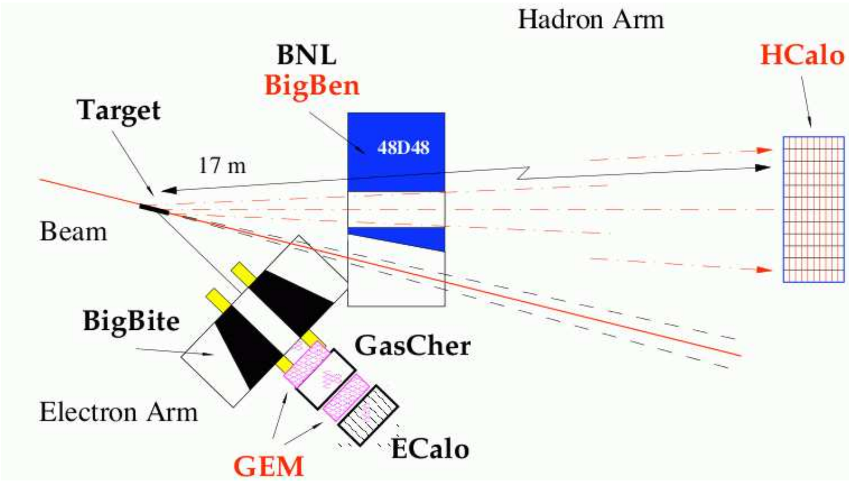


- Systematic uncertainties less than 2.5% across full Q^2 range.

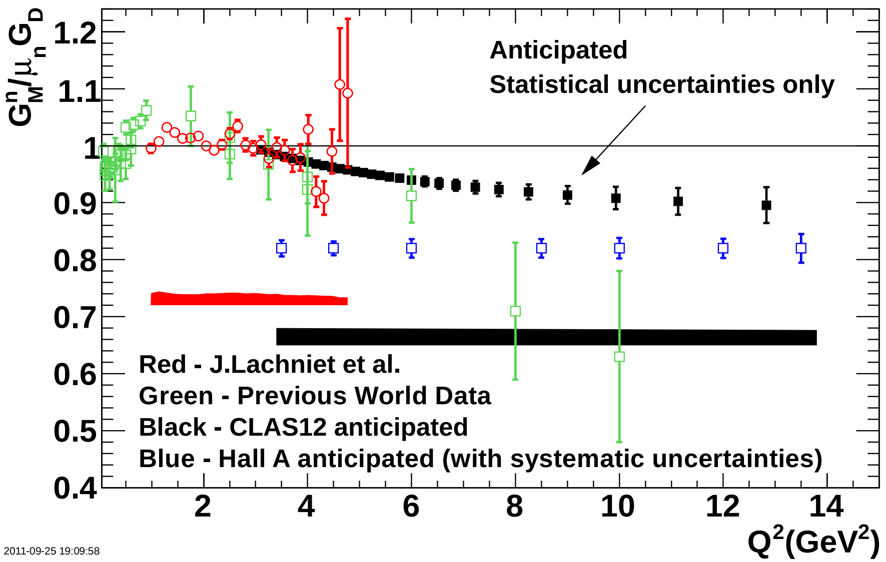
Neutron Magnetic Form Factor G_M^n - 2

- E12-09-019 in Hall A (Quinn, Wojtsekhowski, Gilman).
- Ratio Method on Deuterium as in Hall B:

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



- Electron arm: SuperBigBite spectrometer.
- Hadron arm: hadron calorimeter (HCal).
- Neutron detection efficiency:
  - Use $p(\gamma,\pi^+)n$ for tagged neutrons.
  - End-point method.
- Kinematics: $\mathrm{Q}^2 = 3.5 - 13.5\ (\mathrm{GeV/c})^2$.
- Beamtime: 25 days.
- Systematic uncertainties $< 2.1\%$.
- Two G_M^n measurements 'allow a better control for the systematic error' (PAC34).

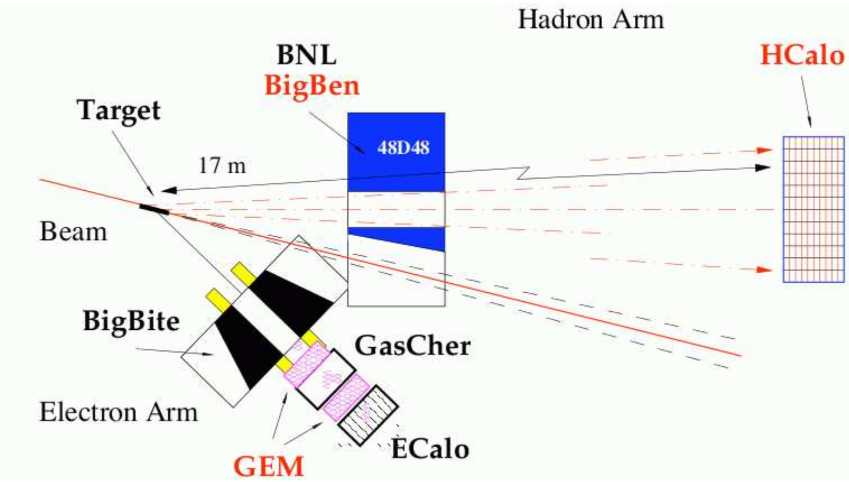


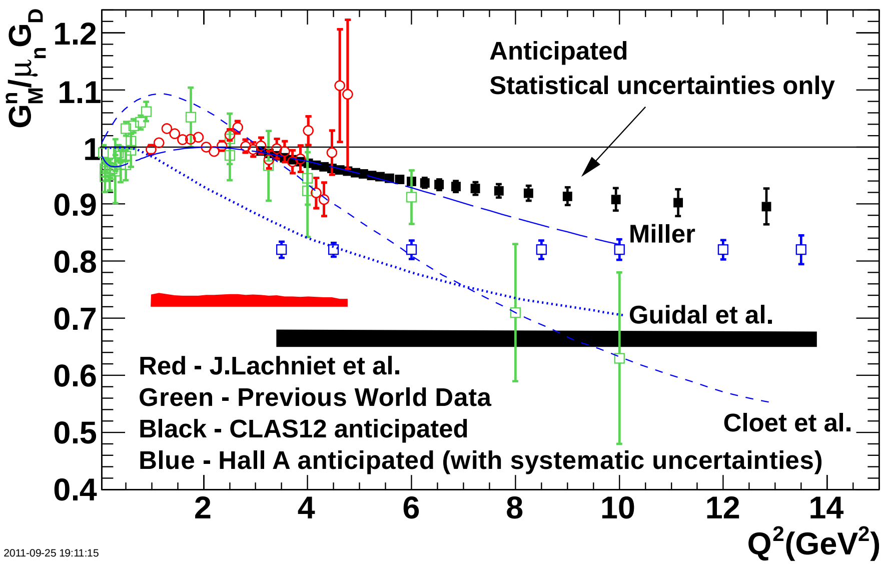
Neutron Magnetic Form Factor G_M^n - 2

- E12-09-019 in Hall A (Quinn, Wojtsekhowski, Gilman).
- Ratio Method on Deuterium as in Hall B:

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

- Electron arm: SuperBigBite spectrometer.
- Hadron arm: hadron calorimeter (HCal).
- Neutron detection efficiency:
  - Use $p(\gamma,\pi^+)n$ for tagged neutrons.
  - End-point method.
- Kinematics: $\mathrm{Q}^2 = 3.5 - 13.5\ (\mathrm{GeV/c})^2$.
- Beamtime: 25 days.
- Systematic uncertainties $< 2.1\%$.
- Two G_M^n measurements 'allow a better control for the systematic error' (PAC34).





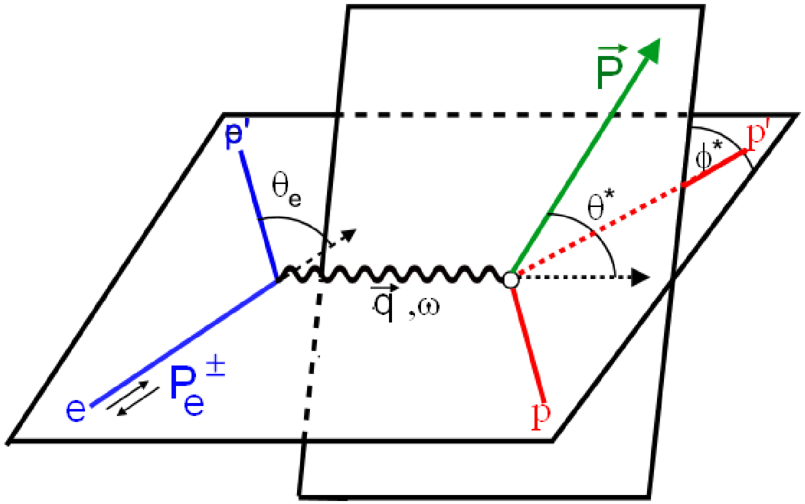
Neutron Form Factor Ratio G_E^n/G_M^n - 1

- E12-09-016 in Hall A (Cates, Wojtsekhowski, Riordan).
- Double Polarization Asymmetry: Get A_{en}^V from $^3\vec{\mathrm{He}}(\vec{e}, e'\vec{n})pp$.
- Longitudinally polarized electron beam.
- $^3\mathrm{He}$ target polarized perpendicular to the momentum transfer.
- Electron arm: SuperBigBite.
- Neutron arm: hadron calorimeter HCal (overlap with GEp(5) and Hall A G_M^n).
- Beamtime: 50 days.
- Kinematics and Uncertainties:

$Q^2\ (\mathrm{GeV}^2)$	5.0	6.8	8.0
$\Delta\left[\frac{\mu G_E}{G_M}\right]_{stat}$	0.027	0.022	0.032
$\Delta\left[\frac{\mu G_E}{G_M}\right]_{syst}$	0.018	0.021	0.013

$$A_{en}^V = \frac{-2\sqrt{\tau(\tau+1)}\tan(\theta_e/2)\cos\phi^*\sin\theta^* G_E^n/G_M^n}{(G_E^n/G_M^n)^2+\tau/\epsilon} + \frac{-2\tau\sqrt{1+\tau+(\tau+1)^2\tan^2(\theta_e/2)}\tan(\theta_e/2)\cos\theta^*}{(G_E^n/G_M^n)^2+\tau/\epsilon}$$

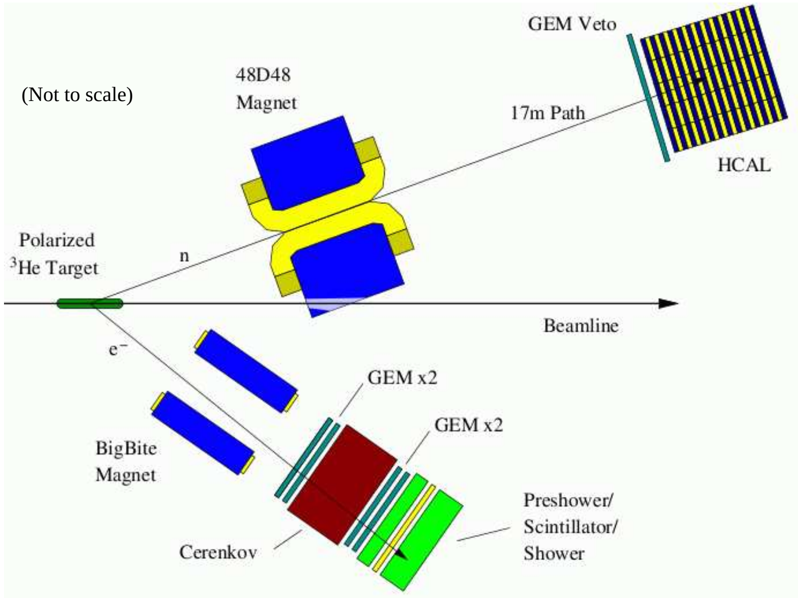
where $\epsilon = 1/\left(1+2(1+\tau)\tan^2(\frac{\theta_e}{2})\right)$



Neutron Form Factor Ratio G_E^n/G_M^n - 1

- E12-09-016 in Hall A (Cates, Wojtsekhowski, Riordan).
- Double Polarization Asymmetry: Get A_{en}^V from $^3\vec{\mathrm{He}}(\vec{e},e'n)pp$.
- Longitudinally polarized electron beam.
- $^3\mathrm{He}$ target polarized perpendicular to the momentum transfer.
- Electron arm: SuperBigBite.
- Neutron arm: hadron calorimeter HCal (overlap with GEp(5) and Hall A G_M^n).
- Beamtime: 50 days.
- Kinematics and Uncertainties:

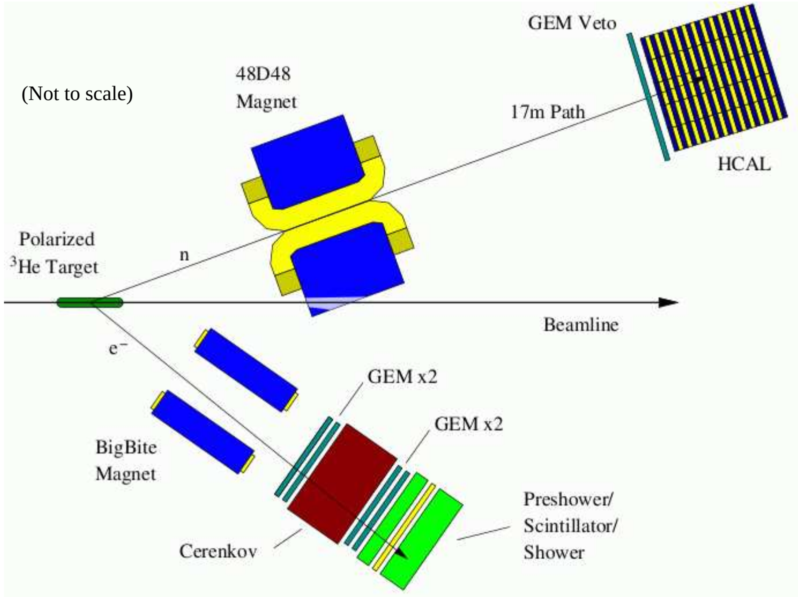
$\mathrm{Q}^2\ (\mathrm{GeV}^2)$	5.0	6.8	8.0
$\Delta\left[\frac{\mu G_E}{G_M}\right]_{stat}$	0.027	0.022	0.032
$\Delta\left[\frac{\mu G_E}{G_M}\right]_{syst}$	0.018	0.021	0.013

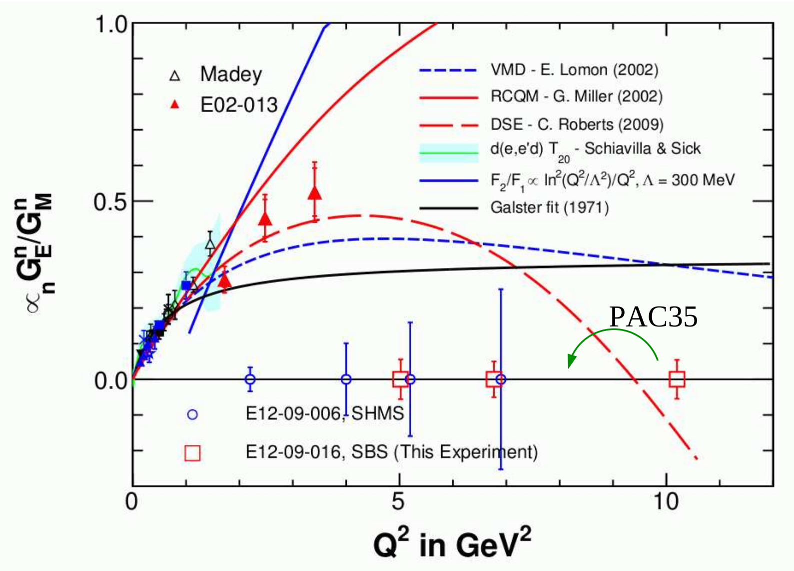


Neutron Form Factor Ratio G_E^n/G_M^n - 1

- E12-09-016 in Hall A (Cates, Wojtsekhowski, Riordan).
- Double Polarization Asymmetry: Get A_{en}^V from ${}^3\vec{\mathrm{He}}(\vec{e}, e'n)pp$.
- Longitudinally polarized electron beam.
- ${}^3\mathrm{He}$ target polarized perpendicular to the momentum transfer.
- Electron arm: SuperBigBite.
- Neutron arm: hadron calorimeter HCal (overlap with GEp(5) and Hall A G_M^n).
- Beamtime: 50 days.
- Kinematics and Uncertainties:

Q^2 (GeV^2)	5.0	6.8	8.0
$\Delta\left[\frac{\mu G_E}{G_M}\right]_{stat}$	0.027	0.022	0.032
$\Delta\left[\frac{\mu G_E}{G_M}\right]_{syst}$	0.018	0.021	0.013



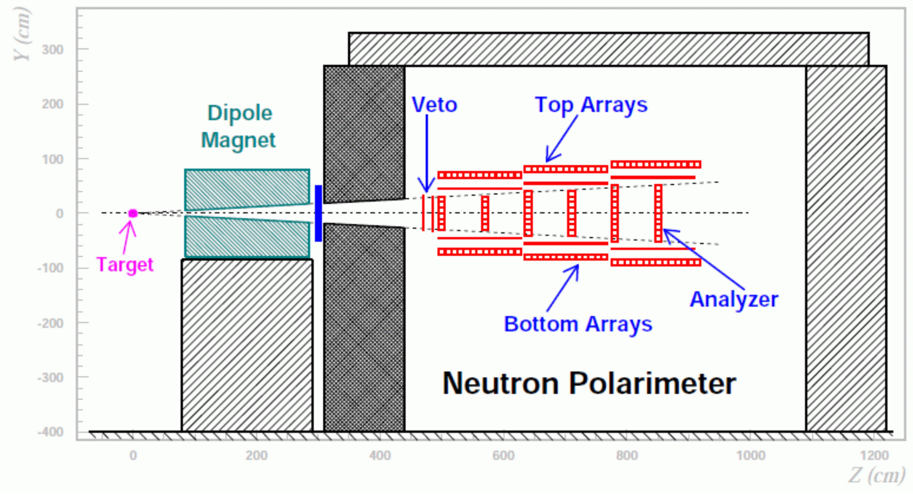


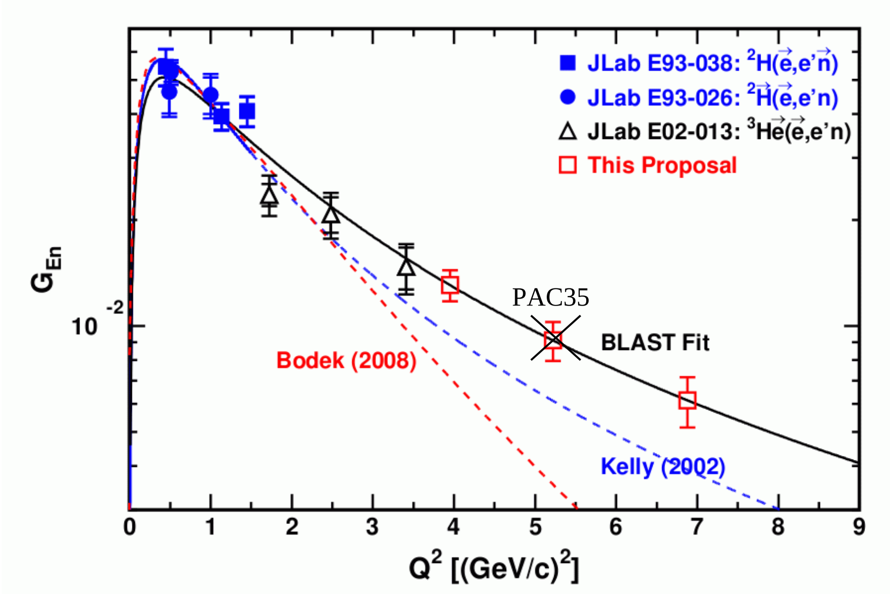
Neutron Form Factor Ratio G_E^n/G_M^n - 2

- E12-11-009 in Hall C (Anderson, Arrington, Kowalski, Madey, Plaster, Semenov).
- Polarization transfer using $^2\mathrm{H}(\vec{e}, e'\vec{n})p$:

$$\frac{G_E^n}{G_M^n} = -\frac{P_t}{P_l}\frac{E+E'}{2M}\tan\left(\frac{\theta_e}{2}\right)$$

- Electron arm: Super High Momentum Spectrometer (SHMS).
- Neutron arm: neutron polarimeter with tapered-gap neutron-spin-precession magnet and proton recoil detection.
- Kinematics: $\mathrm{Q}^2 = 3.95, 6.88\ (\mathrm{GeV/c})^2$.
- Beamtime: 50 days.
- Systematic uncertainties about 2-3%.
- Statistical uncertainties about 10-16%.
- Complementary to the $^3\mathrm{He}$ experiment.



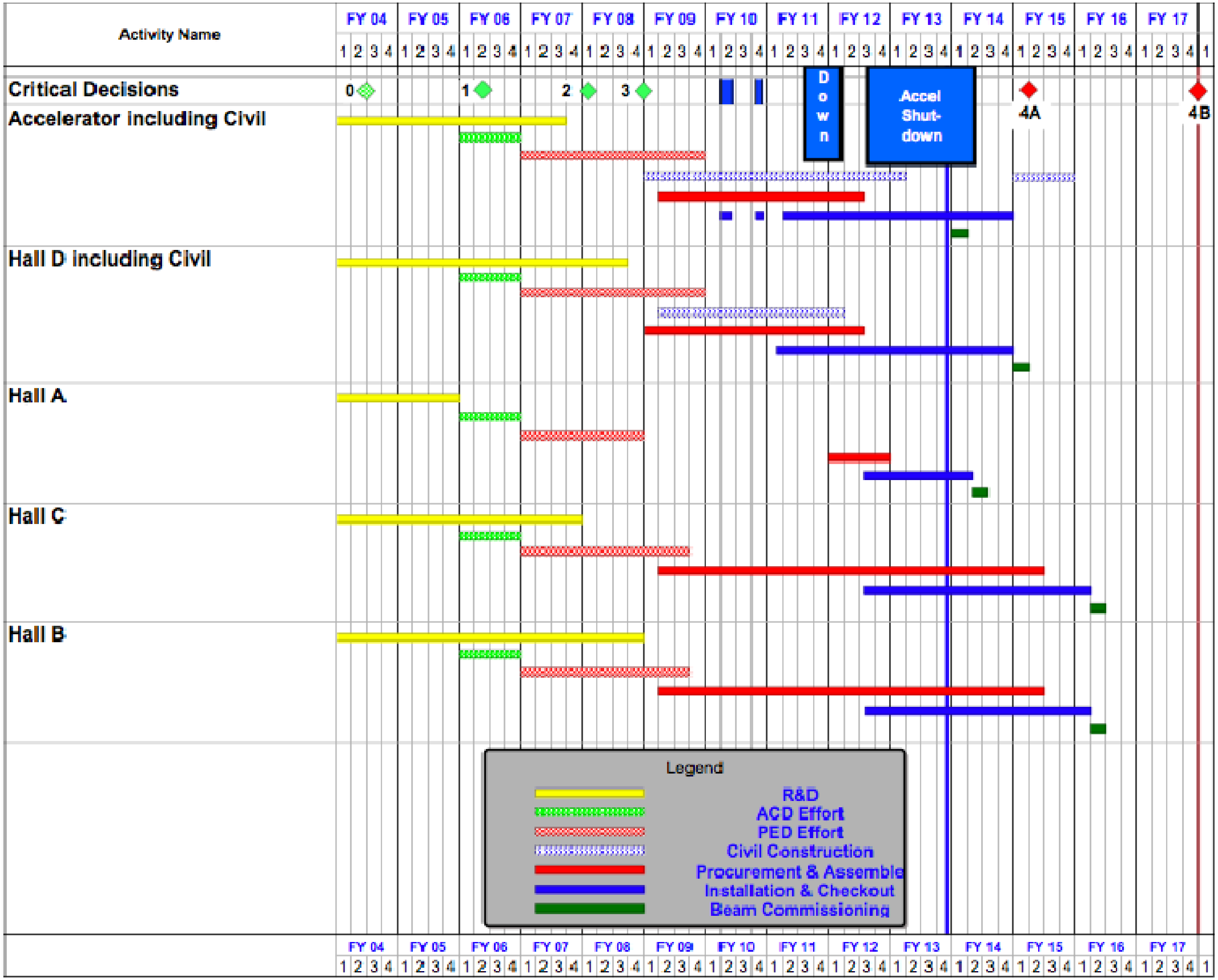


Summary and Conclusions

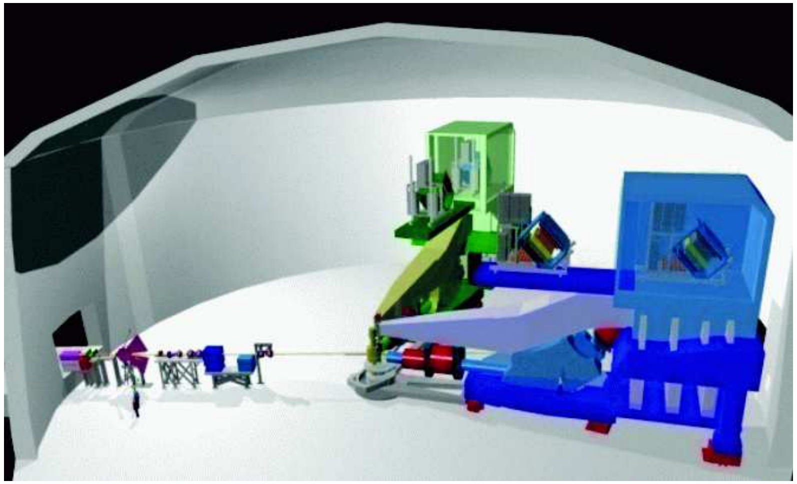
- Large gains over the last decade or so in physics understanding of the EEFFs built on new technologies and capabilities.
- Major changes in our understanding of nucleon structure.
- Jefferson Lab will mount a broad assault on the EEFFs and will significantly expand the physics reach of our understanding.
- Discovery potential in mapping out nucleon structure and understanding QCD.

Additional Slides

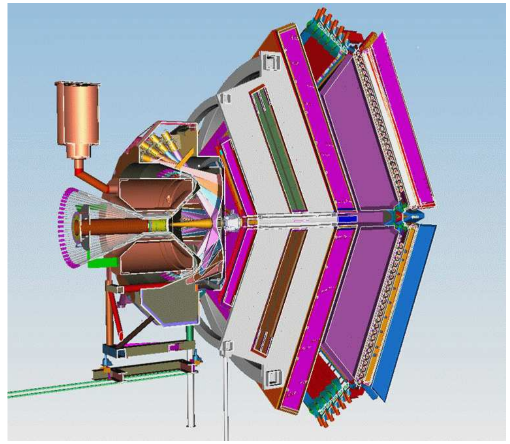
Jefferson Lab 12 GeV Upgrade Schedule



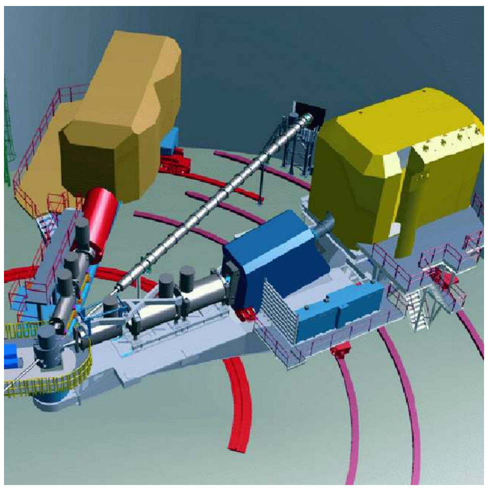
The Experiments - New Detectors



Hall A - High Resolution Spectrometer (HRS) pair, SuperBigBite, neutron detector, and specialized installation experiments.

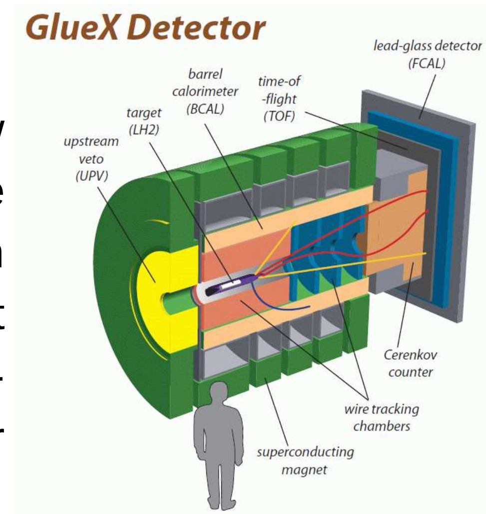


Hall B - CLAS12 large acceptance spectrometer operating at high luminosity with toroid (forward detector) and solenoid (central detector).

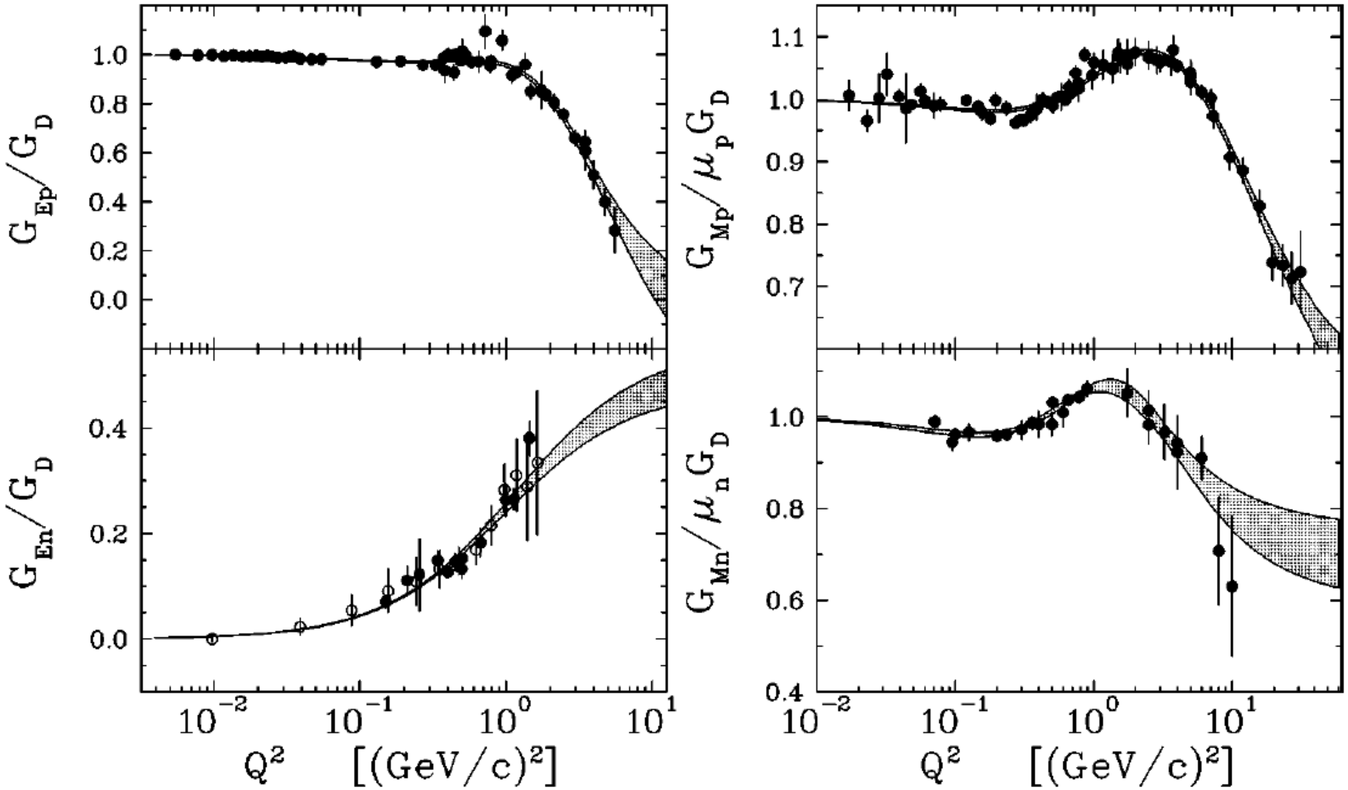


Hall C - New Super High Momentum Spectrometer to be used with the existing High Momentum Spectrometer.

Hall D - A new large acceptance detector based on a solenoid magnet for photon beam experiments is under construction.



Current World Data on EEFFs



J.J.Kelly, Phys. Rev.C, 068202, 2004.

- Proton form factors have small uncertainties and reach higher Q^2.
- Neutron form factors are sparse and have large uncertainties.
- Significant deviations from the dipole form factor.

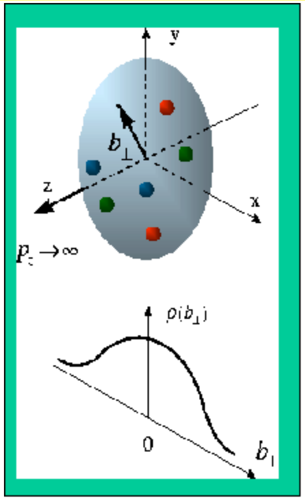
Where We Are Now - Nucleon Structure and GPDs

- Generalized Parton Distributions (GPDs) connect the valence quark distributions in transverse space and longitudinal momentum.
- EEFFs are the first moments of the GPDs and provide an important constraint.

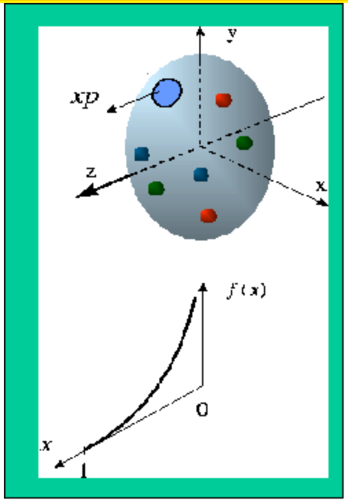
$$\int dx \sum H^q(x,\zeta,t) = F_1(t) \quad \text{Dirac FF}$$

$$\int dx \sum E^q(x,\zeta,t) = F_2(t) \quad \text{Pauli FF}$$

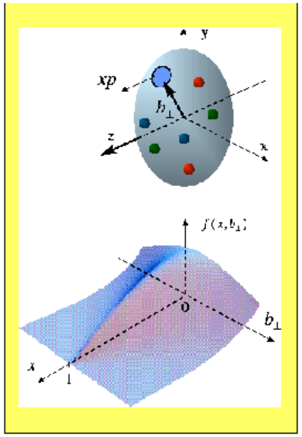
- Unravel the mass $M(t)$, angular momentum $J(t)$, and force and pressure $d_1(t)$.
- Nucleon form factor measurements complement the Semi-Inclusive Deep Inelastic Scattering program.



Transverse spatial distributions.



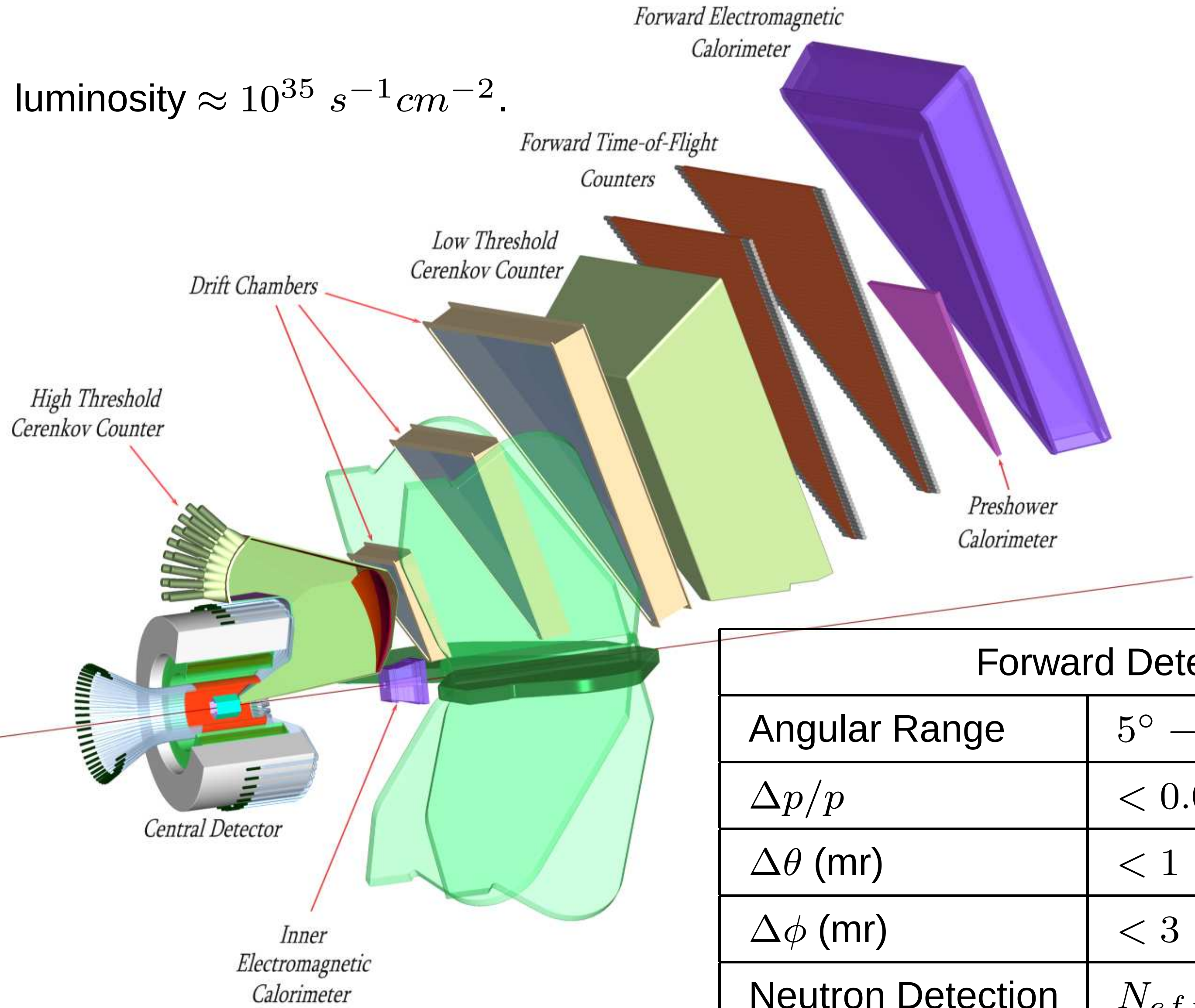
Longitudinal momentum distributions.



Correlated spatial and momentum distributions.

CLAS12 Detector and G_M^n Target

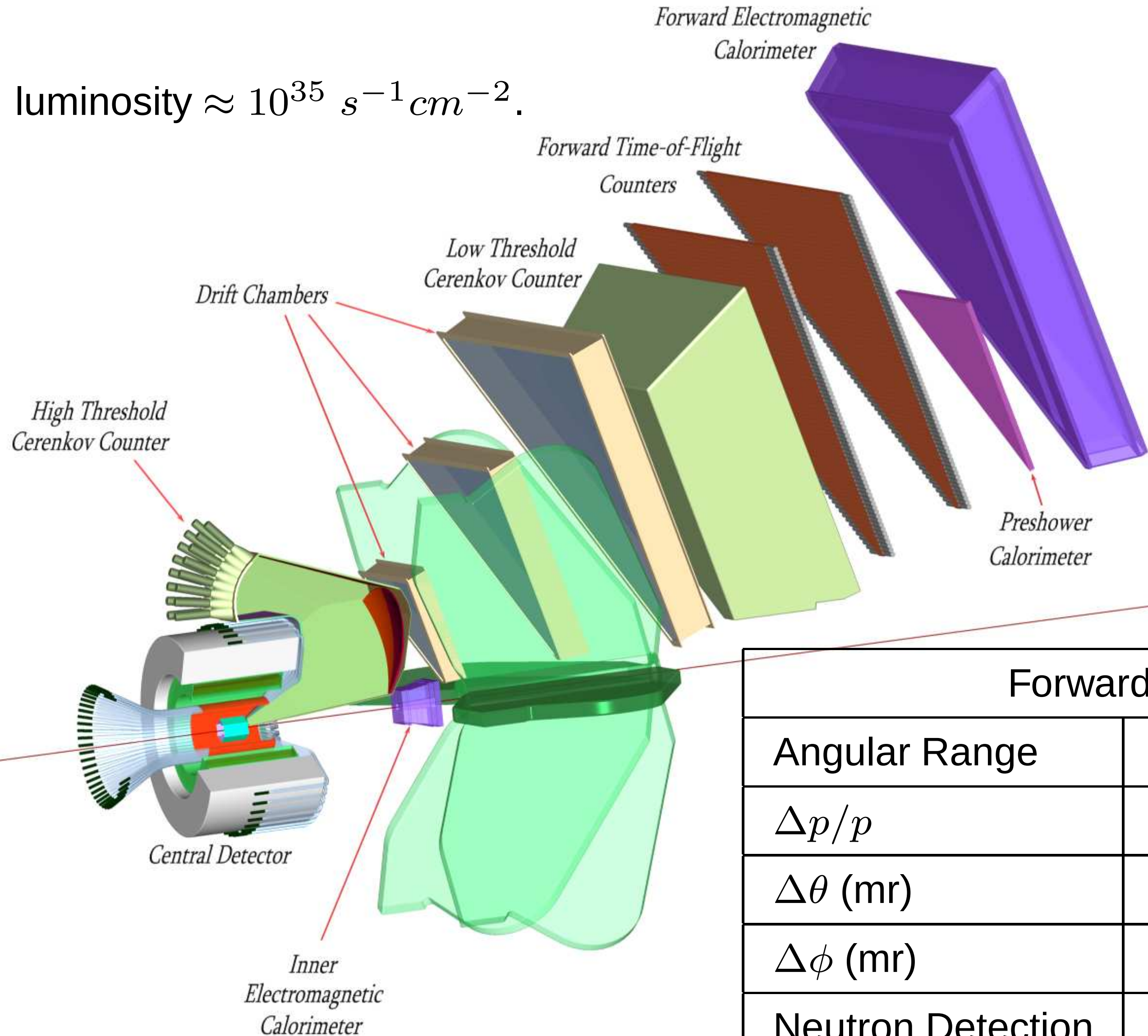
luminosity $\approx 10^{35}\ s^{-1}cm^{-2}$.

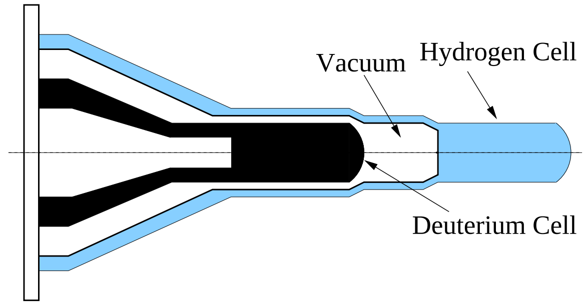


Forward Detector	
Angular Range	$5^\circ - 40^\circ$ (outbenders)
$\Delta p/p$	< 0.01 @ 5 GeV/c
$\Delta\theta$ (mr)	$< 1 \quad p > 2.5$ GeV/c
$\Delta\phi$ (mr)	$< 3 \quad p > 2.5$ GeV/c
Neutron Detection	$N_{eff} = 0.1 - 0.6$

CLAS12 Detector and G_M^n Target

luminosity $\approx 10^{35}\ s^{-1}cm^{-2}$.





The colinear, dual, hydrogen-deuterium target enables us to collect high-precision, *in situ* calibration data so systematic uncertainties $\leq 3\%$.

Forward Detector	
Angular Range	$5^\circ - 40^\circ$ (outbenders)
$\Delta p/p$	< 0.01 @ 5 GeV/c
$\Delta\theta$ (mr)	$< 1 \quad p > 2.5$ GeV/c
$\Delta\phi$ (mr)	$< 3 \quad p > 2.5$ GeV/c
Neutron Detection	$N_{eff} = 0.1 - 0.6$

More on the CLAS12 Detector

	Forward Detector	Central Detector
Angular Range		
Charged Particles	$5^\circ - 40^\circ$	$40^\circ - 135^\circ$
Photons	$2^\circ - 40^\circ$	N/A
Resolution		
$\Delta p/p$	< 0.01 @ 5 GeV/c	< 0.03 @ 0.5 GeV/c
$\Delta\theta$ (mr)	< 0.5	< 10
$\Delta\phi$ (mr)	< 0.5	< 6
Neutron Detection		
N_{eff}	0.1-0.6	0.1

Beyond Elastic Form Factor Measurements

Additional form factor studies after the 12 GeV Upgrade.

Experiment	Spokesperson	Title	Hall	Beamtime
PR12-06-101	G. Huber	Measurement of the charged pion form factor to high Q^2	C	52 days
PR12-09-003	R. Gothe	Nucleon resonance studies with CLAS12	B	40 days

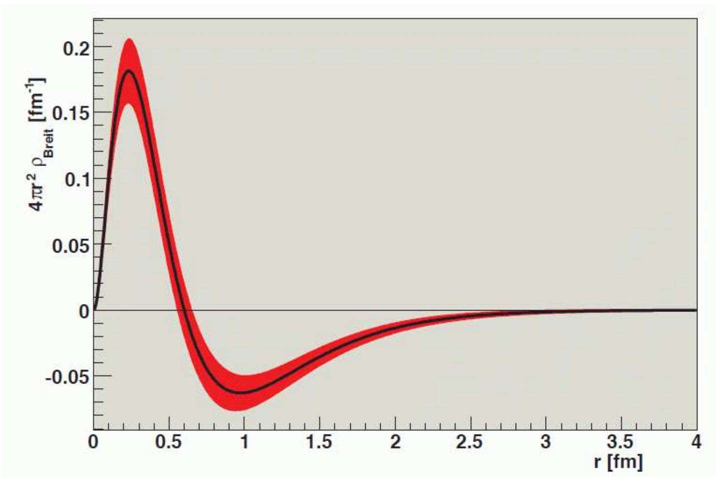
Some More Background - Interpreting the EEFFs

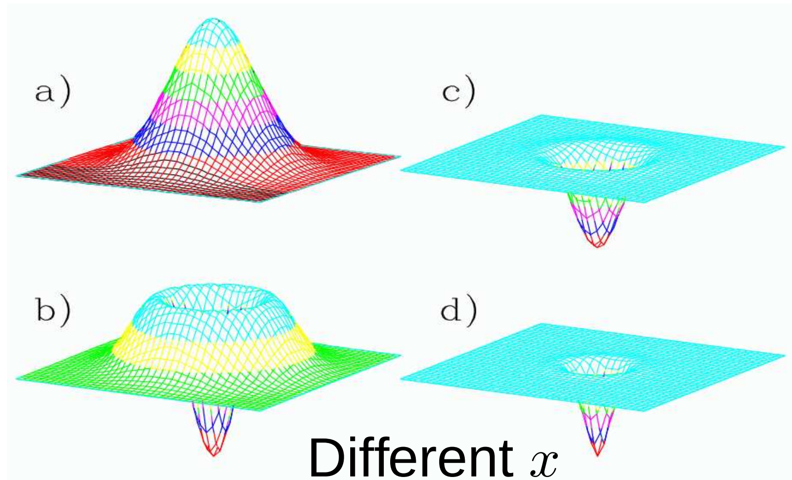
- At low momentum transfer ($Q^2 \ll M_N^2$) G_E and G_M are the Fourier transforms of the densities of charge and magnetization.

$$G_E(Q^2) = \int \rho(r) e^{-i\vec{q}\cdot\vec{r}} d^3 r$$

where $\vec{q}$ is the 3-momentum transferred by the electron.

- At high Q^2 relativistic effects make the interpretation more interesting!





NSAC Long Range Plan

Arrington *et al.*, J.Phys.Conf.Ser. 299 (2011) 01200