Axial form factor measurements: current status and plans

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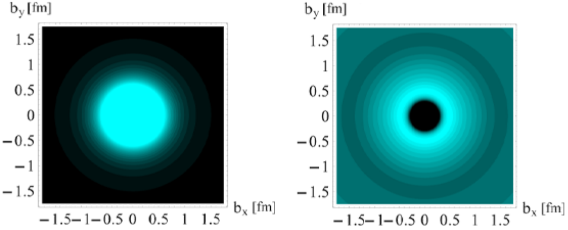
Outline

- Introduction to nucleon form factors
- Experimental ways to measure G_A
- Current status
- New proposal to measure G_A through inverse β decay
- Summary

Nucleon form factors

- Electromagnetic Form Factors (FF) $G_E(Q^2)$ and $G_M(Q^2)$ parametrize the electromagnetic current operator:
  - Well-known over a wide range of Q^2 through eN scattering
  - Fourier transforms of nucleon charge and magnetization distributions



Proton *Neutron*

- Isovector axial-vector current form factors are less known:

$$\langle N(p')|\bar{q}\gamma_\mu\gamma^5\frac{\tau^a}{2}q|N(p)\rangle = \bar{u}(p')\left[\gamma_\mu G_A(Q^2)+\frac{(p'-p)_\mu}{2m}G_P(Q^2)\right]\gamma_5\frac{\tau^a}{2}u(p)$$

Axial form factor $G_A(Q^2)$

- Probes the spin distribution of the nucleon
- Usually parametrized using a "dipole" expansion:

$$G_A(Q^2) = \frac{g_A}{(1 - Q^2/{M_A}^2)^2} \left\{ \begin{array}{l} g_A \text{ axial-vector coupling constant} \\ M_A\text{: adjustable } \textit{axial mass}. \end{array} \right.$$

form inspired by early (old) fits of electromagnetic FF. It assumes exponential spatial distributions, but w/o strong theoretical justification

Measurements of the nucleon axial FF

1. (Quasi-)elastic (anti-)neutrino scattering off protons or nuclei
2. Threshold charged pion electroproduction

Quasi-elastic ν scattering

- Elastic: $\nu p \to \nu p$
- Quasi-elastic: $\nu n \to l^- p, \quad \bar{\nu} p \to l^+ n$

$$\frac{d\sigma^{(\nu p, \bar{\nu} p)}}{dQ^2} = \frac{G_F^2}{8\pi} \frac{m^2 \cos\theta_C}{E_\nu^2} \left[A(Q^2) \mp B(Q^2) \frac{s-m}{m^2} + C(Q^2) \frac{(s-m)^2}{m^4} \right]$$

$$\left.\begin{aligned} A(Q^2) &= f(G_E, G_M, G_A) \\ B(Q^2) &= f'(G_E, G_M, G_A) \\ C(Q^2) &= f''(G_E, G_M, G_A) \end{aligned}\right\}$$

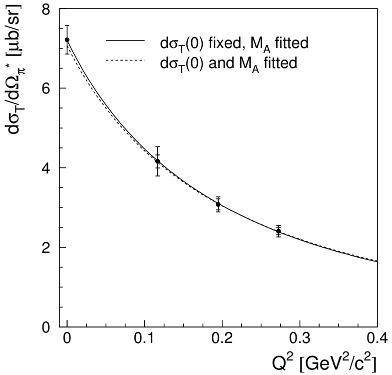
$G_A(Q^2)$ extracted by fitting the Q^2-dependence of the cross section

M_A *obtained using the dipole approximation for* $G_A(Q^2)$

Pion electroproduction

$$eN \rightarrow e'\pi + N' \qquad \frac{d\sigma}{dE'_e d\Omega'_e d\Omega_\pi} = \Gamma_v \left(\frac{d\sigma_T}{d\Omega_\pi} + \epsilon_L \frac{d\sigma_L}{d\Omega_\pi} \right)$$

- $d\sigma_T$ extracted by Rosenbluth separation
- M_A fitted to different models of the Q^2-dependence of $d\sigma_T$



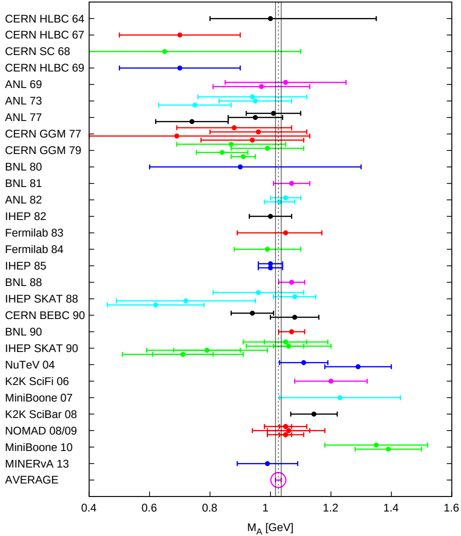
Phys. Lett. B468, 20 (1999)

- Model-dependent extraction

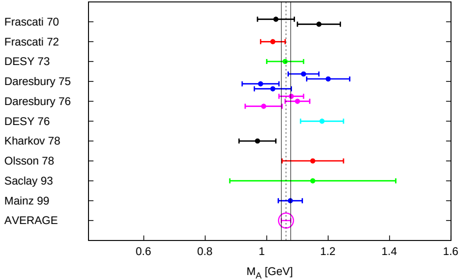
- Assumptions needed for other model parameters

Experimental situation

$\nu-$scattering: $\langle M_A \rangle = 1.026 \pm 0.009$

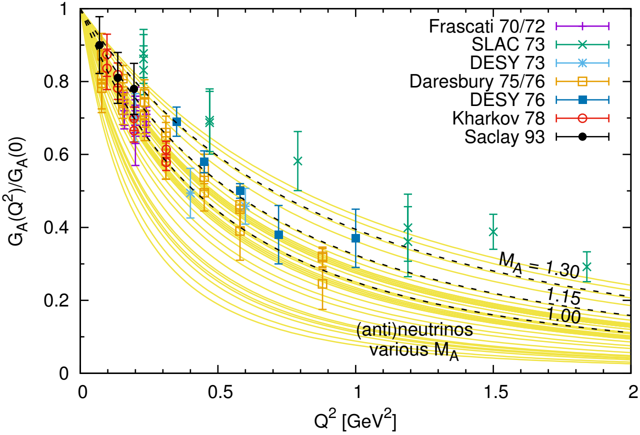


π electroproduction: $\langle M_A \rangle = 1.062 \pm 0.015$



- 2.4 σ difference on average M_A
- But large individual uncertainties & discrepancies

Q^2−dependence of G_A



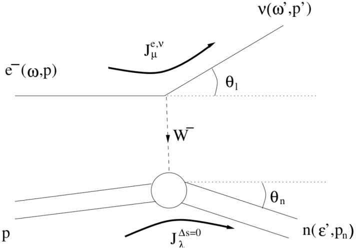
Clean measurements of axial FF by inverse β decay

Weak charge current reaction:

$$\frac{d\sigma}{d\omega'} = M\frac{G^2\cos^2\theta_c}{\pi}\frac{\omega'}{\omega}\left[\cos^2(\theta_l/2)f_2 + \left(2f_1 + \frac{\omega+\omega'}{M}f_3\right)\sin(\theta_l/2)\right]$$

$$e + p \rightarrow \nu + n$$

- $f_1 = f_1(G_A, G_M^p, G_M^n)$
- $f_2 = f_2(G_A, G_M^p, G_M^n, G_E^p, G_E^n)$
- $f_3 = f_3(G_A, G_M^p, G_M^n)$



Model-independent extraction of $G_A(Q^2)$!

High stat. & syst. precision possible

Donnelly, Kronenberg & Norum (1996)
Pauchy Hwang (1996)
Deur, JLab PAC25 LOI

Experimental challenges

1. Neutron detection with accurate kinematics
2. Small cross section ! ($\sim 10^{-40}$ cm^2/sr)
3. (Very) large electromagnetic backgrounds

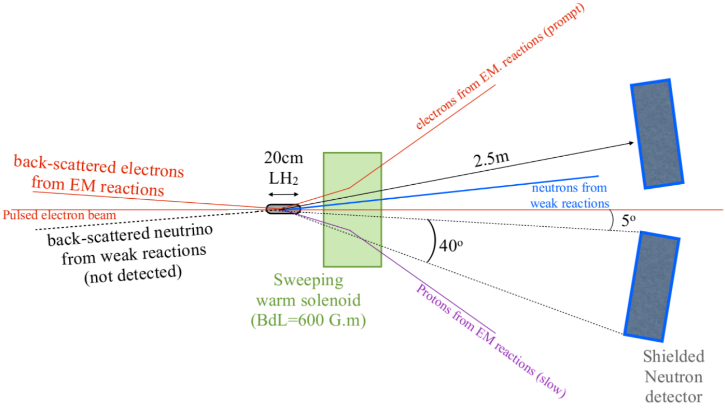
Strategy:

- Backward kinematics to enhance Weak/EM x-sections (forward n)
- High intensity (JLab/Mainz) electron beam + long LH2 target
- Low energy (< 120 MeV) beam to stay below π production threshold
- Polarized beam for background cleanup:

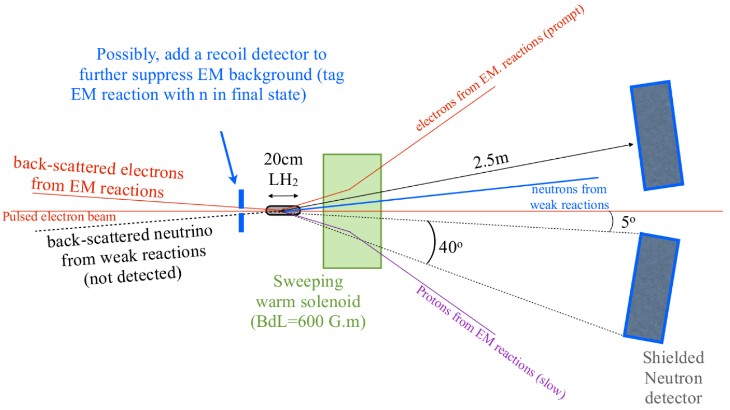
  Weak reaction asymmetry: 100% } pulse(+) to pulse(-) subtraction:
  EM background asymmetry is 0 } clean cancellation of background

- Pulsed beam to remove prompt EM background & TOF for n
- Kinematic identification of the elastic reaction

Experimental setup



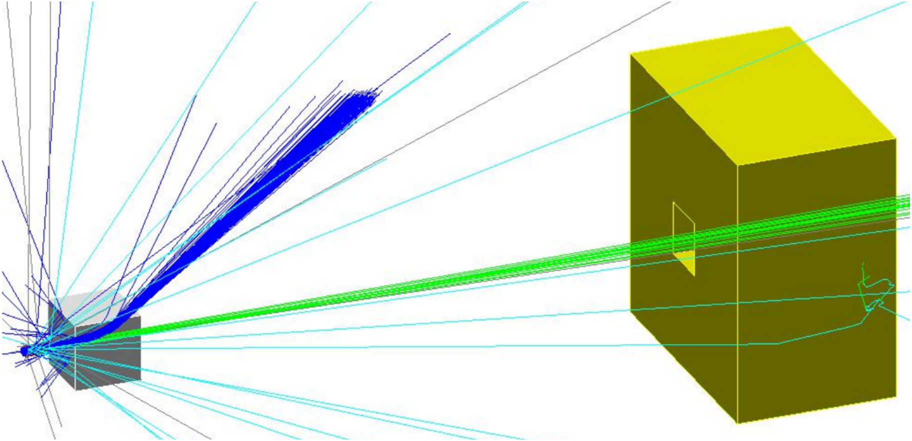
Experimental setup



Potential experimental facilities

- MESA at Mainz:
  - High luminosity, good beam energy, polarized beam
  - Beam pulse structure, beam energy flexibility?
- FEL at JLab:
  - Good energy
  - Mainly a FEL facility
  - Unpolarized electrons, currently no experimental Hall
- Hall D tagger at JLab:
  - Long TOF distance (80 m)
  - Possibility of 100 MeV beam, but invasive to Nuc. Phys. program
  - No cryogenic capability currently
  - 5 μA CW beam limitation
- JLab injector:
  - High intensity pulsed beam, polarized electrons
  - Space constraints may limit TOF distance
  - Possible interference with to Nuc. Phys. program

Background simulation



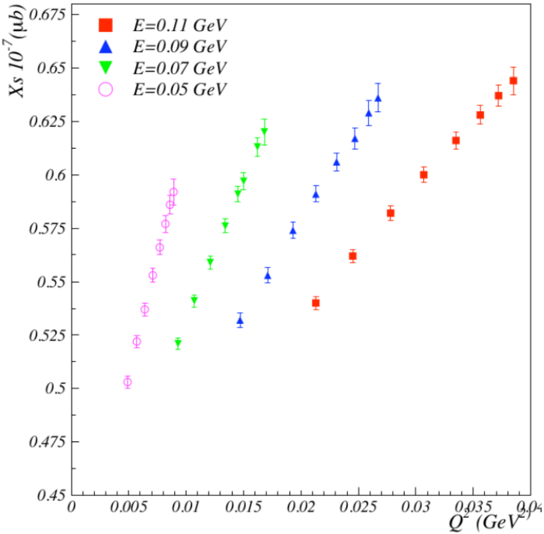
Primary sources of background

- Prompt EM (γ flash, electrons): can be reduced by timing cuts
- Windows: $Be + e \rightarrow n + e + X$:
  can be reduced with thin windows and backwards veto detector
- Scattered electrons (Møller, nuclear scattering):
  small after sweeping magnet

Preliminary background estimates,
detailed MC simulation now underway…

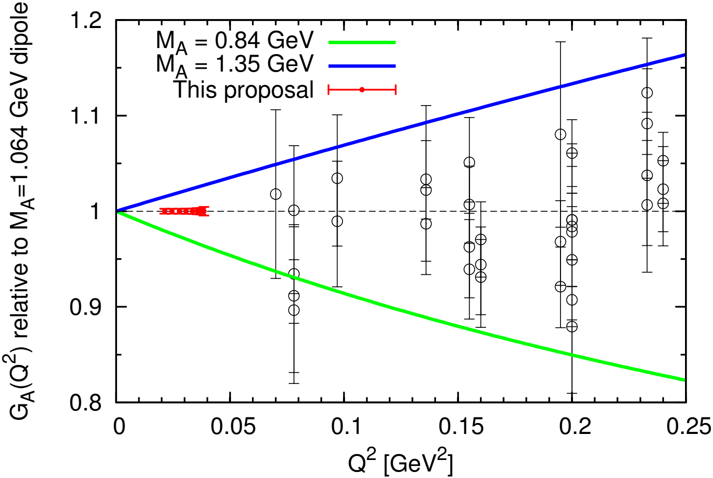
Cross section projections

- 6 days at 110 MeV
- 7 days at 90 MeV
- 17 days at 70 MeV
- 30 days at 50 MeV



– 100% efficiency and no background assumed

Projected $G_A(Q^2)$ results



Status of the project

- Extensive MC simulations ongoing to EM understand backgrounds
- Optimization of experimental setup:
  detector location, shieldings, etc
- Full experimental JLab proposal expected by 2018

New collaborators welcome!

Summary and conclusions

- Measurements of G_A have large uncertainties and dispersion
- Still some discrepancy between ν and e scattering experiments

- Inverse β decay $\rightarrow G_A(Q^2)$ accurately and model-independently
- High precision measurement will check the dipole approximation
- Low E energy experiment relatively easy and clean
- Large EM background supression under investigation
- Experimental JLab proposal expected next year
- Stepping stone to a higher energy experiment (up to $Q^2 = 4$ GeV^2)
  - Additional inelastic EM background
  - Full Q^2 mapping of G_A