5th International Spin Physics Symposium
September 9-14, 2002
Brookhaven National Laboratory

Measuring G_{En} at High Momentum Transfers

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JLAB E02013: Measurement of the Neutron Electric Form Factor G_{En} at High Q^2

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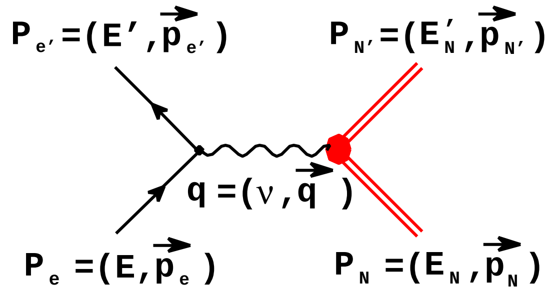
and

the Hall A Collaboration

Outline

- Motivation
- Measurements of G_{En}
- Formalismn of Double Polarization Experiments
- JLab Experiment E02–013
- Future Developements

Electron – Nucleon Elastic Scattering



Nucleon vertex:

$$\Gamma_\mu(p_N, p_{N'}) = \underbrace{F_1(Q^2)}_{Dirac}\gamma_\mu + \frac{i\kappa}{2m}\underbrace{F_2(Q^2)}_{Pauli}\sigma_{\mu\nu}q^\nu$$

Links to the double distributions:

$$F_1(t) \;=\; \Sigma_a e_a \int_0^1 \mathcal{F}^a(x;t)dx \;\; ; \;\; F_2(t) \;=\; \Sigma_a e_a \int_0^1 \mathcal{K}^a(x;t)dx$$

Sachs form factors:

$$G_E(Q^2) \;=\; F_1(Q^2) - \kappa\frac{Q^2}{4m^2}F_2(Q^2)$$
$$G_M(Q^2) \;=\; F_1(Q^2) - \kappa F_2(Q^2)$$

Breit–frame: Sachs form factors are the Fourier transforms of charge and magnetization densities of the nucleon.

pQCD prediction:

$$\frac{Q^2 \cdot F_2}{F_1} = \frac{Q^2(1 - G_E/G_M)}{\kappa(\tau + G_E/G_M)} \to \text{const}$$

Physics Motivation: Why is accurate data on G_{En} at high Q^2 important?

Electromagnetic structure:

- Fundamental property of the nucleon
- Form factors are the key elements to its understanding

G_{En} is poorly known at high Q^2 (>1.5 $(\text{GeV/c})^2$)

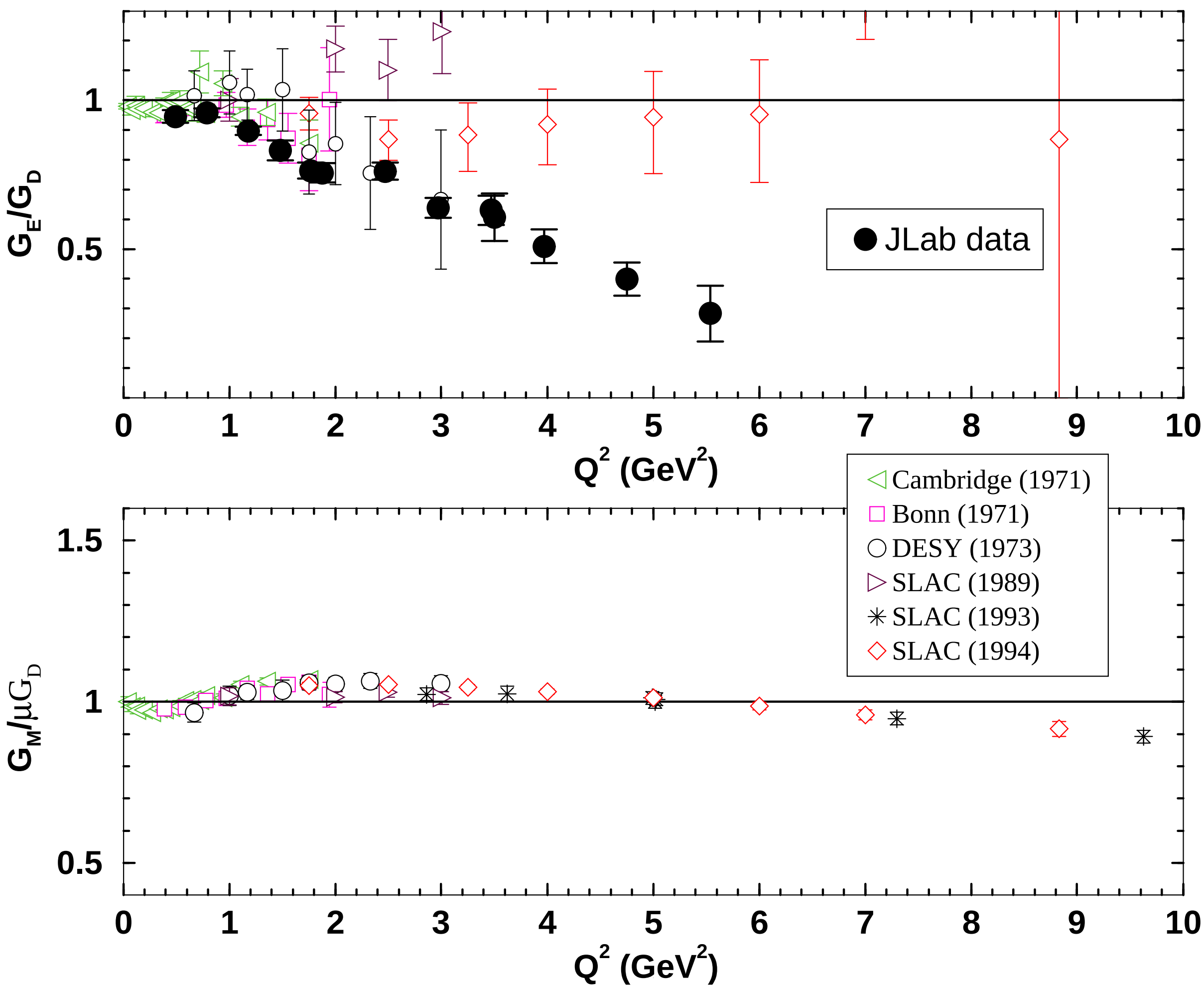
New, accurate data on G_{En} will:

- Provide constraints on new and existing models of the nucleon (e.g. on GPDs through knowledge of $F_2(Q^2)$)
- Essential for understanding form factors of few–body systems

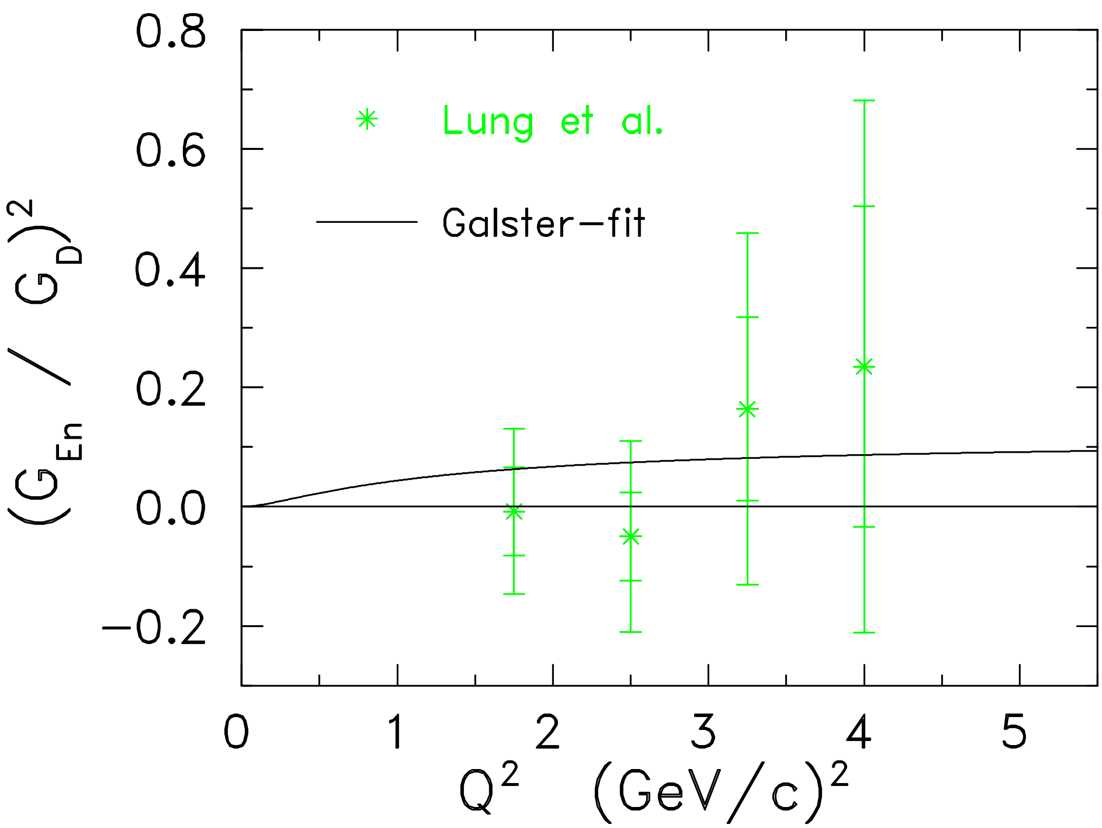
Nucleon Form Factors – a very active and exciting field:

- Jlab Hall A: new results on G_{Ep} (M.Jones et al., Phys. Rev. Lett. 84, 1398 (2000); O.Gayou et al.,arXiv:nucl-ex:0111010)
- Jlab Hall B: experiment E94–017: G_{Mn}
- Jlab Hall C: E93–026, E93–038: G_{En}
- MAMI, MIT–Bates.

World Data on G_{Ep} and G_{Mp}



Data on G_{En} at High Q^2



- No free neutron target ⇒ nuclear effects
- Net charge is 0 ⇒ G_{En} is small at low Q^2
- Cross Section dominated by G_{Mn}

⇒ Extraction of G_{En} from cross section measurements is difficult

⇒ Double polarization experiments, especially semi–inclusive ones

Double Polarization Approaches to Measure G_{En}

- $\vec{D}(\vec{e}, e'n)$ with polarized target. (NIKHEF, JLAB)
- $D(\vec{e}, e'\vec{n})$ with recoil polarimeter (BATES, Mainz, JLAB)
- $^3\vec{H}e(\vec{e}, e'n)$ with high pressure cell (BATES, NIKHEF, Mainz, E02013 at JLAB)

For all three types:

- Asymmetry measurement
- Interference enhances the small amplitude contribution
- avoids Rosenbluth separation and subtraction of large proton contribution

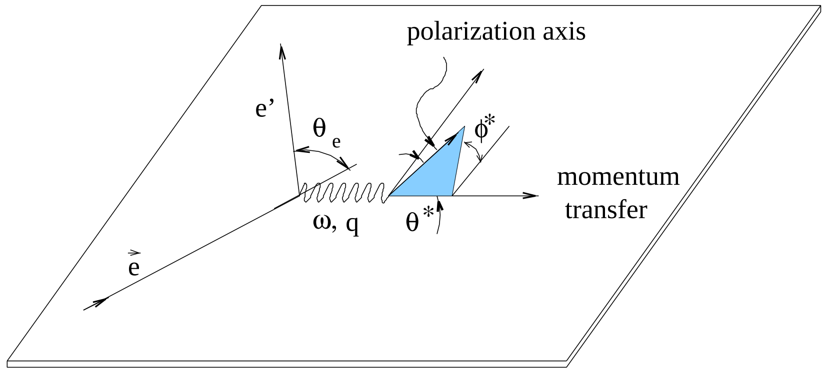
The result for given beam time is defined by Figure-of-Merit:

$$FOM = 1/\sigma^2 \propto A^2 \cdot N_{events}$$

$$FOM_1 : FOM_2 : FOM_3 \sim 1(10) \,/\, 7 \,/\, 175$$

(statistical only)

Double Polarization: Formalism



Asymmetry:

$$A = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}$$

$$= A_\perp \sin\theta^\star \cos\phi^\star + A_\parallel \cos\theta^\star$$

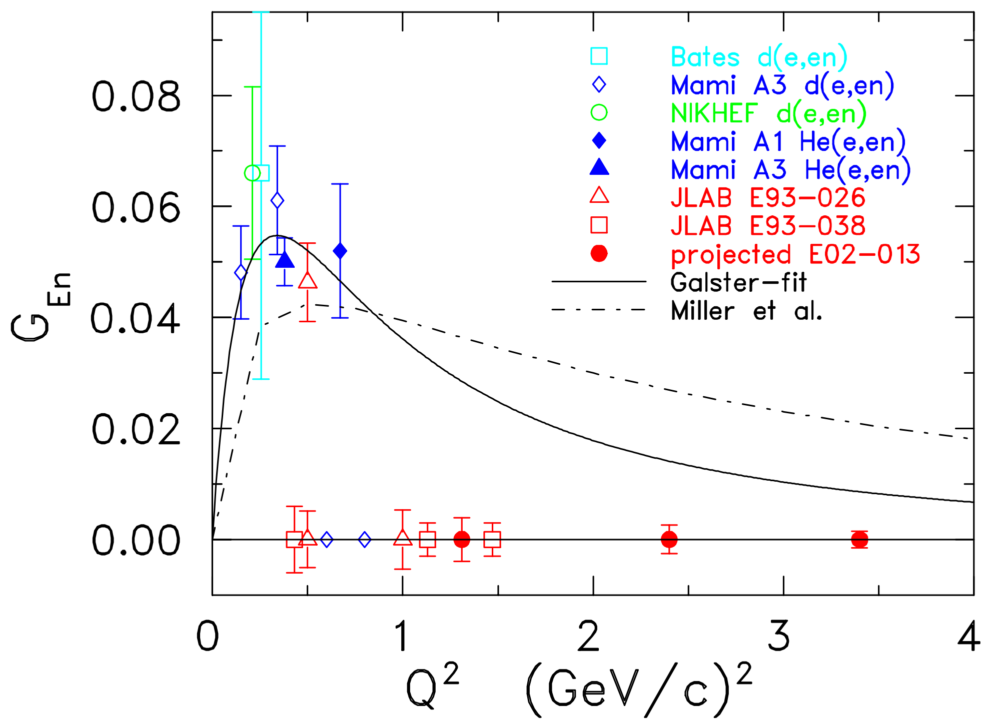
(assuming $P_e = P_n = 1$)

$$A_\perp = -\frac{2\sqrt{\tau(\tau+1)}\tan(\theta/2)\,\frac{G_{En}}{G_{Mn}}}{(\frac{G_{En}}{G_{Mn}})^2 + (\tau + 2\tau(1+\tau)\tan^2(\theta/2))}$$

$$A_\parallel = -\frac{2\tau\sqrt{1+\tau+(1+\tau)^2\tan^2(\theta/2)}\tan(\theta/2)}{(\frac{G_{En}}{G_{Mn}})^2 + (\tau + 2\tau(1+\tau)\tan^2(\theta/2))}$$

(with $\tau = Q^2/4m_N^2$)

Data on G_{En} from Double Polarization Experiments



low Q^2 point of E02-013 will be used to test GEA calculations

Proposed Measurement:

Cross Section Asymmetry in $^3\vec{\mathrm{He}}(\vec{e}, e'n)$

to obtain G_{En} at three different Q^2

Q^2 $(\mathrm{GeV/c})^2$	E_i GeV	θ_e deg	p_e GeV/c	θ_n deg	p_n GeV/c	T_n GeV
1.31	1.644	54.6	0.95	35.2	1.34	0.70
2.40	2.444	54.6	1.17	28.3	2.01	1.28
3.40	3.244	50.6	1.43	25.4	2.58	1.81

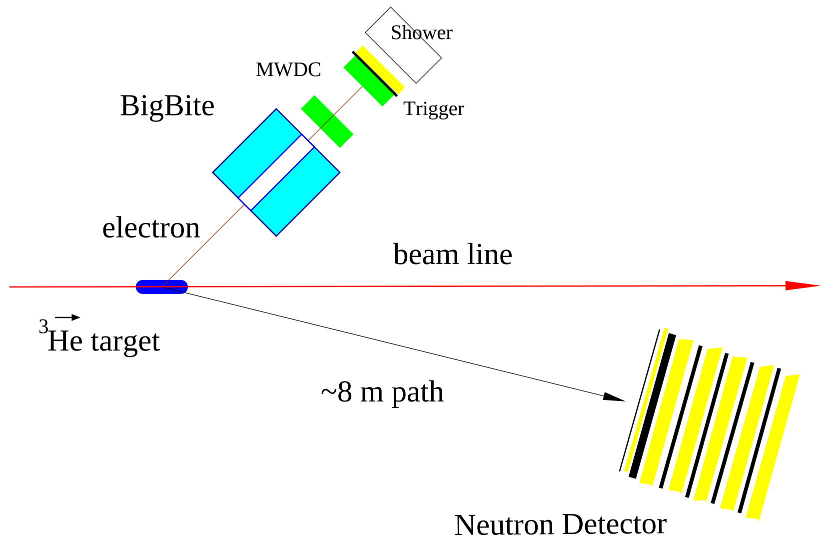
Approved beamtime: 768 hours

Expected (statistical) uncertainty: less than 15%

Optimization of the Experimental Approach for Large Q^2

- QES events selection by using cuts on W and $p_{miss,per}$ is sufficient
- Nuclear corrections for QES from ^{3}He are under control above 2-3 (GeV/c)^2
- Acceptance for electron arm can be large for "low" luminosity of polarized target
- Neutron efficiency vs detection threshold wins at large Q^2 – summing of amplitudes

Experimental Setup



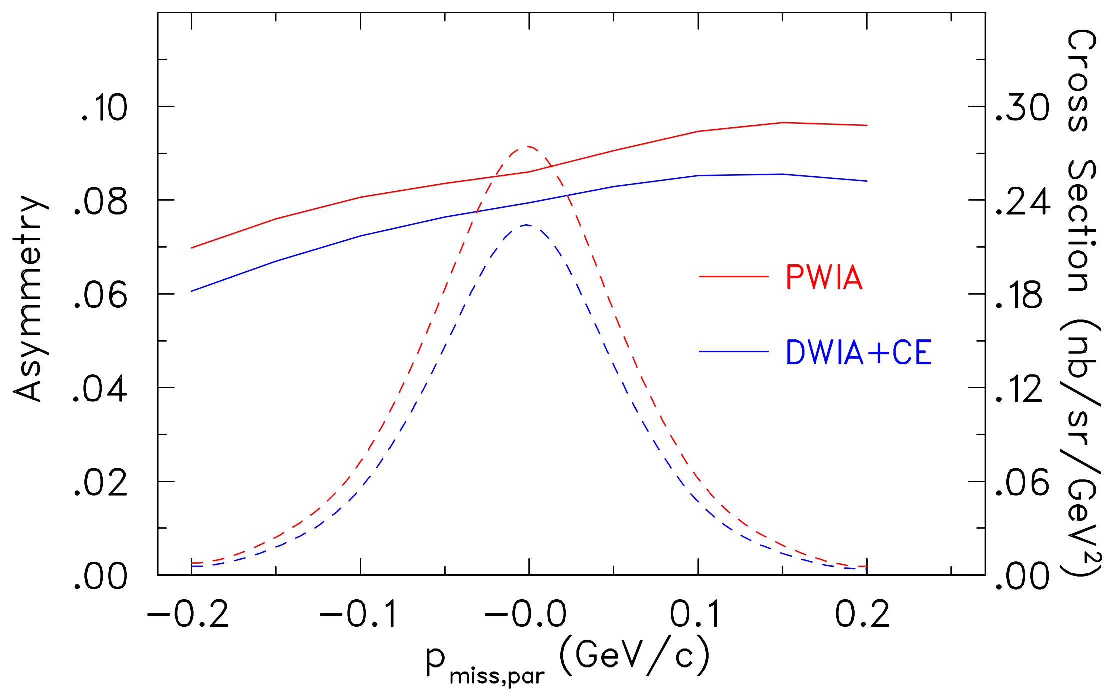
Will be measured:

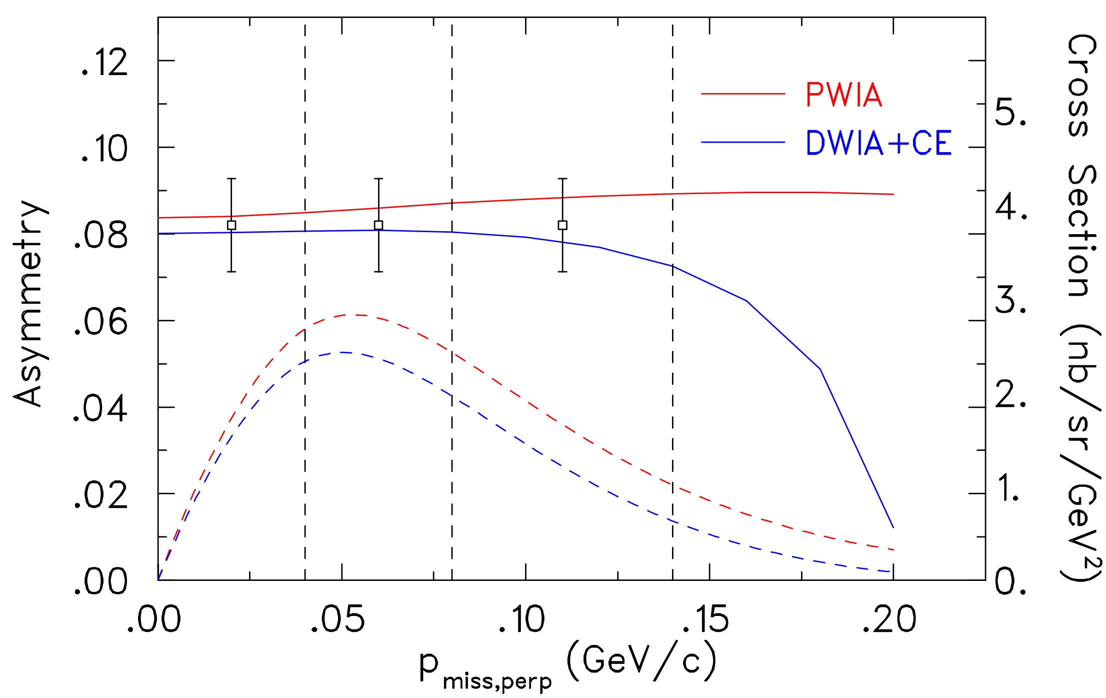
- electron scattering angles ($\pm$ 2-3 mr)
- position of the event vertex on the target ($\pm$ 6 mm)
- electron momentum ($\pm$ 1-1.5 %)
- direction of the neutron momentum ($\pm$ 10 mr)
- neutron speed ($\pm$ 1%)

Will be reconstructed:

- direction of the momentum transfer $\vec{q}$
- parallel missing momentum ($\pm$ 250 MeV/c)
- perpendicular missing momentum ($\pm$ 30 MeV/c)
- invariant mass W ($\pm$ 50 MeV)

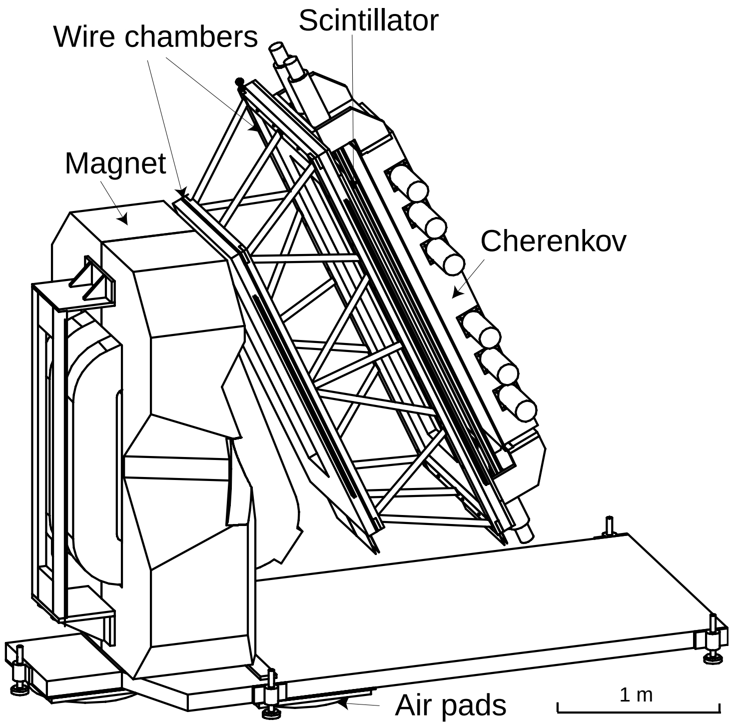
GEA Results (M. Sargsian)





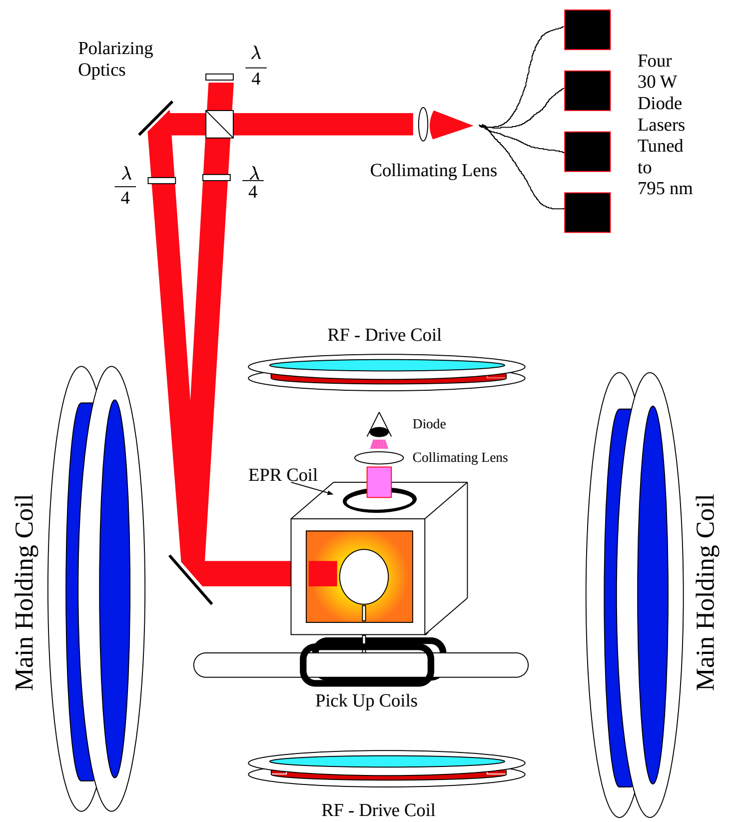
$\Rightarrow$ Asymmetry does not vary strongly within our bins in p_{miss}

BigBite Spectrometer:



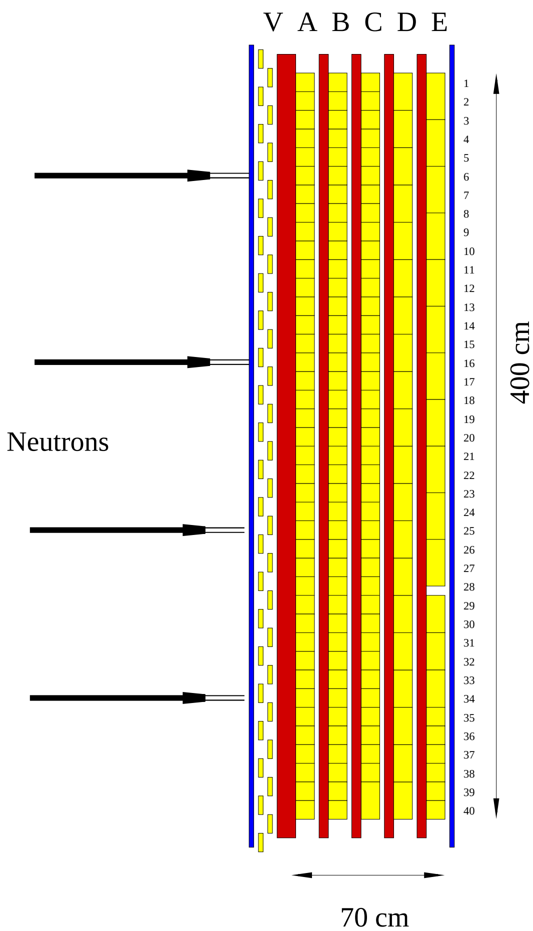
- non focusing, large acceptance, open geometry
- $\Delta p/p = 1 – 1.5$ % (@ 1.2 T) $\Rightarrow \sigma(W) = 50$ MeV
- angular resolution 1.5 mr, extended target resolution 6 mm
- large solid angle 76 msr
- detector package:
  MWDCs, segmented trigger, lead–glass shower

Polarized ^{3}He Target



- luminosity: $1.0 \cdot 10^{36}$ e–neutron/s/cm^2
- beam current: 15 μA
- target polarization: 40%
- cell length: 40 cm

Neutron Detector Array



Neutron Detector:

- 173 neutron bars in 5 layers
- separated by 2.75 cm iron
- efficiency: 60%
- thresholds: 50 – 150 MeVee
- active area: 160 cm x 400 cm
- position resolution: 5–7 cm
- timing resolution: 0.3 ns

$\Rightarrow$ $\sigma(p_{mperp}) = 30$ MeV/c

$\Rightarrow$ $\sigma(p_{mpar}) = 250$ MeV/c

Veto Detector:

- 40 bars
- efficiency: $> 99\%$ (protons, 2.6 GeV/c)
- efficiency: $\approx 12\%$ (neutrons)

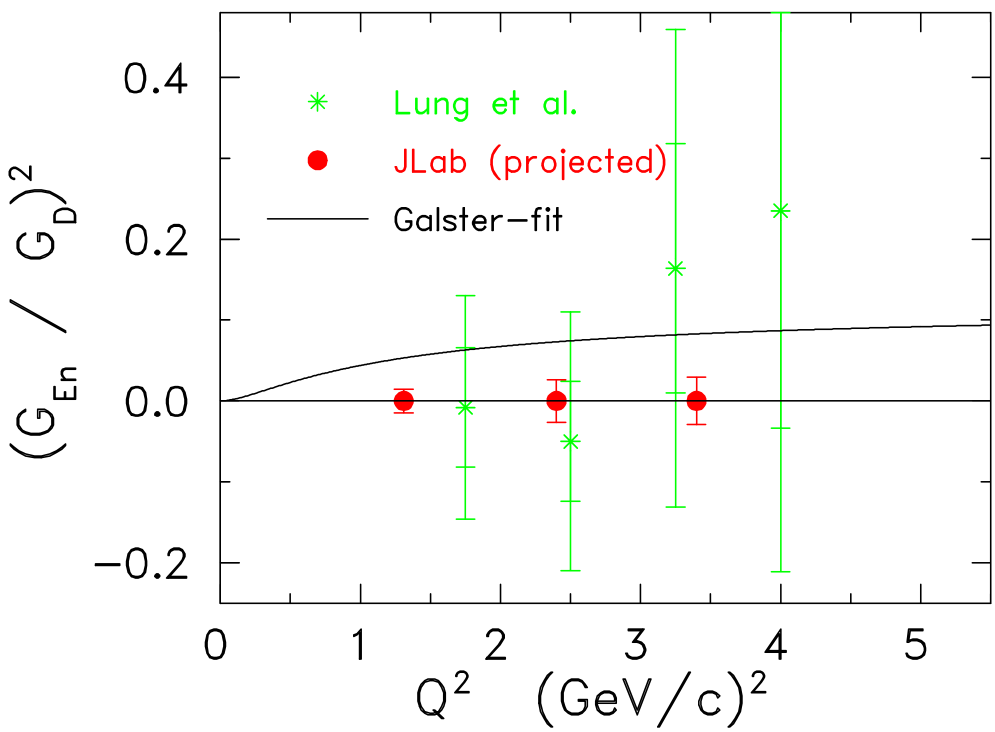
Neutron detector is optimized for

- high efficiency for high momentum neutrons (2.6 GeV/c)
- utilizing high thresholds for background suppression
- large solid angle
- good position resolution

Expected Uncertainties for $Q^2 = 3.4\ (\mathbf{GeV/c})^2$

	expected value	contribution to relative uncertainty of G_{En}
raw asymmetry A_{exp}	-0.0233	
$\Rightarrow$ statistical error in G_{En}		14.2%
beam polarization P_e	0.75	3%
target polarization P_{He}	0.40	4%
neutron polarization P_n	$0.86 \cdot P_{He}$	2%
dilution factor D (nitrogen)	0.94	3%
dilution factor V (background)	0.91	4%
correction factor for $A_{\parallel}$ components	0.94	<3%
G_{Mn}	0.057	5%
nuclear correction factor	1.0 – 0.85	5%
$\Rightarrow$ systematic error in G_{En}		10.4%

Projected data



statistical error for $\delta\left(\frac{G_E}{G_M}\right)$ on level of 0.02

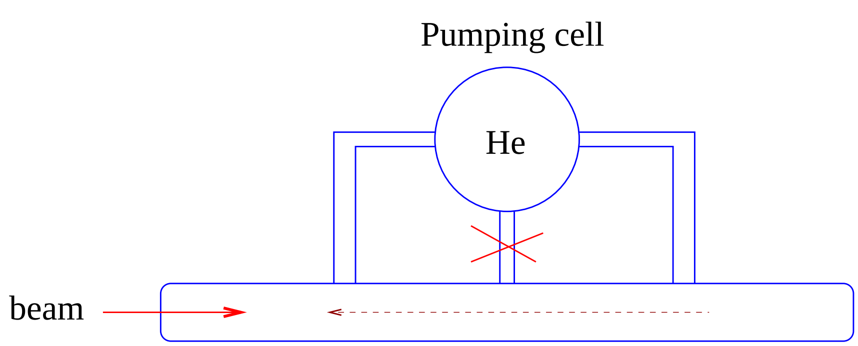
Possible boosts for $^3\vec{He}$ approach

- Super BigBite with 4 T magnet or JLab Hall A MAD spectrometer will allow the use of higher beam energies.

$$FOM \sim \left(\frac{E_f}{E_i}\right)^2 = \left(\frac{E_i - T_n}{E_i}\right)^2$$

FOM by factor of 2–3 higher. Momentum transfers of at least 5 $(\text{GeV/c})^2$ are feasible.

- Higher laser power and flow of the gas inside the target cell can increase usable beam current. This will lead to improvement of FOM by factor of 2-3.



Conclusion

- New exciting data on the nucleon form factors is just getting available
- Jlab E02-013 will significantly increase our knowledge about G_{E_n} at higher momentum transfers Q^2
- Future plans to extend these measurements at Jlab exist