Measurement of G_E^p/G_M^p Using Elastic $\vec{p}(\vec{e},e')p$ up to $Q^2 = 3.50$ (GeV/c)^2

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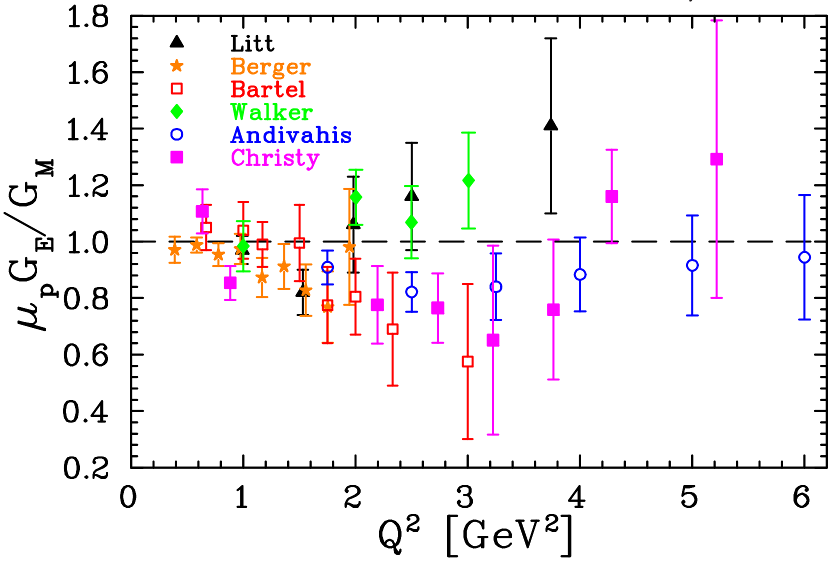
- Introduction
- Experimental Setup
- Uncertainties and Beam Time Request
- Expected Results and Summary
- Answers to PAC-25 Comments

Physics Motivation

METHODS TO MEASURE G_E/G_M

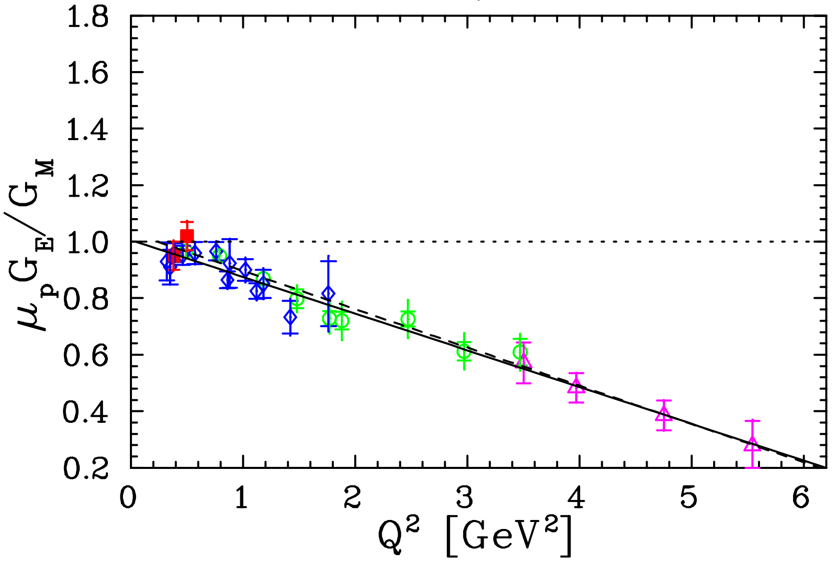
- Rosenbluth Separation Method

$$d\sigma_B = C_B(Q^2,\varepsilon)\left[G_M^2(Q^2) + \frac{\varepsilon}{\tau}G_E^2(Q^2)\right]$$



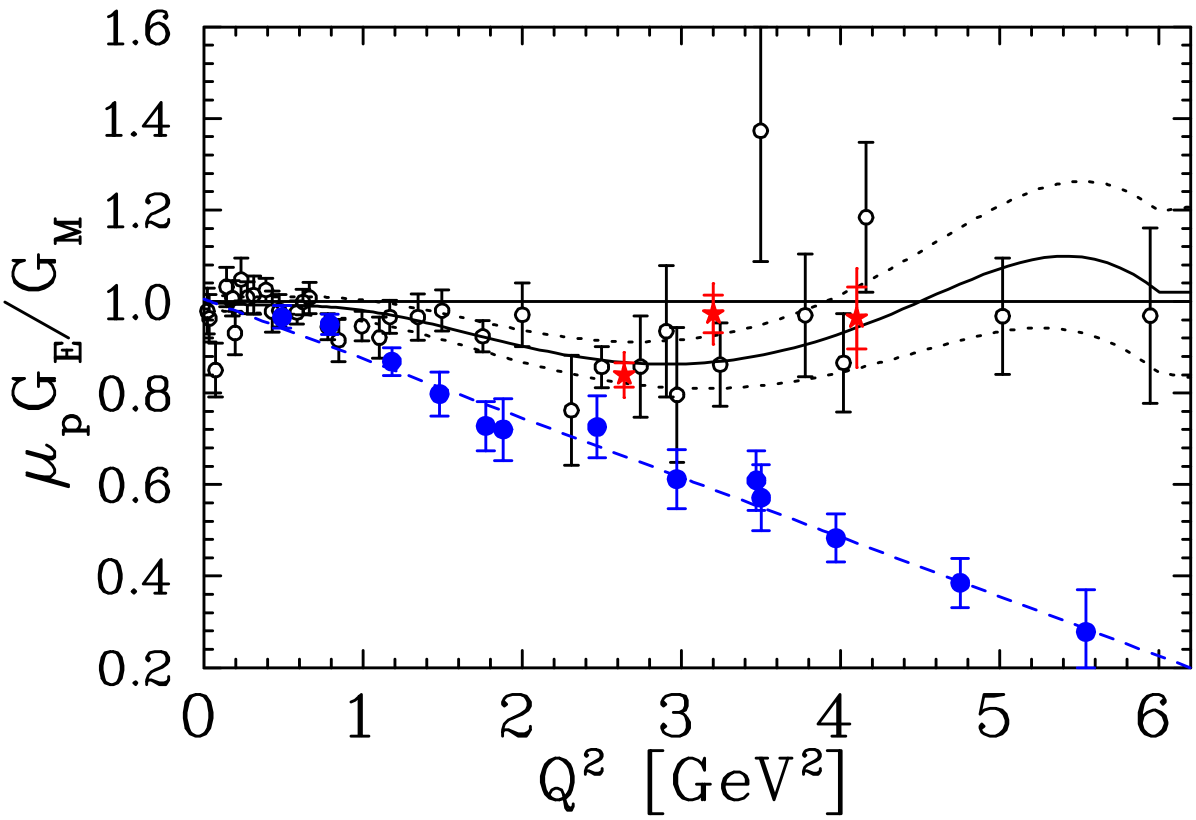
- Polarization Transfer Method

$$\frac{P_t}{P_l} = -\sqrt{\frac{2\varepsilon}{\tau(1+\varepsilon)}}\frac{G_E}{G_M}$$



E01-001 Preliminary Results

There might be problem in combining all cross section data from different laboratories and different experiments. However, preliminary results from a recently completed “high-precision” Rosenbluth experiment in Hall A tend to confirm previous Rosenbluth data.



STUDY OF THE TWO PHOTON EXCHANGE (TPE) EFFECT

- The two photon exchange correction may affect interpretation of the data
- Theoretical
  - Larger correction to Rosenbluth than to polarization transfer data
  - Larger correction at small ϵ (backward angle scattering)
- Experimental
  - Measure the forbidden component: A_N, P_N, A_y - study the $\mathcal{I}m$ part
  - Measure the non-linearity of Rosenbluth plot - study the non-linear component
  - Measure the cross section ratio of e^+ and e^- scattering - direct study of the $\mathcal{R}e$ part, *e.g.* LOI04-005

    new beam-line instrumentation required, Q^2 range limited
- Most likely, still need the discrepancy itself as input for TPE calculations.

THE G_E^p SURPRISE

- the new p.t. data set strong constraint on the theories;
- the reason for the observed discrepancy between the two data sets remains unknown.

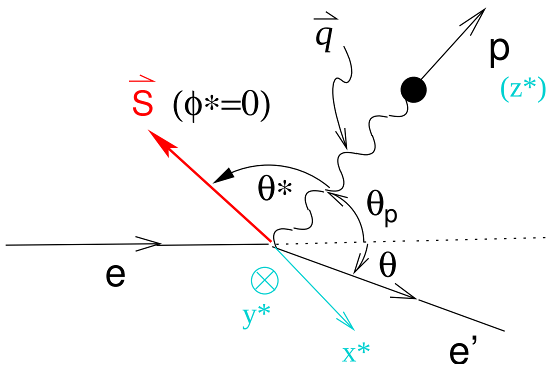
HOW TO PROCEED?

- Problem with Rosenbluth data? - unlikely
- Problem with interpretation of the data? - two photon exchange
  Is it appropriate to attribute the full discrepancy to TPE?
- Other unknown effect? (physics, systematic)
- *Measurement using a new, independent method is highly needed.*

THE PROPOSED EXPERIMENT

Extraction of G_E^p/G_M^p from elastic asymmetry:

$$A \equiv \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-}$$
$$= -\frac{2\sqrt{\frac{\tau}{1+\tau}}\tan\frac{\theta}{2}\left\{\sqrt{\tau\left(1+(1+\tau)\tan^2\frac{\theta}{2}\right)}\cos\theta^\star + \sin\theta^\star\cos\phi^\star\frac{G_E}{G_M}\right\}}{\frac{(\frac{G_E}{G_M})^2+\tau}{1+\tau} + 2\tau\tan^2(\theta/2)}$$



- Measure elastic asymmetries at large ϵ
  – small corrections from two photon exchange
- Measure the spin polarization of initial protons instead of outgoing ones
  Completely different systematics, compared to the polarization transfer method
- Provide the first G_E^p/G_M^p data from polarized target method at $Q^2 = 2.1$ and 3.5(GeV/c)^2, to a good precision.

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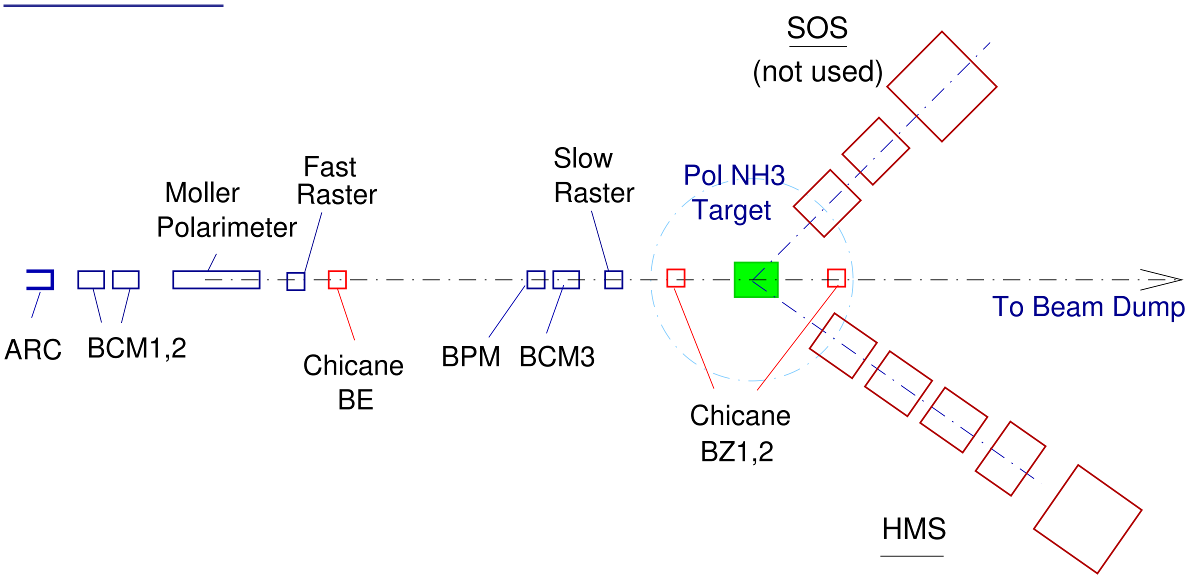
◇ The UVa group has extensive experience in performing polarized NH_3 target experiments in Hall C.

Experimental Setup

Overview

- Polarized electron beam, $E = 3.6$ and 6 GeV, $P_b = 75\%$, $\Delta P_b/P_b = 1.5\%$;
- Polarized NH_3 target, spin aligned at $139°$, $P_t = 75\%$, $\Delta P_t/P_t = 2.5\%$;
- Single-arm electrons detected by the HMS at $Q^2 = 0.6$, 2.1 and 3.5 (GeV/c)^2;

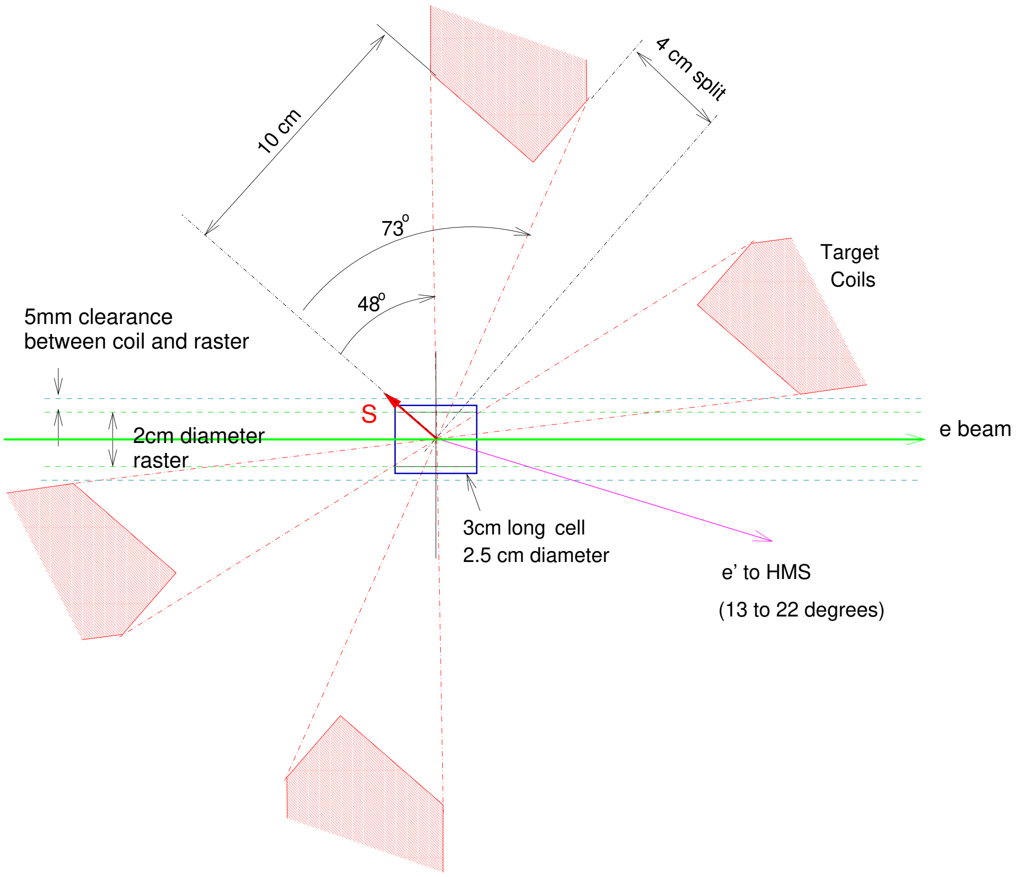
Floor Plan



- Beam-line chicanes and the slow raster system will be used;
- This setup was used in several experiments in Hall C.

TARGET COIL CONFIGURATION

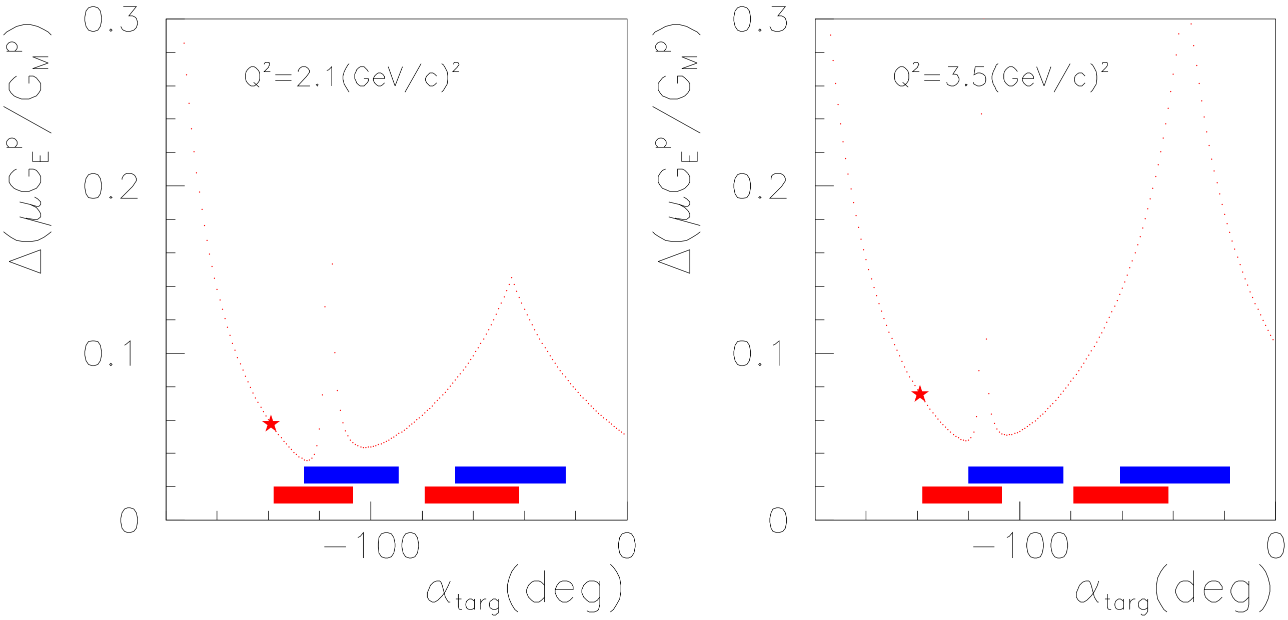
- The main constraint on the kinematics comes from the target Helmholtz coils.



  - interference between coils and the electron beam;
  - blocking of the outgoing electrons.

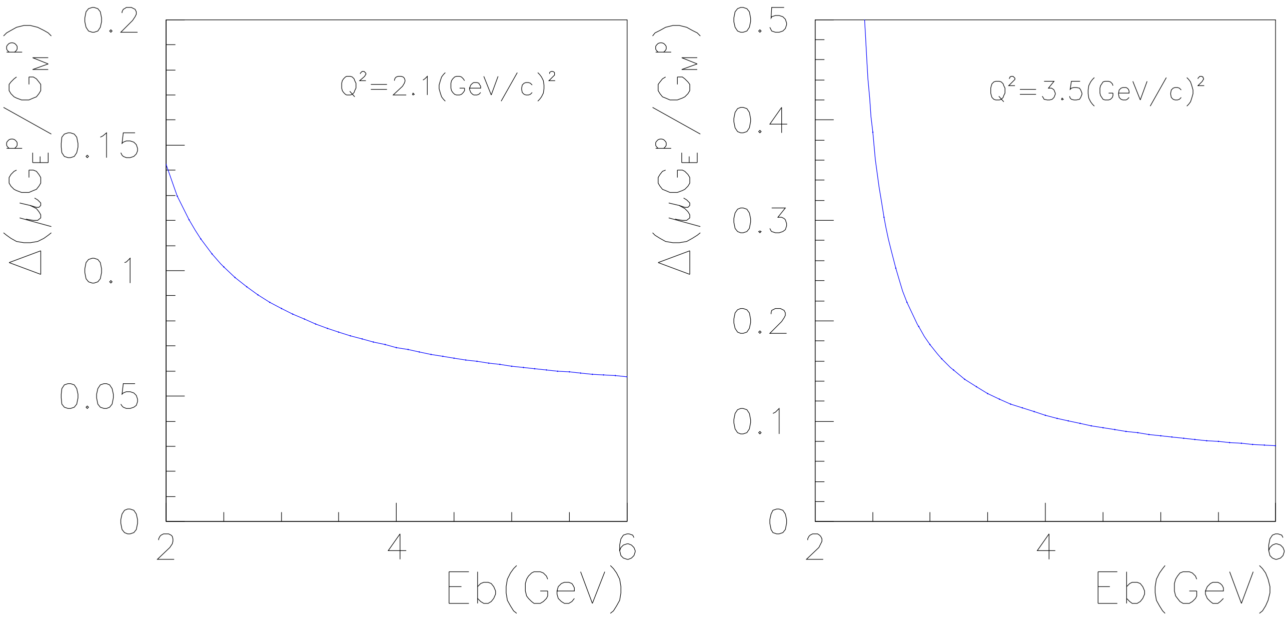
Kinematics Optimization *(both figures updated, different from the proposal)*

- Target spin orientation



  - red: blocking of the scattered electrons; blue: interference with the beam;
  - It is desired to perform measurements at all Q^2 at a single spin configuration. (target rotation takes one day).

- Beam energy



  - Ask for 6 GeV beam, however > 5.5 GeV is acceptable.

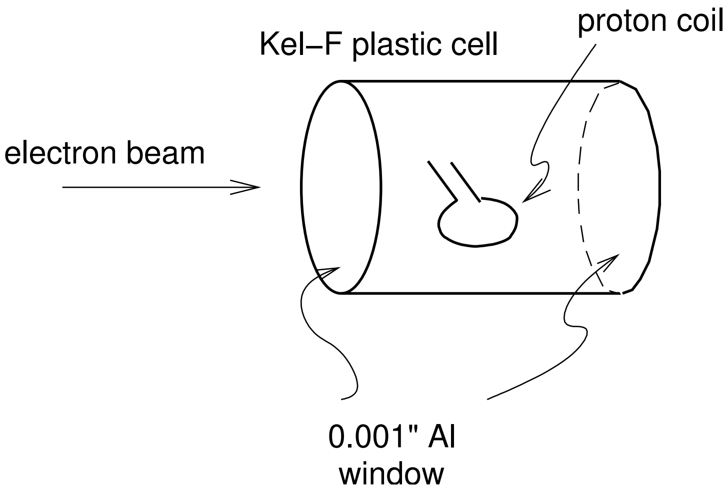
DATA ANALYSIS

$$A = \frac{A_{raw}}{f P_b P_t} - A_N$$

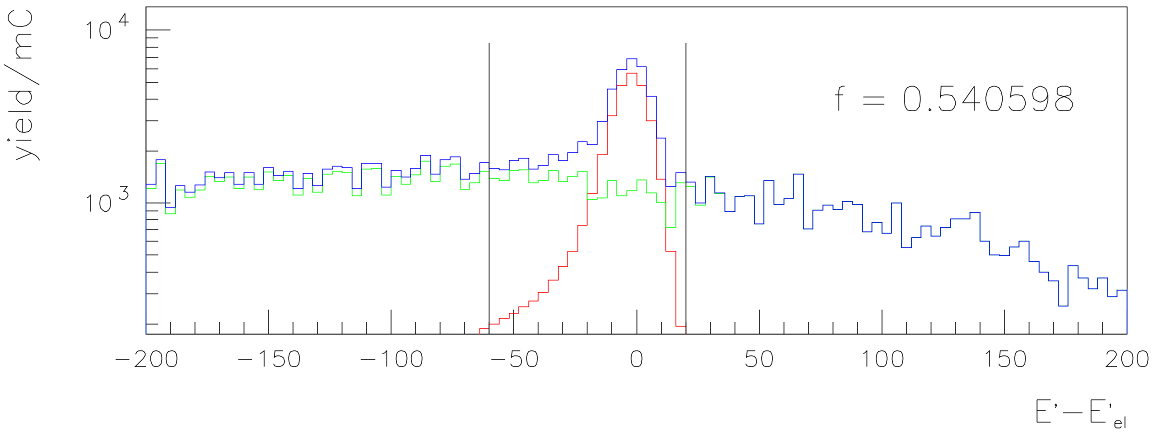
with $P_b = 75\%$, $P_t = 75\%$, $f \approx 0.5$,

A_N is a small correction due to the nitrogen asymmetry

THE CELL



TARGET DILUTION $f = \frac{N_p}{N_p + N_{\mathrm{QE}}}$



Kinematics

Q^2 (GeV/c)^2	0.61	2.10	3.50
E (GeV)	3.60	6.00	6.00
θ_e	13.45°	15.39°	21.65°
E' (GeV)	3.273	4.881	4.135
θ_p	60.95°	45.03°	35.27°
p_p (GeV/c)	0.849	1.831	2.642
$\theta^\star$	78.03°	93.98°	103.75°
$\phi^\star$	177.98°	178.51°	177.89°
A_{el}	0.078	0.119	0.200
A_{raw}	0.0219	0.0335	0.0561
$(A_{el,bosted} - A_{el})/A_{el}$	5.33%	17.56%	27.60%
σ (nb/sr)	375.215	5.893	0.332
elastic rate (SIMC, Hz)	141.430	2.600	0.148
total rate (el rate/f, Hz)	282.860	5.200	0.296
N_{tot}	5202K	862K	262K
$(\Delta A/A)$ Statistical	2.000%	3.218%	3.483%
$(\Delta A/A)$ Systematic	2.811%†	4.050%	4.050%
$(\Delta A/A)$ Total	3.450%	5.173%	5.342%

Uncertainties

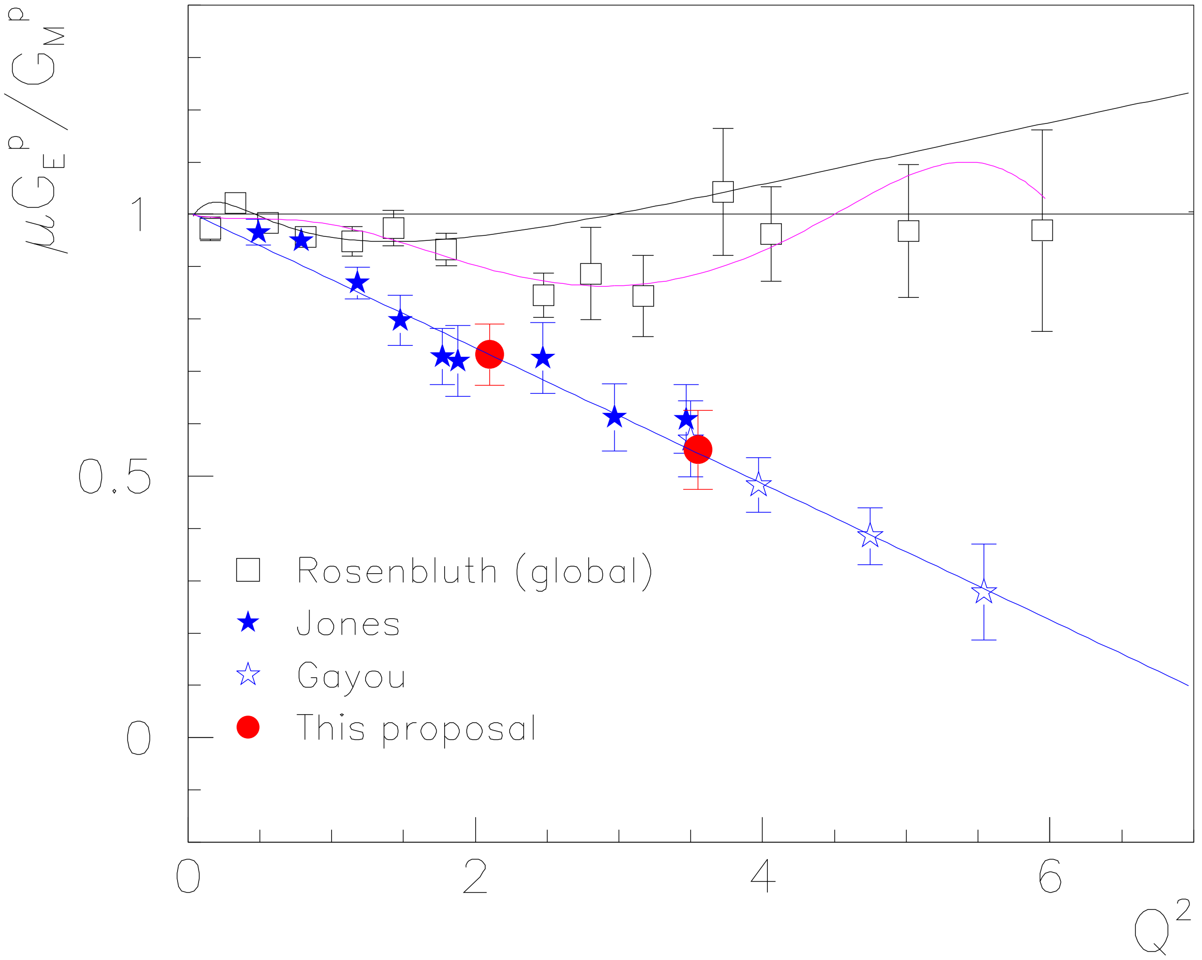
Q^2 (GeV/c)^2	0.61	2.10	3.50
Uncertainty on $\mu G_E^p/G_M^p$			
$\Delta P_{beam}/P_{beam} = 1.5\%$	-	0.0174	0.0222
$\Delta P_{targ}/P_{targ} = 2.5\%$	-	0.0290	0.0370
Target dilution $\Delta f/f = 2.5\%$	-	0.0290	0.0370
Beam charge asymmetry	-	0.0147	0.0179
Nitrogen asymmetry	-	0.0006	0.0007
Deadtime correction	-	0.0012	0.0015
$\Delta E/E = 5 \times 10^{-4}$	-	0.0001	0.0001
$\Delta E'/E' = 1 \times 10^{-3}$	-	0.0008	0.0005
$\Delta\theta_e = 1.0$ mrad	-	0.0003	0.0002
Target spin orientation (inp) 0.1°	-	0.0097	0.0069
Target spin orientation (oop) 0.1°	-	0.0024	0.0025
Total syst.	-	0.0480	0.0600
Total stat.	-	0.0373	0.0515
Beam time (hours)	5.1	46.0	245.4
Expected $\mu G_E^p/G_M^p$	-	0.732 ± 0.058	0.550 ± 0.076

Beam Time Request

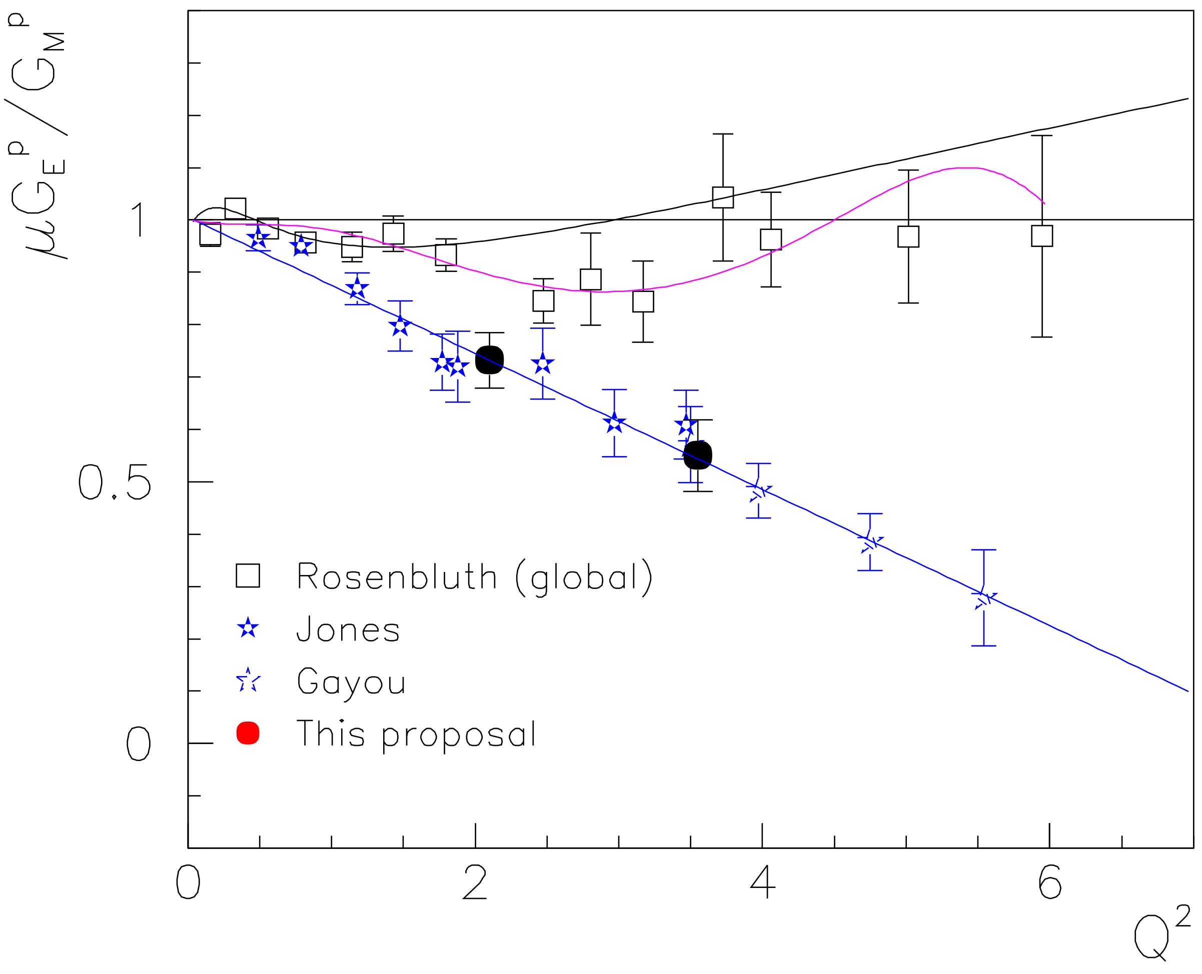
Q^2 (GeV/c)^2	0.61	2.10	3.50
E (GeV)	3.60	6.00	6.00
θ_{HMS}	13.10°	15.39°	21.65°
p_{HMS} (GeV/c)	3.273	4.881	4.135
Production time	5.1	46.0	245.4
carbon and helium runs	2	4	12
Møller measurement	1	2	9
arc measurement	4	4	
Total beam time (PAC hours)		334	
One pass change		8	
HMS configuration change		6	
Target field survey		10	
Target anneal		56	
Two target insert changes		40	
Total overhead (clock hours)		120	

- Total beam time needed: 17 days
- *If scheduled before (or after) SANE, no additional time for target installation will be needed.*

Expected Results



- Expect $\Delta(\mu G_E^p/G_M^p) = 0.058$ and 0.076.



- An improvement in the systematic uncertainties is possible: $\Delta P_t/P_t = 2\%$ and $\Delta f_N/f_N = 2\%$;
- Reduce the total uncertainty to $\Delta(\mu G_E^p/G_M^p) = 0.052$ and 0.069.

Choice of Experimental Design

- Compared to single proton and coincidence measurements:
  - single proton detection (HMS):
    lower rate, background from π^0 production
  - coincidence:
    ◇ advantage: almost no dilution from QES events;
    ◇ possible design:
    * (proton $\rightarrow$ SOS, electron $\rightarrow$ HMS) can only reach $Q^2 = 1.9$(GeV/c)^2
    * proton $\rightarrow$ HMS, electron $\rightarrow$ calorimeter
    lower rate $\Rightarrow$ longer beam time;
    due to target coil blocking, strict constraints on beam energy;

- Compared to PR01-105
  PR01-105: simultaneouly measure A_L and A_T at $Q^2 = 1.1, 2.1$ (GeV/c)^2
  - uncertainties due to fP_bP_t cancel in the ratio A_T/A_L
  - need to precisely measure $A_T/A_L \Rightarrow$ much longer beam time
  - lower $Q^2 \Rightarrow$ less physics impact.

- Compared to LOI04-001: polarized ^{3}He target, two body break-up
  - proton in ^{3}He is not free
  - f.o.m.: NH_3 factor of 2 better than $^3\vec{\mathrm{He}}$

- Overall, the proposed measurement will use the least resources to achieve the best results.

PAC-20 REPORT ON PR01-105

Individual Proposal Report

Proposal: PR-01-105

Title: G_{Ep} / G_{Mp} via Simultaneous Asymmetry Measurements of the Reaction $\vec{p}(\vec{e},e')$

Spokesperson: G. Warren

Motivation: The ratio G_{Ep} / G_{Mp} is vital to our understanding of the structure of the proton. Results from Hall A experiments using electron-proton polarization transfer have shown that this ratio clearly decreases with increasing Q^2. An experiment based on the Rosenbluth separation method (E-01-001) has been approved to check on these findings. The proposed experiment aims at providing another check with different systematic uncertainties and high statistical precision.

Measurement and Feasibility: The polarized beam polarized target asymmetry is to be measured simultaneously, using two spectrometers at the same Q^2, for different orientations of the proton polarization. The ratio of both cross sections is a function of G_{Ep} / G_{Mp} . In this ratio the degrees of polarization and the dilution factor of the target drop out to first order, thus minimizing systematic uncertainties. It is proposed to measure G_{Ep} / G_{Mp} at Q^2=1.1 and 2.1 $(GeV/c)^2$.

Issues: The proposal is clearly written and the underlying idea is very good. However, given the existing data and the approved experiment to check on them, the PAC does not find a compelling reason to approve this proposal at the present time.

Recommendation: Defer

Scientific Rating: N/A

- E01-001 results did not solve the discrepancy. It is time to do polarized target measurement

Why is this measurement important?

- For any unknown quantity, we should measure it to as high precision as possible, and using as many methods as possible.

  For example:

  - E01-001: single-arm proton vs. single-arm electron detection; to solve the proton f.f. discrepancy;
  - E02-005: deuteron $A(Q)$ to solve the 8% discrepancy between Mainz and Saclay data;
  - GEn: polarimeter (E93-026, PR04-003) vs. polarized target (E93-038 ND3, E02-013 polHe3).

Summary

- Request 17 days in Hall C;
- Provide the first results of G_E^p/G_M^p from polarized target method;
- A necessary & logical step in the scientific program to understand the proton form factors.

Updates— Changes to the proposal since submission

- Beam polarization $P_b = 80\% \rightarrow 75\%$
- Uncertainty in scattering angle: $0.3 \rightarrow 1$ mrad
- Figure 11 and 12 (f.o.m.)

(see presentation for corrected uncertanties and figures)