

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

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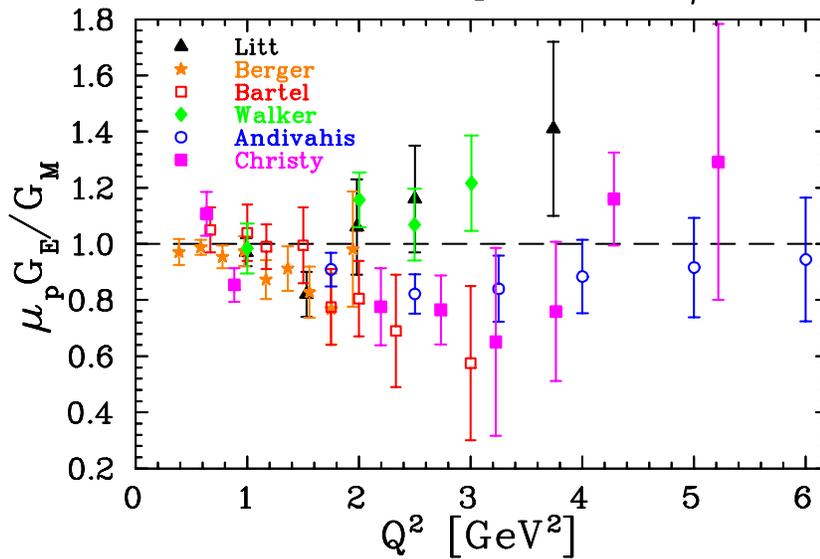
- Introduction
- Experimental Setup
- Uncertainties and Beam Time Request
- Expected Results and Summary
- Answers to PAC-25 Comments

# Physics Motivation

## METHODS TO MEASURE $G_E/G_M$

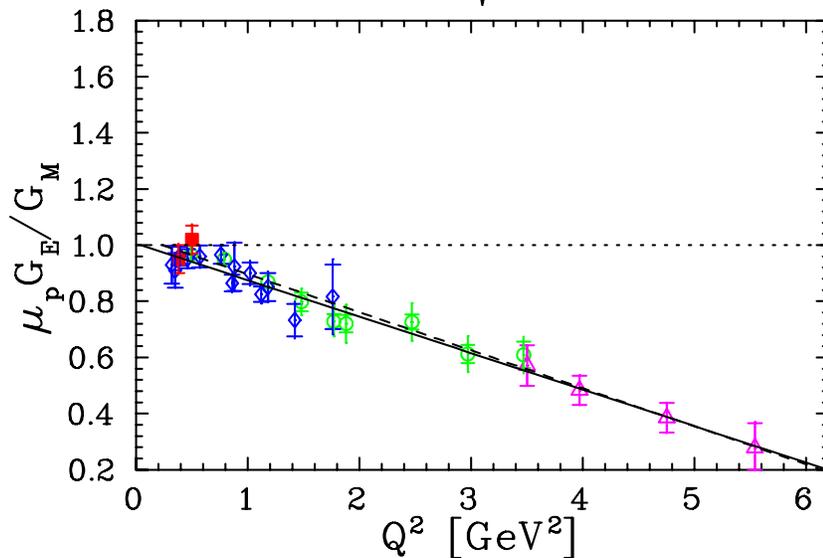
- Rosenbluth Separation Method

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



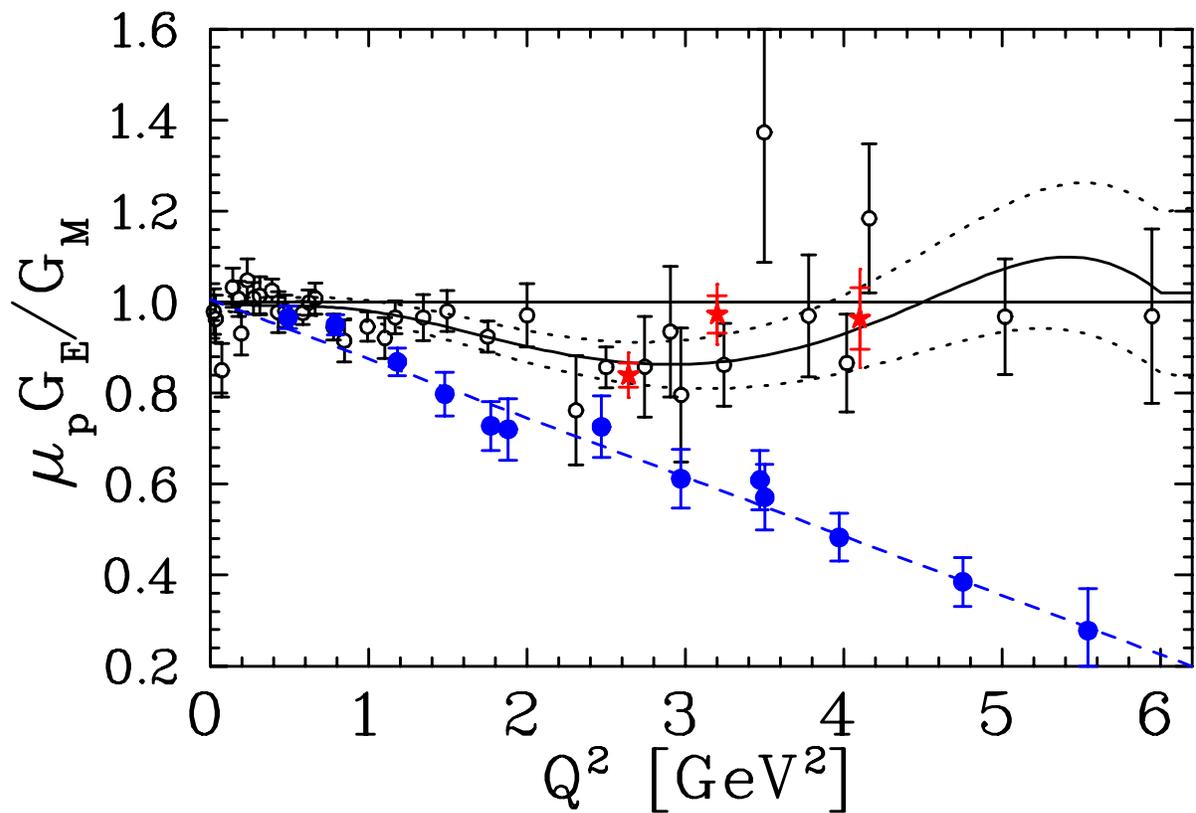
- Polarization Transfer Method

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



## 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  $\epsilon$  (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?

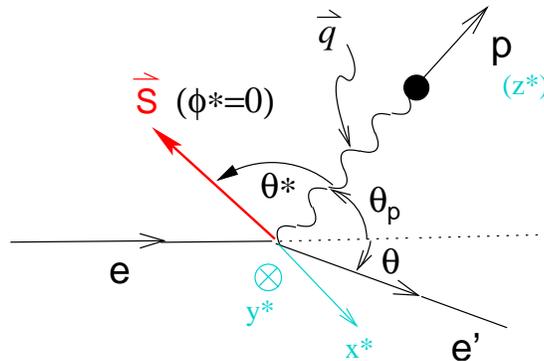
- Problem with Rosenbluth data? - unlikely
- Problem with interpretation of the data? - two photon exchange  
*Is it appropriate to attribute the full discrepancy to TPE?*
- Other unknown effect? (physics, systematic)
- *Measurement using a new, independent method is highly needed.*

## THE PROPOSED EXPERIMENT

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

$$A \equiv \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-}$$

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



- Measure elastic asymmetries at large  $\epsilon$ 
  - 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  $3.5(\text{GeV}/c)^2$ , to a good precision.

## *The Collaboration*

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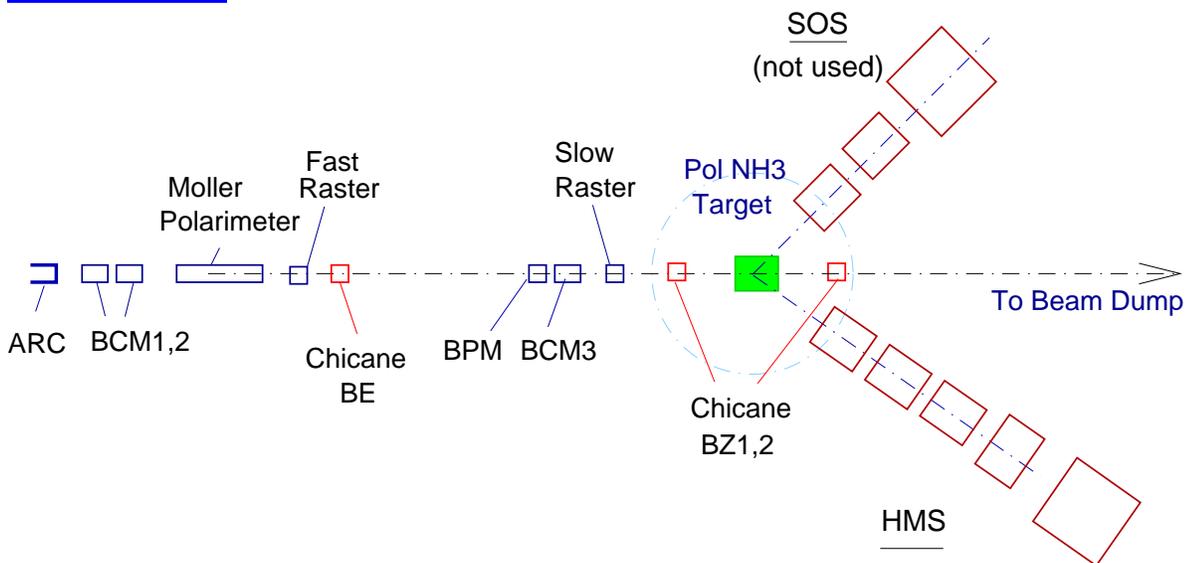
- ◇ The UVa group has extensive experience in performing polarized NH<sub>3</sub> target experiments in Hall C.

## Experimental Setup

### OVERVIEW

- Polarized electron beam,  $E = 3.6$  and  $6$  GeV,  $P_b = 75\%$ ,  $\Delta P_b/P_b = 1.5\%$ ;
- Polarized  $\text{NH}_3$  target, spin aligned at  $139^\circ$ ,  $P_t = 75\%$ ,  $\Delta P_t/P_t = 2.5\%$ ;
- Single-arm electrons detected by the HMS at  $Q^2 = 0.6, 2.1$  and  $3.5$   $(\text{GeV}/c)^2$ ;

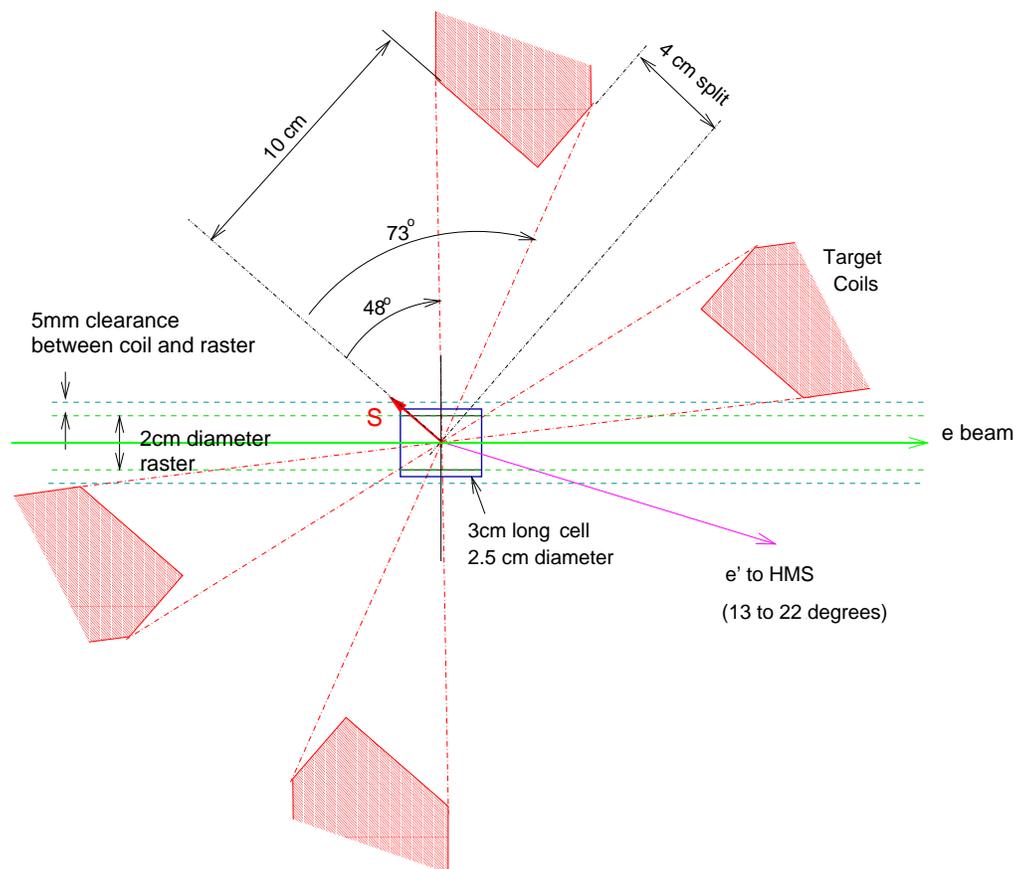
### FLOOR PLAN



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

## TARGET COIL CONFIGURATION

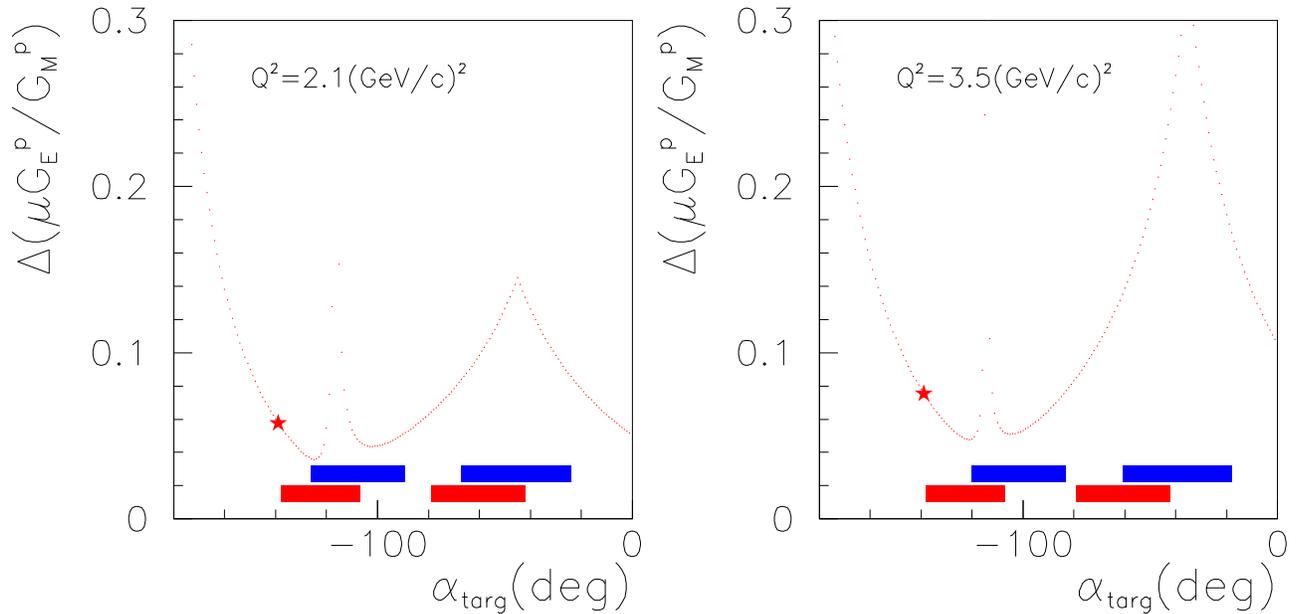
- The main constraint on the kinematics comes from the target Helmholtz coils.



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

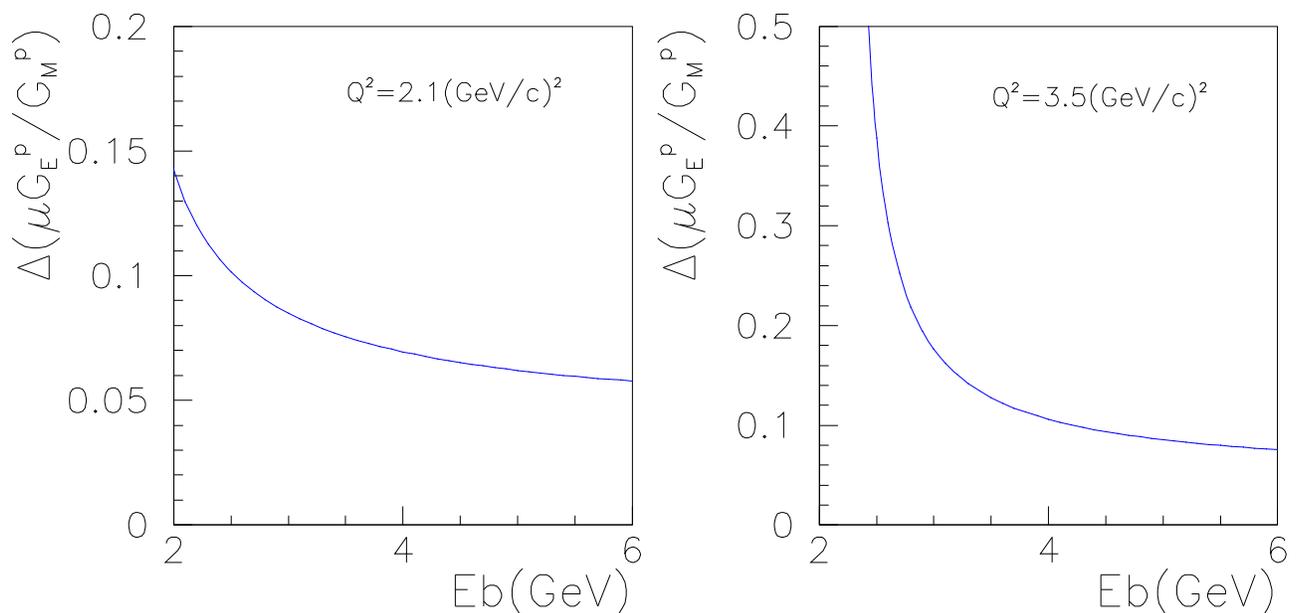
## KINEMATICS OPTIMIZATION *(both figures updated, different from the proposal)*

- 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.

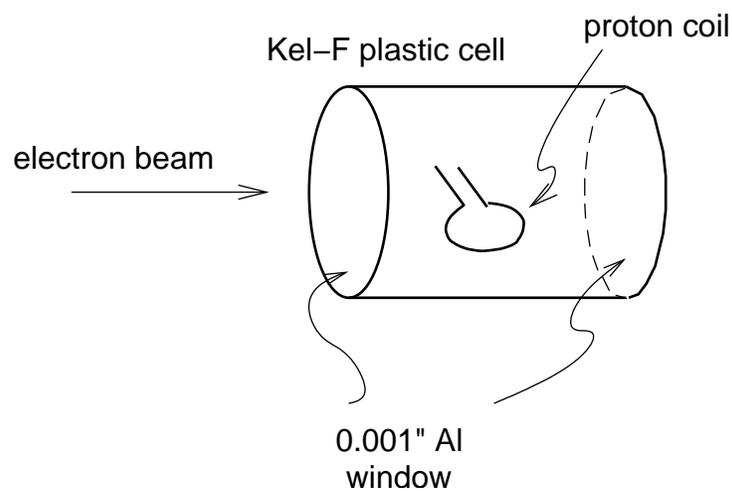
## DATA ANALYSIS

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

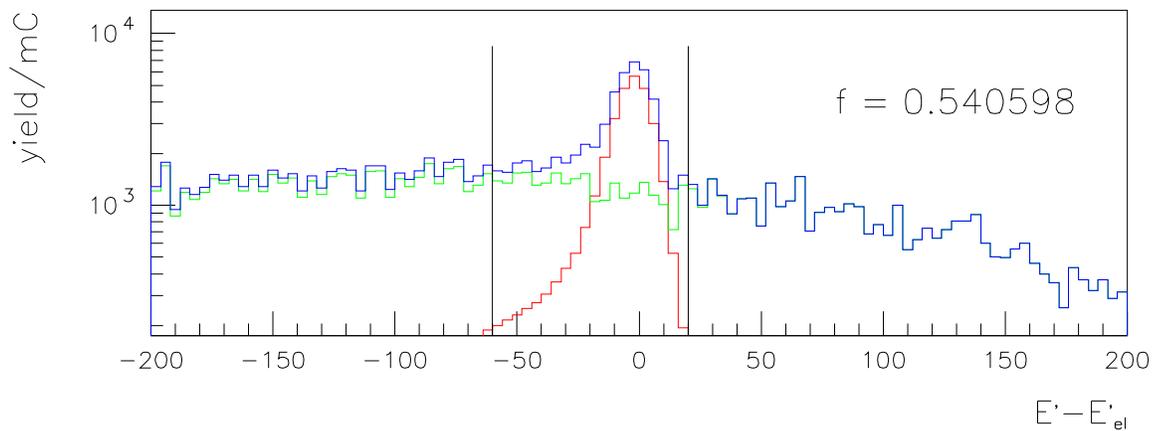
with  $P_b = 75\%$ ,  $P_t = 75\%$ ,  $f \approx 0.5$ ,

$A_N$  is a small correction due to the nitrogen asymmetry

## THE CELL



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



## KINEMATICS

$Q^2$ (GeV/c) <sup>2</sup>	0.61	2.10	3.50
$E$ (GeV)	3.60	6.00	6.00
$\theta_e$	13.45°	15.39°	21.65°
$E'$ (GeV)	3.273	4.881	4.135
$\theta_p$	60.95°	45.03°	35.27°
$p_p$ (GeV/c)	0.849	1.831	2.642
$\theta^*$	78.03°	93.98°	103.75°
$\phi^*$	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%
$\sigma$ (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% <sup>†</sup>	4.050%	4.050%
$(\Delta A/A)$ Total	3.450%	5.173%	5.342%

## Uncertainties

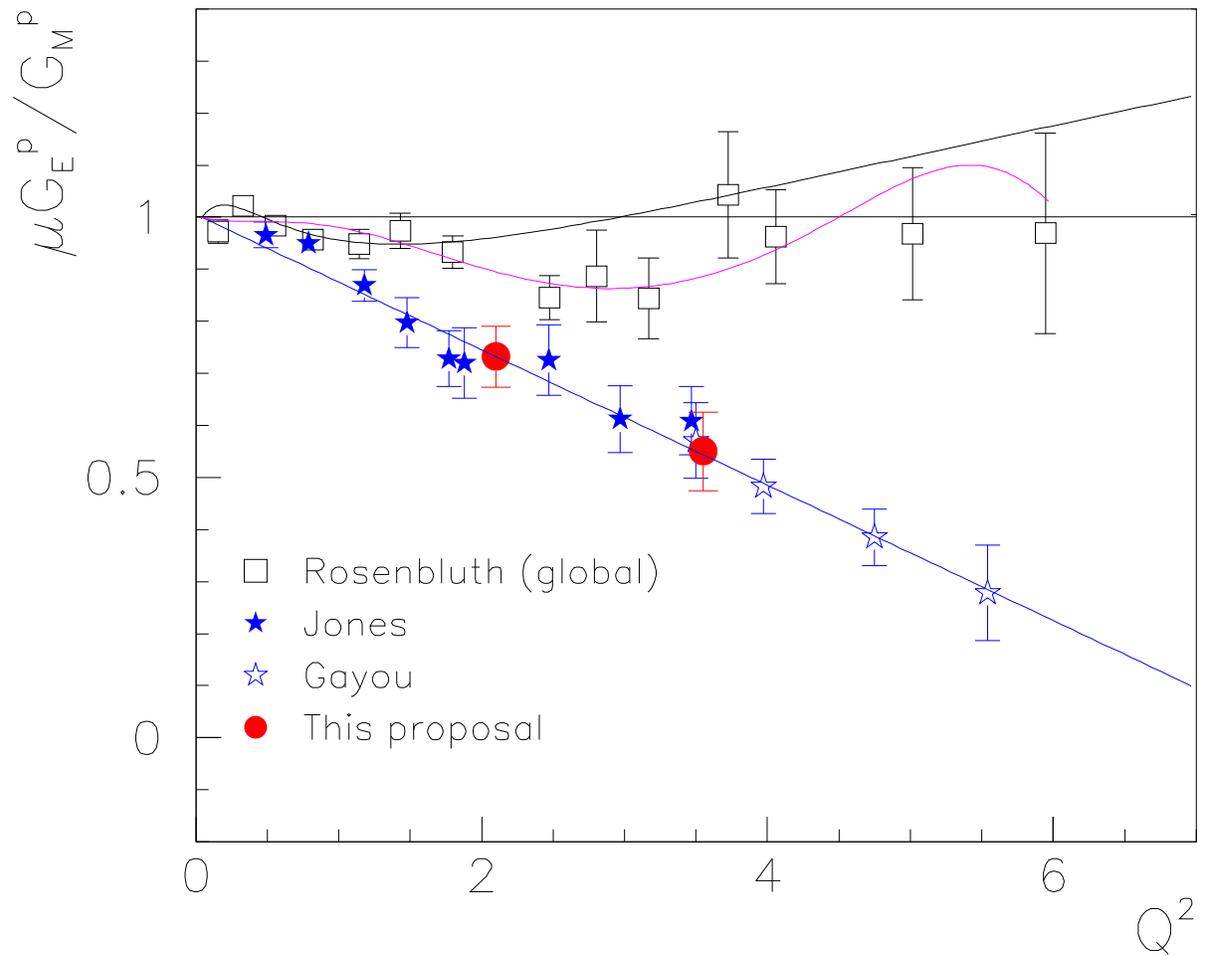
$Q^2$ (GeV/c) <sup>2</sup>	0.61	2.10	3.50
Uncertainty on $\mu G_E^p / G_M^p$			
$\Delta P_{beam} / P_{beam} = 1.5\%$	-	0.0174	0.0222
$\Delta P_{targ} / P_{targ} = 2.5\%$	-	0.0290	0.0370
Target dilution $\Delta f / f = 2.5\%$	-	0.0290	0.0370
Beam charge asymmetry	-	0.0147	0.0179
Nitrogen asymmetry	-	0.0006	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*

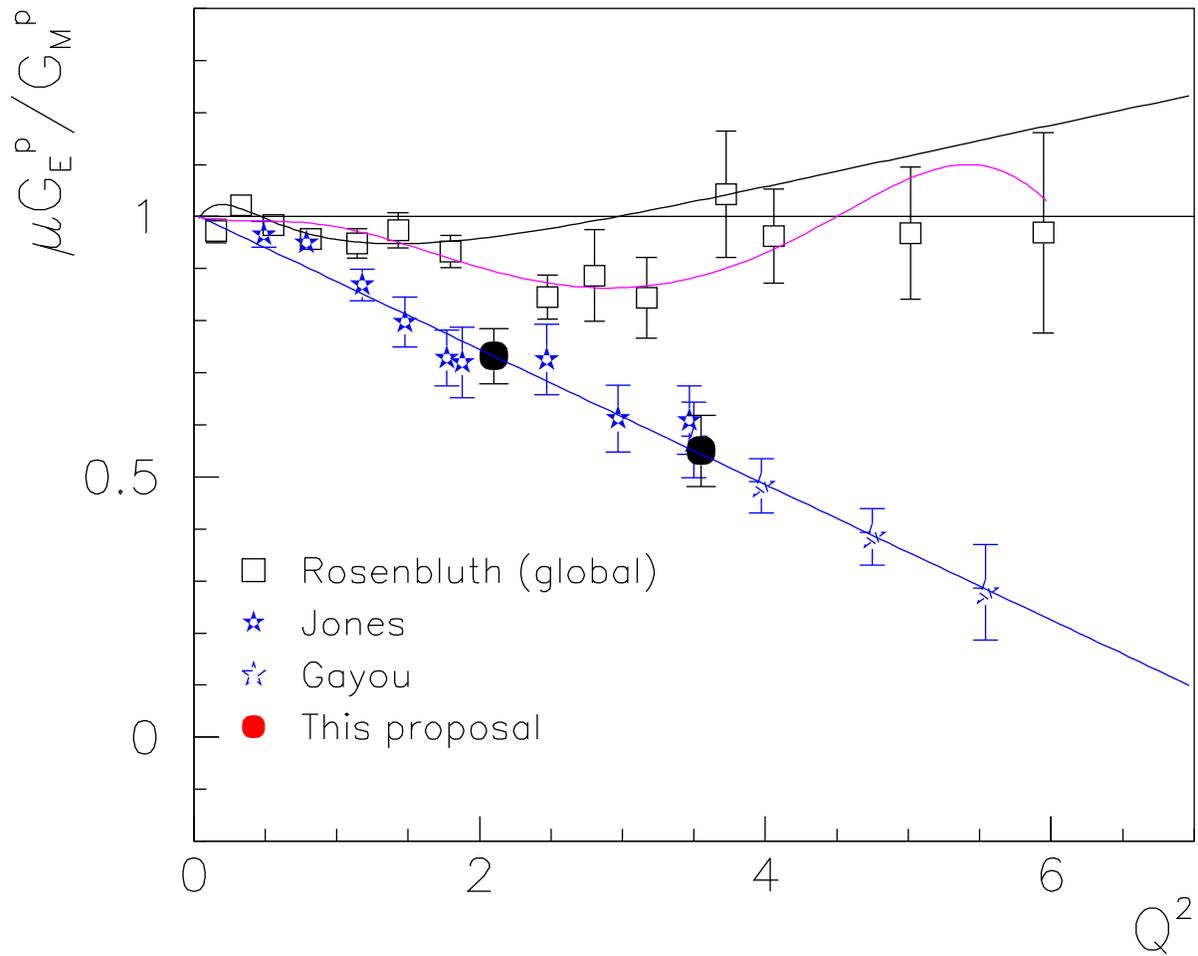
$Q^2$ (GeV/c) <sup>2</sup>	0.61	2.10	3.50
$E$ (GeV)	3.60	6.00	6.00
$\theta_{HMS}$	13.10°	15.39°	21.65°
$p_{HMS}$ (GeV/c)	3.273	4.881	4.135
Production time	5.1	46.0	245.4
carbon and helium runs	2	4	12
Møller measurement	1	2	9
arc measurement	4	4	
Total beam time (PAC hours)		<b>334</b>	
One pass change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

- 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  $\pi^0$  production
  - coincidence:
    - ◇ advantage: almost no dilution from QES events;
    - ◇ possible design:
      - \* (proton  $\rightarrow$  SOS, electron  $\rightarrow$  HMS) can only reach  $Q^2 = 1.9(\text{GeV}/c)^2$
      - \* proton  $\rightarrow$  HMS, electron  $\rightarrow$  calorimeter
- Compared to PR01-105
  - PR01-105: simultaneously measure  $A_L$  and  $A_T$  at  $Q^2 = 1.1, 2.1 (\text{GeV}/c)^2$
  - 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  $^3\text{He}$  target, two body break-up
  - proton in  $^3\text{He}$  is not free
  - f.o.m.:  $\text{NH}_3$  factor of 2 better than  $^3\vec{\text{H}}\text{e}$
- 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)<sup>2</sup>.

**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 uncertainties and figures)