Measurement of the Proton Elastic Form Factor Ratio at Low Q^2

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Abstract

We propose to study the proton elastic form factor ratio $\mu G_E/G_M$ in the range of $Q^2 = 0.25$ – 0.7 GeV^2. Our goal is to provide a high precision data set which will allow a vastly improved determination of the shape of the form factor ratio as a function of Q^2. In this low Q^2 range, substantial deviations from unity have been observed, and recent polarization measurements suggest the presence of structure in the form factor ratio; the proposed experiment will make a definitive measurement of the suggested structure. It has been suggested that structure in this Q^2 region reflects contributions from the pion cloud of the proton, in which case this data will provide insight on the peripheral substructure of the proton. In any case, the form factor ratio is a direct measure of a difference in the electric and magnetic distributions, which is interesting whether or not it is related to the pion cloud. Beyond the intrinsic interest in the structure of the nucleon, improved form factor measurements also have implications for deeply virtual Compton scattering and for determinations of the proton Zemach radius. The time request is for 14 days in Hall A with 80% polarized beam.

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Scientific Background

When the proton and neutron were discovered in 1919 and 1931, respectively, they were thought to be what we now call Dirac particles, like the already well known electron: point-like spin-$\frac{1}{2}$ particles. As a consequence, they should have a Dirac magnetic moment,

$$\mu_D = \frac{q}{mc}|\vec{s}|, \tag{1}$$

where q, m, and s are the electric charge, mass and spin of the particle, respectively. However, later experiments showed the magnetic moments to be $\mu_p = 2.79\mu_D$ and $\mu_n = -1.91\mu_D$. These measurements were the first evidence of structure in the nucleons.

During the 1950's electron scattering experiments revealed both an electric charge and magnetization distribution in the nucleons. Two form factors, for example G_E and G_M, account for these distributions. These form factors contain the information about the internal structure responsible for the deviation from scattering off point-like particles.

The usual method for the measurement of the nucleon form factors has been the "Rosenbluth Separation" method [1], in which the eN elastic cross section is measured at different angles and the well known Rosenbluth cross section formula is used to extract the Form Factors.

The nucleon form factors (except for G_E^n which must go to zero as $Q^2 \to 0$) were found to approximately follow the **dipole form factor** formula:

$$G_D = \frac{1}{1 + \frac{Q^2}{\lambda_D^2}},$$

where $\lambda_D^2 = 0.71$ GeV^2 is an empirical parameter found to be identical for all three form factors (G_E^p, G_M^p, G_M^n), $G_E^p = G_D$, and $G_M^{p,n} = \mu_{p,n} G_D$. Since in the dipole approximation all form factors are equal except for an overall scale, it is evident that the ratio of the proton electric to magnetic form factors (multiplied by the proton magnetic moment) should be equal to one.

Starting in the late 1960's and early 1970's, experiments started to observe deviations from the simple dipole formulas for the form factors. For example, Bartel *et al.* [2] and Berger *et al.* [3] observed deviations at the level of a few tens of percent at high Q^2, 1 GeV^2 or so, for G_E^p and G_M^p. But these measurements were not very precise, and more precise recent cross section measurements from SLAC [4,5] and Jefferson Lab [6,7] indicate better agreement, to within about 10%, with the dipole formula at high Q^2. Some of the recent data, for the form factor ratio, are shown in Figure 1, taken from [7]. In the 1970's and 1980's, more precise cross section measurements on the proton [8–10] at low Q^2 also observed deviations from the dipole formulas of a few percent at low Q^2, but these observation appear to have had little impact, with interest in form factors largely focused on high Q^2 and G_E^n.

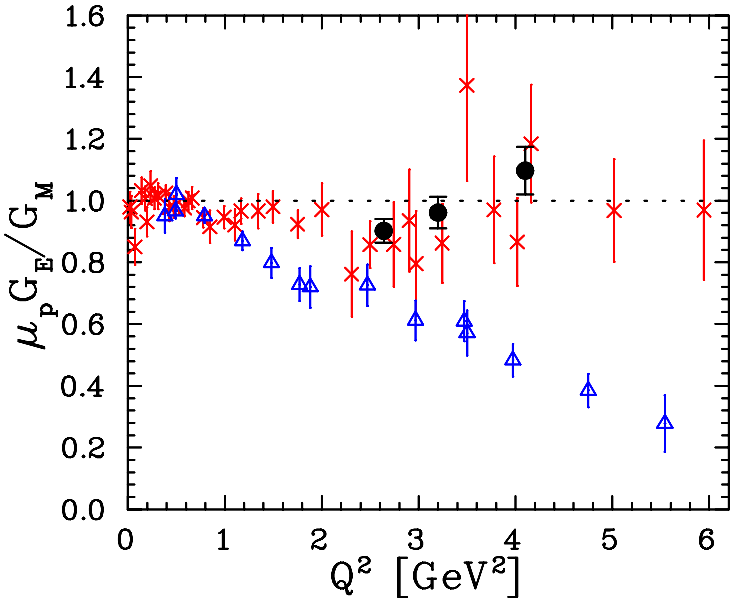

Fig. 1. Data on the proton Electric to Magnetic Form Factor Ratio, including the older Rosenbluth separation data (crosses), newer polarization transfer data (triangles) and the most recent JLab Rosenbluth separation data (filled circles).

Theory for the form factors at low-Q^2 has often used a vector-meson-dominance (VMD) picture, in which a photon couples to a proton through virtual quark–anti-quark states, the vector mesons. While the dipole form factor has some intuitive attraction, as the Fourier transform of an exponential density, in the VMD picture it is simply a good approximation, at the level of uncertainty of the data, to a sum of monopoles that represent vector meson exchange. The point is that there is no fundamental reason why the dipole formula has to hold, and indeed why there cannot be structures present in the form factors.

The *Recoil Polarization* method [11–13] has been used by most recent measurements [14–18] to extract the proton form factor ratio. The ratio is calculated from the ratio of transferred polarization components of the recoil proton:

$$\frac{G_E}{G_M} = -\frac{P_x}{P_z}\frac{E+E'}{2M_p}\tan\frac{\theta_e}{2}. \tag{2}$$

Here P_x and P_z are the transferred polarization components,

$$\sigma_{red}P_x = -2\sqrt{\tau(1+\tau)}\tan\frac{\theta_e}{2}G_E G_M, \quad \text{and} \tag{3}$$

$$\sigma_{red}P_z = \frac{E+E'}{M_p}\sqrt{\tau(1+\tau)}\tan^2\frac{\theta_e}{2}G_M^2, \tag{4}$$

with M_p the proton mass, E, E' the incident and scattered electron energy, $\tau = \frac{Q^2}{4M_p}$, θ_e the electron scattering energy, $\sigma_{red} = G_E^2 + (\tau/\epsilon)G_M^2$ the reduced cross section, and $\epsilon^{-1} = 1 + 2(1+\tau)\tan^2(\theta_e/2)$ the virtual photon polarization.

The recoil polarization form factor measurements show a strong deviation at high Q^2 from the expected ratio of one [14,17,18]; see Figure 1. It is now generally accepted theoretically that two-photon exchange corrections account for much, if not all, of the differences between the Rosenbluth and polarization transfer techniques – see [19–23]. It is believed that these corrections have little impact on the polarization technique for determining form factors, but have large impact on the Rosenbluth technique, as both two-photon corrections and the electric form factor typically contribute a few percent of the cross section. Such corrections have been cleanly demonstrated in low Q^2 parity-violation measurements [24,25], but not in high Q^2 form factor measurements; several such experiments have been approved by the Jefferson Lab PAC and are awaiting beam time.[2]

Interest has been reinvigorated in deviations of the form factors from the dipole formula at low Q^2 in particular by the analysis of Friedrich and Walcher [26]. They fit all the nucleon form factors, finding deviations in the fits that indicate structures at low Q^2, which they interpret as evidence of the virtual pion cloud surrounding the nucleon.[3] Using both a phenomenological fit and a fit based on the constituent quark model, the authors have shown that it is possible to fit all four nucleon form factors coherently with both ansaetzen and that all four show the signal of the pion cloud. This result should not be too surprising, given the earlier history described above, as well as structures seen in quark-model calculations of the nucleon form factors, such as those of Miller [27], and in the recent chiral perturbation theory calculations of Faessler *et al.* [28]. However, these works tend to show that the structures are fairly similar in the two proton form factors, and thus the ratio $\mu G_E/G_M$ varies more or less smoothly away from one.

The evidence for structures has increased with the recent polarized beam – polarized target measurements at Bates BLAST [29], as shown in Figure 2. These double-polarization asymmetries are entirely equivalent to the polarized beam – recoil polarization ones on which we have focused; this is simply an alternative experimental technique to access the form factor ratio. If one starts from the viewpoint that the form factor ratio should be essentially 1 at low Q^2, the Bates BLAST data has five points that are within about 1σ of 1. The highest Q^2 point at 0.6 GeV^2 starts to show the falloff of the form factor ratio seen in the high Q^2 JLab data, and the two points at Q^2 about 0.3 and 0.35 GeV^2 are $\approx 1.6\sigma$ ($\approx$3%) below one, suggesting a structure in the form factor ratio, although the precision is not sufficient to be conclusive. Perhaps though the data simply indicate that the ratio is smoothly decreasing below unity already by $Q^2 = 0.2$ or 0.3 GeV^2, similar to, though shifted in Q^2 from, the prediction of Miller. The structure shown in the form factor fit shown arises because the suggested pion cloud "bump" occurs at lower Q^2 in G_E than in G_M, about 0.15 vs 0.25 GeV^2.

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[2] It is worth noting that in the one photon-exchange (Born) approximation, the induced polarization, the polarization of a proton scattered by an *unpolarized* electron, measured transverse to the scattering plane, is identically zero.

[3] The nucleon form factors have of course been fit with various functional forms. One should not be too surprised if the form factors do not happen to follow some particular parameterization. Furthermore, one should be concerned about whether deviations from a particular functional form represent new physics, as opposed to an inappropriate parameterization.

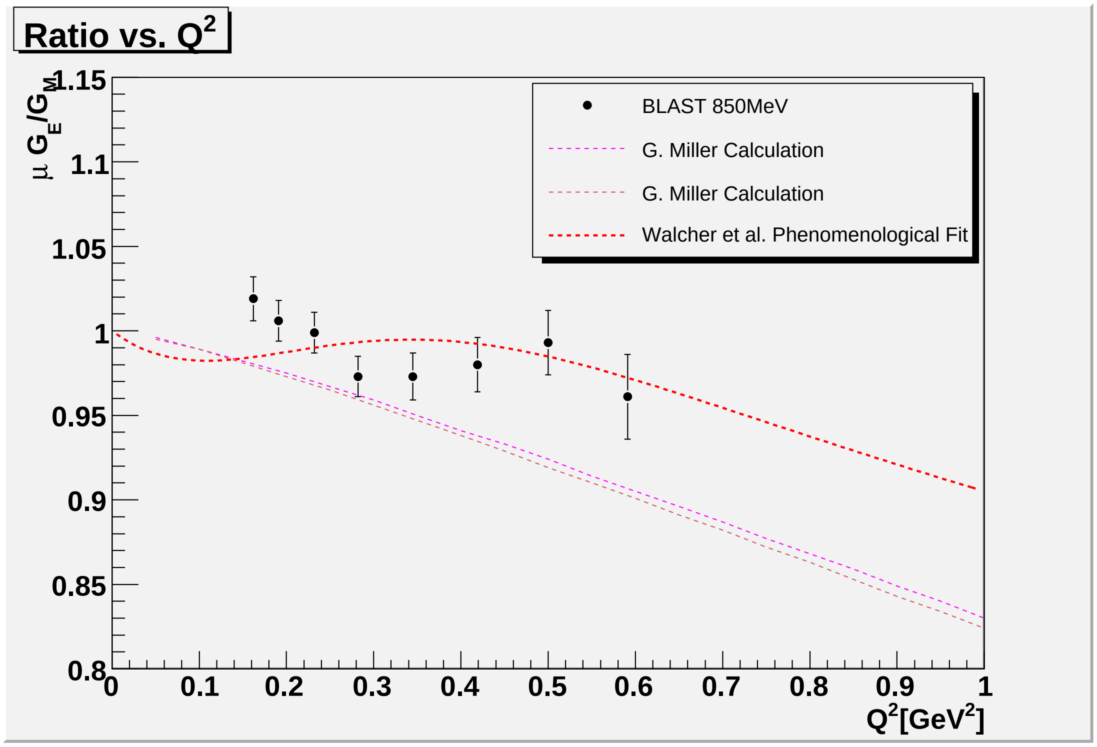

Fig. 2. BATES Data for the Form Factor Ratio, together with the ratio calculated using Friedrich and Walcher parametrization [26] and the calculations of Miller [27].

As part of the low energy running in Hall A during the summer of 2006 [30,31], we calibrated the Focal Plane Polarimeter in the Left HRS with *ep* elastic scattering, leading to a new set of Hall A G_E/G_M measurements at low Q^2 values. These data typically took about 12 – 18 hours per point to measure, with 40% polarized beam. Our data are consistent with the Bates data, but we more clearly find there is a deviation from unity and a suggestion of structure in G_E/G_M, as shown in Figure 3. Our preliminary point at $Q^2 \sim 0.35$ GeV^2 is about 0.95 ± 0.01. But our point, and the Bates point, at Q^2 about 0.5 GeV^2 are both about 0.99 ± 0.02, suggesting the ratio returns to close to unity before the high Q^2 linear fall off. Thus, we expect that when the analysis is final, we will have a conclusive demonstration of a significant deviation from unity in the low Q^2 form factor ratio, along with a fairly conclusive suggestion of a structure in the data.

A detailed understanding of the complex internal structure of the proton is of obvious great interest; for recent surveys of the electromagnetic form factors, see [33,34]. For small Q^2, the data show that the electric to magnetic form factor ratio differs from unity, but the high-precision data are too sparse to establish the shape of the form factor ratio well – our preliminary data indicate that a narrow structure in the data is more likely than a more or less smooth deviation from unity. Furthermore, the structure is not predicted in any of the existing calculations or fits. Structures related to the pion cloud of the nucleon are expected from the calculations or fits of [26–28], and it is possible that the difference between the electric and magnetic structure is simply greater than has been calculated to date. Even if this explanation is not correct, the form factor ratio gives a direct measure of a difference in the electric and magnetic distributions, which is interesting whether or

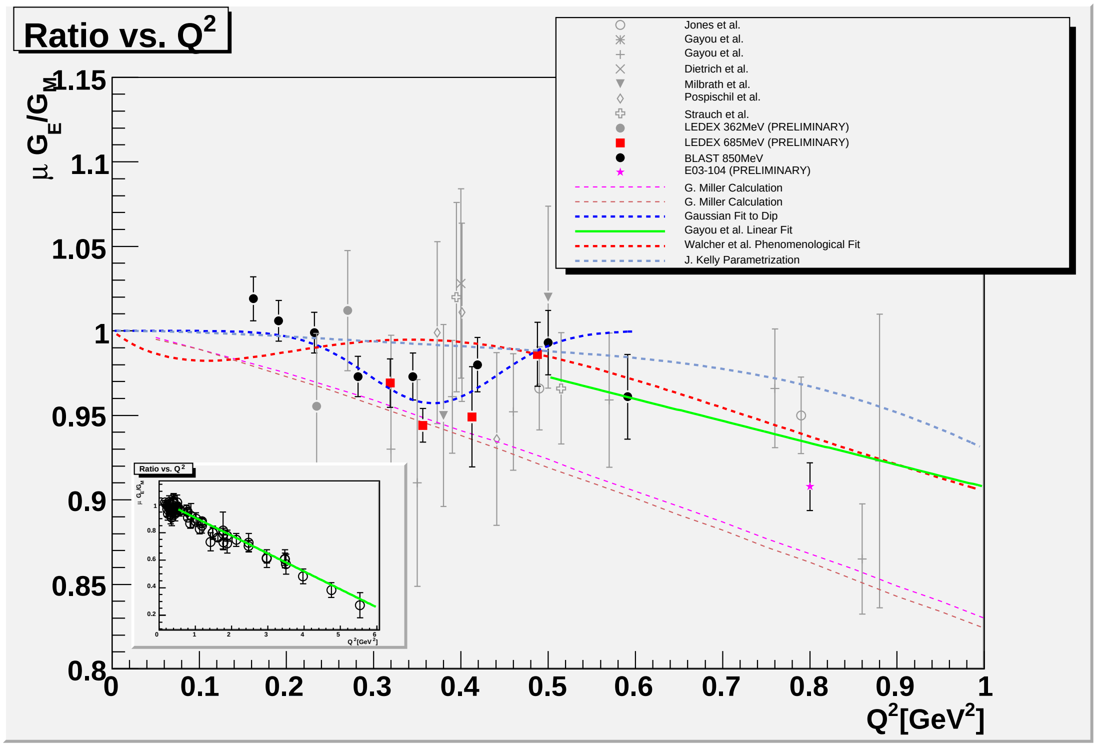

Fig. 3. World Data Points for $\mu G_E/G_M$, including the preliminary points from Jul – Oct 2006. The dashed dark blue line is a Gaussian fit to the $Q^2 = 0 - 0.5$ GeV^2 region ($\chi^2/NDF = 0.75$)), the solid green line is the Gayou *el at.* linear fit, valid above $Q^2 = 0.5$ GeV^2, the dashed red line is the Friedrich and Walcher pion cloud parametrization [26], the dashed blue line is the Kelly parameterization [32], and the dashed purple lines are calculations from Miller [27].

not there are structures, and whether or not the difference is related to the pion cloud of the nucleon.

The goal of this proposal is to perform a precision measurement of the elastic form factor ratio over a Q^2 range which will allow us to determine the shape of the ratio at low Q^2. We propose to measure in 15 days, using the recoil polarization method, the form factor ratios at 9 Q^2 values from 0.25 – 0.7 GeV^2 with uncertainties of 0.3 – 1.0%, as indicated in Fig. 4. These data will allow us with high precison to cover much of the region covering the suggested structure up to the start of the high Q^2 linear fall off. The data have the potential to illuminate a little understood aspect of the proton, its peripheral internal structure.

To separate out the individual form factors with comparable precision, it is necessary to measure cross sections to high precision as well. This is not part of this proposal as new high precision data have already been measured.

During the *ep* calibration runs of [30], we also attempted to measure precise cross sections with the recoil protons in the same kinematics as the polarization measurements. The statistics of these measurements are of the order 0.1%; the uncertainties will be dominated by systematics. While it is much too soon to know how well these data will turn out, we

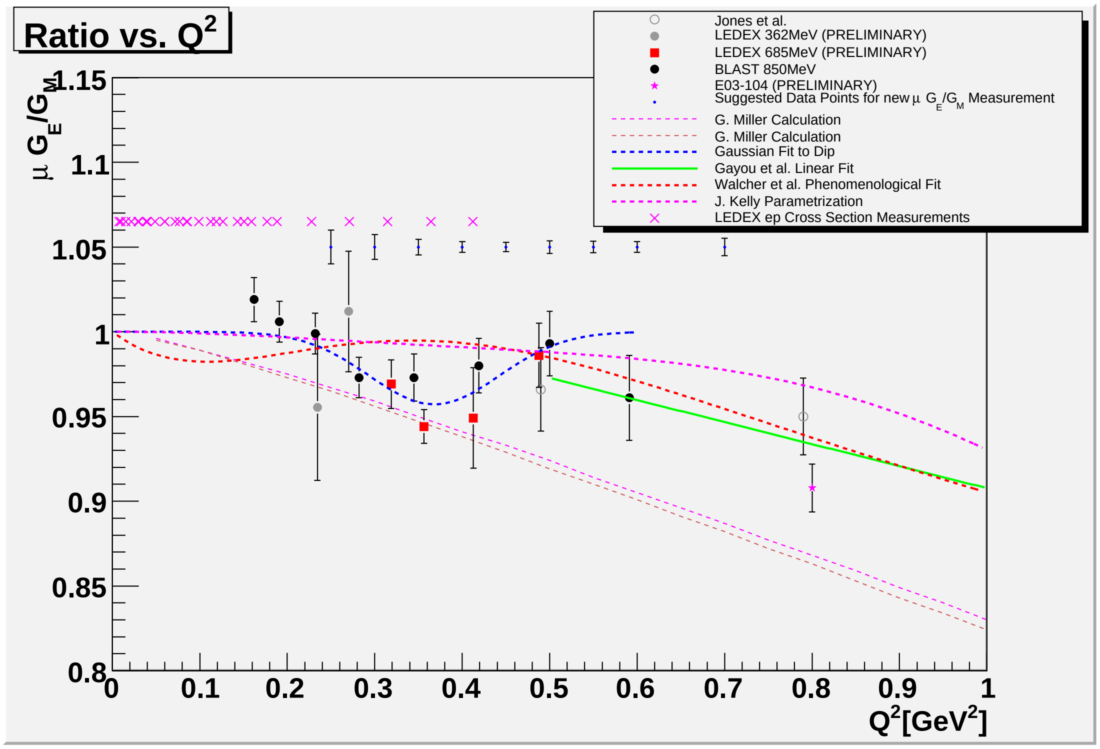

Fig. 4. The higher precision data for $\mu G_E/G_M$, including the preliminary points from Jul – Oct 2006. The Q^2 values of proposed data are indicated. The Q^2 values at which precise cross sections were measured in Hall A during 2006 are also indicated. Curves are the same as in Figure 3.

have the potential to extract the individual form factors from the two measurements at each kinematic point. In addition, as part of the precise cross section measurements of [31], angular distributions for $^1\mathrm{H}(e, e')$ were measured for numerous points in the range $Q^2 \approx 0.01 - 0.5$ GeV^2; the Q^2 values of the data points are indicted in Fig. 4. The goal of these measurements was to have point-to-point systematics better than 1%, with absolute uncertainties at the level of 2-3%. Since these data cover much of the Q^2 range of the polarization measurements, they can also be used to determine individual form factors, or more generally to compare with theory.

An experiment at Mainz [35] is currently measuring the *ep* cross sections to allow both fits and Rosenbluth separations, for 6-7 values for Q^2 from 0.1 to 0.8 Gev^2. The estimated cross section uncertainties are about 0.5% from statistics, with total uncertainty always below 1%. Simulations show that this leads to uncertainties on the individual form factors of about 1%. This expected result, which leads to a ≈1.4% form factor ratio, should be contrasted to the recent results from Bates and from us, along with this proposal. High precision form factor ratios are best done with polarization measurements.

As a range of precise cross sections will be measured independently of this experiment, we cannot justify asking for additional time to perform precise cross section measurements as part of the experiment. It is more natural, based on the state of the cross section data as we approach our run, to instead consider small adjustments to our kinematics to measure at points at which precise cross sections exist.

Our discussion so far has focused on the form factors for the intrinsic interest in directly understanding this aspect of nucleon structure. However, the form factors are also of interest for determining other aspects of nucleon structure. We present two brief examples.

The Deeply Virtual Compton Scattering (DVCS) / Generalized Parton Distribution (GPD) program at JLab is very interested in accurate form factor measurements for $0.15 < Q^2 < 1$ GeV^2, especially $Q^2 < 0.5$ GeV^2. The systematic uncertainties in the GPD extraction is partially due to the knowledge of the form factors, since the Bethe-Heitler (BH) and DVCS contributions add / interfere to produce cross sections and polarization observables. The low Q^2 range is important, because although the measurements are done at high Q^2, the relevant scale for evaluating the form factors to calculate the BH is $-t$. The measurements are done at small $\theta_{\gamma\gamma'}$, or equivalently at forward angles, with small $-t$. Thus, improvements to the form factors in this region directly impact the DVCS uncertainties. Although the relative sizes of the BH and DVCS contributions vary strongly with kinematics, generally the BH dominates in JLab kinematics, and thus small uncertainties in the BH lead to large uncertainties in extracting DVCS.

The proton Zemach radius [36] has been much discussed recently. It is evaluated as

$$r_z = -\frac{4}{\pi}\int_0^\infty \frac{dQ}{Q^2}\left[\frac{G_E(Q^2)G_M(Q^2)}{(1+\kappa_p)} - 1\right],$$

and is of particular interest in understanding the hyperfine splitting in hydrogen. From the expression it is evident that the Zemach radius depends on the form factors at low Q^2. It is pointed out in [36] that differences between modern form factor parameterizations lead to about 0.6 ppm changes in estimates of the Zemach radius correction to the theory; since the theory is at about the 1 ppm level, the form factor uncertainties are then among the leading uncertainties in the theoretical prediction. Thus, efforts to improve the knowledge of the form factors are important to improving the theoretical uncertainties.

Experimental Setup

Overview of Technique

This proposed experiment follows directly on previous Hall A form factor ratio measurements. As compared to our recent low Q^2 data, we improve the uncertainties by a factor of about 3 by requiring a beam polarization of 80%, instead of 40%, and by running each point for approximately twice as long.

An overview of the experimental setup is shown in Fig. 5. We use both HRSs in the standard configuration to perform a coincidence measurement of the scattered proton and electron, to reduce potential backgrounds. The polarization of protons exiting the target is determined by the focal plane polarimeter (FPP) in the left HRS.

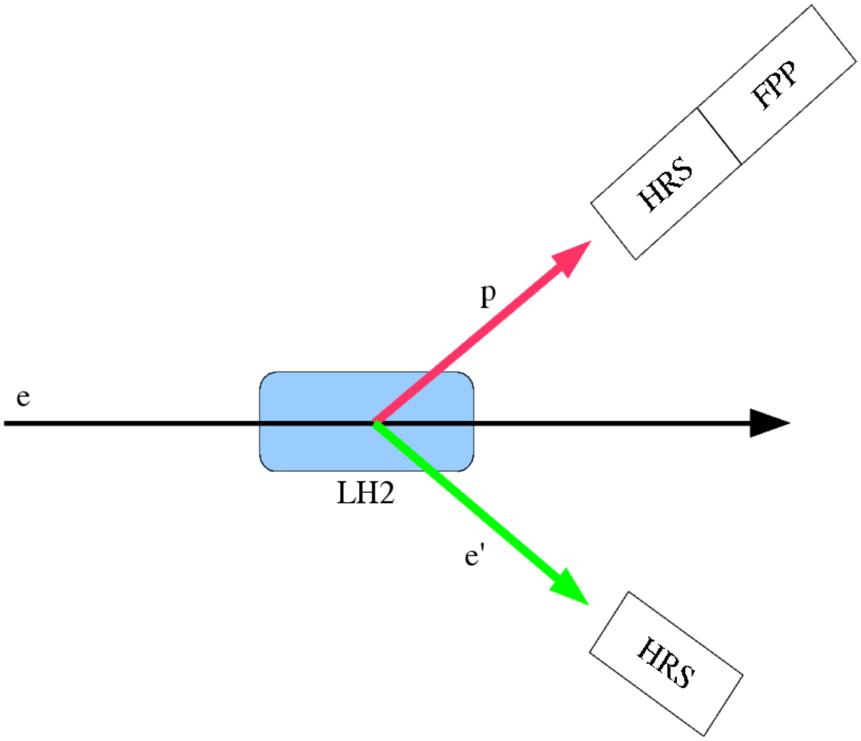

Fig. 5. Experimental Setup for the Proposed Experiment.

Observables

We plan to measure:

- **$P_{x'}$:** The transferred polarization component in the scattering plane perpendicular to the proton momentum.
- **P_y:** The induced polarization perpendicular to the scattering plane.
- **$P_{z'}$:** the transferred polarization component in the reaction plane parallel to the proton momentum.

We extract the proton form factor ratio $\mu\frac{G_E}{G_M}$ from the polarization transfer measurements.

FPP

The experiment measures the polarization of low to medium energy protons, with momenta from 0.5 – 1 GeV/c. We plan to use the thinner carbon analyzers of the Hall A FPP, basing our choice of analyzer on the previous measurements done during the the LEDEX experiments [30,31]. The analyzing power in these kinematics is large, and is a well known function of the proton energy, from both the McNaughton parametrization

[37] and the measured analyzing power of our previous low energy experiment.

The polarization transfer from longitudinally-polarized electrons gives the protons an in-plane polarization. The form factor ratio is basically determined from the orientation of this in-plane polarization, while the product of the beam helicity and FPP analyzing power is determined from its magnitude. Thus, the the form factor ratio can be determined without knowing the analyzing power or the beam helicity; still, if these are large, the asymmetry directly measured by the FPP is larger, and thus the direction of the polarization vector is determined with smaller uncertainties.

The level of the achievable systematics in this kinematic range was studied in the most detail in the first Hall A G_E^p experiment [18]. The systematic uncertainty on the form factor ratio was 0.4% at $Q^2 = 0.5$ GeV^2, increasing to 1% at $Q^2 = 0.8$ GeV^2. The systematic uncertainty is dominated by how well one can determine the spin direction at the target, from the spin direction measured in the spectrometer focal plane. The direction is changed by spin precession in the spectrometer magnets, and thus the uncertainties arise from the limited knowledge of the optics matrix elements of the spectrometer. The optics were tested both by studying distributions in the focal plane with, for example, quadrupoles turned off, and by measuring *ep* elastic scattering at $Q^2 = 2.2$ GeV^2. At this high Q^2, the spin precession is near 180°, and the spin in the focal plane changes sign across the acceptance; thus one has high sensitivity to the spectrometer model.

The reason for the decrease in systematic uncertainty at $Q^2 = 0.5$ GeV^2, and indeed for our entire experiment, is that spin precession is nearly optimal (for this experiment), with spin precession near 90°. Thus small differences in the bend angle make almost no difference in the form factor ratio. There is no reason to expect the systematic precision during this experiment will be significantly different from that achieved previously.

To check the experimental systematics, we always run each Q^2 point at multiple proton-arm momentum settings, so that we can see at what level the polarization is independent of the proton position in the focal plane. We also plan to do a limited series of optics measurements similar to those done for [18]; the central part of these measurements will be a measurement of *ep* elastic scattering at $Q^2 \approx 2.2$ GeV^2. At this point, the central spin precession is 180°, and the P_z' component changes sign in the focal plane. Examining the sign change is extremely sensitive to the spectrometer bend angle, and thus provides the tightest limit on the systematic uncertainty.[4] The statistical precision that we propose roughly matches the expected systematic precision.

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[4] Note that the previous studies were done with the FPP in HRS-right; the FPP is now in HRS-left.

Background

Because the low Q^2 ep coincidence cross sections are large, background rates are relatively small and backgrounds tend to be unimportant. The cosmic ray rate is negligible. Coincidence background events from the target end caps are suppressed due to Fermi motion – only a small fraction of the coincident $(e, e'p)$ protons actually are within the spectrometer acceptance; reconstructed target position cuts remove any remaining background. Thus our expected signal rate is about our DAQ rate, which is about 2 – 2.5 KHz.

Kinematics and Time Request

Our goal of measuring the $Q^2 = 0.25 - 0.7$ GeV^2 region is determined from existing high precision measurements at $Q^2 = 0.8$ GeV^2 – there is no reason to repeat this data – and from the increasing difficulty and time required to do the recoil polarimetry at the low Q^2. Using coincidence mode requires both one-pass and two pass beams, because of the angle ranges of the Hall A spectrometers. The proposed kinematics are shown in Table 1.

Table 1
Proposed Kinematics

Beam Energy [GeV]	Q^2 [GeV^2]	θ_e [deg]	E' [GeV]	θ_p [deg]	P_p [GeV/c]
0.845	0.25	37.611	0.711	57.088	0.517
0.845	0.30	42.191	0.685	53.751	0.570
0.845	0.35	46.726	0.659	50.614	0.620
0.845	0.40	51.288	0.632	47.622	0.667
0.845	0.45	55.942	0.605	44.734	0.712
0.845	0.50	60.750	0.578	41.915	0.756
0.845	0.55	65.774	0.552	39.136	0.797
0.845	0.60	71.089	0.525	36.369	0.838
0.845	0.70	82.969	0.472	30.754	0.916

While all of the data can be obtained with 1-pass beam, the $Q^2 = 2.2$ GeV^2 measurement that tests the spin transport is optimally run at $E_e \approx 3.2$ GeV; it requires one day. It can be run if needed at 2.4 or 4.0 GeV, but it would require an extra day to make up for the decrease in coincidence efficiency due to the mismatch in the spectrometers.

Since we aim to take high statistics data and do not require a low dead time, our plan is to run with data rates of about 2 – 3 KHz, as we did during E05-103. These rates can be attained with beam currents from a few μA up to about 80 μA, and with dead times of about 30%. Other experiments have run with higher dead times; it is not an issue for a recoil polarization experiment. We will use a standard 15 cm ($\approx$1.05 g/cm^2) liquid hydrogen target. Time estimates were made using these conditions and standard ep cross section calculations. Twenty-four hours at each kinematic setting – except 48 hours for the lowest Q^2 point – results in uncertainties of 1% or less – see Table 2 – for the form factor ratio, assuming a beam polarization of ≈80%. Then the statistical and systematic uncertainties are estimated to be approximately matched.

Table 2
Expected Uncertainties in the Form Factor Ratio Measurement

Q^2 [GeV^2]	Δ Ratio/Ratio [%]
0.25	1.00
0.3	0.73
0.35	0.46
0.4	0.32
0.45	0.28
0.5	0.37
0.55	0.34
0.6	0.32
0.7	0.52

Additional time is needed for the following purposes:

- 9 angle changes require 1 hour each.
- 20 spectrometer momentum changes require 30 minutes each.
- 1 straight through run is used to calibrate the FPP alignment. This requires about 1 hour.
- One beam energy change during the experiment, requiring about 8 hours.
- 10 pointing runs will be taken, totaling about 10 hours.
- Two Møller measurements of the beam polarization are needed, requiring about 8 hours.
- Systematic studies of the spin transport are needed to re-verify the results of the studies performed during the G_E^p-I measurement. We plan on about 1 day of measurements using varying magnetic field settings, similar to the earlier studies.

With 10 days of data runs, plus ≈3 days of calibration and overhead, plus 1 day for the higher Q^2 measurement, **our total time request is for 14 days**.

In summary, we propose to do a systematic set of measurements which will, despite a short experiment, improve by a factor of more than 2 on previous limited measurements done in the same Q^2 range. The experimental techniques are standard, and have been used in Hall A previously. By covering this low Q^2 range in detail, we can determine whether there is actually a structure in the low Q^2 data, or whether we have a smooth deviation from unity in the form factor ratio.

Collaboration, Conflicting Experiments and Scheduling

The core of the current collaboration consists of individuals who have been deeply involved in previous Hall A polarization experiments and the construction and configuration of the Hall A FPP. All equipment needed for the experiment exists and is standard Hall A equipment. There is no known conflict with any other experiment. The experiment could be scheduled almost any time.

References

[1] M.N. Rosenbluth. Phys. Rev. **79**, 615 (1950).

[2] W. Bartel *et al.*, Phys. Lett. **33B**, 245 (1970).

[3] C. Berger *et al.*, Phys. Lett. **35B**, 87 (1971).

[4] R.G. Arnold *et al.*, Phys. Rev. Lett. **57**, 174 (1986).

[5] L. Andivahis *et al.*, Phys. Rev. D **50**, 5491 (1994).

[6] M.E. Christy *et al.*, Phys. Rev. C **70**, 015206 (2004).

[7] I. Qattan *et al.*, Phys. Rev. Lett. **94**, 142301 (2005).

[8] F. Borkowski *et al.*, Nucl. Phys. **A222**, 269 (1974).

[9] F. Borkowski *et al.*, Nucl. Phys. **B93**, 461 (1975).

[10] G.G. Simon *et al.*, Nucl. Phys. **A333**, 381 (1975).

[11] A.I. Akhiezer and M.P. Rekalo, Sov. Phys. Doklady **13**, 572 (1968).

[12] N. Dombey, Rev. Mod. Phys. **41**, 236 (1969).

[13] A.I. Akhiezer and M.P. Rekalo, Sov. J. Part. Nucl. **3**, 277 (1974).

[14] M. Jones *et al.*, Phys. Rev. Lett. **84**, 1398, (2000).

[15] Th. Pospischil *et al.*, Eur. Phys. J. A **12**, 125 (2001).

[16] O. Gayou *et al.*, Phys. Rev. C **64**, 038202, (2001).

[17] O. Gayou *et al.*, Phys. Rev. Lett. **88**, 092301 (2002).

[18] V. Punjabi *et al.*, Phys. Rev. C **71**, 055202 (2005).

[19] A. Afanasev, I. Akushevich, and N.P. Merenkov, hep-ph/0208260.

[20] P.A.M. Guichon and M. Vanderhaeghen, Phys. Rev. Lett. **91**, 142303 (2003)

[21] P.G. Blunden, W. Melnitchouk, and J.A. Tjon, Phys. Rev. Lett. **91**, 142304 (2003).

[22] Y.C. Chen *et al.*, Phys. Rev. Lett. **93**, 122301 (2004).

[23] A. Afanasev *et al.*, Phys. Rev. D **72**, 013008 (2005).

[24] S.P. Wells *et al.*, Phys. Rev. C63, 064001 (2001).

[25] F.E. Maas *et al.*, Phys. Rev. Lett. **94**, 082001 (2005).

[26] J. Friedrich and Th. Walcher, Eur. Phys. J. A **17**, 607 (2003).

[27] G.A. Miller, Phys. Rev. C **66**, 032201(R) (2002).

[28] A. Faessler *et al.*, Phys. Rev. D **73**, 114021 (2006).

[29] C.B. Crawford *et al.*, nucl-ex/0609007, submitted to Phys. Rev. Lett.

[30] R. Gilman et al., E05-103, Low Energy Deuteron Photodisintegration (http://hallaweb.jlab.org/experiment/LEDEX/documents/PR05-103.pdf).

[31] D. Higinbotham et al., E05-004, A(Q) at low Q in ed Elastic Scattering (http://hallaweb.jlab.org/experiment/LEDEX/documents/PR05-004.pdf).

[32] J.J. Kelly, Phys. Rev. C **70**, 068202 (2004).

[33] J. Arrington, C.D. Roberts, and J.M. Zanotti, nucl-th/0611050.

[34] C.F. Perdrisat, V. Punjabi, and M. Vanderhaeghen, hep-ph/0612014.

[35] P. Achenbach *et al.*, Mainz A1 Collaboration.

[36] See V. Nazaryan, C.E. Carlson, and K.A. Griffioen, Phys. Rev. Lett. **96**, 163001 (2006) and references therein.

[37] M. W. McNaughton *et al.*, Nucl. Inst. Meth. A **241**, 435-440 (1985).