Update on E12-07-109: Large Acceptance Proton Form Factor Ratio Measurements up to 14.5 GeV² Using Recoil-Polarization Method

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1 Introduction

The first Hall A experiment to measure $G_E^p/G_M^p$ ratio started with two small solid angle spectrometers, which enabled measurements up to $Q^2 = 3.5$ GeV² [1]. To advance to the highest $Q^2$ possible with the CEBAF 6 GeV beam, the electron spectrometer was replaced by a large solid angle calorimeter and $G_E^p/G_M^p$ was measured to $Q^2 = 8.5$ GeV² [2]. To fully take advantage of the CEBAF 12-GeV upgrade in measuring of $G_E^p/G_M^p$, an experiment must use the optimal device for the protons.

This document provides an update for E12-07-109, also known as GEp(5) [3], an experiment that will measure the ratio $G_E^p/G_M^p$ up to $Q^2 = 14.5$ GeV². GEp(5) is one of three measurements of the ground-state electromagnetic nucleon form factors (FFs) that will be performed using the apparatus being constructed under the “Super Bigbite” project. By emphasizing large-solid-angle detection and the ability to tolerate very high luminosity, GEp(5) has a figure-of-merit that is $\times 10$ higher than any competing effort to study $G_E^p/G_M^p$.

Among the issues raised by PAC34 concerning GEp(5) is its relationship to GEp(4), or E12-09-001 [4], which was conditionally approved by PAC34. In particular, noting the similar physics being addressed by the two experiments, PAC34 asked that the two collaborations “...either come up with one common proposal or ... make an extremely compelling case as to why both of them need to be done.” A letter placed in an appendix explains that two collaborations have joined forces behind GEp(5) and have made this experiment a priority, as GEp(5) is the only experiment capable of achieving the goal of the measurement of the proton form-factor ratio at a $Q^2$ of $\sim 15$ GeV². A (new) list of spokespeople now contains all of the spokespeople previously listed on the two separate experiments. The GEp(4) experiment will be resubmitted after the final analysis of the GEp(3) and the study of the existing HMS polarimeter. Other issues raised by PAC32 (the PAC that approved GEp(5)) included a desire to hear an update on two-photon effects, and funding issues, both of which are discussed within this document.

The ground-state electromagnetic nucleon FFs are among the most fundamental quantities that describe the non-perturbative structure of the nucleons. Their study provides a powerful test of our understanding of non-perturbative QCD and confinement. This has been particularly true in recent years because of a rich interplay between theoretical and experimental studies. Some of the outstanding recent accomplishments include:

- The high-$Q^2$ measurements of $G_E^p$ and $G_M^p$ [2, 5].
- The studies of two-photon effects via precision L/T and polarization transfer measurements of the proton form factors [6, 7], and the cross section calculations and global analysis of refs. [8, 9, 10].
- The infinite momentum frame nucleon charge densities [11, 12, 13].
- The novel DSE/Faddeev calculations of the nucleon properties [14].
- The high-$Q^2$ accurate measurement of the proton time-like FF [15].
- The precision low-$Q^2$ measurements of the nucleon FFs at MIT/Bates and JLab [16, 17].
Indeed, the measurements described by Jones et al. in Ref. [1] represent one of the most striking results to come out of JLab. It was found that the ratio of the electric and magnetic form factors of the proton, $G_E^p/G_M^p$, decreases approximately linearly with four-momentum transfer, $Q^2$, for values above roughly 1 GeV$^2$. Prior to this observation, the widely held expectation was that this ratio would be roughly constant. The experimental result has stimulated enormous interest and the initial paper announcing the discovery has received almost 500 citations. It is widely held that these observations have forced a reconsideration of nucleon structure. And as is clear from some of the theoretical work mentioned in the above list, the emerging picture of the nucleon contains important properties that were not well recognized previously. Among them is the dynamical importance of quark orbital angular momentum (OAM). It is also notable that ab initio calculations of form factors using lattice QCD have become increasingly accurate, and have reached to increasingly high values of $Q^2$, thus providing yet another reason to study ground-state form factors.

As will be discussed further in the next section, recent advances in hadronic physics have not been confined to the study of the ground-state nucleon form factors. Other examples have included observations in both inclusive and semi-inclusive deep inelastic scattering (DIS) that have provided new tests of our understanding of nucleon structure in terms of QCD degrees of freedom. Interestingly, the dynamical importance of quark OAM has emerged independently in a number of these experiments. We note also that the value of studies at high $Q^2$ has been seen outside of studies of the nucleon, such as in recent measurements by BABAR of the transition form factor of the pion [18] where large deviations from the predictions of perturbative QCD were observed. The emergence of generalized parton distributions (GPDs) has also been of enormous importance, providing a single framework within which both DIS measurements and form-factor measurements can be understood. GPDs provide new insight into nucleon structure, and form-factor measurements provide critical constraints to their parameterization.

Summarizing these remarks, the present situation is both dynamic and exciting. On one side, the theoretical ideas and methods are rapidly advancing, and on the other side, experiments have discovered new and unexpected features which significantly alter the prevailing description of nucleon structure. Looking forward, the key to expanding our understanding of the underlying quark structure of the nucleon is to make measurements in a regime where the theoretical predictions strongly diverge from one another, and where simplifications occur that aid in the interpretation of the data. All these arguments underscore the importance of reaching high $Q^2$ while simultaneously maintaining high precision. A novel experimental design is needed if running times are to remain reasonable [19, 20].

2 The scientific case for the proposal

A common thread in virtually all of the theoretical explanations of the $Q^2$-dependence of $G_E^p/G_M^p$ is an important role for quark orbital angular momentum (quark OAM) in the nucleon’s dynamics. What is remarkable is that evidence for quark OAM has begun showing up in other processes as well. For example, measurements of the DIS spin asymmetry $A_{1}^n$ for the neutron [21] were performed at high values of Bjorken $x$ where both relativistic quark models and pQCD provide predictions. The pQCD predictions assumed hadron helicity conservation, which implicitly imbeds the notion that quark OAM is not playing a significant role. What was observed was that $A_{1}^n$ was in disagreement with the pQCD prediction, but in reasonable agreement with the quark models which implicitly include the notion that quark OAM has dynamical importance. All of this was taking place as data on single-spin asymmetries from HERMES and COMPASS were showing new unanticipated effects. Subsequent interpretation in terms of the so-called Sivers mechanism again suggests, here quite unambiguously, an important dynamical role for quark OAM. Data from SPIN RHIC seem to suggest that the contribution to the nucleon spin from the spins of gluons, $\Delta G$, is not nearly as large as was once thought possible. While SPIN RHIC has only studied a limited range in Bjorken $x$, the results thus far are consistent with $\Delta G$ being equal to zero. The RHIC results highlight the fact that we still
do not understand the composition of the spin of the nucleon. With polarized DIS results suggesting that only 20-30% of the spin of the nucleon is due to the spin of the quarks, it is certainly possible that some of the remaining spin is due to quark OAM. The fraction of the nucleon spin due to quark OAM is sometimes designated as $\Delta L$. While recent observations of the dynamical importance of quark OAM do not yet yield definite values for $\Delta L$, they may be suggesting that this quantity is quite substantial.

In Fig. 1 we show existing data for $G_E^p/G_M^p$, the projected errors for GEp(5), and the results of several theoretical calculations. The figure makes it clear that the only way to achieve clarity in discriminating between theoretical explanations of the $G_E^p/G_M^p$ data is to measure the proton form factor ratio with considerable precision to high values of $Q^2$.

Figure 1: Shown are existing data for the ratio $G_E^p/G_M^p$ together with the projected errors of GEp(5). Included are the published results of GEp(1) [26] and GEp(2) [27], preliminary results from GEp(3) [2], and the projected results of GEp(5) during a 60-day run. The various theoretical curves are discussed in the text.

For example, three of the predictions shown, the relativistic constituent quark model (RCQM, Miller 2002) [22], the DSE/Faddeev calculation [14], and the refined pQCD calculation ($F_2/F_1 \propto \ln^2(Q^2/\Lambda^2)/Q^2$) [23], all predict $G_E^p/G_M^p$ to cross zero somewhere in the neighborhood of $Q^2 \approx 7$ GeV$^2$. At the same time, the two vector-meson dominance (VMD) models show $G_E^p/G_M^p$ approaching zero much more gradually [24, 25]. GEp(1) and GEp(2) agree reasonably well with all of these predictions. In contrast, the preliminary GEp(3) data appear to favor the VMD models. A definitive resolution to this issue has profound physical implications, and cannot occur without high-precision data at high $Q^2$. We note in passing that the new (near-final) results from GEn(1) tend to favor the DSE/Fadeev and RCQM calculations over the VMD models. Indeed, it appears that form-factor measurements are at the cusp of obtaining crisp answers to the host of questions that were first opened by the work of Jones et al. in Ref. [1].

There are, of course, many additional motivations for measuring the ground-state proton form factors that are not illustrated in Fig. 1. For instance, the ground-state elastic form factors provide stringent model-independent constraints on Generalized Parton Distributions, GPDs. Thus, if we want to know the GPDs over a wide kinematic range, we need to study the elastic form factors over a similar range. We note that GPDs provide a powerful opportunity to determine quark angular momentum in a model-independent fashion. Also, the elastic form factors also provide a powerful check of lattice QCD. As mentioned above, $ab$

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1 The projected points of the GEp(4) experiment are not shown because they will be re-formulated later as explained in the letter placed in an appendix to this document.
lattice calculations of ground-state form factors are making impressive progress, and the comparison of these results with experimental measurements is extremely important.

Setting aside specific models, there is also an experimental question regarding the behavior of \( G_E^p / G_M^p \) that is of great importance. The linearity of the data for \( G_E^p / G_M^p \) up to \( Q^2 \approx 6 \text{ GeV}^2 \) is very striking, but to what value of \( Q^2 \) will this linearity continue? Looking again at Fig. 1, the preliminary results from GEp(3), up to values of around \( Q^2 \approx 8.6 \text{ GeV}^2 \), appear to be breaking somewhat with the earlier trend, that is, the rate of decline of \( G_E^p / G_M^p \) appears to be slowing. It is hard to be certain, however, because the preliminary errors are relatively large. By going to \( Q^2 = 14.5 \text{ GeV}^2 \), the trend of \( G_E^p / G_M^p \) should become clear, but only if the data have sufficient precision. Such precision is offered by the present experiment, which has a figure-of-merit 10 times higher than any other proposed experiments or possible with other equipment than the SBS spectrometer.

The striking linear behavior of \( G_E^p / G_M^p \) is important information for both present and future theoretical formulations, particularly given that it is in disagreement with QCD scaling relations (predicting the ratio \( G_E^p / G_M^p \) to be constant) that are believed to be valid at sufficiently high values of \( Q^2 \). The shape of the ratio \( G_E^p / G_M^p \) up to \( Q^2 = 14.5 \text{ GeV}^2 \) will provide critical guidance to an area in which, presently, there are many open questions.

In the years following the discovery by Jones et al., it is not surprising that models evolved that explained well the existing proton data. It is also not surprising that these models diverge strongly at high-\( Q^2 \) where there is no data to constrain the calculations. Higher values of \( Q^2 \) also offer the advantage of certain theoretical simplifications. For example, the role of vector mesons is suppressed at higher \( Q^2 \), as are higher Fock states in the phenomenological models of GPDs. At high \( Q^2 \) there is increased clarity, and increased discovery potential, and GEp(5) provides an excellent opportunity to explore this region.

### 3 The concept of the experiment

Elastic scattering of the longitudinally polarized 11 GeV electrons from the liquid hydrogen target will be used, \( \text{H}(\vec{e}, e' \vec{p}) \). Polarization transfer to the recoiling proton provides a measure of the \( G_E^p / G_M^p \) as proposed in the double-polarization method [28]. In measuring of the nucleon FF ratio, this method mitigates the difficulties of the Rosenbluth separation method at high momentum transfer and is almost insensitive to the two-photon effects. The most effective realization of the double-polarization approach for the large momentum transfer \( G_E^p / G_M^p \)-ratio experiments was proposed in Ref. [29], which is based on combination of the spin precession in the magnetic spectrometer followed by a polarimeter. This provides directly the ratio of the polarization components of the proton and has a high figure-of-merit as well as a cancellation of most systematic uncertainties related to the polarimeter analyzing power and the efficiency.

**The formalism:** In the one-photon exchange approximation, the scattering of longitudinally polarized electrons from unpolarized hydrogen results in a transfer of polarization to the recoiling proton with two components, \( P_t \) perpendicular to, and \( P_{\ell} \) parallel to the proton momentum in the scattering plane [28]

\[
\begin{align*}
P_t &= -\sqrt{\frac{2\varepsilon(1-\varepsilon)}{\tau}} \frac{G_M G_E}{\sigma_{\text{red}}} \quad P_{\ell} = \sqrt{(1-\varepsilon^2)} \frac{G_M^2}{\sigma_{\text{red}}} 
\end{align*}
\]

where \( \sigma_{\text{red}} \) is the reduced cross-section \( G_M^2 + \varepsilon G_E^2 / \tau \), \( \varepsilon = [1 + 2(1 + \tau) \tan^2 \theta_e / 2]^{-1} \), \( \theta_e \) is the lab electron angle, and \( \tau = Q^2 / 4M_p^2 \).
Measuring these two components simultaneously and taking their ratio gives the ratio of the form factors

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

(2)

Using the double-polarization technique, the form factor ratio \(G_E/G_M\) at a given \(Q^2\) can be obtained without measuring the absolute cross sections and without change of beam energy or detector angle, thus eliminating important sources of systematic uncertainties. Note that the analyzing power of the polarimeter and the beam polarization that come into an actual measurement of \(P_t\) and \(P_l\) cancel out in Eq. 2, and thus do not need to be known particularly well. They do affect the size of the measured asymmetries, however, so they still need to be maximized to increase the experimental figure-of-merit.

**The experimental considerations:** We recall that in the GEp(5) experiment the scattered electron will be detected via the segmented lead-glass calorimeter and the recoiling proton via the Super Bigbite Spectrometer (SBS) in Hall A (Fig 2). The apparatus has a double polarimeter to measure the polarization of the recoiling proton.

At high momentum transfer the coincidence between recoiling proton and scattered electron is required for identification of elastic scattering from a much larger number of inelastic events. Due to kinematical correlations between electron and proton, the planned large acceptance detection system could be considered as a large number of spectrometers effectively increasing the experiment’s productivity.

**The basic equipment:** The scattered electron will be detected, in coincidence with the proton arm, in the lead-glass calorimeter BigCal originally constructed for GEp(3) [2]. The recoiling proton will be detected in a new large acceptance magnetic Super Bigbite spectrometer, SBS.

The new and key part of the detector is a set of tracking chambers using Gas Electron Multipliers (GEM) for the SBS trackers. The GEM chambers are conceptually similar to the ones used in the COMPASS.
experiment at CERN. A two-plane GEM chamber with one-dimensional readout will be installed in front of BigCal. The very high rates associated with the SBS detector configuration are tolerable because of the use of a GEM-based tracking system. The feasibility of such an open geometry design has been unambiguously demonstrated in multiple experiments using Super Bigbite's predecessor, BigBite. The complete description of the Monte Carlo simulations and data analysis are presented in Ref. [19].

Another new detector will be a hadron calorimeter, HCalo, which will be used for triggering in coincidence with BigCal. The individual counter of the hadron calorimeter is similar to the ones used in the COMPASS experiment at CERN.

The dipole magnet of SBS is available from the fixed-target AGS program at BNL. The dipole will bend elastically scattered recoiling protons by 6 degrees upwards, while background charged particles with momenta below 0.3 GeV will be swept out of the tracking detectors. A cutout in the SBS magnet allows for the use of forward angles down to 12° where the recoiling protons need to be detected with a large solid angle.

The proton spin will precess by an angle close to the optimum value of 90°. A track of the proton will be recorded three times: first in the tracker after the dipole magnet, then in the second and third trackers after the first and second analyzers (50 cm CH₂ each).

4 Technical progress toward realizing the experiment

During the last several years significant efforts have been directed toward realization of the form-factor program in Hall A.

Collaboration and coordination: The proposal for this experiment was approved by PAC32 in August 2007 [30]. Understanding the importance of precise high-\(Q^2\) measurements, the spokespersons of the two proton form-factor ratio experiments with 11 GeV beam, E12-07-109 and E12-09-001, decided to consolidate behind the GEp(5) experiment. Two new spokespersons were added to the E12-07-109 team and a coordinated plan of measurements was formulated (see attached letter).

In November 2008 the SBS project was reviewed by a technical committee. The Conceptual Design Report (CDR) and the technical review reports can be found in [19]. In last year’s PAC34, three additional experiments that will use the SBS were approved: the neutron electric (E12-09-016) and magnetic (E12-09-019) form-factor measurements, and the conditionally approved SIDIS experiment (E12-09-018). This makes the collaboration behind the SBS project in Hall A much stronger. A funding proposal [31] to DOE was submitted in November 2009 that will cover the whole experimental apparatus needed for all the three nucleon form-factor experiments: E12-07-109, E12-09-016, and E12-09-019.

Funding of the project: In September 2007 the Italian institute INFN approved the development and construction of the front tracker for the Super Bigbite for the total amount of €720k. The request for SBS funding was submitted by the Glasgow University group (Prof. G. Rosner) to the UK STFC for the amount of $200k. The collaboration submitted a funding request [31] to DOE for the amount of $2.4M (detectors of the SBS project) and for the amount of $1.4M (the magnet and Hall A infrastructure).

Magnet design: The magnet configuration was analyzed with 3D field calculations [32]. The magnet will be used with an excitation current of 2 kA, which is half of the nominal value of the original 48D48 magnet. Therefore, the cross section of the new coils will be reduced. It was demonstrated that for the required main field along the central trajectory of 2.5 T·m, the field inside the beam line will have a transverse component below 200 Gauss, and its integral will be on the level of 0.005 T·m, which have very little effect on the 11 GeV beam and the background rate in the detectors of the SBS apparatus. The power supply of the QWeak experiment will be used to energize the SBS magnet.
GEM chamber design and prototyping: The actual design of the GEM chamber is proceeding at INFN by the Roma group. Both the electronics and the GEM readout board for the 40×50 cm$^2$ unit are in the prototyping stage. All APV25 chips required for the SBS trackers have already been purchased. In 2010 the actual size prototype GEM chamber will be tested in Hall A.

JLab in collaboration with GU has already constructed and tested small GEM chambers which were used for initial studies in Hall A. The UVa group is preparing two small chambers with readout electronics for use during the PREX experiment (Hall A, April 2010) in the HRS spectrometers.

Calorimeters: The existing lead-glass calorimeter BigCal was successfully used in four experiments in Hall C. The UV curing procedure that is planned to be used in the GEp(5) experiment was tested several times during these experiments. The detector will be re-stacked, increasing the vertical aspect ratio, but keeping the same number of channels and total area. The electron arm will be equipped with a two-plane GEM chamber in front of BigCal and behind a 20-cm Al absorber.

Collaboration with the Dubna group (Prof. I. Savin) was organized for the design and construction of the hadron calorimeter. A Monte Carlo simulation of the HCalo calorimeter was performed for a few GeV protons, neutrons, and pions. The Monte Carlo simulation was also used to find the counting rate of the detector by using the DINREG event generator [33].

Simulations: New features were included in the simulation of the elastic events that made it possible to optimize the detector configuration.

Based on the results from the double polarimeter in the GEp(3) experiment, the scattering of the polarized protons in the analyzers was simulated and an analyzing power was assigned for each event. Thus, the polarimeter figure-of-merit, $FOM = \varepsilon(\theta)A_y(\theta)$, where $\varepsilon(\theta)$ is the efficiency for a scattering angle $\theta$ and $A_y$ is the analyzing power, was calculated event by event and used to optimize the geometrical sizes of the detectors. We modified the geometrical sizes of the trackers and the two calorimeters to increase the elastic event rate per unit $Q^2$ interval. This was achieved by increasing the vertical to horizontal aspect ratio to about 3:1, which was possible after reconfiguring the coils of the magnet as explained above. Advanced simulation of the $\pi^0$ photoproduction, the main physical background, has been performed. It demonstrated that the detector resolutions will allow us to reduce this background to a few percents.

Trigger configuration: A Flash ADC was developed by the JLab electronics group. It was used successfully for the Gas Cherenkov counter of the BigBite spectrometer and currently in the detector of the Möller polarimeter. We plan to implement 16 such FADCs in the readout of the hadron calorimeter. A detailed design of the trigger logic based on the FADC and FPGA logic was developed [19].

The polarimeter measurements at JINR: An experimental study of the analyzing power is under way at JINR (Dubna). It will be done with a 7-8 GeV/c polarized proton beam. A set of 25 hadron calorimeter blocks will be used for the triggering as in the GEp(5) experiment.

5 Two-photon exchange update

The JLab PAC32 report approving this experiment required an update on the two-photon exchange effects. The two-photon exchange contribution has been shown to be an important term to add to the standard radiative corrections for cross section data; it has a strong $\epsilon$-dependence and brings the Rosenbluth form-factor ratio closer to the recoil-polarization results. At the same time, two-photon contributions are expected to affect the recoil-polarization results only very weakly. The preliminary results (Fig. 3) from the recent GEp-$2\gamma$ experiment [7] at $Q^2 = 2.5$ GeV$^2$ are consistent with two-photon exchange calculations which explain the cross section data and predict a small effect on $P_t/P_l$. No other experimental results investigating the two-photon exchange effects are available at this time. Hadronic [9], GPD [34] two-photon exchange calculations, and recent pQCD calculations [35] are shown on the same plot. As shown in the original proposal
Figure 3: Preliminary result for the proton form factor ratio measured in GEp-2γ experiment [7] as a function of the virtual photon polarization $\varepsilon$. The plot shows also the GEp(1) [26] result and hadronic [9], GPD [34], and pQCD [35] two-photon exchange calculations. Vertical lines indicate the lower limit of the validity of the corresponding calculations.

for the GPD calculations, the two-photon exchange effects increase very slowly with $Q^2$. Interestingly, the pQCD calculations show the opposite: a slight decrease of the two-photon effects with $Q^2$.

6 Updated kinematics of the measurements

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<th>beam time (days)</th>
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<th>$E_e$ (GeV)</th>
<th>$\theta_{bigCal}$ (deg)</th>
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Table 1: The kinematics of the proposed data points.

Because of the importance of the precise measurements at high $Q^2$, we decided to have one precise measurement at 14.5 GeV$^2$ (instead of two neighboring points at 13 and 15 GeV$^2$ as in the original proposal) and two points at about 5 and 10 GeV$^2$. This will be achieved by reducing the horizontal sizes of the detectors and thus, effectively reducing the $Q^2$ acceptance, but increasing the vertical acceptance and the event rates per unit $Q^2$ interval, while keeping the detector area and the number of channels the same.

The optimized acceptance and use of beam time provides more power to discriminate among different theoretical predictions, while keeping the same total beam time as in the original proposal. The kinematical quantities and anticipated errors for these points are summarized in Table 1. Including four days for optical and spin transport studies, we have in total 60 days of beam on target, as it was requested in the approved experiment E12-07-109.
References


[4] E. Brash, M. Jones, Ch. Perdrisat, V. Punjabi et al., Jefferson Lab experiment E12-09-001 (GEp(4)).


[28] A.I. Akhieser, L.N. Rozenzweig and I.M. Shmushkevich, Sov. Phys. JETP 6, 588 (1958);


APPENDIX D

Individual Proposal Report

Proposal: PR12-07-109

Title: Large Acceptance Proton Form Factor Ratio Measurements at 13 and 15 (GeV/c)^2 Using Recoil Polarization Method


Motivation: This collaboration proposes to extract $G_{Ep}/G_{Mp}$ at $Q^2=12.9$ and $14.8$ (GeV/c)^2 through a measurement of the polarization transfer in elastic $e^+p$ scattering. The estimated absolute statistical accuracy, $\Delta[\mu_p G_{Ep}/G_{Mp}]$, will be about 0.1. This accuracy would match the precision achieved in lower momentum transfer recoil measurements at JLab. Knowledge of the proton form factors is crucial for the understanding of the structure of the nucleon, and their measurements belong to the mainstream of the scientific program of the Laboratory. The form-factors challenge phenomenological models and may be directly compared to lattice QCD calculations.

Measurement and Feasibility: The experiment will run in Hall A. BigCal will be used to detect electrons scattered off a 40 cm cryogenic target; the latter requires a special, dedicated design. A customized setup for detecting the recoil proton will include a dipole magnet, three new fast trackers (GEMs) for the determination of its momentum, interaction point and polarization, as well as a hadron calorimeter to control the trigger rate. The dipole is available from BNL, the polarimeter can be developed from the existing new polarimeter built in Hall C, and several options exit for the hadron calorimeter (e.g. using parts recovered from calorimeters existing at the collaborating institutions). A new and key part of the detector is the set of GEMs. Construction, implementation and installation of those devices will require a large, strongly coordinated organizational and financial effort. The proposal would be strengthened if the new recoil proton detector could be used by the future Hall A experiments, e.g. SIDIS from different polarized targets, GEN measurements, J/ψ photo-production, etc.

Issues: High $Q^2$ measurements at 11 GeV incident energy result in 1/15 of the FOM at 6 GeV. To get statistical errors similar at both energies at the same beam time, detectors with acceptance an order of magnitude larger than classical ones are needed. The idea proposed by the collaboration is novel and challenging, albeit costly. The collaboration will thus also apply for funds to agencies other than NSF/DOE. While the committee is presently convinced that the experiment should run, it also reminds the proponents that all the approved 12 GeV proposals will be subject to (at least) one more examination, just before the upgraded Laboratory program will actually start running. In particular, at that time the proponents are expected to deliver an update of the two-photon exchange correction, based on the newest data and calculations.
Re: Proton Electric Form Factor Measurements with an 11 GeV Beam

December 9, 2009

Prof. Lawrence S. Cardman
Associate Director for Experimental Nuclear Physics
Thomas Jefferson National Accelerator Facility
Newport News, VA 23606

Dear Larry:

The spokespersons of two high-Q² experiments, GEp(4)(E12-09-001) and GEp(5)(E12-07-109), are writing this letter to present to you our common position and coordinated plan which is based on the complementarity of these two experiments.

First and foremost, we would like to reiterate that precise measurements of the electromagnetic form-factor ratio at high Q² are of fundamental importance to hadronic physics, and will continue to be one of the highlights of the JLab program going forward. In that light, our shared goal is to ensure that these measurements are carried out efficiently and lead to the best physics. Indeed, we have decided to consolidate our efforts for the construction of the SBS spectrometer by adding two spokespersons to the GEp(5) team: Ed Brash and Mark Jones.

Furthermore, we are confident that the measurement of the proton form-factor ratio, $\mu G_E/G_M$, at a Q² of $\sim 15 \text{GeV}^2$ with an accuracy of $\sim 0.1$, is both necessary and attainable. Such a precise measurement at this high Q² is required to discriminate among the modern theoretical models of the proton and, together with other experiments at JLab at 12 GeV, will provide critical input to our understanding of nucleon structure.

Based on our previous experiments, together with detailed simulations of the equipment and detectors that should become available following the upgrade, it is our conclusion that the GEp(5) experiment, using the Super Bigbite Spectrometer (SBS), is the only experiment capable of achieving the above goal. The combination of larger acceptance, together with the increased target length that can be accommodated due to this larger acceptance, gives the SBS experiment a 10 times greater statistical Figure-of-Merit compared with the GEp(4) experiment in Hall C.

At the same time, we are convinced that the GEp(4) experiment in Hall C using either the HMS or SHMS spectrometer, together with BigCal and the existing focal plane polarimeter, has a very high value, as it will provide an independent, high-precision result in what presently is an unexplored Q²-region. In addition, the Hall C experiment would be performed without the use of substantial new funds for the experimental preparation. We note, however, that the goals of GEp(4) will be reformulated in accordance with the observed performance of the existing polarimeter such that we have a coherent plan for both experiments.

Based on our experience with the GEp(3) experiment, as well as numerous other recoil-polarimetry experiments in Hall A, the systematic uncertainty at high Q² will come from the following sources. First, and perhaps most important, is the transport of the proton
spin through the magnets of the spectrometer; the issue of spin transport is one that has been studied extensively in all of the form-factor ratio experiments at JLab to date, and is well understood. In addition, the relative importance of the systematic uncertainty originating from instrumental asymmetries in the proton polarimeter is expected to grow with increasing \( Q^2 \). As we have seen in the GEp(3) experiment, instrumental asymmetries cancel out only to first order in the extraction of the form-factor ratio. At high \( Q^2 \), where the ratio of transverse to longitudinal polarization components is very small, the effects beyond first order require special attention.

The crucial point which we wish to emphasize strongly is that the above systematic effects will be different in the GEp(4) and GEp(5) experiments, and will affect the results of the experiments in different ways. Due to the enormous importance of these form-factor ratio measurements to our field, it behooves us to do our utmost to ensure that these effects are fully understood, so that we can have complete confidence in the results. Toward this end, we have worked together to form a coordinated plan for the GEp(4) and GEp(5) experiments which will allow us to evaluate and understand these systematic effects. First of all, both experiments will make a high-precision measurement of the form-factor ratio at a lower value of \( Q^2 \), in the region of 6 GeV\(^2\). Both experiments should be able to achieve a statistical precision of \( \sim 0.03 \), which will allow us to make a detailed assessment of the systematic effects associated with the proton polarimetry and spin precession. Secondly, both experiments will make a measurement of the form-factor ratio in the region of 10-11 GeV\(^2\) with a statistical accuracy of at least \( \sim 0.10 \). As the importance of the systematic effects are expected to be \( Q^2 \)-dependent, having a comparison between GEp(4) and GEp(5) at a value of \( Q^2 \) where these effects are expected to be significant is extremely valuable. **While we are making the GEp(5) experiment our current priority, we emphasize that coordinated measurements from GEp(4) are also essential.**

Sincerely,

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