Jefferson Lab PAC21

Proposal Cover Sheet

JLAB USER GROUP

This document must be received by close of business Monday, December 3, 2001 at:

Jefferson Lab
User Liaison,
Mail Stop 12B
12000 Jefferson Ave.
Newport News, VA
23606

Experimental Hall: A

Days Requested for Approval: 10

❐ **Proposal Title:**
Extracting the Electric Form Factor of the Neutron from Quasi−elastic $^3\vec{He}(\vec{e},e'n)$ scattering at $0.1\ (GeV/c)^2 \leq Q^2 \leq 0.4\ (GeV/c)^2$

Proposal Physics Goals
Indicate any experiments that have physics goals similar to those in your proposal.

To measure the electric form factor of the neutron a low momentum transfer.

Approved, Conditionally Approved, and/or Deferred Experiment(s) or proposals:

Contact Person

Name: Juncai Gao

Institution: Caltech

Address: Kellogg Radiation Laboratory 106−38

Address: Pasadena, CA 91125

City, State, ZIP/Country:

Phone: 626 395 2922 **Fax:** 626 564 8708

E-Mail: jgao@krl.caltech.edu

Jefferson Lab Use Only

Receipt Date:______________________________

By:______________________________

BEAM REQUIREMENTS LIST

JLab Proposal No.: ______ Date: 12/01/01

Hall: A Anticipated Run Date: ______ PAC Approved Days: ______

Spokesperson: Juncai Gao Hall Liaison: J.P. Chen.
Phone: 626−395−2922
E-mail: jgao@krl.caltech.edu

List all combinations of anticipated targets and beam conditions required to execute the experiment. (This list will form the primary basis for the Radiation Safety Assesment Document (RSAD) calculations that must be performed for each experiment.)

Condition No.	Beam Energy (MeV)	Mean Beam Current (μA)	Polarization and Other Special Requirements (e.g., time structure)	Target Material (use multiple rows for complex targets — e.g., w/windows)	Material Thickness (mg/cm²)	Est. Beam-On Time for Cond. No. (hours)
1	1245	12	75% CW Beam	^{3}He gas	50.1	28
2	1645	12	75% CW Beam	^{3}He gas	50.1	95
3	2045	12	75% CW Beam	^{3}He gas	50.1	31
4	2445	12	75% CW Beam	^{3}He gas	50.1	25

The beam energies, E_{Beam}, available are: $E_{Beam} = N \times E_{Linac}$ where N = 1, 2, 3, 4, or 5. E_{Linac} = 800 MeV, i.e., available E_{Beam} are 800, 1600, 2400, 3200, and 4000 MeV. Other energies should be arranged with the Hall Leader before listing.

Computing Requirements List

Proposal Title: Extracting the Electric Form Factor of the Neutron from Quasielastic $^3\vec{He}(\vec{e},e'n)$ scattering at $0.1\ (GeV/c)^2 \leq Q^2 \leq 0.4\ (GeV/c)^2$

Spokesperson: J. Gao/A. Deur/W. Korsch **Experimental Hall:** A

Raw Data Expected

Total: ~200 Gbytes **Per Year (long duration experiments only):** ______

Simulation Compute Power (SPECint95 hours) Required: ______

On-Line Disk Storage Required: ______

Imported Data Amount from Outside Institutions: ______

Exported Data Amount to Outside Institutions:w ______

Expected Mechanism for Imported/Exported Data: ______

Special Requirements

For example, special configuration of data acquisition systems) that may require resources and/or coordination with JLab's Computer Center. Please indicate, if possible, what fraction of these resources will be provided by collaborating institutions and how much is expected to be provided by JLab.

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HAZARD IDENTIFICATION CHECKLIST

JLab Proposal No.: ______________________ (For CEBAF User Liaison Office use only.)   Date: 12/01/01

Check all items for which there is an anticipated need.

Cryogenics	Electrical Equipment	Radioactive/Hazardous Materials
___ beamline magnets ___ analysis magnets ___ target type: ______ flow rate: ______ capacity: ______	___ cryo/electrical devices ___ capacitor banks ___ high voltage ___ exposed equipment	List any radioactive or hazadorous/ toxic materials planned for use: ______ ______ ______ ______
Pressure Vessels ~2cm inside diameter ~12 atm operating pressure glass window material 140μm window thickness	**Flammable Gas or Liquids** type: H_2 gas flow rate: ______ capacity: ______ **Drift Chambers** type: ______ flow rate: ______ capacity: ______	**Other Target Materials** ___ Beryllium (Be) ___ Lithium (Li) ___ Mercury (Hg) ___ Lead (Pb) ___ Tungsten (W) ___ Uranium (U) X Other (list below) ^{3}He gas, Rb, N_2 H_2 gas
Vacuum Vessels ___ inside diameter ___ operating pressure ___ window material ___ window thickness	**Radioactive Sources** ___ permanent installation ___ temporary use type: ______ strength: ______	**Large Mech. Structure/System** ___ lifting devices ___ motion controllers ___ scaffolding or ___ elevated platforms
Lasers type: Diode Laser wattage: 90 W class: IV Installation: X permanent ___ temporary Use: ___ calibration ___ alignment To polarize ^{3}He target	**Hazardous Materials** ___ cyanide plating materials ___ scintillation oil (from) ___ PCBs ___ methane ___ TMAE ___ TEA ___ photographic developers ___ other (list below) ______ ______	**General:** Experiment Class: X Base Equipment ___ Temp. Mod. to Base Equip. ___ Permanent Mod. to Base Equipment ___ Major New Apparatus Other: ______ ______

LAB RESOURCES LIST

JLab Proposal No.: ____________ (For JLab ULO use only.)

Date 12/01/01

List below significant resources — both equipment and human — that you are requesting from Jefferson Lab in support of mounting and executing the proposed experiment. Do not include items that will be routinely supplied to all running experiments such as the base equipment for the hall and technical support for routine operation, installation, and maintenance.

Major Installations *(either your equip. or new equip. requested from JLab)*

Neutron detector (arrays of scintillator bars) + support

Neutron detector shielding

Sweeping magnet

Polarized ^{3}He target

New Support Structures:

Neutron detector

sweeping magnet

Data Acquisition/Reduction

Computing Resources:

standard

New Software:

Major Equipment

Magnets: Sweeping dipole magnet (exists in Hall A: LANL magnet)

Power Supplies: For sweeping magnet

Targets: Polarized ^{3}He target

Detectors: Neutron detector + the two HRS

Electronics:

Computer Hardware:

Other:

Other:

Extracting the Electric Form Factor of the Neutron from Quasielastic $^3\vec{\mathrm{He}}(\vec{e},e'n)$ Scattering at 0.1 (GeV/c)$^2 \leq Q^2 \leq$ 0.4 (GeV/c)^2

B.W. Filippone, J. Gao(co-spokesperson), R.D. McKeown

California Institute of Technology, Pasadena, CA 91125

D. Lhuillier

DSM/DAPNIA/SPhN CEA Saclay , France

B. Milbrath

Eastern Kentucky University, Richmond, KY 40475

J.P. Chen, E. Chudakov, J. Gomez, K. de Jager, O. Hansen, D.W. Higinbotham, J. LeRose
R. Michaels, S. Nanda, B. Reitz, B. Wojtsekhowski

Jefferson Lab, Newport News, VA 23606

P.E.C. Markowitz

Florida International University, Miami FL, 3319

K. McCormick

Kent State University, OH 44242

D. Dale, W. Korsch(co-spokesperson), S. Wadley, G. Wang, P. Zolnierczuk

University of Kentucky, Lexington KY 40506

J. J. Kelly

University of Maryland, College Park, MD 20742

W. Bertozzi, D. Dutta, H. Gao, S. Sirca, R. Suleiman, Y. Xiao
X. Zheng, J. Zhou, L. Zhu

Massachusetts Institute of Technology, Cambridge, MA 02139

Z. Papandreou

University of Regina, Regina, SK S4S 0A2

R. Gilman, C. Glasshauser, X. Jiang, R. Ransome
Rutgers University, Piscataway, NJ 08855

S. Choi, Z.-E. Meziani, N. Ploqvin, K. Slifer, P. Solvignon
Temple University, Philadelphia, PA 19122

G. Cates, D. Day, A. Deur(co-spokesperson), N. Liyanage, J. Singh, A. Tobias
University of Virginia, Charlottesville, VA 22901

D. Armstrong, T. Averett, C. Butuceanu, P. Djawotho, M. Finn, O. Gayou, K. Griffioen
K. Kramer, C. Perdrisat, J. Roche, J. Secrets, D. Steiner, V. Sulkosky, X. Zhu
The College of William&Mary, Williamsburg, VA 23185

1 Motivation for this Experiment

1.1 The Electric Form Factor of the Neutron

Measuring the electric and magnetic form factors of the nucleon is of tremendous interest in the nuclear physics community since these quantities can provide important information to our understanding of the nucleon structure and can be directly compared to many QCD based calculations.

The proton form factors have been measured very precisely over a wide range of kinematics via electron scattering (see e.g. [1, 2]). The magnetic form factor of the proton can be obtained from the elastic *ep* scattering cross sections and, recently, its electric form factor has been measured precisely over a large Q^2 range using the recoil polarization technique [3]. Our knowledge of the proton electromagnetic form factors is at a few percent level for Q^2 values up to about 3 (GeV/c)^2.

The situation changes in case of the neutron. The neutron magnetic form factor was measured accurately in the low and intermediate Q^2 region ($Q^2 \leq 1$ (GeV/c)^2) [4, 5]. Here inclusive scattering off polarized ^{3}He and the ratio of cross sections for the $D(e, e'n)p$ and $D(e, e'p)n$ has been used. The neutron electric form factor G_E^n, however, remains less well known. Two technical difficulties are hampering a precision measurement of G_E^n. Firstly, a free neutron target does not exist in nature, one has to use nuclear targets such as deuteron or helium-3 and rely on theoretical calculations to extract the neutron information. Secondly, G_E^n is extremely small. Nevertheless, the neutron electric form factor is of special interest, because the neutron has zero charge, a non-zero form factor has to come from a nonuniform spatial distribution of valence or sea quarks.

1.2 Measurements and Extractions

With the recent development in both few-body nuclear theories, as well as in experimental techniques including polarized beam and polarized targets, G_E^n has been or is being measured in several laboratories around the world. These measurements can be divided into two categories based on the target used: *i)* G_E^n extracted from the $D(\vec{e}, e'\vec{n})/\vec{D}(\vec{e}, e'n)$ reactions [6, 7, 8, 9, 10] and *ii)* G_E^n extracted from the $^3\vec{H}e(\vec{e}, e'n)$ reaction [11, 12, 13, 14]. Because nuclear effects are present in both ^{2}H and ^{3}He targets, these two methods of measurements are complementary and can cross check each other. A recent exact Faddeev calculation from Golak *et al.*[15] on the extraction of G_E^n using ^{3}He emphasizes that semi-exclusive asymmetry measurements are very well suited for low values of Q^2 (≤ 0.5 (GeV/c)^2), making a low Q^2 ^{3}He experiment interesting and timely.

1.3 Facilities and Luminosities

Except for some measurements at MAMI (Mainz) [11, 12]), the main focus so far has been on precision measurements at intermediate values of Q^2 (0.5 (GeV/c)$^2 \leq Q^2 \leq$ 2.0(GeV/c)^2,

For G_E^n extraction from $\vec{D}(\vec{e}, e'n)$, one can either use an internal polarized deuteron gas target or a solid polarized deuteron target. The thickness of internal gas targets is typically 1×10^{14}/cm^2, therefore, even with currents of 100 mA, the luminosity is only 6.25×10^{31}/cm^2/s. While the solid polarized deuteron target can be as thick as 2.86×10^{23}/cm^2, the beam current can only be $\approx$100 nA which yields a luminosity of 1.8×10^{35}/cm^2/s. The luminosity for $D(\vec{e}, e'\vec{n})$ can be as high as 1×10^{38}/cm^2/s (50 μA beam on a 15 cm LD_2 target), however, one has to measure the recoil polarizations of the neutrons to obtain G_E^n. The typical azimuthal asymmetry of the neutron after the analyzer is only a few percent ($\sim$4%). This gives an effective luminosity of 1.6×10^{35}/cm^2/s.

In the case of the $^3\vec{H}e(\vec{e}, e'n)$ reaction, Mainz used an optically pumped, 1 atm and 20 cm long polarized ^{3}He target. The beam current was 7μA. This amounts to a luminosity of 2.2×10^{34}/cm^2/s. To achieve enough statistics within a reasonable amount of beam time, large acceptance calorimeters had to be used to detect the scattered electrons. Due to lack of sufficient momentum analysis on the electron the virtual photon energy and momentum were not well defined and the theoretical uncertainty in the extraction of G_E^n was large. The polarized ^{3}He program at MIT-Bates is going to extract G_E^n using BLAST a few years from now [17]. Although using the same reaction to extract the neutron information and having enough time and solid angle to compensate for a lower luminosity, the experimental procedures, running time and systematic uncertainties differ significantly from the fixed target experiment we are proposing and thus experimental cross-checks are necessary. The Hall A collaboration at Jefferson Lab operates a polarized ^{3}He target with pressures of $\sim$10 atm or higher using the technique of spin-exchange with alkali atoms. The luminosity has been as high as 1.4×10^{36}/cm^2/s (15 μA beam on 40 cm target). Using one of the High Resolution Spectrometers (HRS) to detect the scattered electrons, one can map out the exclusive asymmetries as functions of the energy transfer ω and neutron energy. This will help to reduce the theoretical uncertainties during the G_E^n extraction process. In addition, the other HRS can be used to measure elastically scattered electrons off ^{3}He. This elastic reaction allows for high precision asymmetry measurements which can be used to monitor the product of beam and target polarizations. A sweeping magnet in front of the neutron detector can be used to deflect low energetic charged particles. As a result, the neutron detector does not have to be shielded against electromagnetic background by means of a Pb wall. Therefore, Hall A is an ideal place to measure G_E^n since one can expect both systematic and statistical uncertainties to be very small. A summary of the available luminosities is given in Table 1.

G_E^n Measurements	Luminosity ($\mathrm{cm}^{-2}\mathrm{s}^{-1}$)
Hall A $^3\vec{H}e(\vec{e},e'n)$	1.0×10^{36}
Mainz $^3\vec{H}e(\vec{e},e'n)$	2.2×10^{34}
Internal Target $\vec{D}(\vec{e},e'n)$	6.3×10^{31}
Solid Target $\vec{D}(\vec{e},e'n)$	1.8×10^{35}
$D(\vec{e},e'\vec{n})$ Recoil Polarization	1.6×10^{35}

Table 1: Luminosities for various G_E^n extractions

We propose measuring G_E^n using the quasi-elastic $^3\vec{H}e(\vec{e},e'n)$ reaction for Q^2 =0.1, 0.2, 0.3, and 0.4 (GeV/c)^2 in Hall A, Jefferson Lab. The beam time we request for this experiment is ten days. The achievable uncertainty, to be compared with the existing data, is given in Fig. 1.

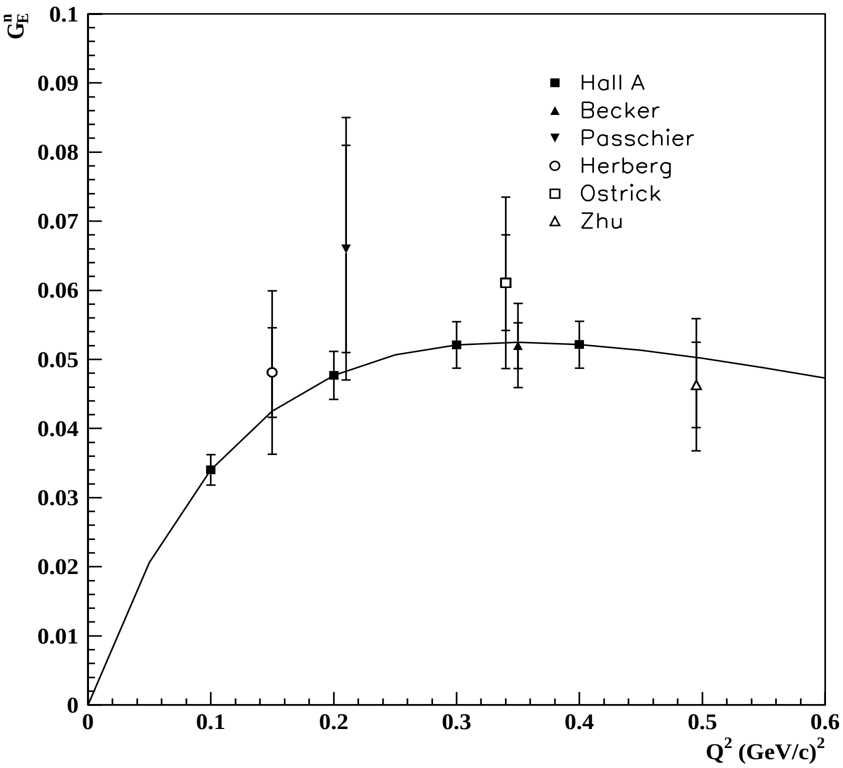


Figure 1: Comparison of projected Hall A measurements with some of the existing G_E^n data. The solid line is the Galster *et al.* parametrization [18]. The projected error bar is the quadratic sum of the systematic and statistic errors.

1.4 Additional Important Reasons to Measure G_E^n at low Q^2

Relevance to the strange quark content of the nucleon: The current uncertainty on G_E^n is a dominant source of systematic error for the parity experiments looking at the strange quark content of the proton. For the Happex experiment [19] which ran at 0.48 (GeV/c)^2, an uncertainty of 5% comes from the form factors. Of this 5%, 4% is due to our limited knowledge of G_E^n. In Hall A, the experiment E99-115 (Happex II) [20] will run at Q^2=0.11 (GeV/c)^2 and similarly the ^{4}He parity experiment E00-114 [21] will run at 0.1 (GeV/c)^2. In Hall C, the G0 experiment [22] will measure the strange form factors G_M^s and G_E^s for a Q^2 range of 0.1 to 1.0 GeV^2. Hence reliable data on G_E^n covering these kinematics will be of particular relevance. With the recent theoretical improvement in the extraction of the neutron information, the experiment proposed here can provide critical input to the extraction of strange form factors.

Tests of Chiral Perturbation Theory: At low values of Q^2 chiral perturbation theory (χPT) can be used to calculate nucleon electromagnetic form factors in a model-independent way. Although the range of applicability of χPT is still limited to Q^2 values less than about 0.2 $(\text{GeV/c})^2$ in most cases, Meissner *et al.* performed a χPT calculation up to $Q^2 = 0.4$ $(\text{GeV/c})^2$[23]. The form factors were calculated in a Lorentz invariant form of baryon χPT to one-loop up to fourth order. The result is shown in Fig. 2. A precision measurement at low values of Q^2 will allow us to test these predictions.

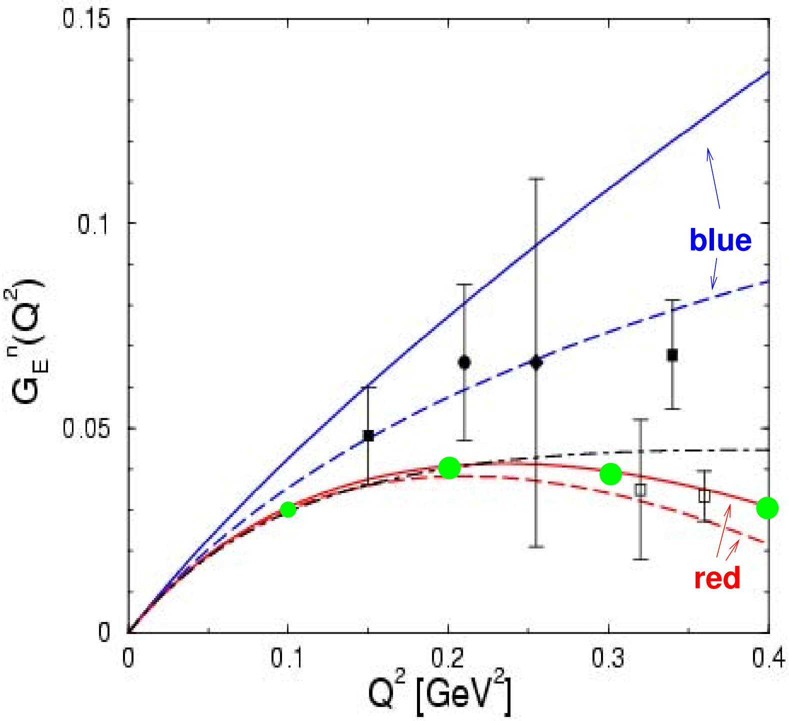


Figure 2: G_E^n in relativistic baryon chiral perturbation theory (including vector meson) up to fourth order (solid red line). Third order is given by the solid blue curve while the blue/red dashed lines give the results without vector mesons. The black dot dashed curve is the results from dispersion theoretical analysis. The size of the solid (green) points on the red line shows the anticipated precision of this experiment (statistical errors only).

2 Theory

The sixfold differential cross section for the ${}^3\vec{H}e(\vec{e},\, e'n)pp$ reaction has the form

$$\frac{d^6\sigma}{d^3\vec{E}'_e d^3\vec{p}_n} = \sigma_{Mott} p_n^2 \frac{pm_N}{2} \int d\hat{p}(v_L R^L + v_T R^T + v_{TT} R^{TT} + V_{TL} R^{TL} + h(v_{TL'} R^{TL'} + v_{T'} R^{T'}) \quad (1)$$

where $\vec{E}'_e, \vec{p}_n, p, \hat{p}$ are the scattered electron energy, neutron momentum, the magnitude and direction of the relative momentum of the two undetected protons. h is the incident electron helicity. In the Plane Wave Impulse Approximation (PWIA), the cross section asymmetry for scattering of longitudinally polarized electrons from neutrons in the polarized ^{3}He target is

$$A = P_e P_n V \frac{a \sin\Theta \cos\Phi G_E^n G_M^n + b\cos\Theta (G_M^n)^2}{(G_E^n)^2 + c(G_M^n)^2} \tag{2}$$

Here P_e, P_n are the polarizations of electron and neutron, V is a dilution factor due to the fact that the electrons do not scatter solely off ^{3}He but also from a small amount of nitrogen (see target section). Θ, Φ are the polar and azimuthal angles of neutron spin with respect to the momentum transfer direction. a, b, and c are the kinematic factors.

$$a = -2\sqrt{\tau(1+\tau)}\tan(\frac{\theta_e}{2}) \tag{3}$$

$$b = -2\tau\sqrt{1+\tau+(1+\tau)^2\tan^2(\frac{\theta_e}{2})}\tan(\frac{\theta_e}{2}) \tag{4}$$

$$c = \tau + 2\tau(1+\tau)\tan^2(\frac{\theta_e}{2}) \tag{5}$$

$$\tau = \frac{Q^2}{4m_N} \tag{6}$$

If the target polarization is perpendicular or parallel to the momentum transfer direction, the asymmetries become

$$A_\perp = P_e P_n V \frac{a G_E^n G_M^n}{(G_E^n)^2 + c(G_M^n)^2} \tag{7}$$

$$A_\parallel = P_e P_n V \frac{b (G_M^n)^2}{(G_E^n)^2 + c(G_M^n)^2} \tag{8}$$

The ratio of the two asymmetries can give G_E^n/G_M^n,

$$\frac{A_\perp}{A_\parallel} = \frac{a G_E^n}{b G_M^n} \tag{9}$$

and the P_e, P_n, and V are all canceled out. The G_M^n data [5] from experiment E95-001 which ran from $Q^2 = 0.1$ to 0.6 (GeV/c)^2 will be used to extract G_E^n. The current precision on G_M^n is 2%.

However, final state interactions (FSI) and meson exchange currents (MEC) can modify the asymmetries. Recently, Golak *et. al* [15] analyzed the $^3\vec{H}e(\vec{e}, e'n)$ with the aim to search for sensitivities in G_E^n. Their Faddeev calculations were based on the high precision NN force AV18 and meson exchange currents (MEC) were included. In the non-relativistic region (0.1 (GeV/c)^2 $< Q^2 <$ 0.4 (GeV/c)^2), extracting the neutron electric form factor appears very promising. The ratio $A_\perp/A_\parallel$ from their calculation is shown in Fig. 3.

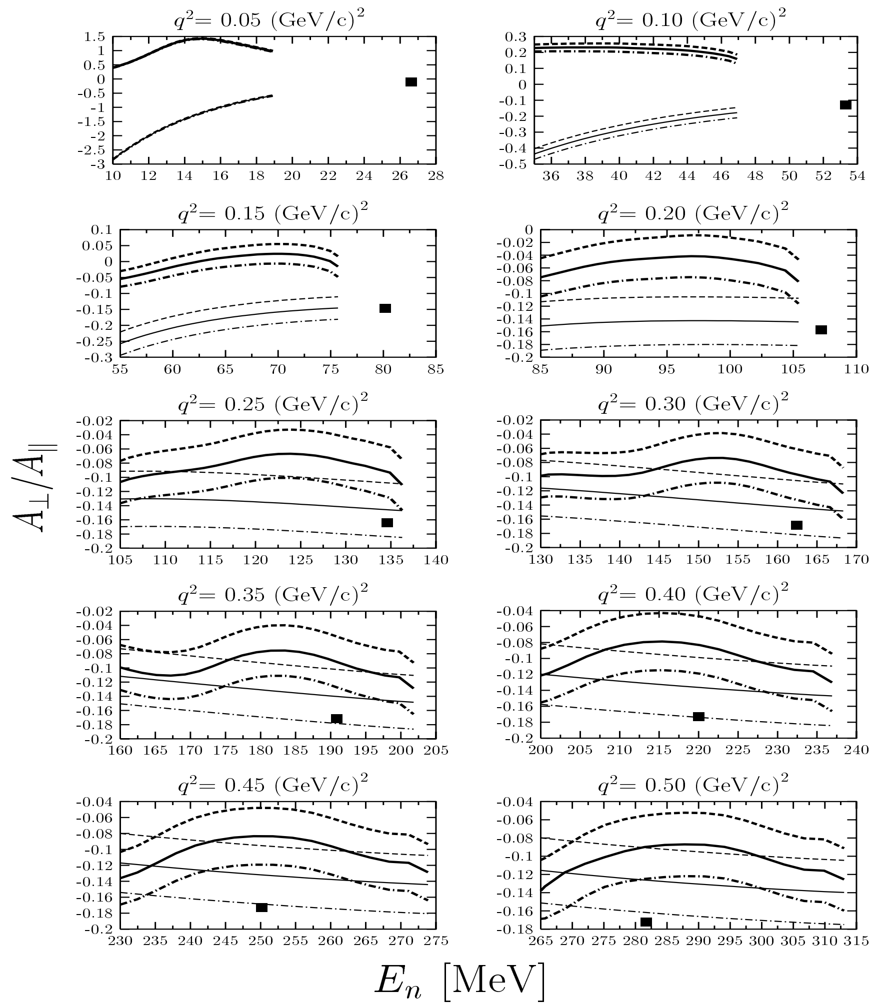


Figure 3: Exact calculation of $A_\perp/A_\parallel$ (solid lines) as function of the neutron energy E_n for different q^2 values and for a 1 GeV beam energy. The thin lines are from PWIA calculations. The filled square is the pure neutron results. The different lines correspond to different values of G_E^n (dotted:0.75G_E^n, solid:1.00G_E^n and dash-dotted 1.25G_E^n).

3 Experimental Setup

The setup of this experiment will consist of the Hall A polarized ^{3}He target, the high resolution spectrometers, a neutron detector system and a sweeping magnet.

3.1 High Resolution Spectrometers

One of the high resolution spectrometers will detect the scattered electrons. Another HRS will detect elastically scattered electrons from ^{3}He to monitor the change of target and beam polarizations. The HRS has a solid angle of 6 msr, $\pm 4.\%$ momentum acceptance and 4×10^{-4} momentum resolution. The standard HRS detector package will be used.

3.2 The Polarized ^{3}He Target

The Hall A polarized ^{3}He target will be used in this experiment. It has been successfully used at the end of 1998 and beginning of 1999 by the experiments E94-010 (measurement of the Q^2 evolution of the generalized GDH sum rule) and E95-001 (measurement of G_M^n). It reached an average polarization of 35%. In summer 2001 experiments E99-117 (measurement of A_1^n at large x) and E97-103 (precise measurement of g_2^n) used the same target with an average polarization of 40%. We took the average of 37 % for our running time estimates.

3.2.1 Description

The target is a 2 chamber glass vessel. The bottom chamber, where the beam scattering occurs, is 40 cm long and contains ^{3}He gas at about 12 atm and 50°C (in running conditions). The length and the high density allow a reasonable counting rate in spite of the gaseous nature of the target: The luminosity achieved is above 10^{36} cm^{-2}s^{-1} for 15 μA. The bottom chamber is connected to a spherical upper chamber where the gas is polarized. This top chamber is surrounded by an oven and heated at about 200°C. The target polarization is achieved in three steps:

- Atoms of Rubidium are optically pumped with a set of diode lasers.
- The Rb polarization is transmitted to the ^{3}He by spin exchange collisions.
- The polarized ^{3}He flows into the bottom chamber by diffusion/convection while the Rb stays in the top chamber because of the colder temperature of the bottom chamber.

With two perpendicular sets of Helmholtz coils which generate a holding field of about 25 Gauss and six lasers of 180 W total power, the target can be pumped in any horizontal direction. Typically, three lasers are used to pump the target when its polarization is along the beam direction and the three others are dedicated to transverse pumping. This feature will allow us to polarize and to align the polarization of the target l ongitudinal or perpendicular to the 3-momentum vector $\vec{q}$ of the virtual photon. Proper orientation of the target polarization requires a particular optics setting but represents no special difficulty or expenditure. This was successfully done for experiment E95-001 which measured G_M^n in the same Q^2 range and hence was running in conditions similar to ours.

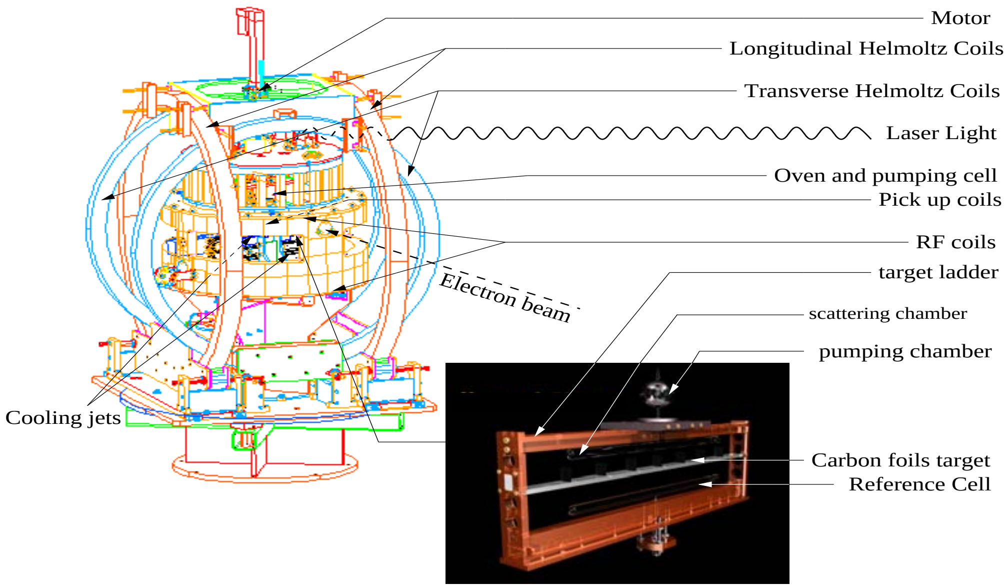
The maximum polarization achievable depends mainly on the quality of the glass vessel containing the gas mixture. The University of Virginia and the College of William and Mary together with JLab have been able to produce and to characterize state of the art quality glass vessels. Other factors affecting the polarization, such as the magnetic field homogeneities, have been optimized.

The ladder supporting the ^{3}He target holds also a reference cell that can be filled with various gases for systematic studies and a solid target made of thin carbon foils for spectrometer and false asymmetry studies. The different targets are set in position with a remotely controlled motor.

For background studies, we will fill the reference cell with about 1 atm. of H_2. We believe there is no safety issue since the reference cell will not be pressurized and since we never experienced a reference cell failure during the past experiments when it was run at 10 atm. In addition, the oxygen in the target chamber is very diluted by the ^{4}He from the jets cooling the target window. The content of the target chamber is constantly pumped out of Hall A.

About 1% of N_2 is added to the ^{3}He and Rb mixture to improve the optical pumping by inducing non-radiative decay of the excited Rb atoms. In order to correct for the N_2 dilution, N_2 runs have to be taken. This is achieved by filling the reference cell with N_2. Scattering off the target windows can be cut by software due to high accuracy of the HRS tracking. The Rb contamination in the bottom chamber is negligible.

The target is represented on the figure below:



The polarized ^{3}He target.

3.2.2 Polarimetry

The target polarization is measured either by:

- Nuclear Magnetic Resonance (NMR) calibrated using the known proton thermal polarization (water calibration). This requires a sweep of the Holding field in the "adiabatic fast passage" conditions and a radiofrequency field. It is generated by a set of smaller coils ("RF" coils). The signal is collected by a third pair of coils (pick-up coils) sandwiching the bottom chamber.
- Electron Paramagnetic Resonance (EPR) by measuring the Rubidium EPR frequency shift proportional to the ^{3}He polarization.
- Monitoring of the elastic asymmetry and the use of the ^{3}He form factors, well measured in our range of interest. This gives the product of the beam and target polarizations and can be viewed as a global check of our understanding of the polarimetries and target characteristics. This experiment uses only one HRS and the second spectrometer will be used for such checks.

For the previous ^{3}He experiments, all polarimetries were consistent and the relative uncertainty on the target polarization was less than 4%. For the measurement of G_E^n/G_M^n, part of the error cancels out since we measure a ratio of asymmetries.

To conclude this section, we will use the Hall A target in a rather standard way. So no difficulties are expected from this part of the experiment.

3.3 Beam characteristics

The polarized source using the strain GaAs photocathode is needed for this experiment. To minimize the target depolarization from beam induced ionization as well as radiation damage, we plan to run the target at 12 μA although it as been operated before up to 15 μA. 75% beam polarization is assumed in this proposal. The Hall A Møller Polarimeter will yield a measurement at the 3% level while the Compton polarimeter will independently provide continuous monitoring of the polarimetry at, at least, the same level. The beam energy will be measured either using the eP or the ARC measurement methods which reach an accuracy at a few 10^{-4} level. The eP device relies on the measurement of the scattering angles of the $H(e, e'p)$ elastic reaction. At the energies of this proposal, a measurement takes typically half an hour. ARC measures the bending of the electron beam under a well known magnetic field. A typical measurement takes 1 to 2 hours. The beam will be rastered before the target and the target windows will be cooled.

3.4 The Neutron Detector

As pointed out above, this experiment plans to extract G_E^n using the exclusive ${}^3\vec{H}e(\vec{e}, e'n)$ reaction. Besides one of the HRS spectrometers for electron detection, a neutron detector is needed. We plan to use a neutron detector similar to the one used in the experiment E93-026 in Hall C. The detector will be provided by our collaborators from the University of Virginia who also provided a similar detector system for the Hall C G_E^n experiment. The neutron detector will consist of 60 neutron scintillator bars. The detector material is Bicron 408 with UVT acrylic lucite light guides attached on each end. The light is collected using Amperex XP2262 phototubes. The dimension of each neutron bar is 160 cm $\times$ 10 cm $\times$ 10 cm. We plan to set up a neutron detector with a total volume of 160 cm $\times$ 10 cm $\times$ 50 cm. Neutron detection efficiency at different energies and different threshold has been calculated based on [24]. The results are listed in Table 2. For event rate estimation, we assume a neutron detection efficiency of at least 25%. Note that this is a conservative estimate. A similar experiment at MAMI (Mainz) achieved 32% neutron detection efficiency for a 40 cm thick neutron detector in the energy range proposed here [12].

T_n (MeV)	Eff. (10 MeVee) %	Eff. (15 MeVee) %	Eff. (20 MeVee) %
57	13.3	10.4	8.5
117	11.9	10.4	9.7
167	9.6	8.6	8.2
216	9.6	8.1	7.3

Table 2: Calculated neutron efficiency for different neutron energy and different threshold (MeV electron equivalent). The neutron bar dimension is 160 cm × 10 cm × 10 cm.

In order to reduce charged particle backgrounds a veto counter consisting of 12 paddles with dimensions of 160 cm × 11 cm × 1 cm will be placed in front of the neutron bars.

The neutron detector will have to be moved in order to accommodate the requirements for the different kinematical settings. We plan to put the detector on a movable platform and change the position during beam energy changes. We do not need to survey the detector each time.

The coincidence time-of-flight resolution is about 1 ns. This corresponds to neutron energy resolution of 1.5, 4.6, 8.1, and 12.3 MeV at $Q^2 = 0.1$, 0.2, 0.3 and 0.4 $(\mathrm{GeV/c})^2$.

4 Kinematics, Beam Time and Systematic Uncertainty Estimates

The table below gives the proposed kinematics.

Q^2 ((GeV/c)^2)	E_e (GeV)	E'_e (GeV)	T_n (MeV)	θ_e (deg)	θ_n (deg)
0.1	1.245	1.18	57	15.01	70.42
0.2	1.645	1.52	117	16.24	66.83
0.3	2.045	1.87	167	16.10	64.43
0.4	2.445	2.22	216	15.61	62.56

Table 3: Proposed kinematics

The systematic error on G_E^n will be dominated by the current uncertainty on G_M^n and the target spin misalignment. Assuming an accuracy of 0.3^o on the spin alignment, which was already achieved by experiment E97-103, the total systematic error on G_E^n for this experiment will be $\sim$4%.

Event rate has been estimated based on the calculations from Golak *et al.*[16] The assumptions made for the event rate calculation are listed in Table 4

Luminosity	1×10^{36}
Electron beam polarization	75%
^{3}He target length	40 cm
^{3}He target polarization	37%
HRS solid angle	6 msr
HRS momentum acceptance	$\pm$4%
HRS overall efficiency	50%
Neutron detector solid angle	25 msr
Neutron detector efficiency	25%

Table 4: Assumptions for the event rate estimation

The total beam time will be about 158 hours, see Table 5. The overhead times needed for momentum changes, energy changes, polarimetries, etc... are listed in Table 6. The total time for the experiment is 240 hours, i.e. ten days.

Q^2 $((\mathrm{GeV/c})^2)$	Rates (Hz)	$A_\parallel/A_\perp$ (%/%)	$\frac{\Delta A_\parallel}{A_\parallel}/\frac{\Delta A_\perp}{A_\perp}$ (%/%)	$(\frac{\Delta G_E^n}{G_E^n})_{stat.}$ (%)	$(\frac{\Delta G_E^n}{G_E^n})_{sys.}$ (%)	Time (hrs)
0.1	58.5	-5.4/1.04	2/5	5.4	3.7	4/18
0.2	45.6	7.13/0.44	2/6	6.3	4.0	3/87
0.3	50.6	7.22/0.97	2/5	5.4	4.1	3/23
0.4	48.2	7.05/1.18	2/5	5.4	4.6	3/17

Table 5: Expected relative uncertainties on the asymmetries, statistic, systematic uncertainties on G_E^n and beam time needed for the different Q^2 points.

Task	Time (hours)
BCM, BPM/ARC calibrations	1
Møller polarimetry	12
eP/arc	6
Target polarimetry	14
ref. cell runs	15
Neutron detector angle changes	10
linac pass changes and energy changes	24

Table 6: Overhead time.

For the overhead time we assume:

- 1 hour for Beam Current Monitor and Beam Position Monitor/HARP calibrations at the beginning of the experiment. The HARP is a beam position measurement device (destructive measurement).
- 3 hours for a Møller measurement at each energy change.
- 1.5 hours for an eP (or ARC) energy measurement at each beam energy. The energy will be then given using the Tiefenback parameterization known to give the energy at 5×10^{-4}.
- 20 minutes for a NMR/EPR target polarimetry, four times a day. Note that we do not need a target polarization measurement as often as other ^{3}He experiments since one of the HRS's will be constantly taking elastic data.
- 2 hours for a ^{3}He pressure curve using the reference cell filled at different pressures in order to check our understanding of the target density. Note that since we are doing an asymmetry measurement, a good knowledge of the density may seem irrelevant. However it is required for the target polarimetry as well as consistency checks such as elastic cross section measurements. 1 hour for window contamination measurement.
- For each kinematics, with the ref. cell: 2 hours for H_2 background measurement and 1 hour for N_2 contamination measurement. Again, since we are interested in the ratio of the longitudinal to the transverse cross section, it may seem unnecessary to take empty cell and N_2 data since the contamination will cancel out. However this is desirable for consistency checks and radiative corrections. The empty target cell runs are, in particular, necessary to define the window cuts.

- 2 hours per energy change. HRS Momentum and angle changes will be done during this time as well as part of the neutron detector and sweeping magnet angle change.

- 4 hours per linac pass change and 8 hours per linac energy change.

- 3 hours per energy to complete the neutron detector/sweeping magnet angle changes.

5 Expected Backgrounds

The rates for the inclusive $^3He(e,e')$ and $^3He(e,\pi^-)$ reactions for the HRS and $^3He(e,N)$ and $^3He(e,\pi)$ for the neutron detector are computed using the codes from Lightbody and O'Connell [25]. We assumed a beam current of 12 μA and a target thickness of 8×10^{21} cm^{-2}. The glass windows of the target are taken into account by assuming a glass density 400 times higher than the 10 atm of the ^{3}He gas and a window thickness of 140 μm. The difference in the form factors between ^{3}He and the heavier components of the glass are not taken into account. This approximation overestimates the background.

Assuming a 50 ns coincidence time window for the trigger and taking the case of $Q^2 = 0.1$ (GeV/c)^2, the background rate from accidentals is $4.\times10^{-5}$Hz.

One major source of backgrounds can be attributed to the $^3\ \vec{H}e(\ \vec{e},\ e'\ p)\ ^d_{np}$ reaction in the target. Therefore, we plan to place a sweeping dipole magnet in front of the neutron detector. Hall A acquired two dipole magnets from LANL with gap dimensions of 7" (height) $\times$ 46.4" (width) $\times$ 60.5" (length). The field in the gap is >1.7 T for this geometry and the gap height can be opened up as needed. In order to minimize field gradients in the target region we plan to place the magnet 2 m (front face) away from the target center. Field clamps can be added to reduce the magnetic field gradients to a tolerable level. Note: The field gradients generated by Q1 of the HRS have no measurable effect on the target polarization. In order to match the magnet gap to the geometry of the neutron detector the gap width has to be increased to about 20". As a result the magnetic field in the gap will drop to about (0.5-0.6) T. In addition, the neutron bars have to be placed 8.4 m away from the target resulting in a solid angle of about 25 msr ($\Delta\phi_n \approx \pm 4.1^\circ, \Delta\vartheta_n \approx \pm 10.0^\circ$).

In order to get an estimate for the background resulting from the $^3\vec{H}e(\vec{e},e'p)^d_{np}$ Monte Carlo studies were performed. The ^{3}He spectral function from R.-W. Schulze and P.U. Sauer [26] served as an input. The expected ratios for the (e,e'p)/(e,e'n)=R$_p$/R$_n$ rates are shown in Table 7.

Q^2 [GeV^2/c^2]	0.1	0.2	0.3	0.4
R_p/R_n	3.88	3.12	2.84	2.65

Table 7: Expected ratio for the $(e, e'p)/(e, e'n)$ rates.

A Geant4 simulation was used to study the effect of the sweeping magnet. Protons with realistic energy distributions were generated and emitted from a 40 cm long target. An integrated field of 0.6 Tm was assumed. Table 8 lists the result of the calculation.

Q^2 [GeV^2/c^2]	0.1	0.2	0.3	0.4
(R_p (B=0.5T))/(R_p (B = 0.0T)) [%]	1.2	1.6	4.4	13.6

Table 8: Relative amount of protons impinging on the neutron detector using a Hall A (LANL) dipole magnet at a pole tip field of 0.5 T.

Even though the expected proton rate is about a factor of 4 higher at the lowest Q^2 point, the sweeping magnet reduces this background far below the expected neutron rate. The proton rates for the highest Q^2 point are about one third of the neutron rates. At these rates we plan to omit Pb shielding in front of the neutron detector for electromagnetic background suppression. This eliminates another possible source of background, namely (p,n) reactions in the Pb wall. The veto counter will be used to finally distinguish neutrons from protons. We plan to measure the magnet and veto rejection efficiency by taking short runs with small amounts of hydrogen in the reference cell.

The magnet will have to be moved for each new kinematic setting. We believe that this can be done during beam energy changes. A precise alignment of the magnet is not needed.

Another possible source of background are inelastic events coming from single pion production. Since the momentum bite of the HRS is ± 4% such inelastic events can be scattered into the acceptance of the detector. However, Day *et al.* performed inclusive measurements on ^{3}He at Q^2 values of 0.15, 0.2, and 0.25 $(GeV/c)^2$ [27]. The measured results were compared to Faddeev calculations for the quasi-elastic yield. The calculations agree perfectly with the measurements and no deviation from the quasi-elastic yield can be seen within the acceptance of the HRS, i.e. the pion yield is negligible. Even at a Q^2 of 1 $(GeV/c)^2$ the relative fraction of inelastic events is only about 0.15. Differences in the time-of-flight (TOF) will allow us to distinguish between any inelastically and elastically scattered events. In addition, we note that inelastically generated neutrons have on average much larger transverse momenta ($>$ 100 MeV/c). This effect leads to a reduction of the solid angle for inelastic neutrons, since $\Delta\vartheta_{qn}$ is larger. Such a background is expected to be less than 0.1%.

6 Conclusion

This experiment will allow us to measure the electric form factor of the neutron, G_E^n with an unprecedented precision. We plan to use the $^3\vec{H}e(\vec{e},e'n)pp$ reaction. We will utilize both HRS spectrometers of Hall A. One spectrometer will be used to detect the quasi-elastically scattered electrons and the other spectrometer will detect elastically scattered electrons to monitor the product of beam and target polarizations. The Hall A polarized ^{3}He target will be used as an effective neutron target and a neutron detector from the University of Virginia will be installed for neutron detection. Within ten days we will be able to extract G_E^n at four different Q^2 values (0.1-0.4 (GeV/c)^2) with a statistical uncertainty of about 6% and a systematic uncertainty of about 4%. The knowledge of G_M^n and the target spin angle will be the major contributions to the systematic error. Nuclear corrections to the extraction of G_E^n have been calculated exactly by Golak *et al.* [15] for the kinematics proposed here.

A Contributions

The contribution from the collaboration will be:

- Installation and operation of the ^{3}He target and the neutron detector.
- Produce and characterize high quality ^{3}He target glass vessels yielding at least 40% polarization with a lifetime greater than 50 hours.
- Provide the veto detectors for the neutron detector.
- Provide the coincidence trigger between the neutron detector and the spectrometer.

We request from JLab:

- 10 days of polarized beam at 12 μA, 75% polarization and four different energies.
- Installation of the sweeping magnet.
- Support for the target, neutron detector and sweeping magnet installation.
- Support for the target, neutron detector and sweeping magnet angle change

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