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PI/PD Name: Gerard P Gilfoyle

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Ethnicity: (Choose one response) ☐ Hispanic or Latino ☐ Not Hispanic or Latino

Race:
(Select one or more)
- ☐ American Indian or Alaska Native
- ☐ Asian
- ☐ Black or African American
- ☐ Native Hawaiian or Other Pacific Islander
- ☒ White

Disability Status:
(Select one or more)
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- ☐ Visual Impairment
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- ☐ Other
- ☒ None

Citizenship: (Choose one) ☒ U.S. Citizen ☐ Permanent Resident ☐ Other non-U.S. Citizen

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Asian. A person having origins in any of the original peoples of the Far East, Southeast Asia, or the Indian subcontinent including, for example, Cambodia, China, India, Japan, Korea, Malaysia, Pakistan, the Philippine Islands, Thailand, and Vietnam.
Black or African American. A person having origins in any of the black racial groups of Africa.
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List of Suggested Reviewers or Reviewers Not To Include (optional)

SUGGESTED REVIEWERS:
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COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

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University of Richmond	University of Richmond 28 Westhampton Way Richmond, VA. 231730001
AWARDEE ORGANIZATION CODE (IF KNOWN) 0037440000	
NAME OF PERFORMING ORGANIZATION, IF DIFFERENT FROM ABOVE	ADDRESS OF PERFORMING ORGANIZATION, IF DIFFERENT, INCLUDING 9 DIGIT ZIP CODE
PERFORMING ORGANIZATION CODE (IF KNOWN)	

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☐ IF THIS IS A PRELIMINARY PROPOSAL THEN CHECK HERE

TITLE OF PROPOSED PROJECT **RUI: Nuclear Physics Research at the University of Richmond**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
$ 161,563	36 months	06/01/07	

CHECK APPROPRIATE BOX(ES) IF THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW

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- ☐ DISCLOSURE OF LOBBYING ACTIVITIES (GPG II.C)
- ☐ PROPRIETARY & PRIVILEGED INFORMATION (GPG I.B, II.C.1.d)
- ☐ HISTORIC PLACES (GPG II.C.2.j)
- ☐ SMALL GRANT FOR EXPLOR. RESEARCH (SGER) (GPG II.D.1)
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PI/PD DEPARTMENT	PI/PD POSTAL ADDRESS
Department of Physics	Richmond, VA 23173 United States
PI/PD FAX NUMBER	

NAMES (TYPED)	High Degree	Yr of Degree	Telephone Number	Electronic Mail Address
PI/PD NAME Gerard P Gilfoyle	Ph.D.	1985	804-289-8255	ggilfoyl@richmond.edu
CO-PI/PD				
CO-PI/PD				
CO-PI/PD				
CO-PI/PD				

CERTIFICATION PAGE

Certification for Authorized Organizational Representative or Individual Applicant:

By signing and submitting this proposal, the individual applicant or the authorized official of the applicant institution is: (1) certifying that statements made herein are true and complete to the best of his/her knowledge; and (2) agreeing to accept the obligation to comply with NSF award terms and conditions if an award is made as a result of this application. Further, the applicant is hereby providing certifications regarding debarment and suspension, drug-free workplace, and lobbying activities (see below), as set forth in Grant Proposal Guide (GPG), NSF 04-23. Willful provision of false information in this application and its supporting documents or in reports required under an ensuing award is a criminal offense (U. S. Code, Title 18, Section 1001).

In addition, if the applicant institution employs more than fifty persons, the authorized official of the applicant institution is certifying that the institution has implemented a written and enforced conflict of interest policy that is consistent with the provisions of Grant Policy Manual Section 510; that to the best of his/her knowledge, all financial disclosures required by that conflict of interest policy have been made; and that all identified conflicts of interest will have been satisfactorily managed, reduced or eliminated prior to the institution's expenditure of any funds under the award, in accordance with the institution's conflict of interest policy. Conflicts which cannot be satisfactorily managed, reduced or eliminated must be disclosed to NSF.

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By electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative or Individual Applicant is providing the Drug Free Work Place Certification contained in Appendix C of the Grant Proposal Guide.

Debarment and Suspension Certification

(If answer "yes", please provide explanation.)

Is the organization or its principals presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from covered transactions by any Federal department or agency? Yes ☐ No ☒

By electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative or Individual Applicant is providing the Debarment and Suspension Certification contained in Appendix D of the Grant Proposal Guide.

Certification Regarding Lobbying

This certification is required for an award of a Federal contract, grant, or cooperative agreement exceeding $100,000 and for an award of a Federal loan or a commitment providing for the United States to insure or guarantee a loan exceeding $150,000.

Certification for Contracts, Grants, Loans and Cooperative Agreements

The undersigned certifies, to the best of his or her knowledge and belief, that:

(1) No federal appropriated funds have been paid or will be paid, by or on behalf of the undersigned, to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with the awarding of any federal contract, the making of any Federal grant, the making of any Federal loan, the entering into of any cooperative agreement, and the extension, continuation, renewal, amendment, or modification of any Federal contract, grant, loan, or cooperative agreement.

(2) If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with this Federal contract, grant, loan, or cooperative agreement, the undersigned shall complete and submit Standard Form-LLL, ''Disclosure of Lobbying Activities,'' in accordance with its instructions.

(3) The undersigned shall require that the language of this certification be included in the award documents for all subawards at all tiers including subcontracts, subgrants, and contracts under grants, loans, and cooperative agreements and that all subrecipients shall certify and disclose accordingly.

This certification is a material representation of fact upon which reliance was placed when this transaction was made or entered into. Submission of this certification is a prerequisite for making or entering into this transaction imposed by section 1352, Title 31, U.S. Code. Any person who fails to file the required certification shall be subject to a civil penalty of not less than $10,000 and not more than $100,000 for each such failure.

AUTHORIZED ORGANIZATIONAL REPRESENTATIVE	SIGNATURE	DATE
NAME		

TELEPHONE NUMBER	ELECTRONIC MAIL ADDRESS	FAX NUMBER

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Intellectual Merit

This project will support the participation of University of Richmond faculty, students, and others in collaborative work on experiments at the Thomas Jefferson National Accelerator Facility (TJNAF). The work will be done as part of the CLAS Collaboration in Hall B at TJNAF. We are mapping out the transition from the hadronic picture of atomic nuclei to one where the quark and gluon degrees of freedom become prominent. We are extracting the out-of-plane structure functions of the deuteron in the region where the hadronic picture should begin to break down. By taking advantage of the nearly $4-\pi$ solid angle of CLAS we can measure components of the deuteron wave function that have been largely unknown before now; ones where the momenta of protons ejected from the deuteron do not lie in the usual scattering plane determined by the incoming and outgoing electron. This method is largely model independent. Using the same data set, we are extracting the magnetic form factor G_M^n of the neutron using the ratio of e-p to e-n quasielastic scattering from deuterium. The elastic electromagnetic form factors are the most basic observables that describe the internal structure of the proton and neutron. This experiment will cover the Q^2 range up to 5 $(GeV/c)^2$ and will extend eventually down to $Q^2 \approx 0.2$ $(GeV/c)^2$ where comparisons can be made with other measurements. We are also developing new ideas to push this method to higher Q^2 as part of the 12-GeV Upgrade at TJNAF.

We are also working to understand the nature of quark confinement. The quest to understand confinement quantitatively is an essential goal of modern nuclear physics. We are part of a broad assault on this mystery using the atomic nucleus essentially as a filter to study how a bare quark propagates through nuclear matter and then how it combines with other quarks to form hadrons. This study is also part of the TJNAF, 12-GeV Upgrade program.

Broader Impact

We expect to have a broad impact on the students and others at the University of Richmond. The University is a primarily undergraduate institution and this project gives our young people the opportunity to engage in high-quality science at a formative stage in their careers. In recent years we have been successful at attracting under-represented groups into our research group at Richmond. We also propose the inclusion of a high school science teacher and students in our research enterprise. This High School Research Fellow (HSRF) would work side-by-side with our research group and, in time, develop new curricular materials for their own classroom. We would then bring on high school students to support the HSRF during the testing and final development phase. The HSRF component of this project has the potential to significantly enhance the impact in our community and on our young people.

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Project Description (Including Results from Prior NSF Support) (not to exceed 15 pages) **(Exceed only if allowed by a specific program announcement/solicitation or if approved in advance by the appropriate NSF Assistant Director or designee)**	15	
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Biographical Sketches (Not to exceed 2 pages each)	2	
Budget (Plus up to 3 pages of budget justification)	6	
Current and Pending Support	1	
Facilities, Equipment and Other Resources	1	
Special Information/Supplementary Documentation	4	
Appendix (List below.) **(Include only if allowed by a specific program announcement/ solicitation or if approved in advance by the appropriate NSF Assistant Director or designee)**		

Appendix Items:

*Proposers may select any numbering mechanism for the proposal. The entire proposal however, must be paginated. Complete both columns only if the proposal is numbered consecutively.

1 Introduction

We are requesting support for the project entitled 'RUI: Nuclear Physics Research at the University of Richmond' for student and faculty research at the Thomas Jefferson National Accelerator Facility or Jefferson Lab (JLab). The work will be done using the CLAS detector in Hall B at JLab. The Principal Investigator (PI), Dr. Gerard P. Gilfoyle is professor of physics at the University of Richmond and is a member of the CLAS Collaboration. This work has been supported in the past by the US Department of Energy (DOE) and we will be submitting a renewal proposal to DOE in fall, 2006. The physics goals of this project are (1) to investigate the transition from hadronic degrees of freedom in the low-Q^2 regime to quark-gluon degrees of freedom at high-Q^2 using the deuteron as our testing ground and (2) to investigate the nature of confinement by measuring the propagation of quarks through nuclear matter and the subsequent formation of hadrons. A summary of the physics projects our group is working on is shown in Table 1. More details are in Section 2. We

Title	Type
Out-of-Plane Measurements of the Structure Functions of the Deuteron (Gilfoyle: spokesperson)	CLAS-Approved Analysis
Measurement of the Neutron Magnetic Form Factor at High Q^2 Using the Ratio Method on Deuterium (Gilfoyle: spokesperson and contact person)	Letter-of-Intent LOI12-06-107
The Neutron Magnetic Form Factor from Precision Measurements of the Ratio of Quasielastic Electron-Neutron to Electron-Proton Scattering in Deuterium	Experiment E94-017
Quark Propagation and Hadron Formation (Gilfoyle: co-spokesperson)	Proposal PR12-06-117

Table 1: Summary of primary physics interests of the Richmond group.

are also involved in a technical project to perform radiative corrections for exclusive reactions and committed to developing software for the JLab 12-GeV Upgrade.[1] An essential aspect of the project is the involvement of undergraduates and student training (the University is a primarily undergraduate institution). Our students have been involved in all aspects of these projects from taking shifts with faculty to developing codes for running simulations of the CLAS detector. They have made seven presentations at local and national meetings in the last two years [2, 3, 4, 5, 6, 7, 8]. They also learn sophisticated data analysis methods using the 34-node, computing cluster in the PI's on-campus laboratory acquired through the NSF's Major Research Instrumentation program. We have also made an impact on under-represented groups in physics; in the last two years two women and two African-American men worked in our laboratory at Richmond. This grant will continue the forward momentum we have built in our program to achieve the physics goals and to involve our undergraduates at the University of Richmond in meaningful, high-quality research. We also request funds to bring a High School Research Fellow (HSRF) into our group to enhance our research productivity and to develop new curricular materials that will reach a large number of young people in the local community. The HSRF would strengthen an already-active outreach program in the our Physics Department. The remainder of the proposal consists of descriptions of

[1] The DOE plans to upgrade the electron accelerator at JLab from a beam energy of 6 GeV to 12 GeV. The upgrade will require extensive changes to the accelerator and to CLAS to take advantage of the new physics opportunities. The upgraded CLAS detector is called CLAS12. The JLab, 12GeV-Upgrade is fourth highest priority out of 28 for the DOE office of Science in the next 20 years [1].

the proposed physics and technical projects (Section 2), the research environment at the University of Richmond and the impact on our students (Section 3), and a description of the HSRF (Section 4). We conclude with a discussion of results from prior NSF support (Section 5). We note here that Dr. Gilfoyle was elected chair of the Nuclear Physics Working Group of the CLAS Collaboration in summer, 2006 and his six-year tenure as chair of Physics ended in May, 2006. He is scheduled to be on sabbatical during the 2009-2010 academic year which will be during the period of this proposal.

2 Project Description

The research effort in nuclear physics is part of the program at the Thomas Jefferson National Accelerator Facility (TJNAF or JLab) in Newport News, VA. The primary goal of TJNAF is to reveal the quark and gluon structure of protons, neutrons, and atomic nuclei and to deepen our understanding of matter and, in particular, the confinement of quarks. In this section we describe the experimental environment and the specific physics programs.

TJNAF is a unique tool for basic research in nuclear physics. The central instrument is a superconducting electron accelerator with a maximum energy of 4-6 GeV, a 100% duty cycle, and a maximum current of 200 μA. These excellent beam characteristics allow for novel experiments that are being used to develop a quark-based understanding of nuclei. The electron beam is used simultaneously for scattering experiments in three halls that contain complimentary experimental equipment. Our research is done in Hall B with the CEBAF Large Acceptance Spectrometer (CLAS). This device is a large (45-ton), toroidal, multi-gap magnetic spectrometer with nearly full solid angle coverage. See Figure 1. A toroidal magnetic field is generated by six iron-free

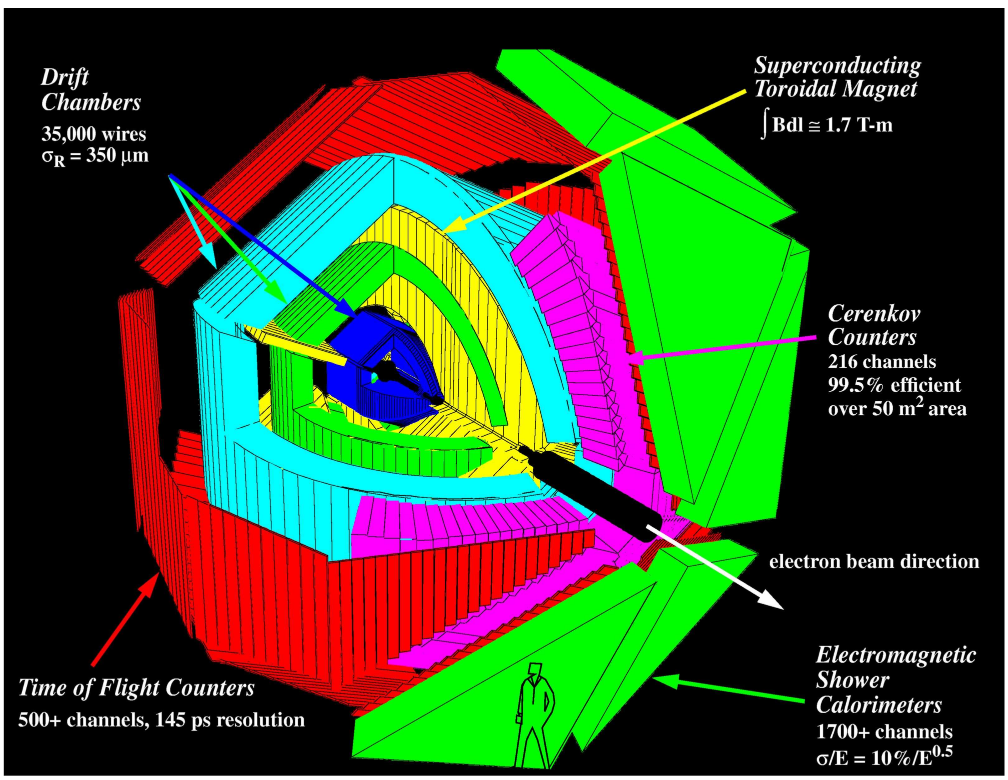

Figure 1: The CLAS detector.

superconducting coils. The particle detection system consists of drift chambers [9] to determine the trajectories of charged particles, Cerenkov detectors [10] for the identification of electrons, scintillation counters [11] for time-of-flight measurements, and electromagnetic calorimeters [12] to identify electrons and to detect photons and neutrons. The six segments are instrumented individually to form six independent spectrometers. Together there are about 33,000 detecting elements. The CLAS detector is capable of acquiring approximately 1 terabyte of data per day. It was constructed and is operated by an international collaboration consisting of thirty-six institutions. The Richmond group has been part of the CLAS Collaboration since its inception, and has been actively involved in the construction of the spectrometer and the development of the physics program.

2.1 Out-of-Plane Structure Functions of the Deuteron

The hadronic model of nuclear physics uses nucleonic degrees of freedom to describe nuclei and has been successful at low Q^2, but it is not well-developed in the GeV region even though we expect it to be valid there. There has simply been no data to challenge theory. The relative importance of relativistic corrections, final-state interactions, meson-exchange currents, and isobar configurations is only now beginning to be studied [13]. To investigate these effects, the deuteron is an essential testing ground because it is the simplest nucleus. This project fits into the overall goal at JLab to understand the transition for nucleon degrees of freedom to quark-gluon ones. We need measurements to provide a baseline for the hadronic model so deviations at higher Q^2 can be attributed to quark-gluon effects with greater confidence. This is an important step in unraveling the quark-gluon substructure of nucleons and nuclei according to the Nuclear Science Advisory Committee (NSAC)[2] and the JLab Program Advisory Committee (PAC)[14, 15]. To this end we are investigating the out-of-plane structure functions of the deuteron using the reaction $D(\vec{e}, e'p)n$ with CLAS. The cross section for the reaction can be written as

$$\frac{d\sigma^5}{d\omega d\Omega_e d\Omega_{pq}} = C\left(\rho_L f_L + \rho_T f_T + \rho_{TT} f_{TT}\cos\phi_{pq} + \rho_{LT} f_{LT}\cos 2\phi_{pq} + h\rho'_{LT} f'_{LT}\sin\phi_{pq}\right) \quad (1)$$

where C and the ρ_i are functions of the known electron parameters, h is the helicity of the electron beam, and ϕ_{pq} is the azimuthal angle of the ejected proton relative to the 3-momentum transfer $\vec{q}$. This angle ϕ_{pq} is the angle between the plane defined by the incoming and outgoing electron 3-momenta and the plane defined by the ejected proton and neutron. See Figure 2. The structure functions are an essential meeting ground between theory and experiment and the unique, nearly-4π solid angle of CLAS coupled with the high-quality, polarized beams at JLab create an inviting opportunity to study f'_{LT}, f_{LT}, and f_{TT}. These structure functions depend on ϕ_{pq} and have not been extensively investigated in the past. They represent a model-independent measurement of a little-studied part of the deuteron cross section and probe its wave function.

The three structure functions are being extracted from the E5 data set by measuring different moments of the out-of-plane production in CLAS. The E5 data set consists of two beam energies (2.6 GeV and 4.2 GeV) with the CLAS torus set for normal polarity (electrons inbending) and another low-beam-energy setting (2.6 GeV) with reversed torus polarity (electrons outbending) to reach lower Q^2. Each of the measured moments of the data is related to a different asymmetry which is, in turn, proportional to a particular structure function. For example, the asymmetry A'_{LT} is associated with f'_{LT} and is called the fifth structure function. It is the imaginary part of the

[2]NSAC is an advisory committee that provides official advice to the Department of Energy (DOE) and the National Science Foundation (NSF) on the national program for basic nuclear science research. NSAC is chartered under the Federal Advisory Committee Act (FACA).

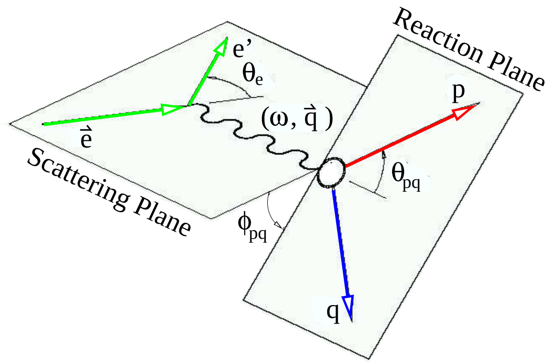

Figure 2: Kinematics of the $D(\vec{e}, e'p)n$ reaction.

LT interference. It can be determined by taking the difference between the the $\sin\phi_{pq}$-weighted average $\langle\sin\phi_{pq}\rangle$ for different beam helicities

$$\langle\sin\phi_{pq}\rangle_{+} - \langle\sin\phi_{pq}\rangle_{-} = \frac{\rho'_{LT} f'_{LT}}{\rho_L f_L + \rho_T f_T} \approx A'_{LT} \tag{2}$$

where the plus and minus subscripts refer to the beam helicity and

$$\langle\sin\phi_{pq}\rangle_{\pm} = \frac{1}{N_{\pm}} \sum_{i=1}^{N_{\pm}} \sin\phi_i \tag{3}$$

where ϕ_i is ϕ_{pq} for an event and $N_{\pm}$ is summed over all events of a particular beam helicity. The accuracy of the approximation in Equation 2 depends on the effect of the LT and TT components of the cross section which are typically small. The data cover the 4-momentum transfer range $Q^2 = 0.1 - 5.0$ (GeV/c)^2. We are studying the reaction in quasi-elastic kinematics first and will later investigate higher energy transfers.

Preliminary results for A'_{LT} are shown in Figure 3 as a function of the missing momentum $\vec{p}_m = \vec{q} - \vec{p}_p$ where $\vec{p}_p$ is the measured proton momentum. In the plane-wave impulse approximation this is the opposite of the initial momentum of the proton in the deuteron. These are the first data measured for this asymmetry in this Q^2 range. The results are for two sets of running conditions at a beam energy of 2.6 GeV; one with normal CLAS torus polarity (electron inbending) and one with reversed torus polarity (electron outbending) to reach lower Q^2. There is also a data set at 4.2 GeV, but the statistics for A'_{LT} are poor. The two sets of points in each panel for are electron and proton fiducial cuts turned off (blue, filled squares) and on (red, open circles). One of the expectations we had in this project is that by using the ratio defined in Equation 3, we would be less sensitive to acceptance corrections. The red and blue points support that expectation. Turning the fiducial cuts on reduces the CLAS acceptance (we lose about half the events), but the asymmetries in each case are consistent with each other within the uncertainties. Our preliminary results also show we can observe small asymmetries with good precision in quasi-elastic kinematics. The curves on each plot are from Arenhoevel [16] averaged over the CLAS acceptance. The Arenhoevel calculations have been successful at low Q^2 and use the hadronic model approach with various corrections added [19]. Those calculations agree with the data for $p_m < 0.22$ (GeV/c), but overpredict the magnitude

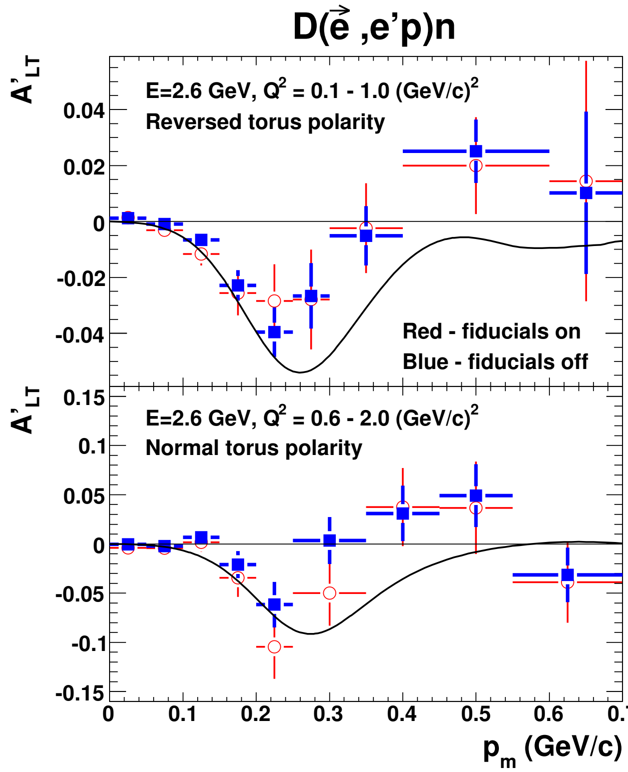

Figure 3: Preliminary results for the asymmetry A'_{LT} for the 2.6-GeV, E5 data sets. The red, open circles are with electron and proton fiducial cuts turned on. The blue, filled squares are with those cuts turned off.

of the asymmetry at higher missing momentum. We also have preliminary calculations from Laget and Jeschonnek that we are preparing for a comparison with our data [17, 18].

The analysis of the structure function f'_{LT} for quasielastic kinematics is far along and will be completed in the near future. We have completed establishing the criteria for event selection including kinematics cuts and electron and hadron fiducial cuts and finished momentum corrections to improve the CLAS resolution for all three sets of running conditions. We have performed a variety of tests and consistency checks on the different E5 running conditions. We are performing simulations of CLAS to ensure that we understand the detector response and test our analysis codes. As mentioned above we expect the ratios in Equations 2 and 3 to be less sensitive to the acceptances. Our simulations support this expectation. There are other JLab experiments that complement this study. Experiment E01-020 in Hall A will measure the angular distributions of $D(e, e'p)n$ in a comparable Q^2 range and extract the LT response function (see Equation 1). The data for that experiment are being analyzed. For our analysis the combination of kinematic coverage and out-of-plane measurements is unique.

This work is part of a CLAS Approved Analysis entitled 'Out-of-Plane Measurements of the Structure Functions of the Deuteron'. The CLAS Collaboration has a procedure where Collaboration members can analyze existing data sets with official Collaboration approval. The member writes a proposal describing an analysis project, it is reviewed by an internal committee, and then defended before the full Collaboration. Gilfoyle is the spokesperson on this analysis project that was approved in November, 2003 [21]. The analysis of f'_{LT} is in its last phases and we will present results at the fall, 2006 Division of Nuclear Physics meeting. A CLAS analysis note is in preparation. A CLAS analysis note is a technical description of the physics analysis that is reviewed by a Collaboration collaboration. If approved, the authors can then go forward to write a paper for publication.

In the period for this proposal, we will complete the analysis of the f'_{LT} results and move on to the other two structure functions f_{LT} and f_{TT} in quasielastic kinematics using similar analysis methods. This is a unique opportunity to measure the three, out-of-plane, ϕ_{pq}-dependent, structure functions in a model-independent way from a single experiment that covers a large Q^2 range under a common set of experimental conditions in the transition region from hadronic to quark-gluon degrees of freedom and has considerable overlaps and cross checks between the different data sets. Once that is complete, we will investigate different energy transfer (*i.e.*, the 'dip' region). These other structure functions and kinematic regions are sensitive to different mixtures of the relativistic corrections, final-state interactions, meson-exchange currents, and isobar configurations. We have a unique chance here to untangle these different effects and clearly establish a hadronic baseline for the transition to quark-gluon degrees of freedom.

2.2 Magnetic Form Factor of the Neutron

The elastic electromagnetic form factors are the most basic observables that describe the internal structure of the proton and neutron. The differential cross section for elastic electron-nucleon scattering can then be calculated in the laboratory frame as [22]

$$\frac{d\sigma}{d\Omega} = \sigma_{Mott}\left(G_E^2 + \frac{\tau}{\epsilon}G_M^2\right)\left(\frac{1}{1+\tau}\right) \tag{4}$$

where σ_{Mott} is the cross section for scattering from a point particle, G_E is the magnetic form factor, G_M is the magnetic form factor, and

$$\tau = \frac{Q^2}{4M^2} \qquad \text{and} \qquad \epsilon = \frac{1}{1 + 2(1+\tau)\tan^2(\frac{\theta}{2})} \tag{5}$$

where M is the nucleon mass and θ is the electron scattering angle. There are a total of four elastic form factors (electric and magnetic ones for each nucleon) and their evolution with Q^2 characterizes the distributions of charge and magnetization within the proton and neutron. These observables also provide stringent tests of non-perturbative QCD [23] and are connected to generalized parton distributions (GPDs) via sum rules. Conventional parton distributions describe the longitudinal momenta of the nucleon constituents, but integrate over the transverse structure losing, for example, information about the orbital angular momentum of the partons. This new generalization of the parton distributions permits us to simultaneously extract information about the longitudinal and transverse parton structure of hadrons. With exclusive measurements one can determine the longitudinal momenta and transverse position of the partons inside the proton, their orbital angular momentum, and quantum interference effects [24]. The elastic form factors are also important challenges for lattice QCD to meet. Lattice QCD is one of the more promising avenues for solving non-perturbative QCD and one if its important tests will be the accuracy that it can reproduce the elastic form factors in this Q^2 range [25].

We are part of a broad assault on the four elastic nucleon form factors at Jefferson Lab [26, 27, 28]. All four elastic form factors are needed to untangle the different quark contributions and our focus is on the magnetic form factor of the neutron. For G_M^n we use the ratio of elastic $e-n$ to elastic

$e-p$ scattering on deuterium. The method is based on the ratio

$$R = \frac{\frac{d\sigma}{d\Omega}(D(e,e'n))}{\frac{d\sigma}{d\Omega}(D(e,e'p))} = a(Q^2)\frac{\frac{{G_E^n}^2+\tau{G_M^n}^2}{1+\tau} + 2\tau{G_M^n}^2\tan^2(\frac{\theta}{2})}{\frac{{G_E^p}^2+\tau{G_M^p}^2}{1+\tau} + 2\tau{G_M^p}^2\tan^2(\frac{\theta}{2})} \tag{6}$$

for quasielastic kinematics where deviations from the 'free ratio' assumption in the right-hand part of Equation 6 are parametrized by the factor $a(Q^2)$ which can be calculated from deuteron models and is close to unity at large Q^2. The ratio method is less vulnerable to systematic uncertainties than previous methods [30]. Equation 6 shows how the extraction of G_M^n depends on our knowledge of the other three nucleon form factors.

We have completed data collection and a significant portion of the analysis for a measurement of G_M^n in the range $Q^2 = 0.5 - 5.0$ (GeV/c)^2 [29, 30]. Preliminary results are shown in Figure 4. These are the results from the E5 running period (the same experiment as the one in Section

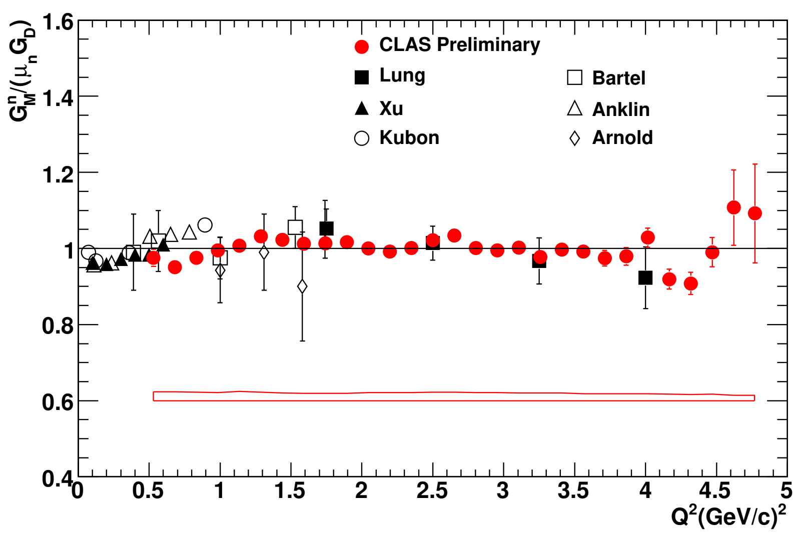

Figure 4: Selected results for the neutron magnetic form factor G_M^n in units of $\mu_n G_D$ as a function of Q^2. See Reference [30] and references therein.

2.1) for two electron beam energies (2.6 GeV and 4.2 GeV) with the CLAS toroid having standard polarity. The reversed polarity (electrons outbending) data at 2.6 GeV is still being analyzed. The data are plotted as the ratio to $\mu_n G_D$ where μ_n is the neutron magnetic moment and G_D is calculated in the dipole approximation. The data are consistent with G_D for $Q^2 > 1.0$ (GeV/c)^2. The are signs of disagreement with previous measurements for the results below 1 (GeV/c)^2. There is considerable interest in these results from the theoretical community. A comparison with some of those calculations can be found in Ref [30]. A CLAS analysis note has been written and is under collaboration review. We have been part of the E5 analysis group for over four years and have provided a number of services to the group like radiative corrections (see Section 2.4), codes to generate electron and hadron fiducial cuts, *etc.*

Our role in the E5 G_M^n analysis is twofold. First, we are developing a proposal for beam time as part of the physics program for the JLab, 12-GeV Upgrade. Second, we have taken on the task of analyzing the E5, 2.6-GeV, reversed torus polarity data to extract G_M^n using the same methods developed for the other sets of running conditions at 2.6 GeV and 4.2 GeV (both have normal torus polarity). We have submitted a Letter-of-Intent to the JLab Program Advisory Committee (PAC) to make the same measurements at higher Q^2 as part of the physics program for the JLab 12-GeV Upgrade. A Letter-of-Intent is a preliminary proposal for beam time at JLab. It provides an opportunity for researchers to get feedback from the PAC on the quality of their idea before they make the large investment of time and effort required to produce a full proposal. One of the results of that analysis is shown in Figure 5. The results from Figure 4 are shown at the low-Q^2 end of the

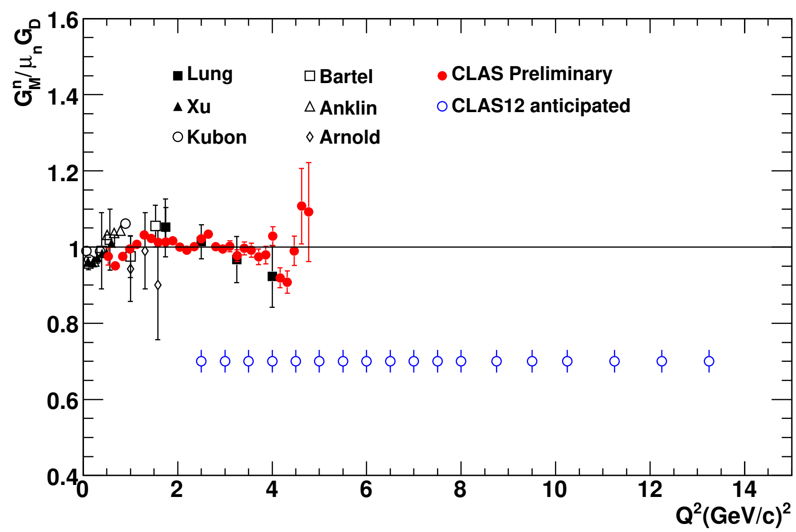

Figure 5: Results of G_M^n analysis (red points) and predictions for 12-GeV Upgrade (blue open points).

plot. The blue, open points show the range of data we expect to collect with the upgraded JLab and CLAS. The error bars show the expected uncertainties. We will significantly expand our knowledge of the neutron's magnetic form factor. Our initial studies of the feasibility of this experiment show one of the important calibration reactions used in the current analysis, the $p(e, e'\pi^+)n$ will have sufficient cross section at these higher Q^2 so that we will be able to use it. The Letter-of-Intent was approved by the PAC in August, 2006 [31]. The PAC report is not yet published. Gilfoyle is co-spokesperson and contact person for the Letter-of-Intent.

As mentioned above, we will also take up the analysis of the existing, 2.6-GeV, reversed-torus-polarity data set from the E5 running period. These data cover the range $Q^2 = 0.1 - 1.0$ (GeV/c)^2. They overlap with our 2.6-GeV, normal-torus-polarity data set and with the results from several other groups. See Figure 4. There are disagreements between our data and some of the previous measurements and our low-Q^2 data could help sort out the experimental situation. At the same time, some recent efforts by Friedrich and Walcher [32] to re-analyze the low-Q^2 data for all four quasielastic, nucleon form factors suggests that a structure they observe at $Q^2 \approx 0.2$ (GeV/c)^2 is due to the pion cloud. Recent measurements from BLAST [33] have shown structure in this Q^2 region and other theoretical work supports the observation of the pion cloud [34, 35]. However, other studies disagree with the observation of a structure near $Q^2 \approx 0.2$ (GeV/c)^2 which contradicts what is known from chiral perturbation theory and dispersion relations [36]. Our low-Q^2 CLAS data from the reversed-torus-field run with a beam energy of 2.6 GeV reach down into this Q^2

range and would overlap with the bump observed in Ref [32]. This is an excellent opportunity to improve our understanding of nucleon structure with data we already have in hand.

During the period of this proposal we will develop the Letter-of-Intent into a full proposal for submission next year. The PAC has approved the Letter-of-Intent, but we have not yet received the report. One of the primary questions to answer for the full proposal will be our ability to identify quasielastic events at high Q^2. The cross section for this process is dropping relative to processes at high W so we need to determine how well we can separate quasielastic events from background. There are strategies for us to explore that are described in the Letter-of-Intent [31]. One method that was used in the current analysis is to restrict the polar angle of the ejected proton relative to $\vec{q}$ to reduce the inelastic background. This proved very effective in the current analysis [30]. We will also perform the analysis of the 2.6-GeV, reversed field data described above. We will be working with M.F. Vineyard (Union College) and W.K. Brooks (JLab), the two spokespersons on the original G_M^n proposal (E94-017). The analysis of these data and for the high-Q^2 G_M^n proposal are similar so we can make efficient use of our time and resources.

2.3 Quark Propagation and Hadron Formation

The confinement of quarks inside hadrons is perhaps the most remarkable feature of QCD. The quest to understand confinement quantitatively and in terms of intuitive physical pictures is an essential goal of modern nuclear physics. Much experimental attention has been focused on understanding confinement through hadron spectroscopy. Alternatively, the subject is often introduced through sketches of the hadronization processes by string-breaking. This picture is confirmed by lattice calculations using static quarks, showing that the gluon field is concentrated in a flux-tube (or string). In hadronization, the color string stretches until $q\bar{q}$ pairs tunnel up from the vacuum, thwarting the struck quark's attempt to escape to isolation. Unfortunately, the real picture with full QCD is more complicated than this simple picture, and lattice calculations of dynamical quarks are not yet possible. Experimental information is necessary to guide models of hadronization, to elucidate the mechanism of confinement.

We have proposed a broad program of measurements and analyzes to determine the mechanisms of confinement in forming systems as part of the JLab 12-GeV Upgrade. This proposal builds on lessons learned at lower energy for the analysis of the EG2 run period at JLab. The essential experimental technique is to employ nuclei as analyzers of hadronization processes. In this approach, the hadron is formed from energetic quarks over distance scales ranging from 0–10 fm, i.e. the dimensions of atomic nuclei. The power of this technique arises from several factors: (1) the dimensions of the analyzing medium are matched to the distance scales of the hadronization process; (2) sophisticated knowledge about nuclear currents and properties can be exploited; (3) detailed experimental data on deep inelastic scattering from the nucleon provide a quantitative baseline against which to compare the data on nuclei. In essence, we use the nucleus as a 'detector' to probe the hadronization formation length and the time scale on which a pre-hadron (such as a bare $q\bar{q}$ pair) becomes dressed with its own gluonic field. The response of the hadron to the presence of the nucleus depends on the time scale on which hadronization takes place inside the nucleus.

The ratio of hadrons produced relative to the production from deuterium (hadronic multiplicity ratio R_M^h) and transverse momentum broadening Δp_T^2 are the two primary observables. These are known to be sensitive to different kinematic regimes (which gives us the opportunity to study their evolution) as well as the average distance through the nuclear medium, $\langle L \rangle$. Using a wide range of nuclear targets one can measure the quark production time and hadron formation times for different hadrons produced in the reaction. The production time τ_p is the lifetime of a deconfined quark, and it will be determined by analyzing the transverse momentum broadening Δp_T^2 as a function of

$\langle L \rangle$ and ν, the energy transferred by the electron beam. The length of the linear region yields the production time. The formation times τ_f^h are the time intervals required to form the color field of hadrons, and these will be determined from the kinematic dependence of the hadronic multiplicity ratio R_M^h by using τ_p and models for interactions of pre-hadrons and hadrons in nuclei. Studying the systematic behavior of formation times for a variety of hadrons will determine the mechanisms by which hadrons are formed.

A proposal for this program was submitted and approved by the JLab PAC in the summer of 2006 [37]. Gilfoyle is a co-spokesperson on the proposal. The PAC report is not yet published. The document describes not a single experiment, but a wide program of measurements and analyzes which share a common set of running conditions: deep inelastic scattering measurements, study of hadronization, an upgraded JLab accelerator and CLAS detector, and the use of 5-6 nuclear targets covering a large range in mass. Gilfoyle is responsible for analysis of the π^0, η, and η' channels along with Dr. K. Joo from the University of Connecticut. Results from a simulation of the π^0 and η channels are shown in Figure 6. The calculation was performed with the PYTHIA

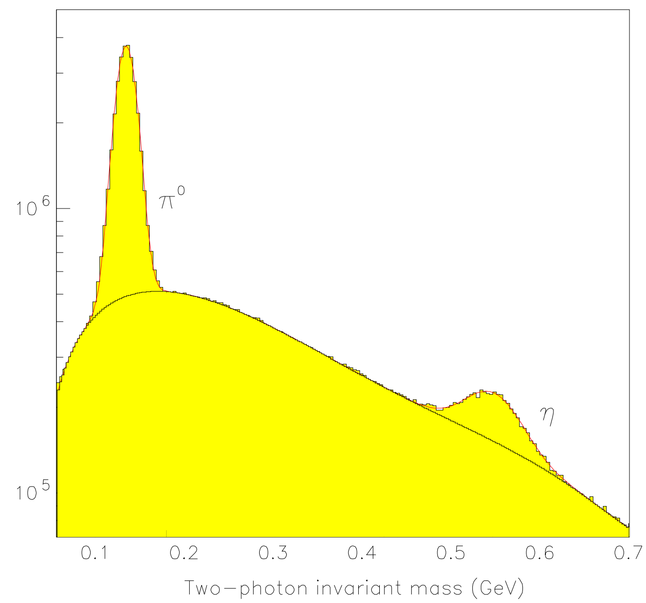

Figure 6: Expected data from a LEPTO simulation at 11 GeV, showing neutral pions and η mesons for a few hours of PAC time.

event generator and a fast Monte Carlo that includes the resolutions expected for upgraded CLAS detector CLAS12. The two-photon invariant mass shown in Figure 6 demonstrates that we will be able to identify and measure the properties of these neutral mesons.

During the period of this grant we will begin work on the simulation of events in CLAS12 to further develop this idea. First beams are not expected until well into the next decade, but work on design and prototyping has already begun. Dr. Joo is part of the effort to develop the calorimeters for CLAS12 and Gilfoyle is committed to work on software including event generation. The event generation is needed for the design of the detectors and to develop the physics program further.

2.4 Technical Projects

The measurements of the nuclear reactions described above are all subject to radiative corrections. A computer code called DEEP_EXCLURAD for calculating these corrections is described here can be used for the $D(e, e'p)n$ reaction. Radiative corrections are usually calculated using the formalism originally developed by Schwinger and Mo and Tsai [38, 39]. In that approach, it was assumed that only the scattered electron was detected (inclusive scattering). That method suffers from several shortcomings. First, detecting the ejected hadron (exclusive reactions) alters the phase space that is allowed for the final radiated photon. Second, more structure functions can contribute in exclusive reactions. Third, the Schwinger/Mo and Tsai approach relies on an unphysical parameter to split the hard and soft regions of the radiated photon's phase space and cancel the infrared divergence. The method used here relies on a covariant procedure of infrared divergence cancellation which does not require the splitting [40].

These calculations are being done with a modified version of the computer program EXCLURAD written by Afanasev *et al.* [41]. The code was originally written for the $p(e, e'\pi^+)X$ reaction and it has been modified to work for the $D(e, e'p)n$ reaction as part of the deuteron-structure-function program described in Section 2.1. The program DEEP is being used to calculate the deuteron response functions [42]. This routine uses the covariant spectator theory and the transversity formalism to calculate the unpolarized, coincidence cross section for $D(e, e'p)n$. The radiative corrections are calculated as the ratio of the cross section in a particular kinematic bin to the plane-wave-impulse-approximation (PWIA) result. Details on running the code can be found in Reference [43].

The code has been up and running for some time and available on the internet [44]. It has been used to to calculate the radiative corrections for the G_M^n analysis (see Section 2.2) and for other CLAS projects. We have recently added another option for the analysis of the out-of-plane structure functions of the deuteron (see Section 2.1). The code used to calculated the deuteron response functions (DEEP) does not include the fifth structure function f'_{LT}. We have modified the code so the user can set the value of f'_{LT} to investigate the effect of this structure function on radiative corrections. In our analysis of f'_{LT} we use an asymmetry that involves the ratio of cross sections (see Equation 3). Part of the appeal of using this asymmetry is that it reduces the sensitivity to radiative corrections. We found this assumption to be accurate.

During the period of this grant proposal we will continue to add to the options available in DEEP_EXCLURAD. We have been working with two theorists (S. Jeschonnek and J-M. Laget) to acquire versions of their codes that include f'_{LT} and will incorporate them into the program. A CLAS Note (number 2005-022) describing the project was published in fall, 2005 [43].

We are also committed to development projects for the JLab 12-GeV Upgrade. We will be responsible for design, prototyping, development, and testing of software for event simulation and reconstruction. Event simulation is an essential aspect of the design of CLAS12 and eventual precision of the detector. For many experiments, the quality of the results will be limited by systematic uncertainties instead of statistical ones. Accurate, precise calculations of the CLAS12 acceptance and response are important to keep those systematic uncertainties small. To do that we expect to generate about four times as much simulated, Monte Carlo data as CLAS12 collects. The CLAS12 simulation will produce data more slowly than the detector itself so the contribution of university groups to this effort is essential. The same issues that arise in designing the physics experiments also arise in the design and prototyping phase of the project we are just entering.

During the period of this grant proposal we will begin event simulation of CLAS12 to, in part, support the development of the physics ideas in LOI12-06-107 (Section 2.2) and PR12-06-117 (Section 2.3). The CLAS12 software group (Gilfoyle is a member) is now beginning the effort to simulate events.

2.5 CLAS Collaboration Service

There is a service component to membership in the CLAS Collaboration and here we mention the activities that we are involved in now and the future. (1) We cover 12-16 data taking shifts a year. (2) In the last two years Gilfoyle has served on review committees for four CLAS-Approved Analysis proposal (one as chair), two CLAS Analysis Note reviews (one as chair), and on an ad hoc review committee of a paper that was published in Physical Review D [46]. (3) The code for calculating radiative corrections is available on the internet for the full Collaboration and it will be updated as more response function models are added. See Section 2.4. (4) We maintain a 34-node supercomputing cluster in our laboratory at Richmond that is available to other collaboration members. See Section 3.3 below for more details. (5) The CLAS is a large, complex detector so it is essential that the incoming data be carefully monitored to enable early detection of problems. The program online RECSIS performs a full event reconstruction on a small portion of the data stream. Gilfoyle is responsible for this tool and has upgraded its capabilities in response to user requests [47, 48]. (6) In June, 2006 Gilfoyle was elected chair of the Nuclear Physics Working Group. He will be responsible for organizing reviews of papers, analysis notes, PAC proposals, *etc.*

3 Physics at the University of Richmond

3.1 The University

The University of Richmond is a private, highly-selective, primarily-undergraduate, liberal arts institution in Richmond, Virginia with about 3000 undergraduates. A $36M expansion and renovation of the Gottwald Science Center was completed in spring 2006. All the teaching and research spaces in Physics were renovated and two new faculty positions were added in Physics (one instructor position and one tenure line). More details are available in the RUI Impact Statement and in this Section.

3.2 The Department of Physics

The Department of Physics consists of seven teaching faculty and we graduate about 4-8 physics majors each year and currently have thirty-four students in our upper-level courses. From last year's graduating class two students have gone on to graduate school in physics at Johns Hopkins and Kentucky including one in nuclear physics at Kentucky. There are no graduate students. The faculty are active in experimental nuclear physics (Gilfoyle), astrophysics (Bunn), experimental nuclear structure physics (Beausang), theoretical nuclear structure physics (Fetea), surface physics (Trawick), and biological physics (Lipan). There is considerable external support from the Department of Energy (two grants), the National Science Foundation (two grants), and NASA (one grant). We emphasize undergraduate involvement in research from early in the students' careers. Students that are involved in undergraduate research are more likely to attend graduate school and to be successful after college [49]. In the summer of 2006 fifteen of our physics majors participated in research at Richmond, JLab, Yale University, and the University of Notre Dame. They have accomplished much in their research careers. Eighteen have given presentations on their work at local and national meetings in the last year. The students in our experimental nuclear physics group have given seven presentations over the last two years [2, 3, 4, 5, 6, 7, 8]. Three more students from our group will be presenting posters at the fall, 2006 meeting of the Division of Nuclear Physics

(DNP) of the American Physical Society as well as another six students from the experimental and theoretical nuclear structure groups. The students in our group obtained travel support in fall, 2005 and again in fall, 2006 from the Conference Experience for Undergraduates program of the DNP. We have also been successful in attracting under-represented groups to work in our nuclear physics group. Of the four people that worked in our laboratory over the last two summers, two of those students were women and two were African-American men. The nuclear physics group each year involves 2-3 students in research. They are integral parts of our research efforts and are deeply involved in many aspects of the physics programs. They receive training in sophisticated analysis methods for extracting signals from complex backgrounds, a range of programming languages (C, C++, FORTRAN, and Perl), and the Linux operating system. They also learn modern supercomputing methods with the group's supercomputing cluster (see Section 3.3).

Professor Gerard P. Gilfoyle, the Principal Investigator, is an accomplished experimentalist with long experience in nuclear physics. He has done research using light ions (Indiana and Princeton cyclotrons), heavy ions (Penn, Stony Brook, Argonne, and Berkeley), pions (Los Alamos), and electrons (JLab). He is a long-time member of the CLAS Collaboration and currently chair of the Nuclear Physics Working Group and member of the CLAS Coordinating Committee. He has recently completed six years as chair of Physics at the University of Richmond. He has also worked on nuclear proliferation issues in the US Department of Defense as a Science and Engineering Fellow of the American Association for the Advancement of Science and on the APS Task Force on Countering Terrorism. He is scheduled to be on sabbatical during the 2009-2010 academic year which will be during the period of this proposal.

3.3 Facilities and Support for Nuclear Physics

Our nuclear physics group at the University of Richmond is supported by a computing cluster developed in 2001 with NSF and University funds obtained by Gilfoyle and a former Richmond faculty member (M.F. Vineyard now at Union College). This cluster is for the exclusive use of our nuclear physics group though we support other Collaboration members who need it. The cluster is, in turn, supported by an array of computers for software development and non-CPU-intensive calculations and analysis. The system now consists of 34, dual-processor machines running the Linux operating system and 3 TByte of RAID storage. Each machine has 18 GByte of disk space and 256 MByte of memory. The entire system resides on its own subnet and another machine acts as a firewall. It is in a laboratory designed for its needs with a 5-ton, 60,000-BTU air conditioner to cool the room, an upgraded electrical panel, and backup power. The support computers are located in an adjacent room. The entire facility is in the Physics Department research area.

The University supports our research efforts. One member of the University's Information Services is a Linux expert and he devotes half of his time to academic projects including support for the supercomputing cluster. He is responsible now for keeping the CLAS software up-to-date, updating the Linux software on the cluster and in our laboratory, and general troubleshooting. The University also supports some undergraduate summer stipends for research. We have taken advantage of those in the past to hire additional students and will continue to apply for those in the future. The University also supports routine faculty travel to JLab.

3.4 Proximity to Jefferson Lab

Jefferson Lab is 75 miles from the University of Richmond enabling us to maintain frequent contacts with the scientific staff and users at JLab. Gilfoyle spends about 1 day each week at JLab. This proximity enables us to take students on shift with us and to attend Collaboration meetings and other events for little cost (*i.e.*, some of our students attended the talk this summer at JLab by the Nobel Laureate Dr. David Gross). The University supports routine faculty travel to JLab.

4 High School Research Fellow

We request funding in this proposal to support an outreach program to create a research experience for a high-school science teacher during the summer months along with two high school students. This High School Research Fellow (HSRF) would join our nuclear physics group at Richmond for eight weeks during the first year and focus primarily on research. They would repeat the experience in the following summer, but also start work on a curricular project. In this second summer, we would bring in two high school students near the end of the summer to work with the HSRF for three weeks developing and testing new curricular materials. The choice of the high school students and the nature of their work would be decided in close consultation with the HSRF. The third year would follow the same pattern as the second year. We also request funds so the HSRF and the students can attend conferences and the HSRF can attend teacher programs at JLab. It is likely this program can be used as professional development that is required for recertification of teachers in Virginia. Many aspects of this part of our proposal were modeled after the NSF's Research Experience for Teachers (RET) program. We are applying the lessons learned in the RET program to an individual research group at a liberal arts institution.

This program supports the goals of the National Science Foundation to 'foster innovation in K-12 science and mathematics education' [50]. It is well known that programs like this one return teachers to the classroom with renewed enthusiasm, technical skills, and a better understanding of the scientific process [51]. The multi-year duration of this project is important because it reinforces the gains made in the first summer so the effects are longer lasting [51]. The participants become better science teachers and can reach many more young people than many university research programs. This program will also enhance the productivity of our nuclear physics group. We will get a more mature, technically sophisticated colleague who is better equipped for research than many undergraduates and will work with us over several summers [51]. Our experience has been that researchers are more productive after their first summer.

The HSRF program is well suited to the University of Richmond, the Department of Physics, and the Principal Investigator. The University of Richmond is a primarily undergraduate institution so there is a greater emphasis on undergraduate education from the classroom to the lab bench to the lunch table. The Department has a strong commitment to combining research and teaching. We have a variety of ongoing research enterprises in the Department with considerable external support and a large number of undergraduate participants (see Section 3.2). At the same time we are constantly innovating in teaching. In the last year alone (and with significant investments from the University) we have developed a new course in biological physics (Feta, $77,000), upgraded our Intermediate Laboratory course for physics majors (Gilfoyle, $25,000), and upgraded our Electronics course (Trawick, $27,000). Some of that work is done during the summer. The Department (and the University) also supports a local Physics Olympics that brings together 50-60 high school juniors and seniors to spend a day competing in various physics events for learning and for fun [52]. This outreach program has created excellent contacts in the local high school science community that we can exploit. The Principal Investigator has a long history of innovation in teaching including receiving curriculum development grants from NSF, co-authoring the Physics Department's introductory physics laboratory manual, and developing new curricular materials for upper-level physics courses [53, 54, 55, 56, 57]. In 2003, he received the University's Distinguished Educator Award. An additional bonus comes from our association and proximity with Jefferson

Lab. JLab runs programs for teachers and high school students to develop scientific skills [58, 59]. For example, the Teacher Academy in Physical Science hosts several high school teachers each summer and has programming to train them to be effective in the research environment at JLab. The HSRF will be able to participate in those programs.

It is worth noting one significant difference between the HSRF and the RET program; the inclusion of high school students. We believe they are an essential piece. They will expand the group focused primarily on curricular development during that part of the summer. The HSRF must assume a leadership role in this group and the high school students will look to the HSRF for guidance, motivation, ideas, and answers. These students will also provide valuable support to get the curricular materials developed by the end of the summer. There is no better testing ground for new classroom methods than the students themselves. Finally, for a fairly small sum we can significantly effect the lives of two young people and many more through the improved teaching of the HSRF.

The impact of this program on the HSRF's teaching will be assessed. We will use some of the materials already developed by the RET program like pre- and post- teacher surveys. The effect on the HSRF's new curricular tools can be studied using an array of well-known tools [60]. Students in the HSRF's class will be tested at the beginning of the term to discover students weaknesses and again at the end to determine if the curricular materials filled those gaps. This sort of assessment is routinely done in our Physics Department at Richmond.

The results of this program will be disseminated. New curricular materials will be made available on the internet as we do with our own materials now at Richmond. More importantly, the travel funds we request will enable the HSRF and the high school students to present their results at conferences. There are abundant opportunities for these presentations from local conferences (the Virginia Academy of Science), regional ones (the Southeastern Section of the American Physical Society), and national ones (the American Association of Physics Teachers, APS). Finally, The HSRF can take advantage of the existing network of RET alumni.

5 Results from Prior NSF Support

An NSF Major Research Instrumentation grant in 2001 provided funds (along with $24,000 in matching funds from the University) to purchase the supercomputing cluster in our nuclear physics laboratory at Richmond. The title of the proposal was 'RUI: Development of a Computing Cluster to Support the University of Richmond Nuclear Physics Research Program at Jefferson Lab' (#6030194) for $151,758 and for the period 6/01/2001 - 5/31/2003. All of the Richmond work described in this proposal has made heavy use of the cluster for data analysis, simulation, and radiative corrections (see Section 3). Other members of the CLAS Collaboration have used the cluster: Vineyard (Union College), Hicks (Ohio U.), Jenkins (Virginia Tech), Wood (UMass) and Lachniet (CMU)) along with members of the accelerator division at JLab (Freiberg, Beard, Yunn, and Zhang).

These projects are now coming to fruition. A CLAS technical note describing the calculation of radiative corrections has been published [43]. The first phase of the measurement of the out-of-plane structure functions of the deuteron (Section 2.1) is nearing completion and a CLAS technical note describing the measurement of G_M^n is under Collaboration review. All the students talks mentioned in Section 3.2 used the cluster [2, 3, 4, 5, 6, 7, 8]. Calculations run on the cluster also lead to the following technical reports: CLAS Note 2004-035 'π^+ Acceptance Corrections for $\pi \rightarrow \mu$ Decay' and CLAS Note 2004-043 'A Comparison of Simple and Full Acceptance'.

References

[1] 'Office of Science Strategic Plan, February, 2004,' US Department of Energy Office of Science, February, 2004.

[2] R.Burrell and G.P.Gilfoyle, 'Momentum Corrections for the CLAS E5 Data Set,' University of Richmond Symposium, April 21, 2006.

[3] K.Greenholt and G.P.Gilfoyle, 'Fiducial Cuts on CLAS for the E5 Data Set,' Bull. Am. Phys. Soc., Fall DNP Meeting, FR.0006(2005).

[4] R.Burrell and G.P.Gilfoyle, 'Momentum Corrections for the E5 Data Set,' Bull. Am. Phys. Soc., Fall DNP Meeting, FR.00068(2005).

[5] K.Greenholt and G.P.Gilfoyle, 'Generating Fiducial Cuts for CLAS E5,' University of Richmond Symposium, April 14, 2005.

[6] R.Burrell and G.P.Gilfoyle, 'Momentum Corrections for the CLAS E5 Data Set,' University of Richmond Symposium, April 14, 2005.

[7] K.Greenholt and G.P.Gilfoyle, 'Generating Fiducial Cuts for CLAS E5,' Bull. Am. Phys. Soc., April Meeting, S.06(2005).

[8] R.Burrell and G.P.Gilfoyle, 'Momentum Corrections for the CLAS E5 Data Set,' Bull. Am. Phys. Soc., April Meeting, S.07(2005).

[9] M. D. Mestayer *et al.*, Nucl. Inst. and Meth. **A449**, 81 (2000).

[10] G. Adams *et al.*, Nucl. Instr. and Meth. **A465**, 414 (2001).

[11] E.S. Smith *et al.*, Nucl. Inst. and Meth. **A432**, 265 (1999).

[12] M. Amarian *et al.*, Nucl. Instr. and Meth. **A460**, 239 (2001).

[13] A. Klimenko, S.E. Kuhn, P.E. Bosted, K.V. Dharmawardane, G.E. Dodge, T.A. Forest, Y. Prok, G. Adams, M. Amarian, P. Ambrozewicz, M. Anghinolfi, G. Asryan, H. Avakian, H. Bagdasaryan, N. Baillie, J.P. Ball, N.A. Baltzell, S. Barrow, V. Batourine, M. Battaglieri, K. Beard, I. Bedlinskiy, M. Bektasoglu, M. Bellis, N. Benmouna, A.S. Biselli, B.E. Bonner, S. Bouchigny, S. Boiarinov, R. Bradford, D. Branford, W.K. Brooks, S. Buhltmann, V.D. Burkert, C. Butuceanu, J.R. Calarco, S.L. Careccia, D.S. Carman, B. Carnahan, A. Cazes, S. Chen, P.L. Cole, P. Collins, P. Coltharp, D. Cords, P. Corvisiero, D. Crabb, H. Crannell, V. Crede, J.P. Cummings, R. De Masi, R. DeVita, E. De Sanctis, P.V. Degtyarenko, H. Denizli, L. Dennis, A. Deur, C. Djalali, J. Donnelly, D. Doughty, P. Dragovitsch, M. Dugger, S. Dytman, O.P. Dzyubak, H. Egiyan, , K.S. Egiyan, L. Elouadrhiri, P. Eugenio, R. Fatemi, G. Fedotov, R.J. Feuerbach, H. Funsten, M. Garcon, G. Gavalian, G.P. Gilfoyle, K.L. Giovanetti, F.X. Girod, J.T. Goetz, E. Golovatch, A. Gonenc, R.W. Gothe, K.A. Griffioen, M. Guidal, M. Guillo, N. Guler, L. Guo, V. Gyurjyan, C. Hadjidakis, K. Hafidi, R.S. Hakobyan, J. Hardie, D. Heddle, F.W. Hersman, K. Hicks, I. Hleiqawi, M. Holtrop, M. Huertas, C.E. Hyde-Wright, Y. Ilieva, D.G. Ireland, B.S. Ishkhanov, E.L. Isupov, M.M. Ito, D. Jenkins, H.S. Jo, K. Joo, H.G. Juengst, C. Keith, J.D. Kellie, M. Khandaker, K.Y. Kim, K. Kim, W. Kim, A. Klein, F.J. Klein, M. Klusman, M. Kossov, L.H. Kramer, V. Kubarovsky, J. Kuhn, S.V. Kuleshov, J. Lachniet, J.M. Laget, J. Langheinrich, D. Lawrence, Ji Li, A.C.S. Lima, K. Livingston, H. Lu, K. Lukashin,

M. MacCormick, J.J. Manak, N. Markov, S. McAleer, B. McKinnon, J.W.C. McNabb, B.A. Mecking, M.D. Mestayer, C.A. Meyer, T. Mibe, K. Mikhailov, R. Minehart, M. Mirazita, R. Miskimen, V. Mokeev, L. Morand, S.A. Morrow, M. Moteabbed, J. Mueller, G.S. Mutchler, P. Nadel-Turonski, J. Napolitano, R. Nasseripour, S. Niccolai, G. Niculescu, I. Niculescu, B.B. Niczyporuk, M.R. Niroula, R.A. Niyazov, M. Nozar, G.V. O'Rielly, M. Osipenko, A.I. Ostrovidov, K. Park, E. Pasyuk, C. Paterson, S.A. Philips, J. Pierce, N. Pivnyuk, D. Pocanic, O. Pogorelko, E. Polli, S. Pozdniakov, B.M. Preedom, J.W. Price, D. Protopopescu, L.M. Qin, B.A. Raue, G. Riccardi, G. Ricco, M. Ripani, F. Ronchetti, G. Rosner, P. Rossi, D. Rowntree, P.D. Rubin, F. Sabatie, C. Salgado, J.P. Santoro, V. Sapunenko, R.A. Schumacher, V.S. Serov, Y.G. Sharabian, J. Shaw, N.V. Shvedunov, A.V. Skabelin, E.S. Smith, L.C. Smith, D.I. Sober, A. Stavinsky, S.S. Stepanyan, S. Stepanyan, , B.E. Stokes, P. Stoler, S. Strauch, R. Suleiman, M. Taiuti, S. Taylor, D.J. Tedeschi, U. Thoma, R. Thompson, A. Tkabladze, S. Tkachenko, L. Todor, C. Tur, M. Ungaro, M.F. Vineyard, A.V. Vlassov, L.B. Weinstein, D.P. Weygand, M. Williams, E. Wolin, M.H. Wood, A. Yegneswaran, J. Yun, L. Zana, J. Zhang, B. Zhao, and Z. Zhao (the CLAS Collaboration), Phys. Rev. C **73**, 035212 (2006).

[14] 'Opportunities in Nuclear Science: A Long-Range Plan for the Next Decade,' DOE/NSF Nuclear Science Advisory Committee, April 2002.

[15] PAC 14 Few-Body Workshop, JLab Program Advisory Committee, Williamsburg, VA, July, 1998.

[16] H.A. Arenhoevel, private communication.

[17] J.-M. Laget, private communication.

[18] S. Jeschonnek, private communication.

[19] S.Gilad, W. Bertozzi, and Z.-L. Zhou, Nucl. Phys. **A631**, 276 (1998) and references therein.

[20] J.-M. Laget, Phys. Lett. **B609**, 49 (2005).

[21] G.P. Gilfoyle, W.K. Brooks, B.A. Mecking, S.E. Kuhn, L.B.Weinstein, and M.F. Vineyard, 'Out-of-Plane Measurements of the Structure Functions of the Deuteron,' CLAS Approved Analysis (2003).

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

[23] G.P. Lepage and S.J. Brodsky, Phys. Rev. D **22**, 2157 (1980).

[24] M.Diehl, 'Introduction to Generalized Parton Distributions,' `wwwcompass.cern.ch/compass/publications/2004_yellow/Body/diehl_new.pdf`, last accessed Sep 4, 2006.

[25] J.D. Ashley, D.B. Leinweber, A.W. Thomas, and R.D.Young, Eur. Phys. J A **19** s01, 9 (2004).

[26] C.E. Hyde-Wright and K.deJager, Ann. Rev. Nucl. Part. Sci. **54**, 217 (2004).

[27] M.K. Jones *et al.*, Phys. Rev. Lett., **84** 1398 (2006).

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

[29] W. Brooks and M.F. Vineyard, 'The Neutron Magnetic Form Factor from Precision Measurements of the Ratio of Quasielastic Electron-Neutron to Electron-Proton Scattering in Deuterium,' Jefferson Lab Experiment E94-017 (1994).

[30] J.D. Lachniet, 'A High Precision Measurement of the Neutron Magnetic Form Factor Using the CLAS Detector,' thesis, Carnegie Mellon University.

[31] G.P. Gilfoyle, M.F. Vineyard, S.E. Kuhn, J.D. Lachniet, L.B.Weinstein, K. Hafidi, M. Holtrop, M. Garcon, 'Measurement of the Neutron Magnetic Form Factor at High Q^2 Using the Ratio Method in Deuterium,' Jefferson Lab Letter-of-Intent LOI-12-06-107 (2006).

[32] J. Friedrich, T. Walcher, Eur.Phys.J. **A17**:607-623 (2003).

[33] C.B. Crawford, *et al.*, 'Measurement of the proton electric to magnetic form factor ratio from $^1\tilde{\mathrm{H}}(\tilde{\mathrm{e}}, \mathrm{e}'\mathrm{p})$,' nucl-ex/0609007.

[34] E.L. Lomon, 'Effect of revised R_n measurements on extended Gari-Krumpelmann model fits to nucleon electromagnetic form factors,'nucl-th/0609020.

[35] C. Dib, A. Faessler, T. Gutsche, S. Kovalenko, J. Kuckei, V. E. Lyubovitskij, K. Pumsa-ard, Phys. Rev. D **73**:114021 (2006).

[36] M.A. Belushkin, H.-W. Hammer, U.-G. Meissner, 'Dispersion analysis of the nucleon form factors including meson continua,' hep-ph/0608337.

[37] K. Hafidi, J.Arrington, L. El Fassi, D.F. Geesaman, R.J. Holt, B. Mustapha, D.H. Potterveld, P.E.Reimer, P. Solvignon, K. Joo, M. Ungaro, G. Niculescu, I. Niculescu, W.K. Brooks, M. Holtrop, K. Hicks, T. Mibe, L.B. Weinstein, M. Wood, G.P. Gilfoyle, H. Hakobyan, 'Quark Propagation and Hadron Formation,' Jefferson Lab Experiment PR-12-06-117 (2006).

[38] J.Schwinger, Phys. Rev., **76**, 898 (1949).

[39] L.W.Mo and Y.S.Tsai, Rev. Mod. Phys., **41**, 205 (1969).

[40] D.Y.Bardin and N.M.Shumeiko, Nucl. Phys. B, **127**, 242 (1977).

[41] A.Afanasev, I.Akushevich, V.Burkert, and K.Joo, Phys.Rev., **D66**, 074004, 2002.

[42] J.Adam, Jr., F.Gross, S.Jeschonnek, P.Ulmer, and J.W. Van Orden, Phys. Rev. C, **66**, 044003 (2002).

[43] G.P. Gilfoyle and A. Afanasev, 'Radiative Corrections for Deuteron Electro disintegration,' CLAS-Note 2005-022.

[44] G.P. Gilfoyle, 'Radiative Corrections Using Deep,' `http://www.richmond.edu/~ggilfoyl/research/RC/wvo.html`, last accessed September 17, 2006.

[45] *Pre-Conceptual Design Report (pCDR) for The Science and Experimental Equipment for The 12 GeV Upgrade of CEBAF*, Jefferson Lab report 2004.

[46] R. De Vita, *et al.*, (the CLAS Collaboration), Phys. Rev, D **74**, 032001 (2006).

[47] G.P.Gilfoyle, 'Using the Online Version of RECSIS,' `http://www.jlab.org/~gilfoyle/recsis_online/recsis_online.html`, Last accessed Sep 24, 2006.

[48] G.P.Gilfoyle, M.Ito, and E.J.Wolin, 'Online RECSIS,' CLAS-Note 98-017.

[49] 'Joint Statement of Principles of Undergraduate Research, Scholarship, and Creative Activities,' endorsed by NCUR Board of Governors, April 2005 and CUR governing board, June 2005, Council on Undergraduate Research, http://www.cur.org/SummitPosition.html, last accessed Sep 24, 2006, and references therein.

[50] A.L. Bement Jr., Director, National Science Foundation, Testimony Before the Senate Health, Education, Labor and Pensions Committee Subcommittee on Education and Early Childhood Education, http://www.nsf.gov/about/congress/109/alb_pace030106.jsp, last accessed Sep 18, 2006.

[51] C. S. C. Johnston, 'Translating the RET Experience to the Classroom,' http://www.retnetwork.org/panel talks/Johnston presentation.doc, last accessed Sep 18, 2006.

[52] 'Richmond Physics Olympics 2006,' University of Richmond Department of Physics, http://oncampus.richmond.edu/academics/physicsOlympics/, last accessed Sep 24, 2006.

[53] G.P. Gilfoyle and M.F.Vineyard, 'New Teaching Technologies in Physics, National Science Foundation Instrumentation and Laboratory Improvement Program, grant DUE-9250502, 1992.

[54] G.P. Gilfoyle, M.F.Vineyard, and P.D. Rubin, 'Video Technology in Introductory Physics,' National Science Foundation Instrumentation and Laboratory Improvement program, grant DUE-9551066, 1994.

[55] E. Bunn, M. Fetea, G.P.Gilfoyle, H. Nebel, P.D.Rubin, and M.F.Vineyard, 'Investigative Physics Student Guide,' Inquiry-based laboratory manual for general physics.

[56] G.P.Gilfoyle, 'A New Teaching Approach to Quantum Mechanical Tunneling,' Computer Physics Communications, 121-122 (1999) 573.

[57] G.P.Gilfoyle, 'Alpha Decay Lab,' Mathematica in Education and Research, Vol. 4, No. 1, p. 24, Winter, 1995.

[58] Teacher Academy in Physical Science Program, Thomas Jefferson National Accelerator, Newport News, VA, http://education.jlab.org/taps/summary_2005.html, last accessed Sep 21, 2006.

[59] Jefferson Lab High School Summer Honors Program, Thomas Jefferson National Accelerator, Newport News, VA, http://education.jlab.org/pcedinfo.html, last accessed Sep 21, 2006.

[60] PERG Research Tools: Concept Surveys, University of Maryland Physics Education Research Group, http://www.physics.umd.edu/perg/tools/diags.htm, last accessed Sep 18, 2006.

Biographical Sketch: Dr. Gerard P. Gilfoyle

Professional Preparation:

Franklin and Marshall College, Physics, A.B., 1979.
University of Pennsylvania, Experimental nuclear physics, Ph..D., 1985.
SUNY, Stony Brook, Postdoctoral Fellow in Experimental Heavy-Ion Physics, 1985-1987.

Appointments:

2004-present - Professor of Physics, University of Richmond.
2002-2003 - Scientific Consultant, Jefferson Laboratory.
2000-2006 - Chair, Department of Physics, University of Richmond.
1999-2000 - AAAS Defense Policy Fellow.
1994-1995 - Scientific Consultant, Jefferson Laboratory.
1993-2004 - Associate Professor of Physics, University of Richmond.
Summer, 1988 - Visiting Research Professor, University of Pennsylvania.
1987-1993 - Assistant Professor, University of Richmond.

Awards and Honors:

1990-present - US Department of Energy ($1,361,000).
2004 - Who's Who Among America's Teachers.
2003 - University of Richmond Distinguished Educator Award.
2002-2003 - SURA Sabbatical Support ($10,000).
2001-2002 - National Science Foundation Major Research Instrumentation Program ($175,000).
1995-1997 - National Science Foundation, Instrumentation and Laboratory Improvement Program ($14,986).
1994-1995 - CEBAF Sabbatical Support ($24,200).
1992-1995 - National Science Foundation, Instrumentation and Laboratory Improvement Program ($49,813).
1989-1991 - Research Corporation($26,000).

Selected Publications Related to the Proposed Research:

See Reference 13 in 'References Cited' for a list of the members of the CLAS Collaborations.

1. K. Egiyan *et al.* (The CLAS Collaboration), 'Measurement of 2- and 3-nucleon short range correlation probabilities in nuclei,' Phys. Rev. Lett. **96**, 082501 (2006).
2. M. Battaglieri, R. De Vita, V. Kubarovsky *et al.* (The CLAS Collaboration), 'Search for $\theta^+(1540)$ pentaquark in high statistics measurement of $\gamma p \to \overline{K}_0 K^+ n$ at CLAS,' Phys. Rev. Lett. **96**, 042001 (2006).
3. P. Rossi, *et al.* (The CLAS Collaboration), 'Onset of asymptotic scaling in deuteron photodisintegration,' Phys. Rev. Lett., **94** 012301 (2005).
4. D. Protopopescu, *et al.* (The CLAS Collaboration), 'Survey of A'_{LT} asymmetries in semi-exclusive electron scattering on ^{4}He and ^{12}C,' Nuclear Physics, **A748**, 357 (2005).
5. K. Joo, *et al.* (The CLAS Collaboration), 'Measurement of Polarized Structure Function σ'_{LT}) for $p(\vec{e}, e'p)\pi^0$ from single π^0 electroproduction in the Delta resonance region,' Physical Review C, Rapid Communications, **68**, 032201 (2003).

Selected Other Publications:

See Reference 13 in 'References Cited' for a list of the members of the CLAS Collaborations.

1. B. Mecking *et al.*, (The CLAS Collaboration), 'The CEBAF Large Acceptance Spectrometer,' Nucl. Instr. and Meth., **503**/3, 513 (2003).

2. G.P.Gilfoyle and J.A.Parmentola, 'Using Nuclear Materials to Prevent Nuclear Proliferation,' Science and Global Security **9**, 81 (2001).
3. G.P.Gilfoyle, 'A New Teaching Approach to Quantum Mechanical Tunneling,' Comp. Phys. Comm., **121-122**, 573 (1999).
4. G.P.Gilfoyle, 'Alpha Decay Lab,' Mathematica in Education and Research, Vol. 4, No. 1, p. 24, Winter, 1995.
5. E.Bunn, M.Fetea, G.P.Gilfoyle, H. Nebel, P.D.Rubin, and M.F.Vineyard, 'Investigative Physics Student Guide,' Inquiry-based laboratory manual for general physics at the University of Richmond.

Synergistic Activities:

We have made broader impacts beyond the scope of this proposal. Gilfoyle served in government (1999-2000) as a scientific consultant on weapons of mass destruction for the US Department of Defense applying his physics skills to a range of policy issues. Our teaching has been illuminated by our scientific work and we have added considerably more computational methods to the upper-level physics curriculum at Richmond and incorporated more computer-based data acquisition and analysis in the introductory physics sequence with the aid of teaching grants from NSF. Finally, we have been able to attract a significant number of women and African-American students to our group in nuclear physics. One of our former female students is now a staff scientist at the Jet Propulsion Lab in California and in the last year two women and two African-American men have worked in our laboratory at Richmond. One of our current students is headed for a career combining nuclear physics and public policy (she is a double major in Physics and Political Science).

List of Recent Collaborators:

See Reference 13 in 'References Cited' for a list of the members of the CLAS Collaborations. Below we list any current Collaboration members not on Reference 13 and additional collaborators.

A. Afanasev	Hampton University	J. Arrington	Argonne National Lab
E. Bunn	University of Richmond	L. El Fassi	Argonne National Lab
A. Freyberger	Jefferson Lab	M. Fetea	University of Richmond
D. F. Geesaman	Argonne National Lab	K. Hafidi	Argonne National Lab
R. J. Holt	Argonne National Lab	S. Jeschonnek	Ohio State University
P. Kroll	Universität Wuppertal	B. Mustapha	Argonne National Lab
H. Nebel	University of Richmond	D. H. Potterveld	Argonne National Lab
P. E. Reimer	Argonne National Lab	P. Rubin	George Mason University
P. Solvignon	Argonne National Lab	J.W. Van Orden	Old Dominion University
H. Arenhoevel	Institut für Kernphysik, Mainz		

Graduate and Postdoctoral Advisors

Graduate Advisor - Dr. H..T. Fortune, University of Pennsylvania.
Postdoctoral Advisor - Dr. R.W. McGrath, SUNY, Stony Brook.

Thesis Advisor and Post-Graduate Advisor

None. The University of Richmond is a primarily undergraduate institution.

SUMMARY PROPOSAL BUDGET

YEAR 1

ORGANIZATION University of Richmond				FOR NSF USE ONLY PROPOSAL NO.	DURATION (months) Proposed / Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR Gerard P Gilfoyle				AWARD NO.	

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Gerard P Gilfoyle - Professor	0.00	0.00	2.00	$ 12,000	$
2.					
3.					
4.					
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	2.00	12,000	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00	0	
2. (1) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	2.00	6,400	
3. (0) GRADUATE STUDENTS				0	
4. (2) UNDERGRADUATE STUDENTS				9,000	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				27,400	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				2,329	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				29,729	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				2,908	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				1,000	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				1,000	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				0	
TOTAL OTHER DIRECT COSTS				2,000	
H. TOTAL DIRECT COSTS (A THROUGH G)				34,637	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) Wages, salaries, and fringe benefits (Rate: 52.0000, Base: 29729)					
TOTAL INDIRECT COSTS (F&A)				15,459	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				50,096	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 50,096	$

M. COST SHARING PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $		
PI/PD NAME Gerard P Gilfoyle	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME*	Date Checked	Date Of Rate Sheet	Initials - ORG

 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

SUMMARY PROPOSAL BUDGET

YEAR 2

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (months)	
	Proposed	Granted
AWARD NO.		

ORGANIZATION
University of Richmond

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR
Gerard P Gilfoyle

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Gerard P Gilfoyle - Professor	0.00	0.00	2.00	$ 12,360	$
2.					
3.					
4.					
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	2.00	12,360	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00	0	
2. (1) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	2.00	6,592	
3. (0) GRADUATE STUDENTS				0	
4. (2) UNDERGRADUATE STUDENTS				9,270	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				28,222	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				2,399	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				30,621	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				2,995	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 1,800 2. TRAVEL 1,600 3. SUBSISTENCE 0 4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (2) TOTAL PARTICIPANT COSTS				3,400	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				1,000	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				1,000	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				0	
TOTAL OTHER DIRECT COSTS				2,000	
H. TOTAL DIRECT COSTS (A THROUGH G)				39,016	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) **Wages, salaries, and fringe benefits (Rate: 52.0000, Base: 30621)**					
TOTAL INDIRECT COSTS (F&A)				15,923	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				54,939	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 54,939	$

M. COST SHARING PROPOSED LEVEL $ 0 AGREED LEVEL IF DIFFERENT $

PI/PD NAME
Gerard P Gilfoyle

ORG. REP. NAME*

FOR NSF USE ONLY		
INDIRECT COST RATE VERIFICATION		
Date Checked	Date Of Rate Sheet	Initials - ORG

 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

SUMMARY PROPOSAL BUDGET

YEAR 3

ORGANIZATION	FOR NSF USE ONLY		
University of Richmond	PROPOSAL NO.	DURATION (months) Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR	AWARD NO.		
Gerard P Gilfoyle			

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Gerard P Gilfoyle - Professor	0.00	0.00	2.00	$ 12,731	$
2.					
3.					
4.					
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	2.00	12,731	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00	0	
2. (1) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	2.00	6,790	
3. (0) GRADUATE STUDENTS				0	
4. (2) UNDERGRADUATE STUDENTS				9,548	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				29,069	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				2,471	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				31,540	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				3,085	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ 1,854					
2. TRAVEL 1,648					
3. SUBSISTENCE 0					
4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (2) TOTAL PARTICIPANT COSTS				3,502	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				1,000	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				1,000	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				0	
TOTAL OTHER DIRECT COSTS				2,000	
H. TOTAL DIRECT COSTS (A THROUGH G)				40,127	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) Wages, salaries, and fringe benefits (Rate: 52.0000, Base: 31540)					
TOTAL INDIRECT COSTS (F&A)				16,401	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				56,528	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 56,528	$

M. COST SHARING PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $		
PI/PD NAME	FOR NSF USE ONLY		
Gerard P Gilfoyle	INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME*	Date Checked	Date Of Rate Sheet	Initials - ORG

 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

SUMMARY PROPOSAL BUDGET

Cumulative

ORGANIZATION **University of Richmond**				FOR NSF USE ONLY PROPOSAL NO.	DURATION (months) Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR **Gerard P Gilfoyle**				AWARD NO.		

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Gerard P Gilfoyle - Professor	0.00	0.00	6.00	$ 37,091	$
2.					
3.					
4.					
5.					
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	6.00	37,091	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00	0	
2. (3) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	6.00	19,782	
3. (0) GRADUATE STUDENTS				0	
4. (6) UNDERGRADUATE STUDENTS				27,818	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				84,691	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				7,199	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				91,890	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				8,988	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 3,654 2. TRAVEL 3,248 3. SUBSISTENCE 0 4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (4) TOTAL PARTICIPANT COSTS				6,902	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				3,000	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				3,000	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				0	
TOTAL OTHER DIRECT COSTS				6,000	
H. TOTAL DIRECT COSTS (A THROUGH G)				113,780	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS (F&A)				47,783	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				161,563	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 161,563	$
M. COST SHARING PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $				

PI/PD NAME **Gerard P Gilfoyle**	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME*	Date Checked	Date Of Rate Sheet	Initials - ORG

C *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

Budget Justification

YEAR 1

A.1 PI's summer salary based on 2/9's of academic years salary or $12,000 whichever is smallest.

B.2 Stipend for local high school teacher for 8 weeks. This is the same amount used by a similar program at Jefferson Lab in Newport News, Va. The University's Human Resources division will cover any advertising costs.

B.4 Two undergraduate students for 10 summer weeks. This rate is the same as the University stipends.

C 8.5% of wages and salaries.

E Domestic travel:

1. $1,000 - One trip for the High School Research Fellow to attend a meeting like the American Association of Physics Teachers or Division of Nuclear Physics of the APS and for travel to JLab.
2. $936 - Round trip mileage charge for students to take shifts at JLab and attend Collaboration meetings. Based on 12-16 shifts per year and three Collaboration meetings of about 3 days/meeting. It is 150 miles round trip from the University of Richmond to JLab, at $0.39 per mile. Note: routine faculty travel of this sort is covered by the University.
3. $972 - Lodging at the JLab residence facility ($54/night) during shifts for faculty and students and Collaboration meetings based on 12-16 shifts/yr and three Collaboration meetings of about 3 days/meeting.

   Total = $2,908

I - 52% of wages, salaries, and fringe benefits.

YEAR 2

A.1 PI's salary adjusted by 3% for inflation.

B.2 Stipend for High School Research Fellow for 8 weeks and adjusted for 3% inflation.

B.4 Two undergraduate students for 10 summer weeks and adjusted for 3% inflation.

C 8.5% of wages and salaries.

E Domestic travel:

1. $1,030 - One trip for the High School Research Fellow to attend an annual meeting like the American Association of Physics Teachers or Division of Nuclear Physics of the APS and for travel to JLab (adjusted for 3% inflation).
2. $964 - Round trip mileage charge for students to take shifts at JLab and attend Collaboration meetings. Based on 12-16 shifts per year and three Collaboration meetings of about 3 days/meeting. It is 150 miles round trip from the University of Richmond to JLab at $0.39 per mile (adjusted for 3% inflation). Note: routine faculty travel of this sort is covered by the University.

3. $1001 - Lodging at the JLab residence facility ($54/night) during shifts for faculty and students and Collaboration meetings based on 12-16 shifts/yr and three Collaboration meetings of about 3 days/meeting (adjusted for 3% inflation).

   Total = $2,995

F.1 Two high school students for three weeks at $300/wk.

F.2 $1,600 - One trip for the two high school students to attend an annual meeting like the American Association of Physics Teachers or Division of Nuclear Physics of the APS.

I - 52% of wages, salaries, and fringe benefits.

YEAR 3

A.1 PI's salary adjusted by 3% for inflation.

B.2 Salary for High School Research Fellow for 8 weeks and adjusted for 3% inflation.

B.4 Two undergraduate students for 10 summer weeks and adjusted for 3% inflation.

B.6 Two high school students of high school science teacher for four weeks, 40 hrs/week at $8/hr and adjusted for 3% inflation.

C 8.5% of wages and salaries.

E Domestic travel:

1. $1,061 - One trip for the High School Research Fellow to attend an annual meeting like the American Association of Physics Teachers or Division of Nuclear Physics of the APS and for travel to JLab (adjusted for 3% inflation).
2. $993 - Round trip mileage charge for students to take shifts at JLab and attend Collaboration meetings. Based on 12-16 shifts per year and three Collaboration meetings of about 3 days/meeting. It is 150 miles round trip from the University of Richmond to JLab at $0.39 per mile (adjusted for 3% inflation). Note: routine faculty travel of this sort is covered by the University.
3. $1,031 - Lodging at the JLab residence facility ($54/night) during shifts for faculty and students and Collaboration meetings based on 16 shifts/yr and three Collaboration meetings of 3 days/meeting (adjusted for 3% inflation).

   Total = $3,085

F.1 Two high school students for three weeks at $300/wk and adjusted for 3% inflation.

F.2 $1,648 - One trip for the two high school students to attend an annual meeting like the American Association of Physics Teachers or Division of Nuclear Physics of the APS and adjusted for 3% inflation.

I - 52% of wages, salaries, and fringe benefits.

Current and Pending Support

(See GPG Section II.C.2.h for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: **Gerard Gilfoyle**

Other agencies (including NSF) to which this proposal has been/will be submitted. **DOE**

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Supercomputing for Physics Research at the University of Richmond**

Source of Support: **Army Research Office**

Total Award Amount: $ **289,337** Total Award Period Covered: **04/01/07 - 04/01/09**

Location of Project: **University of Richmond**

Person-Months Per Year Committed to the Project. Cal: **0.00** Acad: **0.00** Sumr: **0.50**

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Nuclear and Particle Physics Research at the University of Richmond**

Source of Support: **US Department of Energy**

Total Award Amount: $ **52,000** Total Award Period Covered: **06/01/05 - 05/31/07**

Location of Project: **University of Richmond**

Person-Months Per Year Committed to the Project. Cal: **0.00** Acad: **0.00** Sumr: **2.00**

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **RUI: Nuclear Physics Research at the University of Richmond**

Source of Support: **NSF**

Total Award Amount: $ **161,761** Total Award Period Covered: **06/01/07 - 05/31/10**

Location of Project: **University of Richmond**

Person-Months Per Year Committed to the Project. Cal: **0.00** Acad: **0.00** Sumr: **2.00**

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Summ:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

Facilities, Equipment, and Other Resources

Our nuclear physics group at the University of Richmond is supported by a computing cluster developed in 2001 with NSF and University funds obtained by Gilfoyle and a former Richmond faculty member (M.F. Vineyard now at Union College). This cluster is for the exclusive use of our nuclear physics group though we support other Collaboration members who need it. The cluster is, in turn, supported by an array of computers for software development and non-CPU-intensive calculations and analysis. The system now consists of 34, dual-processor machines running the Linux operating system and 3 TByte of RAID storage. Each machine has 18 GByte of disk space and 256 MByte of memory. The entire system resides on its own subnet and another machine acts as a firewall. It resides in a laboratory designed specifically for its needs which require a 5-ton, 60,000-BTU air conditioner to cool the room, an upgraded electrical panel, and a connection to the building's backup power. The support computers are located in an adjacent room. The entire facility is in the Physics Department research area.

The Physics Department also has laboratories in environmental radiation (containing two large, well-shielded germanium, gamma-ray detectors), a surface-physics, condensed-matter laboratory, a biological physics laboratory, and facilities for theoretical work in astrophysics and nuclear structure.

The University has supported our research efforts in the past. One member of the University's Information Services is a linux expert and he devotes half of his time to academic projects including support for the supercomputing cluster. He is responsible now for keeping the CLAS software up-to-date, updating the linux software on the cluster and in our laboratory, and general troubleshooting. The University also supports some undergraduate summer stipends for research. We have taken advantage of those in the past to hire additional students and will continue to apply for those in the future. The University also supports routine faculty travel to JLab. See the RUI Impact Statement of more details on University support.

Jefferson Lab is 75 miles from the University of Richmond enabling us to maintain frequent contacts with the scientific staff and users at JLab. Gilfoyle spends about 1 day each week at JLab. This proximity enables us to take students on shift with us and to attend Collaboration meetings and other events (*i.e.*, some of our students attended the talk this summer at JLab by the Nobel Laureate Dr. David Gross) for little cost. As mentioned above, the University supports routine faculty travel to JLab. The University is a long-time member of the Southeastern Universities Research Association (SURA) which manages JLab for DOE (now in partnership with Computer Sciences Corporation). Gilfoyle acts as the University of Richmond's representative to SURA.

RUI Impact Statement: University of Richmond

The University of Richmond, established in 1830, is one of America's premier private, highly selective, independent liberal arts universities, with a rising national and international profile. An ambitious 10-year strategic plan, approved in 2000, provides a strong momentum for the University's future. Richmond has a full-time enrollment of approximately 3,600 enrolled in the schools of arts and sciences, leadership studies, law and business. In addition, the University annually enrolls more than 1,300 part-time students through its school of continuing studies. Over 90% of the full-time undergraduates live on campus, more than half are involved in internships, 40% participate in study abroad programs, and two-thirds participate in community service. The University's small size and diversity of programs enable and encourage inter-school and interdisciplinary projects with a wealth of opportunities for student-faculty interactions. The University of Richmond is a place where undergraduate students routinely engage in research alongside their professors, an experience more often found in large research universities. For eleven straight years, the University of Richmond has been named the best master's university in the South by US News and World Report. At the end of 2004, the Carnegie Foundation for the Advancement of Teaching moved the University of Richmond to the Baccalaureate Liberal Arts category from the Masters I category. The reclassification resulted in Richmond being ranked 34th among 'best liberal arts colleges' by US News and World Report's 'America's Best Colleges' issue, which also named Richmond in its list of 'Great Schools, Great Prices.' Richmond has been given the highest ranking of four stars in The Princeton Review's 2005 'Best Colleges' issue. (See http://www.richmond.edu.)

Students. The undergraduate population is approximately 3,000 (52% women, 48% men), with outstanding students from nearly every state and about 75 foreign countries. About 12% of the students are American students of color; about 5% are international. Out of 5,408 applications for fall 2006, 767 matriculated; entering students had average SAT I scores in the 1850-2030 range.

There are a number of merit based scholarships for undergraduates that benefit hundreds of students, with 50 significant scholarships for full tuition awarded annually under the Richmond Scholars program. In addition there are one-half and partial tuition scholarships, including more than 250 endowed funds. The University has need-blind admissions and is committed to meeting 100% of the demonstrated need of every student who enrolls. About 65% of our students receive some amount of assistance, when we consider all sources and types of assistance.

Richmond is a coordinate residential college, with men and women students having separate residences and governing structures. About 220 student organizations, including 33 honor societies (among them ODK since 1921 and Phi Beta Kappa since 1928), offer opportunities for interaction, leadership and community involvement. The University's location in the state capital and just 100 miles from Washington, DC provides close proximity to state and national governments as well as a wealth of financial, cultural and civic organizations, insuring students a variety of internship and service-learning opportunities as well as access to major research centers. The University also hosts four projects conducted by the Pew Charitable Trusts — on civic change, state initiatives, food and biotechnology, and election reform — all of which offer research and internship opportunities for students.

Faculty and Research. There are 326 full-time faculty members at all ranks, 244 at the assistant level or above, of whom 98.4% hold the Ph.D. or the equivalent terminal degree in their field. Women and minorities make up about one third of the faculty. The student-faculty ratio is 9.4 to 1; all classes are taught by faculty, not graduate assistants.

Faculty members routinely integrate their research into teaching and engage students as research assistants, collaborators, co-authors and co-presenters at national conferences. Each year, Richmond faculty members make invaluable contributions to society through their research, and have attracted more than $9.8 million in research grants over the past five years, in addition to more than $11.8 million in grants for other non-research projects. Among the topics studied by faculty are tumor growth and cancer treatment, neuroanatomy and the effects of pregnancy on behavior and learning, nuclear physics, proteins involved in metabolism and disease, specification of lymphatic heart myoblasts, interactions in oligomeric proteins, biologically enhanced metallic nanoparticles, morphology of the frog genus Leptodactylus, strategic entrepreneurship, paternal involvement among African Americans, the impact of the growing Hispanic population on the Greater Richmond community, and an array of other topics.

The University of Richmond is a recipient of a 2004 Undergraduate Science Education Program grant from the Howard Hughes Medical Institute. A challenge grant from the Kresge Foundation in 2004 supports scientific instrumentation. Grants also have been provided by the National Science Foundation; National Aeronautics and Space Administration; National Institutes of Health; National Endowment for the Humanities; U.S. Departments of Energy, Education, and Defense; National Park Service; CIES-Fulbright; American Chemical Society - Petroleum Research Fund; Research Corporation; Camille and Henry Dreyfus Foundation; Jeffress Memorial Trust; Jessie Ball duPont Fund; Association for Public Policy Analysis and Management; Associated Colleges of the South; Virginia Foundation for the Humanities; and other local and national foundations, corporations and government agencies.

Strategic Plan and the Sciences. The University completed a campus-wide strategic planning process in 2000. The resulting strategy is to combine at Richmond the best that higher education has to offer tomorrow's leaders: a synthesis of teaching and research, knowledge transmission and knowledge creation, intellectual growth and character development, liberal arts and professional education. The *Science Initiative* is the highest priority in the strategic plan, and includes a revision of the curriculum and comprehensive upgrade of the science facilities. The Science Initiative includes more than $60 million in program enhancements and a $35 million renovation of the Gottwald Science Center. Renovations began in the spring 2003 and were completed in spring 2006. The results will provide increased opportunities for faculty-student research; addition of up to 18 new science faculty, bringing the total to 44; greater emphasis on interdisciplinary studies such as new majors in biochemistry, molecular biology, interdisciplinary physics, and a 3-2 engineering program; state-of-the-art instrumentation in every laboratory; and the development of innovative science experiences for non-science majors. We have developed working relationships for faculty and students to participate in research at such sites as the Massey Cancer Center in Richmond, Thomas Jefferson National Accelerator Facility in nearby Newport News, and Yale University.

The University is committed to encouraging women and minority students toward careers in the sciences, through active recruiting of high school students interested in the sciences, by offering merit scholarships, by nurturing them through peer mentoring for academic progress and socialization, and through faculty advising and guided research experiences. Efforts are ongoing to increase the number of American minority students. The Pre-Health Advisor will help students achieve acceptance at graduate or medical schools. An increasing number of female students are electing to major in the sciences, and the University is committed to their success. The Women Involved in Living and Learning (WILL) Program is a University program, replicated elsewhere, that strengthens and expands the leadership qualities, analytical skills, and self-esteem of undergraduate women through Women's Studies coursework and women/gender-focused programming experiences, often including the sciences. The University has increased the number of female science faculty members, and at present 32% of the science faculty are women, as are many of the science lab managers and adjunct professors.

Richmond has made great strides toward the strategic plan's goals for the sciences. Several private foundations have responded to our science initiative plan, including the Arthur Vining Davis Foundations, as have the NSF and NIH. A number of proposals are pending with, or soon to be submitted to, other national foundations in support of Science Initiative objectives.

Because of our strong foundation in the sciences, in 2001-02 the National Science Foundation's Major Research Instrumentation (MRI) program awarded $480,694 to the Chemistry department for acquisition of a High Field NMR, and $151,758 to the Physics department for the development of a computing cluster for nuclear physics research. In July 2003, the University received two additional NSF-MRI grants — one of $304,714 to acquire a new mass spectrometer in Chemistry and one of $347,005 for new electron microscopy equipment in Biology. The University received two 2001-02 NSF Course, Curriculum and Laboratory Improvement program awards, plus another in 2003-04. About ten faculty members have current NSF grants for scientific research, nearly all of which support one or more students in summer research.

The National Institutes of Health have supported research at the University of Richmond as well, including a grant of more than $600,000 for 'Memory Self Efficacy and Memory Performance in Adulthood,' and smaller AREA grants for explorations in anti-tumor processes, lymphatic heart muscle myoblasts, the effects of reproduction on addiction, and 'Pregnancy and Neural and Behavioral Plasticity in the Female.'

Internal funding from the University of Richmond supports faculty and student research, including faculty summer stipends, research and travel grants, and undergraduate and graduate student research grants, summer fellowships and travel grants. Applications for the faculty grants are peer-reviewed, and in 2003-04, more than $164,000 was awarded. In 2004-05, the University awarded more than $197,000 in grants to support undergraduate student research projects. In addition, the University supports faculty research by offering start-up funds in the range of $80,000 - $100,000 for new faculty in the sciences, one-semester research leave for new faculty in their fourth year, full-year sabbaticals to faculty after seven years, topping-off funds for faculty receiving partial sabbatical support from external grants, and reduced teaching loads when research demands it.

The Department of Physics. The Department of Physics consists of seven teaching faculty and we graduate about 4-8 physics majors each year and currently have thirty-four students in our upper-level courses. From last year's graduating class two students have gone on to graduate school in physics at Johns Hopkins and Kentucky including one in nuclear physics at Kentucky. There are no graduate students. The faculty are active in experimental nuclear physics (Gilfoyle), astrophysics (Bunn), experimental nuclear structure physics (Beausang), theoretical nuclear structure physics (Fetea), surface physics (Trawick), and biological physics (Lipan). There is considerable external support from the Department of Energy (two grants), the National Science Foundation (two grants), and NASA (one grant). We emphasize undergraduate involvement in research from early in the students' careers. Students that are involved in undergraduate research are more likely to attend graduate school and to be successful after college. In the summer of 2006 fifteen of our physics majors participated in research at Richmond, JLab, Yale University, and the University of Notre Dame. They have accomplished much in their research careers. Eighteen have given presentations on their work at local and national meetings in the last year. Nine of our students will be presenting posters at the fall, 2006 meeting of the Division of Nuclear Physics (DNP) of the American Physical Society from the experimental nuclear and nuclear structure groups and the theoretical nuclear structure group. Some of these students obtained travel support in fall, 2005 and again in fall, 2006 from the Conference Experience for Undergraduates program of the DNP. We have also been successful in attracting under-represented groups. Of the fifteen people that did summer research in the summer of 2006 eight of those students were women and two were African-American men. They are integral parts of our research efforts and are deeply involved in many aspects of the physics programs.