COVER PAGE

Project Title: Medium Energy Nuclear Physics at the University of Richmond	
Federal Award Identification Number: DE-FG02-96ER40980	
Agency Code: 8900	**Organization:** Office of Nuclear Physics
Recipient Award Identification Number: Not Provided	**Project Period:** 06/01/2018 - 05/31/2021
Reporting Period: 06/01/2018 - 05/31/2019	**Budget Period:** 06/01/2018 - 05/31/2019
Report Term: Once per Budget Period	**Submission Date and Time:** N/A
Principal Investigator Information: Dr. Gerard P Gilfoyle Professor 138 UR Drive Richmond, VA 23173-0001 **Email:** ggilfoyl@richmond.edu **Contact:** (804) 289-8255	**Recipient Organization:** University of Richmond 28 Westhampton Way Richmond, VA 23173-0001 Country: USA **DUNS:** 056915069 **EIN:** 540505965
Submitting Official Information: N/A **Email:** N/A **Contact:** N/A	

ACCOMPLISHMENTS

1. What are the major goals of the project?

The majors goals are preparation for a scheduled measurement of the neutron magnetic form factor with the CLAS12 detector in Hall B at Jefferson Lab in 2019 and the analysis of those data. See attached report for more details.

2. What was accomplished under these goals?

To prepare for physics with CLAS12 we have (1) developed software to calculate the geometry of the Silicon Vertex Tracker (SVT) for both simulation and data reconstruction, (2) written code to correct the SVT misalignments, (3) begun a study of the p(e,e' pi+ n) reaction from CLAS12 data collected during the Run Group A and Run Group K run periods in 2018. This reaction is used as a source of tagged neutrons to measure the neutron detection efficiency, (4) developed an end-to-end software chain to simulate, reconstruct, and analysis CLAS12 data to extract GMn, and (5) collaborated with the CLAS12 time-of-flight (TOF) group to generate
the analysis algorithms for the forward and central TOF systems. See attached report for more details. Item 3 above is being done in collaboration with a doctoral student Lamya Baashen from Florida International University. Her advisor is Dr. Brian Raue.

3. What opportunities for training and professional development has the project provided?

Three Richmond undergraduates worked in Gilfoyle's laboratory at the University of Richmond and at Jefferson Lab. One has since graduated and is now a masters student at Christopher Newport University. He has plans to eventually pursue a doctorate in physics. One student presented a poster on his summer project at the fall, 2018 meeting of the DNP.

4. How have the results been disseminated to communities of interest?

The results have been disseminated through presentations at conferences - one Richmond undergraduate presented a poster at the fall, 2018 DNP meeting and Gilfoyle gave a presentation at the University of Surrey on future form factor measurements at JLab. Gilfoyle also gave a talk at a CLAS12 workshop at Jefferson Lab. Gilfoyle was co-author
on five refereed papers in 2018. See attached report for more details.

5. What do you plan to do during the next reporting period to accomplish the goals?

We will continue developing the projects described here. In particular, we want to complete the SVT alignment code to improve the detector position resolution to reach the design goals. This will include incorporating our results into the CLAS12 reconstruction code, validating, and testing with real events. The first deuteron data that can be used to extract the neutron magnetic form factor GMn will come in spring, 2019. As mentioned here we have begun the work of calibration using existing data from CLAS12 Run Groups A and K and have developed an end-to-end software chain to simulate, reconstruct, and analyze the GMn data.

Continuation Progress Report

Submitted to the Department of Energy Office of Nuclear Physics

Contract Number DE-FG02-96ER40980

Title: Nuclear and Particle Physics Research at the University of Richmond

PI: Gerard P. Gilfoyle

Department of Physics, University of Richmond, 138 UR Drive, Richmond, VA 23173

Grant Period: June 1, 2018 - May 31, 2021

Reporting Period: January 1, 2018 to December 31, 2018

Annual Reporting Period

1 Introduction

In this report we describe the progress made during the period January 1, 2018 to December 31, 2018 under contract number DE-FG02-96ER40980 entitled *Nuclear and Particle Physics at the University of Richmond*, Gerard P Gilfoyle (PI).[1] See pages 6-7 for a summary. The research is part of the electromagnetic nuclear physics program in Hall B at the Thomas Jefferson National Accelerator Facility (JLab) which houses the new CLAS12 detector. In 2018 the group included one faculty member (Gilfoyle) and three undergraduates at the University of Richmond (a primarily undergraduate institution without graduate students). A masters student from the University of Surrey in the UK will be added in 2019 (with DOE funding). Gilfoyle mentors masters students from the University of Surrey in the UK through a joint Surrey/Richmond program. The Richmond group has begun working closely with Dr. B. Raue at Florida International University and his doctoral student Lamya Baashen. Data from the scheduled deuterium run in CLAS12 in spring 2019 (Run Group B) will be analyzed to extract the neutron magnetic form factor G_M^n and will be the basis of Ms. Baashen's thesis. See below for details. One of the Richmond students who recently graduated, Alexander Balsamo, is now pursuing a masters degree in physics at Christopher Newport University (CNU) as a stepping stone to a doctorate. In this annual report we outline the Richmond physics program, list recent accomplishments, and discuss the budget.

The Richmond group is currently working on analysis projects described below and software for the simulation, reconstruction, and analysis of data from the new CLAS12 detector in Hall B with completion of the 12 GeV Upgrade.[2] Gilfoyle is spokesperson and contact person on an experiment to measure the neutron magnetic form factor G_M^n in Hall B entitled *Measurement of the Neutron Magnetic Form Factor at High* Q^2 *Using the Ratio Method on Deuterium* (JLab experiment E12-07-104) that builds on our experience with the previous detector in Hall B and is scheduled to start running in spring, 2019 (Run Group B)[1, 2, 3]. The experiment received a scientific rating of A^- by PAC35 in 2010 and 30 days of beamtime [4, 5]. Gilfoyle is co-spokesperson on another 12-GeV proposal to measure G_M^n in Hall A entitled *Precision Measurement of the Neutron Magnetic Form Factor Up to* $Q^2 = 18.0$ $(GeV/c)^2$ *by the Ratio Method* (JLab experiment E12-09-019). He is also co-spokesperson on a 12-GeV proposal entitled *Quark Propagation and Hadron Formation* (JLab experiment E12-06-117) [6, 7]. Current physics projects focus on preparations for E12-07-104 and calibrations using data from Run Groups A and K in CLAS12. In the last year we have also continued our work on software to provide the corrected geometry information for the Silicon Vertex Tracker (SVT) to the CLAS12 simulation (*gemc*) and to the reconstruction code. We have also written algorithms to measure the neutron detection efficiency in CLAS12 and extract G_M^n. Gilfoyle continues work on analysis of existing CLAS6 data (CLAS6 is the previous detector that occupied Hall B before the 12 GeV Upgrade). He is spokesperson on a CLAS6 Approved Analysis *Out-of-Plane Measurements of Deuteron Structure Functions* to extract the fifth structure function of the deuteron [8] from existing CLAS6 data.[3] That project has been interrupted by the preparations for data taking with CLAS12 in spring, 2019.

During the period of this report Gilfoyle was co-author on five refereed articles [9, 10, 11, 12, 13] and was invited to give a talk entitled *Future Measurements of the Neutron Magnetic Form Factor at Jefferson Lab* at the University of Surrey, Guildford, UK [14]. Last summer three undergraduates, Alexander Balsamo, Nick Child, and Ben Weinstein worked with Gilfoyle at Richmond and JLab. All of these undergraduates were supported by the DOE grant. Weinstein presented his work at the Fall, 2018 meeting of the Division of Nuclear Physics (DNP) of the APS [15].

We anticipate that at the end of the current budget period (May 31, 2019) there will be less than 10% of the budget period funding remaining in the grant.

2 Physics Projects

We are part of a broad program at JLab to measure the elastic, electromagnetic form factors consisting of seven experiments including two to measure G_M^n. Both G_M^n experiments use methods pioneered in Hall B with the previous detector CLAS6 [16]. The PI is one of the lead authors on that work [1]. Our group's major focus now is on preparations for the measurement of G_M^n with CLAS12.

The extraction of G_M^n will be done using the ratio R of $e-n/e-p$ scattering on deuterium [16]. The first CLAS12 experiment using a deuterium target is scheduled to start at the beginning of February 2019 and

[1] Department of Physics, University of Richmond, 138 UR Drive, Richmond, VA 23173.

[2] The JLab accelerator energy has been doubled to 12 GeV and a new detector CLAS12 in Hall B has been built.

[3] A CLAS Collaboration member can write a proposal to analyze existing, 6-GeV CLAS (CLAS6) data which is reviewed by a committee of Collaboration members, and defended before the Collaboration who then vote to approve it.

run into March, 2019 with additional time expected in fall, 2019. To prepare for the G_M^n experiment we have developed an end-to-end software chain from target simulation to post-reconstruction analysis and extraction of R [17, 18]. The 4-vectors of the reaction are simulated with the computer code QUEEG in quasi-elastic (QE) kinematics including the effect of the internal nucleon momentum in deuterium using the Hulthen distribution [19]. The detector response is simulated with the CLAS12 physics-based Monte Carlo code *gemc* [20]. The calculations were performed on the Richmond computing cluster which consists of thirty, 12-core machines [21]. The simulated data are reconstructed with the Collaboration's CLAS12 Common Tools software [22]. The post-reconstruction analysis is done within the same software framework using the groovy scripting language [23]. Electrons are selected with a standard set of cuts and events with any additional negative tracks (besides the electron) and/or more than one positive track track are rejected. Quasi-elastic electron-proton and electron-neutron events are selected using cuts on W^2 and θ_{pq} - the angle between the 3-momentum transfer $\vec{q}$ and the ejected nucleon. We use the same angular cut on both $e-n$ and $e-p$ events to select the QE events to reduce any bias that might be created by using additional information available for $e-p$ events that is not available for $e-n$ events.

To ensure that the $e-n$ and $e-p$ events have the same solid angle we match the acceptance for both types. We start with the measured electron information for the event. We use that information to predict the trajectory of a neutron and a proton in QE kinematics and 'swim' each particle through CLAS12. If both trajectories intersect the front face of the CLAS12 electromagnetic calorimeter system (ECAL), we accept that event. If either trajectory misses the fiducial region of the ECAL, we reject it. The software tools for swimming the tracks and testing the detector geometry are part of the CLAS12 Common Tools.

The results of this analysis are used to fill $e-n$ and $e-p$ momentum histograms and the ratio R determined bin by bin. Preliminary results of validation tests with simulated data are encouraging though more features need be added like corrections for the Fermi motion of the nucleons, neutron detection efficiency, and others. The actual code writing was done over the last three summers by a Richmond undergraduate, A. Balsamo (now a masters student at CNU) [17, 18].

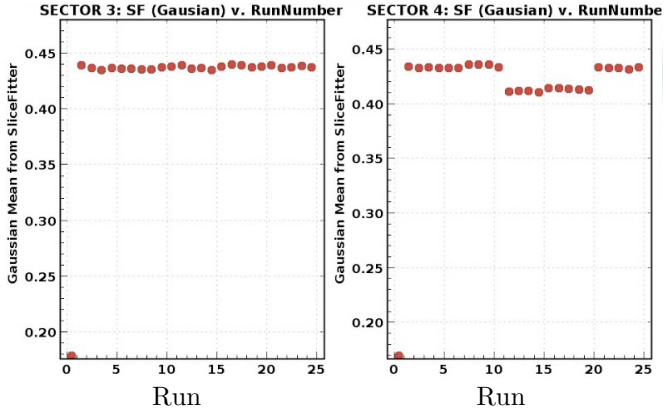

Figure 1: Sampling fraction monitoring plots.

We have also begun programming monitoring tools we plan to use for the G_M^n experiment. In summer, 2018 we developed computer programs to monitor the data quality during event reconstruction or 'cooking' of the data with a particular focus on the G_M^n requirements. This work was the summer project of a Richmond undergraduate Ben Weinstein [15]. The code is used to plot, for example, the centroid of the ECAL sampling fraction as a function of sector (the ECAL consists of six, identical sectors) and run number. The sampling fraction is the ratio of the electron energy from the ECAL to the momentum measured with the drift chambers. The idea is to quickly test for shifts in the CLAS12 performance and identify problems. The code was validated with simulated data by imposing an artificial shift on the sampling fraction for a subset of runs and seeing that shift appear in the monitoring plots. An example is shown in Figure 1. It shows the sampling fraction centroid as a function of run number for two sectors of CLAS12. We inserted an arbitrary shift in the analysis in sector 4 only and for runs 11-19. The shift clearly shows in the monitoring histograms. In addition, notice the sampling fraction is zero for run zero in both sectors. This is due to a feature in the ECAL analysis code that we were unaware of until this study. This inadvertent observation also validates the code. Additional quantities that are monitored include ratios of protons and neutrons to electrons. Other observables can be easily added.

To accurately determine G_M^n we need to measure the neutron detection efficiency (NDE). Our method is to use the reaction $^1\mathrm{H}(e,e'\pi^+)n$ on a hydrogen target as a source of tagged neutrons. We first detect the scattered electron and π^+ in CLAS12. Neutrons are selected with a missing mass cut and we use the missing 3-momentum to predict the location of the neutron in CLAS12. If this predicted track strikes the ECAL fiducial volume we search for nearby hits that are not associated with a charged particle track. Last, we require the distance between the predicted and found ECAL hit to lie within a range determined by the spatial resolution of the ECAL. The NDE is the ratio of the detected neutrons to the ones expected to strike the fiducial volume. We have begun this measurement of the NDE using the CLAS12 data already collected on hydrogen for Run Groups A and K during 2018. Code to perform this analysis was originally developed by a Richmond undergraduate (Keegan

Sherman, now a doctoral student at Old Dominion University) and is now being modified for the current software framework [24, 25]. To validate the code we are testing it at lower energies closer to the ones used in the CLAS6 measurement for comparison and lower backgrounds. Figure 2 shows some of the details of the algorithm for a measured event from CLAS12 at an electron beam energy of 11 GeV. The lower panel is a zoomed-in version of the upper panel. The red planes in the figure represent the front face of the ECAL. The green point in each panel is the intersection of the predicted neutron track with the face of the ECAL. The blue point is the location of the measured ECAL hit. The gray one is the intersection of that measured track with the ECAL face. The vector $\vec{R}$ in the lower panel shows the difference between the intersection points. The magnitude of $\vec{R}$ will be used to make the final cut on the the events of interest to reduce background from other reactions. Ms. Baashen (the FIU doctoral student mentioned above) has begun to extract the NDE from existing CLAS12 data on hydrogen collected in 2018.

We have also developed software to generate the ideal geometry information for the Silicon Vertex Tracker (SVT) and to correct for misalignments created during manufacture [26, 27, 28]. The SVT is a silicon strip detector consisting of 132, flat silicon modules each with 256 strips that form a barrel near to and around the CLAS12 target location. It is part of the CLAS12 Central Detector. To reach its design goals we need to know the geometry within a few microns. We have been working with the SVT group in CLAS (technical lead Yuri Gotra) to maintain these components of the code and to align the SVT. At this time we can accurately align the horizontal sensors in the SVT using cosmic rays, but for tilted ones we obtained unphysical results from the fits to the cosmics. That issue with the fits has now been resolved and we are restarting our work to align all the sensors in the full detector. We used the `millepede` code to fit cosmic-ray tracks to horizontal sensors and are now applying that method to the remaining sensors [28, 29]. The goal is to be ready for the spring, 2019 data cooking.

We also worked with the team developing the analysis code for the time-of-flight (TOF) systems in CLAS12. The project builds on Gilfoyle's experience in 2013 when he mentored a masters student from the University of Surrey who wrote an early version of the program [30]. There are two of these systems, one in the Forward Detector which consists of large flat panels of scintillators. Some of the panels (1a and 1b) are arranged one behind the other so particles typically strike scintillators in both panels. There is also another TOF system in the Central Detector consisting of a single layer of scintillators arranged in a cylinder around the target. Gilfoyle continues to contribute to the weekly meetings, but his main focus is on the other projects describe above.

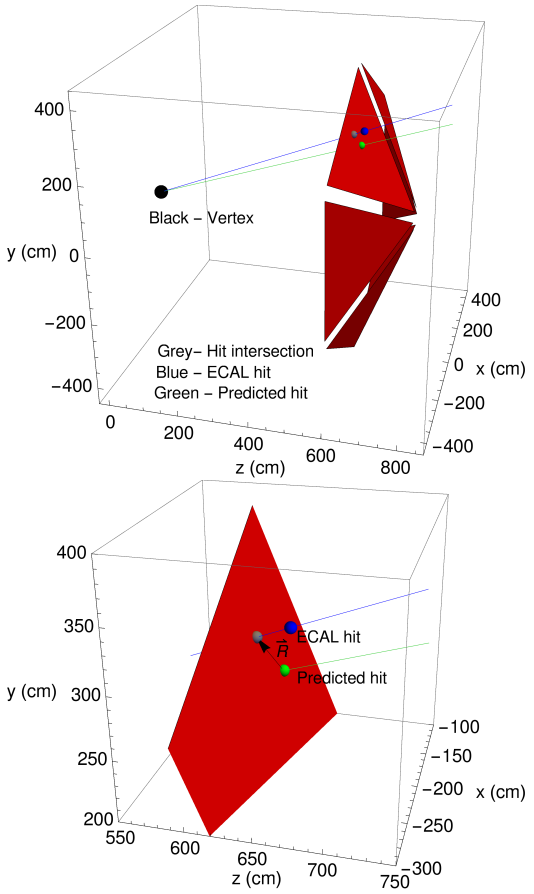

Figure 2: Predicted and measured neutron trajectories in CLAS12.

3 Professional and CLAS Collaboration Service Work

Gilfoyle was chair on one CLAS Collaboration review committee in the last year.[4] That paper has since been accepted for publication. He also reviewed a paper for Physical Review Letters and served on a panel for the Nuclear Physics - Experiment Program of the National Science Foundation including work for several days in Alexandria, VA. He also continues to maintain the Richmond computing cluster consisting of thirty, 12-core nodes for use by CLAS collaborators and his group. The cluster operating system was updated with university funds to Centos 7 in summer, 2018 to be compatible with the JLab computing environment.

[4] As part of the procedure for publishing CLAS6 results, an internal Collaboration committee reviews the paper after the analysis is approved. the draft then goes to the full Collaboration for final approval.

References

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[11] S. Lombardo et al. Photoproduction of K^+K^- meson pairs on the proton. *Phys. Rev.*, D98(5):052009, 2018.

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[13] N. Hirlinger Saylor et al. Measurement of Unpolarized and Polarized Cross Sections for Deeply Virtual Compton Scattering on the Proton at Jefferson Laboratory with CLAS. *Phys. Rev.*, C98(4):045203, 2018.

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Summary of Contract-Related Activities

Refereed Publications

1. Gerard Gilfoyle. Future Measurements of the Nucleon Elastic Electromagnetic Form Factors at Jefferson Lab. *EPJ Web Conf.*, 172:02004, 2018.
2. G. V. Fedotov et al. Measurements of the $\gamma_v p \to p'\pi^+\pi^-$ cross section with the CLAS detector for 0.4 GeV^2 $< Q^2 <$ 1.0 GeV^2 and 1.3 GeV $< W <$ 1.825 GeV. *Phys. Rev.*, C98(2):025203, 2018.
3. S. Lombardo et al. Photoproduction of K^+K^- meson pairs on the proton. *Phys. Rev.*, D98(5):052009, 2018.
4. M. Duer et al. Probing high-momentum protons and neutrons in neutron-rich nuclei. *Nature*, 560(7720):617–621, 2018.
5. N. Hirlinger Saylor et al. Measurement of Unpolarized and Polarized Cross Sections for Deeply Virtual Compton Scattering on the Proton at Jefferson Laboratory with CLAS. *Phys. Rev.*, C98(4):045203, 2018.

Invited Talks

1. G.P. Gilfoyle. Future Measurements of the Nucleon Elastic Electromagnetic Form Factors at Jefferson Lab. Presented at the Physics Department, University of Surrey, Guildford, UK, May 8, 2018, 2014. `https://facultystaff.richmond.edu/~ggilfoyl/research/gilfoyleSurrey2018.pdf`.

Contributed talks and posters.

1. B. S. Weinstein, A. R. Balsamo, and G.P. Gilfoyle. Software to Monitor CLAS12 Data Quality. In *Bull. Am. Phys. Soc., Fall DNP Meeting*, 2018. HA.00136.

Other Presentations

G.P. Gilfoyle. Hunting for Quarks and Gluons. University of Richmond Physics Seminar, August 24, 2016.

Service Work

1. Reviewer, Physical Review Letters
2. Reviewer, CLAS Collaboration.
3. Reviewer, US National Science Foundation, Nuclear Physics - Experiment Program.

PRODUCTS - DETAILS

PUBLICATIONS DETAIL

1. Conference Paper/Presentation: Software to Monitor CLAS12 Data Quality	
Conference Name: Fall DNP Meeting	**Conference Location:** Hawaii
Publication Status: Published	**Conference Date:** 01/31/2018
Author(s): B. S. Weinstein, A. R. Balsamo, and G.P. Gilfoyle	
Acknowledgement of DOE Support: Yes	

2. Journal Article: Measurements of the γ v p → p 0 π + π − cross section with the CLAS detector for 0.4 GeV 2 < Q 2 < 1.0 GeV 2 and 1.3 GeV < W < 1.825 GeV	
Journal: Phys. Rev.	
Publication Date: 2018	**Publication Status:** Published
Volume: C98	**First Page Number or eLocation ID:** 025203
Issue: 2	**Publication Location:** Not Provided
Author(s): G. V. Fedotov et al.	
Publication Identifier Type: DOI	**Publication Identifier:** 10.1103/PhysRevC.98.025203
Acknowledgement of DOE Support: Yes	**Peer Reviewed:** Yes

3. Journal Article: **Probing high-momentum protons and neutrons in neutron-rich nuclei**	
Journal: Nature	
Publication Date: 2018	**Publication Status:** Published
Volume: 560	**First Page Number or eLocation ID:** 617
Issue: 7720	**Publication Location:** Not Provided
Author(s): M. Duer et al.	
Publication Identifier Type: DOI	**Publication Identifier:** 10.1038/s41586-018-0400-z

Acknowledgement of DOE Support: Yes	**Peer Reviewed:** Yes

4. Journal Article: **Photoproduction of *K*+*K*− meson pairs on the proton**	
Journal: Phys.Rev.	
Publication Date: 2018	**Publication Status:** Published
Volume: D98	**First Page Number or eLocation ID:** 052009
Issue: Not Provided	**Publication Location:** Not Provided
Author(s): S. Lombardo et al.)	
Publication Identifier Type: DOI	**Publication Identifier:** 10.1103/PhysRevD.98.052009
Acknowledgement of DOE Support: Yes	**Peer Reviewed:** Yes

5. Journal Article: Measurement of Unpolarized and Polarized Cross Sections for Deeply Virtual Compton Scattering on the Proton at Jefferson Laboratory with CLAS	
Journal: Phys.Rev.	
Publication Date: 2018	**Publication Status:** Published
Volume: C98	**First Page Number or eLocation ID:** 045203
Issue: Not Provided	**Publication Location:** Not Provided
Author(s): N. Hirlinger Saylor et al.	
Publication Identifier Type: DOI	**Publication Identifier:** 10.1103/PhysRevC.98.045203
Acknowledgement of DOE Support: Yes	**Peer Reviewed:** Yes

6. Conference Paper/Presentation: Analysis of Quasi-Elastic e-n and e-p Scattering from Deuterium	
Conference Name: Meeting of the Division of Nuclear Physics of the American Physical Society	**Conference Location:** Pittsburgh, PA
Publication Status: Abstract published	**Conference Date:** 10/27/2017
Author(s): A.Balsamo and G.P.Gilfoyle	
Acknowledgement of DOE Support: Yes	

7. Conference Paper/Presentation: Geometry Calibration of the SVT in the CLAS12 Detector	
Conference Name: Division of Nuclear Physics Meeting	**Conference Location:** Vancouver, CA
Publication Status: Abstract published	**Conference Date:** 10/13/2017
Author(s): P. Davies and G.P. Gilfoyle	
Acknowledgement of DOE Support: Yes	

8. Conference Paper/Presentation: Measuring Quasi-Elastic e-n and e-p Scattering from Deuterium	
Conference Name: Division of Nuclear Physics Meeting	**Conference Location:** Vancouver, CA
Publication Status: Abstract published	**Conference Date:** 10/13/2017
Author(s): A. Balsamo and G.P. Gilfoyle	
Acknowledgement of DOE Support: Yes	

9. Conference Paper/Presentation: Hall B Organization	
Conference Name: CLAS12 Ready-for-Science Review	**Conference Location:** Newport News, VA
Publication Status: Available on indico site	**Conference Date:** 09/25/2017
Author(s): G.P.Gilfoyle	
Acknowledgement of DOE Support: No	

10. Conference Paper/Presentation: Future Measurements of the Nucleon Elastic Electromagnetic Form Factors at Jefferson Lab	
Conference Name: 47th Internatonal Symposium on Multiparticle Dynamics	**Conference Location:** Tlaxcala, Mexico
Publication Status: Submitted	**Conference Date:** 09/12/2017
Author(s): G.P. Gilfoyle et al.	
Acknowledgement of DOE Support: Yes	

11. Conference Paper/Presentation: Future Measurements of the Nucleon Elastic Electromagnetic Form Factors at Jefferson Lab

Conference Name: 47th International Symposium on Multiparticle Dynamics	**Conference Location:** Tlaxcala City, Mexico
Publication Status: Published	**Conference Date:** 09/12/2017
Author(s): G.P. Gilfoyle	
Acknowledgement of DOE Support: Yes	

12. Conference Paper/Presentation: Time of Flight Software Status	
Conference Name: CLAS12 Workshop	**Conference Location:** Jefferson Lab
Publication Status: No proceedings	**Conference Date:** 02/23/2017
Author(s): G.P.Gilfoyle, D.Carman, E. Golovach, V. Ziegler, G.Gavalian	
Acknowledgement of DOE Support: Yes	

13. Journal Article: Target and Beam-Target Spin Asymmetries in Exclusive Pion Electroproduction for Q2>1 GeV2. I. e p -> e pi+ n	
Journal: Phys. Rev.	
Publication Date: 2017	**Publication Status:** Published
Volume: C95	**First Page Number or eLocation ID:** 035206
Issue: 3	**Publication Location:** Not Provided
Author(s): P.E. Bosted et al.	
Publication Identifier Type: DOI	**Publication Identifier:** 10.1103
Acknowledgement of DOE Support: Yes	**Peer Reviewed:** Yes

14. Journal Article: Measurements of ep→e′π+π−p′ cross sections with CLAS at 1.40 GeV<W<2.0 GeV and 2.0 GeV2 <Q2<5.0 GeV2	
Journal: Phys. Rev.	
Publication Date: 2017	**Publication Status:** Published
Volume: C96	**First Page Number or eLocation ID:** 025209
Issue: 2	**Publication Location:** Not Provided

Author(s): E. L. Isupov et al.	
Publication Identifier Type: DOI	**Publication Identifier:** 10.1103
Acknowledgement of DOE Support: Yes	**Peer Reviewed:** Yes

15. Journal Article: Differential cross section measurements for gamma n --> pi- p above the first nucleon resonance region	
Journal: Phys. Rev.	
Publication Date: 2017	**Publication Status:** Published
Volume: C96	**First Page Number or eLocation ID:** 035204
Issue: 3	**Publication Location:** Not Provided
Author(s): P. T. Mattione et al.	
Publication Identifier Type: DOI	**Publication Identifier:** 10.1103
Acknowledgement of DOE Support: Yes	**Peer Reviewed:** Yes

16. Journal Article: Target and double spin asymmetries of deeply virtual pi0 production with a longitudinally polarized proton target and CLAS	
Journal: Phys. Lett.	
Publication Date: 2017	**Publication Status:** Published
Volume: B768	**First Page Number or eLocation ID:** 168
Issue: Not Provided	**Publication Location:** Not Provided
Author(s): A. Kim et al.	
Publication Identifier Type: DOI	**Publication Identifier:** 10.1016
Acknowledgement of DOE Support: Yes	**Peer Reviewed:** Yes

17. Journal Article: Photon beam asymmetry Sigma for eta and eta' photoproduction from the proton	
Journal: Phys. Lett.	
Publication Date: 2017	**Publication Status:** Published
Volume: B771	**First Page Number or eLocation ID:** 213
Issue: Not Provided	**Publication Location:** Not Provided

Author(s): P. Collins et al.	
Publication Identifier Type: DOI	**Publication Identifier:** 10.1016
Acknowledgement of DOE Support: Yes	**Peer Reviewed:** Yes

18. Journal Article: Exclusive eta electroproduction at W>2~ GeV with CLAS and transversity generalized parton distributions	
Journal: Phys. Rev.	
Publication Date: 2017	**Publication Status:** Published
Volume: C95	**First Page Number or eLocation ID:** 035202
Issue: 3	**Publication Location:** Not Provided
Author(s): I. Bedlinskiy et al.	
Publication Identifier Type: DOI	**Publication Identifier:** 10.1103
Acknowledgement of DOE Support: Yes	**Peer Reviewed:** Yes

19. Journal Article: Beam-Target Helicity Asymmetry for $\vec{\gamma} \vec{n} \rightarrow \pi^- p$ in the N^* Resonance Region	
Journal: Phys. Rev. Lett.	
Publication Date: 2017	**Publication Status:** Published
Volume: 118	**First Page Number or eLocation ID:** 242002
Issue: 24	**Publication Location:** Not Provided
Author(s): D. Ho et al.	
Publication Identifier Type: DOI	**Publication Identifier:** 10.1103
Acknowledgement of DOE Support: Yes	**Peer Reviewed:** Yes

20. Journal Article: Photon beam asymmetry Sigma in the reaction \vec{\gamma} p --> p omega for Egamma = 1.152 to 1.876 GeV	
Journal: Phys. Lett.	
Publication Date: 2017	**Publication Status:** Published
Volume: B773	**First Page Number or eLocation ID:** 112

Issue: Not Provided	**Publication Location:** Not Provided
Author(s): P. Collins et al.	
Publication Identifier Type: DOI	**Publication Identifier:** 10.1016
Acknowledgement of DOE Support: Yes	**Peer Reviewed:** Yes

21. Journal Article: Target and beam-target spin asymmetries in exclusive pion electroproduction for Q2>1 GeV2. II. e p --> e pi0 p	
Journal: Phys. Rev.	
Publication Date: 2017	**Publication Status:** Published
Volume: C95	**First Page Number or eLocation ID:** 035207
Issue: 3	**Publication Location:** Not Provided
Author(s): P. E. Bosted et al.	
Publication Identifier Type: DOI	**Publication Identifier:** 10.1103
Acknowledgement of DOE Support: Yes	**Peer Reviewed:** Yes

22. Journal Article: Beam-target double-spin asymmetry in quasielastic electron scattering off the deuteron with CLAS	
Journal: Phys. Rev.	
Publication Date: 2017	**Publication Status:** Published
Volume: C95	**First Page Number or eLocation ID:** 024005
Issue: 2	**Publication Location:** Not Provided
Author(s): M. Mayer et al.	
Publication Identifier Type: DOI	**Publication Identifier:** 10.1103
Acknowledgement of DOE Support: Yes	**Peer Reviewed:** Yes

23. Journal Article: Measurement of two-photon exchange effect by comparing elastic e^(+/-) p cross sections	
Journal: Phys. Rev.	
Publication Date: 2017	**Publication Status:** Published
Volume: C95	**First Page Number or eLocation ID:** 065201

Issue: 6	**Publication Location:** Not Provided
Author(s): D. Rimal et al.	
Publication Identifier Type: DOI	**Publication Identifier:** 10.1103
Acknowledgement of DOE Support: Yes	**Peer Reviewed:** Yes

24. Conference Paper/Presentation: CLAS Collaboration Transition to CLAS12 Operations	
Conference Name: CLAS Collaboration Meeting	**Conference Location:** Jefferson Lab
Publication Status: Available on indico	**Conference Date:** 11/02/2016
Author(s): G.P.Gilfoyle	
Acknowledgement of DOE Support: Yes	

25. Journal Article: Target and beam-target spin asymmetries in exclusive π + and π − electroproduction with 1.6- to 5.7-GeV electrons	
Journal: Phys. Rev. C	
Publication Date: 11/01/2016	**Publication Status:** Published
Volume: 94	**First Page Number or eLocation ID:** 055201
Issue: 5	**Publication Location:** USA
Author(s): P. E. Bosted et al.	
Publication Identifier Type: DOI	**Publication Identifier:** 10.1103/PhysRevC.94.055201
Acknowledgement of DOE Support: Yes	**Peer Reviewed:** Yes

26. Conference Paper/Presentation: Measuring the Neutron Detection Efficiency in CLAS12	
Conference Name: Division of Nuclear Physics Meeting	**Conference Location:** Vancouver, CA
Publication Status: Abstract published	**Conference Date:** 10/13/2016
Author(s): K. Sherman and G.P. Gilfoyle	
Acknowledgement of DOE Support: Yes	

27. Conference Paper/Presentation: Uniformly Rastering an Electron Beam on a Polarized Cryotarget	
Conference Name: Division of Nuclear Physics Meeting	**Conference Location:** Vancouver, CA
Publication Status: Abstract published	**Conference Date:** 10/13/2016
Author(s): D. Brakman, C. Cuevas, and G.P. Gilfoyle	
Acknowledgement of DOE Support: Yes	

28. Conference Paper/Presentation: Hunting for Quarks and Gluons	
Conference Name: University of Richmond Physics Seminar	**Conference Location:** Richmond, VA
Publication Status: no proceedings	**Conference Date:** 08/24/2016
Author(s): G.P.Gilfoyle	
Acknowledgement of DOE Support: Yes	

29. Journal Article: Photoproduction of the f1 (1285) Meson	
Journal: Phys. Rev C	
Publication Date: 06/09/2016	**Publication Status:** Published
Volume: 93	**First Page Number or eLocation ID:** 065202
Issue: 6	**Publication Location:** USA
Author(s): R. Dickson et al.	
Publication Identifier Type: DOI	**Publication Identifier:** 10.1103/PhysRevC.93.065202
Acknowledgement of DOE Support: Yes	**Peer Reviewed:** Yes

30. Journal Article: Photoproduction of Λ and Σ0 hyperons using linearly polarized photons	
Journal: Phys. Rev. C	
Publication Date: 06/08/2016	**Publication Status:** Published
Volume: 93	**First Page Number or eLocation ID:** 065201
Issue: 6	**Publication Location:** USA

Author(s): C. A. Paterson et al.	
Publication Identifier Type: DOI	**Publication Identifier:** 10.1103/PhysRevC.93.065201
Acknowledgement of DOE Support: Yes	**Peer Reviewed:** Yes

31. Conference Paper/Presentation: Future Measurements of the Neutron Magnetic Form Factor at Jefferson Lab	
Conference Name: Probing Transverse Nucleon Structure at High Momentum Transfer	**Conference Location:** Trento, Italy
Publication Status: No proceedings	**Conference Date:** 04/21/2016
Author(s): G.P.Gilfoyle	
Acknowledgement of DOE Support: Yes	

32. Journal Article: First measurement of the helicity asymmetry E in η photoproduction on the proton	
Journal: Phys. Lett. B	
Publication Date: 04/10/2016	**Publication Status:** Published
Volume: 755	**First Page Number or eLocation ID:** 64
Issue: Not Provided	**Publication Location:** Netherlands
Author(s): I. Senderovich et al.	
Publication Identifier Type: DOI	**Publication Identifier:** 016/j.physletb.2016.01.044
Acknowledgement of DOE Support: Yes	**Peer Reviewed:** Yes

33. Journal Article: Measurement of Target and Double-spin Asymmetries for the ep → eπ + (n) Reaction in the Nucleon Resonance Region at Low Q2	
Journal: Phys. Rev. C	
Publication Date: 2016	**Publication Status:** Published
Volume: 94	**First Page Number or eLocation ID:** 045206
Issue: 4	**Publication Location:** USA
Author(s): X. Zheng et al.	

Publication Identifier Type: DOI	**Publication Identifier:** 10.1103/PhysRevC.94.045206
Acknowledgement of DOE Support: Yes	**Peer Reviewed:** Yes

34. Conference Paper/Presentation: Future Measurements of the Nucleon Elastic Electromagnetic Form Factors at Jefferson Lab	
Conference Name: Electromagnetic Interactions in Nucleons and Nuclei 2015	**Conference Location:** Paphos, Cyprus
Publication Status: Abstract published	**Conference Date:** 11/03/2015
Author(s): G.P.Gilfoyle	
Acknowledgement of DOE Support: Yes	

35. Conference Paper/Presentation: Study of the Neutron Detection Efficiency for the CLAS12 Detector	
Conference Name: Fall Meeting of the Division of Nuclear Physics of the American Physical Society	**Conference Location:** Sante Fe, NM
Publication Status: Abstract published	**Conference Date:** 10/30/2015
Author(s): K. Sherman and G.P.Gilfoyle	
Acknowledgement of DOE Support: Yes	

36. Conference Paper/Presentation: Dual Target Design for CLAS12	
Conference Name: Fall Meeting of the Division of Nuclear Physics of the American Physical Society	**Conference Location:** Sante Fe, NM
Publication Status: Abstract published	**Conference Date:** 10/30/2015
Author(s): O. Alam and G.P.Gilfoyle	
Acknowledgement of DOE Support: Yes	

37. Conference Paper/Presentation: Cryotarget Control Software for Liquid Deuterium	
Conference Name: Fall Meeting of the Division of Nuclear Physics of the American Physical Society	**Conference Location:** Sante Fe, NM
Publication Status: Abstract published	**Conference Date:** 10/30/2015
Author(s): D. Brakman, C. Cuevas, and G.P.Gilfoyle	
Acknowledgement of DOE Support: Yes	

38. Conference Paper/Presentation: CLAS12 Track-Based Alignment	
Conference Name: CLAS12 Workshop	**Conference Location:** Newport News, VA
Publication Status: Available on indico site	**Conference Date:** 10/20/2015
Author(s): G.P.Gilfoyle	
Acknowledgement of DOE Support: No	

39. Journal Article: Cross sections for the exclusive photon electroproduction on the proton and Generalized Parton Distributions	
Journal: Phys. Rev. Lett.	
Publication Date: 2015	**Publication Status:** Published
Volume: 115	**First Page Number or eLocation ID:** 212003
Issue: 21	**Publication Location:** Not Provided
Author(s): H. S. Jo et al.	
Publication Identifier Type: DOI	**Publication Identifier:** 10.1103
Acknowledgement of DOE Support: Yes	**Peer Reviewed:** Yes

40. Journal Article: Search for baryon-number and lepton-number violating decays of Λ hyperons using the CLAS detector at Jefferson Laboratory	
Journal: Phys. Rev.	
Publication Date: 2015	**Publication Status:** Published
Volume: D92	**First Page Number or eLocation ID:** 072002
Issue: 7	**Publication Location:** Not Provided
Author(s): M. E. McCracken et al	
Publication Identifier Type: DOI	**Publication Identifier:** 10.1103
Acknowledgement of DOE Support: Yes	**Peer Reviewed:** Yes

41. Journal Article: Determination of the beam-spin asymmetry of deuteron photodisintegration in the energy region Eγ = 1.1 –- 2.3 GeV

Journal: Phys. Rev.	
Publication Date: 2015	**Publication Status:** Published
Volume: C91	**First Page Number or eLocation ID:** 055202
Issue: 5	**Publication Location:** Not Provided
Author(s): N. Zachariou et al.	
Publication Identifier Type: DOI	**Publication Identifier:** 10.1103
Acknowledgement of DOE Support: Yes	**Peer Reviewed:** Yes

42. Journal Article: Precise determination of the deuteron spin structure at low to moderate Q2 with CLAS and extraction of the neutron contribution	
Journal: Phys. Rev.	
Publication Date: 2015	**Publication Status:** Published
Volume: C92	**First Page Number or eLocation ID:** 055201
Issue: 5	**Publication Location:** Not Provided
Author(s): N. Guler et al.	
Publication Identifier Type: DOI	**Publication Identifier:** 10.1103
Acknowledgement of DOE Support: Yes	**Peer Reviewed:** Yes

43. Journal Article: Single and double spin asymmetries for deeply virtual Compton scattering measured with CLAS and a longitudinally polarized proton target	
Journal: Phys.Rev.	
Publication Date: 2015	**Publication Status:** Published
Volume: D91	**First Page Number or eLocation ID:** 052014
Issue: 5	**Publication Location:** Not Provided
Author(s): S. Pisano et al.	
Publication Identifier Type: DOI	**Publication Identifier:** 10.1103
Acknowledgement of DOE Support: Yes	**Peer Reviewed:** Yes

INTELLECTUAL PROPERTIES DETAIL

There are no intellectual properties to report.

TECHNOLOGIES AND TECHNIQUES DETAIL

There are no technologies or techniques to report.

OTHER PRODUCTS DETAIL

1. Other Products: Protocols

Description: CLAS Collaboration Chair Procedures (CLAS12-NOTE 2017-015)

G.P.Gilfoyle, R. De Vita, B. McKinnon, K.Hicks, and D.Ireland

This document is a CLAS Collaboration technical report (CLAS12-NOTE 2017-015, listed 11/25/17) is a set of guidelines for the duties and responsibilities of the CLAS Collaboration Chair. The goal is to provide new CLAS Chairs with a "user's manual" to ensure a smooth transition in the operations of the Collaboration when a newly elected Chair takes up their duties. This document should be updated as those duties evolve with time.

2. Other Products: Software or NetWare

Description: Geometry and Alignment Software for the CLAS12 Silicon Vertex Tracker -

The CLAS12 detector was recently completed in Hall B as part of the CEBAF 12 GeV Upgrade at Jefferson Lab. The Silicon Vertex Tracker (SVT) is a position sensitive detector subsystem in CLAS12, and is the closest one to the target. We have developed a software model of the SVT geometry along with the tools to apply the model to the CLAS12 simulation and reconstruction. The sensors of the SVT consist of long, narrow strips of p-type silicon with aluminum electrodes on an n-type, bulk silicon substrate. There are 256 strips in a sensor, with a readout pitch at the upstream end of 156 µm, and a stereo angle of 0 – 3 deg. The location of the sensor strips must be known to a precision of a few tens of microns in order to accurately reconstruct particle tracks with the required position resolution of 60 µm specified in the CLAS12 design. The geometry of the SVT has been well defined according to the design specification after consultation with the design team and the software developed to align the sectors using cosmic data. The CLAS12 simulation and reconstruction programs can now obtain the core geometry parameters from one source. The SVT geometry code is now part of the standard CLAS12 software distribution. The documentation for the code is a CLAS Collaboration technical report CLAS12-NOTE-015 by P. Davies, V. Ziegler, M. Ungaro, Y. Gotra, A. Kim, and G.P. Gilfoyle and listed 8/9/17.

3. Other Products: Software or NetWare

Description: CLAS12 Dual Target -

An experiment to measure the neutron magnetic form factor(GMn) is planned for the new CLAS12 detector (JLab Experiment E12-07-104). This form factor is extracted from the ratio of quasielastic electron-neutron to electron-proton scattering off a liquid deuterium target. A collinear liquid hydrogen target will be used to measure the proton and neutron detection efficiencies at the same time as production data is collected from a liquid deuterium target. This will ensure that the calibration data are collected under the same running conditions as the production data. This is particularly important to make a precise measurement of the neutron detection efficiency. To test the target design, we have simulated the dual-target geometry, support structures and cryogenic transport systems using the CLAS12, physics-based simulation package called gemc. This program is built on the Geant4 API to define specific geometries and materials for the target. An initial study of the impact of this dual-target structure revealed limited effects on the electron momentum and angular resolutions.

The data and scripts to generate the geometry parameters and their associated database entries are now part of the standard CLAS12 software distribution. The user selects this target by setting a single option. The work was the subject of a poster at the fall, 2015 meeting of the Division of Nuclear Physics ("Dual Target Design for CLAS12", Bull. Am. Phys. Soc., Fall DNP Meeting, EA.00121 (2015)).

4. Other Products: Software or NetWare

Description: A central instrument in CLAS12 is electromagnetic calorimeters system (ECAL) made of altering layers of lead and scintillator. A particle that hits ECAL creates a particle shower that induces light in the scintillators which is converted to a voltage to determine the particle's position and deposited energy. If a particle hits near the edge of the ECAL, some energy may seep out the side and go undetected. To study this effect we simulated and reconstructed CLAS12 electron events, using CLAS12 Common Tools to analyze these near-edge hits. To identify an optimal distance from the ECAL edge for observing complete particle showers we studied the resolution and deposited energy of those events.

5. Other Products: Software or NetWare

Description: One of Jefferson Lab's goals is to unravel the quark-gluon structure of nuclei. We will use the ratio, R, of electron-neutron to electron-proton scattering on deuterium to probe the magnetic form factor of the neutron, GMn . GMn is the magnetic distribution of charge within the neutron. We have developed an end-to-end analysis from simulation to extraction of R in quasi-elastic kinematics for an approved experiment with the CLAS12 detector. We focus on neutrons detected in the CLAS12 calorimeters and protons measured with the CLAS12 forward detector. Events were generated with the Quasi-Elastic Event Generator (QUEEG) and passed through the Monte Carlo code gemc to simulate the CLAS12 response. These simulated events were reconstructed using the latest CLAS12 Common Tools. We first match the solid angle for e-n and e-p events. The electron information is used to predict the path of QE neutrons and protons through CLAS12. If both particles interact in CLAS12 the e-n and e-p events have the same solid angle. We select QE events by searching for nuclei near the predicted position based on the scattered electron information. An angular cut between the predicted 3-momentum of the nucleon and the measured value, θ_{pq} , separates QE and inelastic events. We will show the simulated R as a function of the four-momentum transfer Q^2 and use this value to extract the GMn .

6. Other Products: Software or NetWare

Description: The physics program at Jefferson Laboratory will probe the quark sub-structure of the nucleus with the Continuous Electron Beam Accelerator Facility (CEBAF). We use the CEBAF Large Acceptance Spectrometer (CLAS12) to measure the charge, momentum, and energy of particles pro-duced by electron-nucleus collisions. We are developing software to monitor data quality from the analysis of a scheduled experiment that will measure the neutron magnetic form factor (GMn) among at least six other experiments. The monitoring code was written with a java-like scripting language called groovy and uses the CLAS12 Common Tools. To test the code we gener-ated quasielastic events and simulated the CLAS12 response with the Monte Carlo code gemc. The events were reconstructed and analysed to extract monitoring observables. For example, we obtained the electron sampling fraction as a function of run number. The sampling fraction is the energy deposited in an electromagnetic calorimeter divided by the momentum and is expected to be constant. We will show simulations of the sampling frac-tion, ratio of protons to electrons and other quantities versus run number.

PARTICIPANTS AND OTHER COLLABORATING ORGANIZATIONS

PARTICIPANTS DETAIL

1. Participant: Alexander Balsamo		
Project Role: Undergraduate Student	**Person Months Worked**: 3	**Funding Support (if other than this award)**: Not Provided
Contribution to the Project: One of Jefferson Lab's goals is to unravel the quark-gluon structure of nuclei. We will use the ratio, R, of electron-neutron to electron-proton scattering on deuterium to probe the magnetic form factor of the neutron, GMn . The GMn is a magnetic distribution of charge within the neutron. We have developed an end-to-end analysis from simulation to extraction of R in quasi-elastic kinematics for an approved experiment with the CLAS12 detector. We focus on neutrons detected in the CLAS12 calorimeters and protons measured with the CLAS12 forward detector. Events were generated with the Quasi-Elastic Event Generator (QUEEG) and passed through the Monte Carlo code gemc to simulate the CLAS12 response. These simulated events were reconstructed using the latest CLAS12 Common Tools. We first match the solid angle for e-n and e-p events. The electron information is used to predict the path of QE neutrons and protons through CLAS12. If both particles interact in CLAS12 the e-n and e-p events have the same solid angle. We select QE events by searching for nuclei near the predicted position based on the scattered electron information. An angular cut between the predicted 3-momentum of the nucleon and the measured value, θ_{pq} , separates QE and inelastic events. We will show the simulated R as a function of the four-momentum transfer Q^2 and use this value to extract the GMn .		
International Collaboration: No		
International Travel: No		

2. Participant: Nicholas Child		
Project Role: Undergraduate Student	**Person Months Worked**: 3	**Funding Support (if other than this award)**: Not Provided
Contribution to the Project: A central instrument in CLAS12 is electromagnetic calorimeters system (ECAL) made of altering layers of lead and scintillator. A particle that hits ECAL creates a particle shower that induces light in the scintillators which is converted to a voltage to determine the particle's position and deposited energy. If a particle hits near the edge of the ECAL, some energy may seep out the side and go undetected. To study this effect we simulated and reconstructed CLAS12 electron events, using CLAS12 Common Tools to analyze these near-edge hits. To identify an optimal distance from the ECAL edge for observing complete particle showers we studied the resolution and deposited energy of those events.		
International Collaboration: No		

International Travel: No

3. Participant: Dr. Gerard P Gilfoyle		
Project Role: Principal Investigator/Project Director	**Person Months Worked**: 11	**Funding Support (if other than this award)**: Univerrsity of Richmond
Contribution to the Project: Gilfoyle is the principal investigator on the project and mentors the students listed on the grant. He is also a member of the team on the track-based alignment project for the Central Vertex Tracker in CLAS12 and is leading the effort to calibrate and prepare for the CLAS12 GMn measurement scheduled for spring and fall 2019. See attached report for more details.		
International Collaboration: No		
International Travel: Yes		
#	**Country of Travel**	**Duration of Stay (in days)**
1	United Kingdom (GBR)	4

4. Participant: Ben Weinstein		
Project Role: Undergraduate Student	**Person Months Worked**: 3	**Funding Support (if other than this award)**: Not Provided
Contribution to the Project: We are developing software to monitor data quality from the analysis of a scheduled experiment that will measure the neutron magnetic form factor (GMn) among at least six other experiments. The monitoring code was written with a java-like scripting language called groovy and uses the CLAS12 Common Tools. To test the code we generated quasielastic events and simulated the CLAS12 response with the Monte Carlo code gemc. The events were reconstructed and analysed to extract monitoring observables. For example, we obtained the electron sampling fraction as a function of run number. The sampling fraction is the energy deposited in an electromagnetic calorimeter divided by the momentum and is expected to be constant. We will show simulations of the sampling fraction, ratio of protons to electrons and other quantities versus run number.		
International Collaboration: No		
International Travel: No		

PARTNERS DETAIL
There are no partners to report.

OTHER COLLABORATORS DETAIL
There are no other collaborators to report.

IMPACT

1. What is the impact on the development of the principal discipline(s) of the project?

We are making final preparations for a large JLab experiment with the ClAS12 detector to measure the elastic, electromagnetic form factor of the neutron. The experiment is scheduled to start in 2019. See attached report for more details.

2. What is the impact on other disciplines?

Scientists from other disciplines within the University of Richmond used the computing cluster that was originally obtained with NSF funds. These scientists (biologists) were able to run long calculations more quickly than on single desktop computers.

3. What is the impact on the development of human resources?

Three undergraduates were trained at Richmond and JLab. One has now working towards a masters degree in physics at Christopher Newport University with plans to continue to a doctoral program. The other two are still undergraduates.

4. What is the impact on physical, institutional, and information resources that form infrastructure?

The Richmond program educates young scientists for future work, attracts students into nuclear physics, and builds and maintains the research infrastructure at Richmond. We make heavy use during the summer of the Richmond cluster which helps justify the continued support from the University.

5. What is the impact on technology transfer?

Undergraduates and a masters student are trained in analysis of large, complex data sets. Richmond physics majors have gone on to jobs in industry using precisely the skills they learned as research assistants working on JLab projects. There is also growing interest in data science and support for high-performance computing like that used in physics and for JLab research at the University of Richmond.

6. What is the impact on society beyond science and technology?

Undergraduates and our masters students are technically trained at the leading of technology which prepares them for high-paying jobs that will build our future economy and standard of living.

7. Foreign Spending

Not Provided

CHANGES - PROBLEMS

1. Changes in approach and reasons for change
Nothing to report.
2. Actual or anticipated problems or delays and actions or plans to resolve them
Nothing to report.
3. Changes that have a significant impact on expenditures
Nothing to report.
4. Significant changes in use or care of human subjects, vertebrate animals, and/or biohazards
Nothing to report.
5. Change of primary performance site location from that originally proposed
Nothing to report.
6. Carryover Amount
Estimated carryover amount for the next budget period: $3,000.00