COVER PAGE

Project Title: Medium Energy Nuclear Physics at the University of Richmond	
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Submitting Official Information: N/A **Email:** N/A **Contact:** N/A	

ACCOMPLISHMENTS

1. What are the major goals of the project?

The major goals are (1) the analysis of a measurement of the neutron magnetic form factor (GMn) and (2) the continued development, testing, and validating of software for the CLAS12 data reconstruction and analysis. The GMn measurement was done in 2019-2020 with the CLAS12 detector in Hall B at Jefferson Lab (JLab experiment E12-07-104). We are part of a broad program at JLab to measure the elastic, electromagnetic form factors consisting of seven experiments including two to measure GMn. Both GMn experiments use methods pioneered in Hall B with the previous detector CLAS6. The PI is one of the lead authors on that work. See Part 2 for more details.

2. What was accomplished under these goals?

The data for the GMn measurement (JLab experiment E12-07-104) have been collected. The relevant CLAS12 run groups are Run Groups A, B, and K (RGA, RGB, and RGK). In RGB a liquid deuterium target was used to measure the ratio R of e-n/ep scattering which will enable us to extract GMn. A liquid hydrogen target was used for RGA and RGK and we will use those data to measure the CLAS12 neutron detection efficiency (NDE) which is a key contributor to the systematic uncertainty of GMn.

We now summarize these data sets. RGB was run at beam energies of 10.2, 10.4, and 10.6 GeV during spring and fall 2019 and January 2020 for a total of 39 PAC days out of 90 PAC approved days. A total integrated charge of 155 mC was collected out of 510 mC approved by the PAC. The run group is preparing for pass0 of the analysis of the spring, 2019 data to calibrate the data sets in anticipation of pass1 in the next few months. During RGB Gilfoyle served as run coordinator during spring 2019 (8 days) and January 2020 (11 days).

We are analyzing data from two run groups (RGA and RGK) to measure the CLAS12 NDE. The NDE is needed to correct the measured e-n yield and it is one of the largest components of the systematic uncertainty of GMn. Both run groups used a liquid hydrogen target and we are exploiting the ep->e' pi+ n reaction as a source of tagged neutrons. RGA used beam energies in the range 10.2-10.6 GeV, and collected data during spring and fall 2018 and spring 2019. A total charge of 300 mC out of 648 approved was collected. The data calibration is far along and pass1 of the data cooking is expected soon. We are also taking advantage of RGK. It ran in fall 2018 and collected about 7% of the approved integrated charge. The beam energies were 6.5 and 7.5 GeV giving us the opportunity to study the NDE under different run conditions.

We now discuss the status of the analysis of the GMn measurement and the extraction of the CLAS12 NDE. About one year ago we formed a collaboration with Dr. Brian Raue in the nuclear physics group at Florida International University. Dr. Raue's doctoral student Lamya Baashen will analyze the RGB data and extract GMn for her thesis. She is now working primarily on the GMn analysis and the NDE measurement. She has passed her PhD qualifier. Her focus over the last six months has been measuring the NDE from the RGA and RGK data sets. As mentioned above our method is to use the reaction ep -> e' pi+ n reaction on liquid hydrogen as a source of tagged neutrons. We use the scattered electron and pi+ information to predict the location of the neutron in CLAS12. If this predicted track strikes the calorimeter fiducial volume we search for nearby hits in the CLAS12 calorimeters that are not associated with a charged particle track. We then require the predicted and found calorimeter hits to be near one another. The NDE is the ratio of the detected neutrons to the ones expected to strike the fiducial volume. The program to perform this analysis was originally developed by a Richmond undergraduate (Keegan Sherman, now a post-qualifier doctoral student at Old Dominion University) and has been modified for the current software tools by Ms. Baashen and other members of the group. We are now optimizing the event selection and investigating ways to reduce the neutral background we observe in the CLAS12 Forward Detector.

One step to understanding that neutral background and to validate our algorithms is to use simulation. For the NDE

measurement on hydrogen we are using the Pythia event generator which is widely used in particle and nuclear physics. For the deuterium target My Ahmed El Alaoui, a CLAS12 collaborator at USM in Chile, has written a variation of Pythia that includes Fermi motion for a range of nuclei. This effort is just getting started. The codes and scripts for a full end-to-end simulation are written and tested and production running has begun.

Last summer, two of our undergraduate research students Matthew Heyrich and Xiaodi Hu studied the event selection for ep->e'N events on liquid deuterium to test our analysis codes for measuring the ratio R=e-n/e-p used to extract GMn. We select good electrons first, assume quasi-elastic (QE) scattering on deuterium and determine the 4-momentum of emitted nucleon. We then do acceptance matching by 'swimming' hypothetical neutron and proton tracks through CLAS12. If both of these tracks strike the fiducial volume of CLAS12 the analysis proceeds. This event matching ensures our sample has the same geometric acceptance for protons and neutrons. We then search for a proton or neutron hit in the CLAS12 calorimeters in a narrow angular cone around the predicted hit. This angle is between the detected nucleon momentum and the electron three-momentum transfer q. Last summer we used our standard quasi-elastic event generator and added the nuclear-target Pythia event generator mentioned above. Initially we found that the quasi-elastic peak is overwhelmed by the inelastic contribution. However, implementing the narrow cone constraint significantly reduced the background. The ratio of QE to inelastic events increased by a factor of ten to ~6. This project was the topic of an undergraduate poster from our two Richmond students at the fall meeting of the Division of Nuclear Physics of the APS. Both students were supported by this grant.

Our group continues to contribute to the CLAS12 software project. In particular, a masters student from the University of Surrey, UK joined our group in February, 2019 for a 10-month research experience (Feb-Dec, 2019). He was supported with a stipend from this grant. Mr. Michael Armstrong worked on two software projects. He created a new unit test for the CLAS12 reconstruction code. The unit test is a java method that includes the raw data for a single event generated from the CLAS12 simulation code. Each night the CLAS12 Common Tools are rebuilt and the unit test is executed. This single event is reconstructed and the results compared with a standard set of ranges for the momentum components and track vertex. These ranges were determined from simulations. If the reconstructed results lie outside the expected ranges a warning is generated. This method is designed to catch significant changes to the reconstruction performance even when the code successfully builds. Mr. Armstrong generated the new test event, validated it using the full, CLAS12, simulation chain and extracted the reconstruction resolution. The code is now part of the CLAS12 Common Tools. He presented his results at the fall, 2019 national meeting of the Division of Nuclear Physics of the American Physical Society. We will write up his work over the next few months as a JLab technical report.

Mr. Armstrong developed a second project in the last year investigating the Hough transform as a means to identify the hits of a helical track created by a charged particle in the CLAS12 Central Detector (CD). The Hough transform is a technique developed in the days of bubble chambers and is now used in image processing to identify hits or pixels associated with lines and circles. Dr. Veronique Ziegler (a JLab staff scientist and lead developer of the offline reconstruction code) has implemented a version of the Hough transform in the CLAS12 Common Tools. Mr. Armstrong studied the performance of Dr. Ziegler's algorithm in simulation. He found this early version of the algorithm had a momentum resolution of about 8% (the CD performance specification is 3%), but a large uncertainty in the position of the circle center (~10 cm). This project was included in Mr. Armstrong's masters thesis.

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

We now summarize the training benefits of the Richmond program for the last year. Since 2013 the University of Richmond and the University of Surrey in the UK have supported a joint research program for Surrey physics masters degree students at Jefferson Lab. These students must participate in a 10-month research experience at an appropriate facility. The program at Richmond has been funded by this DOE grant since its inception. The students are typically the age of US college seniors, but they have a deeper physics background than liberal arts students like those at Richmond. They also come with some knowledge of the linux operating system and programming experience from their course work at Surrey which is a good match for our Richmond program at JLab which has a sharp focus on software development. The Surrey students are stationed at JLab to make full use of the resources there. The PI spends one day each week at JLab (during the academic semester and the summer) and holds 1-2 additional meetings via video conference. Four students have

completed the Richmond research year and a fifth, Adrian Saina, recently arrived in the US. These students have made three poster presentations at APS Division of Nuclear Physics meetings and have been co-authors on two JLab technical reports (CLAS12-NOTES). A third report is in preparation based on the work of the most recent student, Michael Armstrong, who completed his research year in December 2019. Components o the programming projects for three of the students has been incorporated into the CLAS12 Common Tools. The students have universally been impressed with the environment at JLab and attended seminars, CLAS12 Collaboration meetings, and traveled to conferences. Michael Armstrong is now applying to graduate schools and technical positions in Europe and the US.

University of Richmond undergraduates also benefit from the training they receive in our program. Each summer 2-3 Richmond students work in my laboratory on-campus at Richmond for 10-12 weeks. This grant provides funding for two of the students and the University supplies some additional funding for summer stipends. Almost all of these student researchers present posters at the fall meeting of the APS Division of Nuclear Physics and, like the Surrey students, benefit from the breadth of talks and learning experiences at a US national lab. We typically visit JLab one day per week during the summer and have 1-2 additional meetings electronically. Two recent University of Richmond physics graduates have gone on to graduate programs. Keegan Sherman is now a post-qualifier PhD student at Old Dominion University and Alexander Balsamo is a masters student at Christopher Newport University.

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

The results have been disseminated through presentations at conferences - two Richmond undergraduates (Matthew Heyrich and Xiaodi) and the University of Surrey masters student (Michael Armstrong) presented posters at the fall, 2019 DNP meeting. Gilfoyle typically gives one invited talk each year, but with Run Group B running in 2019-2020 and serving as run coordinator there was not enough time. Gilfoyle was co-author on seven refereed papers in 2019.

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

During the next reporting period we will focus on the analysis of the CLAS12 GMn experiment (E12-07-104) and the continued software development for the CLAS12 Common Tools. The GMn analysis consists of two major parts - (1) the measurement of the neutron detection efficiency (NDE) and (2) the extraction of GMn. The NDE will be measured with the ep -> e' pi+ n reaction on liquid hydrogen. See Part 2 for more details. This procedure provides us with a sample of tagged neutrons we use to determine the NDE. The liquid hydrogen data for this measurement have already been collected in Run Groups A (RGA) and K (RGK). RGA ran at beam energies 10-2-10.6 GeV and RGK ran at 6.5 GeV and 7.5 GeV. The range of beam energies presents an opportunity to study systematic effects on the NDE and better understand the CLAS12 response. The calibration and reconstruction of the RGA and RGK data is far along. We expect pass1 for RGA soon. The lead analysis person for this part of the project is L.Baashen who is a PhD student at Florida International University working with Dr. B. Raue. She has already passed her PhD qualifier. Gilfoyle will be responsible for simulations of the NDE to test and validate our procedures.

The extraction of the neutron magnetic form factor from the deuterium data will be done using the ratio method. The ratio R of e-n to e-p events is formed, corrected for various effects (e.g. the neutron detection efficiency) and related to the expression for R in terms of the proton and neutron elastic, electromagnetic form factors (EEFFs). The ratio depends on all the EEFFs (electric and magnetic for protons and neutrons). The proton form factors are known much more precisely than the neutron ones and the neutron electric form factor GEn is small and can be estimated from systematics. These features enable us to use the measured R to solve for GMn with a much better resolution than other methods. This technique was

used in the previous 6-GeV-era CLAS measurement of GMn. The data collection for the measurement is complete (RGB) and the calibration and reconstruction are ongoing. Some of the pass0 results are being used for preliminary data selection to study the data sample and test our algorithms. Some more mature, pass1 results will be available in the next few months. For this part of the project L.Baashen will be lead analysis person and Gilfoyle will be responsible for simulations and testing algorithms.

We will also continue our commitment to develop software for the simulation, reconstruction, and analysis of data for CLAS12. The joint Richmond-Surrey program to support a masters student continues with funding from this grant. Past students have made significant contributions to the CLAS12 Common Tools and we plan to follow that precedent. The latest student Adrian Saina arrived in mid-February and is stationed at Jefferson Lab. We are training him in the CLAS12 software and will coordinate his work with Dr. V.Ziegler the JLab staff scientist who leads the CLAS12 software group.

PRODUCTS - DETAILS

PUBLICATIONS DETAIL

1. Conference Paper/Presentation: CLAS12 Drift Chamber Reconstruction Code Validation	
Conference Name: Fall DNP Meeting	**Conference Location:** Crystal City, VA
Publication Status: Published	**Conference Date:** 10/15/2019
Author(s): M.Armstrong, G.P.Gilfoyle, and V.Ziegler	
Acknowledgement of DOE Support: Yes	

2. Conference Paper/Presentation: Event selection in electron scattering from an unpolarized deuterium target	
Conference Name: Fall DNP Meeting	**Conference Location:** Crystal City, VA
Publication Status: Published	**Conference Date:** 10/15/2019
Author(s): X. Hu, M.Heyrich, and G.P.Gilfoyle	
Acknowledgement of DOE Support: Yes	

3. Journal Article: Modified structure of protons and neutrons in correlated pairs	
Journal: Nature	
Publication Date: 2019	**Publication Status:** Published
Volume: 566	**First Page Number or eLocation ID:** 354
Issue: 7744	**Publication Location:** Not Provided
Author(s): B. Schmookler et al.	
Publication Identifier Type: DOI	**Publication Identifier:** DOI: 10.1038/s41586-019-0925-9
Acknowledgement of DOE Support: Yes	**Peer Reviewed:** Yes

4. Journal Article: Measurement of Nuclear Transparency Ratios for Protons and Neutrons.	
Journal: Phys. Lett.	

Publication Date: 2019	**Publication Status:** Published
Volume: B797	**First Page Number or eLocation ID:** 134792
Issue: Not Provided	**Publication Location:** Not Provided
Author(s): M. Duer et al.	
Publication Identifier Type: DOI	**Publication Identifier:** DOI: 10.1103/PhysRevLett.122.172502
Acknowledgement of DOE Support: Yes	**Peer Reviewed:** Yes

5. Journal Article: Direct Observation of Proton-Neutron Short-Range Correlation Dominance in Heavy Nuclei.	
Journal: Phys. Rev. Lett.	
Publication Date: 2019	**Publication Status:** Published
Volume: 122	**First Page Number or eLocation ID:** 172502
Issue: 17	**Publication Location:** Not Provided
Author(s): M. Duer et al.	
Publication Identifier Type: DOI	**Publication Identifier:** DOI: 10.1103/PhysRevLett.122.172502
Acknowledgement of DOE Support: Yes	**Peer Reviewed:** Yes

6. Journal Article: Measurement of the beam spin asymmetry of →e p → e 0 p 0 η in the deep-inelastic regime with CLAS	
Journal: Phys. Lett.	
Publication Date: 2019	**Publication Status:** Published
Volume: B789	**First Page Number or eLocation ID:** 426
Issue: Not Provided	**Publication Location:** Not Provided
Author(s): B. Zhao et al.	
Publication Identifier Type: DOI	**Publication Identifier:** DOI: 10.1016/j.physletb.2018.12.065
Acknowledgement of DOE Support: Yes	**Peer Reviewed:** Yes

7. Journal Article: First results on nucleon resonance photocouplings from the γp → π + π − p reaction

Journal: Phys. Lett.	
Publication Date: 2019	**Publication Status:** Published
Volume: B788	**First Page Number or eLocation ID:** 371
Issue: Not Provided	**Publication Location:** Not Provided
Author(s): E. Golovatch et al.	
Publication Identifier Type: DOI	**Publication Identifier:** DOI: 10.1016/j.physletb.2018.10.013
Acknowledgement of DOE Support: Yes	**Peer Reviewed:** Yes

8. Journal Article: First Measurements of the Double-Polarization Observables F , P , and H in ω Photoproduction off Transversely Polarized Protons in the N* Resonance Region	
Journal: Phys. Rev. Lett.	
Publication Date: 2019	**Publication Status:** Published
Volume: 122	**First Page Number or eLocation ID:** 162301
Issue: 16	**Publication Location:** Not Provided
Author(s): P. Roy et al.	
Publication Identifier Type: DOI	**Publication Identifier:** DOI: 10.1103/PhysRevLett.122.162301
Acknowledgement of DOE Support: Yes	**Peer Reviewed:** Yes

9. Journal Article: Exploring the Structure of the Bound Proton with Deeply Virtual Compton Scattering	
Journal: Phys. Rev. Lett.	
Publication Date: 2019	**Publication Status:** Published
Volume: 123	**First Page Number or eLocation ID:** 032502
Issue: 3	**Publication Location:** Not Provided
Author(s): M. Hattawy et al.	
Publication Identifier Type: DOI	**Publication Identifier:** DOI: 10.1103/PhysRevLett.123.032502
Acknowledgement of DOE Support: Yes	**Peer Reviewed:** Yes

10. 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	

11. 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

12. 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

13. 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

14. 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

15. 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	

16. 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	

17. 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	

18. 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	

19. 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	

20. 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	

21. 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	

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: 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

24. 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

25. 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

26. 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

27. 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

28. 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

29. 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

30. 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

31. 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

32. 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

33. 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	

34. 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

35. 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	

36. 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	

37. 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	

38. 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

39. 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

40. 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	

41. 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

42. 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

43. 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	

44. 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	

45. 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	

46. 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	

47. 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	

48. 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

49. 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

50. 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

51. 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

52. 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

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: Software or NetWare

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

The CLAS12 detector consists of a Forward Detector built around a large toroidal magnet and a Central Detector which fits into the bore of a solenoid magnet that also has the target near its center. 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. In the last year we have worked on applying the millepede program to extract geometric corrections to the positions of the SVT sensors to improve the alignment and hence the resolution.

2. Other Products: Software or NetWare

Description: Jefferson Lab's upgraded CLAS12 detector studies the quark-gluon structure of hadrons with electron scattering experiments. The CLAS12 software reconstructs particle events collected by CLAS12 or simulated. Upgrades to its more than 84,000 lines of executable code are validated on a nightly basis with unit tests that apply it to a standard data set. Scattered electrons bend in the CLAS12 magnetic field leaving tracks in drift chambers (DC). The reconstructed trajectory is used to determine momentum and vertex position. The raw data (e.g. ADCs) for a single event are stored in the code, reconstructed, and compared to standard values. As the software evolved the previous DC test would signal a failure when the reconstruction was done properly. Recent improvements had changed the momentum reconstruction so it was outside the acceptable range. We also discovered a large discrepancy with the vertex position. To fix the test we simulated momentum and vertex distributions using the CLAS12 Common Tools and extracted the reconstruction resolution. We generated new, simulated raw data for a single event, redefined the acceptable momentum ranges, and added a new requirement on the vertex. The results have been tested and incorporated into the Common Tools. This work was presented in a poster at the fall, 2019 Division of Nuclear Physics meeting.

3. 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 (E12-07-104) with the CLAS12 detector. We focus on neutrons detected in the CLAS12 calorimeters and protons measured with the CLAS12 forward detector. Quasi-elastic events were generated with the Quasi-Elastic Event Generator (QUEEG) and passed through the Monte Carlo code gemc to simulate the CLAS12 response. Inelastic events were generated with a recently developed variation of the Pythia program which now includes models of nuclear targets including the deuteron. This program was developed by My Ahmed El Alaoui, a CLAS12 collaborator at USM in Chile. These simulated events were reconstructed using the latest CLAS12 Common Tools. In the analysis 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, θpq , separates QE and inelastic events. We found in our simulations the QE peak was initially overwhelmed by the

inelastic background. However, when we applied the angular θpq cut we see a dramatic reduction in the inelastic background. This result was shown in a poster at the fall, 2019 Division of Nuclear Physics meeting.

PARTICIPANTS AND OTHER COLLABORATING ORGANIZATIONS

PARTICIPANTS DETAIL

1. Participant: Michael Armstrong		
Project Role: Graduate Student (Research Assistant)	**Person Months Worked**: 10	**Funding Support (if other than this award)**: Not Provided
Contribution to the Project: Jefferson Lab's upgraded CLAS12 detector studies the quark-gluon structure of hadrons with electron scattering experiments. The CLAS12 software reconstructs particle events collected by CLAS12 or simulated. Upgrades to its more than 84,000 lines of executable code are validated on a nightly basis with unit tests that apply it to a standard data set. Scattered electrons bend in the CLAS12 magnetic field leaving tracks in drift chambers (DC). The reconstructed trajectory is used to determine momentum and vertex position. The raw data (e.g. ADCs) for a single event are stored in the code, reconstructed, and compared to standard values. As the software evolved the previous DC test would signal a failure when the reconstruction was done properly. Recent improvements had changed the momentum reconstruction so it was outside the acceptable range. We also discovered a large discrepancy with the vertex position. To fix the test we simulated momentum and vertex distributions using the CLAS12 Common Tools and extracted the reconstruction resolution. We generated new, simulated raw data for a single event, redefined the acceptable momentum ranges, and added a new requirement on the vertex. The results have been tested and incorporated into the Common Tools.		
International Collaboration: No		
International Travel: No		

2. Participant: Lamya Baashen		
Project Role: Graduate Student (Research Assistant)	**Person Months Worked**: 11	**Funding Support (if other than this award)**: Florida International University
Contribution to the Project: Florida International doctoral student Lamya Baashen will analyze the CLAS12 Run Group B data and extract GMn for her thesis. She is now working primarily on the GMn analysis and the NDE measurement which is being extracted from data from Run Groups A and K. She has passed her PhD qualifier. Her focus over the last six months has been measuring the NDE from the RGA and RGK data sets.		
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)**: University 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 analyze the CLAS12 GMn data measured in 2019-2020. He is also working with a doctoral student Lamya Baashen at Florida International University (FIU) who is a student of Dr. Brian Raue (faculty member at FIU). Gilfoyle is a member of Ms. Baashen's thesis committee.		
International Collaboration: No		
International Travel: No		

4. Participant: Matthew Heyrich		
Project Role: Undergraduate Student	**Person Months Worked**: 3	**Funding Support (if other than this award)**: Not Provided
Contribution to the Project: We are using Jefferson Lab's 11-GeV electron beam incident on a deuterium target and the CLAS12 detector to measure the electromagnetic form factor of the neutron. We developed and tested code for the extraction of kinematic quantities for quasielastic(QE) event selection. A full simulation chain has been developed and is managed by shell and perl scripts on the Richmond Computing Cluster. Quasi-elastic events are generated with QUEEG and inelastic ones with Pythia. Both sets go through gemc, a CLAS12- standard, physics-based Monte Carlo built on geant4. The simulated CLAS12 events are reconstructed with the CLAS12 Common Tools. We wrote the post-reconstruction analysis code in Groovy, a JAVA-like scripting language. To select electrons we apply fiducial cuts to define the electromagnetic calorimeter (EC) active volume and constrain the sampling fraction (ratio of the electron energy deposited in the EC to the measured electron momentum). We isolated QE events from inelastic background using cuts to the range of θ pq (angle between 3-momentum transfer and the nucleon), and the hermiticity (require only electron and a nucleon). Initial results on extracting the QE component are consistent with the experimental specifications.		
International Collaboration: No		
International Travel: No		

5. Participant: Xiaodi Hu		
Project Role: Undergraduate Student	**Person Months Worked**: 3	**Funding Support (if other than this award)**: Not Provided
Contribution to the Project: We are using Jefferson Lab's 11-GeV electron beam incident on a deuterium target and the CLAS12 detector to measure the electromagnetic form factor of the neutron. We developed and tested code for the extraction of kinematic quantities for quasielastic(QE) event selection. A full simulation chain has been developed and is managed by shell and perl scripts on the Richmond Computing Cluster. Quasi-elastic events are generated with QUEEG and inelastic ones with Pythia. Both sets go through gemc, a CLAS12-standard, physics-based Monte Carlo built on geant4. The simulated CLAS12 events are reconstructed with the CLAS12 Com- mon Tools. We wrote the post-reconstruction analysis code in Groovy, a JAVA-like scripting language. To select electrons we apply fiducial cuts to define the electromagnetic calorimeter (EC) active volume and constrain the sampling fraction (ratio of the electron energy deposited in the EC to the measured electron momentum). We isolated QE events from inelastic background using cuts to the range of θ pq (angle between 3-momentum transfer and the nucleon), and the hermiticity (require only electron and a nucleon). Initial results on extracting the QE component are consistent with the experimental specifications.		
International Collaboration: No		
International Travel: No		

6. Participant: Prof. Brian Raue		
Project Role: Faculty	**Person Months Worked**: 11	**Funding Support (if other than this award)**: Florida International University
Contribution to the Project: Dr. Brian Raue is a faculty member in nuclear physics at Florida International University. He is a long-standing member of the CLAS Collaboration who has worked on a variety of important projects including the CLAS6 two-photon exchange measurement, the development and maintenance of the CLAS6/CLAS12 Moeller polarimeter used to measure the electron beam spin, and the construction and design of drift chambers for CLAS6.		
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?

The elastic electromagnetic form factors (EEFFs) are fundamental observables in electron scattering that encode information about the distribution of electric charge and current in the nucleus and its constituents. We have begun the calibration and analysis of a large JLab experiment (E12-07-104) with the CLAS12 detector in Hall B at Jefferson Lab to measure the magnetic form factor (EEFF) of the neutron. We are part of a broad program at JLab to measure the four EEFFs (electric and magnetic for the proton and neutron) consisting of seven experiments including two to measure GMn . Both GMn experiments use methods pioneered in Hall B with the previous detector CLAS6. The study of the EEFFs already has a long history, but new features have been revealed over the last fifteen years. This new knowledge is built on new technologies in superconducting electron accelerators, high luminosity detectors, and cryogenic and polarized targets. Their application has lead to new discoveries that overturned our previous understanding. Jefferson Lab has a program to measure all of the EEFFs precisely and over a broad kinematic range. This opens the door to extending our understanding of nuclear structure at the quark level (e.g. flavor decomposition to extract individual quark form factors) and to stringently challenge our theoretical understanding of QCD with data (e.g. distinguish between competing theoretical approaches like the Dyson-Schwinger Equation method and light-front holographic QCD). This campaign has begun and we expect much of it to play out in the next few years.

2. What is the impact on other disciplines?

The PI continues to maintain a computing cluster originally obtained with NSF funds that consists of thirty, 12-core nodes. CLAS collaborators have used the cluster in the past (when demand was high on the JLab farm) and we are now investigating the possibility of incorporating the Richmond cluster into the Open Science Grid as part of the CLAS12 program. At the University of Richmond scientists from other disciplines within the University now use the computing cluster. These scientists (mostly 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?

Two University of Richmond undergraduates (Matthew Heyrich and Xiaodi Hu) were trained at Richmond and JLab in 2019 and presented a poster on their work at the Fall, 2019 DNP meeting. A masters student from the University of Surrey (Michael Armstrong) worked at JLab for ten months in 2019 as part of his research experience and developed a software unit test that has been incorporated into the CLAS12 Common Tools. He also presented a poster at the fall, 2019 DNP meeting and will be a co-author on a JLab technical report on his work that is in preparation. Lamya Baashen is a PhD student from Florida International University who has worked with the PI extensively starting in 2019. Analysis of the GMn experiment will be her doctoral thesis.

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. The Richmond cluster has been used by other scientists at Richmond and there is now interest from the Richmond administration to develop more computing resources and to

involve faculty and students in data mining and high-performance computing.

5. What is the impact on technology transfer?

Undergraduates and masters students 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. They have also pursued doctorates in physics. One recent graduate, Keegan Sherman, is now a post-qualifier doctoral student and Alexander Balsamo is a masters student at Christopher Newport University. 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 edge 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

We have recently observed a considerable neutral particle background (photons and neutrons) in our calibration reaction ep-> e' pi+ n used to measure the neutron detection efficiency (NDE). The same background also appears in the production reaction on deuterium where we measure the ratio R of e-n to e-p scattering. We are now investigating ways to optimize the event selection for both reactions and iterating through the process to improve our resolution. We are also developing more complete simulations of the calibration reaction and the production reaction to understand the possible source of the neutral background.

2. Actual or anticipated problems or delays and actions or plans to resolve them

See item 1 above.

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: $4,500.00