Progress Report - Accomplishments

DE-FG02-96ER40980: Medium Energy Nuclear Physics at the University of Richmond

Resources

View

Previous Progress Report | Award Access | Progress Report Instructions | Last Awarded Proposal

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 CLAS12 data reconstruction and analysis. For goal (1) The first period of data collection for the GMn measurement was completed 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 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. For goal (2) we continue to coordinate our software work with the JLab staff. We have a joint program between the University of Richmond and the University of Surrey in the UK to support a masters students for ten months. The Surrey students are required to engage in a significant research year as part of their degree requirements. DOE funding supported these students who are stationed at JLab. In the current grant period funding was available for two students in 2022 (Rocco Monteiro) and 2023 (Ahmed Abdalla). In the fall of 2022 the PI (Gilfoyle) is on sabbatical at JLab and will begin software development to simulate the timing signal of a new detector subsystem in CLAS12. In an effort to increase the operating luminosity of CLAS12, a large-area, high-rate microRWELL detector will be added in front of the CLAS12 drift chambers to study the impact on the reconstruction efficiency. This project is part of a CLAS12-wide project to double the CLAS12 luminosity. In addition, projects by two University of Richmond undergraduates (Jessie Hess and Ryan Sanford) advanced both of these goals. More details are below.

2. What was accomplished under these goals?

Goal 1

Measurement of the Neutron Magnetic Form Factor GMn using the Ratio Method

One of Jefferson Lab's goals is to unravel the quark-gluon structure of nuclei. We are using the ratio, R, of quasi-elastic (QE) electron-neutron (e-n) to electron-proton (e-p) scattering on deuterium as a function of 4-momentum transfer Q^2 to probe the magnetic form factor of the neutron, GMn. It represents the distribution of magnetization within the neutron. We have been analyzing recently collected data from CLAS12 in Run Group B (RGB) to extract GMn. This is part of an approved experiment (E12-07-104). The run group has completed pass1 of the analysis of the Run Group B data.

This work is part of a collaboration with Dr. Brian Raue in the nuclear physics group at Florida International University (FIU). Dr. Raue's doctoral student Lamya Baashen is analyzing the RGB data to extract GMn for her thesis. She is working exclusively on the GMn analysis and calibration. She has passed her PhD qualifying exam.

The analysis of the 2H(e,e'n(p)) and 2H(e,e'p(n)) reactions to extract GMn have made significant progress in the last year. One of the challenges in this work is to extract quasielastic (QE) events from a large inelastic background. To do that we (1) focus on neutrons detected in the CLAS12 calorimeters and electrons and protons measured with the CLAS12 forward detector. If we assume elastic scattering and use the conservation laws and the four-momenta of the electron and nucleon to calculate the precisely known beam energy in different ways with multiple combinations of angles and momenta. We create two-dimensional plots of these combinations and the QE region is clearly visible, but has an inelastic background. (2) Next we calculate the angle, θpq, between the electron three-momentum transfer and the detected nucleon three-momentum. It is expected the QE nucleons will be emitted with a small θpq. For θpq < 2.5 deg we see a dramatic drop in the inelastic background for both e-n and e-p events. Plots of the recoil mass W formed from the region near the beam energy show a clear, nearly symmetric peak close to the neutron mass for both e-n and e-p events as expected. (3) Last we apply acceptance matching so the solid angle for detecting e-n and e-p events is the same. For each event we assume elastic scattering, calculate the trajectory of the nucleon through CLAS12, and require both trajectories to hit the detector. If either nucleon misses, we skip the event.

There are still corrections required before we can form the final ratio and extract GMn. The most important is the neutron detection efficiency (NDE) to correct the measured e-n yield. It is one of the largest components of the systematic uncertainty. Comparison of past measurements at different laboratories reveals considerable tension among those experiments possibly due to variations in detector performance and efficiency. To measure the NDE we use the 1H(e,e' π+ n) reaction on a hydrogen target from Run Group A (RGA) data. This reaction is a source of tagged neutrons which can be detected in the electromagnetic calorimeter (PCAL/EC). To measure the NDE we start with the 1H(e,e' π+ Xn) reaction where Xn can be multiple neutral particles. These neutrals are our neutron candidates. We use the measured electron and pion kinematics to predict/swim the candidate neutron path through CLAS12. This track is required to lie within the CLAS12 acceptance. We call this the expected track. We then search this event for neutral hits in the PCAL/EC near the intersection point of the expected track with the front face of the detector. We select the hit closest to the predicted trajectory and call it the detected track. We calculate the direction cosines of the expected and detected neutron momenta and take their difference. The two-dimensional histograms of this difference are strongly peaked around zero. We add additional cuts to eliminate overlaps with photon events. We continue to optimize the extraction of the neutrons from background. We have used several methods to fit the missing mass distribution to extract the neutron events from the background. These efforts include using a

combination of functions combined with a polynomial background which show good promise. A comparison of these different methods will enable us to understand our systematic uncertainties. This work also holds the potential to push the measurement of the NDE to a neutron momentum of 7 GeV which corresponds to Q2 = 10 GeV2 - about a factor of two greater than the current upper limit on precise measurements of GMn.

Some of these NDE results and a study of simulations of the NDE reaction were the subject of two University of Richmond undergraduate posters presented at the fall, 2022 Division of Nuclear Physics (DNP) meeting (Ryan Sanford and Jessie Hess respectively). More work on extracting the GMn ratio and the NDE was presented by Lamya Baashen of FIU in a contributed talk at the DNP meeting.

Goal 2

CLAS12 Central Vertex Tracker Reconstruction Efficiency

The CLAS12 reconstruction code for the CLAS12 Central Vertex Tracker (CVT) consists of pattern recognition to identify track candidates and subsequent track fitting based on a Kalman filter algorithm. The reconstruction efficiency is the number of tracks successfully reconstructed by the software divided by the total number of real tracks present in the Central Detector.

The motivation here is the need for high luminosity experiments which are necessary to study compelling, but rare nuclear reactions. These high rates lead to more background in all CLAS12 detector subsystems. It becomes difficult to find the hit signals that belong to a real track due to the large number of nearby background hits. A way to reduce the background is to impose constraints to remove tracks with large distances of closest approach (DOCAs). The effect of DOCA cuts on the reconstruction efficiency can be measured by simulating or taking low luminosity (5nA) events where the background is low and merging them with realistic background events. We then measure the effect of background on the reconstruction. Finally, by varying the size of the DOCA cut, we test which method yields the highest efficiency.

We prepare a data file consisting of low-momentum (0.6-1.4 GeV) protons taken from a real 5nA (low background) experiment. We copy the 5nA file and merge with 50nA background from a data experiment. We define a DOCA "sum" cut consisting of the sum of the individual DOCAs from each SVT cross. A cross is a point where two strips that fired in the CVT cross one another and define a 3D point is space on the track. We reconstruct the 5nA file for a range of DOCA sum cuts and select the optimal 5nA DOCA sum cut that has the most tracks matched to the Central TOF detector. We arrange the order of the optimal 5nA event file by event number ID. Next, we reconstruct the background merged file for a range of different DOCA sum cut sizes and order the event files by event number ID. We run a hit-matching algorithm that compares tracks event-by-event from the merged background files to the 5nA file and scans each reconstructed track for similar hit signals. We sort the reconstructed tracks according to the following categories.

1. Fully Matched: Tracks in background merged file share 100% of hits with tracks in 5nA file.
2. Partially Matched: Tracks in background merged file share 80% or more of hits with tracks in 5nA file.
3. Matched by cuts: Tracks in background merged file with momentum, polar angle, and azimuthal angle that were within 3σ (as determined by system resolution specifications) of tracks from the same event.

We calculate the reconstruction efficiency according to success criteria above for the DOCA sum cut range of the merged background files.

We have found the implementation of constraints on track candidate parameters in the CVT improves the reconstruction efficiency. The momentum resolution improves, while the angular resolutions of track candidates degrade with increasing DOCA cuts. This work was done by a University of Surrey masters student, Rocco Monteiro, who presented his work in a poster at the fall, 2022 Division of Nuclear Physics meeting in New Orleans.

Simulation of μRWELL Detector Readout

The single-particle reconstruction efficiency of CLAS12, ~ 75% − 80% is lower than expected due to a high occupancy in the Drift Chamber (DC) Region 1 (R1) in the Forward Detector. Adding a fast tracking detector layer(s) to DC-R1 will help to isolate the correct hits on a track. The plan is to add a large area, lightweight μRWELL detector with a 2-D readout in front of DC-R1. R&D is already under way at JLab. The PI is working on developing the simulation of the electronic readout of the uRWELL detector in gemc, the physics-based simulation of CLAS12. This project began in the fall of 2022 when the PI was on sabbatical at JLab.

The PI has built gemc in his local area and is adding to the existing code that includes an initial simulation of the μRWELL. The existing code generates a timing signal, but still needs elements to be added. He is working to understand the performance parameters of the μRWELL, add to the components of the timing signal, and develop a simulation of the pulse shape in the readout.

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 students at liberal arts institutions like 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. Six students have completed the Richmond research year and a seventh, Ahmed Abdalla, is expected to arrive in the US. These students have made five poster presentations at APS Division of Nuclear Physics meetings and have been co-authors on four JLab technical reports (CLAS12-NOTES). A fifth report is in preparation based on the work of the most recent student, Rocco Monteiro, who completed his research year in December 2022. Components of 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. The last two students Mr. Adrien Saina and Mr. Michael Armstrong are now in graduate school pursuing doctorates and one, Michael Armstrong is about to graduate.

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. The PI typically meets with his research student 1-2 times per day to check on their progress, answer questions, etc. The group meets once a week and the undergrads present 10-15 minute talks about their work. For the last three summers (2020-2022) I worked with two Richmond undergraduate physics majors (Jessie Hess and Ryan Sanford). Summer 2020 was done remotely due to the pandemic. Both students have become adept at presenting posters including ones at the annual Division of Nuclear Physics meeting. Mr. Sanford is pursuing graduate school in medical physics and has already been admitted to some of the top programs in the US. Ms. Hess has decided to pursue a law degree and has already been accepted at Georgetown, Washington University, and others.

The PI (Gilfoyle) typically spends at least one day per week at JLab during the academic year and summer months. During the academic year 2022-2023 Gilfoyle was on sabbatical at Jefferson Lab. He received travel support from JLab and he received 80% of his academic year salary from this grant after conferring with the program officer. He usually met with Ms. Baashen many times per week in-person and remotely to advance the work on GMn.

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

The results have been disseminated through presentations at conferences. Two Richmond undergraduates (Ryan Sanford and Jessie Hess) presented posters at the fall, 2022 DNP meeting. The University of Surrey masters student, Rocco Monteiro, also presented his work at the fall, DNP meeting. Gilfoyle typically gives one invited talk each year which in 2022 was at the University of Surrey to recruit masters students to spend their research year at JLab. See #3 above for more details. Gilfoyle was co-author on seven refereed papers in 2022. Lamya Baashen is a doctoral student at Florida International working on the GMn analysis. She gives regular reports at the weekly Run Group B meeting and gave a contributed talk at the DNP meeting. She also makes annual progress reports to here thesis committee. The PI is a member of that committee.

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

During the next reporting period we will continue our focus on the analysis of the CLAS12 GMn experiment (E12-07-104) and the software development for CLAS12. The GMn analysis consists of several major parts - (1) the measurement of the neutron detection efficiency (NDE), (2) the extraction of the ratio R=e-n/e-p, (3) providing corrections to R to determine GMn, and (4) determining the systematic uncertainty on GMn. As described in part 2 above the NDE will be measured with the ep -> e' pi+ n reaction on liquid hydrogen. That part of the project is far along. We are also far along in extracting quasielastic events from the eD -> e'p and eD -> en reactions. The ratio of these events as a function of Q2 will give the raw, measured value of the ratio R. There are still corrections to this ratio that have to be done. Radiative effects on the different reactions can be significant. The computer code EXCLURAD was used in the CLAS6 GMn measurement and is still working. It will be used to calculate the radiative corrections for these reactions. We found with CLAS6 the corrections were significant in the individual channels, but in the ratio and at higher Q2 the corrections to the ratio were close to one. Nuclear effects, i.e. the impact of scattering electrons off a bound proton or neutron versus a free nucleon can be calculated. We will have to survey our theoretical collaborators to provide these calculations. In the CLAS6 measurement we again found the effect on the ratio was limited above Q2 ~ 1 GeV2. The internal Fermi motion of the nucleons in deuterium can alter the ratio. In our procedure for identifying QE events we predict the location of the nucleon in CLAS12 using just the electron information and assuming elastic scattering from a stationary target. In the real experiment the struck nucleon is moving. If the orientation of the internal Fermi momentum of the stuck nucleon is just right, it could get knocked out of the CLAS12 acceptance and we would not observe it - altering the number of events in our sample. This effect can be calculated for the e-n and e-p events using a semi-classical code QUEEG that includes the Hulthen distribution to model the Fermi momentum distribution of the nucleons in deuterium. The direction of the Fermi momentum is isotropic - the target is unpolarized. The PI maintains and has modified the code in the past for other studies. We will use this code to calculate the impact of the Fermi motion on the ratio. In the CLAS6 measurement the effect of the Fermi motion was quite large (~1.6) at low Q2, but was near one at larger Q2 (>2 GeV2). Most of the data for the CLAS12 measurement are at higher Q2.

Beyond the corrections and analysis described in this report we will also make a comprehensive assessment of the systematic uncertainty. The biggest contributor in this inventory is likely to be the neutron detection efficiency, but we plan to study all of the inputs, cuts, and corrections we have applied to study how the ratio changes as those parameter values change. For example, we require the direction of the quasielastically scattered nucleon to lie with an angle θpq < 2.5 where θpq is the angle between the 3-momentum transfer defined by the electron information and the direction/3-momentum of the nucleon. We can study how GMn changes if we move θpq to smaller or larger values. The CLAS12 angular resolution is ~1 mrad so changes of this size will probe the sensitivity of the ratio. Another example is the calculation of GMn from the ratio which relies on the values for the other three elastic, electromagnetic form factors. For example, the neutron magnetic form factor GEn is known even less precisely than GMn. However, GEn is expected to be small in the Q2 range we are measuring. One can use a parameterization of GEn to predict its value in out Q2 range. There are several such parameterizations available and their variation can be used as a measure of the uncertainty. We then add the impact of GEn to our determination of GMn to assess the systematic uncertainty.

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 Ahmed Abdalla is expected to start work soon and will be stationed at JLab. He will be trained to use the CLAS12 software and we will coordinate his work with the JLab staff. The PI (Gilfoyle) is on sabbatical during the 2022-2023 academic year and will be part of this training. The PI will also continue the development of the simulation of the μRWELL readout.

Accomplishments Attachment (Maximum 1)

No documents attached

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Progress Report - Products

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Resources

View

Previous Progress Report | Award Access | Progress Report Instructions | Last Awarded Proposal

Publications

Number	Type	Title	Author(s)	Revision Type
1	Conference Paper/Presentation	Extracting Neutron Yield From High Mass Background	R.Sanford, G.P.Gilfoyle, L.Baashen,	New
2	Conference Paper/Presentation	Neutron Magnetic Form Factor Measurement at High Q2 with CLAS12	L.Baashen, B.Raue, G.P.Gilfoyle, C.Smith	New
3	Conference Paper/Presentation	Study of Missing Mass Background in the CLAS12 Detector	J.Hess, L.Baashen, G.P.Gilfoyle	New
4	Conference Paper/Presentation	The CLAS12 Central Vertex Tracker Reconstruction Efficiency	R.Monteiro, G.P.Gilfoyle, V.Ziegler, Y.Gotra	New
5	Journal Article	Beam-Recoil Transferred Polarization in K + Y Electroproduction in the Nucleon Resonance Region with CLAS12	D. S. Carman et al.	New
6	Journal Article	Beam-spin asymmetry Σ for Σ − hyperon photoproduction off the neutron	N. Zachariou et al.	New
7	Journal Article	Exclusive π − Electroproduction off the Neutron in Deuterium in the Resonance Region	Y. Tian et al.	New
8	Journal Article	Measurement of charged-pion production in deep-inelastic scattering off nuclei with the CLAS detector	S. Moran et al.	New
9	Journal Article	Multidimensional, High Precision Measurements of Beam Single Spin Asymmetries in Semi-inclusive π + Electroproduction off Protons in the Valence Region	S. Diehl et al.	New
10	Journal Article	Observation of azimuth-dependent suppression of hadron pairs in electron scattering off nuclei	S. J. Paul et al.	New
11	Journal Article	Polarized structure function σ -LT0 from π0 p electroproduction data in the resonance region at 0.4 GeV2 < Q2 < 1.0 GeV2	E. L. Isupov et al.	New
12	Conference Paper/Presentation	**Analysis and Validation of Reconstruction Resolution for CLAS12**	R.J. Sanford, G.P. Gilfoyle, A. Saina, V.Ziegler	No Change
13	Conference Paper/Presentation	**Simulation of Neutron Detection Efficiency in the CLAS12 detector**	J. Hess, G.P. Gilfoyle, L. Baashen	No Change
14	Thesis/Dissertation	The Resolution of the CLAS12 Reconstruction Software	Adrian Saina	No Change
15	Journal Article	Beam Spin Asymmetry in Semi-Inclusive Electroproduction of Hadron Pairs	M.Mirazita et al.	No Change
16	Journal Article	Differential cross sections for Lambda(1520)$using photoproduction at CLAS	U.Shrestha wt al.	No Change
17	Journal Article	Double polarisation observable $\mathbb G$ for single pion photoproduction from the proton	N. Zachariou et al.	No Change

Number	Type	Title	Author(s)	Revision Type
18	Journal Article	Electron-beam energy reconstruction for neutrino oscillation measurements.	M. Khachatryan et al.	No Change
19	Journal Article	First Measurement of Timelike Compton Scattering	Chatagnon et al.	No Change
20	Journal Article	Measurement of deeply virtual Compton scattering off He4 with the CEBAF Large Acceptance Spectrometer at Jefferson Lab	R. Dupre et al.	No Change
21	Journal Article	Measurement of the proton spin structure at long distances	X.Zheng et al.	No Change
22	Journal Article	Observation of Beam Spin Asymmetries in the Process ep-->e' pi+ pi- X with CLAS12	T.B.Hayward et al.	No Change
23	Journal Article	Photoproduction of the f_2(1270) meson using the CLAS detector	M. Carver et al.	No Change
24	Conference Paper/Presentation	The CLAS12 Reconstruction Resolution	A. Saina, V. Ziegler, and G.P. Gilfoyle	No Change
25	Conference Paper/Presentation	Measurement of the Neutron Magnetic Form Factor at High Q2 Using the Ratio Method on the Deuteron	L. Baashen, B. Raue, C. Smith, and G.P. Gilfoyle	No Change
26	Journal Article	CLAS12 Drift Chamber Reconstruction Software Unit Test	M. Armstrong , V. Ziegler , and G.P. Gilfoyle	No Change
27	Thesis/Dissertation	CLAS12 Hough Transform Track Recognition and Drift Chamber Reconstruction Software Validation	Michael Armstrong	No Change
28	Journal Article	Beam–target helicity asymmetry E in K + Σ − photoproduction on the neutron	N. Zachariou et al.	No Change
29	Journal Article	Extraction of beam-spin asymmetries from the hard exclusive π+ channel off protons in a wide range of kinematics	S. Diehl et al.	No Change
30	Journal Article	Probing the core of the strong nuclear interaction	A. Schmidt et al.	No Change
31	Journal Article	The CLAS12 Silicon Vertex Tracker	M. A. Antonioli et al.	No Change
32	Journal Article	The CLAS12 software framework and event reconstruction	V. Ziegler et al.	No Change
33	Journal Article	The CLAS12 Spectrometer at Jefferson Laboratory	V. D. Burkert et al.	No Change
34	Conference Paper/Presentation	CLAS12 Drift Chamber Reconstruction Code Validation	M.Armstrong, V.Ziegler, and G.P.Gilfoyle	No Change
35	Conference Paper/Presentation	Event Selection in Electron Scattering on Deuterium	M.Heyrich, X.Hu, and G.P.Gilfoyle	No Change
36	Journal Article	Measurement of the beam spin asymmetry of vec e p → e' p' η in the deep-inelastic regime with CLAS	B. Zhao et al.	No Change
37	Conference Paper/Presentation	Hunting for Quarks and Gluons	G.P.Gilfoyle	No Change
38	Journal Article	Double KS^0 Photoproduction off the Proton at CLAS	S. Chandavar et al.	No Change

Number	Type	Title	Author(s)	Revision Type
39	Journal Article	Exclusive photoproduction of π 0 up to large values of Mandelstam variables s, t and u with CLAS	M. C. Kunkel et al.	No Change
40	Journal Article	Future Measurements of the Nucleon Elastic Electromagnetic Form Factors at Jefferson Lab	G.P.Gilfoyle	No Change
41	Journal Article	Hard exclusive pion electroproduction at backward angles with CLAS	K. Park et al	No Change
42	Journal Article	Measurement of the beam asymmetry Σ and the target asymmetry T in the photoproduction of ω mesons off the proton using CLAS at Jefferson Laboratory	P. Roy et al.	No Change
43	Journal Article	Measurement of the Q2 Dependence of the Deuteron Spin Structure Function g1 and its Moments at Low Q2 with CLAS	K. P. Adhikari et al.	No Change
44	Journal Article	Semi-Inclusive π 0 target and beam-target asymmetries from 6 GeV electron scattering with CLAS	S. Jawalkar et al.	No Change
45	Conference Paper/Presentation	Analysis of Quasi-Elastic e-n and e-p Scattering from Deuterium	A.Balsamo, K.Sherman, and G.P.Gilfoyle	No Change
46	Conference Paper/Presentation	Future Measurements of the Nucleon Elastic Electromagnetic Form Factors at Jefferson Lab	G.P. Gilfoyle	No Change
47	Journal Article	Determination of the proton spin structure functions for 0.05 ≤ Q 2 ≤ 5 GeV 2 using CLAS	R. Fersch et al.	No Change
48	Journal Article	First Exclusive Measurement of Deeply Virtual Compton Scattering off 4He: Toward the 3D Tomography of Nuclei	M. Hattawy et al.	No Change

Intellectual Property

Number	Type	Title	Revision Type
No intellectual properties to display.			

Technologies or Techniques

Number	Description	Revision Type
No technologies or techniques to display.		

Other Products

Number	Type	Description	Revision Type
1	Data and Research Material	Measurement of the Neutron Magnetic Form Factor with the Ratio Method - 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... (View Details)	No Change
2	Software or NetWare	CLAS12 Reconstruction Resolution - In this project we measure the reconstruction resolution in simulation for each of the subsystems of the CLAS12 Forward Detector (FD). This is done by swimming two... (View Details)	No Change
3	Software or NetWare	Description: CLAS12 Central Vertex Tracker Reconstruction Efficiency - The scientific staff at JLab have begun a project to double the current luminosity limit in the CLAS12 detector. This project is... (View Details)	New

Number	Type	Description	Revision Type
4	Data and Research Material	Description: Measurement of the Neutron Magnetic Form Factor with the Ratio Method - One of Jefferson Lab's goals is to unravel the quark-gluon structure of nuclei. We are using use the ratio, R, of... (View Details)	New
5	Protocols	Measuring the CLAS12 Neutron Detection Efficiency (NDE) - The method to extract GMn described above requires precise knowledge of the neutron detection efficiency (NDE) to correct the measured e-n... (View Details)	New
6	Protocols	Measuring the CLAS12 Neutron Detection Efficiency (NDE) - The method to extract GMn described above to measure GMn does require precise knowledge of the neutron detection efficiency (NDE) to correct... (View Details)	No Change

Publications Detail

Conference Paper/Presentation: The CLAS12 Central Vertex Tracker Reconstruction Efficiency

Authors: R.Monteiro, G.P.Gilfoyle, V.Ziegler, Y.Gotra	**Conference Name:** APS Fall Meeting of the Division of Nuclear Physics
Conference Location: New Orleans, LA	**Conference Date:** 10/28/2022
Publication Status: Published	**Acknowledgement of DOE Support: [X]** Yes [_] No
Revision Type: New	

Conference Paper/Presentation: Study of Missing Mass Background in the CLAS12 Detector

Authors: J.Hess, L.Baashen, G.P.Gilfoyle	**Conference Name:** APS Fall Meeting of the Division of Nuclear Physics
Conference Location: New Orleans, LA	**Conference Date:** 10/28/2022
Publication Status: Published	**Acknowledgement of DOE Support: [X]** Yes [_] No
Revision Type: New	

Conference Paper/Presentation: Neutron Magnetic Form Factor Measurement at High Q2 with CLAS12

Authors: L.Baashen, B.Raue, G.P.Gilfoyle, C.Smith	**Conference Name:** APS Fall Meeting of the Division of Nuclear Physics
Conference Location: New Orleans, LA	**Conference Date:** 10/28/2022
Publication Status: Published	**Acknowledgement of DOE Support: [X]** Yes [_] No
Revision Type: New	

Conference Paper/Presentation: Extracting Neutron Yield From High Mass Background

Authors: R.Sanford, G.P.Gilfoyle, L.Baashen,	**Conference Name:** APS Fall Meeting of the Division of Nuclear Physics
Conference Location: New Orleans, LA	**Conference Date:** 10/28/2022
Publication Status: Published	**Acknowledgement of DOE Support: [X]** Yes [_] No
Revision Type: New	

Journal Article: Beam-spin asymmetry Σ for Σ − hyperon photoproduction off the neutron

Journal: Phys. Lett. B		
Peer Reviewed: [X] Yes [_] No	**Publication Status:** Published	
Volume: 827	**Issue:** Not Provided	**First Page Number or eLocation ID:** 062005
Publication Date: 2022	**Publication Location:** Not Provided	
Authors: N. Zachariou et al.		
Publication Identifier Type: DOI	**Publication Identifier:** https://doi.org/10.1016/j.physletb.2022.136985	
Acknowledgement of DOE Support: [X] Yes [_] No	**Revision Type:** New	

Journal Article: Measurement of charged-pion production in deep-inelastic scattering off nuclei with the CLAS detector

Journal: Phys. Rev. C

Peer Reviewed: [X] Yes [_] No	**Publication Status:** Published	
Volume: 105	**Issue:** 1	**First Page Number or eLocation ID:** 015201
Publication Date: 2022	**Publication Location:** Not Provided	
Authors: S. Moran et al.		
Publication Identifier Type: DOI	**Publication Identifier:** https://doi.org/10.1103/PhysRevC.105.015201	
Acknowledgement of DOE Support: [X] Yes [_] No	**Revision Type:** New	

Journal Article: Observation of azimuth-dependent suppression of hadron pairs in electron scattering off nuclei

Journal: Phys. Rev. Lett.		
Peer Reviewed: [X] Yes [_] No	**Publication Status:** Published	
Volume: 129	**Issue:** 18	**First Page Number or eLocation ID:** 182501
Publication Date: 2022	**Publication Location:** Not Provided	
Authors: S. J. Paul et al.		
Publication Identifier Type: DOI	**Publication Identifier:** https://doi.org/10.1103/PhysRevLett.129.182501	
Acknowledgement of DOE Support: [X] Yes [_] No	**Revision Type:** New	

Journal Article: Multidimensional, High Precision Measurements of Beam Single Spin Asymmetries in Semi-inclusive π + Electroproduction off Protons in the Valence Region

Journal: Phys. Rev. Lett.		
Peer Reviewed: [X] Yes [_] No	**Publication Status:** Published	
Volume: 128	**Issue:** 6	**First Page Number or eLocation ID:** 062005
Publication Date: 2022	**Publication Location:** Not Provided	
Authors: S. Diehl et al.		
Publication Identifier Type: DOI	**Publication Identifier:** https://doi.org/10.1103/PhysRevLett.128.062005	
Acknowledgement of DOE Support: [X] Yes [_] No	**Revision Type:** New	

Journal Article: Polarized structure function σ -LT0 from π0 p electroproduction data in the resonance region at 0.4 GeV2 < Q2 < 1.0 GeV2

Journal: Phys. Rev. C		
Peer Reviewed: [X] Yes [_] No	**Publication Status:** Published	
Volume: 105	**Issue:** 2	**First Page Number or eLocation ID:** L022201
Publication Date: 2022	**Publication Location:** Not Provided	
Authors: E. L. Isupov et al.		
Publication Identifier Type: DOI	**Publication Identifier:** https://doi.org/10.1103/PhysRevC.105.L022201	
Acknowledgement of DOE Support: [X] Yes [_] No	**Revision Type:** New	

Journal Article: Exclusive π − Electroproduction off the Neutron in Deuterium in the Resonance Region

Journal: Phys. Rev. C		
Peer Reviewed: [X] Yes [_] No	**Publication Status:** Published	
Volume: 107	**Issue:** 1	**First Page Number or eLocation ID:** 015201
Publication Date: 2022	**Publication Location:** Not Provided	
Authors: Y. Tian et al.		
Publication Identifier Type: DOI	**Publication Identifier:** https://doi.org/10.1103/PhysRevC.107.015201	
Acknowledgement of DOE Support: [X] Yes [_] No	**Revision Type:** New	

Journal Article: Beam-Recoil Transferred Polarization in K + Y Electroproduction in the Nucleon Resonance Region with CLAS12

Journal: Phys. Rev. C		
Peer Reviewed: [X] Yes [_] No	**Publication Status:** Published	
Volume: 105	**Issue:** Not Provided	**First Page Number or eLocation ID:** 065201
Publication Date: 2022	**Publication Location:** Not Provided	
Authors: D. S. Carman et al.		
Publication Identifier Type: DOI	**Publication Identifier:** https://doi.org/10.1103/PhysRevC.105.065201	
Acknowledgement of DOE Support: [X] Yes [_] No	**Revision Type:** New	

Conference Paper/Presentation:

Analysis and Validation of Reconstruction Resolution for CLAS12

Authors: R.J. Sanford, G.P. Gilfoyle, A. Saina, V.Ziegler	**Conference Name:** 2021 Fall Meeting of the APS Division of Nuclear Physics
Conference Location: Remote	**Conference Date:** 10/12/2021
Publication Status: Contributed poster	**Acknowledgement of DOE Support: [X]** Yes [_] No
Revision Type: No Change	

Conference Paper/Presentation:

Simulation of Neutron Detection Efficiency in the CLAS12 detector

Authors: J. Hess, G.P. Gilfoyle, L. Baashen	**Conference Name:** 2021 Fall Meeting of the APS Division of Nuclear Physics
Conference Location: Remote	**Conference Date:** 10/12/2021
Publication Status: Contributed	**Acknowledgement of DOE Support: [X]** Yes [_] No
Revision Type: No Change	

Thesis/Dissertation: The Resolution of the CLAS12 Reconstruction Software

Authors: Adrian Saina	**Institution:** University of Surrey
Completion Date: 01/02/2021	**Acknowledgement of DOE Support: [_]** Yes [X] No
Revision Type: No Change	

Journal Article: Measurement of deeply virtual Compton scattering off He4 with the CEBAF Large Acceptance Spectrometer at Jefferson Lab

Journal: Phys. Rev. C		
Peer Reviewed: [X] Yes [_] No	**Publication Status:** Published	
Volume: 104	**Issue:** 2	**First Page Number or eLocation ID:** 025203
Publication Date: 2021	**Publication Location:** Not Provided	
Authors: R. Dupre et al.		
Publication Identifier Type: DOI	**Publication Identifier:** 10.1103/PhysRevC.104.02520	
Acknowledgement of DOE Support: [X] Yes [_] No	**Revision Type:** No Change	

Journal Article: Photoproduction of the f_2(1270) meson using the CLAS detector

Journal: Phys. Rev. Lett.		
Peer Reviewed: [X] Yes [_] No	**Publication Status:** Published	
Volume: 126	**Issue:** 8	**First Page Number or eLocation ID:** 082002
Publication Date: 2021	**Publication Location:** Not Provided	
Authors: M. Carver et al.		
Publication Identifier Type: DOI	**Publication Identifier:** 10.1103/PhysRevLett.126.08200	
Acknowledgement of DOE Support: [X] Yes [_] No	**Revision Type:** No Change	

Journal Article: First Measurement of Timelike Compton Scattering

Journal: Phys. Rev. Lett.		
Peer Reviewed: [X] Yes [_] No	**Publication Status:** Published	
Volume: 127	**Issue:** 26	**First Page Number or eLocation ID:** 262501
Publication Date: 2021	**Publication Location:** Not Provided	
Authors: Chatagnon et al.		
Publication Identifier Type: DOI	**Publication Identifier:** 10.1103/PhysRevLett.127.262501	
Acknowledgement of DOE Support: [X] Yes [_] No	**Revision Type:** No Change	

Journal Article: Observation of Beam Spin Asymmetries in the Process ep-->e' pi+ pi- X with CLAS12

Journal: Phys. Rev. Lett.		
Peer Reviewed: [X] Yes [_] No	**Publication Status:** Published	
Volume: 126	**Issue:** Not Provided	**First Page Number or eLocation ID:** 152501
Publication Date: 2021	**Publication Location:** Not Provided	
Authors: T.B.Hayward et al.		
Publication Identifier Type: DOI	**Publication Identifier:** 10.1103/PhysRevLett.126.15250	
Acknowledgement of DOE Support: [X] Yes [_] No	**Revision Type:** No Change	

Journal Article: Double polarisation observable $\mathbb G$ for single pion photoproduction from the proton

Journal: Phys. Lett. B		
Peer Reviewed: [X] Yes [_] No	**Publication Status:** Published	
Volume: 817	**Issue:** Not Provided	**First Page Number or eLocation ID:** 136304
Publication Date: 2021	**Publication Location:** Not Provided	
Authors: N. Zachariou et al.		
Publication Identifier Type: DOI	**Publication Identifier:** 10.1016/j.physletb.2021.136304	
Acknowledgement of DOE Support: [X] Yes [_] No	**Revision Type:** No Change	

Journal Article: Electron-beam energy reconstruction for neutrino oscillation measurements.

Journal: Nature,		
Peer Reviewed: [X] Yes [_] No	**Publication Status:** Published	
Volume: 599	**Issue:** 7886	**First Page Number or eLocation ID:** 565
Publication Date: 2021	**Publication Location:** Not Provided	
Authors: M. Khachatryan et al.		
Publication Identifier Type: DOI	**Publication Identifier:** 10.1103/PhysRevLett.127.262501	
Acknowledgement of DOE Support: [X] Yes [_] No	**Revision Type:** No Change	

Journal Article: Differential cross sections for Lambda(1520)$using photoproduction at CLAS

Journal: Phys. Rev. C		
Peer Reviewed: [X] Yes [_] No	**Publication Status:** Published	
Volume: 103	**Issue:** 2	**First Page Number or eLocation ID:** 025206
Publication Date: 2021	**Publication Location:** Not Provided	
Authors: U.Shrestha wt al.		
Publication Identifier Type: DOI	**Publication Identifier:** 10.1103/PhysRevC.103.02520	
Acknowledgement of DOE Support: [X] Yes [_] No	**Revision Type:** No Change	

Journal Article: Measurement of the proton spin structure at long distances

Journal: Nature Phys.		
Peer Reviewed: [X] Yes [_] No	**Publication Status:** Published	
Volume: 17	**Issue:** 6	**First Page Number or eLocation ID:** 736
Publication Date: 2021	**Publication Location:** Not Provided	
Authors: X.Zheng et al.		
Publication Identifier Type: DOI	**Publication Identifier:** 10.1038/s41567-021-01198-z	
Acknowledgement of DOE Support: [X] Yes [_] No	**Revision Type:** No Change	

Journal Article: Beam Spin Asymmetry in Semi-Inclusive Electroproduction of Hadron Pairs

Journal: Phys. Rev. Lett		
Peer Reviewed: [X] Yes [_] No	**Publication Status:** Published	
Volume: 126	**Issue:** 6	**First Page Number or eLocation ID:** 062002
Publication Date: 2021	**Publication Location:** Not Provided	
Authors: M.Mirazita et al.		
Publication Identifier Type: DOI	**Publication Identifier:** 10.1103/PhysRevLett.126.062002	
Acknowledgement of DOE Support: [X] Yes [_] No	**Revision Type:** No Change	

Conference Paper/Presentation: The CLAS12 Reconstruction Resolution

Authors: A. Saina, V. Ziegler, and G.P. Gilfoyle	**Conference Name:** Fall, 2020 Division of Nuclear Physics Meeting
Conference Location: Remote	**Conference Date:** 10/31/2020
Publication Status: Published	**Acknowledgement of DOE Support: [X]** Yes [_] No
Revision Type: No Change	

Conference Paper/Presentation: Measurement of the Neutron Magnetic Form Factor at High Q2 Using the Ratio Method on the Deuteron

Authors: L. Baashen, B. Raue, C. Smith, and G.P. Gilfoyle	**Conference Name:** Fall, 2020 Division of Nuclear Physics Meeting
Conference Location: Remote	**Conference Date:** 10/30/2020
Publication Status: Published	**Acknowledgement of DOE Support: [X]** Yes [_] No
Revision Type: No Change	

Journal Article: CLAS12 Drift Chamber Reconstruction Software Unit Test

Journal: CLAS12 NOTE (Technical Report)		
Peer Reviewed: [_] Yes [X] No	**Publication Status:** Other	
Volume: 2020	**Issue:** Not Provided	**First Page Number or eLocation ID:** 02
Publication Date: 07/06/2020	**Publication Location:** Not Provided	
Authors: M. Armstrong , V. Ziegler , and G.P. Gilfoyle		
Publication Identifier Type: Collaboration Technical Report	**Publication Identifier:** Not Provided	
Acknowledgement of DOE Support: [X] Yes [_] No	**Revision Type:** No Change	

Thesis/Dissertation: CLAS12 Hough Transform Track Recognition and Drift Chamber Reconstruction Software Validation

Authors: Michael Armstrong	**Institution:** University of Surrey
Completion Date: 01/14/2020	**Acknowledgement of DOE Support:** [X] Yes [_] No
Revision Type: No Change	

Journal Article: The CLAS12 software framework and event reconstruction

Journal: Nucl. Instrum. Meth		
Peer Reviewed: [X] Yes [_] No	**Publication Status:** Published	
Volume: A959	**Issue:** Not Provided	**First Page Number or eLocation ID:** 163472
Publication Date: 2020	**Publication Location:** Not Provided	
Authors: V. Ziegler et al.		
Publication Identifier Type: DOI	**Publication Identifier:** 10.1016/j.nima.2020.163472	
Acknowledgement of DOE Support: [X] Yes [_] No	**Revision Type:** No Change	

Journal Article: Beam–target helicity asymmetry E in K + Σ − photoproduction on the neutron

Journal: Phys. Lett. B		
Peer Reviewed: [X] Yes [_] No	**Publication Status:** Published	
Volume: 808	**Issue:** Not Provided	**First Page Number or eLocation ID:** 135662
Publication Date: 2020	**Publication Location:** Not Provided	
Authors: N. Zachariou et al.		
Publication Identifier Type: DOI	**Publication Identifier:** 10.1016/j.physletb.2020.135662	
Acknowledgement of DOE Support: [X] Yes [_] No	**Revision Type:** No Change	

Journal Article: The CLAS12 Silicon Vertex Tracker

Journal: Nucl. Instrum. Meth		
Peer Reviewed: [X] Yes [_] No	**Publication Status:** Published	
Volume: A962	**Issue:** Not Provided	**First Page Number or eLocation ID:** 163701
Publication Date: 2020	**Publication Location:** Not Provided	
Authors: M. A. Antonioli et al.		
Publication Identifier Type: DOI	**Publication Identifier:** 10.1016/j.nima.2020.163701	
Acknowledgement of DOE Support: [X] Yes [_] No	**Revision Type:** No Change	

Journal Article: Probing the core of the strong nuclear interaction

Journal: Nature		
Peer Reviewed: [X] Yes [_] No	**Publication Status:** Published	
Volume: 578	**Issue:** 7796	**First Page Number or eLocation ID:** 540
Publication Date: 2020	**Publication Location:** Not Provided	
Authors: A. Schmidt et al.		
Publication Identifier Type: DOI	**Publication Identifier:** 10.1038/s41586-020-2021-6	
Acknowledgement of DOE Support: [X] Yes [_] No	**Revision Type:** No Change	

Journal Article: The CLAS12 Spectrometer at Jefferson Laboratory

Journal: Nucl. Instrum. Meth		
Peer Reviewed: [X] Yes [_] No	**Publication Status:** Published	
Volume: A959	**Issue:** Not Provided	**First Page Number or eLocation ID:** 163419

Publication Date: 2020	**Publication Location:** Not Provided
Authors: V. D. Burkert et al.	
Publication Identifier Type: DOI	**Publication Identifier:** 10.1016/j.nima.2020.16341
Acknowledgement of DOE Support: [X] Yes [_] No	**Revision Type:** No Change

Journal Article: Extraction of beam-spin asymmetries from the hard exclusive π+ channel off protons in a wide range of kinematics

Journal: Phys Rev Lett		
Peer Reviewed: [X] Yes [_] No	**Publication Status:** Published	
Volume: 125	**Issue:** 18	**First Page Number or eLocation ID:** 182001
Publication Date: 2020	**Publication Location:** Not Provided	
Authors: S. Diehl et al.		
Publication Identifier Type: DOI	**Publication Identifier:** 10.1103/PhysRevLett.125.182001	
Acknowledgement of DOE Support: [X] Yes [_] No	**Revision Type:** No Change	

Conference Paper/Presentation: CLAS12 Drift Chamber Reconstruction Code Validation

Authors: M.Armstrong, V.Ziegler, and G.P.Gilfoyle	**Conference Name:** Fall 2019 Division of Nuclear Physics Meeting
Conference Location: Crystal City, Virginia	**Conference Date:** 10/15/2019
Publication Status: Published	**Acknowledgement of DOE Support: [X]** Yes [_] No
Revision Type: No Change	

Conference Paper/Presentation: Event Selection in Electron Scattering on Deuterium

Authors: M.Heyrich, X.Hu, and G.P.Gilfoyle	**Conference Name:** Fall 2019 Division of Nuclear Physics Meeting
Conference Location: Crystal City, Virginia	**Conference Date:** 10/15/2019
Publication Status: Published	**Acknowledgement of DOE Support: [X]** Yes [_] No
Revision Type: No Change	

Journal Article: Measurement of the beam spin asymmetry of vec e p → e' p' η in the deep-inelastic regime with CLAS

Journal: Phys. Lett		
Peer Reviewed: [X] Yes [_] No	**Publication Status:** Published	
Volume: B789	**Issue:** Not Provided	**First Page Number or eLocation ID:** 426
Publication Date: 2019	**Publication Location:** Not Provided	
Authors: B. Zhao et al.		
Publication Identifier Type: DOI	**Publication Identifier:** 10.1016/j.physletb.2018.12.065	
Acknowledgement of DOE Support: [X] Yes [_] No	**Revision Type:** No Change	

Conference Paper/Presentation: Hunting for Quarks and Gluons

Authors: G.P.Gilfoyle	**Conference Name:** Physics Department, University of Surrey Seminar
Conference Location: University of Surrey, Guildford, UK	**Conference Date:** 05/08/2018
Publication Status: Not published	**Acknowledgement of DOE Support: [X]** Yes [_] No
Revision Type: No Change	

Journal Article: Future Measurements of the Nucleon Elastic Electromagnetic Form Factors at Jefferson Lab

Journal: EPJ Web Conf.		
Peer Reviewed: [X] Yes [_] No	**Publication Status:** Published	
Volume: 172	**Issue:** Not Provided	**First Page Number or eLocation ID:** 02004
Publication Date: 2018	**Publication Location:** Not Provided	
Authors: G.P.Gilfoyle		
Publication Identifier Type: DOI	**Publication Identifier:** 10.1051/epjconf/201817202004	
Acknowledgement of DOE Support: [X] Yes [_] No	**Revision Type:** No Change	

Journal Article: Exclusive photoproduction of π 0 up to large values of Mandelstam variables s, t and u with CLAS

Journal: Phys. Rev.		
Peer Reviewed: [X] Yes [_] No	**Publication Status:** Published	
Volume: C98	**Issue:** 1	**First Page Number or eLocation ID:** 015207
Publication Date: 2018	**Publication Location:** Not Provided	
Authors: M. C. Kunkel et al.		
Publication Identifier Type: DOI	**Publication Identifier:** 10.1103/PhysRevC.98.015207	
Acknowledgement of DOE Support: [X] Yes [_] No	**Revision Type:** No Change	

Journal Article: Hard exclusive pion electroproduction at backward angles with CLAS

Journal: Phys. Lett.		
Peer Reviewed: [X] Yes [_] No	**Publication Status:** Published	
Volume: B780	**Issue:** Not Provided	**First Page Number or eLocation ID:** 340
Publication Date: 2018	**Publication Location:** Not Provided	
Authors: K. Park et al		
Publication Identifier Type: DOI	**Publication Identifier:** 10.1016/j.physletb.2018.03.026	
Acknowledgement of DOE Support: [X] Yes [_] No	**Revision Type:** No Change	

Journal Article: Measurement of the beam asymmetry Σ and the target asymmetry T in the photoproduction of ω mesons off the proton using CLAS at Jefferson Laboratory

Journal: Phys. Rev.		
Peer Reviewed: [X] Yes [_] No	**Publication Status:** Published	
Volume: C97	**Issue:** 5	**First Page Number or eLocation ID:** 055202
Publication Date: 2018	**Publication Location:** Not Provided	
Authors: P. Roy et al.		
Publication Identifier Type: DOI	**Publication Identifier:** 10.1103/PhysRevC.97.055202	
Acknowledgement of DOE Support: [X] Yes [_] No	**Revision Type:** No Change	

Journal Article: Measurement of the Q2 Dependence of the Deuteron Spin Structure Function g1 and its Moments at Low Q2 with CLAS

Journal: Phys. Rev. Lett.		
Peer Reviewed: [X] Yes [_] No	**Publication Status:** Published	
Volume: 120	**Issue:** 6	**First Page Number or eLocation ID:** 062501
Publication Date: 2018	**Publication Location:** Not Provided	
Authors: K. P. Adhikari et al.		
Publication Identifier Type: DOI	**Publication Identifier:** 10.1103/PhysRevLett.120.062501	

Acknowledgement of DOE Support: [X] Yes [_] No	**Revision Type:** No Change

Journal Article: Double KS^0 Photoproduction off the Proton at CLAS

Journal: Phys. Rev.		
Peer Reviewed: [X] Yes [_] No	**Publication Status:** Published	
Volume: C97	**Issue:** 2	**First Page Number or eLocation ID:** 025203
Publication Date: 2018	**Publication Location:** Not Provided	
Authors: S. Chandavar et al.		
Publication Identifier Type: DOI	**Publication Identifier:** 10.1103/PhysRevC.97.025203	
Acknowledgement of DOE Support: [X] Yes [_] No	**Revision Type:** No Change	

Journal Article: Semi-Inclusive π 0 target and beam-target asymmetries from 6 GeV electron scattering with CLAS

Journal: Phys.Lett.B		
Peer Reviewed: [X] Yes [_] No	**Publication Status:** Published	
Volume: 782	**Issue:** Not Provided	**First Page Number or eLocation ID:** 662
Publication Date: 2018	**Publication Location:** Not Provided	
Authors: S. Jawalkar et al.		
Publication Identifier Type: DOI	**Publication Identifier:** 10.1016/j.physletb.2018.06.014	
Acknowledgement of DOE Support: [X] Yes [_] No	**Revision Type:** No Change	

Conference Paper/Presentation: Analysis of Quasi-Elastic e-n and e-p Scattering from Deuterium

Authors: A.Balsamo, K.Sherman, and G.P.Gilfoyle	**Conference Name:** Meeting of the Division of Nuclear Physics of the American Physical Society
Conference Location: Pittsburgh, PA	**Conference Date:** 10/27/2017
Publication Status: Abstract published	**Acknowledgement of DOE Support:** [X] Yes [_] No
Revision Type: No Change	

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

Authors: G.P. Gilfoyle	**Conference Name:** 47th International Symposium on Multiparticle Dynamics
Conference Location: Tlaxcala City, Mexico	**Conference Date:** 09/12/2017
Publication Status: Published	**Acknowledgement of DOE Support:** [X] Yes [_] No
Revision Type: No Change	

Journal Article: Determination of the proton spin structure functions for 0.05 ≤ Q 2 ≤ 5 GeV 2 using CLAS

Journal: Phys. Rev.		
Peer Reviewed: [X] Yes [_] No	**Publication Status:** Published	
Volume: C96	**Issue:** 6	**First Page Number or eLocation ID:** 065208
Publication Date: 2017	**Publication Location:** Not Provided	
Authors: R. Fersch et al.		
Publication Identifier Type: DOI	**Publication Identifier:** 10.1103/PhysRevC.96.065208	
Acknowledgement of DOE Support: [X] Yes [_] No	**Revision Type:** No Change	

Journal Article: First Exclusive Measurement of Deeply Virtual Compton Scattering off 4He: Toward the 3D Tomography of Nuclei

Journal: Phys. Rev. Lett.		
Peer Reviewed: [X] Yes [_] No	**Publication Status:** Published	
Volume: 119	**Issue:** 20	**First Page Number or eLocation ID:** 202004
Publication Date: 2017	**Publication Location:** Not Provided	
Authors: M. Hattawy et al.		
Publication Identifier Type: DOI	**Publication Identifier:** 10.1103/PhysRevLett.119.202004	
Acknowledgement of DOE Support: [X] Yes [_] No	**Revision Type:** No Change	

Other Products Detail

Other Product: Data and Research Material

Description:
Measurement of the Neutron Magnetic Form Factor with the Ratio Method - 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 probes the distribution of magnetization within the neutron. We have been analyzing recently collected data from CLAS12 to extract GMn. This is part of an approved experiment (E12-07-104).One of the challenges in this work is to extract quasielastic (QE) events from a large inelastic background. We focus on neutrons detected in the CLAS12 calorimeters and protons measured with the CLAS12 forward detector. 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 nucleons 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. We continue to optimize the extraction of GMn using more precise kinematic cuts, momentum corrections, artificial-intelligence (AI) assisted tracking, and corrections to the neutron pathlength. This last item is based on the recent discovery that the reconstruction code uses a neutron pathlength from the target vertex (determined from the scattered electron track) to the front face of the electromagnetic calorimeter. In many cases the neutron does not create the shower at this point, but passes through some portion of the detector before interacting. We are investigating how to correct for this effect to improve the extraction of the QE events for GMn.

Revision Type: No Change

Other Product: Data and Research Material

Description: Description: Measurement of the Neutron Magnetic Form Factor with the Ratio Method - One of Jefferson Lab's goals is to unravel the quark-gluon structure of nuclei. We are using use the ratio, R, of electron-neutron (e-n) to electron-proton (e-p) scattering on deuterium to probe the magnetic form factor of the neutron, GMn. GMn probes the distribution of magnetization within the neutron. We have been analyzing recently collected data from CLAS12 to extract GMn. This is part of an approved experiment (E12-07-104). One of the challenges in this work is to extract quasielastic (QE) events from a large inelastic background. We focus on neutrons detected in the CLAS12 calorimeters and protons measured with the CLAS12 forward detector. For the e-n events we have only included events which had a single charged track (the electron). For e-p events we required two charged particles (electron and proton). However we recently learned of a new parameter included in the reconstruction output called chi2PID. This quantity is the difference between the measured vertex time for a particle and the expected vertex based on the best hypothesis for the particle identity. This difference is then divided by the width of the distribution for that particle type and momentum. The smaller the value of chi2PID the better the particle identification. We found that many events had good tracks for one or two charged particles and then poor values of chi2PID for other charged particles. We were rejecting events with more than two charged particles. We found that if we included tracks with chi2PID < 2 and ignored charged tracks with higher values we significantly increased the number of events in our sample with no loss in quality.

We are part of Run Group B (RGB) and are nearly ready to re-analyze our data using an improved version of the reconstruction software (pass2). Much of the work improving the software has gone into the Central Detector which has no effect on our GMn analysis. Nevertheless, when RGB was validating the new software we were asked to do our analysis using the new software. We went through several cycles of validation and, as expected, found no differences due to the new, pass2 codes.

Revision Type: New

Other Product: Protocols

Description: Measuring the CLAS12 Neutron Detection Efficiency (NDE) - The method to extract GMn described above requires precise knowledge of the neutron detection efficiency (NDE) to correct the measured e-n yield and it is one of the largest components of the systematic uncertainty of GMn. Comparison of past measurements at different laboratories reveals considerable tension among those experiments possibly due to variations in detector performance and efficiency. As discussed in previous sections to measure the neutron detection efficiency we use the 1H(e,e' π+ n) reaction on a hydrogen target from Run Group A (RGA) data. This reaction is a source of tagged neutrons which can be detected in the electromagnetic calorimeter (PCAL/EC). More details on the technique are under Goal 1 in Section 1. At the end of that procedure we impose additional cuts in the mass squared versus neutron momentum plane to eliminate overlaps with photon events. At the end of this process we have the missing mass (MM) spectra in thirty-six bins in the neutron momentum.

We fit each of the thirty-six bins to obtain the neutron peak shape and extract the yield for expected and detected neutrons. The NDE is the ratio of detected to expected neutrons as a function of neutron momentum. To fit each distribution we wrote codes in ROOT (data analysis framework from CERN), PyROOT (a Python interface to

ROOT), and Java to fit each bin and extract the integrated yield. The first fit in the lowest neutron momentum bin is done "by hand" to establish a starting point for the fit parameters. We loop over each neutron momentum bin using the parameters from the previous fit as a starting point. This step guides the fitting process to the appropriate chi-square minimum in each bin. The fit parameters vary smoothly with neutron momentum. We have performed the fits with a variety of functions and constraints and with background. There is some irregularity in the fit results below neutron momentum of 2.5 GeV, but above this value the fits converge to a plateau with NDE ~ 0.75. This consistency is important to the GMn measurement because this is the neutron momentum region where there is currently no precision data. We also have NDE measurements nearly up to a neutron momentum of 7 GeV which corresponds to a Q2~ 10 GeV2 which is double the current upper limit on precision GMn measurements.

Revision Type: New

Other Product: Protocols

Description: Measuring the CLAS12 Neutron Detection Efficiency (NDE) - The method to extract GMn described above to measure GMn does require precise knowledge of the neutron detection efficiency (NDE) to correct the measured e-n yield and it is one of the largest components of the systematic uncertainty of GMn. Comparison of past measurements at different laboratories reveals considerable tension among those experiments possibly due to variations in detector performance and efficiency. To measure the neutron detection efficiency we use the 1H(e,e' π+ n) reaction on a hydrogen target from Run Group A (RGA) data. This reaction is a source of tagged neutrons which can be detected in the electromagnetic calorimeter (PCAL/EC).

We start with the 1H(e,e' π+ Xn) reaction where Xn is a single neutral. We infer the mass of the unobserved neutron from the measured electron and pion kinematics and swim the candidate neutron through CLAS12. This expected track is required to lie within the CLAS12 acceptance. We then search this event for neutral hits in the PCAL/EC and calculate the distance delta_R between the intersection point of the expected track with the front face of the detector and the intersection point of each measured track. We select the hit with the smallest delta_R and call it the measured track. We calculate the direction cosines of the expected and measured neutron 3-momenta and take the difference. The distribution of this difference is strongly peaked around zero. Finally, we add additional cuts in the mass squared versus neutron momentum plain to eliminate overlaps with photon events. We continue the work to optimize the extraction of the neutrons from background. We have used several methods to fit the missing mass distribution to accomplish this goal. These efforts including using a combination of asymmetric Gaussian and Lorentzian functions combined with a polynomial background which shows good promise. We have more recently studied the use of the Crystal Ball function to fit the missing mass distribution. A comparison of these different methods will enable us to understand our systematic uncertainties. This work holds the potential to push the measurement of the NDE to a neutron momentum of 7 GeV which corresponds to Q2 ~ 10 GeVs which is about a factor of two greater than the current upper limit on precise measurements of GMn.

Revision Type: No Change

Other Product: Software or NetWare

Description: CLAS12 Reconstruction Resolution - In this project we measure the reconstruction resolution in simulation for each of the subsystems of the CLAS12 Forward Detector (FD). This is done by swimming two simulated tracks through the CLAS12 FD. One track uses the known (or generated) vertex and the initial 3-momentum from the event generator that was the input to the simulation. The second track uses the reconstructed vertex and momentum produced by the reconstruction code itself. Differences between these two tracks are used to extract the reconstruction resolution. The effects of particle energy, particle type, torus field polarity, sector dependence, and geometry were studied using two recent versions of the CLAS12, physics-based simulation code gemc.

These results can provide benchmarks for hardware and software development for the FD subsystems and guidance for setting goals and specifications. The micro-service architecture of Clara enables developers to quickly swap components of the reconstruction chain and the benchmarks established here can provide test goals. They can also illuminate the different contributions of software and hardware to the CLAS12 resolution and be employed in unit tests as a measure of the stability of new code.

The reconstruction code uses a Kalman filter to extract the track parameters. The results here can be used to parameterize the dependence of the resolution on various kinematic variables and incorporate this dependence into the covariance matrix for the Kalman filter state vector. At each step in the Kalman filter a new state vector is estimated with a weighted average of the track data where the weights are contained in the covariance matrix. This matrix contains both the uncertainties and their correlations and identifies which measurements should have greater weight in the calculation. The results of this study can also be used to validate the matching criteria for the outer detector subsystems.

We have generated a baseline for the reconstruction resolution for five observables and seven dependencies. Most of our results agree with expectations. This work is a starting point for further development of the Kalman filter method used in the CLAS12 reconstruction code. This work was presented at the fall 2021 DNP meeting and is the subject of a CLAS12-NOTE in preparation.

Revision Type: No Change

Other Product: Software or NetWare

Description: Description: CLAS12 Central Vertex Tracker Reconstruction Efficiency - The scientific staff at JLab have begun a project to double the current luminosity limit in the CLAS12 detector. This project is motivated to expand the physics reach of CLAS12 by increasing the data rate to make rare physics processes accessible and reducing the impact of background hits in the detector. The CLAS12 reconstruction code for the CLAS12 Central Vertex Tracker (CVT) consists of pattern recognition to identify track candidates and subsequent track fitting based on a Kalman filter algorithm. The Reconstruction Efficiency, e_R, is a measure of how well the software is able to reproduce the trajectory of a real particle scattered into the Central Detector: e_R = N_S/N_T where N_S is the number tracks successfully reconstructed by the software and N_T is the total number of real tracks. In this study we focus on the Central Detector.

In high-luminosity running a large number of hits background make it difficult to separate these unwanted hits from 'good' hits that are part of a particle track in CLAS12. One way to reduce the number of ghost tracks is to impose constraints to remove tracks with large distances of closest approach (DOCAs). The effect of DOCA cuts on the reconstruction efficiency can be measured by simulating or taking low luminosity (5nA) events where the background is low and merging them with realistic background events. We then measure the effect of background on the reconstruction. Finally, by varying the size of the DOCA cut, we find which configuration yields the highest efficiency. The implementation of constraints on track candidate parameters in the CVT will reduce the impact of background hits at high luminosity and improve the reconstruction efficiency in the Central Detector. The work described here was presented at the fall 2022 meeting of the Division of Nuclear Physics meeting by Mr. Rocco Monteiro, a masters student from the University of Surrey.

Revision Type: New

Close Window

Progress Report - Participants

DE-FG02-96ER40980: Medium Energy Nuclear Physics at the University of Richmond

Resources

View

Previous Progress Report | Award Access | Progress Report Instructions | Last Awarded Proposal

Participants Summary

Number	Name	Project Role	Months
1	Baashen, Lamya	Graduate Student (Research Assistant)	11
2	Gilfoyle, Gerard	Principal Investigator/Project Director	11
3	Hess, Jessie	Undergraduate Student	3
4	Monteiro, Rocco	Graduate Student (Research Assistant)	10
5	Raue, Brian	Faculty	11
6	Sanford, Ryan	Undergraduate Student	3

Partners Summary

Number	Name	Location	Contribution to the Project
No partners to display.			

Other Collaborators Summary

Number	Description
No other collaborators to display.	

Participants Detail

Participant: Baashen, Lamya

Project Role: Graduate Student (Research Assistant)	**Person Months Worked**: 11	**Funding Support**: Florida International University (if other than this award)

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 Run Groups A data). Her focus over the last year has been fitting the missing mass distributions to determine the NDE from the RGA data set and extracting the ratio R for GMn. She has passed her PhD qualifier.

International Collaboration: No	**If Yes, Country of International Collaborator:** Not Provided
International Travel: No	

Participant: Gilfoyle, Gerard

Project Role: Principal Investigator/Project Director	**Person Months Worked**: 11	**Funding Support**: University of Richmond (if other than this award)

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	**If Yes, Country of International Collaborator:** Not Provided
International Travel: No	

Participant: Hess, Jessie

Project Role: Undergraduate Student	**Person Months Worked**: 3	**Funding Support**: Not Provided (if other than this award)

Contribution to the Project:

At Jefferson Lab we use the CLAS12 detector to measure the neutron magnetic form factor. An accurate measurement of the CLAS12 neutron detection efficiency (NDE) is required. We use the nuclear reaction ep → e′π+ n as a source of tagged neutrons and obtain the NDE from the ratio of expected neutrons to detected ones. We assume the final state consists of e′π+ n only, use the e′π+ information to predict the neutron's position (we call these neutrons expected) and then search for that neutron. If we find it in the event we call that neutron detected. We select neutrons with the missing mass (MM) technique. We use simulation to validate our methods. We simulated events with the Monte-Carlo code GEMC and included background events. We found the simulation had worse resolution than the data. The CLAS12 software group made a concerted effort to improve GEMC and make the resolution more realistic. We were able to use the improved to validate our codes for selecting events. This work was presented at the fall, 2022 DNP meeting.

International Collaboration: No	**If Yes, Country of International Collaborator:** Not Provided
International Travel: No	

Participant: Monteiro, Rocco

Project Role: Graduate Student (Research Assistant)	**Person Months Worked**: 10	**Funding Support**: Not Provided (if other than this award)

Contribution to the Project:
Mr. Monteiro is a masters student from the University of Surrey, UK performing a Research Year at past of his master requirements. He is part of a Richmond-Surrey program funded by DOE. Below is a description of his project.

The CLAS12 Detector at Jefferson Lab is used to study the structure of nucleons by tracking and measuring particles produced in electron scattering experiments. The Central Vertex Tracker (CVT) determines the trajectory information for particles scattered in the Central Detector at polar angles of $35° < \theta < 135°$. Event data is processed using the CLAS12 reconstruction software. This project aims to measure the rate at which trajectories for “real” particles (as opposed to 'fake' tracks created by noise) are successfully reconstructed in the CVT. This analysis was done using the CLAS12 simulation software, gemc, that generates a desired particle state vector from the target position and simulates its passage through CLAS12. Background noise files from previous experiments were merged with the simulated data to mimic experimental results. The reconstruction software was then used to create initial guesses, known as seeds, for the trajectories of the simulated particles. By knowing the truth information of the generated particle, we can determine whether the right track was found and estimate the reconstruction efficiency. Furthermore, the seed information such as the chi-square, number of degrees of freedom, detector signals associated with a track candidate etc. were studied. The goal is to validate the parameters that characterize track candidates and how cuts on these specific track parameters affect the efficiency of the continually developing seeding algorithm. This study of track parameters could also be used to give seeds a quality rating by which the best candidates may be chosen for track fitting. Reducing the total number of seeds through poor seed selection leads to reductions in computational time and increased reconstruction efficiency. In addition, the outer subsystems in the Central Detector depend on the track information from the CVT for particle identification and momentum calculation so this algorithm will improve the reconstruction efficiency in the Central Detector as a whole. This project was presented in a poster at the fall, 2022 meeting of the Division of Nuclear Physics.

International Collaboration: No	**If Yes, Country of International Collaborator:** Not Provided
International Travel: No	

Participant: Raue, Brian		
Project Role: Faculty	**Person Months Worked**: 11	**Funding Support**: Florida International University (if other than this award)
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		**If Yes, Country of International Collaborator:** Not Provided
International Travel: No		

Participant: Sanford, Ryan		
Project Role: Undergraduate Student	**Person Months Worked**: 3	**Funding Support**: Not Provided (if other than this award)
Contribution to the Project: The Neutron Detection Efficiency (NDE) is an essential property of the CLAS12 Detector at Jefferson Laboratory. It is measured with the ratio of detected neutrons and expected neutrons from the ep → e' π+ n reaction which is a source of tagged neutrons. Expected neutrons are found by swimming the neutron track, using only the e' π+ information, to see if it strikes the CLAS12 detector. Detected neutrons are ones observed near the expected neutron. Missing mass (MM) spectra of the neutron are created through four-momentum conservation and can be used to determine the neutron yield. We fit the spectra to separate the neutron events from the higher missing mass background. The fitting is done asymmetrically using the Crystal Ball function. The function is a combination of a gaussian fit around a central peak and a low-MM tail that is fit with a power law, MM^n, where n is a fit parameter. The overlap point of the two functions is determined by another fit parameter, α. The fit is done with the CLAS12 Common Tools written in Java. We found the Crystal Ball function produces better fits to the neutron peak as measured by the average reduced chi-square (<χ2/v> ~ 1.3) than a gaussian alone. The fit parameters vary smoothly with neutron momentum, over the range of p_mm = 0.4 GeV - 7.0 GeV. This work was presented at the fall, 2022 DNP meeting.		
International Collaboration: No		**If Yes, Country of International Collaborator:** Not Provided
International Travel: No		

Close Window

Progress Report - Impact

DE-FG02-96ER40980: Medium Energy Nuclear Physics at the University of Richmond

Resources

View

Previous Progress Report | Award Access | Progress Report Instructions | Last Awarded Proposal

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 are calibrating and analyzing data from 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) 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?

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

Two University of Richmond undergraduates (Ryan Sanford and Jessie Hess) were trained at Richmond and JLab in 2021 and presented a poster on their work at the Fall, 2021 DNP meeting. A masters student from the University of Surrey (Rocco Monteiro) recently arrived at JLab for ten months in 2022 as part of his research requirement. We are now working with the JLab staff to identify the best area for him to contribute to the CLAS12 research program. 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. The PI maintains a lab at the University of Richmond with several high-powered laptops (additional memory and storage than the University standard models) and monitors for summer researchers. The PI also has an office at JLab where he maintains a similar machine for the use of the Surrey masters student. All of the students in the PI's group make heavy use of local computing resources and the JLab farm. The projects described in this annual report make intense of computing to filter large quantities of data for the signal of interest and to understand simulation and data analysis.

5. What is the impact on technology transfer?

Undergraduates and masters students are trained in analysis of large, complex data sets. Richmond physics majors who worked in the PI's lab 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 doctoral student at Old Dominion Unversity who received a supplemental research award from the DOE Office of Science Graduate Student Research Program. One of current undergraduate researchers, Ryan Sanford, is going to graduate school in medical physics. My other recent undergraduate researcher will be attending law school. 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

Number	Country	Amount
No countries have been added.		

Close Window