Continuation Progress Report

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PI: Gerard P. Gilfoyle

Department of Physics, University of Richmond, 28 Westhampton Way, Richmond, VA 23173

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Annual Reporting Period
1 Introduction

In this report we describe the progress made during the period January 1, 2013 to December 31, 2013 under contract number DE-FG02-96ER40980 entitled Nuclear and Particle Physics at the University of Richmond, Gerard P Gilfoyle (PI). See pages 6-7 for a summary. The experimental work is part of the electromagnetic nuclear physics program in Hall B at the Thomas Jefferson National Accelerator Facility (JLab). The group includes a single faculty member (Gilfoyle) and 3-5 undergraduates at the University of Richmond (a primarily undergraduate institution). Gilfoyle is co-author on eight refereed articles during this period [1, 2, 3, 4, 5, 6, 7, 8]. He is currently working on physics analysis projects described below and software for the simulation, reconstruction, and analysis of data to be collected with the new CLAS12 detector in Hall B after the completion of the 12 GeV Upgrade. Gilfoyle is spokesperson and contact person on a new experiment to measure the neutron magnetic form factor $G_M^n$ in Hall B entitled Measurement of the Neutron Magnetic Form Factor at High $Q^2$ Using the Ratio Method on Deuterium (JLab experiment E12-07-104) that will run in the first five years after the 12 GeV Upgrade at JLab [9, 10]. The experiment was assigned a scientific rating of A by PAC35 in January, 2010 and 30 days of beamtime were allocated [11, 12]. Gilfoyle is co-spokesperson on another JLab 12-GeV proposal to measure $G_M^n$ in Hall A entitled Precision Measurement of the Neutron Magnetic Form Factor at $Q^2 = 16.0$ and 18.0 (GeV/c)$^2$ by the Ratio Method (JLab experiment E12-09-019). He is also co-spokesperson on a JLab 12-GeV proposal entitled Quark Propagation and Hadron Formation (JLab experiment E12-06-117) that was approved by PAC30 [13, 14]. Current physics projects include the analysis of existing data from CLAS6 experiment E94-017 to measure the magnetic form factor of the neutron or $G_M^n$ [15]. CLAS6 is the previous detector in Hall B. The results for two out of three sets of run conditions have been published [16] and his group continues work on the third set. He is spokesperson on a CLAS6 Approved Analysis Out-of-Plane Measurements of Deuteron Structure Functions to extract the fifth structure function of the deuteron [17].

During the period of this report Gilfoyle was invited to give talks on JLab physics at the Workshop on High-Energy Physics in the LHC Era [18] and Hall B software development during an external review of the JLab software enterprise [19]. He also presented the group’s program at the DOE Comparative Review [20, 21]. In the last year Gilfoyle mentored a masters student, Alex Colvill, from the University of Surrey in the UK who wrote the reconstruction software for the time-of-flight (TOF) systems in CLAS12 [22, 23]. Mr. Colvill is part of a joint Surrey/Richmond program where a Surrey masters student fulfills his/her requirement to spend a year doing physics research under Gilfoyle’s guidance at Jefferson Lab. He was supported by a supplemental grant from DOE. Last summer three undergraduates, Keegan Sherman, Liam Murray, and Justin Ruger, worked under Gilfoyle’s guidance at Richmond and JLab. Mr. Ruger also worked closely with one of the JLab staff scientists Dr. Dennis Weygand. Two of these undergraduates were supported by the DOE grant and one was supported by other University of Richmond funds. Two of the undergraduates presented their work at the Fall, 2013 meeting of the Division of Nuclear Physics (DNP) of the APS [24, 25]. Our laboratory at Richmond was enhanced with the purchase of an Intel Xeon MIC (Many Integrated Co-processors) with DOE funds. We used this machine to investigate it potential as a tool for CLAS12 analysis.

We anticipate that at the end of the current budget period (May 31, 2014) there will be about $26,000 remaining in unexpended funds with about $1,100 in students stipends and the rest in the travel and equipment categories. See the budget justification for more details. In the past, we have routinely obtained University of Richmond support for undergraduate stipends. This allows us to stretch the summer stipends further (Keegan Sherman worked an additional two weeks last summer to build code on the Intel Xeon MIC). We were also able to obtain support for conference travel from the University of Richmond and the American Physical Society (for Gilfoyle and two undergraduates). We will use these unexpended funds to support additional students and travel in the future. The University of Richmond supported routine travel to JLab. As usual, undergraduates were involved in all aspects of our work. Below, we discuss recent accomplishments and describe plans for the next budget period.

1Department of Physics, University of Richmond, 28 Westhampton Way, Richmond, VA 23173.
2The DOE is now doubling the accelerator energy at JLab from 6 GeV to 12 GeV. A new detector in Hall B is under construction, CLAS12, to take advantage of the new physics opportunities.
3A CLAS Collaboration member can write a proposal to analyze existing, 6-GeV CLAS (CLAS6) data which is reviewed by a committee of Collaboration members, and defended before the Collaboration who then vote to approve it.
2 Physics Projects

The elastic electromagnetic form factors are basic observables that describe the internal structure of the proton and neutron. The differential cross section for elastic electron-nucleon scattering can be calculated in the laboratory frame in terms of four elastic form factors (electric and magnetic ones for each nucleon) that characterize the distributions of charge and magnetization within the proton and neutron. We are part of a broad assault on the four elastic nucleon form factors at JLab and our focus is on $G_M^N$, the magnetic form factor of the neutron. As part of that effort we are analyzing an existing CLAS6 data set using the same methods that will be used for the proposed experiments (E12-07-104 and E12-09-019) mentioned in the Introduction. Experiment E94-017 consists of three data sets with different running conditions. The analysis of the first two data sets has been published and we have begun work on the third [16]. In the last year we have rebuilt the software (written about 2005) used to analyze those first two data sets and have it operating on the Richmond cluster. We were able to reproduce some of the analysis such as the neutron detection efficiency of the first two data sets and continue to test the code and update the software so it runs properly on current machines. The event generator used to simulate the reaction in CLAS6 has been resurrected and is being used for this study and the analysis of the fifth structure function of the deuteron (see description below).

The hadronic model of nuclear physics has been successful at low $Q^2$, but it is not well-developed in the GeV region where there are few measurements. To put our understanding of the $NN$ force on firmer footing, we are investigating the out-of-plane structure functions of the deuteron using the reaction $^3\text{H}(e,e'p)n$ with CLAS6 in quasielastic (QE) kinematics [17]. In particular, the so-called fifth structure function is nonzero only outside the plane defined by the incoming and scattered electron. This structure function has been rarely measured and never at these kinematics. To study the fifth structure function we use an asymmetry $A$ only outside the plane defined by the incoming and scattered electron. This structure function has been extracted CLAS6 in quasielastic (QE) kinematics [17]. In particular, the so-called fifth structure function is nonzero

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3 Technical Projects

We are committed to development projects for the JLab 12-GeV Upgrade to double the beam energy of the electron accelerator and enhance the experimental equipment in Hall B [27]. We are responsible for design, prototyping, development, and testing of software for event simulation and reconstruction in the new Hall-B detector CLAS12. During the period of this report we developed the reconstruction code for the two TOF sub-systems of CLAS12. The reconstruction of these CLAS12 data is a challenging software project - The CLAS12 Forward Detector is built around a toroidal magnet and consists of layers of Cherenkov counters, drift chambers, TOF counters, and calorimeters. It has six, identical, independent sectors that cover a large solid angle with about 28,000 readouts. The TOF sub-system has 540 scintillator paddles in the TOF sub-system arranged in three separate panels in each of six sectors with 1080 readouts (one for each end of the paddle). A large-angle device (the Central Detector) is based on a solenoid magnet using a silicon vertex tracker and TOF system with nearly 34,000 readouts. The TOF sub-system here has 48 paddles with 96 readouts (one for each end of the paddle). CLAS12 will collect about five TByte of data each day that will require reconstruction and simulation. The TOF sub-systems will produce fast timing signals

The first step to publish CLAS6 results is for an internal Collaboration committee to review a report describing the technical details of the analysis.
that, when combined with the measured trajectory of the particle, can be used to accurately determine the
time-of-flight of the detected particle - a crucial element of the particle identification. When the data from
an event are first analyzed, each component of the software system performs a standalone analysis. For the
TOF systems, photo-multiplier (PMT) signals are collected (one from each end of the PMT) and the timing
signals, positions, and deposited energy in each scintillator paddle are extracted. Clusters of adjacent hits
are identified for later use. Calculating the time-of-flight is done later when tracking information is available.
In the last year Alex Colvill, the masters student from Surrey, worked on this project under the guidance
of the PI (Gilfoyle) and the other members of the CLAS12 software group. Starting from the Fortran code
used in the CLAS6 Forward Detector analysis, the algorithm for the CLAS12 Forward Detector has been
written in Java and incorporated into CLARA, the CLAS12 reconstruction environment. CLARA is part
of an innovative service-oriented architecture (SOA) developed in Hall B for reconstruction that is robust,
modular and takes full advantage of modern distributed and multi-threaded environments [28]. This Java
code has been made readily configurable (the old TOF code had many hard-wired parameters) and
validated with simulations performed with the CLAS12 standard simulation gemc. The simulations were run
on the Richmond cluster using deep-inelastic scattering kinematics with many different final particle states.
We compared simulations at CLAS6 energies (5.7 GeV) with ones at CLAS12 energies (11 GeV), with and
without beam-related backgrounds or scattering from other CLAS12 hardware components. We investigated
different methods for forming clusters of adjacent paddles with hits and have evidence for a better method
to form clusters. In the CLAS6 algorithm, for example, a multiple of the time difference between paddles
relative to the uncertainty in the individual time measurements was used as a cut-off to determine which
paddles should be grouped into a cluster. We found that an absolute time difference was more efficient
at identifying true clusters. The optimal choice of the parameters was determined using a wide range of
simulations. The reconstruction code for the TOF system in the Central Detector is similar to the Forward
Detector and that code has been written, tested, and optimized in a similar way. The code was part of the
stress test in fall, 2013 where the full analysis chain available at the time was distributed over many compute
nodes in the JLab farm and simulation data were analyzed for several days. The TOF code worked without
error. A CLAS-NOTE on this work is in preparation.

In the last year we obtained an Intel Xeon Phi co-processor with DOE funds. It uses the MIC (Many
Integrated Coprocessors) architecture to perform parallel computations. It is a competitor to the Graphical-
Processing Units (GPUs) that perform the same function, but the MIC is easier to program (a significant
barrier in using the GPUs). Two undergraduates programmed the MIC last summer. One student, Justin
Ruger, adapted an existing algorithm that performs a partial-wave analysis to work on the MIC and saw a
considerable increase in speed. The other student, Keegan Sherman, was able to build and run the CERN
analysis code ROOT on the MIC. The performance improvement here was limited. This project is ongoing.
Mr. Ruger’s work was the subject of a poster at the fall meeting of the DNP [25].

The Richmond cluster (obtained in 2010 with NSF funds) continues to be a major development tool
for the CLAS12 software group especially for CLARA [28]. In the last year the operating system on the
cluster was updated (using University of Richmond funds) to keep it synchronized with the JLab farm.
Gilfoyle continues to work on software planning for CLAS12. The software effort for the entire Labor-
atory was assessed in November, 2013 by an external panel. Gilfoyle gave a presentation on the CLAS12
software user environment [19]. He was responsible for updating the estimates of the computing requirements
for CLAS12 which included the needs for processing power for data acquisition, calibration, reconstruction,
simulation, analysis, and storage.

4 Professional and CLAS Collaboration Service Work

Gilfoyle was chair of four CLAS Collaboration review committees in the last year. Three reviews were ad
hoc ones of drafts of papers for submission to be published.5 The other review considered an analysis of the
2H(\bar{e},e^\prime p)n reaction. He also wrote a review of one grant proposals for the Experimental Nuclear Physics
program at the National Science Foundation and served as chair of the CLAS Collaboration chair nominating
committee.

5As part of the procedure for publishing CLAS6 results, an internal Collaboration committee reviews the paper after the
analysis is approved. the draft then goes to the full Collaboration for final approval.
References


[3] W. Tang et al. Cross sections for the $\gamma p \to K^{+}\Lambda$ and $\gamma p \to K^{+}\Sigma^0$ reactions measured at CLAS. Phys.Rev., C87:065204, 2013.


Summary of Contract-Related Activities

Refereed Publications


Other Publications and Reports


Invited Talks


Contributed talks and posters.


Other Presentations


Service Work

1. Reviewer, CLAS Collaboration, chair of four review committees.

2. Reviewer, National Science Foundation, Nuclear Physics Program, Physics Division, Directorate for Mathematical and Physical Sciences.

3. Chair of CLAS Collaboration chair nominating committee.