Measuring the Neutron Magnetic Form Factor with CLAS and CLAS12

Proposal for JSA Sabbatical/Research Leave Support at Jefferson Lab

Submitted by Gerard P. Gilfoyle

Professor, Department of Physics, University of Richmond, Richmond, VA 23173

In this proposal we request sabbatical support for nine months for Dr. Gerard P Gilfoyle during the 2009-2010 academic year to relocate to Jefferson Lab (JLab) in Newport News, VA. His sabbatical leave has already been approved by the University of Richmond. One focus of the work proposed here will be completing the analysis of the data from the E5 running period to extract the magnetic form factor of the neutron G_M^n at low Q^2. The results for the high Q^2 portion of the data set have been submitted for publication [1]. The second focus will be developing and studying simulations of neutron detection in the CLAS12 detector as part of the JLab 12-GeV Upgrade. This work is motivated by an approved 12-GeV experiment (E12-07-104) to apply the same method for measuring G_M^n to higher Q^2. Dr. Gilfoyle is spokesperson and contact person for that experiment [2].

Dr. Gilfoyle is professor of Physics and the Clarence E. Denoon Professor of Science at the University of Richmond. Richmond is a primarily undergraduate institution and there are no graduate students in physics. He is a long-time member of the CLAS Collaboration that built and now operates the CLAS detector in Hall B. In the early days of CLAS he was responsible for developing data acquisition software to monitor the quality of the incoming data by doing a full reconstruction of a subset of events from the datastream [3]. More recently he has focused his efforts on measuring G_M^n. He is one of the lead authors on the recent CLAS publication [1] and spokesperson for the CLAS12 G_M^n experiment. Dr. Gilfoyle also serves as chair of the Nuclear Physics Working Group in the CLAS Collaboration and on the CLAS Coordinating Committee.

The physics motivation of this project is to measure the neutron magnetic form factor. The elastic electromagnetic form factors are basic observables that describe the internal structure of the proton and neutron. The electromagnetic structure of the proton has been mapped out for over 50 years with high precision and over a large Q^2 range. However, only recently has it been possible to access the neutron magnetic structure with similarly high precision. The G_M^n measurement is a goal of the current NSAC Long-Range Plan [4] and is Milestone HP4 in the DOE Performance Measures [5]. We measured the magnetic form factor of the neutron using the ratio method on deuterium [1]. The precision and coverage of these results eclipse the world's data on this elastic form factor in the Q^2 range of 1.0 – 4.8 GeV^2. See Fig 1 from Ref [1]. Surprisingly, G_M^n deviates from the dipole form by no more than 10% over the entire Q^2 range covered. The CLAS results are consistent with the previous world's data for $Q^2 > 1$ GeV^2, but have smaller uncertainties and better coverage.

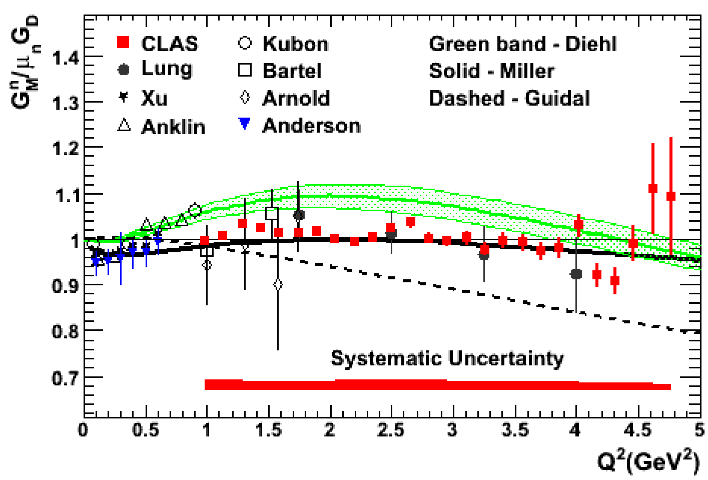

Figure 1. The magnetic form factor of the neutron normalized to the dipole form factor is shown with results from other measurements and theoretical curves [1]. The red symbols are the new CLAS results.

We note that our measurement in Fig. 1 at $Q^2 = 1.0$ GeV^2 is about 6-7% below the one by Kubon *et al*. (open circle) [6] at nearly the same Q^2. The data from Anklin *et al*. (open triangles) [7] range from 2-5% above the dipole and are a few percent above the Anderson *et al*. results (blue, inverted triangles) [8] and Xu, *et al*. results (black stars) [9]. We have preliminary results in this Q^2 range that agree with Anderson *et al*. and Xu, *et al*. and are below the results of Anklin *et al*. and Kubon *et al.* To shed light on these apparent disagreements Gilfoyle is analyzing CLAS data from the E5 running period in the range $Q^2 < 1$ GeV^2 region. In particular, we have data for an electron beam energy of 2.6 GeV with normal CLAS torus polarity (electrons inbending) that extends down to $Q^2 \approx 0.5$ GeV^2 and data for the same beam energy with reversed CLAS torus polarity that goes lower; down to $Q^2 \approx 0.3$ GeV^2.

There are additional motivations to study the low-Q^2 region. Efforts by Friedrich and Walcher [10] to re-analyze low-Q^2 data for all four quasielastic, nucleon form factors suggest that a structure they observe at $Q^2 \approx 0.2$ GeV^2 in all the elastic form factors is due to the presence of the pion cloud. Measurements of G_E^p and G_M^p from Bates [11], of G_E^n from Mainz [12], and of G_M^n from JLab [9], have shown structure in this Q^2 region ($\approx 0.1 - 1.0$ GeV^2). Additional theoretical work supports the observation of the pion cloud [13]. There are hints of structure around $Q^2 \approx 0.38$ GeV^2 in the ratio G_E^p / G_M^p from polarization measurements in a recent Hall A experiment [14]. However, others disagree. The observation of a structure near $Q^2 \approx 0.2$ GeV^2 contradicts what is known from chiral perturbation theory and dispersion relations [15]. A recent measurement of G_E^n from Bates [16] found no evidence of a bump due to the pion cloud. Our low-Q^2 CLAS data reach down into this Q^2 range and could overlap with the bump observed in Ref [10]. We expect statistical and systematic uncertainties of about 3% each and the E5 data set has abundant overlaps and consistency checks to ensure the quality of the results. This is an excellent opportunity to improve our understanding of nucleon structure with data we already have in hand. Completing the analysis of these data is one of the major goals of this proposal.

We also have plans to extend these measurements of the neutron magnetic form factor to higher Q^2; from the current upper limit of 4.8 GeV^2 (see Fig 1) to 13.5 GeV^2. A proposal to do this experiment was approved by JLab PAC32 [17] (E12-07-104) for running in the first five years after the JLab 12-GeV Upgrade is completed. The PAC committee report [17] stated the following.

> Proposal PR12-07-104 is a measurement of the neutron magnetic form-factor G_M^n in Hall B using a deuterium target. The method proposed is elegant and its physics essential to the program. The results of this experiment, if successful, will provide neutron data, which when combined with proton results determine the isovector form factor, that is more readily computable on the lattice, having no disconnected quark contributions. This essential measurement will thus have the added benefit of providing a valuable test of the efficacy of lattice calculations.

The second major goal of this proposal, to develop and study simulations of neutron detection in the CLAS12 detector, is motivated by the need to prepare for this measurement.

Event simulation is an essential aspect of the design of CLAS12 and eventual precision of the detector. For many experiments, the quality of the results will be limited by systematic uncertainties instead of statistical ones so accurate, precise calculations of the CLAS12 acceptance and response are essential. We anticipate needing about four times as much Monte Carlo data as CLAS12 collects. The CLAS12 simulation will produce data more slowly than the detector itself by about a factor of 1000 (at ≈ 10 Hz for the simulation versus ≈ 10 kHz in CLAS12). Experiment E12-07-104 will measure the neutron magnetic form factor G_M^n out to $Q^2 = 13.5$ GeV^2. The neutron measurement will be done with both the electromagnetic calorimeters and the TOF system providing an important consistency check as in our previous measurement [1]. Over most of the Q^2 range we will have excellent statistical precision so that understanding the CLAS12 response to neutrons is important for extracting G_M^n with the anticipated systematic uncertainty.

We now describe the current status of the neutron simulation in CLAS12. Neutrons will be measured in two ways: (1) using the time-of-flight (TOF) scintillators and (2) the combined electromagnetic calorimeters (EC) and pre-shower calorimeters (PCAL). The CLAS12 simulation package called gemc (for Geant4 Monte Carlo) is a Geant4-based simulation package with the following features: C++ language, object-oriented architecture, GUI interface, mysql database used for geometry, hits, magnetic field, materials, and physics output. The TOF system has been implemented in the code, but only limited studies of its performance have been done. The EC and PCAL code has not been written. For neutron simulation one can choose a variety of physics algorithms to describe the process, but none have been tested with the CLAS12 geometry. From our experience in CLAS we know there are differences between the neutron detection efficiency measured in CLAS and the same quantity derived from the current Geant3-based CLAS simulation called GSIM. We are now investigating those differences in our analysis of the low-Q^2 G_M^n data. In order to have an adequate CLAS12 neutron simulation a number of tasks must be completed. (1) The EC and PCAL geometries have to be implemented in gemc. (2) A materials database is needed to provide the information on the composition of each component of the EC and PCAL. (3) The Geant4 algorithms for 'swimming' tracks through CLAS12 need to be tested in gemc.

(4) We then construct the detector information produced by the track (digitization) and (5) test the results. To test the neutron simulation in CLAS12 we can take advantage of our experience from CLAS with the neutron detection efficiency of the EC because the same device will be reused in CLAS12. If the CLAS12 simulation and the measured, CLAS neutron detection efficiency are consistent, then we have greater confidence in our results when we add in the PCAL. We will be working with M. Ungaro at JLab who is now the lead developer for gemc. We note here that Gilfoyle has long experience with CLAS software. He was one of the early developers of the primary CLAS reconstruction software (RECSIS) and developed and maintains one of the CLAS online monitoring tools (online RECSIS [3]).

The expected timeline for this proposal is the following. Gilfoyle will relocate to JLab in September, 2009. He will begin the work on the low-Q^2 E5 data in summer, 2009 using the Richmond Physics computing cluster so we expect the analysis will be reasonably far along by the official start of the Gilfoyle's sabbatical. The work on the CLAS12 software will also begin in earnest at about the same time. Gilfoyle has been collaborating with the members of the CLAS12 Software Group to prepare this proposal and attending the weekly meeting of the group. He now regularly commutes to JLab from Richmond, usually spending one day per week there. During the period of his sabbatical he will be at JLab full time. Dr. V. Burkert is Gilfoyle's JLab collaborator.

References

1. J. Lachniet, A.Afanasev, H.Arenhövel, W.K.Brooks, G.P.Gilfoyle, S.Jeschonnek, B.Quinn, M.F.Vineyard *et al.* (CLAS Collaboration), arXiv:0811.1716 [nucl-ex].

2. G.P. Gilfoyle *et al.*, *Measurement of the Neutron Magnetic Form Factor at High Q^2 Using the Ratio Method on Deuterium*, JLab Experiment E12-07-104, PAC32, 2007.

3. G.P.Gilfoyle, M.Ito, and E.J.Wolin, *Online RECSIS*, CLAS-Note 98-017.

4. Nuclear Science Advisory Committee, *The Frontiers of Nuclear Science*, US Department of Energy, 2007.

5. NSAC Subcommittee on Performance Measures, *Report to the Nuclear Science Advisory Committee*, US Department of Energy, 2007.

6. G. Kubon *et al*., Phys. Lett. B, **524**:26–32, 2002.

7. H. Anklin *et al*., Phys. Lett. B, **336**:313–318, 1994.

8. B. Anderson *et al.,* Phys. Rev. C, **75**:034003, 2007.

9. W. Xu *et al*., Phys. Rev. C **67**, 012201 (2003).

10. J. Friedrich and T. Walcher, Eur. Phys. J., **A17**:607–623, 2003.

11. C. B. Crawford *et al*., Phys. Rev. Lett., **98**:052301, 2007.

12. D. I. Glazier *et al*., Eur. Phys. J., **A24**:101–109, 2005.

13. E. Lomon. Phys. Rev. C, **66**:045501, 2002.

14. G. Ron *et al.,* Phys. Rev. Lett. , **99**:202002, 2007.

15. M. A. Belushkin, H. W. Hammer, and U. G. Meissner. Phys. Rev. C, **75**:035202, 2007.

16. E. Geis *et al.,* Phys. Rev. Lett., **101**:042501, 2008.

17. JLab Physics Advisory Committee, *PAC32 Report*, Jefferson Laboratory, 2007.