

## Research Summary

### Gerard P. Gilfoyle

My research program at the University of Richmond is focused primarily on understanding how the fundamental particles in nature, quarks and gluons, form the atomic nuclei that make up our world. We have a deep understanding of the force in play among quarks and gluons; the color force described by Quantum Chromodynamics or QCD. QCD has been spectacularly successful at high energies where the particles are close together and the force is weak. At low energies we can understand nuclear physics using protons and neutrons as the building blocks of nuclei (the hadronic model). In the transition region between these extremes great mysteries await. QCD cannot yet be solved for the real quarks and gluons in nuclei and there are few data to guide us. We are making those measurements at the Thomas Jefferson National Accelerator Facility (JLab) in Newport News, VA. Below, I describe the main thrusts of our research, and work of our undergraduates, and other work in science policy.

If we are to understand how quarks and gluons form nuclei we need to locate the electric charges and currents in the proton and neutron first. We have measured the neutron's magnetic form factor (called  $G_M^n$ ) to unprecedented breadth and precision using the CLAS detector at JLab. With the powerful electron beam at JLab and a deuteron target we measured the scattering of electrons off protons and neutrons to extract  $G_M^n$ , collecting three times the world's data in the range  $Q^2 = 1 - 5 \text{ GeV}^2$  ( $Q^2$  is the square of the momentum transferred to the target). That work was published last summer and we are now analyzing data collected at lower  $Q^2$  where there is a simmering controversy among different groups with contradictory results. We are also forging ahead into the future. The US Department of Energy (who administers JLab) has given us the go-ahead to double the energy of the accelerator and build new detectors to expand our physics horizons. We have been approved to extend our measurements of  $G_M^n$  to higher  $Q^2$  (up to  $14 \text{ GeV}^2$ ) where we can map the charges and currents of individual quarks.

As we move into the transition region between the hadronic model and QCD we need to establish a theory baseline so we can distinguish between new features of quarks and gluons and inadequacies in the hadronic model. As an electron scatters off a proton in the deuteron, that proton can bounce off the neutron on its way out (a final state interaction or FSI), providing a unique opportunity to study the proton-neutron interaction. To isolate those collisions we measure the protons scattered out of the plane formed by the incoming and outgoing electron momenta; giving us a clean, FSI signal where the hadronic model should accurately describe the interaction. A recent calculation by our theory collaborators reproduces many features of the data and shows the power of the hadronic model.

The University of Richmond is a primarily undergraduate institution and we have no graduate students in Physics. My group consists of a single faculty member (Gilfoyle) and 2-5 undergraduates. Collaboration rules at JLab prevent me from adding undergraduates to my papers, but my students have still published their research. Since 2007 my students have presented six posters at the annual Division of Nuclear Physics meetings, presented posters at campus-wide and local science symposia, and used their research as the basis for their senior capstone experiences.

It is worth mentioning another aspect of my research program. In 1999-2000 I served in the US Department of Defense as a scientific consultant on weapons of mass destruction. Over the last three years, I have used that expertise as a consultant for local media (*i.e.* commenting on the impact of Iranian missile tests) and to educate the public on issues of nuclear proliferation.

## Research Summary

### Gerard P. Gilfoyle

Gilfoyle's research program at the University of Richmond is focused primarily on understanding how the fundamental particles in nature, quarks and gluons, form the atomic nuclei that make up our world. Their work is funded by the US Department of Energy and is centered on the nearby Thomas Jefferson National Accelerator Facility (JLab) in Newport News VA. The group consists of one faculty member and 3-4 undergraduates working mostly in the summer. Data are collected at JLab and then analyzed on the supercomputing cluster in Gilfoyle's campus laboratory. In recent years the group's efforts have focused on three projects. First, measuring  $G_M^n$ , the magnetic form factor of the neutron with the CLAS detector at JLab. A Physical Review Letter on this measurement was published in 2009 and work is continuing on an additional data set. An experiment to measure  $G_M^n$  in the first five years of running after the JLab 12 GeV Upgrade was approved by the JLab Program Advisory Committee in 2007. Gilfoyle is spokesperson and contact person for that experiment. The second part of the program is testing largely unknown components of the hadronic model and the proton-neutron force by studying the out-of-plane production of protons in the  ${}^2\text{H}(e, e'p)n$  reaction in quasielastic kinematics. The third component of the research program is development of simulations and analysis codes for the CLAS12 detector. This device will replace the current CLAS detector in Hall B after the Upgrade.

Some sample projects of the undergraduates working our group are described here. **Mark Moog** (2010) worked on a project in the summer of 2009 developing simulations and analysis of neutron production in the CLAS12 detector. He was able to show the predicted neutron efficiency of CLAS12 is consistent with our previous measurements at lower neutron momentum. He presented his work in a poster at the Fall, 2009 meeting of the Division of Nuclear Physics (DNP) of the American Physical Society (APS). **Calina Copos** (2010) programmed and ran simulations of the out-of-plane production of the  ${}^2\text{H}(e, e'p)n$  reaction in quasielastic kinematics. She showed our analysis algorithms produced results consistent with the physics input to the simulation. She also presented a poster at the Fall, 2009 DNP meeting. **Matt Jordan** (2010) extracted the uncertainties on our analysis of the  ${}^2\text{H}(e, e'p)n$  reaction in quasielastic kinematics. He was able to determine the sensitivity of our results to a wide range of effects. He also presented a poster at the Fall, 2009 DNP meeting.

Collaboration rules at JLab prevent us from adding undergraduates to our papers, but the students in our group have still published their research. Since 2007 our students have presented six posters at the annual Division of Nuclear Physics meetings, presented posters at campus-wide and local science symposia, and used their research as the basis for their senior capstone experiences.

It is worth mentioning another aspect of Gilfoyle's research program. In 1999-2000 he served in the US Department of Defense as a scientific consultant on weapons of mass destruction. Over the last three years, he has used that expertise as a consultant for local media (*i.e.* commenting on the impact of Iranian missile tests) and to educate the public on issues of nuclear proliferation.

## Nuclear Physics Student Research Projects Since 2007

1. C.Copos and G.P.Gilfoyle, "Testing Analysis Algorithms for the  $^2\text{H}(e, e')n$  Reaction", Bull. Am. Phys. Soc., Fall DNP Meeting, GB.00059 (2009).
2. M.Jordan and G.P.Gilfoyle, "Systematic Uncertainties of Out-of-Plane Measurements of the Fifth Structure Function of the Deuteron", Bull. Am. Phys. Soc., Fall DNP Meeting, GB.00059 (2009).
3. M.Moog and G.P.Gilfoyle, "Simulating the Neutron Detection of the CLAS12 Detector", Bull. Am. Phys. Soc., Fall DNP Meeting, GB.00086 (2009).
4. M.King and G.P.Gilfoyle, "Software Development for Simulation of the CLAS12 Detector".
5. M.Jordan and G.P.Gilfoyle, "Analysis of Out-of-Plane Measurements of the Fifth Structure Function of the Deuteron", Bull. Am. Phys. Soc., Fall DNP Meeting, DA.00047 (2008).
6. M.Moog and G.P.Gilfoyle, "Study of Inelastic Background for Quasielastic Scattering from Deuterium at 11 GeV", Bull. Am. Phys. Soc., Fall DNP Meeting, DA.00068 (2008).
7. J. Nguyen and G.P.Gilfoyle, "Nuclear Physics at Jefferson Lab", Howard Hughes summer research student, 2008.
8. Kirill Dergachev and G.P.Gilfoyle, "CLAS 12 Simulation Analysis and Optimization", senior thesis in Physics, April, 2008.
9. Kuri Gill and G.P.Gilfoyle, "Investigating Asymmetries in the  $D(e, e')n$  Reaction", Kuri Gill, senior thesis in Physics, January, 2008.
10. K.Dergachev and G.P.Gilfoyle, "CLAS 12 Simulation Analysis and Optimization", Bull. Am. Phys. Soc., Fall DNP Meeting, DA.00019 (2007).
11. J. Nguyen and G.P.Gilfoyle, "Simulation Software for Nuclear Physics at Jefferson Lab", Howard Hughes summer research student, 2007.

## Intermediate Laboratory Major Equipment

1. Coulomb Balance (13)
2. Millikan oil drop (2)
3. e/m apparatus (13)
4. Electronics laboratory apparatus (13)
5. Geometric Optics apparatus
6. Physical Optics apparatus
7. Microwave Optics apparatus
8. Interferometer
9. Instrumented gas piston for adiabatic gas studies
10. X-ray Diffractometer
11. Compound Pendulum and video analysis apparatus
12. h/e apparatus
13. Cavendish torsion balance to measure Newtons's gravitational constant
14. Large plastic scintillator for atmospheric muons
15. Leslie's Cube
16. Hall Effect probes and precision current loop (13)
17. Spectrometers (20) and discharge tubes(50)
18. Geiger-Muller tubes (17) and Ba-137 source.
19. 565 MHz oscilloscope.

## **Current Major Research Laboratory Equipment for Nuclear Physics**

1. 16-node supercomputing cluster with 4 TByte of storage, \$162,000, National Science Foundation Major Research Instrumentation grant, 2009.
2. 15-node supercomputing cluster with 2 TByte of storage, \$175,000, National Science Foundation Major Research Instrumentation grant, 2002.

## **Research Funding for Nuclear Physics Since 2007**

1. US Department of Energy Intermediate Energy Nuclear Physics, \$139,000, 2009.
2. JSA/SURA Initiatives Fund, \$5,000 for CLAS12 Software Workshop, 2009.
3. JSA/SURA Sabbatical Support Program, \$13,500, 2009.
4. Jefferson Lab sabbatical support, \$65,000, 2009.
5. National Science Foundation Major Research Instrumentation grant, \$162,000, 2009.
6. American Physical Society Conference Experience for Undergraduates (3), student travel funds, \$2,250, 2009.
7. University of Richmond, student travel funds (3), \$3,000, 2009.
8. University of Richmond undergraduate summer stipends (2), \$9,000, 2009.
9. American Physical Society Conference Experience for Undergraduates (2), student travel funds, \$1,500, 2008.
10. University of Richmond, student travel funds (2), \$2,000, 2008.
11. University of Richmond undergraduate summer stipends (3), \$13,500, 2008.
12. University of Richmond, student travel funds (1), \$2,000, 2007.
13. University of Richmond undergraduate summer stipends (2), \$9,000, 2007.
14. US Department of Energy Intermediate Energy Nuclear Physics, \$45,000, 2007.