Institute of Nuclear and Particle Physics

2011 - 2016

Institute of Nuclear and Particle Physics
Department of Physics and Astronomy
Ohio University
Athens, OH 45701
http://inpp.ohiou.edu

March 2017

Prepared for:

College of Arts and Sciences

Prepared by:

Daniel Phillips, Director

Center/Institute Summary

Center/Institute:	Institute of Nuclear and Particle Physics
Director:	Daniel Phillips Department of Physics and Astronomy College of Arts and Sciences
Active Affiliated Faculty:	Carl Brune, Professor of Physics Charlotte Elster, Professor of Physics Justin Frantz, Associate Professor of Physics Kenneth Hicks, Professor of Physics David Ingram, Professor of Physics, Department Chair Zach Meisel, Assistant Professor of Physics Daniel Phillips, Professor of Physics Madappa Prakash, Professor of Physics Julie Roche, Associate Professor of Physics Mark Lucas, Senior Lecturer in Physics (Group II) Paul King, Research Assistant Professor of Physics Thomas Massey, Research Associate Professor of Physics Gabriela Popa, Associate Professor of Physics (Zanesville) Alexander Voinov, Research Assistant Professor of Physics Steven Grimes, Distinguished Professor of Physics, Emeritus

Mission:
The INPP promotes and supports research in theoretical and experimental subatomic physics. We do this by pro-actively educating graduate and undergraduate students in these fields of study, sponsoring joint seminars, hosting visiting scientists, and providing funds for new research initiatives. We investigate the dynamics of the matter that makes up the atomic nucleus, and examine manifestations of these dynamics in systems ranging in size from a single proton to a neutron star. We combine data from laboratory experiments, astronomical observations, and theoretical studies in order to examine the role of the fundamental forces of nature within these systems and we apply the techniques and insights of nuclear physics to important problems facing our society.

Future Activity:
The INPP will support the activities of its members by: (a) assisting with the salaries of postdoctoral research fellows, and funding undergraduate and beginning graduate students during the summer; (b) financially supporting research faculty and staff; (c) providing matching funds to leverage larger external research grants; (d) enhancing the intellectual climate through regular seminars, a journal club, and conference support; and (e) helping with start-up funds for new faculty.

Awards (2011-2016): External Grants totalling $8,940,000

Contents

1 Mission Statement

The Institute of Nuclear and Particle Physics was established at Ohio University in 1991 to bring coherence to the several successful, but diverse, nuclear and particle physics activities taking place within the Department of Physics and Astronomy, and to coordinate the activities of both theoretical and experimental subatomic physics.

The faculty, postdoctoral researchers, and students of the Institute investigate the dynamics of the matter that makes up the atomic nucleus, and examine manifestations of these dynamics in systems ranging in size from a single proton to a neutron star. We combine data from laboratory experiments, astronomical observations, and theoretical studies in order to examine the role of the fundamental forces of nature within these systems and we apply the techniques and insights of nuclear physics to important problems facing our society.

The Institute is the perfect vehicle for promoting and supporting research in theoretical and experimental subatomic physics, pro-actively educating graduate and undergraduate students in these fields of study, sponsoring joint seminars, hosting visiting scientists, and providing funds for new research initiatives.

Activities within the Institute include:

- Vigorous pursuit of research in experimental and theoretical nuclear and particle physics, by faculty, postdoctoral researchers, and graduate and undergraduate students.
- Significant enhancement of the intellectual climate through regular seminars, a journal club for students, and support for conferences and visitors.
- Provision of matching funds for initiatives with funding agencies and national laboratories, with the goal of leveraging larger amounts of external research funding.
- Financial support of research faculty and staff, postdoctoral researchers, graduate students, and undergraduate students.

For the purposes of this report, we consider the time period from from July 1, 2011 through December 31, 2016.

2 Brief history

The Institute of Nuclear and Particle Physics was established in 1991 with the goal of enhancing interactions among faculty and students in the Department of Physics and Astronomy conducting research in these areas. Before 1991, nearly three decades of successful programs in nuclear physics research and graduate education had brought significant national and international recognition to Ohio University. Some highlights from this time are: the first Ph.D. in the Department of Physics and Astronomy (1963); construction of the Edwards Accelerator Laboratory (1969); sustained external research support from DOE and NSF; and three faculty becoming Distinguished Professors: Lane (1972), Rapaport (1981), and Finlay (1991). (INPP member Steve Grimes became a Distinguished Professor in 2001.)

The Edwards Accelerator Laboratory (EAL) currently houses the highest-energy particle accelerator in the State of Ohio. This facility was the main focus of the nuclear experimental research during the 1970s and 1980s. Its unique experimental capabilities, in particular its neutron production and detection equipment, played a special role in nuclear experiments of that period. Those capabilities continue to pay dividends today as evidenced by several contracts for use by outside researchers, e.g., Lawrence Livermore National Laboratory (LLNL) and the National Institute of Standards and Technology (NIST). The accelerator also plays an important role in the research program of INPP faculty: it is used in experiments that study the formation of elements in stars and the structure of complex nuclei. During the previous reporting period the accelerator underwent a significant NSF-funded upgrade to a modern Pelletron charging system, enabling the laboratory's continued efforts in forefront research. In this reporting period we recruited a new tenure-track faculty member in this research area.

In addition to our efforts at Edwards, experimental investigations of nuclear structure and dynamics are carried out using short-lived exotic nuclei at the National Superconducting Cyclotron Laboratory (NSCL) at Michigan State University and at the Argonne Tandem Linear Accelerator System (ATLAS) at Argonne National Laboratory. In the future, INPP faculty will be involved at the Facility for Rare Isotope Beams (FRIB) that is presently under construction at Michigan State University. This $700M facility will be available for physics experiments in about five years and will be the world-leading facility for studying the properties of exotic nuclei.

INPP's research in experimental nuclear physics has broadened substantially over the past twenty-five years. INPP faculty now work at national and international facilities doing experiments at "intermediate" and "high" energies. A significant part of that effort is at the Thomas Jefferson National Accelerator Facility (JLab), where the beam consists of electrons or photons with energies roughly a factor 500 larger than those achieved at Edwards. These national facilities allow the investigation of the internal structure of the nucleus—and the structure of neutrons and protons themselves—at distances 100 times smaller than the size of a typical nucleus. Our faculty there also perform precise tests of the Standard Model of Particle Physics: the theory that is our best current fundamental understanding of the universe. Lastly, one INPP faculty member carries out experiments at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory in Upton, NY and the Large Hadron Collider (LHC) at CERN in Geneva, Switzerland. At these facilities nuclei are accelerated to even higher energies, permitting the study of matter under conditions of extreme temperature, as in the first moments after the universe was created.

Our participation in experiments at these national and international facilities allows us to do science that simply cannot be pursued at Edwards. However, Edwards is invaluable both for its special capabilities alluded to above, and for the opportunities it gives graduate students to do an entire experiment on a particle accelerator.

It is also used for research into various applications of nuclear science. One example is investigations of the surface properties of thin films. This research has potential applications in the semiconductor industry. These studies are undertaken at the Keck Thin-Film Laboratory (housed within the Edwards Accelerator Laboratory), which was established to pursue this work with a grant of $400,000 from the Keck Foundation. Other applications include homeland security (explosives detection) and nuclear power.

Similar to the experimental efforts, the theory program has grown over the years and now has considerable breadth in its research scope. In the beginning, the theoretical investigations within the institute were concentrated on exploring the structure of nuclei using electromagnetic probes. Successful research in this area was later complemented by efforts to understand the structure of the lightest nuclei with hadronic probes, i.e., protons and neutrons, through large-scale, computationally intensive, *ab initio* calculations that start from the fundamental inter-nucleon forces. We also have considerable expertise in applying systematic "effective field theories" to treat this problem. Over the past decade we have broadened our efforts to include nuclear astrophysics and the study of hot and dense matter, thus creating a theory group with extensive interests in modern nuclear physics and strong intellectual overlap with INPP's experimental research.

3 Current activities and status

3.1 Number and role of faculty and students

The faculty at the INPP pursue a broad spectrum of research in nuclear physics. Activities include experimental and theoretical investigations on-campus as well as off-campus. Roughly speaking, there are three different groups within the INPP: (i) "Low-energy" experiments, (ii) "Medium/high-energy" experiments, and (iii) Theoretical nuclear and particle physics and astrophysics.

The research of the low-energy experimental group is concerned with the study of exotic nuclei, nuclear astrophysics, nuclear structure, and applications of nuclear physics. Many of these experiments are carried out in the Edwards Accelerator Laboratory, with others carried out at national facilities such as the NSCL at Michigan State University. Assistant Professor Zach Meisel's Ph.D. experiments were carried out at NSCL: they focused on refining the rates of processes that affect nucleosynthesis in extreme stellar environments. Meisel was hired in 2016 to replace Prof. Heather Crawford, who was hired in 2013. In 2015 Prof. Crawford was recruited by Lawrence Berkeley Lab to fill a (permanent) Research Scientist position there. The low-energy effort now includes three tenured or tenure-track faculty (Brune, Ingram, and Meisel), two grant-supported research faculty (Massey and Voinov), and 7 to 8 Ph.D. students. In addition, Distinguished Emeritus Professor Steve Grimes remains very active; he is co-PI on several research grants.

The research of the medium/high-energy experimental group is conducted at large national facilities. The group contains Assoc. Profs. Julie Roche and Justin Frantz, as well as Prof. Ken Hicks. In addition, Paul King is a Research Assistant Professor. This group presently supports 6 Ph.D. students.

The Nuclear Theory group consists of Professors Elster, Phillips, and Prakash. Prakash joined the faculty in 2005, significantly expanding the research breadth of the group. The study of the lightest nuclei probed with protons, neutrons, and electromagnetic probes has been extended to include objects of astrophysical scales as encountered in the physics and astrophysics of supernova explosions and the evolution of neutron stars from their birth to old age. The theory group has supported 3–4 Ph.D. students and 1–2 postdoctoral researchers throughout the reporting period. Associate Professor Gabriella Popa is also a nuclear theorist and is faculty at Ohio University's Zanesville campus. Her research interests lie in the area of low-energy nuclear structure, which overlaps with the work of our low-energy experimental group.

All of the research groups involve undergraduate students, particularly via Honors Theses and summer research. Lists of graduate and undergraduate students are given in Appendices A–C and a list of postdoctoral researchers in Appendix D.

3.2 Meeting objectives

3.2.1 Research

The INPP is blessed with faculty who are leaders in their respective research fields. The faculty, with their postdoctoral fellows and graduate students, have authored over 250 publications during the past five years. Another indication of our research productivity is our external funding, which reached $8.9 million over the past five years. Research highlights from the last five years are described in Appendix F.

3.2.2 Intellectual climate

The INPP has continued to host a regular seminar series consisting of approximately 12 seminars per semester over the academic year. Nearly all of the seminar speakers are invited from outside Ohio University. These visitors typically spend a day on campus meeting with faculty, postdoctoral researchers, and students.

In addition, the INPP runs a student-led weekly journal club. Two major purposes of this activity are keeping the students and faculty aware of current events in our fields and providing speaking experience for our students. More details are provided in Appendix A.

The INPP also sponsored a number of major conferences and workshops over the last five years. In 2015 the INPP organized, together with the Physics Division at Argonne National Laboratory (ANL), the 21st International Conference on Few-body Problems in Physics in Chicago, IL. Elster, Phillips, and C. D. Roberts from ANL co-chaired the meeting, which drew over 200 scientists from all around the world. That same year we also co-sponsored the RHIC Users' Group meeting—Frantz was the lead organizer, and it too had over 200 participants. In 2016 INPP supported, and Ohio University hosted, the "JINA-CEE International Symposium on Neutron Stars in the Multi-Messenger Era: Prospects and Challenges", of which Prakash was the lead organizer.

The reputation of a group is built over time, and the national/international visibility of a scientist or group of scientists carries weight in funding decisions. A lively visitor program—of seminar speakers and collaborators—helps the INPP to maintain and grow connections with the nuclear-physics community. These visitors experience the quality of our institute and Ohio University first hand. Our vigorous visitor program has contributed to our external-funding success. It has also catalyzed invitations for INPP faculty to join large, multi-institutional collaborations, e.g., Elster's participation in the DOE Topical Collaboration "Theory Of Reactions for UnStable nuclei", or Prakash's and Phillips' membership in the NSF- and Heising-Simons-funded Network for Neutrinos, Nuclear Astrophysics, and Symmetries (N3AS) (see *https://n3as.wordpress.com*).

The visitor program also enhances the intellectual atmosphere for graduate and undergraduate students by providing students with opportunities to discuss cutting-edge research with outside experts. A list of visiting collaborators who made extended stays in Athens is given in Appendix E. Their collaboration on projects enhanced our scientific productivity. A particularly notable use of INPP money is to leverage funds from the University's Robert and Rene Glidden Visiting Professor program, and our faculty successfully hosted two Glidden Visiting Professors during the reporting period.

3.2.3 Research by undergraduate and graduate students

An important goal of the INPP is the education and training of students (undergraduate and graduate) for careers in advanced technical professions or academia. INPP faculty supervised twenty Ph.D. dissertations that were completed between 2011 and 2016. We are proud of our students' accomplishments, which include several awards for posters they presented at national conferences. Particularly notable were Roche's student, Rakitha Beminiwattha, receiving the annual JLab thesis prize for the best dissertation on work at the laboratory in 2014, and Crawford's student, Andrea Richard, winning a DOE Office of Science Graduate Student Research (SCGSR) Award in 2016.

More than half of our Ph.D. graduates initially pursue an academic career, by moving into post-doctoral fellowships. Some ultimately transition into faculty positions in the U.S. or abroad. But many work in industry, e.g., in advanced computing, medical physics (including radiation therapy), and private research corporations. Some of our graduates since 1993, including their current positions, are given in Appendix B, and a full list of graduate students over the last five years is also provided there. INPP supports the research programs in which these students work, and also provides direct financial support for stipends in some instances, e.g., if there is a need to smooth out irregularities in federal funding or transitions as one student from a group graduates and another comes on board.

During 2011–6 INPP also supported several undergraduate research projects, either in full, or in conjunction with faculty's research grants. A list of undergraduate-research participants is given in Appendix C.

During 2016–7 the INPP has been updating its promotional materials to reflect our current personnel and research activities. The new website design, postcards, and posters will aid in student recruitment and inform visitors about our activities.

3.2.4 Research personnel

Postdoctoral fellows contribute strongly to research within the INPP, working with faculty mentors to advance their own career and perform cutting-edge research. A list of postdoctoral fellows with the INPP, together with their current positions, is given in Appendix D. The INPP has been particularly successful using matching funds to leverage support for postdocs from federal agencies.

A major component of INPP's present personnel costs is support for research-staff members Don Carter and Devon Jacobs, whose work is essential to the smooth functioning of the Edwards Accelerator Laboratory. We assumed partial responsibility for their salaries and benefits after the University's budget cuts early this decade, and this is now absorbing a substantial fraction of our yearly income, see also below.

3.2.5 Faculty

A key accomplishment of the INPP over the past five years has been the hiring of Assistant Professors Crawford and Meisel. These hires maintained the number of Group-I faculty in the INPP at the same level that it was in 2001. Frantz and Roche were tenured and promoted during the reporting period.

The national and international visibility of the INPP, the Department of Physics and Astronomy, and the university is elevated through leadership of its faculty in national/international organizations and review panels. INPP members have been both active and effective in this regard over the last five years. For example, Roche is currently the Vice-chair of the JLab Users' Group (she'll become Chair in 2018), and Frantz recently chaired the RHIC Users' Executive Committee. INPP members have had significant involvement with discussions on future directions for nuclear physics in the U.S.: Phillips is presently on the Nuclear Science Advisory Committee, which provides advice to NSF and DOE, and Elster was a member of the group that wrote the 2015 Nuclear

Physics Long-Range Plan "Reaching for the Horizon", which sets priorities for the field for the next five years. Hicks held a temporary appointment as Director of the NSF Experimental Nuclear Physics program from 2014–6 . A list of the high-profile activities of INPP faculty is given in Appendix G.

3.2.6 The Edwards Accelerator Laboratory

The primary nuclear physics experimental facility at Ohio University is the 4.5-MV tandem van de Graaff accelerator located in the Edwards Accelerator Laboratory. In addition to in-house users performing research in low-energy nuclear science, many outside researchers come to do experiments with the accelerator. Edwards has historically been key to INPP's activities, and federal support for our low-energy nuclear-physics research still brings in approximately 50% of INPP's grant income. A detailed description of Edwards' capabilities and a table of external users from 2011–6 is given in Appendix H.

4 Planned future activities

The INPP has successfully fulfilled its mission over many years now. We therefore will continue the activities on which that success is founded:

- Enhance the intellectual climate by organizing regular seminars, hosting a journal club for students, and supporting conferences and visitors.
- Provide matching funds for initiatives with funding agencies and national laboratories, with the goal of leveraging larger amounts of external research funding.
- Provide financial support for research faculty and staff, postdoctoral researchers, graduate and undergraduate students.
- Assist with startup, and other, funds as needed in order to ensure we have a strong group of research and tenure-track faculty.

A much-needed capability for the Edwards Accelerator Laboratory is a modern high-intensity ion source, such as the TORVIS source manufactured by the National Electrostatics Corporation. It is expected that federal grant funding can be found to cover much of the ≈$450,000 cost of this instrument, but some University and INPP matching funds will most likely be required.

In FY11, due to budget cuts in the College of Arts & Sciences and the Department of Physics and Astronomy, the INPP began providing $50,000/year of financial support for research staff (Nuclear Instrumentation Engineer Don Carter and Accelerator Engineer Devon Jacobs). INPP plans to continue to support the two 0.36 FTE salary and benefits we committed to then.

We do not anticipate any retirements of Group I faculty within the next five years. There will be opportunities for bridge-funded positions associated with the Facility for Rare Isotope Beams in the next few years. In this scenario a federal funding agency pays at least 50% of the faculty member's salary until tenure. We will attempt to obtain an advance replacement for a future retirement via this mechanism. In the event of a Group-I faculty search, it is likely that the INPP would contribute significantly to the faculty's startup package.

5 Funding commitments and needs

The overhead generated by the external grants of the INPP faculty is the sole source of funding for the Institute. The INPP receives no direct funding from the College of Arts & Sciences or the VP for Research, Scholarship, and Creative Activity. Most of the external grants come from the U.S. Department of Energy and the National Science Foundation.

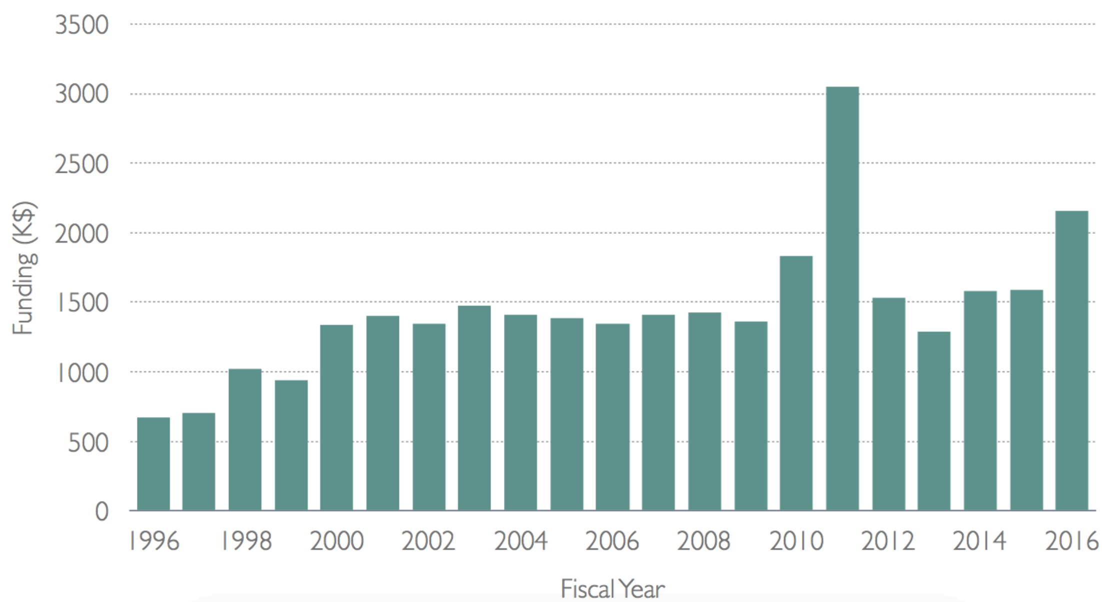

Figure 1: Total amount of external funding (in thousands of dollars) obtained by INPP faculty from FY96-FY16 (inclusive).

The history of INPP's external funding is shown in Figure 1. We started in 1991 with a funding level of $678,000. Through 1997, the funding level was nearly constant, and it then grew sharply in the late '90s. The total external funding of the INPP faculty was fairly constant from 1999–2008, despite all of the changes in faculty (retirements of Onley, Brient, Wright, and Grimes; departures of Opper, Carman; hiring of Phillips, Brune, Prakash, Roche, Schiller, Frantz). In 2009–10 our funding increased, due to a combination of our then newly-hired faculty members being successful in grant applications and the additional availability of federal research money through the American Recovery and Reinvestment Act (ARRA). Since 2010 we have—with the exception of FY13—maintained a healthy level of over $1.5M/year. Last fiscal year some large grants came in, giving INPP a total of $2.16M.

The significant grant activity of the INPP faculty exerts pressure on the administrative staff in the Department of Physics and Astronomy. In this context we note that Cindy White, who was located in the Edwards Accelerator Laboratory and supplied strong administrative support for much of INPP, retired in 2008 and was never replaced. The department has done a fine job covering this loss, but faculty in INPP need help with grant preparation, grant administration, and budgeting if they are to continue to be successful.

INPP's ability to provide matching and bridging funding for faculty has been key to our success. For example, the NSF's Major Research Instrumentation (MRI) program requires the institution to supply 30% of the monies for the project. INPP has worked with the VP for Research to fund Ohio University's contribution to MRI projects. This, in turn, facilitates the hardware contributions necessary for membership in some large experimental collaborations. And, when INPP faculty suffer funding pauses, as can happen in today's competitive funding environment, the institute can help smooth out, e.g., graduate-student funding, and also supply money for travel, so that the faculty member can stay active in the research community until their next opportunity to apply for grants.

Since the income of the INPP results from the overhead return of grant expenditure, the income lags essentially 6-10 months behind the grant awards. The average income over the past 5 years was roughly $150K per year.

As mentioned above, INPP now funds 0.36 of the FTEs for technical-staff members Carter and Jacobs. Up until FY11 these two positions were fully supported by the Department of Physics and Astronomy.

The INPP supports a vigorous seminar and visitor program at a cost of about $12K per year. The INPP also provides some support for undergraduate summer research. Over the past five years, the INPP also contributed to the startup of two new faculty, provided matching funds for external grants, and helped co-sponsor conferences. We've also assisted with the salary of approximately one postdoctoral researcher a year, providing $10K-$20K per year for that, which is a good approach to leverage bigger external grants. Expenditures of all these types may also be incurred in the coming years.

In summary, the INPP has managed to maintain its historical funding level over the past five years, mainly because we've maintained our number of Group I faculty and allowed them to progress in their careers. Our expansion into research areas beyond our traditional strength in nuclear structure and dynamics, e.g., most recently into relativistic heavy-ion physics, helped to diversify our risk in what has become an increasingly challenging environment for federal funding.

A Current INPP Graduate Students

Name	**Advisor**	**Research Topic**
M. Abdullah Al Mamun	Prakash	Nuclei and bulk nuclear matter at finite temperatures
Nadyah Alanzi	Voinov	The fusion evaporation reaction (α, n) in iron isotopes
Harsha Atanayake	King/Brune	Two-Neutron decay from the ground state of ^{26}O
Kristyn Brandenburg	Meisel	Cross sections for supernova nucleosynthesis
Matt Burrows	Elster	*Ab initio* optical potentials for proton scattering from He
Taya Chetry	Hicks	Coherent vector meson photoproduction off the deuteron
Nick Compton	Hicks	Photoproduction of $K^0\Lambda$ from deuterium
Mongi Dlamani	Roche	Internal structure of the nucleon in a GPD framework
Tyler Danley	Frantz	Isolated photon-hadron correlations at PHENIX-RHIC
Rekam Giri	Brune	Measurements of ^{12}C$(\alpha, \gamma)^{16}$O above $E_{\mathrm{c.m}} = 3$ MeV
Gula Hamad	Roche	Internal structure of the nucleon in a GPD framework
Bishnu Karki	Roche	Internal structure of the nucleon in a GPD framework
Sudhanva Lalit	Prakash	Thermal effects in relativistic models of dense matter
Som Paneru	Brune	The scattering of protons by ^{7}Be
Abinash Pun	Frantz	Hadron-hadron di-jet correlations in collisions at RHIC
Andrea Richard	Crawford/Brune	Spectroscopy of neutron-rich Mg isotopes
Doug Soltesz	Meisel	Transfer experiments for rp-process reaction rates
Shiv Subedi	Meisel	Nuclear physics in ^{44}Ti production in supernovae

Enrollment in PHYS 8501 (formerly PHYS 897A)

As mentioned in Section 4, the INPP faculty will continue to hold the weekly student "Nuclear Lunch" journal club in order to introduce and discuss a variety of current research topics in nuclear/particle physics and astrophysics. An important objective fulfilled by these meetings is that they enable communication between students performing diverse research in experimental and theoretical physics. As students in experimental physics have their offices in the Edwards Accelerator Laboratory and those in theoretical physics are located in Clippinger Labs, interaction between these students is not as natural as it would be were they to be housed in the same building. In addition to the more advanced students (who lead the discussion with assistance from faculty), the seminars are attended by many interested first-year students.

By adding the student component to our regular seminar, the INPP faculty deemed it necessary for students get a broader education in current topics than can be provided by the regular course sequence PHYS 7501 and 7502, which covers the basics in nuclear and particle physics. The seminars are conducted with sufficient flexibility for students to absorb advances made and to partake of the excitement in the field. This series of journal clubs thus effectively constitutes a course in frontier topics in nuclear/particle physics. The growth in the enrollment for PHYS 8501 (which was PHYS 897A before the Q2S transition) over the years is unmistakable (Fig. 2) and is both a contributor to and reflection of the significant number of graduate students working with INPP faculty during the reporting period. (In fact, enrollment was mistakenly capped at 20 in Fall 2016, or the number would be higher there.)

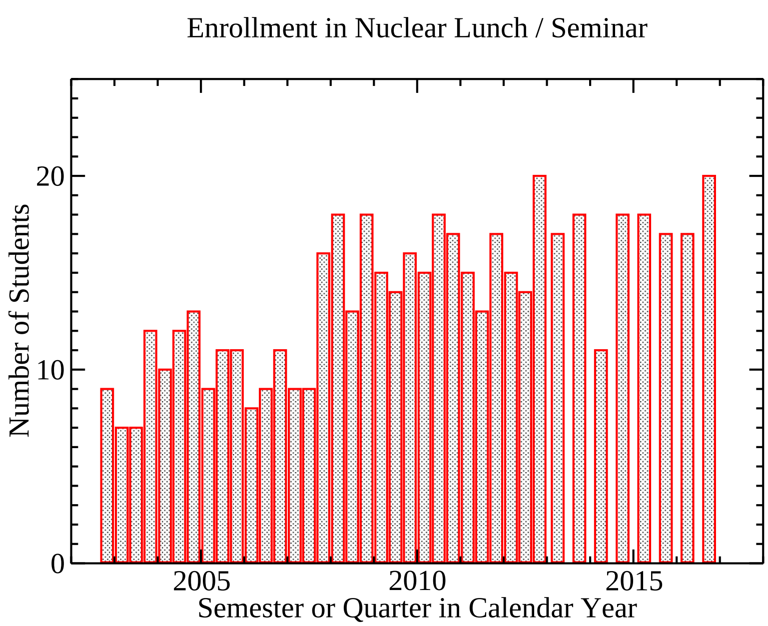

Figure 2: Enrollment in PHYS 897A and PHYS 8501 since the inception of "Nuclear Lunch" in the Fall Quarter of 2002.

B INPP Graduates – 2011-2016

Name	Ph.D.	Advisor	Current Position
Bijaya Acharya	2015	Phillips	Post-doc, University of Tennessee
Shamim Akhtar	2016	Brune	Visiting Asst. Prof., Colorado State (Pueblo)
Rakitha Beminiwatha	2013	Roche	Asst. Prof., Louisiana Tech University
Youngshin Byun	2013	Grimes/Voinov	High school teacher, South Korea
Shloka Chandavar	2015	Hicks	Post-doc, Michigan State University
Constantinos Constantinou	2013	Prakash*	Post-doc, Forshungszentrum, Jülich, Germany
Kevin Cooper	2013	Ingram	Asst. Prof., Lincoln Memorial University, TN
Sushil Dhakal	2016	Brune	Laboratory Technician, Barry University
Dilupama Divaratne	2014	Brune	Visiting Asst. Prof., Miami University, OH
Linda Hlophe	2016	Elster	Post-doc, Michigan State University
Chen Ji	2012	Phillips	Post-doc, ECT*, Trento, Italy
Brian Muccioli	2016	Prakash	Software developer in Boston, MA
Azamat Orazbayev	2013	Elster	Faculty, Nazarbayev University, Kazakhstan
Cody Parker	2016	Brune	Post-doc, MIT
Anthony Paul Ramirez	2014	Voinov	Post-doc, University of Kentucky
Nowo Riveli	2014	Frantz	Asst. Prof., Universitas Padjadjaran, Indonesia
Arbin Thapaliya	2016	Phillips	Asst. Prof., Franklin University, IN
Wei Tang	2012	Hicks	Post-doc, Brookhaven National Lab
Buddhini Waidyawansa	2013	Roche	
Bing Xia	2014	Frantz	Research Tech, Biological Sciences, Ohio U.

Masters Degrees – 2011-2016

Name	M.S.	Advisor	Current Position
M. Abdullah Al-Mamun	2016	Prakash	Ph.D. student, Physics and Astronomy, Ohio U.
Matt Burrows	2016	Elster	Ph.D. student, Physics and Astronomy, Ohio U.
Tyler Danley	2015	Frantz	Ph.D. student, Physics and Astronomy, Ohio U.
Norman Israel	2014	Roche	Lecturer, University of Technology, Jamaica
Alina Karki	2013	Brune	Ph.D. student, Materials Science, U. Vermont
Cody Parker	2011	Brune	Post-doc at MIT
Sudhanva Lalit	2016	Prakash	Ph.D. student, Physics and Astronomy, Ohio U.
Andrea Richard	2014	Brune	Ph.D. student, Physics and Astronomy, Ohio U.
Leo Zelia	2016	Ingram	Ph.D. student, Materials Science, U. Tennessee

* Constantinou was officially a student at SUNY Stony Brook, but did all his research in Athens under Prakash's supervision.

Selected Previous INPP Graduates

Name	Ph.D.	Advisor	Current Position
Daniel Sayre	2011	Brune	Staff member at Lawrence Livermore NL
Dustin Keller	2010	Hicks	Staff scientist at University of Virginia
Christopher Bade	2006	Hicks	Officer in the U.S. Navy
Deepshikha Choudhury	2006	Phillips	Assoc. Prof., Rockford University, Illinois
Catalin Matei	2006	Brune	Research Scientist, ELI, Bucharest, Romania
Ishaq Hleiqawi	2006	Hicks	Assist. Prof., King Faisal Univ., Saudi Arabia
Hang Liu	2005	Elster	Research Assoc., Texas Advanced Computer Center
Yannis Parpottas	2004	Grimes	Assoc. Prof., U. of Cyprus
Asghar Kayani	2003	Ingram	Faculty, Western Michigan Univ.
Chen-Hu Chang	2000	Wright	Software Engineer (Bradley Corp.)
Po-Lin Huang	1999	Grimes	College Teaching (Taiwan)
Cheri Hautala	1999	Rapaport	Science Specialist (Washington DC)
Steven Weppner	1997	Elster	Prof., Eckard College, FL
Saleh Al-Quraishi	1997	Grimes	Assoc. Prof., Saudi Arabia
Kyungsik Kim	1996	Wright	Assist. Prof. (Korea)
Rodney Michael	1995	Hicks	Assoc. Prof. Ashland Univ.
Hong Zhang	1995	Hicks	Computer Programmer
Fred Bateman	1994	Grimes	Staff Scientist NIST
Jim Guillemette	1994	Grimes	Junior College Instructor, Maine
Anita Kumar	1994	Onley	Computer Programmer
Xun Yang	1994	Rapaport	Sen. Systems Engineer Motorola
Werner Abfalterer	1994	Finlay	Staff Scientist LANL
Lian Wang	1993	Rapaport	Computer Programmer
Henry Clark	1993	Hicks	Senior Staff Scientist, Texas A&M
Frank Lee	1993	Wright	Assoc. Prof. GWU
Nourridine Boukharouba	1992	Grimes	Associate Professor, Guelma, Algeria

C Undergraduate Research Participation – 2011–2016

Name	Period	Advisor	Current Position
Jeremy Browne	2016–7	Inrgam	Mech. Eng. undergraduate at Ohio U.
Zach Bernens	Summer 2016	Roche	Ohio U. undergraduate
Colton Feathers	Summer 2016	Brune	Ohio U. undergraduate
Daniel Ivory	Summer 2016	Prakash	Ohio U. undergraduate
Jamison Lahman	Summer 2016	Prakash	Ohio U. undergraduate
Erin Grimes	2015–7	Ingram	
Cates Harman	2015–6	Frantz	USAF Electronic Warfare Engineer Program
Michelle Scott	Summer 2015	King	Undergraduate at Ohio State
John Thiebert	Summer 2015	Roche	Engineering undergraduate at Ohio U.
Miguel Gomez	2014–6	King/Frantz	Hux marketing intern
Natalie Klco	2014–5	Phlllips/Hicks	Grad. school in physics at U. Washington
Alex Carroll	2014–5	Brune	Ohio U. undergraduate
David Overton	2014–5	Brune	Grad. school in physics at Texas A&M
Kylie Holmes	Summer 2014	Roche	Grad. school at Hampton University
Robert Radloff	Summer 2014	Roche	Grad. school on physics at Ohio U.
Henry Cornell	2013	Brune	Masters in Teacher Education at U. Michigan
Tyler Coy	Summer 2013	King	Research Associate Batelle
Justin Hunneshagen	Summer 2013	Roche	Technician at Boehringer Ingelheim
Maxwell Camp	2012–6	Hicks	Grad. school in Economics
Helen Cothrell	2012	Prakash	Grad. school
Austin Wood	Summer 2012	King	High-school physics teacher
Andrew Dewald	2011–6	Frantz/Prakash	Grad. school in physics at Oklahoma U.
Shaila Meeker	Summer 2011	King	Americorps
Brooks Ziegler	Summer 2011	Roche	Faculty, Pellissippi State Comm. Coll., TN

D INPP Postdoctoral Researchers during reporting period

Name	INPP	Area	Current Position
Jared Vanasse	2015–17	N Theory	Post-doc at Ohio U.
Vasily Eremenko	2013–15	N Theory	Research faculty at Moscow State University
Constantinos Consantinou	2013	N Theory	Post-doc at the Forschungszentrum, Jülich
Mohammadreza Hadizadeh	2012–15	N Theory	Asst. Prof. at Central State University, OH
John Goetz	2012–15	M-E Expt	Software developer in Seattle, WA
Xilin Zhang	2012–14	N Theory	Post-doc at U. Washington, Seattle
Jeong-Han Lee	2019–12	M-E Expt	Engineer at European Spallation Source
Dmitry Kotchekov	2009–13	M-E Expt	Research Faculty, University of Hawaii
Nikolay Kornilov	2008–14	L-E Expt	

E Visiting Scientists

Interactions with scientists visiting for a few days up to a few weeks are not only important for collaborations with the INPP faculty, but also allow the students to interact with scientists from outside of Ohio University on a person-to-person basis. In addition, these visits allow scientists to get to know the INPP and Ohio University and spread the word about us. For this reason, the INPP often helps to support collaboration visits financially. In particular, the Institute's partial financial support has helped several INPP faculty host Glidden Visiting Professors at Ohio University. Recipients of the Robert and Rene Glidden Visiting Professorship are indicated by a * on the list below.

During the last five years, the INPP has hosted, and in several cases supported, extended visits by:

- Andreas Nogga*, Fall 2016–Spring 2017, Forschungszentrum, Jülich, Germany
- Constantinos Constantinou, Summer 2016, Forschungszentrum, Jülich, Germany
- Stephen Weppner, January 2016, Eckerd College, FL
- Gregoire Daumy, Summer 2015, Unviersite de Nantes, France
- Evgeny Isupov*, Fall 2014–Spring 2015, Moscow Institute for Nuclear Physics
- Bruno Strandberg, Summer 2014, University of Glasgow
- Harald Grießhammer, multiple visits, George Washington University
- Ken Nollett, Fall 2012–Summer 2014, now Asst. Prof. at San Diego State University
- Daris Samart, Spring 2014, Suranaree University of Technology, Nakhon Ratchasima, Thailand
- Carlos Schat, Spring 2014, COINCET, Buenos Aires, Argentina
- Mohand Ihadddadene, Summer 2012, Universite Paris VI, France.

We have also hosted several scientific visitors who came to use the Edwards Accelerator Laboratory for their experiments. Those visitors are listed separately in Appendix H.

F Research Highlights

The research activities of the INPP roughly fall into three broad categories: (1) Low-Energy Experiments, (2) Medium/High-Energy Experiments, and (3) Theoretical Nuclear and Particle Physics and Astrophysics. Both experimental and theoretical activities include on-campus as well as off-campus components, and include mutual collaboration amongst Ohio University faculty whenever possible. As great advances are generally made by intense discussions, the INPP strives for synergy between theorists and experimentalists in order to spur creativity in both groups.

Low-Energy Experimental Nuclear Physics

Experimental low energy nuclear physics research within the INPP spans a variety of topics, including nuclear astrophysics, nuclear structure, nuclear energy, homeland security, and materials science. **Carl Brune**, **Steve Grimes**, **David Ingram**, **Tom Massey**, **Zach Meisel**, and **Alexander Voinov** pursue a diverse set of research programs, frequently collaborating on joint projects.

Several aspects of nuclear astrophysics are investigated through the low-energy nuclear experimental program within the INPP. Broadly speaking, this work aims to explain the origin of the elements in the universe and the behavior of extremely dense, low-temperature matter. Each of these investigations involves a varied array of experimental and theoretical low-energy nuclear physics techniques.

One outstanding question involves the origin of the carbon and oxygen that feature prominently in daily life. This is primarily controlled by the fusion of ^{12}C and ^{4}He in red giant stars. Under the supervision of **Carl Brune**, **Shamim Akhtar** (Ph.D. 2016) has completed her Ph.D. thesis on the α-transfer reactions induced by ^{6,7}Li nuclei on ^{12}C which provides new constraints on this process. A direct measurement of the $^{12}\mathrm{C}(\alpha,\gamma)^{16}\mathrm{O}$ reaction is underway at TRIUMF (Canada's national laboratory for nuclear and particle physics located in Vancouver, BC).

Zach Meisel performs low-energy nuclear physics experiments with stable and radioactive ion beams, coupled with astrophysics model calculations using open-source software to investigate similar questions. Recent areas of emphasis for the Meisel group are the investigation of Urca nuclide (nuclei which produce strong ν-emission via e^--capture/β^--decay cycling) production and impact on accreting neutron stars and the development of new techniques to measure (α, n) reactions that are thought to play a key role in the production of the elements from $\sim$zinc to $\sim$tin. Meisel recently published two works in *The Astrophysical Journal* highlighting the observational impacts of Urca nuclides. This work provides new constraints on astrophysics models of accreting neutron stars and motivates a new area of exploration for low energy nuclear physics experiments. Several of these experiments are in their beginning stages, including reviving and upgrading the $(^3\mathrm{He},\mathrm{n})$ indirect reaction measurement technique and the first application of the β-Oslo indirect measurement technique for a (p, γ) reaction. Meisel recently performed the first measurement of an (α, n) cross-section on a neutron-rich radioactive nucleus in a technique he developed in collaboration with Michigan State University. The commissioning of this detector was performed at the Edwards Accelerator Laboratory at Ohio University in collaboration with **Tom Massey**, **Carl Brune**, and **Alexander Voinov**. Meisel is currently developing a variant of this technique for use at the Edwards Accelerator Laboratory.

Reaction mechanism studies have featured prominently in the low-energy nuclear physics program within the INPP, where motivations span topics in nuclear astrophysics, nuclear structure, and nuclear energy. The research of **Alexander Voinov** and **Steve Grimes** focuses on low-energy nuclear reaction mechanisms, where the energies of projectiles are up to 5 MeV/A. These are the type of reactions important for the nuclear power industry and national security, and are often of importance in nuclear astrophysics. The experimental study of nuclear structure properties such as the nuclear level density, the γ-strength function, and optical model potentials is an important direction of experimental research conducted at the laboratory. These quantities are used as an input for calculation of reaction cross sections, including reactions with neutrons important for nuclear power and r-process nucleosynthesis. Most experiments have been conducted at the Edwards Accelerator Laboratory on the tandem machine. Specific reactions studied include ^{55}Mn(^{6}Li, p), ^{63,65}Cu(d, p)^{64,66}Zn, ^{54,56,58}Fe(d, p/n), and ^{89}Y(d, p)^{90}Zr. Two students have recently completed PhD degrees with research in this area. **Anthony Ramirez** (PhD 2014) has examined reaction mechanisms for deuteron induced reactions and **Young-shin Byun** (PhD 2013) has studied γ-ray strength function and level densities. These reactions allowed us to study reaction mechanisms and level densities for ^{62}Ni, ^{64,66}Zn, ^{55,57,59,60}Co, ^{90}Zr nuclei. These data helped us to rule out some of theoretical models used for cross section calculations in modern reaction codes. The γ-strength function has been studied for ^{144}Nd using a technique based on Monte-Carlo approach, when randomly shaped γ-strength functions are used as an input to calculate the α-spectrum from ^{143}Nd(n, $\gamma\alpha$) reaction. We showed that the $M1$ γ-strength function has to be enhanced in the low-energy region (up to 3 MeV) to be able to reproduce the experimental α spectrum. Theoretical calculations based on microscopical model have been conducted to calculate the spin distribution and corresponding spin cutoff parameter over wide range of mass numbers. These calculations indicate that although the rigid body model works well above 10 MeV, shell effects are significant below this energy. Work continues to learn whether spin cutoff parameters have a parity dependence at low energy. Such a dependence could significantly influence level densities derived from counting of low-energy neutron resonances. Also a new computer code based on the statistical Hauser-Feshbach model has been developed including novel features such as isospin conservation (complete or partial), the calculation of the angular distribution of reaction products, and the effect of nuclear deformation. Originally, this model was formulated for spherical nuclei but has very frequently been applied to deformed nuclei. **Steve Grimes**, with assistance from **Alexander Voinov** and **Tom Massey**, has reformulated the model for deformed nuclei and written the code to apply the formalism. Results show that a shift of cross sections to small angular momentum levels from large angular momentum levels occurs. This particularly affects two and three step reactions and nuclear isomers.

Tom Massey's research emphasis is neutron-induced reactions and applications for neutron beams. This work has driven advances in detector development for nuclear structure and nuclear astrophysics studies, as well as fundamental improvements in data analysis of neutron-emitting reactions. This includes commissioning of the HABANERO and VANDLE neutron detection arrays, which are key devices at NSCL and will be used for high-profile experiments at FRIB. Additionally, Massey is leading an effort to re-evaluate the $^{10}\mathrm{B(n,Z)}$ reaction cross sections, where a substantial improvement has been realized with regards to the proton, alpha, and triton emission channels for energies above 2 MeV. The $^{10}\mathrm{B+n}$ reaction plays a vital role in several low-energy nuclear physics experiments requiring neutron-detection and this work is poised to correct a long-standing systematic issue with the presently employed $^{10}\mathrm{B(n,Z)}$ cross section data.

Several studies within the INPP low-energy nuclear physics are in the category of applied nuclear physics. This includes efforts focused on improving the understanding of internal confinement fusion, as well as improved data for modeling of neutron transport in materials. **Carl Brune** studies nuclear reactions in thermal plasmas, such as can be generated at Lawrence Livermore National Laboratory's National Ignition Facility (NIF) and Rochester's Laboratory for Laser Energetics (LLE). An important new result using these techniques is the measurement and interpretation of the $\mathrm{T}(t,2n)$ neutron spectrum which was published in Physical Review Letters. In addition, **Cody Parker** (Ph.D. 2016) completed her Ph.D. thesis, an experimental measurement of the $^{3}\mathrm{H}(d,\gamma)$ reaction at Ohio University's Edwards Accelerator Laboratory. Interestingly, these measurements are also useful for the interpretation of measurements of γ rays from thermal plasmas. Under the guidance of **Carl Brune**, **Steve Grimes**, and **Tom Massey**, **Sushil Dhakal** (Ph.D. 2016) recently completed his experimental study of the transport of MeV neutrons in iron. This work is important for understanding the behavior of neutrons in applications such as nuclear power. Under the supervision of **David Ingram**, **Kevin Cooper** (Ph.D. 2013) completed his Ph.D. thesis on the characterization of diamond-like carbon films. Together with David Ingram and **Tom Massey**, Kevin also measured the $^{11}\mathrm{B}(d,n)$ and $^{11}\mathrm{B}(d,n\gamma)$ reactions, which are prolific sources of neutrons and 15.1-MeV γ rays which may be useful for detecting fissionable materials.

Research in low-energy nuclear physics experiments within the INPP also includes active collaboration with several outside groups that come to Ohio University for the unique capabilities of the Edwards Accelerator Laboratory. As with the local program, research driven by outside visitors is motivated by a host of topics, including nuclear astrophysics, nuclear structure, applied nuclear physics, and development of nuclear instrumentation. Recent examples include measurements of $^{12}\mathrm{C(n,2n)}$ in collaboration with the State University of New York Geneseo (2013), measurements of the $^{13}\mathrm{C,B,^{9}Be(d,n)}$ reactions in collaboration with Lawrence Livermore National Lab (2014), measurements of $^{13}\mathrm{C(n,n'\gamma)}$ in collaboration with Los Alamos National Lab (2015), commissioning of the HABANERO neutron long-counter in collaboration with Michigan State University and the University of Notre Dame (2016), nuclear level density studies in collaboration with the University of Oslo (2016), radiation damage studies in collaboration with Ohio State University (2015), and radiation damage studies in collaboration with the United States Air Force (2016).

Medium- and High-Energy Experimental Nuclear Physics

The research program of **Ken Hicks** has been funded continuously by the NSF since 1989 in the area of medium-energy physics, a boundary between nuclear physics and particle physics. Traditional nuclear physics assumes the proton and neutron are fundamental objects, whereas particle physics views the proton (and neutron) as made up of quarks. By examining the quark makeup of the proton, physicists learn more about the fundamental theory of the strong force, called Quantum Chromodynamics (QCD). Hicks and his students are especially interested in particles made from new combinations of quarks, such as the exotic pentaquark (made from four quarks and one antiquark) which was just discovered in 2015. Although Hicks was not part of that discovery, due to his expertise on this subject he was asked to write a ViewPoint article (published by the American Physical Society) that accompanied the scientific paper.

Hicks students and postdocs have made a number of contributions to the scientific literature. Postdoc **John Goetz** published a conference proceedings on his study of Cascade baryons produced when medium-energy photons interact with protons, the first measurement of its kind, and a follow-up journal paper is in progress. Glidden Visiting Professor **Evgeny Isupov**, working with Hicks, has now submitted his paper on electroproduction of two charged pions, leading to evidence for new nucleon resonances. Graduate student **Shloka Chandavar** completed her PhD in 2015 on the topic of scalar mesons, which are of interest because these particles have the same quantum numbers as exotic particles called glueballs, and her paper is under review for publication. Graduate student **Nicholas Compton** defended his PhD in 2016 on the topic of strange-particle photoproduction from the neutron, and his paper is also under review for publication. Another graduate student, **Taya Chetry**, is expected to complete his dissertation by 2018 and has already presented several talks at meetings of the APS. An undergraduate student working under Hicks direction, **Maxwell Camp**, completed a project on a search for pentaquark particles, and his analysis is now under review by the CLAS Collaboration; a paper will be published with Max as the lead author.

The future of the research group led by Hicks will take advantage of the energy-doubling upgrade of JLab, which will start taking data in the fall of 2017. Hicks has been appointed Chair of a committee called the ACE (Analysis Committee of Experts) which has an important role of making recommendations for the analysis procedures for all data from the first run of the so-called CLAS12 detector. The goal of this research is to better understand the structure of the proton using three-dimensional visualization of the quarks inside the proton. This new experimental technique is expected to provide a wealth of information about how QCD confines quarks inside the proton.

The research program of **Julie Roche** and **Paul King** focuses on the study of the electro-weak structure of the nucleon using the electron beam of JLab as a probe. Their medium-energy nuclear experimental program aims to obtain information which will help to answer the questions: "How does subatomic matter organize itself and what phenomena emerge?" and "Are the fundamental interactions that are basic to the structure of matter fully understood?" Both questions have been framed as overarching questions central to nuclear physics in the 2013 report of the National Research Council on the Assessment of and Outlook for Nuclear Physics.

The goal of Deeply Virtual Compton Scattering (DVCS) experiments is to study the Generalized Parton Distributions (GPD) of the proton over a broad kinematic range. In the past twenty years, the theoretical "discovery" of the GPDs has opened up a new exciting era of hadronic physics. The GPDs provide a unique framework based on a 3D tomographic image of the quark structure of the nucleon that links its momentum and coordinate quark distributions. Roche is a co-spokesperson of three experiments dedicated to the study of GPDs in Hall A & C at JLab. Roche and King's work on this program over the past five years focused on the data taking and analysis of experiment E12-06-114, which was one of the first experiments to run at JLab after the energy upgrade. Over the past five year, they worked with two Ph.D. students, two M.S. students and five undergraduate summer interns on this part of their program.

In contrast to high-energy colliders, an alternative strategy to search for new physics is to perform precision measurements of interactions which can be reliably predicted by the Standard Model. While not directly exciting new forms of matter, any deviation from the prediction of the Standard Model provides a signature of these new forms of matter. It is in this low-energy domain where the QWEAK and MOLLER experiments contribute. King and the Ohio U. group have played a key role for DAQ and software for QWEAK. King and Roche worked on QWEAK with a postdoctoral fellow, three undergraduate summer interns, and Ph.D. students **Rakitha Beminiwattha** and **Buddhini Waidyawansa**. In 2014 Beminiwattha won the prize for the best thesis submitted by a student working at JLab during the previous year.

Roche and King are also preparing their research program for the medium term (5 to 10 years outlook). In 2013, Roche and collaborators proposed a new experiment on DVCS in configurations not previously explored. Their proposal was accepted for beam time by the JLab Program Advisory Committee (JLab-PAC). Subsequently, Roche and collaborators received Major Research Instrument funding from NSF. In 2015, King and collaborators proposed an experiment that explores the internal structure of pions (Tagged-DIS). Their proposal was also conditionally accepted for beam time by the JLab PAC. In the longer term King will use his expertise in DAQ and software development for the preparation of the next generation of PVES experiments at JLab: the MOLLER experiment. This experiment will test the standard model of particle physics through an incredibly precise measurement of parity-violating electron-electron scattering.

Justin Frantz's main research interest is studying the Quark Gluon Plasma (QGP) created in collisions of heavy nuclei at the highest achievable energies and more generally, studying nuclear and plasma effects on high energy elementary processes. He's especially interested in photon and QCD jet production in nuclear collisions and the interactions of the jets with the QGP plasma. QCD jets, which are fast moving quarks or gluons, lose energy as they traverse the QGP, which allows physicists to deduce the plasma's properties and also learn about the largely uncertain processes involved in normal jet formation. To this end, Frantz's group has continued a strong involvement in the PHENIX Experiment at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory. In 2014 he had two students earn their Ph.D.'s both in 2014: both performed PHENIX data analyses related to the correlations produced by certain processes involving photons and jets. Both students developed a new techniques, with one involving a technical breakthrough for identifying photons within QGP-producing collisions, which is a challenging environment that contains many false candidates.

Besides his work in PHENIX over the past five years, Frantz has initiated new research directions. He has joined two new relativistic heavy ion experimental collaborations: the ATLAS collaboration at the Large Hadron Collider, CERN Switzerland, and also a new collaboration at RHIC called sPHENIX which exists independently from PHENIX but which aims to re-use certain aspects of PHENIX along with a large new detector. sPHENIX will focus on very precise measurements of jets and photons, and is scheduled to be built and start running within the next four years. The activities of Frantz's group in sPHENIX activities have focused on running simulations to help develop the new detector technologies that will be used, and also included partnering with another institution to construct a prototype of a specific detector type called a hadronic calorimeter and then performing a beam test of this prototype. Frantz's ATLAS work at CERN involves studying collisions with about 10-20 times the collision energy—around 5 TeV—of that available at RHIC, and comparing jet modification and thus properties of the same QGP plasma at these very different temperature/energy scales.

Theoretical Nuclear/Particle Physics and Astrophysics

In the past five years, **Charlotte Elster, Daniel Phillips,** and **Madappa Prakash** have made significant contributions to our understanding of nuclear/particle physics and astrophysics. The work of **Elster** and **Phillips** is primarily concerned with the forces that act between, and within, protons and neutrons. The research of **Prakash** is focused on understanding nuclear matter under conditions of extreme temperature and density, and the application of this understanding to compact astrophysical objects such as neutron stars and high-energy nuclear collisions. The group has been continuously funded by the U.S. Department of Energy, and in the last five years the grant has supported the three PIs, one post-doctoral researcher, and the full salary of three-four Ph.D. students. This DOE grant was renewed at the end of 2016 and the group receiving an increase in funding—in spite of the flat budget for nuclear physics in the DOE Office of Science.

The research of **Charlotte Elster** is primarily concerned with theoretical studies of scattering and reactions of light nuclei. Between 2010 and 2015 she was part of the Topical Collaboration *TORUS: Theory of Reactions for Unstable Isotopes*, one of the first Topical Collaborations in nuclear theory funded by the U.S. Department of Energy. This multi-institional Topical Collaboration aimed at developing new methods that will advance nuclear reaction theory for unstable isotopes by using three-body techniques to improve direct-reaction calculations and developing a new partial-fusion theory to integrate descriptions of direct and compound nuclear reactions. The institutions involved were Lawrence Livermore National Laboratory, Michigan State, Ohio, and Texas A&M University. A major focus of the collaboration were deuteron-induced one-nucleon transfer reactions, which provide a unique tool for extracting relevant nuclear physics information; (d, p) and (d, n) reactions can be employed to study the structure of exotic nuclei and for determining neutron and proton capture rates which cannot be measured directly due to the short life time of the target nuclei involved.

Elster and collaborators aimed at improving the description of direct reactions. The specific goal was employing few-body techniques to develop an advanced treatment of breakup channels during transfer reactions, especially for transfers of nucleons to weakly-bound or unbound (continuum) states. The best available methods still make approximations to the three-body dynamics which render inaccurate transfer cross sections to just those states which are expected to be important for neutron capture reactions, namely the weakly-bound states. Though exact few-body methods are available, they fail for nuclei with more than about 20 protons in the nucleus, since the Coulomb force of the charged particles is treated with screening methods that do not converge for charges larger than 20 protons. Therefore, the collaboration developed new three-body equations that do not rely on screening the charges but rather use basis states that already include the effect of the Coulomb force. Elster and collaborators, together with postdoctoral researcher **Vasily Eremenko** carried out successful proof of principle calculations that show that nuclear matrix elements can be computed in this Coulomb distorted momentum space basis which consists of singular functions and had not been attempted before. Graduate student **Linda Hlophe** created the necessary nuclear potential matrix elements in the form required by the new three-body equations by picking up a sophisticated representation scheme developed in the 1970s and extending it to describe the complex and energy-dependent effective potentials describing the interaction of a single proton or neutron with a composite nucleus. This work lead to six journal publications and constituted the base work leading to a successful collaborative grant application of Profs. Nunes (MSU) and Elster to the Computational Division of the National Science Foundation for funding the next step, namely the numerical implementation of the three-body formulation of (d, p) and (d, n) reactions on exotic nuclei with postdoctoral researcher **Jin Lei**. Visiting Glidden Professor **Andreas Nogga** from the Forschungszentrum Jülich is currently also heavily involved in the project.

An essential ingredient of nuclear reaction calculations are the effective potentials describing the interactions between a proton or neutron with a composite nucleus. Though these are usually described by global phenomenological fits to a large data base, it is desirable to derive them from the underlying interaction between the nucleons in the nucleus. Especially exotic nuclei are not solid spherical object, but rather may have weakly bound nucleons in an outer shell or may be deformed. This physics has been neglected in earlier microscopic calculations of the effective interactions. Elster and collaborators together with graduate student **Azamat Orazbayev** carried out the first proto-type calculation which accounts for the two weekly bound neutrons in Helium-6, however using a simplistic ansatz for the nuclear structure and found that the contributions of those neutrons are not negligible. Now graduate student **Matt Burrows** will repeat those calculations using highly sophisticated modern nuclear structure calculations as input.

Elster continued to be interested in reactions at high energies, which require novel computational approaches as the partial wave expansion usually employed to solve three-body Faddeev equations ceases to be efficient. In addition, for momenta of the order of the nucleon mass, special relativity must be reckoned with. In order to implement the relevant symmetries, the relativistic three-body problem is treated within the framework of Poincaré invariant quantum mechanics. Poincaré invariance is implemented as an exact symmetry realized by the use of a unitary representation of the Poincaré group on a three-particle Hilbert space. Funded by a collaborative grant Prof. W. Polyzou (U. Iowa) and Elster from the National Science Foundation, postdoctoral researcher **Mohammadreza Hadizadeh** developed the theoretical and numerical implementation to study relativistic effects in a three-body bound state and continues this collaboration as faculty at Central State University to implement realistic two-nucleon interactions into the application.

Daniel Phillips is gradually shifting his research focus towards nuclear reactions. **Bijaya Acharya**'s Ph.D. focused on using effective field theories (EFTs) to treat halo nuclei, systems where there are a few neutrons or protons which orbit at a large distance from a core. Acharya's Ph.D. already produced two papers in refereed journals, with calculations for two further papers still being finalized.

Phillips also worked in the nuclear-reactions direction with Ohio U. post-doc, **Xilin Zhang** and Visiting Assistant Professor **Ken Nollett**. They combined information from *ab initio* calculations of light nuclei with EFT methods in order to obtain new predictions for electromagnetic reactions in halo systems, employing these ideas to markedly reduce the uncertainty in the reaction rate for $^7\text{Be}(p,\gamma)^8\text{B}$, a reaction of significant importance in the Sun. Phillips gave several talks on these—and other—halo nuclei projects during the reporting period. Furthermore, together with Hans-Werner Hammer (TU, Darmstadt), and his former Ph.D. student Chen Ji (now a post-doc at ECT* in Trento, Italy), he completed an invited review article on "An effective field theory description of halo nuclei" for *Journal of Physics G*.

Phillips' research on electromagnetic reactions from lighter systems (A=1–3) continues to be productive. Judith McGovern (Manchester), Harald Griesshammer (George Washington), and Phillips finalized an analysis of proton Compton scattering data from 0 to 450 MeV photon energy and a manuscript describing this work was published in *European*

Physical Journal A, where it was featured on the cover of the January 2013 issue. These same three researchers also collaborated on a review of EFT Compton scattering results which was published in *Progress in Particle and Nuclear Physics* in 2012. In addition, Phillips wrote a review article for *Annual Reviews of Nuclear and Particle Science* on electromagnetic reactions in these few-nucleon systems. Phillips' involvement in this research led to him being co-chairing a Compton Scattering Working Group that is part of a larger effort to generate a white paper on science opportunities with a "Next Generation Laser Compton Gamma-ray Beam Facility". (Scientists from Duke University are leading the white-paper effort.)

Phillips also did notable work on nuclear forces in the limit of a large number of quark colors. Working with former INPP research visitor **Carlos Schat** he published a paper on Three-nucleon forces in the $1/N_c$ expansion, which discussed what the three-nucleon force would look like in this limit of QCD. This paper was featured in the September issue of *Physical Review C* as an Editor's Suggestion. Phillips, Schat, and visitor Daris Samart then collaborated on an extension of this work to the parity violating component of the nucleon-nucleon interaction, with their results published in the high-impact journal *Physical Review Letters*.

During the reporting period Phillips resuscitated previous research from 2008–10 on the application of Bayesian methods in the context of effective field theories. He collaborated with Dick Furnstahl (Ohio State) and Furnstahls's Ph.D. student Sarah Wesolowski to produce a paper for a special issue of *Journal of Physics G* that focused on uncertainty quantification in nuclear physics. Undergraduate Natalie Klco worked on these problems for her (prize-winning) Honors Tutorial College thesis. The work that Natalie and Sarah did in this direction led to two papers: one already published in *Physical Review C* and the other in *Journal of Physics G*.

The research led by **Madappa Prakash** covers topical issues in astrophysics, nuclear physics and relativistic heavy-ion physics. Topics addressed in astrophysics included the thermal properties of the dense matter encountered in core-collapse supernovae, proto-neutron stars and mergers of binary compact objects. Investigations of the thermal properties of nuclei and their level densities of relevance to the synthesis of nuclei in the cosmos were performed. Transport properties, such as bulk and shear viscosities of interacting hadrons, which are central inputs to viscous hydrodynamic simulations of relativistic heavy-on collisions were calculated in detail.

Simulations of astrophysical phenomena involving compact objects for which general relativistic effects are important require the equation of state (EOS) of matter for wide ranges of densities, temperatures and lepton content. Prakash and collaborators have calculated such EOS's and rendered them in tabular forms for use in large-scale computer simulations by researchers worldwide. By contrasting results from models based on contact and finite-range interactions including approaches beyond mean field theory, the crucial role of the effective masses of nucleons in determining the thermal properties of matter has been identified. Additionally, a model independent approach to calculate all of the thermal properties of bulk matter beyond leading order and valid for entropies per baryon S of up to 2 (of relevance to core-collapse supernova explosions in which $S \leq 2$) has been developed. The progress made here enables results of zero-temperature calculations of microscopic theories to be used to determine finite temperature properties in lieu of expensive and time-consuming calculations at finite temperature. The most recent advance made is the development of a thermodynamically consistent method by which EOS's based on non relativistic potential models can be modified so that they respect causality at high densities both at zero and finite temperature (entropy).

The pairing phenomenon is ubiquitous in systems of fermions interacting through attractive interactions. Through measurements of nuclear level densities at closely spaced excitation energies E_x, several attempts have been made to determine the critical temperature T_c at which the pairing gaps $\Delta(T)$ in nuclei vanish. The procedure adopted has been to examine the behavior of the specific heat at constant volume C_V vs E_x (or vs T) inferred from data, and looking for a discontinuity of C_V at a critical excitation energy $E_{x,c}$ (or critical temperature T_c) which signals the phase transition from the superfluid to the normal phase. The moderate success achieved thus far is due to issues associated with the normalization of level densities close to the neutron separation energy. When the single-particle levels of a large number of nuclei are examined, they appear to resemble those generated randomly around the Fermi surface. Exploiting this similarity, **Prakash** and graduate student **Al Mamun** have examined the pairing properties from randomly distributed single-particle energy levels with appropriate constraints imposed to model single-particle energy levels of nuclei, and established (i) the extent to which the basic characteristics such as T_c/Δ_0 (where $\Delta_0 = \Delta(T=0)$), the ratio of superfluid to normal specific heats at constant volume, $C_V^{(s)}/C_V^{(n)}$, and $\frac{1}{T_c}\left.\frac{d\Delta^2}{dT}\right|_{T_c}$ depart from those a Fermi gas and HFB calculations, and (ii) placed statistically-based bounds for the case randomly distributed energy levels. In concert with the experimental colleagues of the INPP **(A. Voinov, T. Massey and S. Grimes)**, work is in progress to calculate the level densities of ^{197}Pt recently measured, and of ^{60}Zn proposed to be measured **(Z. Meisel)**, at the Edwards Accelerator.

Prakash has also been active in the research area of relativistic heavy-ion physics, and is the theoretical counterpart to the experimental work of **Justin Frantz**. To account for the observed characteristics of the elliptical flow in high energy heavy-ion collisions, viscous hydrodynamic calculations require the shear viscosity as an essential input. Prakash and collaborators have calculated the shear viscosity η and entropy density s of a hadronic resonance gas using the Chapman-Enskog and virial expansion methods using the K-matrix parameterization of hadronic cross sections which preserves the unitarity of the T-matrix. In the $\pi - K - N - \eta$ mixture considered, a total of 57 resonances up to 2 GeV were included. Comparisons were also made to results with other hadronic cross sections such as the Breit-Wigner (BW) and, where available, experimental phase shift parameterizations. Hadronic interactions forming resonances were shown to decrease the shear viscosity and increase the entropy density leading to a substantial reduction of η/s as the QCD phase transition temperature is approached.

G National/International Activities of INPP Faculty

In this Appendix, selected activities of the INPP faculty are highlighted. The activities include involvement in organization of conferences or workshops, participation in review panels of Federal Agencies as well as Program Advisory Committees at different national facilities.

Conference/Workshop Organization

- Elster is a co-organizer of the 2017 Institute for Nuclear Theory program "Toward Predictive Theories of Nuclear Reactions Across the Isotopic Chart (INT-17-1a)".
- Roche was Vice-Chair of the Gordon Research Conference in Photonuclear reactions in 2016, held in Tilton, NH.
- Brune was a co-organizer of the 2016 R-Matrix Workshop on Methods and Applications, held in Santa Fe, NM. INPP was a co-sponsor.
- Frantz co-organized both the 2015 and 2016 RHIC/AGS Annual Users' Meeting.
- Prakash served as the chair of the "JINA-CEE International Symposium on Neutron Stars in the Multi-Messenger Era: Prospects and Challenges" held during May 2016, in Athens, OH. He also co-organized the "JINA-CEE Satellite Workshop on Experiments for X-ray Burst Nucleosynthesis", which took place just before the symposium.
- Phillips and Elster were co-chairs (together with C. Roberts, ANL) of the 21st International Conference on Few-Body Problems in Physics, 2015, held in Chicago, IL. Brune was also a member of the Organizing Committee. INPP was a co-sponsor.
- Phillips organized (together with M. Safronova, M. Snow, and C. Ticknor) a pre-workshop on Tests of Fundamental Symmetries at the American Physical Society's April meeting in Baltimore, MD, April 2015.
- Elster was a co-organizer (together with I. Thompson and W. Dickhoff) of the Institute for Nuclear Theory workshop "Reactions and Structure of Exotic Nuclei" in March 2015.
- Elster was co-convenor of the Joint Division of Nuclear Physics town meeting on Nuclear Structure and Nuclear Astrophysics in August 2014.
- Phillips organized (together with E. Epelbaum, A. Parreño, and J. Soto) a Benasque (Spain) Center for Science Workshop on "Bound States and Resonances in Effective Field Theories in July 2014.

- Roche was a co-organizer of the Jefferson Lab Hall A collaboration meeting in June 2014.

- Phillips organized (together with D. Blume, C. Greene, and F. Ferlaino) an Institute for Nuclear Theory Workshop on "Few-body Universality: Recent Experimental and Theoretical Developments in May 2014.

- Frantz was a co-organizer of the Midwest Critical Mass Workshop in March 2014.

- Roche was a co-organizer of the Jefferson Lab Hall A collaboration meeting in December 2013.

- Hicks co-organized (with 3 others) the Topical Group on Hadron Physics pre-conference workshop of the 2013 April American Physical Society meeting.

- Frantz and Hicks co-organized the American Physical Society Ohio Section Meeting in Athens, OH in April 2013.

- Elster and Phillips co-organized (with C. Roberts) of the Mid-west Theory Get-together held at Argonne National Laboratory, in Chicago, IL in September 2012.

- As Chair of the CLAS Collaboration from 2012–4, Hicks organized the three CLAS meetings that occurred each year.

Advisory Committees

- Phillips, Nuclear Science Advisory Committee, 2016–present.

- Brune, Program Advisory Committee, High-Intensity Gamma-Ray Source (HIGS) at Triangle Universities Nuclear Laboratory, 2016–present.

- Brune, International Advisory Committee, Jinping Underground Laboratory for Nuclear Astrophysics, 2016–present.

- Phillips, Advisory Committee, Department of Energy's Institute for Nuclear Theory at the University of Washington, 2012–2016. He chaired the committee between 2014 and 2016.

- Elster, Scientific Advisory Committee, International Conference 'Nuclear Theory in the Supercomputing Era–2016', Khabarovsk, Russia, 2016.

- Phillips, International Advisory Committee, International Workshop on Chiral Dynamics: Theory and Experiment, Pisa, Italy, 2015.

- Elster, International Advisory Committee, ARIS2014, the 2nd conference on "Advances in Radio-isotope Science", 2014.

- Elster and Phillips, International Advisory Committee, European Conference on Few-Body Problems in Physics, Cracow, Poland, 2013.
- Hicks, International Advisory Committee, Reimei Workshop on Hadron Physics at J-PARC, Tokai, Japan, 2013.
- Hicks, International Advisory Committee, the XV International Conference on Hadron Spectroscopy, Nara, Japan, 2013.
- Elster, International Advisory Committee for the 20th International Conference on Few-Body Problems in Physics, Fukuoka, Japan, 2012.
- Frantz, International Advisory Committee, Winter Workshop on Nuclear Dynamics, 2011–5.
- Phillips, Program Advisory Committee, MAX-Lab (Lund, Sweden), 2011–6.
- Brune, Nuclear Diagnostics Review Committee at Lawrence Livermore National Laboratory, 2010–2.

Review Panels of Federal Agencies

- Elster was a member of the U.S. Department of Energy, Office of Nuclear Science, Review Committee of the Nuclear Theory Programs of the National Laboratories in 2016.
- Roche was a member of the Committee of Visitors for the National Science Foundation's Division of Physics in 2015.
- While serving in his temporary position at NSF from 2014–6 Hicks co-chaired a number of site visits and review panels for the NSF Experimental Nuclear Physics program.
- Elster was a member of the review and site-visit committee that conducted the five-year review of the Triangle Universities National Laboratory (TUNL) at Duke University for the Department of Energy in 2014.
- Hicks was a member of the NSF panel for Experimental Nuclear Physics in 2013.
- Prakash served on the NSF site-visit committee that assessed the performance of the Physics Frontier Center "JINA-2" in 2013.
- Elster was a panelist for NSF on the solicitation prepanel S2I2 (Scientific Software Innovation Institutes) in 2012.
- Phillips was a member of the Committee of Visitors for the National Science Foundation's Division of Physics in 2012.

Activities in Professional Organizations

- Brune, Facility for Rare Isotope Beams (FRIB) Users Group, Executive Committee, 2017–present.
- Elster, Few-Body Systems Editorial Board, 2016–9.
- Roche, Vice-chair, Jefferson Lab Users Group, 2016.
- Frantz, co-organizer, Community-wide Nuclear Physics US Congress Lobbying Day, 2016.
- Roche, Executive Committee, Ohio section of the American Physical Society, 2015–.
- Frantz, Newsletter Committee, Appalachian Chapter of American Association of Physics Teachers, 2015.
- Elster, Nuclear Physics Long-Range Plan Writing Committee, 2015, and Co-chair of Writing Committee for White Paper on Low-energy Nuclear Physics, 2014.
- Frantz, Chair line of the RHIC/AGS Users Executive Committee, 2014–7.
- Frantz, Founding Chair of Diversity Working Group of the RHIC/AGS Users Executive Committee, 2014–2017.
- Roche, Ohio U. representative, Southeastern Universities Research Association—JLab program committee, 2014–.
- Roche, JSA/JLab Graduate Fellowship Evaluation Committee, 2014–.
- Brune, Nuclear Physics Long-Range Planning process, White Paper on Nuclear Astrophysics, Writing Committee, 2014–5.
- Brune, Nuclear Physics Long-range Planning process, Association for Research at University Accelerators (ARUNA), White Paper Writing Committee, 2014–5.
- Elster, Vice-chair and then Chair, American Physical Society Division of Nuclear Physics Nomination Committee, 2014–5.
- Phillips, Vice-chair, Chair-elect, Chair, and then Past Chair, American Physical Society Topical Group on Few-body Systems, 2012–6.
- Roche, Secretary and then Chair, Jefferson Lab Hall A collaboration, 2013–4.
- Hicks, Program Committee for the American Physical Society Topical Group for Hadron Physics, 2013.
- Hicks, Chair of the CEBAF Large Acceptance Spectrometer (CLAS) collaboration, 2012–4.

- Brune, Nuclear Astrophysics Town Meeting, Working Group Organizer, 2012.
- Frantz, BNL RHIC/AGS thesis competition judge, 2012, 2015–7.
- Phillips, Division of Nuclear Physics Dissertation Award Committee, 2012.
- Brune, Physical Review C Editorial Board, 2011–3.
- Brune, Nuclear Science Advisory Committee, Subcommittee on Public Access to Research Results, 2011.

Prizes and Awards

- Brune, Outstanding Referee, Physical Review and Physical Review Letters, 2016.
- Hicks, Ohio University Newsmaker Award, 2016.
- Hicks, Certificate of Appreciation for work on Graduate Research Fellowship Program, National Science Foundation, 2015 & 2016.
- Phillips, Honors Tutorial College Distinguished Mentor Award, 2015.
- Phillips, Outstanding Referee, Physical Review and Physical Review Letters, 2014.
- Brune, Dean's Outstanding Teaching Award, College of Arts & Sciences, 2013.
- Phillips, Jeanette G. Grasseli Brown Teaching Award, College of Arts & Sciences, 2012.

Courses Presented at Schools and Workshops

- Brune, Exotic Beam Summer School, 2016, "Nuclear Astrophysics", 2 lectures.
- Roche, Hampton University Graduate School (JLab summer school), 2016, "Nucleon spatial imaging", 6 lectures.
- Brune, National Nuclear Physics Summer School, 2015, "Nuclear Science in High Energy Density Plasmas", 1 lecture.

Visiting Appointments

- King, visiting scientist at Jefferson Lab, Fall 2016.
- Roche, visiting scientist at Jefferson Lab, Spring 2016.
- Roche, visiting scientist at Jefferson Lab, Spring 2014, funded by Jefferson Science Associates/JLab sabbatical/research leave support program.

- King, visiting scientist at Jefferson Lab, Fall 2014.
- Hicks, Program Director, Experimental Nuclear Physics, National Science Foundation, 2014–6.
- Phillips, Visiting Scholar, University of Washington, May 2014.
- Phillips, Visiting Scholar, University of Washington, August 2013.
- Hicks, Japan Society of Physical Science Fellow with the Japan Atomic Energy Association, March–June 2012.

Other Activities

- Ken Hicks writes a monthly column for the *Columbus Dispatch*.
- In 2016 Charlotte Elster was a member of the Search Committee for the Associate Director for Theoretical and Computational Physics at the Department of Energy's Jefferson Laboratory.
- Zach Meisel authored a popular science article for Ohio University's College of Arts & Sciences "Forum" in 2016.
- Daniel Phillips contributed to a *Columbus Dispatch* article on "Chalkboard equations" in 2013.

H The Edwards Accelerator Laboratory

Carl Brune is presently the Director of the Edwards Accelerator Laboratory. In addition to its key role in the research of the local nuclear-structure-and-reactions group (Brune, Grimes, Massey, Meisel, Voinov), and work in applied nuclear physics (Ingram—often in collaboration with people in other departments), the laboratory hosts a wide variety of basic and applied nuclear science projects led by outside users (see Table 1). The projects range from basic nuclear science (level-density measurements), to calibrations of detectors destined for national user facilities (e.g., HABANERO), to applications (detector development for inertial confinement fusion).

Edwards hosts the primary nuclear-physics experimental facility at Ohio University: the 4.5-MV tandem van de Graaff accelerator located there. This machine is equipped with a sputter ion source and a duoplasmatron charge-exchange ion source for the production of proton, deuteron, ^{3,4}He, and heavy-ion beams. Pulsing and bunching equipment are capable of achieving 1-ns bursts for proton and deuteron beams, 2.5-ns bursts for ^{3,4}He beams, and 3-ns bursts for ^{7}Li.

The accelerator has been upgraded to a Pelletron charging system with NSF funding. The work was completed in January 2012, just as the last five-year INPP review report was being written. The accelerator has run very smoothly since the upgrade, including stable operations at terminal voltages up to 4.6 MV (before the upgrade we were limited to 3.7 MV). In addition, the accelerator has required much less maintenance. Over the past five years, the accelerator has operated an average of 900 hours/year.

Several other significant enhancements or repairs have been made in the laboratory over the pas five years. The low-energy-tube and column resistors in the accelerator have been replaced with modern silicone-coated resistors. We have also replaced the pump which circulates and cleans the SF_6 gas that is inside the the accelerator tank. The replacement included some re-engineering of the gas handling system to allow for more pressure measurements at various points in the system. Other significant work in the lab included the installation of a new fire alarm system, replacement of the process water chiller, and the installation of a security system for radiative sources. Finally, the roof of the building was replaced in 2015, as the old roof had reached the end of its life, with numerous leaks affecting student and faculty offices, the conference room, and library.

The Laboratory is very well equipped for neutron time-of-flight experiments. A beam-swinger magnet—acquired from Michigan State University in 1981—and time-of-flight tunnel allow flight paths ranging from 4 to 30 m. The tunnel is very well shielded, and the swinger-magnet assembly allows angular distributions to be measured with a single flight path. Several types of neutron detectors are available, including lithium glass and NE213. Three intrinsic Ge detectors are available for high-resolution γ-ray studies (two coaxial detectors of 40% and 75% relative efficiency and one 15-mm-thick$\times$2000-mm^2-area planar detector). Two 10.2-cm-diameter $\times$ 10.2-cm-length BGO and one 5.1-cm-diameter $\times$ 5.1-cm-length Lanthanum Bromide scintillators are also available for gamma-ray detection.

A scattering chamber is available for Rutherford backscattering measurements and other charged-particle measurements. A time-of-flight spectrometer is also available for charged-particle studies. Finally, a beamline for γ-ray spectroscopy studies available.

The Edwards Accelerator Laboratory building is well supplied with computational resources. Every student, postdoc, staff member, and faculty member has a modern PC-based computer system (Linux, Mac, or Windows operating system) on their desk. Many additional computers are available for special purposes (e.g. data acquisition, data analysis). Several Intel "Core i7" processor systems that are fully expanded with RAM (12 GBytes) are available for general-purpose computing. In addition, we have two Thinkmate workstations equipped with 8-core Intel XEON processors for computationally-intensive jobs.

Several standalone DAQ systems are available for experiments. We also have a "Distributed DAQ" data acquisition system which consists of up to 15 dual-PC nodes connected via ethernet to a central computer used for system control and data display. Each node is an independent computer with Distributed DAQ hardware that is dedicated to a single detector or detector-telescope system. This system is running the Linux version of the Ohio University DDAQ software [1]. The Distributed DAQ hardware consists of a board with two charge-to-time converters (MQT300A) and one multi-hit eight-channel time-to-digital converter (MTD133B) from LeCroy. The charge converter has 3 selectable ranges and an optional variable range. Each charge converter has a maximum dynamic range of over 500. This system can operate at high data rates, has excellent time stability, and eliminates cross talk between detectors. It is particularly advantageous for time-of-flight experiments.

Lastly, we note that the building in which the accelerator is housed was expanded in 1993. This expansion was funded via a mortgage that was repaid over several years from institute funds. Individual professors also assisted with the funding using money from their research-incentive accounts. This early success of the INPP's collaborative approach to science established the fine environment that we enjoy today.

[1] see http://www.daqlinux.com

Date(s)	PI	Institution - Project
10/30/2011-11/4/11	C. Lawrence, A. Enqvist	University of Michigan Detector Calibration
11/7/11-11/11/11 8/2/13-8/9/13	B. Czirr, J. Ellsworth	Brigham Young University Capture Gated Detector Efficiency
11/14/11-11/17/11	D. Sayre, L. Bernstein	Lawrence Livermore National Lab. (n,n'γ) measurements
6/25/12-6/30/12 7/9/12-7/13/12 7/7/13-7/19/13	S. Padalino, M. Yuly *et al.*	SUNY Geneseo, Houghton College $\sigma(E)$, $^{12}C(n,2n)^{11}C$
9/30/13-10/4/13	C. Lawrence	University of Michigan Detector Response Matrix
3/20/14-3/28/14 5/2/16-5/13/16	A. Enqvist, D. Murer K. Jordan *at al.*	University of Florida, Arktis Inc. Detector Calibration, ^{4}He Detectors
9/7/14-9/15/14	J. Hall, D. Bleuel	Lawrence Livermore National Lab. (d,n) on ^{9}Be, B, and ^{13}C
2/23/15-2/27/15 4/13/15-4/17/15	A. McEvoy	Los Alamos National Lab. $^{12,13}C(n,n'\gamma)$
5/21/15	B. Wilson, T. Blue	Ohio State University Radiation Damage
1/25/16-1/30/16 11/7/16-11/18/16	A.C. Larsen, S. Liddick, G. Perdikakis *et al.*	Oslo, Michigan State University, U. of Central Michigan level densities in $^{74,76}Ge$
4/3/16-4/25/16	T. Ahn, Z. Meisel *et al.* (HABANERO Collab.)	Michigan State University, Notre Dame HABANERO long counter calibration
8/18/16, 9/16/16	M. Hogsed	Airforce Inst. of Tech. (Dayton) Radiation Damage
10/3/16-10/9/16	N. Kabadi, C. Parker	MIT CVD diamond detector testing

Table 1: Outside users of the Edwards Accelerator Laboratory since July 1, 2011.