Institute of
Nuclear and Particle Physics
Self-Study

January 2017 - December 2021

March 2022

Prepared for:

College of Arts and Sciences

Prepared by:

Julie Roche, Director

Institute of Nuclear and Particle Physics
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Center/Institute Summary

Center/Institute:	Institute of Nuclear and Particle Physics
Director:	Julie Roche Department of Physics and Astronomy College of Arts and Sciences
Active Affiliated Faculty:	Carl Brune, Professor of Physics Chaden Djalali, 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, Associate Professor of Physics Daniel Phillips, Professor of Physics Madappa Prakash, Professor of Physics Julie Roche, Professor of Physics Mark Lucas, Professor of Instruction Paul King, Research Associate Professor of Physics Thomas Massey, Research Associate Professor of Physics Gabriela Popa, Associate Professor of Physics (Zanesville) Alexander Voinov, Research Associate 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 (January 2017-December 2021): External Grants totalling \$12,974,610

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, to leverage larger amounts of external research funding.
- Financial support of research faculty and staff, postdoctoral researchers, graduate students, and undergraduate students.

For this report, we consider the period from January 1, 2017, through December 31, 2021.

2 Brief history

The Institute of Nuclear and Particle Physics (INPP[1]) was established in 1991 to enhance interactions among faculty and students in the Department of Physics and Astronomy

[1] A table of acronyms is provided as reference in Appendix H

(P&A) 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 U. 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 experimental nuclear research during the 1970s and the 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 essential 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.

In the Fall of 2021, INPP sponsored a celebration of "50 Years of Discovery at the Edwards Accelerator Laboratory"(OHIO News article). Past and present EAL and INPP researchers gathered for a two-day meeting with presentations covering past and current experiments and innovations at the EAL. Around that celebration, INPP and EAL received two generous gifts from past EAL and INPP researchers. Distinguished Professor Rapaport established the "Distinguished Professor J. Rapaport Endowment for the Institute of Nuclear and Particle Physics" to be used at the discretion of the INPP director. Alumnus Charles Nelson established the "Dr. Raymond O. Lane Fund in Support of Graduate Study at the Edwards Accelerator Lab" in honor of Dr. Lane, his thesis advisor.

In addition to our efforts at Edwards, experimental investigations of nuclear structure and dynamics are carried out using short-lived exotic nuclei at Argonne National Laboratory and TRIUMF in Canada. INPP faculty are also involved at the newly built Facility for Rare Isotope Beams (FRIB) at Michigan State University (https://frib.msu.edu/) This $750M facility is available for physics experiments and is the world-leading facility for studying the properties of exotic nuclei.

INPP's research in experimental nuclear physics has broadened substantially over the past thirty 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 JLab (https://www.jlab.org/), where the beam consists of electrons or photons with energies roughly a factor 500 larger than those achieved at Edwards. This national facility allows 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, https://www.bnl.gov/rhic/) at Brookhaven National Laboratory in Upton, NY. At this facility, 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's creation.

Our participation in experiments at these national and international facilities allows us to do science that cannot be pursued at Edwards. However, Edwards is invaluable both for its unique capabilities alluded to above and 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), 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 start from the fundamental inter-nucleon forces. We also have considerable expertise in applying systematic "effective field theories" to treat this problem. Since the addition of Prakash in 2005 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 FRIB at Michigan State University. The low-energy effort now includes three tenured faculty (Brune, Ingram, and Meisel), two grant-supported research faculty (Massey and Voinov), two postdoctoral fellows and seven Ph.D. students. In addition, Distinguished Emeritus Professor Steve Grimes remains very active.

The research of the medium/high-energy experimental group is conducted at large national facilities. This group focuses on understanding hadronic matter made up of quarks and gluons. This type of matter represents over 90% of the visible mass of the universe, and Quantum Chromodynamics governs its dynamics (QCD). While the fundamental laws of QCD are elegant, concise, and firmly established, understanding the composite structure of matter resulting from them is still incomplete. Profs. Djalali, Hicks, Roche, and Associate Professor Frantz make up this group. In addition, Paul King (Julie Roche's husband) is a Research Associate Professor. This group presently supports five 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 currently supports three Ph.D. students and three postdoctoral researchers. Associate Professor Gabriella Popa is also a nuclear theorist and is a faculty member at OHIO U'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. Prakash and Elster will both retire within a few years. For a nationally visible effort in nuclear theory, the minimum number of faculty is two. Phillips, Elster, and Prakash applied for participation in the nationally competitive FRIB Theory Alliance Bridge program. Through this program, bridge faculty positions have 50% of the cost covered by DOE through the FRIB-TA and 50% by the home institution, over an initial period of up to 6 years or until the faculty member is granted tenure. The OHIO U. program was selected in the Fall of 2021, and a faculty search is being conducted in the Spring of 2022, with five candidates interviewed (in person) in February 2022.

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–B and a list of postdoctoral researchers in Appendix C.

3.2 Meeting objectives

3.2.1 Research

The INPP is blessed with faculty who are leaders in their respective research fields. INPP researchers, including postdoctoral fellows and graduate students, have authored over 275 publications during the past five years. Another indication of our research productivity is our external funding, which reached $12.9 million over the past five years. This represents a significant increase compared to the previous reporting period. Indeed in 2020, the Bayesian Analysis of Nuclear Dynamics (BAND, website) collaboration led by Professor Phillips received $3.7M support for NSF to cover their activities over the next five years.

Research highlights from the last five years are described in Appendix E.

3.2.2 Intellectual climate

The INPP hosts 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 U. Before the Covid-19 pandemic, these visitors typically spent a day on campus meeting with faculty, postdoctoral researchers, and students. During the pandemic, seminar speakers gave their presentations remotely. We are now resuming in-person seminars, with the first in-person INPP seminar speaker scheduled to visit Athens in late March 2022.

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

The INPP also sponsored several major conferences and workshops over the last five years. Between 2018 and 2021, in his position of Secretary-Treasurer of the DNP, Hicks was one of the lead organizers of the two annual meetings of the division. In 2018, Roche chaired the 2018 Photo-nuclear Reaction Gordon Conference, which drew about 100 scientists from all over the world. Phillips was the lead organizer of the Sixth Workshop on Information and Statistics in Nuclear and Theory, held in Darmstadt, Germany, in October 2018. A comprehensive list of the conference and workshop organization by INPP Researchers is compiled in Appendix F.

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 U. 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. Phillips is the leader of the BAND collaboration, which consists of over 20 physicists and statisticians from Ohio, Michigan, and Illinois.

In Spring 2021, Roche was asked to co-chair the Exclusive Reaction working group of the ECCE collaboration (https://www.ecce-eic.org/). This consortium is comprised of 96 international institutions assembled around the idea of developing a detector to be used at the upcoming Electron-Ion Collider (EIC).

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 D. 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 Dr. Andreas Nogga from the Institute of Nuclear Physics in Jülich Germany for the 2016-2017 academic year, Dr. Gleb Fedotov from Moscow State University for the 2017-2018 academic year, as well as Associate Professor Adam Fritsch from Gonzaga University for the 2021-2022 academic year.

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. Between 2017 and 2021, INPP faculty members supervised eighteen Ph.D. dissertations and five Master's theses. We are proud of our student's accomplishments, including several awards for posters they presented at national conferences. For example, graduate student Rowley won an honorable mention at the National Nuclear Physics Summer School poster competition in 2019. Graduate student Brandenburg won the outstanding poster presentation award at the 2018 Stewardship Sciences Academic Program Symposium hosted by the National Nuclear Security Administration. In addition, undergraduate Carver won first place at the OHIO U. Society of Physics Students Research Conference in 2019.

More than half of our Ph.D. graduates initially pursue an academic career by moving into postdoctoral 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 listed in Appendix A, 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 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 another comes on board.

During the reporting period, INPP also supported several undergraduate research projects, either in full or as complement to faculty's research grants. A list of undergraduate students who participated to research projects is given in Appendix B.

3.2.4 Research personnel and grant financial specialist

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

Two engineers and one grant financial specialist are essential to the smooth functioning of the INPP research enterprise. Historically (before 2008), those three positions were fully supported by CAS. Over the past five years, INPP used some of its funds to complement fluctuations in CAS support. For example, in 2017 INPP spent [redacted] for the EAL engineers but nothing on the grant financial specialist. In contrast in 2021, INPP spent [redacted] for a combination of the three positions (see table 1).

3.2.5 Faculty

The number of tenure-track faculty members in the INPP has been about constant over the reporting period and in fact, is at the same level as it has been since 2001. This is because the group has been proactive and strategic in seeking replacements for natural attrition, retirement, and firing due to OHIO U., financial turmoil. For example, one key accomplishment of the INPP over the past five years has been its successful bid for a Nuclear Theory bridge position with FRIB Theory Alliance. The theory group's national reputation and good connections to different aspects of INPP's experimental work were instrumental in securing this opportunity. Natural attrition of the group will continue; for example, Hicks announced that he will take advantage of the 2022 VSRP and take a permanent position as an officer of the Department of Energy. Prof. Djalali started in Fall 2020, coming to the INPP from his former position as Provost and following a semester of Faculty Fellowship Leave. Turmoil in the OHIO U. finances resulted in the firing/non-renewal of many employees, including instructional-faculty members Lucas and King, in the summer of 2020. Both of them were re-hired by the University using non-CAS funds: Lucas as a Professor of Instruction with a shared appointment between Physics and Astronomy and the Honors College and King as a Research Associate Professor. King's position is supported half by INPP and half by JLab on a year-per-year contract with a three-year commitment contingent on the availability of funds. During the reporting period, Meisel was tenured and promoted to Associate Professor, and Roche was promoted to Full Professor.

The national and international visibility of the INPP, the Department of Physics and Astronomy and OHIO U. is elevated through the 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, Hicks was the Secretary-Treasurer of the Division on Nuclear Physics (DNP) of the American Physical Society (APS) from 2018 to 2021. Elster is a member of the Department of Energy Facility

JLab Program Advisory Committee since 2018. This group of 12 international scientists reviews the scientific merits of the beam proposals put forward by users. Meisel served on the 2021 Program Advisory Committee for the LANSCE facility at Los Alamos National Laboratory. Phillips was a DOE/NSF Nuclear Science Advisory Committee member from 2016 to 2019. Meisel was chair of the FRIB Users Organization in 2021. A list of the high-profile activities of INPP faculty is given in Appendix F.

3.2.6 The Edwards Accelerator Laboratory

The primary nuclear physics experimental facility at OHIO U. 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 2017 to 2021 is given in Appendix G.

3.2.7 Impacts of the Summer 2020 CAS re-organization

In 2020, two successive blows hit INPP researchers (and their CAS colleagues). In the Spring of 2020, the COVID19 pandemic abruptly halted on-campus activities. Many INPP researchers were already used to working with distant colleagues; the transition to remote work happened more or less seamlessly.[2] For example, Ph.D. candidate Karki defended his thesis in March 2020 on schedule. As soon as possible, EAL Director Meisel wrote a Research-Restart Plan, and operation at the Edwards Accelerator resumed in June 2020. King resumed travel to JLab in Virginia in the Spring of 2021 after the two-weeks quarantine period mandated by JLab was removed.

The summer 2020 CAS reorganization is the second blow to the INPP work landscape. Until that summer, INPP researchers relied on administrative staff embedded in the P&A department. All were fired in July 2020 and replaced by a much smaller CAS centralized contingent. After a very confusing period, some centralized administrative support started to operate efficiently. For example, the CAS HR liaison persons supporting the hiring of our accelerator engineer, postdocs, and FRIB bridge faculty was efficient and professional. Unfortunately, the management of grant money has been altered in two ways:

- In the FY 2021, INPP faculty members operated 14 different grant awards with individual start and end dates and supported about 25 research personnel, students, and professors. The administration of these grants is by itself a complex task. It is made more complicated because of the shortcomings of the OBI Oracle database

[2] The pandemic of course, took a toll on the personal lives of INPP researchers both physically and mentally.

provided by the University. This system doesn't allow PIs to account for encumbered grant funds (e.g., salaries in coming months) and is often several months behind in recording billed expenses. For INPP researchers to be efficient and diligent in their use of grant funding P&A administrative staff had developed a shadow system so that PIs could make maximum use of their grant funding without overspending accounts. Before the CAS reorganization of summer 2020, a grant specialist (Ms. Goettge) provided this support. In the summer of 2020, this position was eliminated. In the Fall of 2020, INPP decided to fund their own grant specialist as CAS and re-hired Ms. Goettge.

- CAS implemented a tightly controlled centralized purchasing system in a significant departure from previous practices. The new system is more complicated than earlier. For example, all purchases need to be made through a CAS finance person and then a CAS purchase specialist rather than using an individual P-card like it was done in the past. In a significant breakdown of shared leadership, new purchase procedures were established without consultation of the faculty members. In September 2021, Phillips, Roche, and NQPI director Stinaff met with the CAS purchase leadership to discuss a 9-page document outlining the P&A faculty member's complaints about purchasing. To this day, many of the problems outlined in this document remain while CAS's purchase leadership continues to promise some change. The reported problems reported in September 2021 were : (1) CAS process inserts extra steps that are not necessary, (2) CAS process is untimely resulting in excessive delays, (3)CAS interferes in decisions regarding purchases, resulting in worse outcomes, (4) CAS Process is sufficiently cumbersome that people will put off important maintenance to avoid it and/or just bring items from home, (5) It is unclear who has responsibility for following up on purchases once an order is placed, (6) No-one is checking grant expenditures, so mistakes regarding allocation of costs to grants are often not caught until too late and (7) The steps required to organize grant-funded travel are burdensome, time-consuming and costly.

4 Funding commitments

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 shows the history of INPP's external funding. We started in 1991 with a funding level of $0.7M. 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

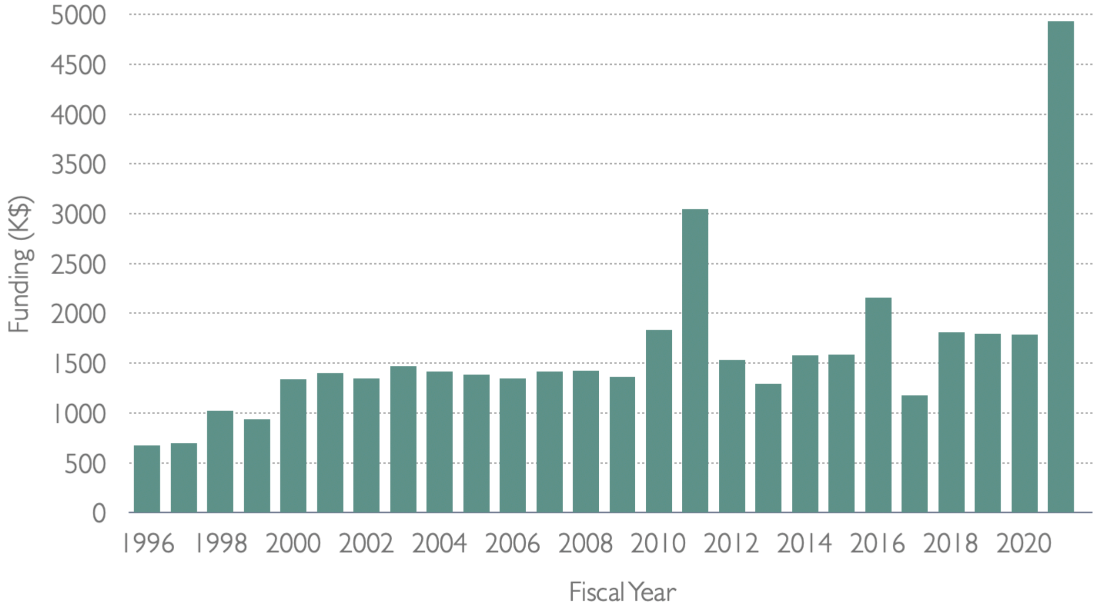

Figure 1: Total amount of external funding (in thousands of dollars) obtained by INPP faculty inclusive from FY 1996 to FY 2021 (until June 2021). An additional $2.3M was received in the first half of FY 2022 (July to December 2021).

of our then newly-hired faculty members (Frantz, King, and Roche) being successful in grant applications and the additional availability of federal research money through the American Recovery and Re-investment Act (ARRA). The average funding level increased starting in 2016 in-part due to successful grant applications of newly hired faculty member Meisel. Since 2010 we have on average, maintained a healthy level of over $1.5M/year. FY 2021 saw a significant boost of funding thanks to the $2.8M NSF support to cover the Bayesian analysis of nuclear dynamics (BAND) collaboration led by Professor Phillips. For FY 2021, INPP received a total of $4.9M, which is about 30% of the FY21 CAS's federal grant income.

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 five years was roughly $150K per year. Table 1 shows a breakdown of projected INPP expenditures for FY22. While the particular expenditures change from year-to-year the balance between different activities (conference support, grant matching, postdocs, staff support, etc.) is quite typical. Senior personnel expenses constitute a large portion of the budget; some years CAS provides support for these line items. For example, in summer 2020, CAS eliminated grant administration support, and INPP had to start bearing the cost of this vital need by itself.

In a typical year, INPP spends less than its generated revenues. The remainder is saved for spending on non-recurring and expansion projects. INPP's ability to provide matching and to bridge funding for faculty has been key to our success. For example, INPP is will provide $70k toward the startup fund of the 2022 FRIB-bridge hire. Similarly, the NSF's

Carter's support (engineering)	[redacted]
King's support (research)	[redacted]
Goettge's support (financial)	[redacted]
Glidden Professor's support	[redacted]
Undergraduate research support	[redacted]
Graduate research support	[redacted]
EAL 50th support	[redacted]
Seminars	[redacted]
Journal Club	[redacted]
TOTAL	$127,000

Table 1: FY2022 projected INPP expenditures. Carter is one of the EAL engineer. Goettge is our grant financial specialist.

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 U's contribution to MRI projects. This, in turn, facilitates the hardware contributions necessary for membership in some large experimental collaborations. INPP also assisted with the salary of approximately one postdoctoral researcher a year to leverage bigger external grants. 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.

5 2019 Strategic Plan

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, to leverage 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 to ensure we have a strong group of research and tenure-track faculty.

Specifically, in 2019, at the request of the Physics and Astronomy department Chair Ingram, INPP prepared a strategic plan. The conclusions of this planning exercise are copied below. They articulate the thinking of our group both in terms of hiring - Ingram had asked for this special focus- and in terms of the role of INPP in the Physics and Astronomy department. Updates on these 2019 conclusions are italicized. The whole 2019 INPP Strategic plan is available upon request.

The INPP's position is strong. We have faculty doing forefront research across a broad range of nuclear-physics sub-fields. We play an important role in the education of undergraduates in the Department of Physics & Astronomy. And we contribute significantly to Ph.D. and scholarly production within the Department and the College of Arts & Sciences.

Continued strength over the next decade thus involves the following points, which are not listed in order of priority:

- Prakash and Elster will both retire within that time frame. For a nationally visible effort in nuclear theory, the minimum number of faculty is two, so at least one hire in nuclear theory is essential. The theory group's national reputation and good connections to different aspects of INPP's experimental work, together with continued investment by agencies in nuclear theory, mean there are several good options for such hiring. *The FRIB bridge position which search is taking place in the Spring of 2022 is fulfilling this point.*

- The Institute's effort in QCD research faces challenges and opportunities. King's position must be stabilized through funding from INPP, JLab, and other sources. The construction of the Electron-Ion Collider will allow the successful JLab and RHIC groups to form a cohesive, high-impact effort there. Adding another experimentalist to this group would establish a prominent OHIO U's presence at the EIC.

- The on-campus Edwards Accelerator Laboratory plays a key role in INPP's current research. The research performed there in basic nuclear physics and astrophysics has an excellent reputation and is well-funded. Maintaining the strong operation of the facility is a high priority.

- The EAL's capabilities for neutron science mean we are well-positioned to perform measurements that are of interest to applied communities. Several opportunities exist, e.g., in neutron imaging, medical applications, and cross-sections for nuclear-data needs. The development of novel materials with accelerator techniques is an intriguing possibility that could mesh well with expertise in NQPI. Hiring a scientist who uses the Edwards Accelerator Lab to address questions within this very broad space would provide good funding opportunities and ensure thorough utilization of the accelerator.

- Hiring Zach Meisel produced a notable upswing in the visibility and funding of INPP's work in nuclear structure, reactions, and astrophysics. This area could be strengthened still further. FRIB is expected to provide funding for bridge positions as it seeks to develop a sizable external user community. Many Ph.D. students graduating in this area and federal funding is expected to continue to be robust.

- Continued University and INPP support for the accelerator's technical staff is a crucial element of our plans. Managing the anticipated transition from the current two staff to two new staff members is critical. A bridging plan to begin that transition has in-principle approval from the college but will need to be managed carefully in the current budget environment. *Engineer Leblanc was hired in the Fall of 2020 to replace Engineer Jacobs who retired in December 2020 after a six-month notice. While the overlap between them was not optimal, some overlap happened and INPP members are grateful for the help CAS provided for this replacement including administrative support and the flexibility with salary.*

- INPP faculty teach upper-level undergraduate and graduate laboratory classes, a biennial graduate nuclear-physics sequence, and elective graduate classes on advanced topics. We organize seminars and a journal club, supervise undergraduate researchers, and mentor graduate students. We will continue our efforts to give students an excellent education in nuclear physics.

- We value the OHIO U. community and the nuclear-physics community and so participate vigorously in University and national committees. We will continue to provide service and leadership in these contexts.

- The Department's machine shop and the grant-management support provided by Julie Goettge are essential to INPP's operations. *In summer 2020, Julie Goettge's position was terminated. Given the importance of this position and the drastic reduction of support staff in the CAS centralized model, INPP decided to fund that position.*

- We support a timely hire in the Astrophysical Institute. Good intellectual overlap and a vigorous connection between the two institutes benefits the Department.

6 Conclusion

In summary, the INPP has managed to expand its funding and productivity level over the past five years while navigating a drastically changing landscape at the College of Arts and Sciences. In some cases, like personnel hiring, the new centralized systems are working well. Purchasing and post-grant management remain a worrisome degradation of our ability to perform competitive and efficient research at this R1 institution. Acting as a coherent and well-disciplined group, INPP researchers have formulated a 10-year strategic plan and are preparing for a promising future. The retirement of some of our most senior colleagues has been anticipated. The local Edwards Accelerator Laboratory has been upgraded. New off-campus collaborations started (e.g. at FRIB, at the EIC, and with the BAND collaboration).

A Graduate Students

This section summarizes INPP activities related to graduate students. The following pages show (a) the list of graduate students currently working with INPP faculty members, (2) the vitality of the INPP graduate research seminar, (3) the list of students who graduated during the reporting period (2017 to 2021) and (4) a list a selected previous INPP graduates.

Spring 2022 Graduate students

Name	Advisor	Research Topic
Ibrahim Alnamlah	Phillips	Effective Field Theory treatment of rotational bands
Kristyn Brandenburg	Meisel	Cross sections for supernova nucleosynthesis
Justin Bryan	Frantz	Au+Au Dijet Angular Correlations
Bikash Chauhan	Brune	TBD
Shyam Chauhan	Frantz	Cu+Au Dijet Angular Correlations
Joseph Derkin	Brune	n+^{16}O scattering at the EAL
Gula Hamad	Meisel	α-n astrophysical measurements at the EAL
Yenuel Jones-Alberty	Brune	p+^{10}Be reactions at the EAL
Bradley McClung	Elster	SRG transformations in nucleon-nucleus elastic scattering
Jacob Murphy	Roche	Internal structure of the nucleon
Maheshwor Poudel	Phillips	Effective field theory applied to solar-fusion reactions
Robert Radloff	King	Parity violation in electron scattering
Alexandra Semposki	Phillips	Nuclear-physics applications of Bayesian Model Mixing
Nisha Singh	Meisel	TBD
Pramita Tiwari	Roche	Internal structure of the nucleon
Justin Warren	Brune	n+^{35}Cl reactions at the EAL

Enrollment in PHYS 8501

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[3], 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.

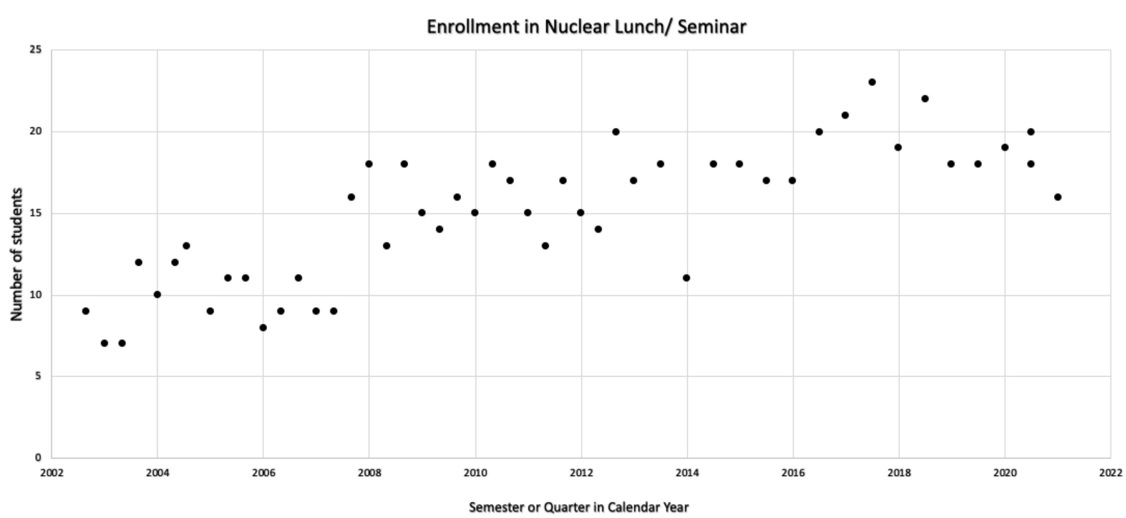

Figure 2: Enrollment in PHYS 897A and PHYS 8501 since the inception of "Nuclear Lunch" in the Fall Quarter of 2002.

[3] Theory faculty have been relocated to Bentley Hall during the renovation of Clippinger Labs.

INPP Ph.D. Graduates, 2017–2021

Name	Ph.D.	Advisor	Current Position
Arbin Thapaliya	2017	Phillips	Asst. Prof., Franklin U.
Nick Compton	2017	Hicks	Mathematician, King Show Games
Nadyah Alanzi	2018	Voinov	Asst. Prof. King Saud U. Riyadh, Saudi Arabia
Mongi Dlamini	2018	Roche	Lecturer, U. of Eswatini, Eswatini
Abinash Pun	2018	Frantz	Postdoc, New Mexico State U.
Andrea Richard	2018	Crawford & Brune	Postdoc, LLNL
M. Abdullah Al Mamun	2019	Prakash	Intel, USA
Taya Chetry	2019	Hicks	Postdoc, Mississippi State University
Tyler Danley	2019	Frantz	Operations Research Analyst at United States Air Force
Rekam Giri	2019	Brune	Instructor, Holmes Comm. College
Sudhanva Lalit	2019	Prakash	Postdoc, OHIO U./Michigan State U.
Matt Burrows	2020	Elster	Postdoc, Louisiana State U.
Bishnu Karki	2020	Roche	Postdoc, Duke U.
Som Paneru	2020	Brune	Postdoc, Michigan State U.
Joseph Rowley	2021	Hicks	Data Analyst, Private sector
Ustav Shrestha	2021	Hicks	Postdoc, U. of Connecticut
Doug Soltesz	2021	Meisel	Medical Physics Trainee, U. Victoria
Shiv Subedi	2021	Meisel	Scientist, Canon Medical

INPP Master Graduates, 2017–2021

Masters Degrees with Thesis, 2017–2021

Name	Date	Advisor	Current Position
Kristyn Brandenburg	2017	Meisel	Ph.D. student, P&A, OHIO U.
Justin Bryan	2021	Frantz	Ph.D. student, P&A, OHIO U.
Gula Hamad	2017	Roche	Ph.D. student, P&A, OHIO U.
(Md M) Hassan Anik	2018	King	Ph.D. student, P&A, University of Tennessee, Knoxville
Robert Radloff	2018	King	Ph.D. student, P&A, OHIO U.
Cole Raisbeck	2018	Frantz	Working in Industry
Joseph Rowley	2018	Hicks	Data Analysis, Private sector
Irin Sultana	2019	Meisel	Ph.D. student, Central Michigan U.
Yenuel Jones-Alberty	2019	Brune	Ph.D. student, P&A, OHIO U.
Joseph Derkin	2020	Brune	Ph.D. student, P&A, OHIO U.
Justin Warren	2021	Brune	Ph.D. student, P&A, OHIO U.

Masters Degrees with Project, 2017–2021

Name	Date	Advisor	Current Position
Shiv Subedi	2017	Meisel	Scientist, Canon Medical
Ibrahim Alnamlah	2018	Phillips	Ph.D. student, P&A, OHIO U.
Mahesh Poudel	2018	Phillips	Ph.D. student, P&A, OHIO U.
Shyam Chauhan	2019	Frantz	Ph.D. student, P&A, OHIO U.
Jacob Murphy	2020	Roche	Ph.D. student, P&A, OHIO U.
Alexandra Semposki	2021	Phillips	Ph.D. student, P&A, OHIO U.
Nisha Singh	2021	Meisel	Ph.D. student, P&A, OHIO U.

Selected Previous INPP Graduates

Name	Ph.D.	Advisor	Current Position
Brian Muccioli	2016	Prakash	Software developer in Boston, MA
Cody Parker	2016	Brune	Postdoc, Texas A&M U.
Bijaya Acharya	2015	Phillips	Fermilab Neutrino Theory Network Fellow, Oak Ridge National Laboratory
Nowo Riveli	2014	Frantz	Asst. Prof., U. Padjadjaran, Indonesia
Rakitha Beminiwattha	2013	Roche	Asst. Prof., Louisiana Tech U.
Youngshin Byun	2013	Grimes/ Voinov	High school teacher, South Korea
Kevin Cooper	2013	Ingram	Asst. Prof., Lincoln Memorial U., TN
Dustin Keller	2010	Hicks	Asst. Research Prof., U. of Virginia
Christopher Bade	2006	Hicks	Officer in the U.S. Navy
Deepshikha Choudhury	2006	Phillips	Dean, College of Science, Math and Nursing; Rockford U.
Catalin Matei	2006	Brune	Research Scientist, ELI, Bucharest, Romania
Ishaq Hleiqawi	2006	Hicks	Asst. Prof., King Faisal U., Saudi Arabia
Hang Liu	2005	Elster	Research Assoc., Texas Advanced Computer Center
Yannis Parpottas	2004	Grimes	Assoc. Prof., Frederick U., Cyprus
Asghar Kayani	2003	Ingram	Prof., Western Michigan U.
Chen-Hu Chang	2000	Wright	Software Engineer (Bradley Corp.)
Cheri Hautala	1999	Rapaport	Science Specialist (Washington DC)
Steven Weppner	1997	Elster	Prof., Eckard College, FL
Kyungsik Kim	1996	Wright	Asst. Prof. (Korea)
Hong Zhang	1995	Hicks	Computer Programmer
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
Nourridine Boukharouba	1992	Grimes	Assoc. Prof., Guelma, Algeria

B Undergraduate Research Participation

Name	Period	Advisor	Current Position
Kevin Boyd	Su. 2018	Roche	Graduate student, U. of Illinois
Matt Brooks	2018	Meisel	Software Developer, Applied Technologies
Sam Carryer	Su. 2021	King	OHIO U. undergraduate
Nathan Carter	Su. 2021	Popa	OHIO U. undergraduate
Miranda Carver	2018 - 2020	Hicks	Physicist, Crane Naval Support Activity
Matthew Connell	2019 - 2021	Phillips/ Brune	Graduate student, University of Maryland
Evan Conner	Su. 2019	Roche	In the workforce, applying to grad school
William Eshbaugh	Su. 2018 & Su. 2020	Roche/ King	Graduate student, West Virginia U.
Ryan Frontz	Su. 2019-20	Frantz	OHIO U undergraduate
Sam Hanson	Su. 2017	Frantz	High School Science Teacher
Greta Hibbard	Sp. 2022 - present	Voinov	OHIO U. undergraduate
Casey Ann Horvath	Sp. 2022 - present	Brune	OHIO U. undergraduate
Michael Ickes	2019-2021	Brune	OHIO U. undergraduate
Lyric Jones	Sp. 2019	Roche	OHIO U. undergraduate
Britney Kenady	Su. 2018 - Sp. 2021	Brune	Software engineer
Sofia Medvid	2017-2019	Meisel	Software Engineer at Radiance Technologies
Grant Merz	2017-2019	Meisel	OHIO U. graduate student
Alex Nemeneck	Fa. 2021 - present	Roche	OHIO U. undergraduate
Sandro Nuakey	Su. 2021	Roche	OHIO U. undergraduate
Riley Reedy	Su. 2017	Brune	OHIO U. undergraduate
Michael Riehl	Su. 2019-21	Frantz	OHIO U undergraduate
Graham Tupper	Su. 2018 - Sp. 2019	Elster	MS student Appalachian State University in NC
Michael Vallee	Su. 2018 & Su. 2019	King	Graduate student OHIO U.
Kevin Ward	Su. 2020	Hicks	Risk Analyst at Lockton Companies
Alexandra Semposki	Su. 2019-2020	Prakash	OHIO U. graduate student
Justin Warren	Su. 2017-2018	Brune	Ohio U. graduate student

The list of web-links below compiles a selection of large audience articles on the Experiential Learning Opportunity offered by INPP researchers:

- William Eshbaugh:Testing HV dividers for experiment E12-13-010 at Jefferson National Lab
- Miranda Carver: Analyzing Particle Physics at Italy's National Institute of Nuclear Physics
- Grant Merz: Simulating nuclear explosions on neutron stars
- Brittney Kenady Studying the efficiency of an NE213 Neutron Detector

C Postdoctoral Researchers

Name	date	Area	Current Position
Jin Lei	2016–19	N Theory	Asst. Prof., Tongji U., Shanghai
Rodrigo Navarro-Perez	2017-18	N Theory	Asst. Prof., San Diego State U.
Sophia Han	2019-21	N Theory	Asst. Prof at Shanghai U.
Robert Baker	2019-present	N Theory	Postdoc at OHIO U.
Daniel Odell	2019-present	N Theory	Postdoc at OHIO U.
Mansi Saxena	2019-present	LE Exp.	Postdoc at OHIO U.
Caleb Marshall	2020-present	LE Exp.	Postdoc at OHIO U.
Bing Xia	2020-2021	ME Exp.	
Tianqi Zhao	2021-present	N Theory	Postdoc at OHIO U.

D 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 U. on a person-to-person basis. In addition, these visits allow scientists to get to know the INPP and OHIO U. 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 U.. 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:

- Gleb Fedotov*, Fall 2017 – Spring 2018, Physicist, Moscow State University
- Andreas Nogga*, Fall 2017 – Spring 2018, Staff Scientist of the Institute for Nuclear Physics at the Jülich Research Center, Germany, CAS Forum article
- Constantinos Constantinou, 2018-19, Currently senior Postdoc at ECT*, Trento, Italy
- Adam Fritsch,* Fall 2021 – Spring 2022, Associate professor of physics at Gonzaga University, CAS Forum article

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 G.

E 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 U. 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 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 and 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**, **Rekam Giri** (Ph.D. 2019) has completed his Ph.D. dissertation thesis on a direct measurement of the $^{12}\mathrm{C}(\alpha,\gamma)^{16}\mathrm{O}$ reaction at TRIUMF (Canada's national laboratory for nuclear and particle physics located in Vancouver, BC). Another student **Som Paneru** (Ph.D. 2020) has studied $^{3}\mathrm{he} + {}^{4}\mathrm{He}$ scattering at TRIUMF in order to better understand the generation of neutrinos by our sun. Brune's other current nuclear astrophysics experiments include studies of reactions on the rare isotope Be^{10} and measurements to better understand the $^{13}\mathrm{C}(\alpha,n)$ reaction rate, and working with **Zach Meisel** and postdoc **Caleb Marshall** on the first science experiments with the SECAR recoil separator at FRIB. He is also collaborating with **Daniel Phillips** and postdoc **Daniel Odell** on the phenomenological analysis of nuclear reactions, a research area that lies at the interface between theory and experiment.

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. Primary areas of research involve nuclear physics of compact objects in the universe and their formation. Major efforts include studying the properties of proton-rich nuclei for X-ray bursts on neutron stars, e.g. with students **Doug Soltesz** (PhD 2021) and **Irin Sultana** (MS 2019); and identifying and reducing important nuclear physics uncertainties for core-collapse supernovae, e.g. with **Shiv Subedi** (PhD 2021) and **Kristyn Brandenburg** (MS 2017, current PhD student). These efforts have also involved postdoctoral research associates **Mansi Saxena** (since 2019) and **Caleb Marshall** (since 2021), where Caleb is stationed at the Facility for Rare Isotope Beams. **Caleb Marshall** has played a significant role in the commissioning and first science measurements with the SECAR recoil separator, which is a flagship nuclear astrophysics device at the Facility for Rare Isotope Beams.

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 the 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 $^{54-58}\mathrm{Fe}(\alpha, \mathrm{n})$, $^{68,70}\mathrm{Zn}(^{7}\mathrm{Li}, \mathrm{p})^{74,76}\mathrm{Ge}$, and $^{48}\mathrm{Ca}(^{11}\mathrm{B}, \mathrm{n/p}/\alpha)$. One student has completed PhD degrees with research in this area. **Nadya Alanazi** (Ph.D. 2018) has examined the angular distribution of neutrons from α induced reactions on iron isotopes to study the spin distribution of levels in nickel nuclei. It was found that the spin cutoff parameter determining the spin distribution is lower than predicted by the commonly used rigid body model at excitation energies below the neutron separation energy. The rotational enhancement factor for the level density has been studied theoretically for deformed nuclei by Prof. S. Grimes. Studies conclude that the rotational enhancement factor should be taken into account when the spin cutoff parameter for deformed nuclei is calculated. The level density of the $^{74,76}\mathrm{Ge}$ nuclei has been studied and found to be lower than predicted by commonly used level density models. Efforts on understanding this feature are currently in progress. The isovector neutron optical potential has been studied for the neutron-rich $^{59}\mathrm{Mn}$ nucleus from the $^{48}\mathrm{Ca}(^{11}\mathrm{B}, \mathrm{n/p}/\alpha)$ reaction. From examining the ratio of proton to neutron and α to neutron cross-sections, the isovector imaginary optical potential was found to be bigger than predicted by current models. This finding indicates the importance of the neutron isovector imaginary optical for nuclei away from the stability line. It might have a substantial impact on neutron capture reaction rates in astrophysical r-process nucleosynthesis.

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 neutron detection array, which is a key device at NSCL/FRIB. Additionally, Massey is leading an effort to re-evaluate the $^{10}B(n, Z)$ 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 $^{10}B + n$ 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 $^{10}B(n, Z)$ cross-section data.

Several studies within the INPP low-energy nuclear physics are in the category of applied nuclear physics. This includes efforts to improve the modeling of future nuclear reactors and internal confinement fusion. **Carl Brune** and **Tom Massey** are working with graduate students to measure the cross section for neutrons interacting with ^{35}Cl, which is important for the design of molten-salt reactors. These reactors have several advantages of traditional water-cooled reactors and are seriously being considered for future power generation applications. **Brune** and **Alexander Voinov** study 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).

David Ingram uses the facilities in the Edwards Accelerator Laboratory for the analysis of materials and occasionally the modification of materials. He specializes in the analysis and modification of optoelectronic, spintronic, magnetic, and superconducting materials. He has published 22 papers since 2016 in collaboration with faculty and students at Ohio University in the departments of Physics & Astronomy, Chemistry & Biochemistry, Electrical Engineering and Computer Science, Mechanical Engineering, and Chemical Engineering, as well as collaborators at John Hopkins University, University of Illinois, Yale University, Brookhaven National Laboratory, and international collaborators in Canada, France, Spain, Luxembourg, and China.

Research in low-energy nuclear physics experiments within the INPP also includes active collaboration with several outside groups that come to OHIO U. 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 several neutron detector calibrations in separate collaborations with Purdue University (2017), Oak Ridge National Laboratory (2018), and the University of Tennessee (2019); radiation damage tests of space-based x-ray detectors with Penn State University (2018-19); nuclear astrophysics cross section measurements in separate collaborations with Notre Dame (2017), Central Michigan University (2018, 2021), and Texas A&M University (2020); sample irradiations for applications by the Air Force Institute of Technology (2018-19); and neutron science measurements in collaboration with Lawrence Livermore National Laboratory (2017 and 2021).

Medium- and High-Energy Experimental Nuclear Physics

Research in medium energy at OHIO U. focuses on the understanding of hadronic matter made up of quarks and gluons. This type of matter represents over 90% of the visible mass of the universe and its dynamics are governed by Quantum Chromodynamics (QCD). While the fundamental laws of QCD are elegant, concise, and firmly established, understanding the composite structure of matter resulting from them is still incomplete. The INPP experimental program aims at answering the following 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 have been framed as overarching questions central to nuclear physics in the 2013 report of the National Research Council report titled *Assessment of and Outlook for Nuclear Physics titled Nuclear Physics: Exploring the Heart of Matter*. At the INPP, five faculty members and their students are experimenting to further this understanding. Professor K. Hicks started at OHIO U. in 1988 and will retire in May 2022. Associate Professor Frantz, Associate Research Professor King, and Professor Roche were hired around 2007. Prof. Djalali started in Fall 2020, coming to the INPP from his former position as Provost and following a semester of Faculty Fellowship Leave.

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 particle called a tetraquark (made from two quarks and two antiquarks), and other particles with quark structure beyond the standard quark model arrangements. Most of this research is carried out at Thomas Jefferson National Accelerator Lab (JLab).

Hicks' students and postdocs have made several contributions to the scientific literature during the time of this review. Graduate student **Nick Compton** received his Ph.D. in 2017, after publishing two landmark papers on photoproduction of the Lambda particle (similar to the neutron, except one down quark is replaced by a strange quark) from the neutron, the first statistically significant data of this reaction. Nick continues to work with Hicks on the analysis of data from the CLAS detector at JLab, even though this is not part of his current (private sector) job. Graduate student **Taya Chetry** received his Ph.D. in 2018, after publishing a paper in the journal Physics Letters B on coherent vector-meson photoproduction from a deuteron target. He took a postdoc position at Mississippi State, where he continues to work on a variety of activities (analysis, calibration, new software, etc.) for the CLAS detector. He is now on the shortlist for several possible permanent positions. Graduate student **Utsav Shrestha** received his Ph.D. in 2020 and published an archival paper in the journal Physical Review C on the topic of photoproduction of a resonant state of the Lambda particle. This result extended measurements at lower energy and paved the way for studying several higher-energy resonant states of the Lambda. Graduate student **Joey Rowley** defended his Ph.D. in 2021, after receiving an MS degree in 2018 while working with Hicks. Joey's Ph.D. results were recently published in the prestigious journal Physical Review Letters on the topic of Lambda-proton scattering, which is the first data on this reaction since the 1970s when bubble-chamber technology was used for high-energy scattering reactions. This letter has important consequences for calculations relevant to the structure of neutron stars, where Lambda particles are predicted at the huge pressures at the center of neutron stars. In addition to research with graduate students, Hicks has also worked with two undergraduate students, **Miranda Carver** and **Kevin Ward**, and published papers in professional journals based on their research. Of special note is the publication by Miranda, where she was the first author, in the journal Physical Review Letters, on the topic of the so-called f1 meson, which was predicted by competing theoretical models to have either a standard meson (diquark) or an exotic tetraquark structure. Miranda's data clearly showed that the f1 has a structure consistent with the standard meson model, which places significant limits on the theoretical models of tetraquarks. Needless to say, it is very unusual (and noteworthy) that an undergraduate student would be the first author on a paper in Physical Review Letters.

The future of the research group led by Hicks will take advantage of the energy-doubling upgrade of JLab, which started taking data in the fall of 2017. Hicks was asked to Chair a committee for the CLAS Collaboration called the ACE (Analysis Committee of Experts) which has an important role in 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. Data from the clas12 detector is expected to provide a wealth of information about how QCD confines quarks inside the proton. However, Hicks has had to step away from research at the DOE-funded JLab, due to his current position as a Program Manager in the Office of Nuclear Physics at DOE. Hence, he will not be part of the clas12 program, but he has permission to complete existing analysis projects from the older CLAS detector's data.

The research program of **Chaden Djalali** focuses on the study of Hadron Spectroscopy as well as Medium Effects with the CLAS12 Collaboration at JLab. He is currently helping with the analysis of the RGA experimental program looking at inclusive electron scattering observables in the resonance region as well as exclusive K-$\Lambda(1520)$; ω, ρ and ϕ electroproduction. He is also involved in the analysis of CLAS 6 GeV data using secondary beams of particles (Lambda, n, p, d, etc..) produced in photo-production reactions on large targets (g12, g13 experimental runs) using the techniques and methods developed by OHIO U./INPP graduate student **Rowley**.
He is also involved with two collaborations at J-PARC in Japan. The TREK collaboration E36 experiment main goal is to test Lepton Universality by careful measurement of kaons

decay channels. The data analysis is in its final stages and will lead to several publications. He is also involved with UCONN and Lamar University in the US-Japan Hadronic Physics exchange program and preparing to run the E45 experiment which will use the complementary tool of pion beams to study the inner structure of protons. The E45 data will complement the electron scattering data allowing a full study of the space-like and time-like electromagnetic baryonic resonances.

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. The base research program of Roche and King has been continually funded by NSF since 2007. These base awards cover travel expenses, students' wages, and summer salaries. Their current NSF award ends in September 2022; they have an NSF proposal out for review aiming to start in the Fall of 2022. In addition to this support, Roche received a $0.1M MRI award for the procurement of a new detector from 2015 to 2019. Similarly, King is receiving a $1.0M MRI funding for the procurement of another detector from 2021 to 2025.

The goal of Deep Exclusive Reaction 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 coordinates 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 analysis of experiment E12-06-114, the data taking of experiment E12-19-006, and the preparation of E12-13-010 (MRI award). Over the past five years, they worked with three Ph.D. students (**Dlamini** and **Karki** defended their dissertations during the reporting period), two M.S. students (**Hamad** defended her thesis during the reporting period) and seven undergraduate summer interns on this part of their program. During the reporting period, the group published 5 papers (2 in the Nature Publication family) on the GPD topic.

Parity violating electron scattering (PVES) probes the role of the weak nuclear force in subatomic interactions. **King** has been a major contributor to the JLab PVES experiments in Hall A & C, focusing on data acquisition and analysis for the QWEAK, PREX-II, CREX, and MOLLER experiments. King was the data acquisition lead and the Analysis Coordinator for the QWEAK experiment and served in similar roles for the PREX-II and CREX experiments. On the MOLLER project, King is the L2 Technical Lead for data acquisition and is a co-PI on the Mid-Scale Award from the NSF to construct the detectors and instrumentation for the experiment ($1.0M awarded to OHIO U.). PVES measurements of electron-proton and electron-electron elastic scattering test the precise Standard Model predictions of the electro-weak properties of the particles and are sensitive to possible "new physics" with a mass-scale reach comparable or higher than the LHC. The QWEAK and MOLLER experiments are two such Beyond the Standard Model tests on the proton and electron respectively; QWEAK has been completing the analysis over this reporting period, and MOLLER is now starting the construction of the apparatus. Neutrons have a much larger weak coupling than protons, so PVES electron-nucleus measurements are sensitive to the radius of the neutron distribution in large nuclei, yielding insight into the properties of nuclear matter and the properties of neutron stars. The PREX-II and CREX experiments ran during this reporting period, and have largely completed the analysis. Over the past five years, three undergraduate students had summer internships on this topic (one of the three had internships in two years). The group also had three master's students (**Anik** and **Radloff** both defended their M.S. theses during the reporting period), and currently has one student working on their Ph.D. on this topic. Five papers from the QWEAK and PREX-II experiments were published (one of them in *Nature*) during the reporting period. The MOLLER project has passed the DOE CD-1 review and is anticipating a combined CD-2/3 review soon. MOLLER anticipates the conclusion of construction and the start of the multi-year experimental data collection period in about 2025.

Justin Frantz's main research interest in the past 5 years has been 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 2018/2019 he graduated two Ph.D. students (**Tyler Danley/Abinash Pun**): both performed PHENIX data analyses related to the correlations produced by certain processes involving photons and jets. Frantz also has a history of interest and expertise in the main detectors for making these measurements on PHENIX and other experiments, calorimeter detectors, especially Electromagnetic calorimeters.

Presently PHENIX is being replaced with a new collaboration and experiment at RHIC called sPHENIX which exists independently from PHENIX but aims to re-use certain aspects of PHENIX along with a large new detector. sPHENIX will have more precision than PHENIX and is scheduled to start in early 2023. So the bulk of Frantz's research has recently switched to sPHENIX. Frantz was named sPHENIX Calorimeter Calibrations Coordinator in 2021, having acted in that role for a year previous. This position encompasses primarily the calibrations software but also involves some DAQ and hardware systems for both of the key core calorimeter detectors (Hcal and EMCal) which are the heart of sPHENIX. Frantz's group also provides key technique development and software implementation in these roles, through which they have provided several innovations which have significantly improved the expected sPHENIX calorimeter calibrations. With the arrival of the first sPHENIX data, Frantz's group will continue its leadership in the same kind of measurements as on PHENIX but focusing on the even better photon-detection capabilities in the measurements of isolated "prompt" photon spectra. These should NOT be modified by the QGP, whereas later in the certain collision types, there have been non-QGP modifications detected that sPHENIX's may allow the study of. A few-year collaboration in the ATLAS experiment at the LHC which ended in 2017-18, allowed Frantz to learn new techniques in the isolated photon measurements which his group will apply on sPHENIX.

One of the expected physics effects causing the non-QGP effects for prompt photons leads to the last area that Frantz was recently active in researching for most of 2021. Gluon saturation is a long-predicted sub-state of nucleon structure. Its presence can affect the before-mentioned photon production but also is expected to exhibit measurable effects in a new research interest area of Frantz, called Diffractive or Deeply Exclusive production of mesons. These are medium-to-high energy scattering events where the energy is transferred completely through intermediaries emitted by both of the two incoming particles, which themselves remain largely unmodified. A recently approved new facility that RHIC will be transformed into within the next decade is called the Electron-Ion Collider (EIC). In 2021 Frantz joined forces with Ohio U colleague Julie Roche to collaborate as the first steps to an INPP opportunity at the EIC (see below). The main focus was another new experiment for Frantz and Roche, the ECCE Detector which was proposed to potentially reuse some parts of sPHENIX. Frantz's work focused on showing that ECCE and EIC detectors, in general, should be able to detect Gluon Saturation through the Diffractive production of the ϕ mesons. Frantz intends to continue studying the feasibility and requirements (especially on electron and other calorimetry) of making this measurement at the EIC no matter which detector concept is chosen.

Long-term opportunity Every seven years or so, the USA nuclear physics community at large produces a Long Range Plan that describes its long-term priorities. In the 2015 version of this Long Range Plan, the community recommended "a high-energy high-luminosity polarized EIC as the highest priority for a new facility construction following the completion of FRIB". The scientific goals of this Electron-Ion Collider (EIC) were endorsed by the National Academies of Sciences, Engineering, and Medicine in the summer of 2018. The collider will unite the present QCD programs at JLab and RHIC in a single facility. The fundamental issues explored by the EIC include the origin of the mass of atomic nuclei, the origin of the spin of neutrons and protons, how gluons hold nuclei together, and how dense gluon matter evolves both inside and outside nuclei. The research programs of Frantz, King, and Roche are well aligned with the goals of the EIC and they plan to use this facility. For example, King and Roche's programs on the internal structure of the proton have a natural and well-documented extension at the EIC. Components of the sPHENIX detector, especially its magnet, are expected to be reused for the EIC, which will provide Frantz a natural path into the corresponding EIC collaboration. Also, over the next 10 years, Frantz plans to join the growing community studying "ultra-peripheral" Au+Au collisions at RHIC, the physics of which is also a pre-cursor to EIC physics and straightforwardly connected to the nucleon structure research of Roche.

In the Fall of 2019, the US Department of Energy chose RHIC to be the site of the future EIC. Researchers are currently planning for the start of operation at the earliest in 2030. Frantz, King, and Roche are ideally placed to take advantage of their existing ties to the RHIC facility. In the summer of 2021, Frantz and Roche joined one of the three detector proposals for the EIC. The ECCE consortium (https://www.ecce-eic.org/) is comprised of 96 international institutions assembled around the idea of developing a detector to be used at the upcoming Electron-Ion Collider. In December 2021, the consortium submitted a proposal to the US Department of Energy for a $250M detector. There are two other proposals; only one proposal will be funded. The working group Roche co-chaired and in which Frantz was a major contributor estimated the results that can be obtained from Deep Exclusive Reactions with the ECCE detector.

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 postdoctoral researcher, and the full salary of three Ph.D. students. This DOE grant was renewed at the end of 2019.

The research of **Charlotte Elster** is primarily concerned with theoretical studies of scattering and reactions of light nuclei. Between 2015 and 2018 Elster and F. Nunes (Michigan State University) were PIs on a collaborative grant from the National Science Foundation to develop a computational approach for solving calculating (d,p) reactions for nuclei with masses larger than A=20 based on a momentum space three-body approach. This grant funded a postdoctoral researcher at OHIO U. (Dr. Jin Lei).

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 10 protons.

An essential ingredient of nuclear reaction calculations is 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 database, it is desirable to derive them from the underlying interaction between the nucleons in the nucleus, i.e. in an *ab initio* framework. Elster together with collaborators at Iowa State and Louisiana State University and graduate student **Matt Burrows** developed the theoretical and computational framework to obtain effective interactions for proton- and neutron-nucleus scattering in the leading order of the spectator expansion of multiple scattering theory in an *ab initio* fashion. That means that the only ingredient for the effective nucleon-nucleus interaction is the force between neutrons and protons.

To facilitate this, an important step is obtaining a translationally invariant, fully off-shell one-body nuclear density matrix from the *ab initio* structure calculations of our collaborators from Iowa State and Louisiana State University. Those structure calculations are traditionally carried out in a fixed frame, thus the first important step was removing the center-of-mass motion inherent in those calculations. Another equally important step is taking into account the spin of the struck nucleon in the target. This step is essential making the effective nucleon-nucleus interaction truly *ab initio* in the sense that the force between neutrons and protons is treated on the footing in the structure as well as reaction calculation. It should be pointed out, that our work is the first and still the only one, in which this is carried out consistently. Postdoctoral researcher Dr. Robert Baker joined this effort in 2020.

The nucleon-nucleon forces on which we base the leading order effective nucleon-nucleus interaction are rooted in chiral effective field theory, and as such a diagrammatic expansion. The effect of truncation errors in the chiral effective theory on two- and three-nucleon observables as well as ground- and excited states of light nuclei were studied. We extended those studies to proton-nucleus scattering observables to gain an understanding of the effect of a diagrammatic expansion of the two-nucleon force influences elastic scattering of protons (neutrons) off light nuclei.

Daniel Phillips co-founded the BUQEYE (Bayesian Uncertainty Quantification: Errors for your Effective Field Theory) collaboration in 2014, together with Dick Furnstahl (Ohio State). During the reporting period Phillips and his BUQEYE collaborators:

- Demonstrated that Bayesian methods improve parameter estimation in effective field theories. The technology developed by Phillips, Furnstahl, and other BUQEYE collaborators Wesolowski and Melendez, was applied in the Ph.D. thesis of INPP student **Ibrahim Alnamlah**.
- Developed an approach—based on Gaussian Processes—to account for correlations in EFT uncertainties across input variables such as momentum.
- Applied this approach to correlated errors to the estimation of EFT uncertainties in the nuclear- and neutron-matter equations of state. The latter work yielded a publication in *Physical Review Letters*.

Phillips also began collaborating with Carl Brune on the application of Bayesian methods to R-matrix analysis. This research was funded by the National Nuclear Security Administration and helped bring postdoc Daniel Odell to OHIO U. Odell, Brune, and Phillips showed how Bayesian methods improved the evaluation of the S-factor for the dt fusion reaction. Odell also developed a Bayesian wrapper for the AZURE2 R-matrix code, working in collaboration with James deBoer (Notre Dame). Odell, deBoer, Brune, Phillips, and Brune's former Ph.D. student Som Paneru, then applied the resulting Bayesian R-matrix Inference Code Kit (BRICK) to data on ^{3}He-α scattering and the ^{3}He(α,γ) reaction.

In 2020 Phillips became PI of a new multi-institutional effort to develop a set of Bayesian software tools that, like BRICK, would facilitate Bayesian analyses in nuclear theory. The Bayesian Analysis of Nuclear Dynamics (BAND) Cyberinfrastructure Framework is funded by the NSF's Office of Advanced Cyberinfrastructure. The five-year project involves approximately twenty faculty, postdocs, and grad students from OHIO U., Michigan State University, Ohio State University, and Northwestern University.

Phillips has also continued his work on few-body reactions. During his 2018–9 sabbatical at the Technical University of Darmstadt he began collaborating with Hans-Werner Hammer of TU Darmstadt and Hammer's student Matthias Göbel. A notable product of this collaboration was an assessment of the feasibility of a proposed extraction of the neutron-neutron scattering length from the reaction $^6\mathrm{He}(p, p'\alpha)$. This paper was an Editor's Selection in Physical Review C. While in Darmstadt Phillips also collaborated with Achim Schwenk and Corbinian Wellenhofer on new techniques to join expansions at small and large expansion parameters in model-independent ways.

Lastly, Phillips has continued his long-term collaboration with Harald Grießhammer and Judith McGovern on Compton scattering from light nuclei. They performed a comprehensive study of the sensitivity of various proton Compton scattering observables to proton polarizabilities, a study that was later the basis for a novel application of Bayesian experimental design by Grießhammer, McGovern, Phillips, and BUQEYE collaborators. They also pushed forward their examination of Compton scattering from ^{3}He. In a 2018 paper with Ph.D. students Arman Margaryan (Duke) and Bruno Strandberg (Glasgow) they examined the impact of the $\Delta(1232)$ on this reaction. Then, during his sabbatical at Ohio U. (partly funded by INPP) Andreas Nogga participated in a collaboration that reformulated the treatment of this process in terms of densities. This has opened the way for *ab initio* calculations of Compton scattering on ^{4}He and even heavier targets.

The research led by **Madappa Prakash** covers topical issues in astrophysics and nuclear 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 also performed.

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 (postdocs

Schneider, Constantinou and graduate student Muccioli)) 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 by Constantinou, OU graduate student Lalit and Prakash. 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) (Constantinou and Prakash).

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 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, graduate student Al Mamun and postdoc Constantinou 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 $\frac{1}{T_c}\frac{d\Delta^2}{dT}\Big|_{T_c}$ 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), the level densities of ^{197}Pt and of ^{60}Zn recently measured Z. Meisel and collaborators at the Edwards Accelerator have been calculated.

During the mergers of NSs, the magnitude of the densities, temperatures, rotation, and magnetic fields far exceed those characteristic of isolated NSs. Lalit, Al Mamun, Constantinou and Prakash have examined the influence of such effects on the NS EOS. In this research, the sub-nuclear EOS was also extended to include various light nuclei such as $\mathrm{d}, \mathrm{t}, ^3$He, etc., beyond the commonly used representative nucleus ^{4}He.

At supra-nuclear densities, the possibility exists for deconfined quarks to appear in neutron stars (NSs). Together with postdocs Han and Constantinou, and graduate students Al Mamun and Lalit, Prakash led investigations of the various treatments of including quarks and their ensuing consequences. In all cases, consistency with recently estimated tidal deformations of NSs in the binary merger event GW180718 was sought. Han and Prakash also established lower limits for very massive NSs ($\simeq 2M_\odot$) which have since been confirmed in observations utilizing the NICER observatory by two independent groups.

A highlight of the research conducted in 2020 was the likely observation of NS 1987 A in SN 1987A. The collaboration that included Page, Beznogov and Garibay from UNAM, Mexico, Lattimer from Stony Brook, USA, Thomas-Janka from Max Planck institute, Germany, and Prakash pointed out that the most natural explanation of the warm blob detected by the ALMA observatory is thermal emission from the remnant NS in SN 1987A. Followup observations by ALMA and other observatories are underway to confirm our findings.

Chiral effective field theory enables first-principle calculations of the EOSs relevant to NSs for up to twice the nucelar saturation density, n_0. Utilizing such EOSs, Drischler (MSU), Han (OU/Berkeley), Reddy (Seatlle), Lattimer and Zhao (Stony Brook) and Prakash have explored limits to radii of NSs of various masses by extending the EOS beyond $2n_0$ using general arguments of causality. These calculations also delimit radii of NSs beyond $2M_\odot$ were they to be observed in future detections.

Thus far, the information to be gleaned from gravitaional wave observations have been limited to the masses and radii of the merging NSs. Prakash has initiated a concentrated effort to extend the ability of such detections to provide information about the interior composition of NSs. The idea here is to disentangle gravity waves associated with the so called g-mode oscillations from those arising from angular momentum loss during the inspiral in future upgraded/new-generation LIGO/Virgo detectors. The generation of these g-modes is caused by differences in the equilibrium and adiabatic sound speeds in NSs, the latter of which depends on the composition. This collaboration included Jaikumar (California State Univ., Long Beach), Han (Berkeley), Constantinou (Trento), and Semposki, Zhao and Prakash (Ohio Univ.). In a series of papers, they have isolated hybrid quark stars as promising candidates.

During 2016-21, Prakash, along with Daniel Phillips, was a senior collaborator in the Network for Nuclear and Neutrino Astrophysics (N3AS), a postdoctoral hub funded by NSF and led by Berkeley University in a multi-institutional effort. Since 2021, N3AS has been converted to a Physics Frontier Center (for an initial 5 years duration) for which Prakash and Phillips continue to contribute. As a part of N3AS, Prakash was able to productively work with postdoc Sophia Han situated at Ohio university during 2019-21.

F National/International Activities of Faculty Members

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

- Hicks was a co-organizer of both of the annual meetings of the DNP during his tenure as the secretary of the organization, May 2018 to February 2021.
- Phillips is the lead organizer of the Kavli Institute for Theoretical Physics Program, "Living Near Unitarity: Universal Few-body Physics in Molecules and Nuclei", to be held in Santa Barbara, CA in May 2022.
- Phillips is a co-organizer of the NSF Project Scoping Workshop "Towards accurate and precise calculations of neutrinoless double beta decay", held online in January-February 2022.
- Frantz was co-lead organizer of the Brookhaven National Lab RHIC Facility Annual Users meeting held in Upton, NY in June 2017 (as well as 2015-16)
- Roche was the lead organizer of the JLab User Organization annual meeting held in Newport News, VA in June 2018.
- Phillips, Brune, and Meisel organized the meeting "50 years of Physics at Edwards Accelerator Laboratory", held on OHIO U.'s campus in September 2021.
- Brune was a co-organizer of virtual R-matrix workshops in June of 2020 and 2021. These were originally planned to be in person, but went virtual because of COVID. We now plan to host the in-person workshop at Ohio University in June 2023.
- King was a co-organizer of the 2019 JLab Joint Hall A & C Summer Collaboration Meeting, held in Newport News, VA in June 2019.
- Frantz was co-organizer of Plenary Workshop on Diversity and Career Development at the 2018 Brookhaven National Lab RHIC Facility Annual Users meeting held in Upton, NY, June 2018.
- Phillips was a co-organizer of the ECT* workshop "Precise beta-decay calculations for searches for searches for new physics", held in Trento, Italy, April 2019.

- Frantz was the organizer of the Plenary Session "Jets and Prompt Photon Physics" at the 2019 International Symposium on Multi-particle Dyanmics (ISMD19), held in Sante Fe, NM in September 2019.
- King was the lead organizer of the 2019 JLab Hall A Winter Meeting, held in Newport News, VA in January 2019.
- Frantz was the organizer of the annual meetings of the Appalachian Section of the American Association of Physics Teachers, (AAPT) October 2020 and April 2021.
- Phillips was the lead organizer of the Sixth Workshop on Information and Statistics in Nuclear Experiment and Theory, held in Darmstadt, Germany in October 2018
- Roche was the chair of the Photonuclear Reactions Gordon conference, held in Holderness, NH in August 2018.
- Phillips was a co-organizer of the 2018 Institute for Nuclear Theory program "Fundamental physics with Electroweak Probes of Light Nuclei (INT-18-2a)" held in Seattle, WA in June 2018.
- Elster was a co-organizer of the 2017 Institute for Nuclear Theory program "Toward Predictive Theories of Nuclear Reactions Across the Isotopic Chart (INT-17-1a)" held in Seattle, WA in March–April 2017.

Advisory Committees

- Phillips, Member, International Advisory Committee, "Chiral Dynamics" conference, 2018 and 2021.
- Phillips, Member, Triangle Universities Nuclear Laboratory Advisory Board, 2020.
- Phillips, Chair, International Advisory Committee, International Conference on Few-body Problems in Physics, 2015–8.
- Frantz, Member, International Advisory Committee, "Winter Workshop of Nuclear Dynamics (WWND)" conference, 2012–18.
- Phillips, Member, Nuclear Science Advisory Committee, 2016–9.
- Elster, Member of the JLab Program Advisory Committee, 2018–present.
- Brune, Program Advisory Committee, High-Intensity Gamma-Ray Source (HIGS) at Triangle Universities Nuclear Laboratory, 2016–present.

Review Panels of Federal Agencies

- Elster was chair of NSF laboratory site visit committees at Notre Dame University, Michigan State University, Florida State University in 2020.
- Hicks was the chair of the NSF's LIGO Facility 5-year Cooperative Agreement Review Panel, 2017.
- Hicks was the chair of the NSF's LIGO Facility Annual Review Panel, 2018.
- While on leave from the university (since Jan. 2020), Hicks has chaired several DOE reviews, for both detector upgrades and computing facilities.
- Roche was a Member of the DOE / Small Business Innovation Research review panel in 2020.
- Frantz was a Member of the NSF Mathematics and Physical Sciences (MPS) Review Panel Launching Early-Career Academic Pathways (LEAPS-a new Diversity/Equity aimed NSF program) in 2021.
- Phillips was a member of the DOE site visit committee at Texas A&M University in 2019.
- Elster was a member of the U.S. DOE, Office of Nuclear Science, Review Committee of the Nuclear Theory Programs of the National Laboratories in 2016.

Activities in Professional Organizations

- Hicks, Secretary-Treasurer of the DNP, May 2018 – Feb 2021.
- Phillips, Member (2020), Director Elect (2021), Director (2022), FRIB Theory Alliance Executive Board.
- Roche, Member, Thesis Prize Committee of the DNP, 2021-2024.
- Phillips, Member, Fellowship committee of APS Topical Group on Hadronic Physics, 2020.
- Roche, Member, Award Committee of the Eastern Great Lakes Region section of the American Physical Society, 2020– present.
- Roche, Member, Executive Committee of the DNP, 2019-2021.
- Brune, FRIB Users Group, Executive Committee, 2017–2020.
- Meisel, FRIB Users Group Executive Committee, Member (2020-Present), Chair (2021)
- King, Member (2017-2018), Chair (2018-2019), JLab Hall A Coordination Committee

- Elster, Few-Body Systems Editorial Board, 2016–9.
- Roche, Vice-chair(2016-17), Chair-Elect(2017-18), Chair (2018-19) and Past Chair (2020-21), JLab Users Organization.
- Roche, Member, Executive committee of the Ohio Section of the American Physical Society, 2015-2018.
- Frantz, Chair line of the RHIC/AGS Users Executive Committee, 2015-17.
- Frantz, Founding Chair of Diversity Working Group of the RHIC/AGS Users Executive Committee, 2016-Present.
- Roche, Ohio U. representative, Southeastern Universities Research Association—JLab program committee, 2014–present.
- Frantz, various periodic roles on the Executive Committee of the Appalachian Section of the American Association of Physics Teachers (AAPT) including President, Vice-President, and Webmaster, 2014–present.

Prizes and Awards

- Prakash, American Physical Society Han's Bethe Prize, 2021, OHIO News article.
- Roche, OHIO U. Presidential Research Scholar, 2021.
- Meisel, CAS Outstanding Faculty Research, Scholarship, and Creative Activity Awards, 2021.
- Meisel, CAS, Dean's Outstanding Teacher Award, 2020.
- Frantz, Excellence in Service to Students Award by the Ohio University chapter of the National Society of Leadership and Success (NSLS), 2017
- Frantz, Service Award to Nuclear Physics Community, Brookhaven National Lab RHIC/AGS User's Executive Committee (UEC), 2017
- Brune, OHIO U. Presidential Research Scholar, 2019.
- Phillips, OHIO U. Presidential Research Scholar, 2017.
- Meisel, DOE Early Career Award, 2018.

Courses Presented at Schools and Workshops

- Brune, FRIB TA - TALENT Course 6: "Theory for exploring nuclear reaction experiments," 2019 (East Lansing, MI), 6 lectures.

- Elster, FRIB TA - TALENT Course 6: “Theory for exploring nuclear reaction experiments,” 2019 (East Lansing, MI), 7 lectures.
- Phillips, TALENT school, 2019 (York, UK) “Learning from Data: Bayesian Methods and Machine Learning in Nuclear Physics”, 9 lectures.
- Elster, 2nd RISP Intensive Program on ‘Rare Isotope Physics’, 2017 (Daejeon, Republic of S. Korea), 6 lectures.

Visiting Appointments

- Phillips, ExtreMe Matter Institute Visiting Professor, 2018–9.

Other Activities

- Hicks, Program Manager for Heavy Ion Research, DOE, Jan. 2020 – present.
- Hicks writes a monthly column for the *Columbus Dispatch*.
- Phillips is the Guest Editor for a special issue of *Journal of Physics G* on “Further enhancing the interaction between nuclear experiment and theory through information and statistics”.
- In 2021, Phillips chaired the national search for FRIB Theory Fellows.
- In 2019, Elster chaired the national search for FRIB Theory Fellows.
- During the reporting period, Phillips served as an external thesis examiner for both the University of British Columbia and the Hebrew University of Jerusalem.
- During this reporting period, Meisel served as an external thesis examiner for both Monash University and for two thesis committees of Central Michigan University

G The Edwards Accelerator Laboratory

The EAL hosts the primary nuclear-physics experimental facility at Ohio University: the 4.5-MV Pelletron tandem accelerator located there. The accelerator has been available for nuclear science experiments since 1971. The experimental work at EAL has been continuously funded by the U.S. Atomic Energy Commission (AEC), DOE (successor to the AEC), and other federal sources. More information about the history and capabilities of the laboratory are available here: http://inpp.ohio.edu/~oual/.

In addition to the key role in the research of the INPP low-energy experimental faculty, the laboratory hosts a wide variety of basic and applied nuclear science projects led by outside users. The projects range from basic nuclear science (level-density measurements), to calibrations of detectors destined for national user facilities (e.g., VANDLE, HABANERO), to applications (neutron source development for neutron imaging). These outside users are very valuable to the INPP. These projects help connect INPP scientists with the greater nuclear science community. They also expose our undergraduate and graduate students to a broader range of science, including that done by national laboratories. In some cases, the outside users pay for our service, which helps with lab maintenance and equipment upgrades.

G.1 Lab overview

The 4.5-MV accelerator is located on the first floor of the EAL. The laboratory includes a vault for the accelerator, two target rooms, a control room, a chemistry room, an electronics shop, an undergraduate teaching laboratory, and offices for students, staff, and faculty. The Laboratory building supplies approximately 10,000 square feet of lab space and 5,000 square feet of office space.

This machine is presently equipped with a sputter ion source and an RF-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 RF-exchange ion source is an Alphatross system from National Electrostatics Corporation, which we obtained in 2019 using a $187,000 Major Research Instrumentation award from the National Science Foundation.

The laboratory is very well equipped for neutron time-of-flight experiments. A beam swinger magnet 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.

The laboratory has six instrumented beamlines, which allows for a wide variety of experimental setups to be in place at one time. Other established capabilities include a charged-particle scattering chamber, chambers for charged-particle time-of-flight and γ-

ray measurements, a neutron counting station, a neutron counting station, and the W.M. Keck thin film analysis facility. Some new capabilities we are developing are discussed in Subsection G.3.

G.2 Summary of past investments

The EAL building in which the accelerator is housed was expanded in 1993, 50% of which was funded via a mortgage that was repaid over several years from INPP. Individual professors also assisted with the funding using money from their research-incentive accounts. This addition provided our teaching laboratory, electronics shop, the Roger Finlay Conference Room, and office space. This early success of the INPP's collaborative approach to science established the fine environment that we enjoy today.

In 2004, the INPP and the Astrophysical Institute successfully competed in University Research Priorities competition, which led to a new faculty position in low-energy nuclear experimental (Meisel's position). This proposal also led to a $100K in the EAL infrastructure (refurbishing the SF_6 compressor, modernizing vacuum systems, and other improvements). In 2009, the laboratory's process chiller was replaced using INPP and university funds ($75K total).

The accelerator was upgraded to a Pelletron charging system via a $321K NSF Major Research Instrumentation (MRI) grant. This project was completed in January 2012. This modern charging system provides more stable voltage regulation. It has also allowed us to routinely run 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.

Since then we have continued to modernize the laboratory, using funds from the INPP, the Physics and Astronomy Department's modest supplies budget, and Brune's Research Incentive (RI). 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. We have also continued to modernize the vacuum systems in the laboratory, with a purchase of two cryopumps and a compress for $35K in 2018.

Several improvements have also funded by other sources. The roof of the EAL building was replaced in 2015 (university funded). A new fire alarm system was installed in the laboratory in 2016 (university funded). Finally, a security system for our radioactive sources was installed (DOE-funded).

In 2019, the existing duoplasmatron He ion source was replaced by a new Alphatross source produced by the National Electrostatics Corporation. This project was funded by a $187K MRI (PI: Meisel), with matching money coming from the INPP and Brune's RI. It significantly improves the intensity of the ^{3}He and ^{4}He beams available in the laboratory, enabling many new types of measurements to be undertaken. Examples include (α, n) cross section measurements important for element creation in core collapse supernovae and $(^3\text{He}, n)$ spectroscopy measurements to constrain proton-rich nuclei important for explosions on neutron stars.

G.3 Ongoing and future investments

We are upgrading our detection capabilities. A silicon "lampshade" detector, a large-solid-angle array for efficiently detecting charged particles has been purchased and will be housed in a new chamber such that charged particles and be measured in coincidence with neutrons in our time-of-flight tunnel. One possibility for this is measurement of charged particle neutron coincidence without pulsed beam. We recently completed development and commissioning of an efficient neutron detector based on the thermalization of neutrons in polyethylene and their subsequent detection in either ^{3}He- and/or BF_3-filled proportional counters. The detector, the Helium Boron-trifluoride Giant Barrel (HeBGB), is particularly well suited for measurements of (α, n) cross sections, which are important in astrophysics (α-rich freeze out) and other applications. The development of these detection systems is led by Meisel and is largely financed using his startup funds. Brune and Massey are leading the development of a new beamline for neutron scattering measurements. This capability compliments the beam swinger by allowing for shorter flight paths and more flexible detector positioning.

Our approach to data acquisition in the laboratory is also evolving. We are moving towards using modern VME-based systems for our new detection systems, including a state-of-the-art digital data acquisition system. This combination of hardware and software is more efficient and also trains our students using the most common standard in the field of nuclear science. Part of Meisel's start-up funds were used to support this effort, including the purchase of state-of-the-art digital data acquisition electronics from Mesytec.

Electronics engineer Don Carter recently developed a new portable data acquisition system known as the PiDAQ. It is a $400 system consisting of a RaspberryPi and auxilliary electronics. The first working prototypes were built by an electrical engineering student performing a research internship in the Edwards Lab. These prototypes are now being used in the undergraduate and graduate laboratory class to replace the old data acquisition systems. We have also used the PiDAQ for some research projects involving simple detector set-ups.

In the future, we will continue to upgrade and modernize our infrastructure, as the need and opportunity presents itself. We will also continue to develop our detection systems. One possibility under consideration is building a high-efficiency γ-detection array based upon lanthanum bromide scintillators. These detectors provide excellent energy resolution and efficiency and would enable two types of experiments. One is that

γ-rays could be measured in coincidence with neutrons in our time-of-flight tunnel. These measurements could be made without using pulsed beam, which means they could be done more efficiently. Such a detector array would also enable Oslo-type measurements [?] of the γ-ray strength function, where γ rays are measured in coincidence with neutrons or charged particles. Other possible upgrades include more comprehensive diagnostic systems for all beamlines, energy boosting via a supplemental acceleration system, and/or improved timing resolution from a radiofrequency cavity based beam-bunching system.

G.4 Staffing

We summarize the present staffing of the EAL and provide some guidance for the future.

G.4.1 Technical Staff

The EAL is presently supported by two technical staff: an Accelerator Engineer and a Nuclear Instrumentation Engineer. In FY 2021, these positions were supported by a combinations of CAS, INPP and grant funds (Accelerator Engineer : 100% CAS, Nuclear Engineer: 64% CAS, 12% INPP and 24% research grants). The low-energy instrumentalists strive to support the Nuclear Engineer position as much possible with research grants. Since the level of grant support fluctuates, the breakdown between INPP and research grant support fluctuates from year to year.

The Accelerator Engineer's primary responsibility is maintaining the accelerator and other mechanical systems in the laboratory. This includes all vacuum systems, the insulating gas (SF_6) handling system, chilled water, and compressed air in the laboratory. In addition, this individual is responsible for training operators (students, postdocs, and faculty) of the accelerator and interfacing the laboratory with Ohio University's office of Environmental Health and Safety, which includes radiation safety. This position is currently filled by Greg Leblanc, who joined us in 2020, following the retirement of Devon Jacobs. INPP funded a one-month overlap period between Leblanc and Jacobs, which enabled important transfer of subject matter expertise.

The Nuclear Instrumentation Engineer is primarily responsible for building up and maintaining the electronics and computers in the laboratory. Some specific responsibilities include our data acquisition systems, power supplies, and the ethernet and wireless connectivity within the laboratory. Significant ongoing examples are the recently-developed portable PiDAQ systems, bringing our new VME-based data acquisition system online and implementing EPICS control protocol for the new helium ion source. There are also several specialized systems that this position in responsible for, such as the Terminal Potential Stabilizer which regulates voltage at the terminal of the accelerator and the beam bunching and chopping system. This position is currently filled by Donald Carter, who has been with us since 1974.

The Nuclear Instrumentation Engineer and Accelerator Engineer were critical for the installation and commissioning of the Alphatross Ion Source. They led communications with the National Electrostatics Corporation to make sure the system could be integrated into the laboratory, designed and implemented custom plumbing and a custom communication interface, safely removed the original duoplasmatron, installed and commissioned the Alphatross, and trained our students and faculty on operations. This was a major task requiring months of dedicated effort from technical experts. Completing the Alphatross project ensured continued reliability for research and education at the accelerator laboratory.

These staff do much more than just support our research program. They support the experiments and data acquisition in our teaching laboratory. The PiDAQ system provides a more modern and dependable laboratory experience for students in the nuclear physics laboratory course. The Nuclear Instrumentation Engineer also provides computer support for all of the experimental nuclear physicists in the INPP and maintains the INPP server. These efforts directly support undergraduate and graduate education at Ohio University as these computing resources are used for the nuclear physics laboratory courses and to host webpages other courses.

Due to the essential role that the staff play in enabling our research and education program, it is crucial that both positions are maintained in place as we move forward. Engineer Devon retired in the Fall of 2020 after a short overlap with newly hired Engineer Leblanc. Engineer Carter has expressed interest in retiring within the next two years.

G.4.2 Tenure-Track Faculty

Tenure-Track faculty play a key role in the EAL, as they supervise the majority of the Ph.D. students and lead most of the funding proposals. They also direct day-to-day operations in the laboratory, supervise staff, represent the EAL in the department and college, and maintaining an EAL presence at important national and international scientific meetings. In order to efficiently utilize the laboratory and leverage the university's investment, it is necessary to have a certain critical mass of faculty, particularly to supervise graduate students and to write grant proposals. Presently, the EAL has two tenure-track faculty, Brune and Meisel. In the mid 1990s, this number was as large as six. While there can be no formula for what the exact number should be, it is certainty more than two. Already we have difficulty meeting the demand for graduate and undergraduate students interested in research at the EAL. In 2015, the INPP sought external advice on the future direction of the EAL from two respected nuclear scientists, Ani Aprahamian (Notre Dame) and Kirby Kemper (Florida State University). Their report indicated that three tenure-track faculty was the minimal number for the viability of the laboratory. It is thus a priority of the INPP to hire an additional tenure-track faculty member, whose research program would have a significant component centered at the EAL. The Aprahamian-Kemper report also fully endorsed our roughly 50%-50% split between in-house and outside experiments, and recommended that approach for future hires.

G.4.3 Research Faculty

The EAL currently has two research faculty, Massey and Voinov, who are non-tenure track and are 100% grant supported. These faculty play a very important role in the functioning of the EAL. They supply much-needed expertise in certain areas – for example, neutron detection in the case of Massey and statistical nuclear physics in the case of Voinov. These faculty are also important for assisting students and outside users in the laboratory, as tenure-track faculty are sometimes busy with teaching and other university responsibilities. Voinov has also supervised two Ph.D. students. Massey frequently provides technical assistance for the nuclear physics laboratory courses. We feel the current level of research faculty staffing is healthy and appropriate for the EAL and we plan to continue this approach moving forward.

G.5 External Users

The EAL has several users from outside Ohio University who come to access the unique capabilities of the laboratory. Visitors may use the laboratory on a collaborative basis (which results in a publication with Ohio U authors) or a paying basis. A list of visitors from the reporting period is below. Note that the COVID19 pandemic resulted in smaller-than-usual number of users for 2020 and 2021.

Institution	**Contact**	**Purpose**	**Visit Dates**	**Paying (Y/N)**
CMU	George Perdikakis	$^{11}B + ^{48}Ca$	2017 Mar. 20-21, Apr. 17-25	N
OSU	Raymond Cao	neutron imaging	2017 May 2-4, Jul. 10	Y
Perdue	Anthony Sansone	n-detector calibration	2017 Jun. 19-20	N
LLNL	Darren Bluell	n-production cross sections	2017 Jun. 27-Jul 7	Y
ND	James deBoer	$^{10}B(p, \alpha)$	2017 Sep. 5-17	N
PSU	Evan Bray	X-ray detector study	2018 Feb. 12-20	N
UTK	Eric Lukoski	neutron imaging	2018 Mar. 12-14	N
LLNL	Darren Bluell	n-production cross sections	2018 Jun. 26-29, Aug. 6-10	Y
AFIT	Mike Hogsed	sample irradiation	2018 Aug. 29-31	Y
LLNL	Dan Bower	n-detector calibration	2018 Sep. 10-14	Y
Photonis	Larry Thorne	n-detector characterization	2018 Sep. 24-28	Y
AFIT	Mike Hogsed	sample irradiation	2018 Nov. 8-9	Y
CMU	George Perdikakis	(p,n) cross section	2018 Nov. 13-16	N
ORNL	Mike Febbraro	n-detector calibration	2018 Nov. 26-30	N
CMU	George Perdikakis	(p,n) cross section	2019 Feb. 4-8	N
CMU	George Perdikakis	n-detector calibration	2019 Mar. 18-20	N
PSU	Evan Bray	X-ray detector study	2019 Mar. 4-15	Y
PSU	Evan Bray	X-ray detector study	2019 Apr. 30 - May 10	N
AFIT	George Peterson	sample irradiation	2019 Aug. 1	Y
UTK	Miguel Madurga	n-detector calibration	2019 Aug. 19-23	N
UTK	Robert Grzywacz	n-detector calibration	2019 Oct. 14-18	N
TAMU	Jack Bishop	(n,n') cross section	2020 Mar. 2-27	N
TAMU	Jack Bishop	(n,n') cross section	2020 Aug. 30 - Sep. 4	N
CMU	George Perdikakis	(a,n) cross section	2021 Mar. 1-8	N
LLNL	Richard Hughes	(n,n') cross section	2021 Sep. 13-17	Y

H List of Acronyms

Acronyms repetitively used in this report are listed below:

- CAS: College of Arts and Science
- DOE: U.S. Department of Energy
- EAL: Edwards Accelerator Laboratory, OHIO U., https://inpp.ohio.edu/∼oual/
- EIC: Electron Ion Collider, State of New York, https://www.bnl.gov/eic/
- FRIB: Facility for Rare Isotope Beams, Michigan State University,https://frib.msu.edu/
- FRIB-TA : FRIB Theory Alliance, https://fribtheoryalliance.org/
- JLab: Thomas Jefferson National Accelerator Facility, Virginia, https://www.jlab.org/
- INPP: Institute of Nuclear and Particle Physics
- P&A: Physics and Astronomy
- QCD: Quantum Chromo-Dynamics
- RHIC: Relativistic Heavy Ion Collider, New York State, https://www.bnl.gov/rhic/