Institute
of Nuclear and Particle Physics

2006 - 2011

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

January 2012

Prepared for:

College of Arts and Sciences

Prepared by:

Carl Brune, Director

Center/Institute Summary

Center/Institute:	Institute of Nuclear and Particle Physics
Director:	Carl Brune Department of Physics and Astronomy College of Arts and Sciences
Affiliated Faculty:	Carl Brune, Professor of Physics Charlotte Elster, Professor of Physics Justin Frantz, Assistant Professor of Physics Kenneth Hicks, Professor of Physics David Ingram, Professor of Physics, Department Chair Daniel Phillips, Professor of Physics Madappa Prakash, Professor of Physics Julie Roche, Assistant Professor of Physics Andreas Schiller, Assistant Professor of Physics Mark Lucas, Associate Professor of Physics (Group II) Paul King, Research Assistant Professor of Physics Thomas Massey, Research Associate Professor of Physics Gabriela Popa, Assistant Professor of Physics (Zanesville) Alexander Voinov, Research Assistant Professor of Physics Charles Brient, Associate Professor of Physics, Emeritus Steven Grimes, Distinguished Professor of Physics, Emeritus David Onley, Professor of Physics, Emeritus Louis E. Wright, Professor of Physics, Emeritus

Mission:
The mission of the INPP is to promote activities in theoretical and experimental subatomic physics, and to pro-actively educate graduate and undergraduate students in these fields. The faculty and students in the INPP have access to the most sophisticated particle accelerator in the State of Ohio, and in addition, have access to national and international accelerators using a variety of probes at low and high energies.

Future Activity:
The INPP will support the on-going and future activities of its members by (a) providing support for 1-2 postdoctoral research fellows and summer undergraduate students; (b) providing support for research faculty and staff; (c) providing matching funds to leverage larger external research grants; (d) enhancing the intellectual climate by organizing regular seminars, hosting a journal club, and supporting conferences; and (e) providing start-up funds for new faculty.

Awards (2006-2011): External Grants $9,971,000

Contents

1 Mission Statement

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

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

The Institute is an ideal 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.
- Enhancement of the intellectual climate by organizing regular seminars, hosting a journal club for students, and supporting conferences and visitors.
- Provide matching funds for initiatives with funding agencies and national laboratories, with the goal to leverage larger amounts of external research funding.
- Provide financial support for research faculty and staff, postdoctoral researchers, graduate and undergraduate students.

For the purposes of this report, we consider the time period from from July 1, 2006 through December 31, 2011.

2 Brief History

The Institute of Nuclear and Particle Physics was established in 1991 with the goal of enhancing interactions among faculty and students in the Department of Physics and Astronomy conducting research in these areas. Before 1991, nearly three decades of successful programs in nuclear physics research and graduate education had brought significant national and international recognition to Ohio University. Some highlights from this time are:

- The first Ph.D. in the Department of Physics and Astronomy, 1963.
- Awarding of 85 Ph.D. degrees in Physics during 1963-1991.
- Construction of the Edwards Accelerator Laboratory, 1969.
- Sustained external research support from DOE and NSF.
- Four Distinguished Professors (Lane, 1972; Rapaport, 1981; Finlay, 1991; Grimes 2001).

The Edwards Accelerator Laboratory currently houses the highest-energy particle accelerator in the State of Ohio. This facility was the main focus of the nuclear experimental research during the 1970's and 1980's. Its unique experimental capabilities, in particular its neutron production and detection equipment, played a special role in nuclear experiments of that period. These unique 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). Currently, the accelerator is also being utilized for experiments to study the formation of elements in stars and to study the structure of complex nuclei. The accelerator is presently undergoing a significant NSF-funded upgrade to a modern Pelletron charging system, helping to enable the laboratory to continue to conduct forefront research. We have also continued to recruit new tenure-track faculty in this research area.

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

Concurrently with the progress being made at the Edwards Laboratory, the INPP research efforts in experimental nuclear physics have broadened substantially over the past two decades. The INPP members now work at a number of national and international "intermediate" and "high" energy facilities. A significant part of INPP's experimental effort is located at the Thomas Jefferson National Accelerator Facility (JLab), where the beam consists of electrons or photons with energies roughly a factor 100 larger than that at the Edwards facility. These national facilities allow the investigation of the internal structure of the nucleus – and the structure of neutrons and protons themselves – at very small distances. They also perform precise tests of the so-called Standard Model of particle physics that represents our current best fundamental understanding of subatomic physics. We have also recently added a faculty member who carries out research using the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory, where nuclei are accelerated to even higher energies. This facility permits the study of nuclear matter under conditions of extreme temperature, such as may have been present in the first moments after the universe was created. Future work in this area will also be carried out using nuclei accelerated by the Large Hadron Collider (LHC), located in Geneva, Switzerland.

Additional experimental research is carried out using short-lived exotic nuclei at the National Superconducting Cyclotron Laboratory (NSCL) at Michigan State University, the Holifield Radioactive Ion Beam Facility (HRIBF) at the Oak Ridge National Laboratory, and at Argonne Tandem Linear Accelerator System (ATLAS) at Argonne National Laboratory. In the future, INPP faculty will be involved at the Facility for Rare Isotope Beams (FRIB) that is presently under construction at Michigan State University. This facility will be available for physics experiments in about a decade and will be the world-leading facility for studying the properties of exotic nuclei.

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 ab-initio calculations as well as those utilizing the framework of effective field theories. A recent new direction is in nuclear astrophysics and the study of hot and dense matter. These efforts have created a theory group with extensive research breadth. Ohio University's theory group ranks among the ten best funded nuclear theory groups in the country.

3 Current Activities

3.1 Number and Role of Faculty and Students

The faculty at the INPP encompass a broad spectrum of research in nuclear physics. Activities include both 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 these experiments are partly carried out in the Edwards Accelerator Laboratory, with others being carried out at national facilities such as the NSCL at at Michigan State University. Assistant Professor Andreas Schiller was added in 2007, bringing considerable experience with exotic nuclei and nuclear structure to the group. The group includes three tenured or tenure-track faculty (Brune, Ingram, and Schiller), two grant-supported research faculty (Massey and Voinov), one postdoctoral researcher, and 7 to 8 Ph.D. students. In addition, Distinguished Emeritus Professor Steve Grimes remains very active in research and is co-PI on several research grants.

The research of the Medium/High Energy experimental group is conducted at large national facilities. The makeup of this group has undergone several changes over the past several years. Associate Professor Allena Opper left Ohio University in 2005 for a position at George Washington University. Associate Professor Daniel Carman departed in 2006 to become a Staff Scientist at Jlab. In both cases, the moves occurred for personal reasons unrelated to Ohio University. Two Assistant Professors have been hired, Julie Roche in 2006 and Justin Frantz in 2008. In addition, Paul King (Julie Roche's husband) also joined the group as a Research Assistant Professor in 2006. In addition to the above-mentioned faculty, this group also contains long-time faculty member Professor Ken Hicks. Since returning to full strength, this group now supports three postdoctoral researchers, and 6 Ph.D. students.

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

All of the research groups involve undergraduate students, particularly via Honors Theses and summer research. Lists of graduate and undergraduate students is given in

Appendix A and that 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. The faculty, with postdoctoral fellows and graduate students, have authored over 300 publications in refereed journals during the past five years. Another indication of our research productivity is our external funding, which reached $9.97 million dollars over the past five years. For brevity, the research highlights of the last five years are described in more detail in Appendix E.

3.2.2 Intellectual Climate

The INPP has continued to host a regular seminar series consisting of approximately 10 seminars per quarter over the academic year. Nearly all of the seminar speakers are invited from outside of Ohio University. These visitors typically spend a day on campus meeting with faculty, postdoctoral researchers, and students.

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

The INPP, along with the Joint Institute for Nuclear Astrophysics, hosted the workshop *Workshop on Statistical Nuclear Physics and Applications in Astrophysics and Technology.* It was held July 8-11, 2008 at Ohio University and included approximately 50 national and international scientists (see `http://inpp.ohiou.edu/~SNP2008/`).

The INPP hosts many visiting scientists, who play several roles. First, they exchange ideas with our faculty and students. Second, their close association with Ohio University raises the national profile of the INPP. They also collaborate and/or participate in experiments which enhances our scientific productivity. A list of visiting scientists is given in Appendix D.

In 2011, the INPP updated its brochure to reflect our current personnel and research activities. A new design and graphics were also implemented. The brochure was produced with the help of private consultant Christina Ullman at a cost of about $600. The primary uses of the brochure are student recruitment and for informing visitors about our activities.

3.2.3 Research Personnel and Student Support

An important goal of the INPP is the education and training of students (undergraduate and graduate) as post-doctoral fellows for careers in advanced technical professions. Whereas some take up academic careers, many work in industry in advanced computing, medical physics (including radiation therapy), and private research corporations. A list of graduates since 1993, including their current positions, are given in Appendix B. Likewise, a list of postdoctoral fellows with the INPP, together with their current positions, is given in Appendix C. The INPP also provided support for a few undergraduate research projects. This INPP support is either supplied directly, or as matching funds to external grants. The INPP has been particularly successful using matching funds to leverage support for postdocs from federal agencies.

The INPP also provides financial support for Research Assistant Professor Paul King which leverages funding from JLab and the NSF. Due to budget cuts in the College of Arts and Sciences and the Department of Physics and Astronomy, the INPP has begun providing financial support for research staff members Don Carter and Devon Jacobs.

3.2.4 Faculty

A key accomplishment of the INPP over the past five years has been the hiring of Assistant Professors Roche, Schiller, and Frantz. These hires have maintained the number for Group-I faculty in the INPP at the same level that it was in 2001. Phillips and Brune were also promoted to full professor positions over the past five years.

The national and international visibility of the INPP, the Department of Physics and Astronomy, and Ohio University can be elevated through leadership of its faculty in national/international organizations, leadership in conferences, and participation in national/international review panels. INPP members have been very active and successful in this regard during the last five year period. For example, two faculty of INPP were elected as Fellows of the American Physics Society (APS): Phillips in 2009 and Brune in 2010. Only 1% of all members of the APS can be elected Fellows each year; Elster, Grimes, Hicks, and Prakash had been elected prior to 2006. A selected list of high profile activities is given Appendix F.

3.2.5 The University Research Priority: Structure of the Universe

The University Research Priority (URP) project entitled "The Structure of the Universe: From Quarks to Superclusters" was chosen as Ohio University's highest priority out of 20 URP proposals selected for this competition held in 2003-04. The science issues addressed in this proposal lie in the interface between nuclear/particle and astrophysics. This project has led directly to the hiring of Prakash and Schiller. Research in nuclear astrophysics and radioactive beams has consequently become a major focal area of the INPP. Another major benefit of the URP has been $100,000 worth of infrastructure improvements for the Edwards Accelerator Laboratory. The URP officially ending on July 1, 2009 and has been by all accounts a successful venture. Although the financial support of the URP has ended, it continues to strongly influence the research directions of the INPP, particularly via the hiring of Prakash and Schiller. Our recent increases in external funding (documented below) are also partially due to the URP, through the increased breadth of our faculty and improved infrastructure. There are also several research accomplishments that are directly attributable to the URP, such as Prakash's work on neutron stars and Schiller's research on neutron-rich oxygen isotopes. Another positive result is that the INPP and ApI seminars are periodically held jointly, as will occur in the spring quarter of 2012.

3.2.6 The Edwards Accelerator Laboratory

The primary nuclear physics experimental facility at Ohio University is the 4.5-MV tandem van de Graaff accelerator located in the Edwards Accelerator Laboratory. In addition to in-house users, many outside visitors come to do experiments with the accelerator. The URP provided $100,000 for infrastructure improvements to the laboratory (split between the INPP and the Research Office). In addition, the facility is presently undergoing a major upgrade, to a moder Pelletron charging system. This upgrade is financed via a $321,000 grant from the National Science Foundation. A detailed description of these upgrades is given in Appendix G.

4 Proposed Future Activities

The INPP will continue to support activities that have proved successful over the past years:

- Enhancement of the intellectual climate by organizing regular seminars, hosting a journal club for students, and supporting conferences and visitors.
- Provide matching funds for initiatives with funding agencies and national laboratories, with the goal to leverage larger amounts of external research funding.
- Provide financial support for research faculty and staff, postdoctoral researchers, graduate and undergraduate students.

The reputation of a group is built over time, and the national/international visibility of a scientist (or a group of scientists) can carry some weight in funding decisions. A lively visitor program (seminar speakers and collaborators) helps the INPP to maintain and grow connections with the national and international communities of nuclear physicists. In addition, the visitor program enhances the intellectual atmosphere for graduate and undergraduate students by providing students opportunities to discuss cutting-edge research with outside experts. The visitors experience the quality of our institute and Ohio University on site. A list of visiting scientists is given in Appendix D.

The INPP has several specific new plans for the next five years. We plan to put forth a proposal to the Division of Nuclear Physics of the APS to host the National Nuclear Physics Summer School in 2014. This annual summer school brings together about 50 top students and postdoctoral researchers (from all over the world) in their early careers for 2 weeks. Lectures on a variety of current topics in nuclear physics are presented by renowned researchers in the field. By hosting this School, the national and international visibility of the INPP and Ohio University would be increased and we would make connections with up-and-coming young scientists. The majority of the funding would be provided by a grant from the National Science Foundation; however, it is customary and necessary that hosting institutions co-sponsor the summer school. The INPP would certainly contribute a share.

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

In the area of faculty, the INPP will opportunistically seek to augment its number of group-I faculty, while also considering the broader needs of the department. In particular, there may be opportunities for bridge-funded positions, for which much of the faculty salary is paid by a federal funding agency for the first five years. In the event of a group-I faculty search, it is likely that the INPP would contribute significant funds to the faculty startup package. It should be noted that INPP faculty member David Ingram became Chair of the Department of Physics and Astronomy in August of 2011, to fill the vacancy created by Joe Shields's departure to become Vice President for Research and Creative Activity and Dean of the Graduate College. To what extent this change has a negative impact on the INPP's research productivity remains to be seen.

Five years ago, the INPP began efforts to increase the numbers of masters students studying in the area of applied nuclear physics. Generally speaking, these efforts have not been successful, primarily because of a lack of student interest. However, we have been quite successful involving undergraduate and Ph.D. students in applied nuclear physics research. Presently, we have two students pursuing Ph.D. projects in this area. We plan to continue our efforts in this area in our present (modest) mode. Further growth in this area would require either hiring a faculty member to specifically work in the area of applied nuclear physics or collaboration with scientists in other departments on campus such as medicine or engineering.

Due to budget cuts in the College of Arts and Sciences and the Department of Physics and Astronomy, the INPP has begun providing $50,000/year of financial support for research staff (Nuclear Instrumentation. Engineer Don Carter and Accelerator Engineer Devon Jacobs). In the past, these two positions were fully supported by the Department of Physics and Astronomy. The financial future of Ohio University is difficult to predict, but it is possible that this amount could be decreased (by returning some or all of these expenses to the Department budget) in the future. Some INPP funds will be reserved for unforeseen ideas and initiatives as well as challenges. Sufficient flexibility must be present to exploit new windows of opportunity.

5 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 and Sciences or the Vice President of Research. The majority of the external funds come from the U.S. Department of Energy and the National Science Foundation.

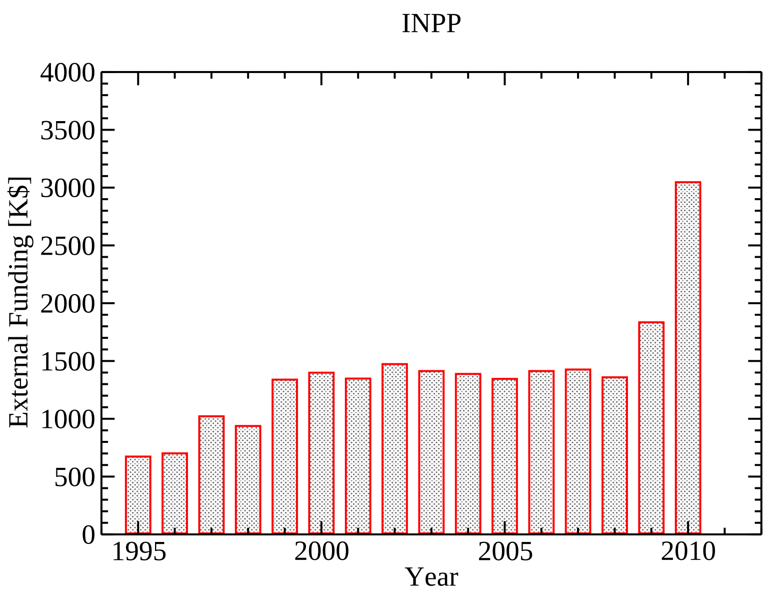

Figure 1: Total amount of external funding (in thousands of dollars) received by the INPP faculty over the last 15 fiscal years.

The history of the INPP's external funding is shown in Figure 1. The INPP started in 1991 with a funding level of $678,000. Through 1997, the funding level was nearly constant. It is interesting to note that the total external funding of the INPP faculty was fairly constant from 1999-2008, with an average of about $1.4M/year, despite all of the changes in faculty (retirements of Onley, Brient, Wright, and Grimes; departures of Opper and Carman; hiring of Phillips, Brune, Prakash, Roche, Schiller, and Frantz). Over the past two years, our funding has increased, due a stabilization of our faculty and the establishment of our junior faculty. It should be noted that every group-I INPP faculty member presently has a significant research grant and at least one Ph.D. student. It should also be noted that very high funding level for FY-2010 shown in Figure 1 is due in part to the the one-time \$321K grant for the accelerator upgrade and some unusual grant accounting. The NSF lumped three of our three-year grants into FY-2010 for reasons related to the federal stimulus program; thus \$695K of the FY-2010 funding will in fact be spent in FY-2011 and FY-2012. Nevertheless, we do expect the funding level to remain at or above the \$2.0M/year level in coming years.

In summary, the INPP has managed to increase its funding level, largely by maintaining its number of faculty and allowing them to become established. The expansion into new research areas, such as nuclear astrophysics, relativistic heavy-ion physics, and applied nuclear physics has also helped to increase our funding.

We wish to emphasize that the grant amount of the INPP faculty is such that there is pressure exerted on the very lean administrative staff in the Department of Physics and Astronomy. Faculty in the INPP and the Department are sorely in need of help with grant preparation, grant administration and budgeting. It should be noted that administrative staff member Cindy White retired in 2008 and was not replaced. She was stationed in the Edwards Accelerator Laboratory and much of her duties were in support of the INPP and our research efforts in nuclear and particle physics. A further increase in grant funding will clearly increase the need for additional staff.

Since the income of the INPP results from the overhead return of grant expenditure, the income lags essentially 6-10 months behind the grant awards. The average income over the past 5 years was roughly \$120,000 per year. From this, the INPP is presently supplying \$40K/year for the support of Research Assistant Professor Paul King, and starting in FY2011 \$50K/year for the support of research staff. Presently, the INPP can assist in the support of one postdoctoral researcher at a level of \$20K per year, which is a good approach to leverage bigger grants from external funding agencies. The INPP supports a vigorous seminar and visitor program at a cost of about \$12K per year. The INPP also provides some support for undergraduate summer research.

It should be noted that the support of research faculty and staff is a recent development and is placing a strain on the INPP budget. This may limit the INPP's ability support postdoctoral researchers and the intellectual climate in the future.

Over the past five years, the INPP also contributed to the startup of two new faculty, contributed \$50K over five years for renovations in the Edwards Accelerator Laboratory within the URP program, and \$5K to co-sponsor conferences. Expenditures of this type may also be incurred in the coming years.

A Current INPP Graduate Students

Name	**Adviser**	Research Topic
Bijaya Acharya	Phillips	Coulomb Dissociation of Halo Nuclei
Shamim Akhtar	Brune	Alpha-Particle Transfer Reactions on Carbon
Harsha Attanayake	Schiller	Two-Neutron Decay of ^{26}O
Rakitha Beminiwatha	Roche	QWEAK: the Proton's Weak Charge
Younshin Byun	Schiller	Level Density and Radiative Strength Functions
Shloka Chandavar	Hicks	Scalar Meson Photo-Production at CLAS
Constantinos Constantinou*	Prakash	Supernova Equation of State
Kevin Cooper	Ingram	Experimental Study of Amorphous Carbon
Sushil Dhakal	Brune	Fast Neutron Transport in Iron
Dilupama Divaratne	Schiller	Structure of the Ground state of ^{24}O
Linda Hlophe	Elster	Separable Representation of Optical Potentials
Chen Ji	Phillips	Effective Field Theory for Cold Atoms and Halo Nuclei
Brian Muccioli	Prakash	Topics in Neutron Star Physics
Azamat Orazbayev	Elster	Polarization Phenomena in the Reaction ^{6}He(p,p)^{6}He
Cody Parker	Brune	The $^3\mathrm{H}(d,\gamma)^5$He Reaction
Anthony Pual Ramirez	Schiller	Level Density in Nuclei in the Mass 88-90 Region
Nowo Riveli	Frantz	Hot Plasma Effects at RHIC
Wei Tang	Hicks	K*+ Photo-Production Reactions at CLAS
Buddhini Waidyawansa	Roche	QWEAK: Physics Beyond the Standard Model
Bing Xia	Frantz	Nuclear Effects at RHIC

*Officially a Stony Brook student but doing his Ph.D. work at Ohio University.

Current Undergraduate Research Participation

Name	**Adviser**	Research Topic
Paul Adams	Ingram	Neutron Source Reactions
Gary Canter	Prakash	Computational Physics
Shaila Meeker	King	
Joe Zeallear	Frantz	Calorimeter Design and Triggering
Brooks Ziegler	Roche	

Enrollment in Phys 897A

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

By adding the student component to our regular seminar, the INPP faculty deemed it necessary for students get a broader education in current topics than can be provided by the regular course sequence PHYS 726, 727, and 728, 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. In a given quarter, themes are generally linked to topics covered by colloquium or seminar speakers so that students can better appreciate the presentations. This seminar series thus constitutes a course in frontier topics in nuclear/particle physics and astrophysics. The growth in the enrollment for PHYS 897A in recent years is unmistakable (Fig. 2) and is largely due to the growing number of graduate students in our program.

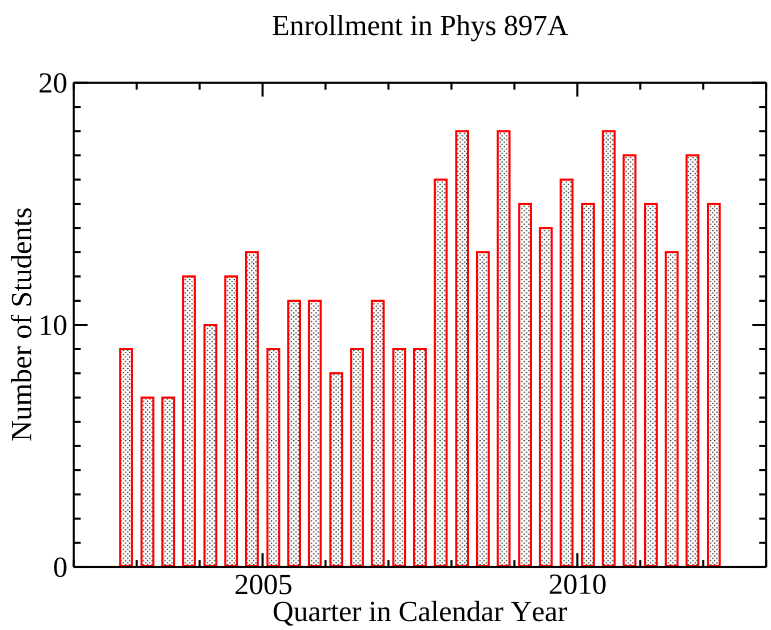

Figure 2: Enrollment in Phys 897A since its inception in the Fall Quarter of 2002.

B INPP Graduates – 2006-2011

Name	Ph.D.	Adviser	Current Position
Daniel Sayre	2011	Brune	Postdoc at Lawrence Livermore NL
Anton Wiranata	2011	Prakash	Postdoc at LBL and Cent. Chinal Normal Univ.
Aderemi Adekola	2010	Brune	Scientist at Canberra Industries
Dustin Keller	2010	Hicks	Postdoc at Univ. Tecnica Federico Santa Maria
Serdar Kizilgul	2009	Hicks	Staff at CERL (U.S. Army Research Lab)
Babatunde Oginni	2009	Grimes	Scientist at Canberra Industries
Ting Lin	2008	Elster	Postdoc at the Harvard Smithsonian Institute
Sergey Postnikov	2008	Prakash	Postdoc at Inst. de Astron., UNAM, Mexico
Shaleen Shukla	2008	Grimes	Assist. Prof., James Madison
Chieh-Jen Yang	2008	Phillips	Postdoc at the U. of Arizona
Christopher Bade	2006	Hicks	Officer in the U.S. Navy
Deepshikha Choudhury	2006	Phillips	Assist. Prof., James Madison
Ishaq Hleiqawi	2006	Hicks	Assist. Prof. at King Faisal Univ., Saudi Arabia
Catalin Matai	2006	Brune	Postdoc, IRMM, Geel, Belgium

Master Degrees – 2006-2011

Name	Degree	Advisor	Current Position
Ken Moore	2011	Prakash	Software Engineer with PC-BSD
Cody Parker	2011	Brune	Ph.D. program in Physics at OU
Kellen Murphy	2008	Phillips	Ph.D. program in Physics at OU

Undergraduate Research Participation – 2006-2011

Name		**Advisor**	**Current Position**
Peng Zhao	2011	Hicks	Engineering Graduate Student, OU
David Bauer	2010	Grimes	
Gary Canter	2010	Grimes	
James Ralston	2010-11	Grimes	Graduate Student, Ohio State
Joshua Kaisen	2009-10	Roche, Hicks	
Ryan Braid	2009-10	Brune, King	Graduate Student, Col. School of Mines
Jonathan Clark	2010	Hicks	
Chris Diltz	2009	Prakash	Graduate Student, OU
Robert Hatton	2009	King	
Brian Helbig	2009	Roche	Graduate Student, Columbia University
Joseph Snell	2009	Prakash	
Mira Vicente	2009	Hicks	
Torrance Freeman	2009	Hicks	Communications Specialist
Andrew Dilullo	2008-9	Grimes	Graduate Student, OU
David Principe	2008	Schiller	
Katie Kinsley	2007-8	Roche	Administrator, RPI
Sean Elling	2007	Roche	
Colin McCrone	2006-7	Prakash	Graduate Student, Cornell
Patrick Greene	2006-7	Prakash	
Daniel Sayre	2006	Carman	Lawrence Livermore National Lab
Ryan Zavislak	2006	Hicks	Math Division, NSA

Selected Previous INPP Graduates

Name	Ph.D.	Advisor	Current Position
Yannis Parpottas	2004	Grimes	Assoc. Prof., U. of Cyprus
Asghar Kayani	2003	Ingram	Faculty, Western Michigan Univ.
Chen-Hu Chang	2000	Wright	Software Engineer (Bradley Corp.)
Po-Lin Huang	1999	Grimes	College Teaching (Taiwan)
Cheri Hautala	1999	Rapaport	Science Specialist (Washington DC)
Steven Weppner	1997	Elster	Assoc. Prof., Eckard College, FL
Saleh Al-Quraishi	1997	Grimes	Assoc. Prof., Saudi Arabia
Kyungsik Kim	1996	Wright	Assist. Prof. (Korea)
Rodney Michael	1995	Hicks	Assoc. Professor, Ashland Univ.
Hong Zhang	1995	Hicks	Computer Programmer
Fred Bateman	1994	Grimes	Staff Scientist NIST
Jim Guillemette	1994	Grimes	Junior College Instructor, Maine
Anita Kumar	1994	Onley	Computer Programmer
Xun Yang	1994	Rapaport	Sen. Systems Engineer Motorola
Werner Abfalterer	1994	Finlay	Staff Scientist LANL
Lian Wang	1993	Rapaport	Computer Programmer
Henry Clark	1993	Hicks	Senior Staff Scientist, Texas A&M
Frank Lee	1993	Wright	Prof., GWU
Nourridine Boukharouba	1992	Grimes	Associate Professor, Guelma, Algeria

C INPP Postdoctoral Researchers

Name	INPP	Area	Current Position
Saravanan Veerasamy	2011-12	N Theory	
Dustin Keller	2011	ME Exp	Postdoc at Univ. Tec. Fede. Santa Maria
Johannes Kirscher	2010-11	N Theory	Industrial position in Germany
Deborah Aguilera	2009-11	N Theory	Faculty at CNEA, Buenos Aires, Argentina
Jeong Han Lee	2009-	ME Exp	
Dimitri Kotchetkov	2009-	ME Exp	
Carlos Schat	2009-11	N Theory	Faculty at CNEA, Buenos Aires, Argentina
Aji Daniel	2008-11	ME Exp	
Nikolai Kornilov	2008-	LE Exp	
Matthias Schindler	2007-9	N Theory	Assist, Prof., U. of South Carolina
Prashant Jaikumar	2006-7	N Theory	Assist. Prof. Cal. St. U. Long Beach
Lucas Platter	2005-7	N Theory	Assist. Prof., Chalmers U., Sweden
Tsutomu Mibe	2004-7	ME Exp	Assist. Prof., KEK, Japan
Simon Taylor	2004-06	ME Exp	Postdoc TJNAF
Michael Hornish	2003-06	LE Exp	Bechtel Nevada, DOE SubContractor
John Mahon	2002-06	ME Exp	Postdoc BNL

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 outside of Ohio University on a person-to-person basis. In addition, these visits allow scientists to get to know the INPP and Ohio University and to spread the word about us. For this reason, the INPP often helps to support collaboration visits financially. It is likely because of our partial financial support that the INPP has been able to successfully apply for several Glidden Visiting Professorships from Ohio University.

During the last five years, the INPP has hosted the extended visits of:

- Lee Bernstein, Daniel Sayre, Lawrence Livermore National Lab (Fall 2011)
- Elliot Grafil, Colorado School of Mines (Fall 2011)
- Andreas Enqvist, Chris Lawarence, University of Michigan (Fall 2011)
- David A. Kasimatis, Lawrence Livermore National Lab (Fall 2011)
- Gang Shen, Los Alamos National Lab (Fall 2011)
- Glen Myer, Lawrence Livermore National Lab (Summer 2011)
- Steve Reese, Oregon State University (Summer 2011)
- Mike Slaughter, Washington State University (Summer 2011)
- C.-J. Yang, U. of Arizona (Spring 2011)
- Jolie Cizewski, Rutgeers University (Fall 2010)
- Phil Datte, Lawrence Livermore National Lab (Fall 2010, Fall 2011)
- Martin Hoferichter, University of Bonn (Fall 2010, Winter 2011)
- Bernard Kelly, Lawrence Livermore National Lab (Fall 2010)
- Stefan Kölling, U. of Bonn/FZ, Jülich (Fall 2010)
- Teresa Peña, IST, Lisbon (Glidden Visiting Professor, Fall 2010)
- William Peters, David Walter, Oak Ridge National Laboratory (Fall 2010)
- Robert Hatarik, David Bower, Lawrence Livermore National Lab (Summer 2010)
- C. Constantinou, Stony Brook (Summer 2009-present)
- James Hall, Lawrence Livermore National Lab (Summer 2009, Spring 2010, Fall 2010, Fall 2011)
- Dany Page, UNAM (Spring 2009, Glidden Visiting Professor 2011-12)
- P. Chakraborty, U. of Minnesota (Winter 2009)
- Steve Weppner, Eckerd College (Winter 2009, 2010-11 sabbatical at OU)
- D. Chatterjee, Saha Institute, India (Fall 2008)
- Harald Grießhammer, George Washington U. (Spring 2008)
- Prashanth Jaikumar, Argonne National Lab (Spring 2008)
- James Lattimer, Stony Brook (Glidden Visiting Professor, 2008-9 additional visits in 2010-11)
- Fred Klaas, Photonis (Summer 2008)
- Tae-Sun Park, Korean Institute of Advanced Study, Seoul, Korea (Spring 2008)

- Roxanne Springer, Duke University (Glidden Visiting Professor, Spring 2008)
- Tom Barnatt, Jeff Nelson, Darrl Wittenberg, U.S. Department of Energy, Winter (2007)
- Purnendu Chakraborty, University of Minnesota (Fall 2008, Winter 2010)
- Dan Bower, Tim Meehan, George Morgan, Pete Pazuchaics, Doug Sorensen, Los Alamos National Lab (Summer 2007)
- Robert Buckles, David Fittinghoff, Ted Perry, Paul Weiss, Lawrence Livermore National Lab (Summer 2007)
- Magne Guttormsen, Sunniva Siem, Ann-Cecilie Larsen, Naeem Ul-Hasan Syed, U. of Oslo (Fall 2006)
- Wanpeng Tan, Notre Dame (Fall 2006, Winter 2007)
- S.I. Dutta, SUNY Stony Brook (Fall 2006)
- Matthew Carmel, SUNY Stony Brook (Fall 2006)
- Micheal Belbot, Thomas McKnight, Brigham Young University (Summer 2006)
- Bart Czirr, Photonis, Brigham Young University (Summer 2006, Spring 2007, Summer 2008, Fall 2011)
- Richard Sheffield, Los Alamos National Lab (Summer 2006)
- Terry Tadeucci, Los Alamos National Lab (Summer 2006, Summer 2010, Summer 2011)
- Allan Carlson, NIST (Spring, Fall 2006; Winter 2008)
- Robert Haight, Los Alamos National Lab (Spring 2006)

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 University faculty whenever possible. As great advances are generally made by intense discussions, the INPP strives for synergy between theorists and experimentalists in order to spur creativity in both groups. The description that follows emphasizes this fortunate and unbreakable connection in the physics world.

Low-Energy Experimental Nuclear Physics

This research area involves the measurement of nuclear reactions and structure on the scale of nuclear sizes (a typical nucleus is several times 10^{-13} cm). Nuclear processes in this energy range have important applications, including astrophysics, nuclear reactors, medicine, and homeland security. Our experiments utilize the in-house Edwards Accelerator Lab as well as outside facilities.

We have an active research program in the area of nuclear structure. **Andreas Schiller** has led a number of investigations into the structure of unstable neutron-rich oxygen nuclei at the National Superconducting Cyclotron Laboratory (NSCL) located at Michigan State University. Measurements of the neutron decay of the first excited state of ^{23}O indicate that it is a collective state, in which many nuclei move collectively in potential generated by an inert core. The nucleus ^{24}O has caught the eye of nuclear theorists as it is both the most neutron-rich bound oxygen nucleus and thought to be a closed shell nucleus which should make it simple to describe. On top of that, the closed neutron shell, with 16 neutrons, is one of the recently discovered "new" shell closures. As experimentalists, the goal was to measure the size of the new N=16 shell closure. In this study, the shell gap was measured to be almost 5 MeV, which clearly makes it a sizable gap, although it is slightly less than the traditional shell gaps in the valley of stability, which are on the order of 8 MeV. Still, with a 5-MeV gap, it is likely the largest of the new shell gaps. Two of our Ph.D. students are doing Ph.D. work on neutron-rich oxygen isotopes at the NSCL.

An important aspect of nuclear structure research that we are investigating is statistical nuclear physics. Essentially, this description of nuclear structure is concerned with understanding problems that are governed by many nuclear states, such that average, or statistical, properties of states can be utilized. All of the low-energy experimental faculty are involved in this work to some degree, but **Steven Grimes**, **Andreas Schiller**, and **Alexander Voinov** are particularly active in this area. Much of the work involves the measurement of continuum spectra from nuclear reactions to infer level densities. These have included some nuclei off of the stability line to look for possible differences between these nuclei and those on the stability line.

Another line of research is the study of gamma-ray strength functions, which describe how nuclei absorb photons. The study of the quasicontinuum of ^{117}Sn revealed an interesting fact. It was discovered that beside the well-known giant electric dipole resonance (a resonance in the radiative strength function at roughly 15 MeV), there is a second, weaker resonance in the region around 7 MeV. It is unclear what type of motion the newly discovered resonance corresponds to. Speculations include the oscillation of a skin of neutrons, against a core of protons and neutrons.

An innovative project in statistical nuclear physics is the development of a Hauser-Feshbach computer code for the calculation of reaction cross sections and evaporation spectra for deformed nuclei. Despite the importance of nuclei such as uranium or thorium, these nuclei are usually modeled with Hauser-Feshbach codes which assume spherical symmetry. Initial calculations with the new code indicate some significant differences between the present approach and those in the literature. Work has also continued on a project to look for $(N - Z)$ dependencies in nuclear level densities. Nuclear structure in lighter nuclei is being pursued via measurements led by **Tom Massey** of reactions on boron, iron, and nickel included by neutrons with energies between 1 and 20 MeV. The measurements are being conducted at the WNR/LANSCE facility at Los Alamos National Laboratory.

Understanding the detectable abundance of elements in the Universe is an outstanding problem in modern science that physicists, chemists, geologists and astrophysicists are all striving to solve. In many hot and dense astrophysical environments, such as type I supernovae, it is necessary to understand nuclear processes involving radioactive isotopes. Fortunately, it is possible to study these nuclear reactions in the laboratory using radioactive beams. Prof. **Carl Brune** utilizes the ^{17}F and ^{18}F beams of the HRIBF facility at Oak Ridge National Laboratory to measure cross sections of proton induced reactions on these isotopes. The reaction ^{18}F(p,α)^{15}O in the temperature range of (1-4)$\cdot 10^8$ K plays an important role in classical novae as its rate significantly affects the production of heavy elements. **Carl Brune** and graduate student **Aderemi Adekola** have recently published two papers on the ^{18}F(d, n) reaction that address these questions. Other experiments seek to better understand the fusion rate between ^{12}C and ^{4}He, which controls the abundance of carbon and oxygen in the Universe today. The Ph.D. thesis of **Daniel Sayre** investigated the role of a narrow resonance in this process at $E_{c.m.} = 2.68$ MeV. Measurements of α-transfer reactions induced by ^{6,7}Li nuclei, which provide an indirect way to study this process, are presently underway.

In the 2009-10 academic year, **Carl Brune** spent part of his sabbatical at Lawrence Livermore National Laboratory, developing nuclear physics research at the National Ignition Facility (NIF). The primary goal of this multi-billion dollar facility is to demonstrate the ignition of fusion in the laboratory for the first time. The term "ignition" in this context means that more energy is generated than is put in. This project is multi-disciplinary in nature, with key contributions coming from plasma physics, x-ray physics, laser and optics technology, and nuclear physics. Nuclear physics will provide important information about the fusion reactions that occur. We are also seeking to develop basic science experiments for the NIF, utilizing the intense neutron fluxes that are present. Some experiments at at the Edwards Accelerator Laboratory are being conducted in order to study nuclear processes which take place at the NIF.

Several projects are underway to improve our understanding of nuclear physics in important applications which may benefit society. **David Ingram** is pursuing research on the remote detection of fissile materials. This work is funded by a grant from the Defense Threat Reduction Agency, "Basic Research on Remote Sensing of Fissile Materials utilizing Gamma-rays and Neutrons." This project involves measuring the cross section of reactions that will produce photo-fission gamma rays as well reactions that will produce fast neutrons useful in the detection of fissile materials. Part of the work involves collaboration with Dr. Terry Taddeucci of Los Alamos National Laboratory in the identification of reactions for which little or no data currently exists, but which might be useful reactions.

Steve Grimes and **Tom Massey** are leading Ohio University's contribution to develop a fission time projection chamber (TPC). This is a multi-institution effort to improve our understanding of neutron-induced fission cross sections and involves Los Alamos National Laboratory, Lawrence Livermore National Laboratory, Idaho State University, and several other university partners. These measurements are needed for the next generation of nuclear power reactors. Ohio University is leading the work on improving our knowledge of the n-p elastic cross section which is needed for the absolute calibration of the measurements. Some of the TPC measurements will be performed at Ohio University in the future. **Carl Brune** and **Tom Massey** are working on another applied nuclear physics project in which the transmission of 1-10 MeV neutrons in iron is measured.

Medium- and High-Energy Experimental Nuclear Physics

In medium- and high-energy experiments, the structure of protons, neutrons, and nuclear matter are probed to reveal the structure and interactions of their constituents – the quarks and gluons. This research typically looks at structures that are smaller than the size of a proton (about 10^{-13} cm). This research is carried out at large facilities located at national laboratories, and provide outstanding opportunities for both graduate and undergraduate students to obtain hands-on experience with hardware and software tools and contribute to research at major national facilities.

The research of **Ken Hicks**, **Julie Roche**, and **Paul King** utilizes beams of electrons or photons to study the substructure of neutrons and protons. The majority of these measurements are conducted at the Thomas Jefferson National Accelerator Facility (JLab) located in Newport News, Virginia. Three quarks, two up and one down, primarily account for the proton's charge and baryon number. However, the proton's spin, mass and magnetism remain a mystery. Gluons, that mediate interactions between quark-quark and quark-antiquark pairs of all varieties, hold the key to a satisfactory explanation. This is because the proton is constantly filled with quark / antiquark pairs of not only the light up and down variety, but also by the more massive strange quark / antiquark pair. A major fundamental question is: compared to the up and down quark / antiquark pairs how much does the strange quark / antiquark pair, pried out of the sea of filled quarks of all known types, contribute to the proton's spin, mass and magnetism. A quantitative experimental answer to this question including the case of the neutron has far reaching consequences extending to the interior structure a 10 km neutron star that may contain a kaon (made of anti-up and strange quark) condensate.

The **QWEAK experiment** at Jlab, in which the INPP faculty participate actively, investigates the above fundamental issues. **Julie Roche** and **Paul King**, who joined the OU faculty in Fall 2006, are experts in the field of nuclear electro-weak physics. The QWEAK experiment is a precision measurement of the weak charge of the proton at a very low energy scale. The weak charge of the proton at various energy scales is predicted by the Standard Model of Particle Physics, and its precise value at low energy scale would be sensitive to various physics processes beyond the Standard Model. Thus QWEAK may provide a measure of the influence of new particles which would be complimentary to the direct observation at the Large Hadron Collider. The group is responsible for the data acquisition and data analysis systems for the QWEAK experiment.

Julie Roche and **Paul King** are also leading Ohio University's involvement in a measurement of Deeply Virtual Compton Scattering (DVCS) at Jlab. This experiment studies of the correlation between the momentum and spatial distribution of the quarks within the proton. This correlation provides a novel way to study the proton that bridges between two well explored avenues of nucleon studies: form factor (spatial) distributions and parton distribution (momentum) functions.

Ken Hicks continues to study the properties of mesons and baryons produced by electromagnetic interactions with protons or neutrons. Along with his students and post-doctoral researcher working with him, his group has been very prolific, producing many publications over the past few years, including two large papers on the electromagnetic decays of baryons containing a strange quark, and two short papers in the prestigious journals Physical Review Letters and Physics Letters B. Two more papers are nearing publication stage, and one of these is expected to be published in Physical Review Letters.

Ken Hicks is also the PI on a Major Research Instrumentation grant from the National Science Foundation, in addition to his regular funding from this agency. The grant is shared among four universities, with a total of nearly $700,000, and allowed the construction of a new detector for the upgrade to Hall B of Jlab. He was elected as Chair of the CLAS Collaboration, a group of about 200 physicists from around the world focused on the large-acceptance spectrometer at Jlab. His role is to oversee the transition from experiments using the CLAS detector to the upgraded CLAS12 detector that will take data starting in 2014.

When **Justin Frantz** came to Ohio University in the summer of 2008, he already had a strong involvement in the PHENIX Experiment at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory, and since arriving his involvement in that collaboration of nearly 500 international scientists has increased. His main research interests are photon and jet production in collisions of heavy nuclei at the highest achievable energies, and interactions of those probes with the Quark Gluon Plasma (QGP) that is created. After establishing his group here, he has continued pursuing analysis of PHENIX data related to these research programs. Jets, which are fast moving quarks or gluons, lose energy as they traverse the QGP, which allows the OU group and other scientist to deduce properties of this newly discovered state of matter. Foremost, the group, including especially one OU graduate student, is developing a new technique for identifying Direct Photons within QGP-producing collisions, a challenging environment that contains many false candidates. If successful, this would be a technical breakthrough. The group is also measuring correlations of Direct Photons with other particles which will make measurements of the QGP properties even more precise.

Justin Frantz became the "convener" of an important subdivision of the PHENIX Collaboration in 2009, the Hard Scattering Physics Working Group, for which he coordinates, facilitates, and approves new PHENIX results. Additionally, in 2010, he became the manager of operating one of the important PHENIX subdetectors, the Lead-Glass Electromagnetic calorimeter. In 2011, he led a group of analyzers here at OU and from other institutions on PHENIX in an important analysis and paper in which it was discovered that the QGP seen at RHIC has "lumpy" features, which were not predicted, and may allow for an even more precise understanding of the QGP properties. Most recently, the OU group has also started developing, and studying the physics of, particle detectors called calorimeters. They are currently partnering with another institution to construct a hadronic calorimeter prototype for potential use at RHIC.

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 research of **Charlotte Elster** is primarily concerned with theoretical studies of scattering and reactions of light nuclei. Investigation of reactions at high energies require novel computational approaches as the partial wave expansion usually employed to solve Faddeev equations ceases to be efficient. In addition, for momenta of the order of the nucleon mass, special relativity must be reckoned with. In order to implement the relevant symmetries, the relativistic three-body problem is treated within the framework of

Poincaré invariant quantum mechanics. Poincaré invariance is implemented as an exact symmetry realized by the use of a unitary representation of the Poincaré group on a three-particle Hilbert space.

The work of T. Lin, Elster, Polyzou (U. Iowa), and Glöckle (Ruhr-University Bochum) showed how to successfully embed the two-body interaction in a three-body frame of reference while satisfying the (instant-form) Poincaré algebra. This project formed the basis of T. Lin's Ph.D. thesis. These calculations provided new perspectives on the description of exclusive proton-deuteron (pd) breakup reactions at 508 MeV. They were able to qualitatively describe this measurement and found that in pd breakup reactions at only moderately high energies the difference between a Poincaré invariant and a Galilei invariant calculation can be an order of magnitude when considering quasi-free scattering conditions. In addition they could easily explain discrepancies between the data and calculations in plane-wave impulse approximation as being due to rescattering contributions, which are naturally contained in the Faddeev formalism. These specific findings are published in *Physics Letters B.* Furthermore, they carried out a careful study of elastic scattering, as well as inclusive and exclusive breakup reactions up to projectile energies of 2 GeV. This is an important first step for studying dynamical models of strongly interacting particles in the energy range where sub-nuclear degrees of freedom are thought to be relevant.

Daniel Phillips and Ph.D. student Deepshikha Shukla completed the first calculation of elastic Compton scattering from Helium-3. This calculation showed that this process is a good place to measure the electromagnetic polarizabilities of the neutron: fundamental quantities which parametrize the response of the neutron to applied electric and magnetic fields. This work is motivating a number of experiments at the HIGS facility at TUNL.Their paper was published in Physical Review Letters and Shukla's work was recognized by the **APS Dissertation Award** in Nuclear Physics.

Working with collaborators at the University of Bonn, **Daniel Phillips** obtained new precision results for the low-energy scattering of pions, protons, and neutrons from recent data on the spectrum of "atoms" where a negatively charged pion is bound to a proton and a deuteron. These quantities contain important information about the properties of quantum chromodynamics. Extracting the pertinent numbers from these data required a careful and detailed treatment of both few-body dynamics and violations of isospin symmetry.

The research led by **Madappa Prakash** covers topical issues in astrophysics, nuclear physics and relativistic heavy-ion physics. Topics addressed in astrophysics included the structure and thermal evolution of neutron stars, the equation of state of supernova matter and signatures of gravity wave emission from mergers of binary neutron stars. Transport properties, such as bulk and shear viscosities of interacting particles, which are central inputs to viscous hydrodynamic simulations of relativistic heavy-on collisions were investigated in detail. The most recent research that will likely have a long-standing impact are summarized below.

Ten years of Chandra observations of the neutron star "Cas A" have revealed that it is presently in a phase of rapid cooling, a behavior unobserved previously. **Prakash** and collaborators have presented a natural explanation of Cas A's cooling based on neutron superfluidity and proton superconductivity. These phenomena set in when the temperature drops below some critical temperature. They proposed that neutrons inside Cas A are presently entering the superfluid phase. During this phase transition, expected to last for several decades, the developing superfluid emits copious amounts of neutrinos inducing the rapid cooling. Being 330 yrs old, Cas A is the youngest known neutron star; no other known neutron star is young enough to observe the onset of superfluidity. From Cas A's age, they deduced the neutron p-wave superfluid critical temperature to be a half billion degrees. The star's observed high surface temperature, about 2 million degrees, and its cooling rate requires protons to be in an s-wave superconducting state. This phase transition has a larger critical temperature because it occurred previously when the star's core was warmer. This is the first direct evidence that these phenomena occur within neutron stars.

The determinations of neutron star masses has been reviewed by **Prakash** and collaborators in light of a new measurement of 1.97 $M_\odot$ for PSR J1614-2230 and an estimate of 2.4 $M_\odot$ for the black widow pulsar. Using a simple analytic model related to the so-called maximally compact equation of state, model-independent upper limits to thermodynamic properties in neutron stars, such as energy density, pressure, baryon number density and chemical potential, are established which depend upon the neutron star maximum mass. Using the largest well-measured neutron star mass, 1.97 $M_\odot$, it is possible to show that the energy density can never exceed about 2 GeV, the pressure about 1.3 GeV, and the baryon chemical potential about 2.1 GeV. Further, if quark matter comprises a significant component of neutron star cores, these limits are reduced to 1.3 GeV, 0.9 GeV, and 1.5 GeV, respectively. They also find the maximum binding energy of any neutron star is about 25% of the rest mass. Neutron matter properties and astrophysical constraints additionally imply an upper limit to the neutron star maximum mass of about 2.4 $M_\odot$. A measured mass of 2.4 $M_\odot$ would be incompatible with hybrid star models containing *significant* proportions of exotica in the form of hyperons, Bose condensates or quark matter.

Prakash has also been active in the research area of relativistic heavy-ion physics, and can be considered a theoretical counterpart to the experimental work of **Justin Frantz**. Specifically, a detailed quantitative comparison between the results of shear viscosities from the Chapman-Enskog and Relaxation Time methods is performed for the following test cases with specified elastic differential cross sections between interacting hadrons: (i) The non-relativistic, relativistic and ultra-relativistic hard sphere gas with angle and energy independent differential cross section $\sigma = a^2/4$, where a is the hard sphere radius, (ii) The Maxwell gas with $\sigma(g,\theta) = m\Gamma(\theta)/2g$, where m is the mass of the heat bath particles, $\Gamma(\theta)$ is an arbitrary function of θ, and g is the relative velocity, (iii) Chiral pions for which the $t-$averaged cross section $\sigma = 5s/(48\pi f_\pi^4)$, where s and t are the usual Mandelstam variables and f_π is the pion-decay constant, and (iv) Massive pions for which the differential elastic cross section is taken from experiments.

Quantitative results of the comparative study conducted revealed that: (i) the extent of agreement (or disagreement) depends sensitively on the energy dependence of the differential cross sections employed, stressing the need to combine all available experimental knowledge concerning differential cross sections for low-mass hadrons and to supplement it with theoretical guidance for the as yet unknown cross sections so that the temperature dependent shear viscosity to entropy ratio can be established for use in viscous hydrodynamics; and (ii) the result found for the ultra-relativistic hard sphere gas for which the shear viscosity $\eta_s = 1.2676\ k_B T\ c^{-1}/(\pi a^2)$ offers the opportunity to validate ultra-relativistic quantum molecular dynamical (URQMD) codes that employ Green-Kubo techniques.

F National/International Activities of INPP Faculty

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

Conference/Workshop Organization

- Charlotte Elster is serving on the International Advisory Committee for the *20th International IUPAP Conference on Few-Body Problems in Physics*, Fukuoka, Japan, 2012.
- Steven Grimes and Andreas Schiller organized the session on *Nuclear Level Density* at the *Gordon Research Conference on Nuclear Chemistry*, Colby-Sawyer College, New London, NH, June 12-17, 2011.
- Ken Hicks was the co-organizer of the CEBAF Large Acceptance Spectrometer collaboration meetings (2011).
- Justin Frantz organized the *Midwest Critical Mass Workshop* in 2010.
- Carl Brune, together with Lee Bernstein from Lawrence Livermore National Laboratory, organized the workshop *Neutron Capture using the National Ignition Facility* that was held March 23-25, 2010, at Lawrence Berkeley National Laboratory. This workshop was attended by approximately 50 national and international visitors.
- Daniel Phillips was a co-organizer of a program on *Simulations and Symmetries: Cold Atoms, QCD, and Few-hadron Systems* held at the Institute for Nuclear Theory at the University of Washington, March-May 2010.
- Daniel Phillips served on the International Advisory Committee for the *19th International IUPAP Conference on Few-Body Problems in Physics*, Bonn, Germany, September 2009.
- Justin Frantz serves as an organizer for the *HIP-Ohio Statewide Relativistic Heavy Ion Physics Organization*, 2009-present.
- Daniel Phillips and V. Pascalutsa organized a workshop on *Bound states and resonances in effective field theories* held at the ECT* in Trento, Italy, in October 2008.
- Daniel Phillips was a co-organizer of the workshop *Soft photons and light nuclei* held at the Institute for Nuclear Theory at the University of Washington, July 2008.

- Carl Brune, Steve Grimes, Tom Massey, Andreas Schiller, and Alexander Voinov organized the *Workshop on Statistical Nuclear Physics and Applications in Astrophysics and Technology* held at Ohio University July 8-11 2008. The workshop was co-sponsored by the Joint Institute for Nuclear Astrophysics. Approximately 50 scientists from around the world gathered to discuss research topics in the area of statistical nuclear physics.

- Madappa Prakash was a co-organizer of the 5-week summer program *The Neutron Star Crust and Surface* held at the Institute for Nuclear Theory at the University of Washington, June 18 – July 20, 2007.

- Madappa Prakash was a co-organizer of the 1-week workshop on *The neutron star crust and surface: observations and models* held at the Institute for Nuclear Theory at the University of Washington, June 25 – June 29, 2007.

- Daniel Phillips was a working group convener for the *2006 Workshop on Chiral Dynamics* held in Chapel Hill, NC (2006).

Advisory Committees

- Carl Brune served on the Nuclear Science Advisory Committee, Sub-committee on Public Access to Research Results (2011).

- Steve Grimes is member of the Program Advisory Committee of the Weapons Neutron Research Facility at Los Alamos National Laboratory (2010-12).

- Carl Brune serves on Nuclear Diagnostics Review Committee, Lawrence Livermore National Laboratory (2010-present).

- Charlotte Elster was a member of the Committee of Visitors of the NSF Directorate for Mathematical & Physical Sciences (2009).

- Daniel Phillips is a member of the Program Advisory Committee of MAX-Lab (Lund, Sweden) (2008-present).

- Charlotte Elster was an appointed member of the Nuclear Science Advisory Committee of the U.S. Department of Energy and National Science Foundation (2007-9).

- Charlotte Elster is a member of the Committee of Visitors of U.S. Department of Energy, Office of Science Nuclear Physics Program (2007).

- Charlotte Elster is a member of the National Advisory Committee of the Institute for Nuclear Theory at the University of Washington (2006-8).

Review Panels of Federal Agencies

- Carl Brune and Charlotte Elster served as a proposal reviewers for the U.S. Department of Energy Nuclear Physics Early Career Award (2011-12).

- Justin Frantz served a proposal reviewer for the National Science Foundation (2011).

- Prakash served on the visiting panel for the National Science Foundation to conduct a five-year review of the Joint Institute for Nuclear Astrophysics (Physics Frontier Center) at Notre Dame University (2010).

- Justin Frantz served on the Forward Calorimeter Review Panel for Brookhaven National Laboratory (2010).

- David Ingram has served on the National Science Foundation grant review panel for the Domestic Nuclear Detection Office–National Science Foundation Academic Research Initiative (2009-11).

- Carl Brune served on the review panel for the National Science Foundation Site Visit Panel for the National Superconducting Cyclotron Laboratory, Michigan State University (2009).

- Carl Brune served on the review panel for the U.S. Department of Energy, National Nuclear Security Agency, Center of Excellence Site Review, Oak Ridge National Laboratory (2009-10).

- Charlotte Elster was a member of the Site Visit Committee of the Natural Sciences and Engineering Research Council of Canada for the DNA Bar-coding Center at the University of Guelph (2009).

- Charlotte Elster was a member of the Natural Sciences and Engineering Research Council of Canada Panel for Major Research Support (2009).

- Charlotte Elster is member of the U.S. Department of Energy, National Nuclear Science Agency Stewardship Science Graduate Fellowship Selection Committee (2008-12).

- Ken Hicks was a member of the U.S. Department of Energy grant panel for High Energy Physics (summer 2008).

- Charlotte Elster was a member of the U.S. Department of Energy Review Panel of the Nuclear Physics Research Program and the Free Electron Laser Facility at the Triangle University Laboratory at Duke University, Durham, NC (2007-8).

- Carl Brune served on the visiting panel for the U.S. Department of Energy review the Wright Nuclear Structure Laboratory at Yale University (2006).

- Carl Brune served on the visiting panel for the National Science Foundation to conduct a five-year review of the Joint Institute for Nuclear Astrophysics (Physics Frontier Center) at Notre Dame University (2006).

Activities in Professional Organizations

- Carl Brune is a member of the Physical Review C Editorial Review Board (2011-present).
- Daniel Phillips served on the Nomination Committee of the Few-Body Topical Group of the American Physical Society (2010).
- Charlotte Elster is serving on the Bonner Prize Committee of American Physical Society, Division of Nuclear Physics (Chair: 2010-11, Vice-Chair 2009-10).
- Steven Grimes is a member of the American Physical Society Committee on International Freedom of Scientists (2009-present).
- Daniel Phillips served on the Nomination Committee for the American Physical Society, Division of Nuclear Physics (2006).
- Charlotte Elster served on the Steering Committee for the National Nuclear Physics Summer School of the American Physical Society, Division of Nuclear Physics (Member 2005-9, Chair 2007-8).
- Carl Brune served on the American Physical Society, Division of Nuclear Physics Program Committee (2005-7).
- Charlotte Elster is serving as Secretary-Treasurer and Web-Master of the Few-Body Topical Group of the American Physical Society (2003-present).

Prizes and Awards

- Carl Brune was elected as Fellowa of the American Physics Society in 2010. Only about 1% of all members of the APS can be elected Fellows each year.
- Daniel Phillips was awarded a “Mercator Professorship” from the German Research Foundation that supported his sabbatical at the Helmholtz Insitut fuer Strahlen und Kernphysik, Universitaet Bonn, Bonn, Germany (2009).
- Daniel Phillips was elected as Fellow of the American Physics Society in 2009. Only about 1% of all members of the APS can be elected Fellows each year.
- Daniel Phillips was given the Distinguished Alumni Award by Flinders University of South Australia (2008).

- Steven Grimes was selected as an Outstanding Referee by the American Physical Society, an honor given to approximately 500 of the 35,000 referees who work with the Society's journals (2008).

Courses Presented at Schools and Workshops

- Daniel Phillips, 'Effective field theory for light nuclei' at the University of Barcelona, Barcelona, Spain, June 2010.
- Carl Brune, 'Nuclear Astrophysics,' at the Exotic Beam Summer School, Oak Ridge National Laboratory, Oak Ridge, TN, August 2010, 3 lectures.
- Carl Brune, 'R-Matrix Methods and an Application to $^{12}C(\alpha,\gamma)^{16}O$,' at the 5th European Summer School on Experimental Nuclear Astrophysics, Santa Tecla, Sicily, September 2009, 2 lectures.
- Daniel Phillip, 'Effective field theory for light nuclei,' at the University of Bonn, April and May 2009, 6 lectures.
- Madappa Prakash, 'Neutron Stars I & II,' at Medium Properties, Chiral Symmetry and Astrophysical Phenomena, the Second School of Collective Dynamics in High-Energy Collisions, Berkeley, California, May 21-25, 2007, 2 lectures.
- Madappa Prakash, 'The Physics and Astrophysics of Neutron Stars' at the National Nuclear Physics Summer School, Bloomington, Indiana, July 23 - Aug 5, 2006, 5 lectures.
- Carl Brune, 'Nuclear Astrophysics,' at the School-cum-Workshop on Low Energy Nuclear Astrophysics, Saha Institute of Nuclear Physics, Kolkata, India, January 16-20, 2006, 3 lectures.

Visiting Appointments

- Carl Brune, Faculty Scholar, Lawrence Livermore National Laboratory, September 2009-March 2010.
- Charlotte Elster, Visiting Faculty, Ohio State University, Winter 2009.
- Charlotte Elster, Visiting Faculty, Instituto Superior Técnico, Deptartment of Physics, Lisbon, Portugal, Winter 2009.
- Charlotte Elster, Visiting Faculty Scholar, Institute of Modern Physics, CAS, Lanzhou, China, September 2008.
- Charlotte Elster, JUSTIPEN Fellow, Nuclear Science Research Center at RIKEN, summer 2008 and December 2011.

- Daniel Phillips, Visiting Researcher, University of Manchester, July 2008-October 2008.
- Daniel Phillips, Visiting Professor, Helmholtz Insitut fuer Strahlen und Kernphysik, Universitaet Bonn, Bonn, Germany, March 2009-July 2009.

Other Activities

- Ken Hicks writes a monthly column for the Columbus Dispatch, which continues to be published in spite of cutbacks at daily papers.
- Justin Frantz was quoted in Columbus Dispatch article "Mothballed (but not finished)," by Spencer Hunt, October 9, 2011.
- Ken Hicks also pursues research in Mathematics and has published several papers in this field. His most recent work in this area will be published in the April 2012 issue of American Mathematical Monthly.

G The Edwards Accelerator Laboratory

The primary nuclear physics experimental facility at Ohio University is the 4.5-MV tandem van de Graaff accelerator located in the Edwards Accelerator Laboratory. This machine is equipped with a sputter ion source and a duoplasmatron charge-exchange ion source for the production of proton, deuteron, ^{3,4}He, and heavy ion beams. Pulsing and bunching equipment are capable of achieving 1-ns bursts for proton and deuteron beams, 2.5-ns bursts for ^{3,4}He beams, and 3-ns bursts for ^{7}Li. The accelerator has functioned very reliably over the five years; since January 1, 2005, a total of 13,610 hours have been logged on the machine.

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. Several types of neutron detectors are available, including lithium glass and NE213. Three intrinsic Ge detectors are available for high-resolution γ-ray studies (two coaxial detectors of 40% and 75% relative efficiency and one 15-mm-thick$\times$2000-mm^2-area planar detector). Two 10.2-cm-diameter $\times$ 10.2-cm-length BGO and one 5.1-cm-diameter $\times$ 5.1-cm-length Lanthanum Bromide scintillators are also available for gamma-ray detection. A scattering chamber is available for Rutherford backscattering measurements and other charged-particle measurements. A time-of-flight spectrometer is also available for charged-particle studies. Finally new beamline for γ-ray spectroscopy studies available.

The Edwards Accelerator Laboratory building is well supplied with computational resources. Every student, postdoc, staff member, and faculty member has a modern PC-based computer system (Linux, Mac, or Windows operating system) on their desk. Many additional computers are available for special purposes (e.g. data acquisition, data analysis).

Several new Intel "Core i7" processor systems were purchased to replace some ageing computer systems and enhance our computer capabilities. These systems were also fully expanded with RAM (12 GBytes) to allow programs requiring large amounts of memory to run without swapping to disk.

Several new standalone DAQ systems were placed in operation for new experiments. DAQ software has also been enhanced to allow new hardware and add new features. We also have a "Distributed DAQ" data acquisition system which consists of up to 15 dual-PC nodes connected via ethernet to a central computer used for system control and data display. Each node is an independent computer with Distributed DAQ hardware that is dedicated to a single detector or detector-telescope system. This system is running the Linux version of the Ohio University DDAQ software [1]. The Distributed DAQ hardware consists of a board with two charge-to-time converters (MQT300A) and one multi-hit eight-channel time-to-digital converter (MTD133B) from LeCroy. The charge converter

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

has 3 selectable ranges and an optional variable range. Each charge converter has a maximum dynamic range of over 500. This system can operate at high data rates, has excellent time stability, and eliminates cross talk between detectors. It is particularly advantageous for time-of-flight experiments.

Pelletron Upgrade:

A critical component of the accelerator is the charging system, which supplies the current that maintains the high voltage. The belts for the original charging system were no longer available from High Voltage Engineering Inc., as that company is no longer in business and was unsuccessful at transferring the belt making process to another company, or to High Voltage Europa, based in the Netherlands, who took over the rest of their business for spare parts. The lifetime of a new belt is typically 1-2 years under our normal operating conditions. We have exhausted our supply of new original belts.

Due to the diligent efforts of technical staff members Don Carter and Devon Jacobs, we were sucessfully able to utilize belts manufactured by Siegling Incorporated that were designed for unrelated industrial applications. However, the use of the Siegling belts has been in several respects sub-optimal. One problem was that the Siegling belts have a seam, which introduces an instability into the ion beam energy and leads to a loss of beam intensity and also makes beam tuning more difficult. This situation leads to a significant loss of useable beam for experiments which require tuning the beam through small aperatures. Another problem was that the Siegling belts are thinner and less robust than the original belts and can be ruined by a single spark. In addition, Siegling cannot guarantee that the belts that they supply will be manufactured consistently.

Consequently, we have sought to upgrade our charging system to the more modern and superior Pelletron design produced by the National Electrostatics Corporation (NEC). A grant application to the National Science Foundation was **sucessful** in obtaining $321,000 that covered nearly the entire cost of the upgrade. The upgrade was completed in January 2012 and the accelerator has been sucessfully tested up to a terminal voltage of 4.0 MV. An Ohio University Research Communications story on the project can be read here:

`http://www.ohio.edu/research/communications/accelerator.cfm`

It should be noted that, in spite of the belt difficulties noted above, the accelerator performed very well over the past five years, logging over 2,000 hours per year for each calander year. We expect the upgrade will only serve to enhance our productivity in future years.

Refurbishment with URP/INPP Funds:

As part of the URP enhancement of our facilities, $100K was allocated over 5 years for upgrading the Edwards Accelerator Laboratory ($50K from the URP and $50K INPP).

In year one we addressed the gas compressor which is used to transfer sulfur hexafluoride (SF-6) gas to and from a storage tank when the accelerator needs maintenance. The compressor had been leaking considerably - we estimated the cost in lost SF-6 to be $3K

/ year. The refurbishment was carried out by the Norwalk Compressor Company at a cost of $23,457.

In year two we have purchased the following items for accelerator monitoring and control:

- 3 Agilent Multifunction Switches (34980A)
- 2 Agilent 40-channel Multiplexers (34921A)
- 1 Agilent 40-channel Reed Multiplexer (34923A)
- 2 Agilent 4-channel D/A Converters (34951A)
- 6 Agilent terminal blocks

We are currently able to control all magnet power supplies by computer. In addition we are continuously logging approximately 65 streams of data from various devices in the laboratory (typically currents, voltages, pressures, or temperatures). These data is made available to the accelerator operator in the control room. Data are accumulated weekly, then archived, and a new data set is started. A two-hour graph of the monitored parameters can be viewed online at

http://edwards1.phy.ohiou.edu/~carterkde/tandem/tandem.html

at any time. This feature allows the accelerator technicians and scientists to monitor machine performance from anywhere with internet access (e.g. from home on the evenings or weekends). The logged parameters are stored forever in a database which can be queried. No purchases of computers, networking hardware, or software have yet been necessary. All software was written for Linux/X-Windows in-house. One particularly unique aspect of the logging system is the use of wireless networking to deliver data from the 40-kV ion source platform.

In year three, we have purchased several resistors for the accelerator column. We also purchased a straddle truck. This item can be used as a forklift to move heavy items in the laboratory and can also be used to lift a person so that elevated items (such as ceiling lights) can be accessed. The straddle truck is very helpful for organizing equipment which is not presently being utilized.

In the fourth year of funding, significant progress has been made by upgrading the vacuum infrastructure at the Edwards Accelerator Lab. The particles must be accelerated under high vacuum, else these particles would collide with air molecules resulting in substantial beam loss and excess radiation. A pair of 15 year-old vacuum pumps on the low-energy side of the accelerator was replaced with a pair of modern CTI cryopumps and a CTI helium compressor. A failure in the pumping system causes a loss of vacuum which takes at least six hours to restore, assuming that the failure can be diagnosed and fixed quickly, and repeated failures can significantly delay the experimental schedule. Hence, it is important to have reliable, up-to-date pumping systems such as the newly installed CTI instruments. This is especially true when outside users, such as paying customers like Lawrence Livermore National Lab, travel to OU to do experiments on a fixed schedule.

In the final year of funding, three rotary vacuum pumps were purchased. These replaced pumps which are more than 30 years old, which were failing. These pumps are used to remove most of the air inside beam pipes, from atmospheric pressure until specialized high vacuum equipment can be engaged. Parts for the failing pumps were no longer available from the manufacturer, and these old pumps were taking longer and longer to get to the point where high-vacuum pumps could be engaged. The new pumps have oil traps which significantly reduce contamination of pump-oil in the beam lines, thereby providing better high-vacuum (and less beam loss) for the accelerated beam.

In addition, several bulky old monitors were replaced with flat-screen monitors in the control room of the accelerator (one with SoU funds, others with INPP funds). The new monitors take up less space and are significantly more energy efficient. Also the new flat-screen monitors have a longer expected lifetime. The new screens are used to monitor the operation of the accelerator, including the magnet currents and vacuum readings. There are many monitors in use in the control room, so this upgrade significantly improves both available space and power use in the control room, in addition to presenting a more modern view during frequent tours of the accelerator to prospective students.