GRADUATE STUDIES
2015

NSCL

NATIONAL SUPERCONDUCTING CYCLOTRON LABORATORY

nscl.msu.edu

TABLE OF CONTENTS

Portions of this brochure were adapted from the Department of Chemistry at Michigan State University. Some images provided by NASA.

National Superconducting Cyclotron Laboratory
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Operation of NSCL as a national user facility is supported by the Experimental Nuclear Physics Program of the U.S. National Science Foundation.

1. DIRECTOR'S WELCOME

Konrad Gelbke, NSCL Director

- NATIONAL SCIENCE FOUNDATION-FUNDED USER FACILITY: WORLD-LEADING FACILITY FOR THE PRODUCTION AND STUDY OF RARE ISOTOPES
- LARGEST UNIVERSITY CAMPUS-BASED NUCLEAR SCIENCE LABORATORY IN THE UNITED STATES – ONE OF THREE U.S. FLAGSHIP USER FACILITIES IN NUCLEAR SCIENCE, AND THE **ONLY ONE LOCATED ON A UNIVERSITY CAMPUS**
- GRADUATE PROGRAM **IN NUCLEAR PHYSICS RANKED NO. 1** BY U.S. NEWS AND WORLD REPORT
- EDUCATES 10% OF ALL U.S. NUCLEAR SCIENCE DOCTORAL STUDENTS WITH AN AVERAGE TIME TO **PHD AWARD OVER A YEAR FASTER THAN THE NATIONAL AVERAGE**
- LARGEST NUCLEAR SCIENCE FACULTY IN THE NATION ENABLES RESEARCH OPPORTUNITIES IN MANY AREAS OF RARE ISOTOPE RESEARCH

I have worked in nuclear science for most of my life and have seen tremendous advances since my early student days some 40 years ago. Experiments we could not dream of doing then are possible today, and the field is poised for major breakthroughs due to recent advances in accelerator technology and experimental equipment.

During the past half-century, nuclear science research essentially was confined to nuclei close to the line of beta stability, but soon thousands of new, short-lived nuclei (rare isotopes) will become accessible to experimental research – nuclei with unusual proton-to-neutron ratios that play an important role in the ongoing nucleosynthesis in the cosmos and whose often unexpected properties we do not know and cannot predict. NSCL is a pioneer in this new field of rare isotope research and has world-unique capabilities. In addition, MSU is in the process of establishing the next generation Facility for Rare Isotope Beams (FRIB) as a national user facility for the U.S. Department of Energy Office of Science. FRIB is designed as the most powerful rare isotope beam facility in the world and MSU is poised to become the world-hub for rare isotope scientists. FRIB will open a vast terrain of unchartered science to experimental investigations. Substantial discoveries and breakthroughs in nuclear theory will almost certainly result as NSCL and subsequently FRIB push the envelope at the sensitivity frontier of field.

Progress in rare isotope research is rapid and high-tech. Many innovative and creative new concepts are continually being developed and put into immediate use for experiments at NSCL and later at FRIB.

As a campus-based national user facility, the laboratory offers unparalleled education and research opportunities to graduate students, who routinely meet and work side by side with leading researchers in nuclear physics, nuclear astrophysics, nuclear chemistry, accelerator physics and engineering, plus related instrumentation and societal applications.

There is no better way to jump-start a career in science than learning and working at a world-leading user facility that attracts scientists from all over the world in the pursuit of their research.

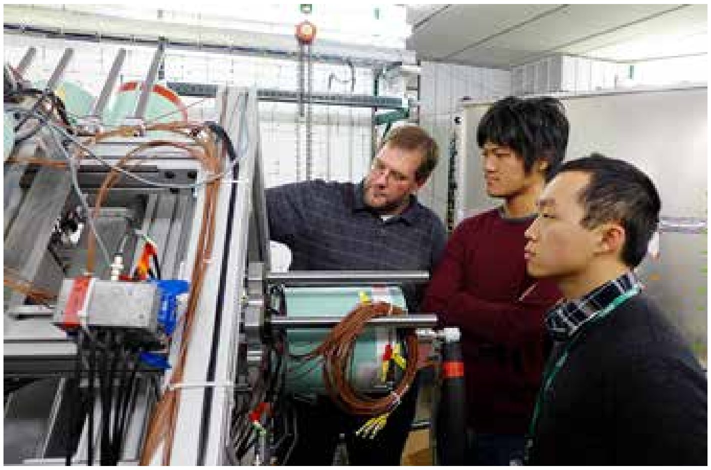
Konrad Gelbke, Director

2. NUCLEAR SCIENCE

To probe the mysteries of an atom's nucleus is to seek answers to some of the most fundamental of questions about how the elements were formed and what keeps nuclei together. Nuclear science pursues these big questions by colliding and examining the tiniest of particles. In collisions at half the speed of light, new isotopes are created in a billionth of a trillionth of one second. To do this, scientists need particle accelerators, state-of-the-art computers and specially designed equipment.

Research at NSCL concentrates on the study of exotic nuclei, one of the current frontiers in nuclear science. Compared to the more familiar stable nuclei, these exotic nuclei have large excesses of either protons or neutrons and tend to decay quickly, sometimes within fractions of seconds. Experimental groups use the world-leading capabilities of the coupled cyclotrons at NSCL to produce exotic nuclei through fragmentation of accelerated stable nuclei that bombard a solid target. The exotic fragments are transported to the experimental stations within hundreds of nanoseconds, where a wide range of experiments can be carried out using state-of-the art equipment.

Some experiments determine the existence of a particular nucleus for the first time, while others stop the nuclei to study their decay or to measure their mass. Other experiments have the exotic nuclei bombard another target and study the ensuing nuclear reactions revealing information about the internal structure of the nucleus, or the behavior of nuclear matter during the extreme temperatures and densities encountered in a nuclear collision.



All these experiments have revealed many surprising properties of exotic nuclei and many more remain to be discovered.

Coming additions to the lab's capabilities will reaccelerate beams of rare isotopes after they have been slowed down in order to precisely study reactions at energies important to astronomical phenomena.

NSCL theorists are working closely with experimentalists to interpret these results and to use exotic nuclei as probes to uncover hidden aspects of the nuclear force that holds together all atomic nuclei. Understanding this force and building a nuclear theory that can predict its properties is one of the ultimate goals in nuclear science.

Exotic nuclei also play an important role in astrophysics. They are created in stellar explosions such as X-ray bursts and supernovae, and they might exist inside neutron stars. Often, the decays of exotic nuclei are intermediate steps in the astrophysical processes that created the elements in nature. Many NSCL groups work at the intersection of nuclear physics and astrophysics to address open questions raised by astronomical observations concerning the origin of the elements, the nature of stellar explosions and the properties of neutron stars.

3. GRADUATE STUDENT LIFE

Graduate students at NSCL have outstanding opportunities to do research at a national laboratory located on the campus of a major research university. The strong interaction between the experimental and theoretical scientists and the frequent visitors and users of the facility creates an open and academically stimulating atmosphere. NSCL is widely recognized for its cutting-edge research in nuclear science, nuclear astrophysics, accelerator physics and engineering. As evidenced by a large number of publications in high-quality refereed journals and invited talks at national and international conferences. Most graduate students are financially supported with research assistantships when working on thesis projects. Exceptional students can be awarded an NSCL fellowship.

As the premier rare isotope facility in the U.S. for the next decade, NSCL and FRIB are a high national priority, as expressed in the recommendations in the 2007 Long Range Plan of the DOE/NSF Nuclear Science Advisory Committee. Experimental and theoretical insight gained at FRIB will lead to a comprehensive description of nuclei, elucidate the origin of the elements in the cosmos, provide an understanding of matter in the crust of neutron stars, and establish the scientific foundation for applications of nuclear science to society.

Graduate students in experimental nuclear science will be involved in all aspects of performing an experiment at NSCL: writing a proposal which will be reviewed by an external Program Advisory Committee, designing an experiment, setting up the hardware, writing data acquisition and analysis code, analyzing and interpreting the results, and finally writing a manuscript for a peer-reviewed journal. Theory students have access to world experts who frequently visit the laboratory and collaborate closely with local faculty. Students in accelerator physics participate in the development of state-of-the-art technologies to create and manipulate beams of charged particles and greatly benefit from the in-house expertise and resources associated with the running of the Coupled Cyclotron Facility and the newly constructed Reaccelerator, as well as the development of FRIB.

Our graduate students routinely present their new results at important national and international conferences. This provides exposure to senior colleagues and helps in finding new job opportunities after graduation. Graduate students take an active part in the organization and daily business of NSCL, and are represented on most laboratory committees. NSCL graduate students administer their own office space, meet weekly, and organize their own seminar series. They also contribute to many of the outreach activities offered through NSCL and participate in the governance process of the College of Natural Science and the Council of Graduate Students.

NSCL graduate students also are encouraged to participate in some of the many student organizations at MSU, such as Women and Minorities in the Physical Sciences (WaMPS), an all-inclusive organization founded by NSCL students and generously supported by the Physics and Astronomy department and NSCL. Dedicated to supporting and promoting the participation of underrepresented groups in science, WaMPS activities include an undergraduate mentoring program, monthly meetings to discuss topical news items, semi-annual social events, informal networking lunches with seminar speakers and local faculty, and professional development workshops. WaMPS membership and activities are open to all graduate students, and active participation can provide valuable leadership training and service opportunities.

NUMBER ONE
NUCLEAR SCIENCE
GRADUATE PROGRAM
IN THE UNITED STATES

4. NSCL

Imagination, creativity and scientific knowledge are the lifeblood of nuclear physics research, but the equipment is the skeleton that brings form and substance to research. NSCL has been at the forefront of developing technology that makes nuclear science a reality.

Beams of atomic nuclei begin as ions in an ion source that then are accelerated in the K500 and K1200 cyclotrons. After fragmenting on a target, the rare isotopes, which are our specialty, are selected by the A1900 fragment separator. When the beam of rare isotopes reaches its destination, the reaction products are either measured with special detectors, or cooled before being measured or reaccelerated.

For example, the S800 spectrograph can identify the exotic fragments produced and measure their energies. Protons and light atomic nuclei are measured and studied in various charged particle detectors, including the high-resolution silicon strip detector array HiRA. Neutrons are studied with the neutron emission ratio observer NERO, the low energy neutron detector array LENDA, and the modular neutron array MoNA-LISA. Gamma-rays are detected in the segmented germanium array SeGA and the scintillation array CAESAR. The rare isotopes also can be stopped and their properties studied with the low energy beam ion trap LEBIT, the beta counting system BCS, and in the beam cooler and laser spectroscopy endstation BECOLA. The construction of the ReA facility for experiments with reaccelerated rare isotope beams will open up completely new opportunities and new detector systems are being developed for that purpose.

NSCL has complete electronics and mechanical engineering departments and a modern machine shop equipped with a variety of CNC machines capable of building complex parts for experimental equipment.

If you need something for your research project, the purchasing department at NSCL is there to help. Purchasing approval, placement of an order, and receiving are all handled in-house – saving a lot of time.

Graduate students will work on personal desktop computers and have access to the NSCL linux clusters, as well as to MSU's high performance computing center.

Additionally, students benefit from strong National and International Collaborations, for example the Joint Institute for Nuclear Astrophysics (JINA-CEE) and the Mesoscopic Theory Center (MTC). In addition, several NSCL faculty are members of the NUCLEI (NUclear Computational Low-Energy Initiative) SciDAC project or the Center of Excellence for Radioactive Ion Beam Studies for Stewardship Science.

5. LAB HISTORY & FUTURE PLANS

Nuclear physics research began at Michigan State University in 1958. In the decades that followed, MSU became known, both in the United States and worldwide, for its innovations in nuclear science and associated cross-disciplinary research. Major contributions have been made in the fields of nuclear structure, nuclear astrophysics, heavy-ion reaction mechanisms, accelerator physics, beam dynamics and experimental techniques.

NSCL is the source of innovations that improve lives. A medical cyclotron built by the laboratory in the 1980s was used to treat cancer patients at Harper University Hospital in Detroit for more than 15 years. More recently, NSCL technology and design were used in a new, higher-powered medical cyclotron built by Varian Medical Systems. The collaboration agreement, an example of technology transfer that returns benefits to the university, will bring more advanced nuclear therapy to cancer patients in several countries.

Over the years, NSCL has evolved into the largest campus-based nuclear science facility in the country. Today, the laboratory has close to 600 employees, including 42 faculty and about 140 students, half of them in doctoral programs. MSU awards approximately 10 percent of the nation's nuclear science doctorates and, according to U.S. News & World Report, is the number one program in nuclear physics graduate education. The laboratory also offers several programs designed to give undergraduates meaningful, hands-on research experiences. Several dozen undergrads participate in such programs annually.

In December 2008, the U.S. Department of Energy announced the selection of Michigan State University to design and establish the Facility for Rare Isotope Beams (FRIB). Currently being constructed, the facility will provide intense beams of rare isotopes for a wide variety of studies in nuclear structure, nuclear astrophysics and nuclear theory. FRIB will impact the study of the origin of the elements and the evolution of the cosmos, and offers many opportunities for exploring the limits of nuclear existence and identifying new phenomena, with the goal of constructing a broadly applicable theory of nuclei. By creating exotic nuclei that have previously existed only in stellar explosions, FRIB will offer key input for models that describe stellar evolution and other astrophysical phenomena which will help us understand the origin of the elements and the processes that drive galactic chemical evolution. FRIB is anticipated to be completed early in the next decade. Experiments performed at NSCL not only serve to make new discoveries now, but also are used to prepare the tools and methods for the next-generation experiments at FRIB. NSCL extends the frontiers of nuclear science, and enhances the nation's workforce as it trains the next generation of science and technology professionals.

6. CAREERS

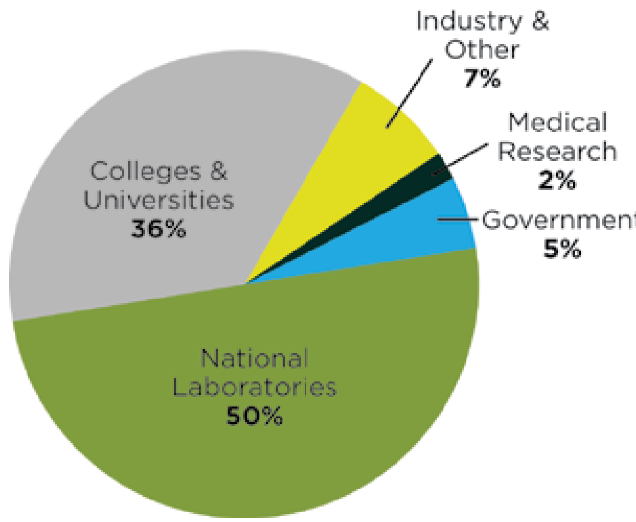
Your success as a graduate student is important to us. Our graduates are in high demand, and they are the best testimony to the quality of our top- ranked graduate education program.

As a nuclear or accelerator physicist, engineer, or nuclear chemist educated at NSCL, you are well positioned to pursue a variety of career paths. You are expertly trained to do research at a university, at a national laboratory or in an industrial setting. You are well-qualified to teach at a small college or a large university. You can pursue science policy or specialize in business. You can work for the U.S. Patent Office, on Wall Street or at Mayo Clinic. If you are not sure which direction to take, we have a large network of NSCL alumni who will gladly speak with you about their professions.

NSCL graduates now occupy many important positions at universities, national laboratories and the private sector, making valuable contributions to society in many different areas. For example, recent NSCL graduates now work on cancer therapy, airport anti-terrorist safety, environmental protection, weapons safeguards, national security, nuclear fusion and radiation safety of space travel. Others have chosen careers where they apply their problem solving and goal-oriented teamwork skills in diverse areas of the economy, including car manufacturing, electronics, computing and finance.

The Statistical Research Center of the American Institute of Physics disseminates data on education and employment in physics and related fields. The center publishes reports on common career paths, workforce dynamics, salaries and employment prospects. The reports and additional statistical data can be found at www.aip.org/statistics/

Employment of NSCL PH.D.s since 2010



7. ADMISSIONS

NSCL is committed to providing the highest quality graduate education in nuclear science, nuclear astrophysics, accelerator physics and related instrumentation technologies. The degree requirements and curricula differ, depending on whether you matriculate in the Department of Chemistry, Department of Physics & Astronomy or the College of Engineering. We refer you to the corresponding departments for application procedures and admission, course and degree requirements.

Based on your background, the Graduate Advisors in each department will put together an individual curriculum for you. Students accepted into the graduate program at NSCL receive teaching or research assistantships. At NSCL, your first contact point is the Associate Director for Education who will discuss with you the various options and opportunities for research topics. He will continue to serve as contact between you, NSCL and your respective department for the duration of your thesis studies.

Graduate students at NSCL will perform their research under the guidance of a faculty member. NSCL faculty can serve as the direct thesis supervisor as they have either joint or adjunct appointments at one of the departments. The research environment at NSCL is collaborative and the connection between individual research groups is strong. For example, within a collaboration a professor in the Department of Physics & Astronomy can supervise a chemistry student and vice versa.

After you choose your area of research, you will form your guidance committee, which will meet with you at least once a year to ensure satisfactory progress towards your degree.

All NSCL graduate students actively participate in Research Discussion, Nuclear Seminars, Departmental Colloquia and the daily laboratory business. Essential to a doctoral degree is that you develop and then demonstrate the ability to conduct vital, independent research. To become an independent researcher, you will need to develop a set of proficiencies. After you advance to Ph.D. candidacy, it usually takes two to four years to complete the original research that forms the basis for your dissertation.

MSU AWARDS APPROXIMATELY

10%

OF THE NATION'S NUCLEAR SCIENCE

DOCTORATE DEGREES

8. FACULTY LIST

Wolfgang Bauer
Theoretical Nuclear Physics

Daniel Bazin
Experimental Nuclear Physics

Scott Bogner
Theoretical Nuclear Physics

Georg Bollen
Experimental Nuclear Physics

Alex Brown
Theoretical Nuclear Physics

Edward Brown
Theoretical Nuclear Astrophysics

Paul Chu
Accelerator Physics & Engineering

Pawel Danielewicz
Theoretical Nuclear Physics

Alberto Facco
Accelerator Physics & Engineering

Alexandra Gade
Experimental Nuclear Physics

Konrad Gelbke
Experimental Nuclear Physics

Thomas Glasmacher
Experimental Nuclear Physics

Ulrike Hager
Experimental Nuclear Astrophysics

Morten Hjorth-Jensen
Theoretical Nuclear Physics

Hironori Iwasaki
Experimental Nuclear Physics

Zach Kohley
Nuclear Chemistry

Daniela Leitner
Experimental Nuclear Physics

Sean Liddick
Nuclear Chemistry

Steven Lund
Accelerator Physics

Bill Lynch
Experimental Nuclear Physics

Paul Mantica
Nuclear Chemistry

Wolfgang Mittig
Experimental Nuclear Physics

Kei Minamisono
Experimental Nuclear Physics

Dave Morrissey
Nuclear Chemistry

Oscar Naviliat Cuncic
Experimental Nuclear Physics

Filomena Nunes
Theoretical Nuclear Physics

Witold Nazarewicz
Theoretical Nuclear Physics

Scott Pratt
Theoretical Nuclear Physics

Kenji Saito
Accelerator Physics

Hendrik Schatz
Experimental Nuclear Astrophysics

Bradley Sherrill
Experimental Nuclear Physics

Jaideep Singh
Experimental Atomic & Nuclear Physics

Artemis Spyrou
Experimental Nuclear Physics

Andreas Stolz
Experimental Nuclear Physics

Michael Syphers
Accelerator Physics

Michael Thoennessen
Experimental Nuclear Physics

Betty Tsang
Experimental Nuclear Physics

Jie Wei
Accelerator Physics & Engineering

Gary Westfall
Experimental Nuclear Physics

Christopher Wrede
Experimental Nuclear Astrophysics

Yoshishige Yamazaki
Accelerator Physics & Engineering

Remco Zegers
Experimental Nuclear Physics

Vladimir Zelevinsky
Theoretical Nuclear Physics

Wolfgang Bauer

University Distinguished Professor of Physics

Theoretical Nuclear Physics

M.S., Physics,
University Giessen,
1985

PhD, Physics,
University Giessen,
1987

Joined NSCL in
October 1988

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Selected Publications

Zipf's Law in Nuclear Multifragmentation and Percolation Theory, K. Paech, W. Bauer, and S. Pratt, Phys. Rev. C 76, 054603 (2007)

Modeling Nuclear Dynamics and Weak Interaction Rates During the Supernova Collapse Phase, T. Strother and W. Bauer, Prog. Part. Nucl. Phys. 468 (2009)

Fragmentation and the Nuclear Equation of State, W. Bauer, Nucl. Phys. A787, 595c (2007)

Cancer Detection on a Cell-by-Cell Basis Using a Fractal Dimension Analysis, W. Bauer and Ch.D. Mackenzie, Heavy Ion Physics 14, 39 (2001)

Common Aspects of Phase Transitions of Molecules, Nuclei, and Hadronic Matter, W. Bauer, Nucl. Phys. A681, 441 (2001)

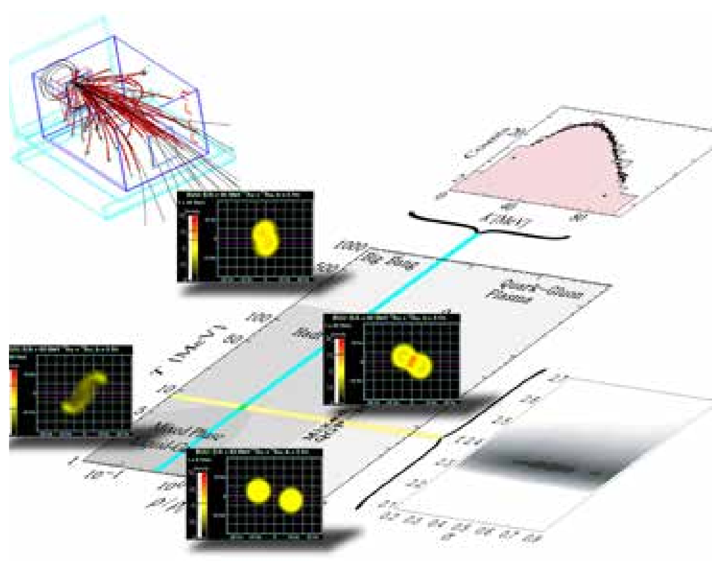
I am a theoretical physicist and work mainly on phase transitions in nuclear systems, on transport theory for heavy ion collisions, and on the determination of the nuclear equation of state. Much of my work is in close connection with experimentally accessible observables, and I have enjoyed many collaborations with my experimental colleagues from NSCL and around the world. Approximately one half of my roughly 120 publications in peer-reviewed journals are collaborations with experimentalists.

During the last few years I have found out that many advances in one particular field of science can be applied in an interdisciplinary way. One example is my application of algorithms developed in my work on nuclear fragmentation to the detection of cancer cells in human bodies. Another example is the application of our methods to solve the transport problem for heavy ion collisions to the dynamics of supernova explosions. This project is still ongoing and first results look very promising.

I also have worked on chaos, non-linear dynamics, and self-organized criticality. All of these areas of study have applications to nuclear physics, but also to a great range of other systems, from molecules to traffic flow, and from the stock market to the weather.

Finally, I am interested in research on teaching and learning. Here I have a long-standing collaboration that has produced the LON-CAPA course management and learning system, which is now in use at over 100 universities, colleges, and high schools around the country and in several other countries around the world.

For the near future I am planning on a continuation of the work on nuclear fragmentation, as well as the transport problem for supernova explosions. In addition, I have become interested in the physics of double β decay and the hunt for a neutrino-less double-β decay mode, which would overthrow the standard model of particle physics. I also am continuing my practice of tight collaborations with my experimental colleagues at NSCL by working on the physics case for a time projection chamber experiment for the next upgrade of the accelerator complex at NSCL.



Using transport theories and models of phase transitions to determine the nuclear matter phase diagram.

Daniel Bazin

Senior Physicist& Adjunct Professor

Experimental Nuclear Physics

Selected Publications

The program LISE: a simulation of fragment separators, D. Bazin, O. Tarasov, M. Lewitowicz and O. Sorlin, Nuclear Instruments and Methods in Physics Research A 482, (2002) 307

New direct reaction: two-proton knockout from neutron-rich nuclei, D. Bazin, B. A. Brown, C. M. Campbell, ..., Physical Review Letters 91, (2003) 012501

Mechanisms in knockout reactions, D. Bazin, R. J. Charity, R. T. de Souza, ..., Physical Review Letters 102, (2009) 232501

Prototype AT-TPC: Toward a new generation active target time projection chamber for radioactive beam experiments, D. Suzuki, M. Ford, D. Bazin, W. Mittig, ..., Nuclear Instruments and Methods in Physics Research A 691 (2012) 39

B.S. Physics
National Institute
for Applied Science,
Rennes, France
1984

PhD, Nuclear Physics
University of Caen,
France
1987

Joined NSCL in 1994

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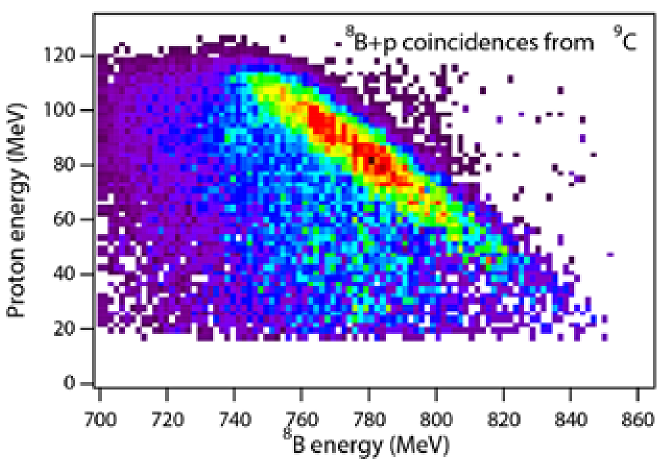
The focus of my research is centered on the study of exotic nuclei and the most efficient ways to unravel their properties. It is now well established that these radioactive nuclei - which depart from the usual balance of the number of protons and neutrons - have very different properties than the stable ones. Their structures, shapes and modes of excitation can reveal new phenomena, such as haloes or molecular states for instance, that are essential to our understanding of the forces that bind nuclei together via comparison with theoretical models. Finding the most sensitive and relevant experimental methods to reveal these phenomena has been the focus of my career since its beginning.



This two-dimensional spectrum shows events recorded during a knockout reaction where a proton was removed from a 90 MeV/u Carbon-9 projectile. The energies of the resulting Boron-8 (horizontal) and proton (vertical) show two distinct regions corresponding to elastic and inelastic breakup processes.

More specifically, I am conducting an experimental program aimed at using and studying in detail one of the most successful type of reactions used to study the structure of very rare exotic nuclei. These so-called knockout reactions are peripheral collisions where one or two nucleons at most are removed from a fast moving projectile. The aim of my program is to understand the reaction mechanisms that take place during such collisions, and validate the theory that is used to model them in order to deduce useful information on the structure of both the projectile and residual nuclei. A very interesting use of knockout reaction that I am pursuing is to map the wave function composition of light nuclei located in the p-shell, for which calculations from first principles are now available. Studying these light radioactive isotopes, several of them at the edge of being unbound, is paramount to test these new theories and guide their development.

In addition to fast beams and knockout reactions techniques, I am developing a new type of detector particularly well designed for lower energy collisions, such as transfer reactions or resonant scattering for instance. Low energy reactions require the use of very thin targets to preserve the characteristics of the emitted particles. This severely limits the sensitivity of such measurements, as the low number of nuclei in the target must be compensated by large intensities in the beams. The Active Target Time Projection Chamber, or AT-TPC, is a novel type of detector where the gas volume is at the same time a target and a detector medium. By literally detecting the reaction within the target itself, this new technique alleviates the shortcomings of the traditional solid target method. This detector is especially well suited for the future radioactive re-accelerated beams of the ReA3 linear accelerator, planned to be operational by the end of 2013. The AT-TPC is expected to be ready for experiments at about the same time.

Scott Bogner

Associate Professor of Physics
Theoretical Nuclear Physics

B.S., Nuclear Engineering, University of Cincinnati, 1996

PhD, Theoretical Physics, SUNY Stony Brook, 2002

Joined NSCL in July 2007

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Selected Publications

In-Medium Similarity Renormalization Group for Open-Shell Nuclei, K. Tsukiyama, S.K. Bogner and A. Schwenk, Phys.Rev. C 85, 061304 (2012).

Testing the density matrix expansion against ab-initio calculations of trapped neutron drops, S.K. Bogner et al., Phys. Rev. C 84, 044306 (2011).

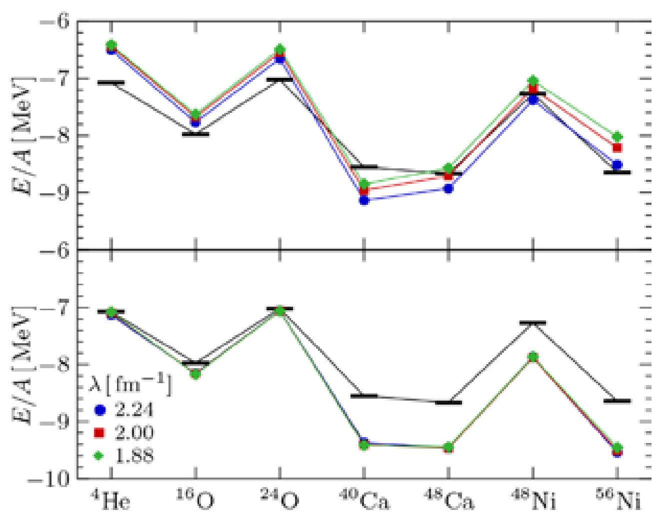
In-medium similarity renormalization group for nuclei, K. Tsukiyama, S.K. Bogner and A. Schwenk, Phys. Rev. Lett. 106, 222502 (2011).

From low-momentum interactions to nuclear structure, S.K. Bogner, R.J. Furnstahl and A. Schwenk, Prog. Part. Nucl. Phys. 65, 94 (2010).

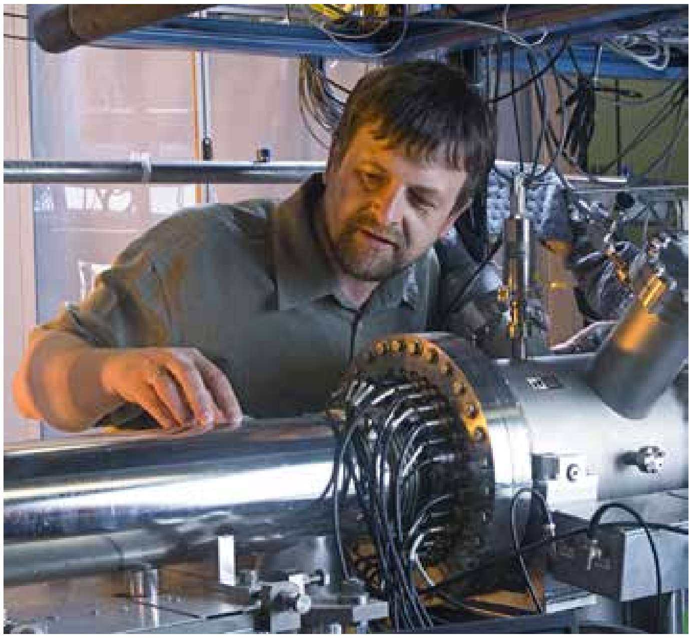
My research focuses on applications of renormalization group (RG) and effective field theory (EFT) methods to the microscopic description of Wnuclei and nuclear matter. EFT and RG methods have long enjoyed a prominent role in condensed matter and high energy theory due to their power of simplification for strongly interacting multi-scale systems. More recently, these complementary techniques have become widespread in low-energy nuclear physics, enabling the prospect foWr model-independent calculations of nuclear structure and reactions with controllable theoretical errors and providing a more tangible link to the underlying quantum chromodynamics.

From a computational perspective, EFT and RG techniques simplify many-body calculations by restricting the necessary degrees of freedom to the low-energy scales of interest. In addition to extending the reach of ab-initio calculations by eliminating unnecessary degrees of freedom, many problems become amenable to simple perturbative treatments. Since a mean-field description now becomes a reasonable starting point for nuclei and nuclear matter, it becomes possible to provide a microscopic foundation for extremely successful (but largely phenomenological) methods such as the nuclear shell model and nuclear density functional theory (DFT) that are used to describe properties of the medium-mass and heavy nuclei where ab-initio methods are computationally prohibitive. The use of RG and EFT methods to construct effective nuclear shell model Hamiltonians and energy density functionals from the underlying nuclear force is a major component of the DOE-funded Scientific Discovery thru Advanced Computing (SciDAC) project "Nuclear Computational Low-Energy Initiative (NUCLEI)" of which I am a member.

My research program presents a diverse range of research opportunities for potential Ph.D. students, encompassing three different (but interrelated) components that offer a balance of analytical and numerical work: 1) effective inter-nucleon interactions, 2) ab-initio methods for finite nuclei and infinite nuclear matter, and 3) density functional theory for nuclei. Specific topics that I'm currently interested in are: calculating the equation of state for nuclear matter from microscopic inter-nucleon interactions, exploring the role of three-nucleon forces in neutron-rich nuclei, microscopic construction of shell model Hamiltonians and effective operators, developing microscopically-based density functional theory for nuclei, and loosely-bound systems at the limits of stability.



Ground-state energies of closed shell nuclei without (top) and with (bottom) 3N forces at different resolution scales {lambda}. 3N forces are crucial to reproduce the experimental trend (black bars) in the Calcium isotopes.



Georg Bollen

Professor of Physics
Experimental Systems Division Director, FRIB
Experimental Nuclear Physics

Selected Publications

First Direct Double-Beta Decay Q-Value Measurement of 82Se in Support of Understanding the Nature of the Neutrino, D. Lincoln et al., Phys. Rev. Lett. 110 012501 (2013)

"Ion Surfing" with Radiofrequency Carpets. G. Bollen, Int.J. Mass Spectrom. 299 (2011) 131. doi: 10.1016/j.ijms.2010.09.032

Precision test of the isobaric multiplet mass equation for the A=32, T=2 quintet, A.A. Kwiatkowski, et al., Phys. Rev. C80 051302 (2009)

rp Process and Masses of N~Z~34 Nuclides, J. Savory, P. Schury, C. Bachelet et al. Phys. Rev. Lett. 102 132501 (2009)

Manipulation of rare isotope beams - from high to low energies, G. Bollen, et al., Nucl. Instr, Meth. B266 4442 (2008)

Discovery of a nuclear isomer in Fe-65 with Penning trap mass spectrometry, M. Block, C. Bachelet, G. Bollen et al., Phys. Rev. Lett. 100 132501 (2008)

M.S., Physics,
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1984

PhD, Physics,
Mainz University,
1989

Joined NSCL in
June 2000

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My research interests are related to nuclear and atomic physics with focus on the study of basic properties of atomic nuclei very far away from the valley of stability. A major activity in my group is the determination of the mass of such rare isotopes, which is their most fundamental property. An accurate knowledge of atomic masses is important for revealing the inner structure of exotic nuclei and providing crucial tests for nuclear model predictions. Atomic masses are one of the key pieces of information required for the description of the synthesis of the elements in the universe.

Certain special nuclei are important for testing our understanding of symmetries and the fundamental forces in nature; their masses need to be determined with an accuracy of 10 parts per billion or better. Such high-precision mass measurements have become possible at NSCL with the Low Energy Beam and Ion Trap facility, or LEBIT. This device makes use of very low-energy ions that are obtained by slowing down fast beams from the A1900 through gas-stopping technologies. This technique slows the ions enough that they can be kept floating in a vacuum in a device called an ion trap. Here, their masses can be determined with very high precision via the observation of their cyclotron motion in a strong 9.4 Tesla magnetic field. LEBIT, in operation since 2005, has started its mass measurement program very successfully; rare isotopes with half-lives of less than 100ms have been captured and studied and mass accuracies below 10^{-8} have been reached.

In addition to determining their mass, I am interested in atomic spectroscopy of rare isotopes using lasers. This can provide information on the size and shape of the atomic nucleus. My group is involved in the on-going realization of such a laser spectroscopy facility at NSCL. Another research area is the development of advanced manipulation techniques for rare isotope beams. Developments of that kind are critical for maximizing the performance of experiments and for creating new experimental opportunities for the study of rare isotopes. My group is working on techniques that allow fast rare isotope beams to be slowed down and converted into low-energy beams efficiently and fast, on beam-cooling and bunching techniques, and on the development of a device that increases the charge state of ions. Such a charge breeder is a key component of the re-accelerator project presently underway at NSCL, which will provide rare isotope beams that are world-unique and add a new and exciting component to the strong research program of NSCL.

The LEBIT ion trap: shown are the gold-plated high-precision electrodes that provide the electric fields needed for capturing and storing rare isotope ions in the 9.4 T field of the LEBIT Penning trap mass spectrometer.

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Theoretical Nuclear Physics

B.A., Physics,
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M.S., Physics,
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Selected Publications

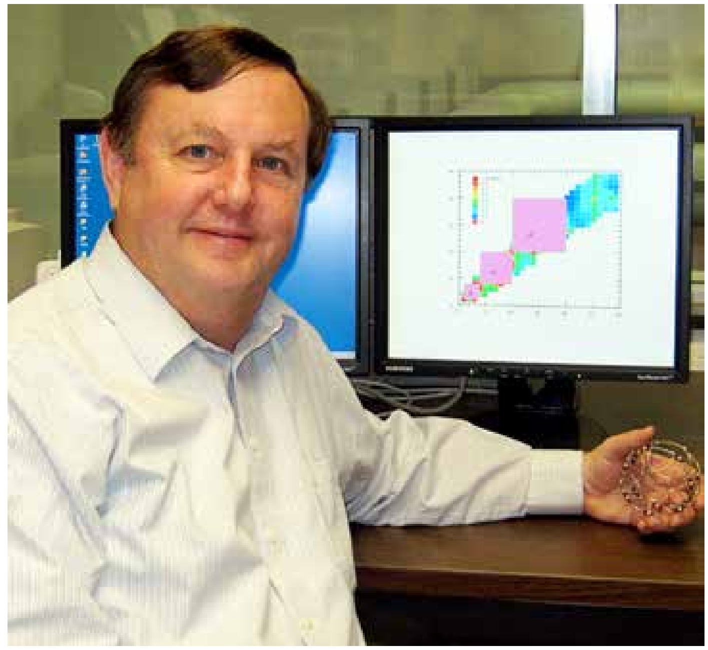
The Nuclear Pairing Gap, How Low Can it Go? B. A. Brown, Phys. Rev. Lett. 111, 162502 (2013).

Constraints on the Skyrme Equations of State from Properties of Doubly Magic Nuclei and ab initio calculations of low-density neutron matter, B. A. Brown and Achim Schwenk, Phys. Rev. C 89 011307(R) (2014).

New USD Hamiltonians for the sd Shell, B.A. Brown and W.A. Richter, Phys. Rev. C 74, 034315 (2006)

Tensor Interaction Contributions to Single-Particle Energies, B.A. Brown, T. Duguet, T. Otsuka, D. Abe and T. Suzuki, Phys. Rev. C 74, 061303(R) (2006)

Magic Numbers in Neutron-Rich Oxygen Isotopes, B.A. Brown and W.A. Richter, Phys. Rev. C 72, 057301 (2005)

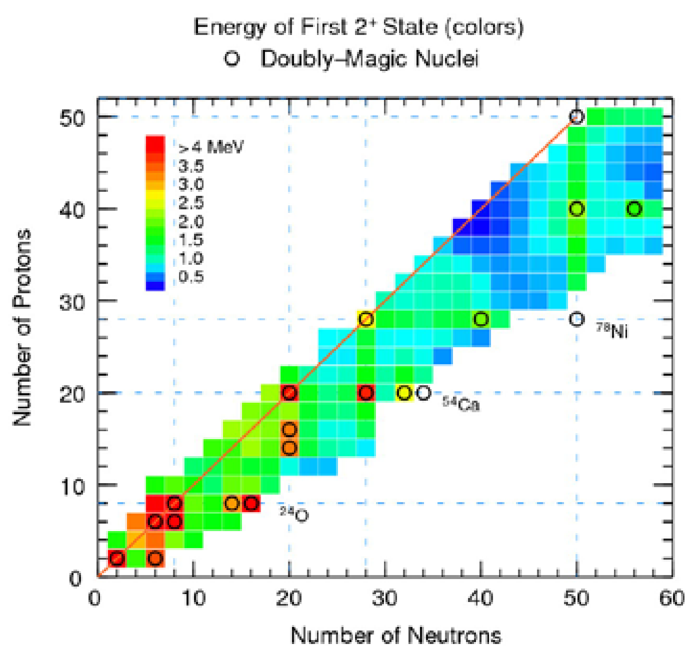


My research in theoretical nuclear physics is motivated by broad questions in science: What are the fundamental particles of matter? What are the fundamental forces and their symmetries that govern their interactions? How were the elements formed during the evolution of the universe? How do the simplicities observed in many-body systems emerge from their underlying microscopic properties?

The diverse activities within our nuclear theory group, coupled with the forefront experimental work in nuclear structure, nuclear reactions and nuclear astrophysics at NSCL provide the perfect environment for the development of new theoretical ideas. I have collaborations with theoretical and experimental groups in many countries including Germany, France, England, Italy, Norway, Japan and South Africa.

I pursue the development of new analytical and computational tools for the description of nuclear structure, especially for nuclei far from stability. The basic theoretical tools include the configuration-interaction and energy-density functional methods. I work with collaborators to develop software for desktop computing as well for high-performance computing.

Specific topics of interest include: the structure of light nuclei, nuclei near the driplines, di-proton decay, proton and neutron densities, double β decay, tests of unitarity from Fermi β-decay, isospin non-conservation, anapole moments and parity non-conservation, neutrino-nucleus interactions, quantum chaos and the rapid-proton capture process in astrophysics.



Edward Brown

Associate Professor of Physics

Theoretical Nuclear Astrophysics

Selected Publications

Strong neutrino cooling by cycles of electron capture and β –decay in neutron star crusts, H. Schatz et al., Nature, 505, 62 (2014)

Low-temperature triple-alpha rate in a full three-body model, N.B. Nguyen, F.M. Nunes, I. J. Thompson, and E.F. Brown, Phys. Rev. Lett., 109 14 (2012).

The Equation of State from Observed Masses and Radii of Neutron Stars, A. W. Steiner, J. M. Lattimer, and E. F. Brown, Astrophys. J. 722, 33 (2010)

Possible Resonances in the $^{12}C+^{12}C$ Fusion Rate and Superburst Ignition, R.L. Cooper, A.W. Steiner, and E.F. Brown, Astrophys. Jour., 702, 660 (2009)

Mapping Crustal Heating with the Cooling Lightcurves of Quasi-Persistent Transients, E.F. Brown and A. Cumming, Astrophys. Jour., 698, 1020 (2009)

B.S. Physics, The Ohio State University, 1993

M.S., Physics, University of California, Berkeley, 1996

PhD, Physics, University of California, Berkeley, 1999

Joined NSCL in February 2004

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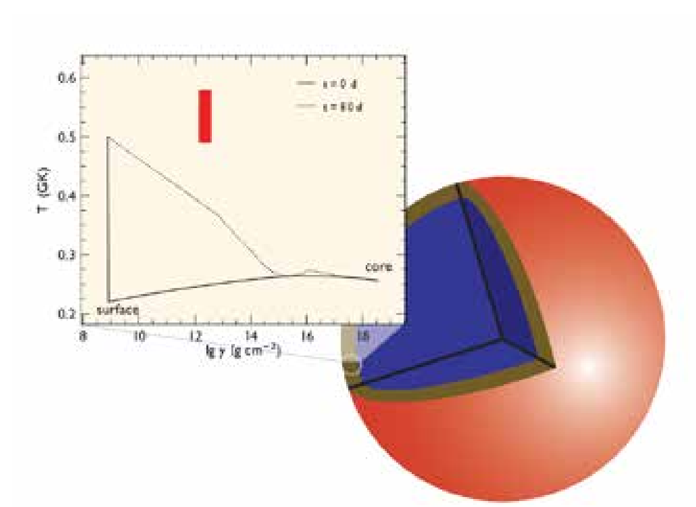
High-energy and nuclear astrophysics are truly in a golden period. I conduct theoretical research in the exciting area of compact stars, neutron stars and white dwarfs. Neutron stars are the most dense objects in nature, and have long fascinated astronomers and physicists alike. With X-ray telescopes such as *Chandra and XMM* to study these objects, nuclear experiments such as heavy-ion collisions to study the nuclear force, and the promise of gravitational wave detectors such as LIGO, our knowledge of these enigmatic objects and the nature of dense matter is rapidly improving. Many neutron stars accrete gas from a binary, solar-like companion. As this gas accumulates on the surface of the neutron star, unstable nuclear reactions produce bursts of X-rays.

New observations of these nuclear processes provide clues about the properties of superdense matter, but these observations also challenge our understanding of how the fuel is accreted and burned. Particularly exciting are the recently discovered “superbursts,” energetic explosions that are believed to be powered by unstable fusion of carbon-12. The “crust” of the neutron star, where the density is less than nuclear, must be sufficiently hot in order for the superburst to ignite. By studying these superbursts we can learn about the physics of the core, which cools by emitting neutrinos.

Recently, I have collaborated on the first calculation of electron captures in the crust of an accreting neutron star using realistic nuclear physics input, and have investigated the “sinking” of heavy nuclei in the outer layers. These calculations quantified the heating of the neutron star from these reactions, and the results have been used in simulations of the “freezing” of ions into a lattice in the neutron star crust. A surprise from these simulations is that the “ashes” of these bursts chemically separate as they are compressed to high densities.

In an exciting new development, a superburst was detected from an intermittently, or transient, accreting neutron star. Because the crust cools when the neutron star is not accreting, it was previously thought that superbursts could not occur in this system, because the temperature in the crust would be too cool for carbon-12 fusion to occur.



Cutaway of an accreting neutron star, with a calculation (Keek et al. 2008) of the temperature across the crust shown in the inset plot. The calculation is for an intermittently accreting neutron star that produced an energetic explosion just 50 days after it started accreting, before the crust could heat sufficiently. The plot shows the temperature when accretion began (solid line) and at the time of the superburst (dotted line). In order for the superburst to have ignited, the dotted line should pass through the red rectangle. The fact that it doesn’t suggests that another source of heating must be present in the crust, or that the fusion cross section is much larger than currently estimated.

Paul Chu

Professor

Accelerator Physics

B.S., Physics, Fu-Jen Catholic University, 1986

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Selected Publications

Accelerator Lattice and Model Services, P. Chu et al., 2013 International Conference on Accelerator and Large Experimental Control Systems (2013)

Database for Accelerator Modeling, P. Chu et al., 2013 International Particle Accelerator Conference (2013)

Online Physics Model Platform, P. Chu et al., 2012 International Particle Accelerator Conference (2012)

Generic Model Host System Design, P. Chu et al., 2010 International Particle Accelerator Conference (2010)

Service Oriented Architecture for High Level Applications, P. Chu et al., 2010 International Particle Accelerator Conference (2010)

XAL-based Applications and Online Model for LCLS, P. Chu et al., 2009 Particle Accelerator Conference (2009)

My recent research has been covering accelerator physics software. Before joining NSCL, I was involved in the commissioning of two recent large accelerator projects in the U.S. - the Linac Coherent Light Source (LCLS) at SLAC National Accelerator Laboratory and the Spallation Neutron Source (SNS) at Oak Ridge National Laboratory. In order to deliver the right beam for cutting-edge experiments, one of the many technical challenges is to control the particle beams at all times in order to satisfy many separate physics parameters along the beam lines. The complexity of any modern accelerator makes manual beam tuning virtually impossible. Computer software, then, is heavily used for beam tuning and operation automation. This software effort includes data handling, interaction with the control systems and physics modeling for the beam. Quick online physics modeling calculation provides a powerful tool for such beam tuning. Additionally, in order to achieve high availability for an accelerator as a user facility, high performance and reliability for software is crucial.

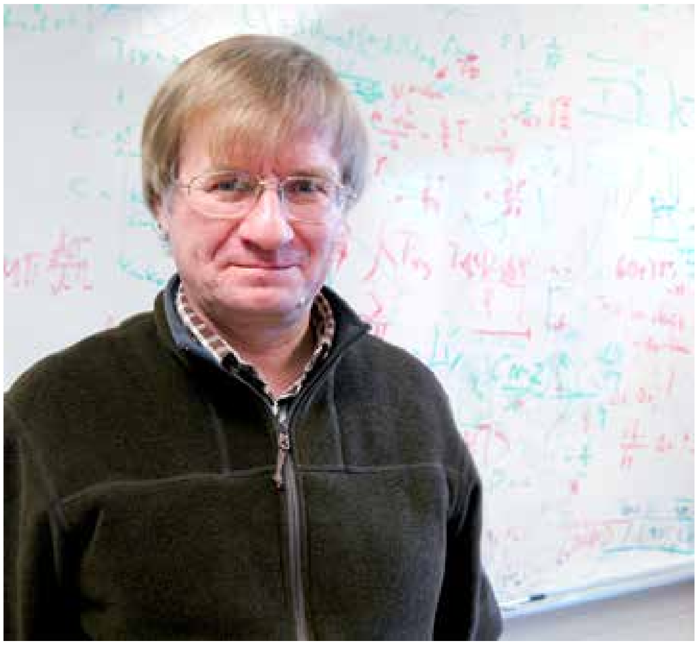
For FRIB, the beam tuning is even more difficult than any of the existing similar accelerators, because multi-charge-state beams will travel concurrently in narrow beam pipes to be delivered to a tiny spot on a target. An online model is a quick but not detailed method to simulate a particle beam. A modified online model is under development to take into account FRIB-specific hardware. The figure shown here is an example of online model calculation for beta function along the LCLS beam line.

If a simple online model is not sufficient for the sophisticated FRIB beam online control, a more detailed beam particle tracking can be run on High Performance Computing (HPC) clusters. A recent study showed that low-cost Graphical Processing Unit (GPU) based parallel computing is feasible to push large amounts of particle tracking computation for practical online purposes.

For beam tuning, online model serves as a computer library. There are many applications based on the online model, such as beam trajectory correction, emittance matching and fast feedback. In addition to these physics-related applications, there are many other general purpose tools ,such as data archiving and electronic logbook, to facilitate the operation.

In order to operate the FRIB at its design goal, a complete software solution is essential. There will be numerous applications developed. A well-designed architecture to host these applications is a must. An integrated software infrastructure with solid physics support is our research interest. Industrial standard approach such as service-oriented architecture (SOA) is introduced. It is to separate heavy computation and data processing from the rest of the software so the computation part can take advantage of fast computing provided on servers. The SOA approach will be the foundation for future accelerator control with cloud computing. Overall the research is a combination of beam physics and computer engineering.

Example of online model for LCLS linac.



Pawel Danielewicz

Professor of Physics
Theoretical Nuclear Physics

Selected Publications

Symmetry Energy II: Isobaric Analog States, Pawel Danielewicz and Jenny Lee, Nucl. Phys. A 922, 1 (2014).

Towards a nonequilibrium Green's function description of nuclear reactions: one-dimensional mean-field dynamics, A. Rios, B. Barker, M. Buchler and P. Danielewicz, Ann. Phys. (N.Y.) 326, 1274 (2011)

Has the QCD Critical Point been Signaled by Observations at RHIC? R.A. Lacey, N.N. Ajitanand, J.M. Alexander, P. Chung, W.G. Holzmann, M. Issah, A. Taranenko, P. Danielewicz and H. Stocker, Phys. Rev. Lett. 98, 092301 (2007)

Determination of the Equation of State of Dense Matter, P. Danielewicz, R. Lacey and W.G. Lynch, Science 298, 1592 (2002)

M.S., Physics,
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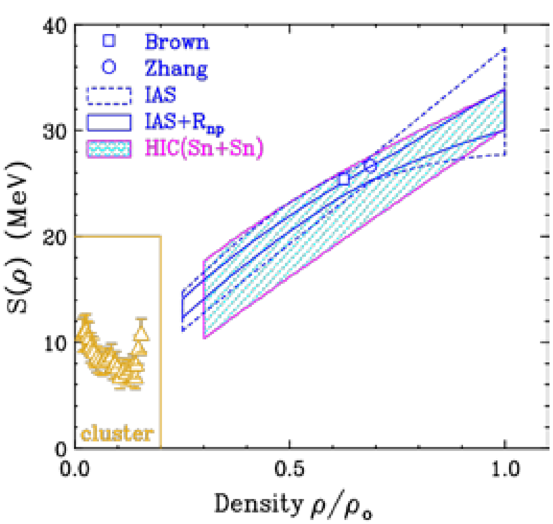
My research is in nuclear theory with much emphasis on the central energetic reactions of heavy nuclei. In the latter reactions, characteristics of matter out of which the nuclei are made, are explored. That matter is also the material out of which the neutron stars are made. That matter further filled completely the early, still compact, Universe. Of importance is dependence of the energy and pressure of the matter on density, occurrence of phase transitions and the manner in which different quantities, such as charge or momentum, get transported through the matter. My interest in the properties of matter takes me further to the investigations of nuclear structure, i.e. nuclei in their ground states, and of peripheral nuclear reactions.

In the central reactions unique conditions are created where nuclear matter gets compressed to densities much larger than those typical for nuclei and it may be heated gaining thermal energy far in excess of the nuclear binding energy. The pressures achieved in those reactions are the highest produced by man. The compression of matter during a reaction is followed by a decompression that ejects reaction products into different directions. Learning about the pressures pushing out the products and other aspects of the reactions requires a careful modeling of the reactions within transport theory. For most part, the employed transport theory is semiclassical, but important advances were made towards developing a practical quantal methodology.

Neutron stars are the largest nuclear objects in the Universe, dense as nuclei and at the verge of collapsing into black holes. They primarily consist of neutrons and these are held together, at the high density, by gravity. To understand neutron stars on the basis of laboratory investigations of nuclei, one must determine how nuclear properties evolve as a function of neutron-proton content, since the nuclei tend to contain similar numbers of protons as neutrons, unlike neutron stars. Of particular interest is the change in nuclear energy when protons get replaced by neutrons, named symmetry energy, and the density dependence of that energy, giving rise to pressure in neutron stars, acting against gravity and inhibiting collapse of the star to a black hole.

By examining systematics of measured excitations to isobaric analog states (IAS) in nuclear structure, where the excitation process is analogous to the conversion between protons and neutrons, with a former NSCL student, Jenny Lee, we deduced the symmetry energy on a nucleus-by-nucleus basis. This facilitated extrapolation of the symmetry energy to infinite matter and constrained the density dependence of the symmetry energy, needed to understand neutron stars, see the figure.



Constraints on the density dependence of the symmetry energy, from IAS and other data in the literature. ρ_o is the density in the interior of nuclei.

Alberto Facco

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Accelerator Physics

Laurea in Fisica,
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Selected Publications

A. Facco and V. Zvyagintsev, "Beam steering in superconducting quarter-wave resonators: An analytical approach", Phys. Rev. ST Accel. Beams 14, 071001 (2011)

A. Facco, R. Paparella, D. Berkovits and I. Yamane, "Splitting of high power, cw proton beams", Phys. Rev. ST Accel. Beams 10, 091001 (2007)

A. Facco et al., "Low- and intermediate-β, 352 MHz superconducting half-wave resonators for high power hadron acceleration", Phys. Rev. ST Accel. Beams 9, 110101 (2006)

A. Facco et al., "On-line performance of the mechanically damped superconducting low beta resonators", proc. of the European Particle Accelerator Conf., Stockholm , Sweden, 1998.

A. Facco, "Mechanical mode damping in superconducting low-β resonators", Particle Accelerators, Vol. 61, 1998, pp. 265-278.

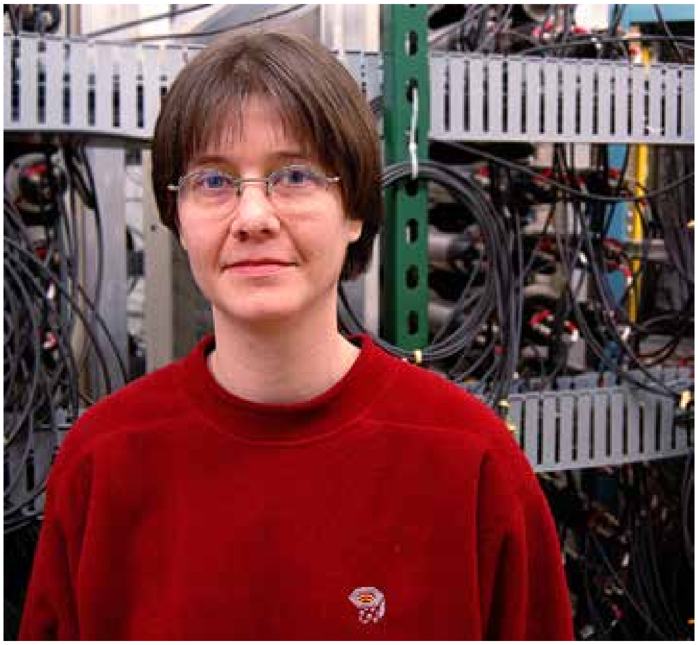
Low-beta Superconducting Radio Frequency (SRF) is presently one of the main fields of linear accelerators technology, and it is used in many projects worldwide for acceleration of protons and heavy ions up to several MW of beams power. Applications include fundamental and applied research in physics, material sciences, biology, chemistry, medicine, energy production, waste transmutation, cancer therapy, medical diagnostics and many others. The low-beta SRF technology is in a continuous expansion, and recently became the first option for heavy ion linacs: FRIB at MSU is presently the most important example worldwide.

My main field of activity is Accelerator Physics - Linac technology, in particular superconducting low- and medium-beta resonators. I moved from nuclear physics to accelerator physics in 1987 during my stay as Postdoctoral Fellow at the Weizmann Institute (Israel), where I joined a pioneering and exciting work on low-beta superconducting linacs for heavy ions. At that time we designed and prototyped the first full Niobium, double wall Quarter-Wave Resonator (QWR), precursor of the FRIB QWRs and many other ones in several laboratories worldwide.

In 1988 I moved to INFN (Istituto Nazionale di Fisica Nucleare), in Italy, joining from its start the innovative ALPI-PIAVE low-beta superconducting linac project at the National Laboratories of Legnaro, near Padua, where for the first time Bulk Nb double wall QWRs, Cu/Nb sputtered QWRs and superconducting RFQs were used in a linac. I worked in the design, construction and commissioning of low-beta QWRs with various optimum velocities, and of related cryomodules and pulsing systems. We extended high pressure water rinsing (HPR) as final treatment to low-beta cavities (at that time used only in elliptical cavities), reaching high Q and reduced field emission; we developed and introduced in superconducting QWRs special mechanical dampers, now utilized in many QWRs worldwide, which limit the resonators detuning caused by mechanical vibrations; we studied beam steering caused by QWRs, which was largely underestimated or neglected until 2001, and developed an analytical method to calculate and correct it. At Legnaro I worked also in intermediate-beta superconducting cavities (Half-Wave, Reentrant) and beam dynamics for high current proton and heavy ion linacs, for future Radioactive Ion Beam (RIB) Facilities and Accelerator Driven Systems (ADS) for nuclear waste transmutation.

I have worked in the development and construction of the superconducting cavities of the ISAC-II facility at TRIUMF (Vancouver, Canada); in mechanical damping of the superconducting low-beta cavities of the superconducting linac at Argonne National Lab. (Chicago, IL, USA); in the design study and technological development for the European radioactive beam facility project EURISOL with CEA Saclay, IPN Orsay and SOREQ NRC (Israel), and in other projects. I am presently working in the IFMIF-EVEDA project for the construction of a 100 mA deuteron linac prototype, a large Europe-Japan collaboration involving several contributing institutions.

I started collaborating in superconducting linac development at Michigan State University since 2001, when the ReA3 linac conceptual design based on QWRs started taking form. I joined the FRIB project in spring 2011, leading the Superconducting RF department for one year; in that period the ReA3, beta=0.085 QWRs were brought to full performance and the design of the FRIB superconducting resonators was finalized. I am presently Accelerator System Division Senior Advisor, working especially in superconducting resonators and cryomodule development for FRIB, ReA and in development of high gradient, low-beta resonators for future accelerators.



Alexandra Gade

Professor of Physics
NSCL Chief Scientist
Experimental Nuclear Physics

Selected Publications

Quadrupole collectivity beyond N=28: Intermediate-energy Coulomb excitation of $^{47,48}Ar$, R. Winkler et al., Phy. Rev. Lett. 108, 182501 (2012).

Intermediate-energy inverse-kinematics one-proton pickup reactions on neutron-deficient fp-shell nuclei, S. McDaniel et al., Phys. Rev. C 85, 014610 (2012).

Collectivity at N=40 in neutron-rich ^{64}Cr. A. Gade et al., Phys. Rev. C 81, 051304(R) (2010)

In-beam nuclear spectroscopy of bound states with fast exotic ion beams. A. Gade and T. Glasmacher, Prog. Part. Nucl. Phys. 60, 161 (2008)

Spectroscopy of ^{36}Mg: Interplay of normal and intruder configurations at the neutron-rich boundary of the "Island of Inversion.", A. Gade et al., Phys. Rev. Lett. 99, 072502 (2007)

M.S., Nuclear Physics,
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PhD, Physics,
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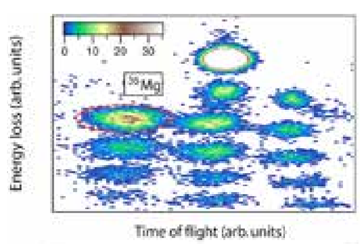
The structure of the atomic nucleus at the extremes of neutron-proton asymmetry is presently the focus of my research interest. Short-lived, radioactive nuclei that are composed of many more neutrons than protons, for example, often reveal surprising properties. The shape, the excitation pattern as well as the energy and occupation of the nucleus' quantum mechanical orbits by protons and neutrons may be significantly altered compared to expectations that are based on the well-known properties of stable nuclei.

My group performs scattering experiments to characterize the bulk effects of these changes by assessing the deformation of a nucleus and its excitation pattern. Nucleon knockout or pickup experiments track these exciting modifications of the nuclear structure on the level of the neutron and proton orbits that make up the nucleus on a microscopic level.

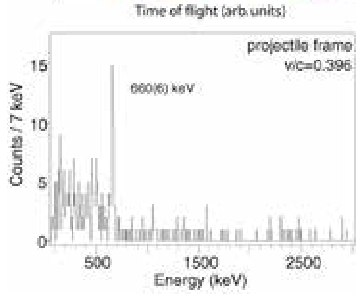
In the grazing collision of an exotic projectile beam with a light target one or two protons or neutrons can be removed in direct, so-called knockout reaction. The heavy residue of this reaction is identified and its kinematics measured with NSCL's large-acceptance S800 spectrograph. Spectroscopy of de-excitation γ-rays performed with NSCL's segmented germanium array SeGA around the target then tells us if the reaction led to an excited state. The energy of the detected γ-rays measures the energy difference between two nuclear states and its intensity tells us how likely the state was actually populated in such a knockout reaction.

In intermediate-energy Coulomb excitation, the exotic nuclei are scattered off a stable gold target and excited in the electromagnetic Coulomb field of the target nuclei. Excited energy levels decay back by the emission of γ radiation, which photon detectors surrounding the target register. The energy of the γ-ray reveals the energy of the excited state and its intensity relates to the probability of the excitation process. This probability increases with increased deformation of the nucleus and thus provides a method to characterize the nuclear shape.

The results from those experiments are often surprising and reveal that exciting changes take place in the structure of exotic nuclei compared to stable species. We work in close collaboration with nuclear structure theorists and reaction theorists. Our experimental input helps to unravel the driving forces behind the often spectacular modifications in nuclear structure and adds to the improvement of modern theories that are aimed to provide a model of the atomic nucleus with predictive power also in the exotic regime.



Reaction residues generated in the collision of a ^{38}Si beam with a ^{9}Be target. Energy loss versus flight time allows for unambiguous identification of all produced nuclei. The exotic nucleus of interest in this experiment was ^{36}Mg which has twice as many neutrons as protons.



γ-ray energy spectrum detected in coincidence with ^{36}Mg. The peak at 660 keV energy constitutes the first measurement of the energy of the first excited state in ^{36}Mg, the heaviest Mg isotope studied with γ-ray spectroscopy to date.

Ulrike Hager

Assistant Professor

Experimental Nuclear Astrophysics

M.S. Physics,
University of
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2004

PhD, Physics,
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2007

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Selected Publications

Direct measurement of the 16O(a,γ) 20Ne reaction at Ec.m. = 2.26 MeV and 1.69 MeV
U. Hager, L. Buchmann, B. Davids, J. Fallis, U. Greife, D. A. Hutcheon, D. Irvine, D. Ottewell, A. Rojas, S. Reeve, and C. Ruiz
Phys. Rev. C 86, 055802 (2012)

Measurement of the 17O(p,γ) 18F reaction rate at astrophysically relevant energies. U. Hager, L. Buchmann, B. Davids, J. Fallis, B. R. Fulton, N. Galinski, U. Greife, D. A. Hutcheon, D. Ottewell, A. Rojas, C. Ruiz, and K. Setoodehnia
Phys. Rev. C 85, 035803 (2012)

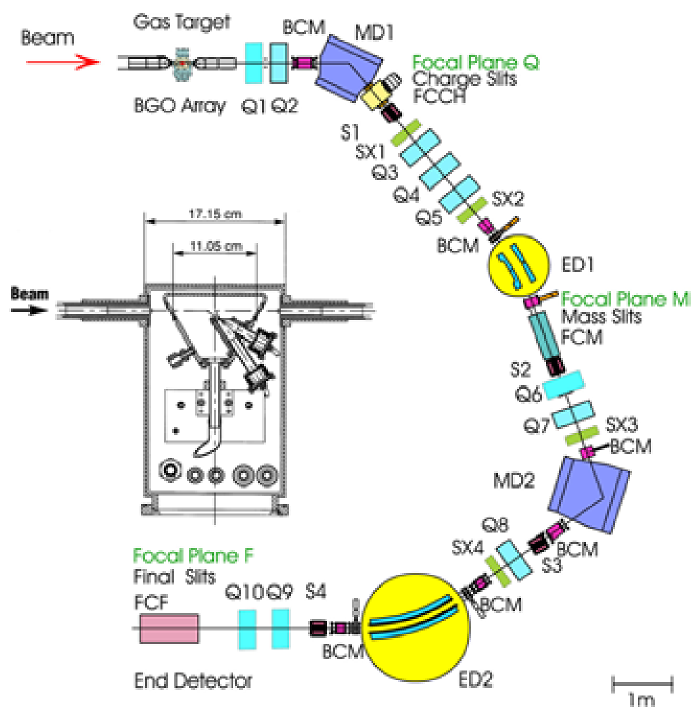
Direct total cross section measurement of the 16O(a,γ)20Ne reaction at Ec.m. = 2.26 MeV
U. Hager, J. R. Brown, L. Buchmann, M. Carmona-Gallardo, L. Erikson, J. Fallis, U. Greife, D. Hutcheon, D. Ottewell, C. Ruiz, S. Sjue, C. Vockenhuber Phys. Rev. C 84, 022801(R) (2011)

My research focuses on measuring reaction rates important for nuclear astrophysics. These rates determine how quickly isotopes are created or destroyed at various astrophysical sites such as novae.

Most of my experiments are performed at the DRAGON facility at TRIUMF, Vancouver. DRAGON (Detector of Recoils And Gammas Of Nuclear reactions) was designed to provide a recoil separator to study radiative capture reactions, both on protons and alpha particles, using post-accelerated radioactive ion beams. The windowless target can contain either hydrogen or helium gas; since these are the most abundant elements in the universe, they are involved in many important reactions taking place in various stellar events.

There is currently an effort underway to build a similar separator at the NSCL to take advantage of the rare isotope beams far from stability that FRIB will provide. This will open up unique possibilities for determining rates of previously unmeasured reaction rates that are not accessible elsewhere.

In addition to recoil separators, time projection chambers (TPCs) are a useful tool for studying certain reactions. I am currently exploring the possibility of designing a TPC to study neutron-capture reactions via surrogate reactions.

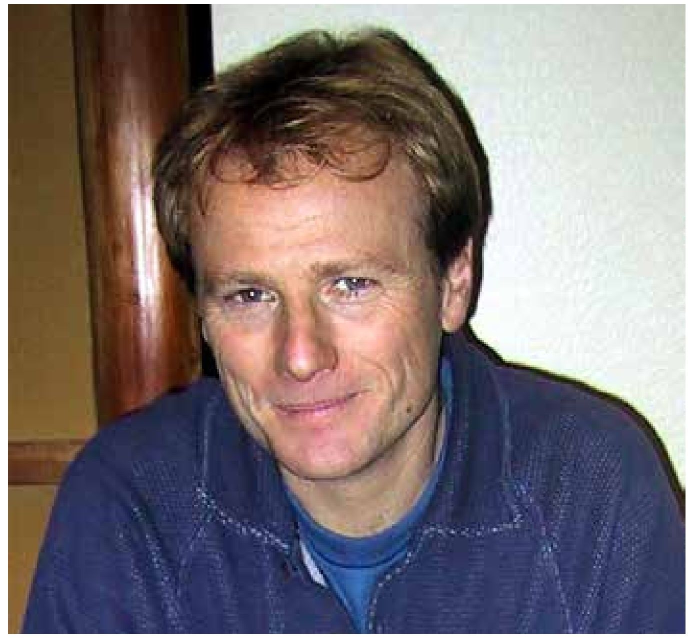


Schematic view of the DRAGON recoil separator showing the locations of the gas target, the magnetic and electric dipoles, and the focal plane detectors.

Morton Hjorth-Jensen

Professor of Physics

Theoretical Nuclear Physics



M.S., Science, Norwegian University of Science and Technology 1988

PhD, Theoretical Nuclear Physics, University of Oslo 1993

Joined NSCL in January 2012

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Selected Publications

Optimized chiral nucleon-nucleon interaction at next-to-next-to-leading order, A. Ekström et al, Phys. Rev. Lett. 110, 192502 (2013).

Living on the edge of stability, the limits of the nuclear landscape, C. Forssén, G. Hagen, M. Hjorth-Jensen, W. Nazarewicz, J. and Rotureau, Physica Scripta T152, 014022 (2013).

Evolution of Shell Structure in Neutron-Rich, Calcium Isotopes, G Hagen, M Hjorth-Jensen, GR Jansen, R Machleidt, T Papenbrock, Phys. Rev. Lett. 109, 032502 (2012).

Continuum effects and three-nucleon forces in neutron-rich oxygen isotopes, G Hagen, M Hjorth-Jensen, GR Jansen, R Machleidt, T Papenbrock, Phys. Rev. Lett. 108, 242501 (2012).

Pairing in nuclear systems: from neutron stars to finite nuclei, D. J. Dean and M. Hjorth-Jensen, Rev. Mod. Phys. 75, 607 (2003).

I am a theoretical nuclear physicist with an interest in many-body theory in general, and the nuclear many-body problem and nuclear structure problems in particular. This means that I study various methods for solving either Schroedinger's equation or Dirac's equation for many interacting particles, spanning from algorithmic aspects to the mathematical properties of such methods. The latter also leads to a strong interest in computational physics as well as computational aspects of quantum mechanical methods. A large fraction of my work, in close collaboration with colleagues at the NSCL and worldwide, is devoted to a better understanding of various quantum mechanical algorithms. This activity leads to strong overlaps with other scientific fields. Although the main focus has been and is on many-body methods for nuclear structure problems, I have also done, and continue to do, research on solid state physics systems in addition to studies of the mathematical properties of various many-body methods.

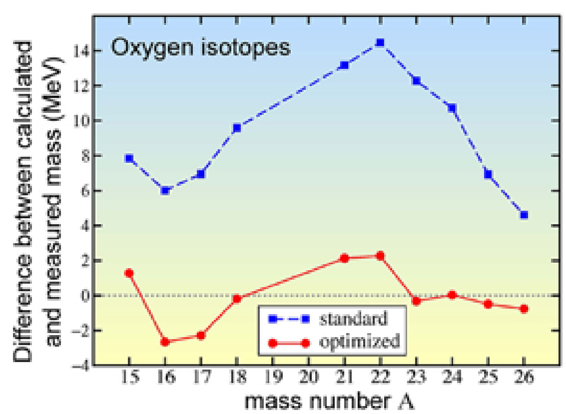
Why the nuclear many-body problem, you may ask. Well, for me, to understand why matter is stable, and thereby shed light on the limits of nuclear stability, is one of the overarching aims and intellectual challenges of basic research in nuclear physics and science. To relate the stability of matter to the underlying fundamental forces and particles of nature as manifested in nuclear matter is central to present and planned rare isotope facilities.

Examples of important properties of nuclear systems that can reveal information about these topics are masses (and thereby binding energies), and density distributions of nuclei. These are quantities that convey important information on the shell structure of nuclei with their pertinent magic numbers and shell closures, or the eventual disappearance of the latter away from the valley of stability.

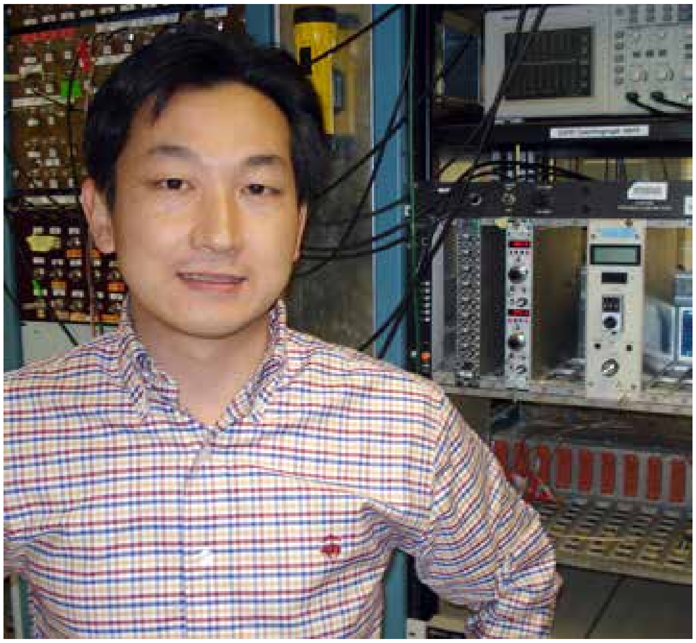
Neutron-rich nuclei are particularly interesting. As a particular chain of isotopes becomes more and more neutron rich, one reaches finally the limit of stability, the so-called dripline, where one additional neutron makes the next isotopes unstable with respect to the previous ones. In an article published in Phys. Rev. Lett. 109, 032502 (2012) we computed several properties of calcium isotopes, including three-body forces, a much debated and studied issue in nuclear many-body theory. Our calculations predict the dripline of the calcium isotopes at mass 60, partly in conflict with present results from mean-field and mass models used in astrophysical calculations. To understand the limits of stability of the calcium isotopes is one of the benchmarks experiments of the coming Facility for Rare Isotope Beams at Michigan State University. The computed first excited 2+ state for calcium-54 was later observed in an experiment, confirming our theoretical predictions.

A promising recent development involves a proper parametrization of the strong force, resulting in better Hamiltonian for nuclear physics studies. Combining very powerful effective field theory derivations of the nuclear interaction and multidimensional optimization techniques, we were able to generate a very precise two-body interaction that reproduces experimental data in neutron rich oxygen and calcium isotopes.

Finally, I have a strong interest in educational matters, with an emphasis on computational physics and computing as a tool to enhance insights and understandings of scientific problems. At the University of Oslo (I have the privilege to share my time there and MSU) I have been very much involved in a large project called Computing in Science Education which deals with the introduction of computing in basic science courses as a way to enhance research based teaching, and hopefully lead to a better insight of physical systems. I'd be more than happy to discuss such matters as well.



Difference between calculated and experimentally measured masses of oxygen isotopes as a function of mass number. The blue line represents the predictive power of the standard interaction model approach in calculating mass. The line in red represents the optimized coupled cluster method. The prediction power of the new optimized method shows less deviation between the calculated and measured mass (the difference hovers around zero), indicating that it is much closer to measured values than those computed with the standard interaction (blue). See Phys. Rev. Lett. 110, 192502 (2013)



Hironori Iwasaki

Assistant Professor of Physics

Experimental Nuclear Physics

Selected Publications

Evolution of collectivity in ^{72}Kr; evidence for rapid shape transition; H.Iwasaki, A.Lemasson, et al., Phys. Rev. Lett. 112 (2014) 142502.

Observation of mutually enhanced collectivity in self-conjugate ^{76}Sr, A.Lemasson, H.Iwasaki et al., Phys. Rev. C85, 041303(R) (2012)

“Enhanced Quadrupole Collectivity at N=40: The Case of Neutron-Rich Fe Isotopes” W.Rother, A.Dewald, H.Iwasaki et al., Phys. Rev. Lett. 106, 022502 (2011)

Breakdown of the Z=8 Shell Closure in Unbound ^{12}O and its Mirror Symmetry, D. Suzuki, H. Iwasaki et al., Phys. Rev. Lett. 103, 152503 (2009)

Low-Lying Neutron Intruder State in ^{13}B and the Fading of the N = 8 Shell Closure, H. Iwasaki et al., Phys. Rev. Lett. 102, 202502 (2009)

M.S., Physics, University of Tokyo, 1998

PhD, Physics, University of Tokyo, 2001

Joined NSCL in September 2009

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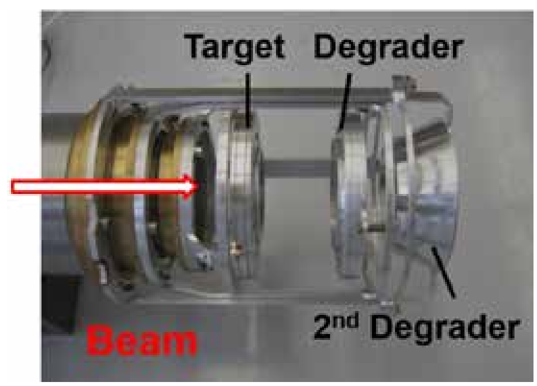
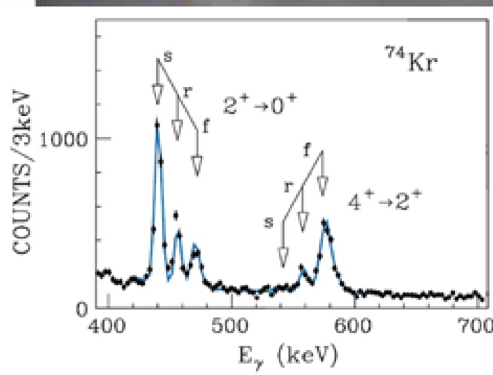
My research has focused on spectroscopy of exotic nuclei far from stability. Unstable nuclei with very unusual proton-to-neutron ratios, called as “exotic nuclei”, often show surprising phenomena, presenting important challenges for our understanding of atomic nuclei. The goal of present-day nuclear physics is to establish the unified understanding of nuclear structure for stable and exotic nuclei, by exploring the spin and isospin degree-of-freedom of the shell structure and collective properties of nuclei. The physics outputs thus serve as vigorous tests for modern nuclear theories, as well as provide answers to questions concerning the nature of neutron stars and the origin of the elements in the Universe. Nuclear structure information can also be used to make tests of fundamental symmetries that describe the weak and strong forces in nature.

At NSCL, my group performs in-beam gamma and particle spectroscopy with rare isotope beams, with an emphasis on lifetime measurements for nuclear levels. Lifetimes for bound levels are directly related to transition probabilities between the relevant states, which provide sensitive probes for anomalies in structure of exotic nuclei, for example, shape coexistence, changes of magic numbers, and proton-neutron decoupling phenomena, and so on. For unbound levels, lifetimes can be associated with the energy uncertainties to be measured as the resonance widths, which play important roles in the stability of extreme quantum systems as well as in nuclear reaction rates of astrophysical interest.

Recently, a new plunger device TRIPLEX (TRIple PLunger for EXotic beams, Fig.1) dedicated for the recoil-distance Doppler-shift measurements has been developed at NSCL. The device uses three thin metal foils separated by very precise distances. In this approach, Coulomb excitation or knockout reactions are used to populate excited states in the exotic, projectile-like reaction residues that decay in flight after traveling a distance related to its lifetime. Two degraders are positioned downstream of the target to reduce the velocity of the ion. As a consequence, gamma-rays emitted behind each foil will have different Doppler shifts. The lifetime of the state can then be determined using relative gamma-ray yields measured at different foil separations. An example from recent GRETINA measurements is shown in Fig.2 where gamma-ray line shapes characteristic of lifetimes on the order of picoseconds are evident.





(1) The TRIPLEX plunger device.

(2) Energy spectrum of γ rays measured in coincidence with ^{74}Kr. The spectrum clearly shows the fast (f), reduced (r), and slow (s) components in the recoil-distance measurement, indicating sensitivities to different lifetimes of the excited states.

Zach Kohley

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Nuclear Chemistry

B.S. Chemistry,
Hillsdale College,
2006

PhD, Physical Chemistry,
Texas A&M University,
2010

Joined NSCL in
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Selected Publications

Near-barrier reactions with radioactive ino beams at the ReA3 facility. Z. Kohley. EPJ Web of Conferences 63, 02003 (2013).

Heavy-ion Collisions: Direct and indirect measurements of the density and temperature dependence of Esym. Z. Kohley, S.J. Yennello. Eur. Phys. J. A 50,31 (2014)

Exploiting neutron-rich radioactive ion beams to constrain the symmetry energy. Z. Kohley, et al. Phys. Rev. C 88, 041601(R) (2013).

Study of two-neutron radioactivity in the decay of 26O. Z. Kohley, et al. Phys. Rev. Lett. 110, 152501 (2013).

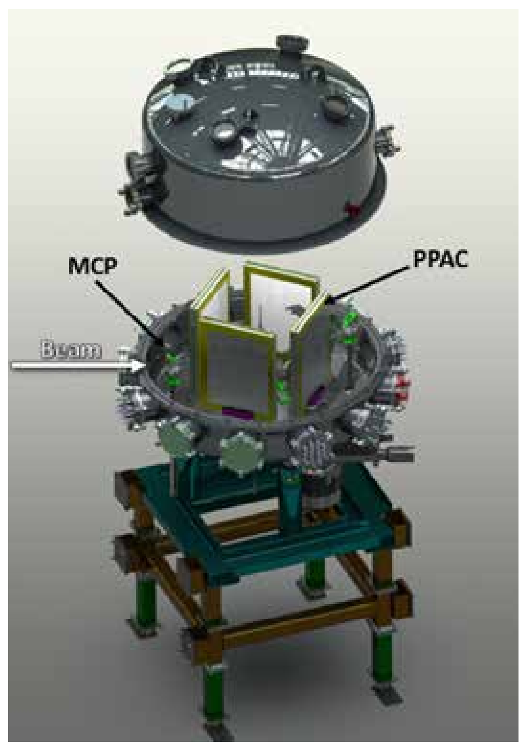
The unresolved question of the 10He ground state resonance. Z. Kohley, et al. Phys. Rev. Lett. 109, 232501 (2012).

My research in nuclear chemistry is focused on studying the dynamics of heavy ion reactions over a wide range of energies. While heavy ion reactions have been studied for many years using beams of stable isotopes, the NSCL provides a unique opportunity to explore these reactions with radioactive ion beams (RIBs). These radioactive isotopes can have exotic properties such as neutron skins, halos, or unexpected changes in the shell structure. I am interested in how these exotic properties manifest themselves in heavy ion collisions, specifically fusion reactions.

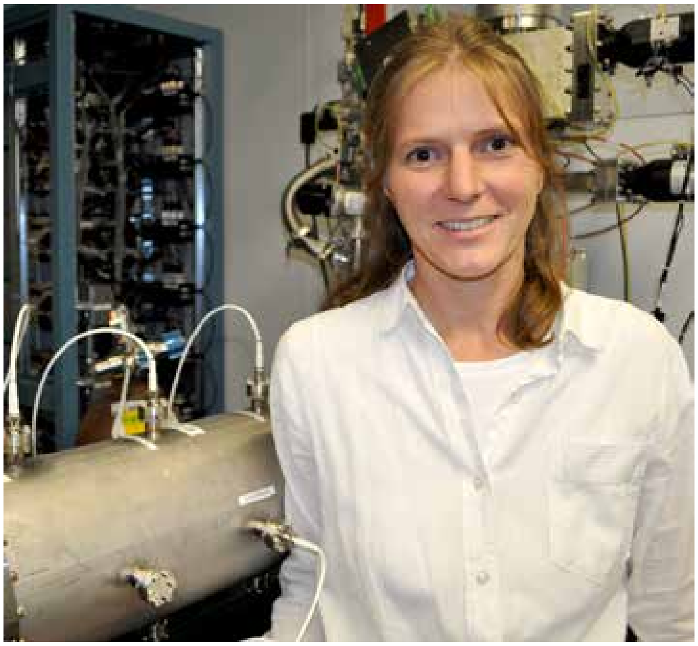
At energies around the Coulomb barrier, we will study the probability (or cross section) for the fusion of the heavy ions. Heavy-ion fusion has a historic role in the field of chemistry as it is the only known mechanism for producing the heaviest elements of the periodic table. The new ReA3 facility will allow for the RIBs produced at the NSCL to be stopped and reaccelerated at conditions suitable for fusion reactions. Surprisingly, only three fusion experiments with RIBs between the fluorine and tin isotopes have ever been completed. ReA3 will allow us to begin to explore heavy ion fusion with a new arsenal of beams. We plan to examine the possible enhancement and hindrance of fusion due to the exotic properties of the RIBs as well as investigate the quasifission mechanism which hinders the production of super-heavy elements.

Currently, the construction of a fission fragment detector is one of the main activities in the group. In relatively heavy systems the compound nucleus formed from the fusion of the heavy ions will decay dominantly through the fission process. Thus we can measure the probability of fusion by counting the number of times fission occurred. The setup, as shown in the figure, will consist of four large area gas filled detectors called PPACs which will provide high efficiency and precision for measuring fission fragments.

At higher energies (well beyond the Coulomb barrier), heavy ion collisions can be used to explore the nuclear equation of state (EoS). Like any material, nuclear matter has an EoS which relates properties such as pressure, density, internal energy, and temperature to each other. Heavy ion collisions allow us to create and study nuclear matter at different densities, temperatures, and pressures. We want use RIB induced reactions to investigate how the EoS depends on the neutron-to-proton ratio of the nuclear matter. Future plans include using the Modular Neutron Array (MoNA) and the superconducting Sweeper magnet at the NSCL to measure the emission of neutrons in coincidence with heavy charged particles from reactions induced with RIBs. The results from the experiment compared with theory should provide new insight into the nuclear EoS.



Mechanical design rendering of the fission detector setup. The radioactive ion beam enters from the left (white arrow) and travels through the micro-channel plate timing detector (MCP) and impinges on a target. Fission fragments resulting from the fusion of the projectile and target will be detected in the four l arge area Parallel Plate Avalanche Counters (PPACs).



Daniela Leitner

Professor of Physics
Associate Director for Operations
Accelerator Physics

Selected Publications

Progress towards the development of a realistic electron cyclotron resonance ion source extraction model, D. Winklehner, et. al., Rev. Sci. Instrum. ***83****, 02B706 (2012)*

Status Of The Reaccelerator Facility Rεa For Rare Isotopes Beam Research, Daniela Leitner, et. al.,http://accelconf.web.cern.ch/AccelConf/SRF2011/papers/thiob03.pdf

Ion beam properties for ECR ion source injector systems D. Leitner, D. Winklehner, M. Strohmeier, 2011 JINST **6** *P07010*

High intensity production of high and medium charge state uranium and other heavy ion beams with VENUS, D. Leitner, et. al., Rev. Sci. Inst. **79** *02C710 (2008)*

Measurement of the high energy component of the x-ray spectra in the VENUS electron cyclotron resonance ion source, D. Leitner, et al., Rev. Sci. Inst. **79** *033302 (2008)*

Degree in Physics, Technical University, Vienna, 1988

PhD, Physics with Distinction, University of Technology, Vienna, 1995

Joined NSCL in October, 2010

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My research interests have centered on the development and implementation of high-intensity Electron Cyclotron Resonance (ECR) ion sources for high charge state heavy-ion beams and recently have expanded to include heavy-ion linear accelerators; specifically the construction of the ReA3 ReAccelerator at NSCL.

Electron Cyclotron Resonance (ECR) ion sources utilize resonantly heated magnetically confined plasmas to create highly charged ions similar to fusion plasma devices. In the last three decades, remarkable performance improvements of ECR injector systems have been made, mainly due to advances in magnet technology as well as an improved understanding of the ECR ion source plasma physics. As senior scientist at Lawrence Berkeley National Laboratory, I led the development of the fully superconducting Versatile ECR ion source for Nuclear Science (VENUS), which is currently the highest performance ECR ion source worldwide. At NSCL, VENUS will be used as the injector for the high-power driver LINAC of FRIB, and I am looking forward to continuing ECR ion source development for the FRIB facility.

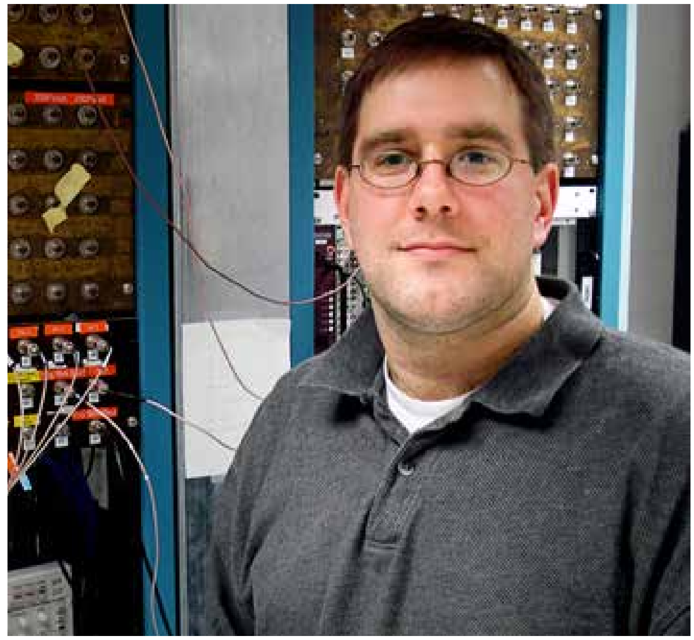
Michigan State University is on the forefront of ECR ion source development. The fully superconducting ECR ion source SuSI is one of the highest performance ECR ion sources worldwide. Together with the room temperature ECR ion source ARTEMIS ECR ion source, SuSI provides intense ion beams to the Coupled Cyclotron Facility. The two sources are also used to investigate fundamental plasma properties and ion beam transport properties of the multispecies beam extracted from the ECR ion sources. Due to the magnetic confinement necessary to sustain the ECR plasma, the ion density distribution across the extraction aperture is inhomogeneous and charge-state dependent. The initial ion beam distribution at the extraction aperture is still a subject of research. Developing adequate simulation tools for ion beams extracted from ECR ion source injectors is one of the research goals of my group.

Additionally, I am overseeing the commissioning and operation of the NSCL's new reaccelerator called ReA3. Though rare isotopes flying at half the speed of light have many uses, many experiments require these beams to be at lower energies. To do this, the lab is constructing beam thermalizers to cool the beam down before bunching and reaccelerating the rare isotopes to energies of 0.3 to 12 MeV/nucleon. This will allow experiments such as low-energy Coulomb excitation and transfer reaction studies as well as for the precise study of astrophysical reactions.

Sean Liddick

Assistant Professor of Chemistry

Nuclear Chemistry



Selected Publications

Low-energy structure of $_{27}^{66}Co_{39}$ and $_{27}^{68}Co_{41}$ populated through β decay, S.N.Liddick et al., Phys.Rev. C ***85****, 014328 (2012)*

Algorithms for pulse shape analysis using silicon detectors, S.N. Liddick, I.G. Darby, R.K. Grzywacz, Nucl. Instrum. and Meth. Phys. Res. A ***669****, 70 (2012)*

Shape coexistence along N=40, S.N.Liddick et al., Phys.Rev. C ***84****, 061305 (2011)*

Orbital Dependent Nucleonic Pairing in the Lightest Known Isotopes of Tin, I.G. Darby et al., Phys.Rev.Lett. ***105****, 162502 (2010)*

Discovery of ^{109}Xe and ^{105}Te: Superallowed α Decay near Doubly Magic ^{100}Sn, S.N. Liddick et al., Phys. Rev. Lett. ***97****, 082501 (2006)*

B.S. Chemistry,
Texas A&M University, 2001

PhD, Chemical Physics,
Michigan State University,
2004

Joined NSCL in December
2009

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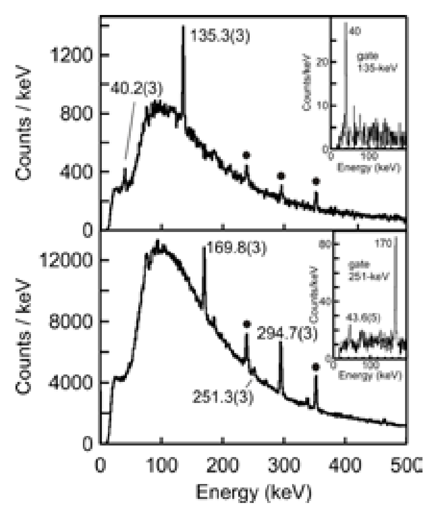
My research focuses on experimentally identifying changes in nuclear structure far from the valley of beta stability. The changes are the result of evolving single-particle level configurations as a progression is made from stability towards more exotic nuclei and leads to specific observables in the low-energy level structure of a nucleus. Decay spectroscopy provides a sensitive and selective means to populate and study low-energy excited states of daughter nuclei looking for the signatures of changing shell structure. A variety of different decay modes can be employed depending on the nucleus of interest and the experimental setup and can include beta, alpha, and proton decay. Experiments have been performed both on the neutron-deficient nuclei near 100Sn and neutron-rich nuclei near ^{68}Ni.

In the neutron-rich region near ^{68}Ni, decay spectroscopy is used to understand the rapid disappearance of the spectroscopic features that indicate a shell closure as protons are removed from ^{68}Ni along the N = 40 and neighboring isotones. Long-lived excited nuclear states have been taken as evidence for the existence of competing nuclear shapes, prolate and spherical, in the low-energy level schemes of the odd-A ^{67}Co nucleus and the odd-odd ^{66,68}Co and ^{64,66}Mn nuclei. Investigations into the even-even Fe nuclei have led to the tentative identification of excited 0^+ states which, when compared to theoretical calculations, demonstrate the inversion between spherical and deformed configurations below ^{68}Ni with approximately one proton and two neutrons excited across the Z = 28 and N = 40 shell closures, respectively.

Alpha decay experiments near ^{100}Sn, originally intended to look for fast alpha decays, have instead dembetween a nucleus that can be described by single-particle excitations (^{101}Sn) and a nucleus that displays a large amount of collectivity (^{103}Sn). That such a discrepancy occurred demonstrated the danger of extrapolating nuclear structure information from nuclei closer to stability and the need for continued experimental investigation.

The development of new detectors and techniques is critical to improving the sensitivity of the experimental system enabling access to increasingly exotic nuclei. The implementation of a digital acquisition system with an extraordinary low dead time was critical for the observation of isomeric states in ^{64,66}Mn. The newest hardware development in the group has been the commissioning of a planar Ge detector for beta-decay spectroscopy experiments. The main goal of the detector is to increase the detection efficiency for beta-decay electrons.



Gamma rays detected within 5 ms of the arrival of either a ^{64}Mn or ^{66}Mn ion to the experimental station. Transitions attributed to either ^{64}Mn or ^{66}Mn are indicated by their energies and background transitions are marked with black circles. Coincidence spectra are shown as insets.

Steven Lund

Professor of Physics

Accelerator Physics

Selected Publications

Envelope model for passive magnetic focusing of an intense proton or ion beam propogating through thin foils, S.M. Lund, R.H. Cohen, and P.A. Ni, Phys. Rev. ST – Accel. and Beams 16, 044202 (2013).

Sheet beam model for intense space-charge: Application to Debye screening and the distribution of particle oscillation frequencies in a thermal equilibrium beam, S.M. Lund, A. Friedman, and G. Bazouin, Phys. Rev. ST – Accel. and Beams 14, 054201 (2011).

Space-charge transport limits of ion beam in periodic quadrupole channels, S.M. Lund and S.R. Chawla, Nuc. Instr. Meth. A 561, 203-208 (2006).

Simulations of beam emittance growth from the collective relaxation of space-charge nonuniformities, S.M. Lund, D.P. Grote, and R.C. Davidson, Nuc. Instr. Meth. A 544, 472-480 (2005).

B.S. Physics
Auburn University, 1987

PhD Physics
Massachusetts Institute of Technology, 1992

Joined FRIB in April 2014

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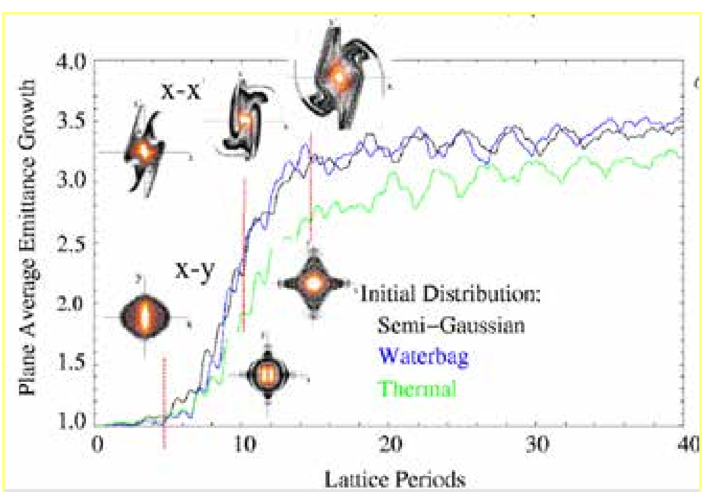
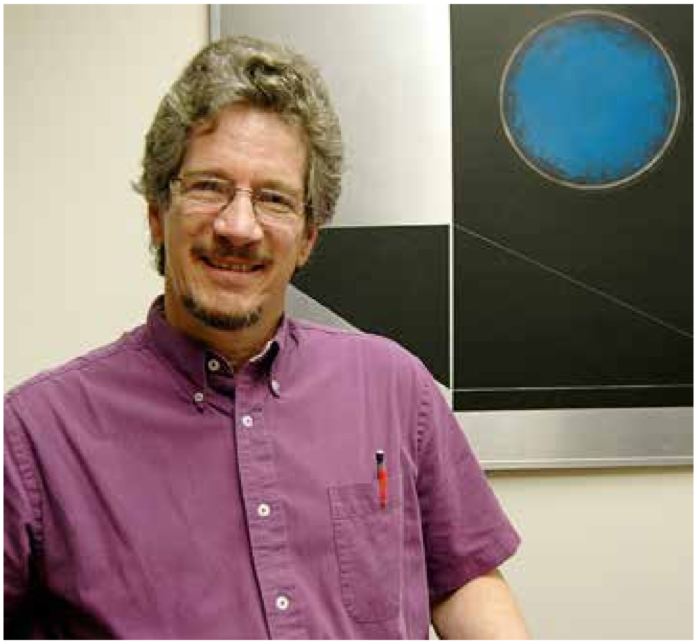
Charged particle accelerators have long been the driving engine of discovery in fundamental areas of physics such as high-energy physics, nuclear physics, and astrophysics as well as vital tool to probe material properties in a wide variety of manners in applied physics via accelerator driven light sources, spallation neutron sources, and microscopes. Accelerators also play a key role in applications such as materials processing, medical diagnostics and therapies, and potential advanced energy sources. This central role in science and technology has driven the field for many years and accelerator physics itself is a vibrant discipline of physics. Machines represent a tour de force on the creative use of physics and technology to produce a plethora of machines based on different concepts/architectures generating a broad range of beams for diverse applications. The field produces a rich range of applied physics problems providing opportunities for researchers and students to extend advances.



Simulations on the growth of beam phase-space volume due to violent space-charge induced instabilities.

My field is theoretical accelerator physics emphasizing analytic theory and numerical modeling. Before arriving at MSU in 2014 to work on the Facility for Rare Isotope Beams (FRIB), I held a joint appointment at Lawrence Livermore and Berkeley National Labs working on physics issues associated with the transport of beams with high charge intensity, design of accelerator and trap systems, large- and small-scale numerical simulations of accelerators, support of laboratory experiments, and design of electric and magnetic elements to focus and bend beams. A common theme in my research is to identify, understand, and control processes that can degrade the quality of the beam by increasing phase-space area or can drive particle losses. Typically, laboratory experiments and support simulations identify effects, which are then further analyzed with reduced simulations and analytic theory to understand and mitigate any deleterious consequences. Graduate level teaching is used to clarify advances and place developments into context within the broader field.

At FRIB, I am presently seeking physics students with interests in charged particle dynamics, electromagnetic theory, and numerical modeling to assist me in simulations and theory in support of FRIB now under construction at MSU. The FRIB linear accelerator will deliver exceptionally high-power beams to support nuclear physics via beams of rare isotopes produced post-target. This should be one of the premier accelerator facilities for nuclear physics and will provide a fertile training ground for the next generation of accelerator physicists to join this vibrant field with broad opportunities.



Bill Lynch

Professor of Physics

Experimental Nuclear Physics

Selected Publications

Constraints on the Density Dependence of the Symmetry Energy, M.B. Tsang et al., Phys. Rev. Lett. **102**, 122701 (2009)

Probing the symmetry energy with heavy ions, W.G. Lynch et al., Prog. Part. Nucl. Phys. **62**, 427 (2009)

Comparision of Statistical Treatments for the Equations of state for Core-collapse Supernovae, S.R. Souza et al., AP. J., **707** 1495 (2009)

Determination of the Equation of State of Dense Matter, P. Danielewicz, R. Lacey, W.G. Lynch, Science **298**, 1592 (2002)

Imaging Sources with Fast and Slow Emission Components, G. Verde, et al., , Phys. Rev. C **65**, 054609 (2002)

B.S., Physics,
University of Colorado,
1973

PhD, Nuclear Physics,
University of Washington,
1980

Joined NSCL in
December 1980

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Our research is focused upon understanding nuclear collisions and how the information derived from such collisions can improve the understanding of nuclei, nuclear matter and neutron stars. Surprising as it may seem at first, constraints on the pressures that support a neutron star can be obtained by probing the pressures that are achieved in nuclear collisions or by examining the nuclear forces that bind very neutron-rich nuclei. Such nuclear properties can be related to neutron star properties through their common dependence on the equation of state of nuclear matter, which plays the same role for nuclear systems as the ideal gas law plays for gases. Finding appropriate constraints on the nuclear equation of state requires the development of new experimental devices, new experimental measurements and theoretical developments.

One of the largest uncertainties in the nuclear equation of state concerns the symmetry energy, which de-scribes how the energy of nuclei and nuclear matter changes as one replaces protons in a system with neutrons, making the system more and more neutron rich. In some regions in the interiors of neutron stars, matter can be of the order of 95% neutrons. Whether this matter collapses under the gravitational attraction of the neutron star depends on the repulsive pressure from the symmetry energy. Experimental measurements presently do not constrain the pressure from the symmetry energy satisfactorily. Some of our recent experiments have provided constraints on the symmetry pressure; one of our goals is to make such constraints more stringent.

Recently, our group combined five detector systems to probe the density dependence of the symmetry energy. This experiment compared the outward flow of neutrons to that of protons to probe the pressures attained by compressing neutron-rich nuclear systems in the laboratory. The picture to the left shows the experimental setup and the group of students and post-docs that built it. We recently have begun developing two time projection chambers that will enable us to probe the symmetry energy at densities twice the saturation value typical of the centers of nuclei. Students play leading roles in developing such devices. Students also play important roles in the interpretation and theoretical modeling of the data that they measure, providing them with opportunities also to probe theoretical aspects of the phenomena that they are investigating.

Paul Mantica

University Distinguished Professor of Chemistry

Nuclear Chemistry

B.S., Chemistry, Rensselaer Polytechnic Institute, 1985

PhD, Nuclear Chemistry, University of Maryland, College Park, 1990

Joined NSCL in August 1995

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Selected Publications

Collinear laser spectroscopy on the ground state and an excited state in neutron ^{55}Mn, A. Klose, K. Minamisono, and P.F. Mantica, *Phys. Rev. A* 2013, 88, 042701.

New half-lives of very neutron-rich iron isotopes, C. Mazzocchi, R. Surman, R. Grzywacz, J.C. Batchelder, C.R. Bingham, D. Fong, J.H. Hamilton, J.K. Hwang, M. Karny, W. Krolas, S.N. Liddick, P.F. Mantica, A.C. Morton, W.F. Mueller, K.P. Rykaczewski, M. Steiner, A. Stolz, J.A. Winger, and I.N. Borzov, *Phys. Rev. C* 2013, 88, 064320.

Commissioning of the collinear laser spectroscopy system in the BECOLA facility at NSCL, K. Minamisono, P.F. Mantica, A. Klose, S. Vinnikova, A. Schneider, B. Johnson, and B.R. Barquest, *Nucl. Instrum. Methods Phys. Res. A* 2013, 709, 85.

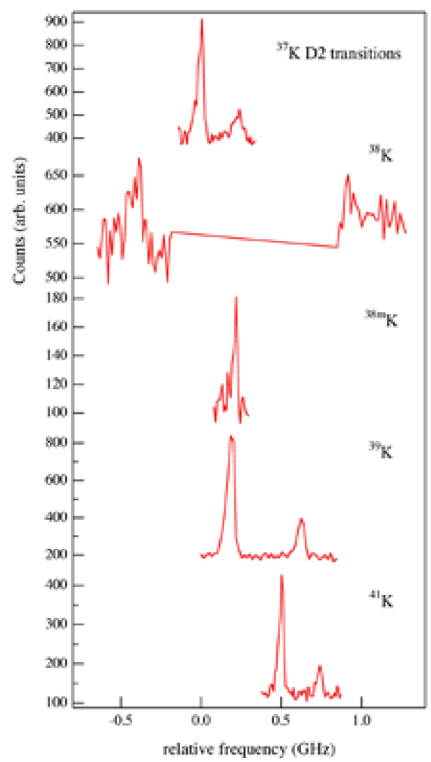
Tests of atomic charge-exchange cells for collinear laser spectroscopy, A. Klose, K. Minamisono, Ch. Geppert, N. Froemmgen, M. Hammen, J. Kraemer, A. Krieger, C.D.P. Levy, P.F. Mantica, W. Noertershaeuser, and S. Vinnikova, *Nucl. Instrum. Methods Phys. Res. A* 2012, 678, 114.

The low-energy properties of atomic nuclei are predicted to show dramatic changes when the ratio of neutrons-to-protons in the nucleus becomes extremely unbalanced. My research group is working to deduce the electromagnetic properties of nuclei which have extreme neutron-to-proton ratios. The desired nuclei, which exist for only fractions of a second, are produced in very small quantities using intermediate-energy reactions at the National Superconducting Cyclotron Laboratory (NSCL) at Michigan State University.

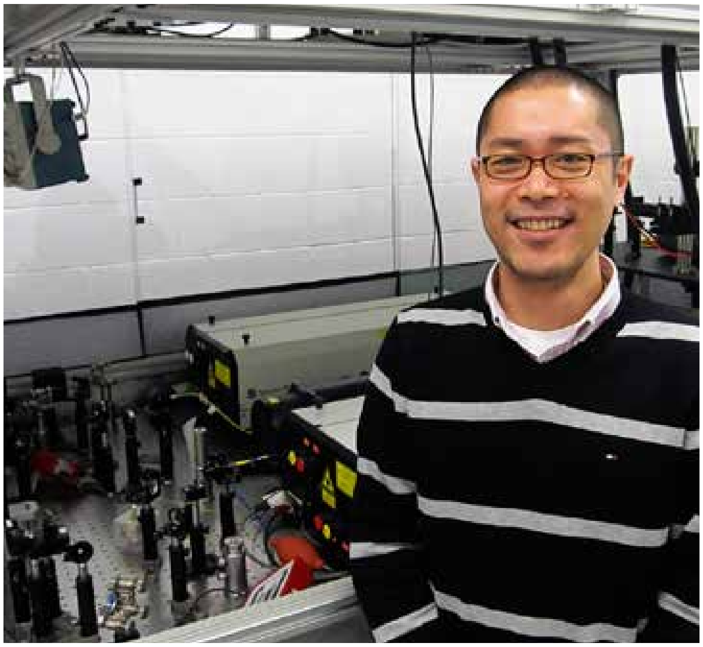
Two electromagnetic properties of interest are the nuclear magnetic dipole moment and nuclear electric quadrupole moment. The dipole moment is sensitive to the orbital component of the angular momentum of any unpaired protons and/or neutrons in the nucleus. The dipole moment provides information on the nuclear quantum structure and the occupied single-particle states. The quadrupole moment is a measure of the deviation of the average charge distribution of the nucleus away from spherical symmetry. The shape of the collection of protons and neutrons in the nucleus, e.g. the nuclear collectivity or "deformation", can be inferred from the quadrupole moment.

One way to deduce the electromagnetic moments of nuclei is via Collinear Laser Spectroscopy (CLS). The CLS method involves the co-propagation of a low-energy beam (~ 60 keV) of atoms/ions with laser light. Fixed-frequency laser light is Doppler tuned into resonance by varying the energy of the beam, with the subsequent fluorescence detected by a photomultiplier tube. The resulting hyperfine spectrum, a product of the interaction of atomic electrons with the nucleus, is analyzed to extract the nuclear magnetic dipole and electric quadrupole moments.

We have installed and commissioned a CLS beam line in the low-energy experimental area at NSCL as part of the Beam Cooling and Laser Spectroscopy (BECOLA) facility. The BECOLA facility also includes a cooler and buncher, which accepts the rare isotope beams from the NSCL beam thermalization area and converts them into a low-emittance, pulsed beam to improve the sensitivity of the CLS measurement. Stable beams of Ca, K, Fe, and Mn have been produced from off-line ion sources, and the hyperfine spectra have been collected and analyzed. A hyperfine spectrum was measured for the short-lived radioisotope ^{37}K ($T_{1/2}$ = 1.2 s), which was delivered to BECOLA at a rate of order 103 per second. The shift in the center of gravity of the hyperfine spectra for the K isotopes presented in the accompanying figure relates directly to a systematic change in nuclear size. On-line CLS measurements on neutron-deficient K and Fe isotopes are planned for the near term.



Hyperfine spectra for ^{37}K – ^{41}K measured via CLS at the BECOLA Facility



Kei Minamisono

Research Staff Physicist and Adjunct Professor of Physics

Experimental Nuclear Physics

Selected Publications

Collinear laser spectroscopy on the ground state and an excited state in neutral ^{55}Mn, A. K. Klose, K. Minamisono, and P. F. Mantica, Phys. Rev. A, in press.

Commissioning of the Collinear Laser Spectroscopy System in the BECOLA Facility at NSCL, K. Minamisono et al., Nucl. Instrum. Methods A 709, 85 (2013).

Low Energy Test of SCC in beta Decays of Spin Aligned ^{20}F and ^{20}Na, K. Minamisono et al., Phys. Rev. C 84, 055501 (2011).

Doubly-Magic Nature of ^{56}Ni: Measurement of the Ground State Nuclear Magnetic Dipole Moment of ^{55}Ni, J. S. Berryman et al., Phys. Rev. C 79, 064305 (2009).

Quadrupole moment of Neutron-Deficient $^{20, 21}$Na, K. Minamisono et al., Phys. Lett. B 672, 120 (2009).

M.S., Physics,
Osaka University,
1996

PhD, Physics,
Osaka University,
1999

Joined NSCL in
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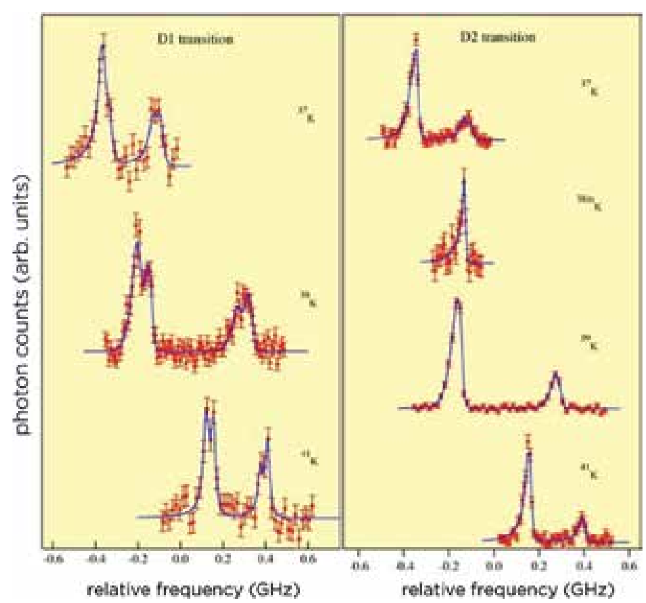
One of my current research interests as an experimentalist is to determine some of the fundamental ground-state properties, the magnetism and shapes, of radioactive isotopes away from the beta stability line, and towards the nucleon drip lines in the nuclear chart. The nuclear magnetic-dipole moment arises from orbital angular momentum and intrinsic spin and sensitive to the valence-nucleon configuration in a nucleus. The nuclear-quadrupole moment and charge radius represent the charge distribution inside the nucleus and sensitive to the shape and deformation.

Laser assisted techniques are used in the experiment; the collinear laser spectroscopy with bunched beams and beta-ray detecting Nuclear Magnetic Resonance technique. Laser light and ion beam are co-propagated through the interaction region and resulting resonant fluorescence and/or nuclear polarization is detected. High precision/resolution laser systems and a detection system with great sensitivity are required to resolve hyperfine structure of low production-rate radioactive isotopes.

I am also interested in testing the time reversal (T) invariance in the light quark system. The T invariance is essential as a complementary symmetry to the CP symmetry, which is thought to have played a crucial role in producing the excess of matter over antimatter early in the history of the universe, which cannot be explained in the Standard Model. A specific nucleus that enhances such symmetry breaking effect is carefully selected to perform beta-decay correlation measurements with spin polarized/aligned nuclei.

Such studies can be realized at the BEam COoling and LAser spectroscopy (BECOLA) facility at NSCL. Both laser-hyperfine-structure measurements and atomic/nuclear spin manipulation to produce polarization will be performed for rare isotopes at low-production rates. BECOLA has been online since the summer 2013 and will explore, as an initial experimental project, nuclear structure of radioactive isotopes of the first row transition elements, which are only available at NSCL.

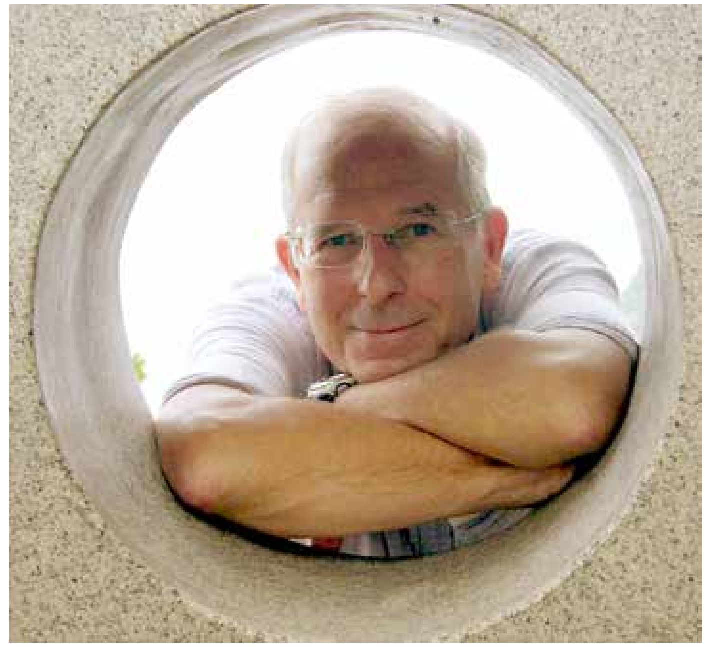


Hyperfine structures and isotope shifts of stable and radioactive potassium isotopes are shown for D1 and D2 transitions. Relative shift of centroids of the resonance structures from that of 39K is the isotope shift, from which charge radius can be extracted. The hyperfine structure (splittings) of each spectrum corresponds to the isotope's nuclear moments i.e. magnetic and quadrupole moments.

Wolfgang Mittig

John A. Hannah Distinguished Professor of Physics

Experimental Nuclear Physics



Docteur ès Sciences, Université de Paris, 1971

Livre Docente, University of Sao Paulo, 1977

Joined NSCL in January 2008

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Selected Publications

Prototype AT-TPC: Toward a new generation active target time projection chamber for radioactive beam experiments, D. Suzuki, M. Ford, D. Bazin, W. Mittig, et al., Nuclear Instruments and Methods in Physics Research A ***691*** (2012)39

Thermo-mechanical behaviour of a single slice test device for the FRIB high power target, Pellemoine, F.; Mittig, W.;... Nuclear Instruments and Methods in Physics Research Section A, Volume 655, (2011) 3

Probing nuclear forces at the extreme of isospin: the 7H resonance, D. Cortina-Gil and W. Mittig, Europhysics News, 41/2 (2010) 23,

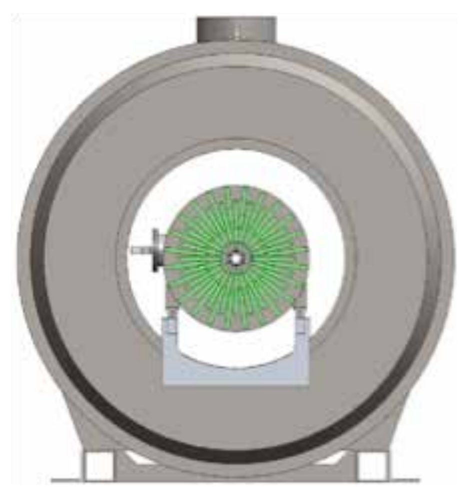
Resonant neutrino scattering: An impossible experiment?, D.Suzuki,T. Sumikama, M.Ogura, W.Mittig,..., Physics Letter B 687(2010)144

Since my university studies, first in Germany and later in France, I involved myself often in very general problematics, such as the foundation of quantum mechanics (Bell inequality), precision measurements to search for nuclear color-VanderWaals forces, nuclear energy and environment, formation of superheavy systems, and very recently the possibility of resonant neutrino scattering.

Recently, I mainly was working on experimental nuclear physics, and more specifically on the spectroscopy of exotic nuclei. This domain is at the frontline of present nuclear physics and is extremely challenging for an experimental physicist. Many new techniques have to be developed in order to study very rare nuclei far from stability. We developed an “active target,” a detector in which the detection gas is at the same time the target. This technique combines a large solid angle, in principle 4ϖ, with a thick target and good resolution. The particles, beam and reaction products, are visualized by their ionization path in the gas. A detailed event-by-event analysis provides the reaction angles, Q-values, angular distributions and excitation functions of the reactions.

At NSCL, we formed an international collaboration for the development of such a device with an increased performance called the AT-TPC to become operational in about two years, together with the future linear post-accelerator ReA3 for rare unstable beams, financed by the NSF. The main tasks here are to construct highly integrated electronics for the 10,000 channels (ASICs), a data-acquisition compatible with the high data flow of such a device, and a high resolution gas-amplifying device such as micromegas. A reduced size prototype was constructed and used in several experiments. The combination of this detector with the new post-accelerator will provide new and competitive possibilities to study properties of very exotic nuclei.

My other present domains of work are related to FRIB. I am working on the project of an achromatic isochronous large angle spectrometer called ISLA, and a technical R&D subject of how to have a 200-kW beam energy loss in a spot of 1-mm diameter in a production target (about 1GW/cubic inch) without destroying it.



A schematic view of the active target time projection chamber. AT-TPC. The chamber is operated within a large bore (1.2m) solenoid, to determine the energy of the charged reaction products by the curvature of their trajectory. The image of the trajectories will be read out by ten thousand electronic channels.

Dave Morrissey

University Distinguished Professor of Chemistry

Nuclear Chemistry

Selected Publications

The NSCL Cyclotron Gas Stopper - Under Construction, S. Schwarz, et al., Proc. EMIS Conf. 2012,

Experimental investigation of the ion surfing transport method, M. Brodeur, A.E. Gehring, G. Bollen, S. Schwarz, and D.J. Morrissey, Intl. J. Mass Spec. 2013 336, 53.

Production cross sections from 82Se fragmentation as indications of shell effects in neutron-rich isotopes close to the drip-line, O.B. Tarasov, M. Portillo, D.J. Morrissey, et al., Phys. Rev. C 2013, 87, 054612.

Evolution of the momentum distribution with mass loss in projectile fragmentation reactions, K. Meierbachtol, D.J. Morrissey, M. Mosby, and D. Bazin, Phys. Rev. C 2012, 85 034608

Systematic studies of light neutron-rich nuclei produced via the fragmentation of 40Ar, E. Kwan, D.J. Morrissey, D.A. Davies, M. Steiner, C.S. Sumithrarachchi, and L. Weissman, Phys. Rev. C 86 (2012) 014612

B.S., Chemistry, Pennsylvania State University, 1975

PhD, Chemistry, University of California, 1978

Joined NSCL in September 1981

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Research in nuclear chemistry that is centered on the production and use of the most exotic, short-lived nuclei. We routinely apply this knowledge to produce beams of very exotic radioactive ions. These short-lived nuclei are interesting in their own right, some of which have not been observed before.

My graduate students work on unraveling the mechanisms of nuclear reactions, on studying the decay properties of the most exotic nuclei, or on developing new techniques to separate, capture and control fast ions. The NSCL is a unique facility that brings together a strong group of nuclear scientists and provides an exceptional setting for studying the properties of nuclei right on the MSU campus. The cyclotrons accelerate ions that span the periodic table to very high kinetic energies. When the fast ions react with a target nucleus, the incident ion is often broken into nuclear fragments with a distribution of sizes, some of which are very unstable and quite unusual. The probability distributions of the products were early subjects of study by my group and can be predicted with reasonable accuracy. We also showed that the momenta, or velocities, of the fragments are distributed around that of the beam and can be predicted by models of the nuclear reaction. These fast moving fragments can be passed through an isotope separator to produce beams of individual radioactive ions. We help to design and develop these fragment separators, which have become the central instruments for research at the NSCL and the Facility for Rare Ion Beams (FRIB) under construction at MSU. The NSCL currently relies on its second generation fragment separator completed in 2001 while a revolutionary new fragment separator is being designed for the FRIB facility that will replace the NSCL.

Along with using the new fragment separator for production and decay studies, our group has completed the construction and development of an auxiliary device to slow down the exotic reaction products to thermal energies. In this project, we have extended the ion-guide ion-source (IGISOL) technique to collect individual radioactive ions. A helium-filled chamber is tailored to stop and collect the exotic isotopes produced by the A1900 fragment separator at NSCL using a differentially pumped gas-filled cell in a process related to atmospheric-sampling mass spectrometry. The so-called gas-catcher system was used in many successful and extremely precise mass measurements at the NSCL carried out by the group headed by Prof. Bollen (MSU Physics). More recently the thermalized ions were used in collinear laser spectroscopy experiments, precision decay studies, and nuclear reaction studies. We are currently constructing a next-generation device for thermalization of projectile fragments based on the concept of a reverse cyclotron that will be able to provide the large variety of fragments needed for mass measurements and other new experiments at the NSCL. The cyclotron-stopper is based on a four meter diameter superconducting magnet that weighs approximately 200 tons (see below).

Photograph of the gas-filled reverse-cyclotron during testing in 2014. The device relies on an inner 2 meter diameter beam chamber contained inside a 200 ton superconducting magnet. The particles will enter parallel to the floor from the right and be bent onto spiral paths by the magnetic field. They will slow down by collisions with helium gas and the thermalized ions will be extracted along the central axis.

Oscar Naviliat Cuncic

Professor of Physics

Experimental Nuclear Physics

M.S., Nuclear Physics
Cath. University of Louvain,1984

PhD, Nuclear Physics
Cath. University of Louvain, 1989

Joined NSCL in August 2010

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Selected Publications

Symmetry Tests in Nuclear Beta Decay
N. Severijns and O. Naviliat-Cuncic
Annu. Rev. Nucl. Part. Sci. 61, 23 (2011)

Test of the Conserved Vector Current Hypothesis in T=1/2 Mirror Transitions and New Determination of |Vud|
O. Naviliat-Cuncic and N. Severijns
Phys. Rev. Lett. 102, 142302 (2009)

Paul Trapping of Radioactive $^6He^+$ Ions and Direct Observation of Their b Decay
X. Flechard et al., Phys. Rev. Lett. 101, 212504 (2008)

Tests of the standard electroweak model in nuclear beta decay
N. Sverijns, M. Beck and O. Naviliat-Cuncic Rev. Mod. Phys. 78, 991 (2006)

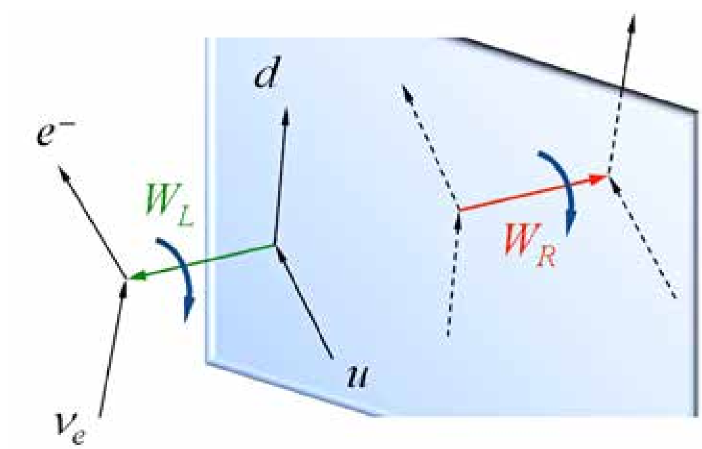
The experimental tests of the foundations of physical theories is a cross disciplinary domain that can hardly be grabbed by any particular subfield of physics. The measurements carried out for such tests are indeed made with particles, nuclei, atoms, molecules or crystals. What does concern each of the specific subfields are the experimental techniques being used.

I have been involved in experimental tests of discrete symmetries in the weak interaction (parity violation and time reversal invariance) and in searches for new interactions through measurements using muons, neutrons and nuclei, which in most cases were polarized. Some measurements also required the use of traps (material-, electromagnetic-, or magneto-gravitational) for the confinement of particles for their study. Such precision measurements at low energies are considered an alternative route to the searches for new particles or phenomena carried out at the highest possible energies in collider experiments. In general, the principles of the experiments at low energies are rather simple but the measurements are difficult and challenging. The design of new experiments requires implementing modern techniques in order to reach new levels of sensitivity.

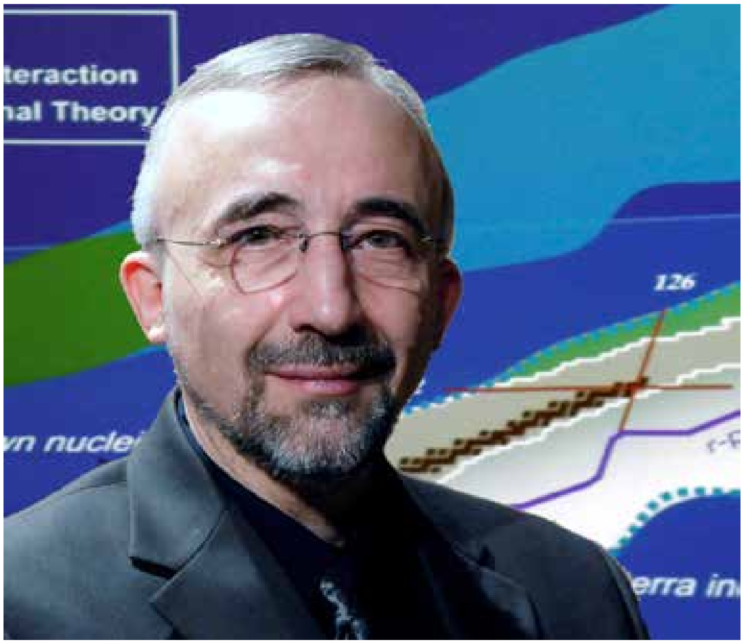
Atomic nuclei offer a very rich spectrum of candidates for precision measurements at low energies due to the large number of isotopes, the diversity of states and the different decay modes involving the fundamental interactions. The abundant production of rare isotopes opens further the spectrum for the design of new sensitive experiments.

My current activities focus in the measurement of correlation observables in nuclear beta-decay that search for possible contributions of new interactions as a signature of physics beyond the standard model. Current projects include measurements of correlations in Gamow-Teller transitions to search for tensor type couplings and the measurements of correlations using polarized nuclei to search for maximal parity violation.

The intellectual creativity in the design of experiments, and in particular those addressing the foundations of physical theories, is fascinating to me. The role of judge that some experiments may have in the survival of new concepts and the construction of theories is very exciting.



The test of parity (mirror symmetry) in nuclear beta decay provides a window to search for new interactions, like those which could be mediated by right-handed vector bosons.



Witek Nazarewicz

John A. Hannah Distinguished Professor in Physics
FRIB Chief Scientist

Theoretical Nuclear Physics

Selected Publications

"Spontaneous fission lifetimes from the minimization of self-consistent collective action," J. Sadhukhan, K.Mazurek, A. Baran, J. Dobaczewski, W. Nazarewicz and J. A. Sheikh, Phys. Rev. C 88, 064314 (2013).

"The limits of the nuclear landscape," J. Erler, N. Birge, M. Kortelainen, W. Nazarewicz, E. Olsen, A.M. Perhac, and M. Stoitsov, Nature 486, 509 (2012).

"Shell model in the complex energy plane," N. Michel, W. Nazarewicz, M. Ploszajczak, and T. Vertse, J. Phys. G (Topical Review) 36, 013101 (2009).

"Shape coexistence and triaxiality in the superheavy nuclei," S. Cwiok, P.H. Heenen, and W. Nazarewicz, Nature 433, 705 (2005).

M.S. Engineer in Technical Physics and Applied Mathematics Warsaw University of Technology, 1977

Ph. D., Physics, Institute for Nuclear Research, Warsaw, 1981

Dr. hab., Physics, Warsaw University, 1986

Joined NSCL in August 2014

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Atomic nuclei, the core of matter and the fuel of stars, are self-bound collections of protons and neutrons (nucleons) that interact through forces that have their origin in quantum chromo-dynamics. Nuclei comprise 99.9% of all baryonic matter in the Universe. The complex nature of the nuclear forces among protons and neutrons yields a diverse and unique variety of nuclear phenomena, which form the basis for the experimental and theoretical studies. Developing a comprehensive description of all nuclei, a long-standing goal of nuclear physics, requires theoretical and experimental investigations of rare atomic nuclei, i.e. systems with neutron-to-proton ratios larger and smaller than those naturally occurring on earth. The main area of my professional activity is the theoretical description of those exotic, short-lived nuclei that inhabit remote regions of nuclear landscape. This research invites a strong interaction between nuclear physics, many-body-problem, and high- performance computing. Key scientific themes that are being addressed by my research are captured by overarching questions:

- How did visible matter come into being and how does it evolve?
- How does subatomic matter organize itself and what phenomena emerge?
- Are the fundamental interactions that are basic to the structure of matter fully understood?
- How can the knowledge and technological progress provided by nuclear physics best be used to benefit society?

Quantum Many-Body Problem

Heavy nuclei are splendid laboratories of many-body science. While the number of degrees of freedom in heavy nuclei is large, it is still very small compared to the number of electrons in a solid or atoms in a mole of gas. Nevertheless, nuclei exhibit behaviors that are emergent in nature and present in other complex systems. For instance, shell structure, symmetry breaking phenomena, collective excitations, and superconductivity are found in nuclei, atomic clusters, quantum dots, small metallic grains, and trapped atom gases.

Although the interactions of nuclear physics differ from the electromagnetic interactions that dominate chemistry, materials, and biological molecules, the theoretical methods and many of the computational techniques to solve the quantum many-body problems are shared. Examples are ab-initio and configuration interaction methods, and the Density Functional Theory, used by nuclear theorists to describe light and heavy nuclei and nucleonic matter.

Physics of Open Systems

Today, much interest in various fields of physics is devoted to the study of small open quantum systems, whose properties are profoundly affected by environment, i.e., continuum of decay channels. Although every finite fermion system has its own characteristic features, resonance phenomena are generic; they are great interdisciplinary unifiers. In the field of nuclear physics, the growing interest in theory of open quantum systems is associated with experimental efforts in producing weakly bound/unbound nuclei close to the particle drip-lines, and studying structures and reactions with those exotic systems. In this context, the major problem for nuclear theory is a unification of structure and reaction aspects of nuclei, which is based on the open quantum system many-body formalism.

Physics of FRIB

The Facility for Rare Isotope Beams will be a world-leading laboratory for the study of nuclear structure, reactions and astrophysics. Experiments with intense beams of rare isotopes produced at FRIB will guide us toward a comprehensive description of nuclei, elucidate the origin of the elements in the cosmos, help provide an understanding of matter in neutron stars and establish the scientific foundation for innovative applications of nuclear science to society. FRIB will be essential for gaining access to key regions of the nuclear chart, where the measured nuclear properties will challenge established concepts, and highlight shortcomings and needed modifications to current theory. Conversely, nuclear theory will play a critical role in providing the intellectual framework for the science at FRIB, and will provide invaluable guidance to FRIB's experimental programs.

Filomena Nunes

Professor of Physics
Theoretical Nuclear Physics Department Head

Theoretical Nuclear Physics

Selected Publications

Low-temperature triple-alpha rate in a full three-body nuclear model, N.B. Nguyen, F.M. Nunes, I.J. Thompson, E.F. Brown, Phys. Rev. Lett. **109** 141101 (2012)

The magic nature of ^{132}Sn explored through the single-particle states of ^{133}Sn, K.L. Jones et al., *Nature*, **465** , 454-457 (2010)

Benchmark on neutron capture extracted from (d,p) reactions. A.M. Mukhamedzhanov, F.M. Nunes and P. Mohr, Phys. Rev. C **77** 051601 (2008)

"Extracting (n,g) direct capture cross sections from Coulomb Dissociation: application to ^{14}C(n,g)^{15}C" N.C Summers and F.M. Nunes, Phys. Rev. C **78** 011601 (2008)

B(E1) strengths from the Coulomb excitation of ^{11}Be N. Summers *et al.*, Phys. Lett. B **650**, 124 (2007)

Scaling and interference in the dissociation of halo nuclei, M.S. Hussein, R. Lichtenthäler, F.M. Nunes and I.J. Thompson, Phys. Lett. B **640**, 91 (2006)

Engenharia Fisica Technologica, Instituto Superior Tecnico Lisboa, 1992

PhD, Theoretical Physics, University of Surrey, England, 1995

Joined NSCL in February 2003

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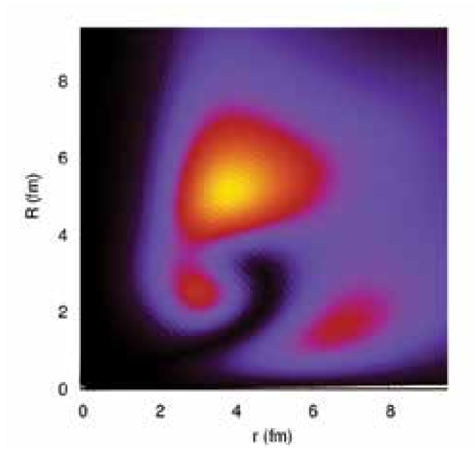
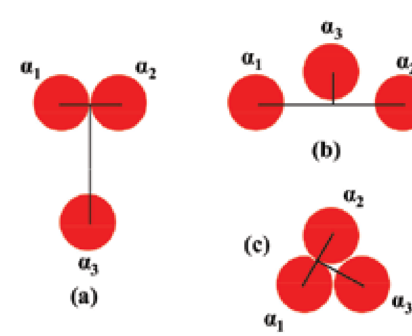
I study direct nuclear reactions and structure models that are useful in the description of reactions. Unstable nuclei are mostly studied through reactions, because they decay back to stability, often lasting less than a few seconds. My work focuses on developing models for reactions with exotic unstable nuclei. Reaction theory is very important because it makes the connection between experiments such as the ones performed at NSCL and the nuclear structure information we want to extract. Within the realm of direct reactions, my contributions have been toward understanding inelastic excitation, breakup and transfer reactions.

The motivation to study these reactions are three-fold. Breakup and transfer reactions can be used as indirect methods to obtain capture rates of astrophysical relevance. These capture rates enter in the simulations of stars, and explosive sites such as novae and supernovae. In addition, reliable models for some specific direct reactions are crucial for nuclear waste management. Finally, and most importantly, we also need reactions to unveil the hidden secrets of the effective nuclear force which binds some exotic systems and not others.

Nuclei are many body systems of large complexity. Describing a reaction while retaining all the complexity of the projectile and target nuclei would be a daunting task. Fortunately, to describe many direct reactions, only a few structure degrees of freedom are necessary. Thus, we develop simplified few-body structure models that retain the important features of the nucleus of interest and can be used as input to the reaction calculations. When comparing with the data, we learn whether our initial assumptions were correct. Given that many unstable nuclei break up so easily, the nucleus can go through the continuum (scattering states) in the reaction. Introducing breakup accurately involves computer intensive calculations, so we use the High Performance Computers at MSU.



The Hoyle state is essential for the production of 12C in stars. Three alpha particles come together to form a resonance.



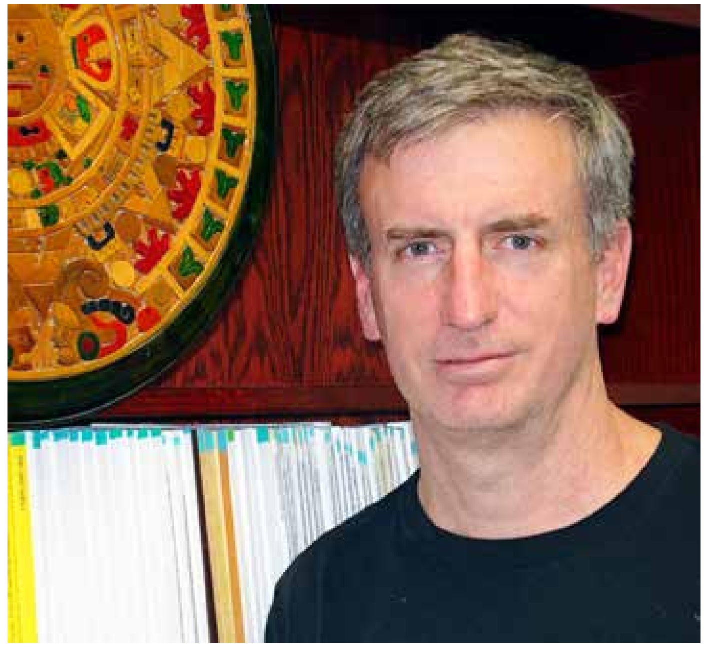
Recently we performed three-body scattering calculations for the three alpha particles and obtained a complex structure for the Hoyle state represented above, through a probability distribution.

The strongest peak corresponds to a 8Be-alpha like structure (a) , the weaker peak to the lower right corresponds to an alpha-alpha-alpha linear structure (b) and the peak in the lower left corresponds to a triangular configuration (c).

Scott Pratt

Professor of Physics
Associate Chair and Director of Graduate Studies,
Department of Physics and Astronomy

Theoretical Nuclear Physics



PhD, Theoretical Nuclear Physics, University of Minnesota, 1985

Joined NSCL in October 1992

pratt@nscl.msu.edu

Selected Publications

Determining Fundamental Properties of Matter Created in Ultrarelativistic Heavy-Ion Collision, J. Novak, K. Novak, S. Pratt, C. Coleman-Smith, R. Wolpert, arXiv:1303.5769 (2013)

Identifying the Charge Carriers of the Quark-Gluon Plasma, S. Pratt, Physical Review Letters, 108, 212301 (2012)

Resolving the HBT Puzzle in Relativistic Heavy-Ion Collisions, S. Pratt, Physical Review Letters 102, 232301 (2009)

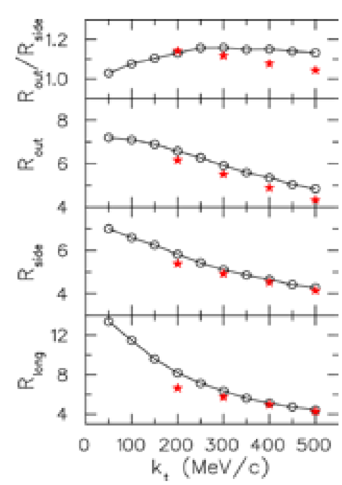
Sonic booms at 1012 Kelvin, S. Pratt, Viewpoint, Physics 1, 29 (2008)

Canonical and Microcanonical Calculations for Fermi Systems, S. Pratt, Phys. Rev. Lett. 84, 4255 (2000)

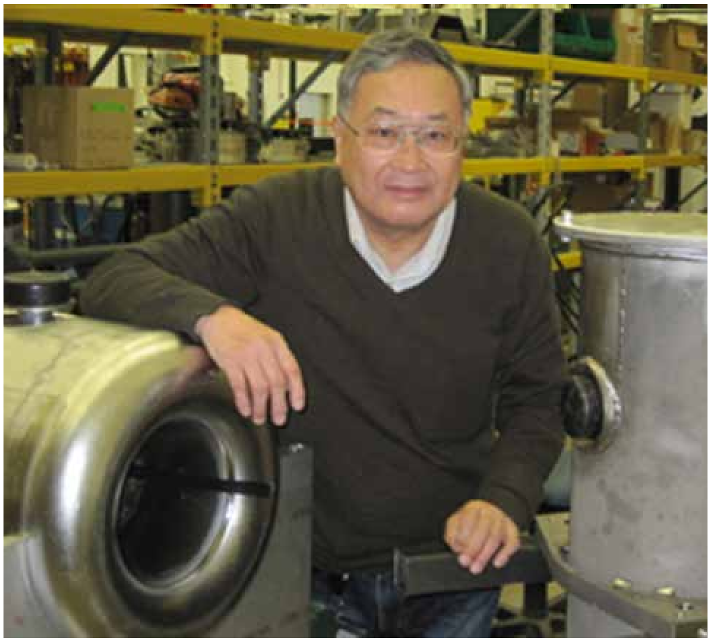
My research centers on the theoretical description and interpretation of relativistic heavy-ion collisions. In these experiments, heavy nuclei such as gold or lead are collided head on at ultrarelativistic energies at RHIC, located at Brookhaven, or at the LHC at CERN. The resulting collisions can create mesoscopic regions where temperatures exceed 10^{12} Kelvin. At these temperatures, densities become so high that hadrons overlap, which makes it impossible to identify individual hadrons. Thus, one attains a new state of matter, the strongly interacting quark gluon plasma. The QCD structure of the vacuum, which through its coupling to neutrons and protons is responsible for much of the mass of the universe, also melts at these temperatures. Unfortunately, the collision volumes are so small (sizes of a few time 10-15 m) and the expansions are so rapid (expands and disassembles in less that 10^{-21} seconds) that direct observation of the novel state of matter is impossible. Instead, one must infer all properties of the matter from the measured momenta of the outgoing particles. Thus, progress is predicated on careful and detailed modeling of the entire collision.

Modeling heavy ion collisions invokes tools and methods from numerous disciplines: quantum transport theory, relativisitic hydrodynamics, non-perturbative statistical mechanics, and traditional nuclear physics - to name a few. I have been particularly involved in the development of femtoscopic techniques built on two-particle correlation measurements. After their last randomizing collision, a pair of particles will interact according to the well-understood quantum two-body interaction.
This results in a measurable correlation that can be extracted as a function of the pair's center of mass momentum and relative momentum. Since the correlation is sensitive to how far apart the particles are emitted in time and space, it can be used to quantitatively infer crucial properties of the space-time nature of the collision. These techniques have developed into a field of their own and have proved invaluable for determining the space-time evolution of the system from experiment. I have also developed phenomenological tools for determining the chemical evolution of the QGP from correlations driven by charge conservation. These correlations, at a quantitative level, have shown that the quark content of the matter created in heavy-ion collisions at RHIC or at the LHC indeed have roughly the expected densities of up, down and strange quarks. Other work has included transport tools, such as as hydrodynamics and Boltzmann distributions, as applied to relativistic collisions, and methods for exact calculations of canonical ensembles with complicated sets of conserved charges.

From 2009-2014, I am the principal investigator for the MADAI collaboration, which was funded by the NSF through the Cyber-Enabled Discovery and Innovation initiative. MADAI involves nuclear physicists, cosmologists, astro-physicists, atmospheric scientists, statisticians and vizualization experts from MSU, Duke and the University of North Carolina. The goal is to develop statistical tools for comparing large heterogenous data sets to sophisticated multi-scale models. In particular, I have worked to use data from RHIC and the LHC to extract fundamental properties of the matter created in high-energy heavy-ion collisions.



Femtoscopic source radii (in femtometers) characterize the size of the outgoing phase space cloud for particles of given momentum, kt. Experimentally determined sizes from two-particle correlations taken by the STAR collaboration (stars) are compared to model predictions (circles).



Kenji Saito

Professor of Physics

Accelerator Physics

Selected Publications

State-of-the-Art and Future Prospects in RF Superconductivity, K. Saito, 2012 International Particle Accelerator Conference (2012).

Multi-wire Slicing of Large Grain Ingot Material, K. Saito et al., the 14th Workshop on RF Superconductivity 2009 (SRF2009).

Gradient Yield Improvement Efforts for Single and Multi-Cells and Progress for Very High Gradient Cavities, K. Saito, the 13rd Workshop on RF Superconductivity 2007 (SRF2007).

Theological Critical Field in RF Application, K. Saito, the 11th Workshop on RF Superconductivity SRF2003 (2003).

Superiority of Electropolishing over Chemical Polishing on High Gradients, K. Saito et al., The 8th Workshop on RF Superconductivity (1997).

B.S. Mathematics and Physics, Ritsumeikan University, 1977

Ph. D Nuclear Physics, Tohoku University, Japan, 1983

Joined NSCL in April 2012

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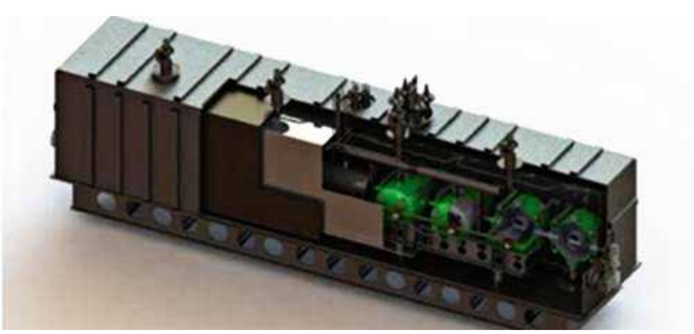
Accelerator is the base tool for nuclear physics, high energy physics, light sources, medical applications, and so on. Superconducting Radio Frequency (SRF) Systems are an application of microwave acceleration for ion beams. The principle is the same as normal conducting RF system, but SRF systems use superconducting technology, which allows high quality beam acceleration with very high efficiency. It is a key technology for current world-wide accelerator projects for nuclear science and high energy physics. SRF systems are a state-of-the art technology to open new areas of particle physics. The FRIB project at MSU utilizes this system for a major part of the accelerator. I joined the NSCL graduate school education program servicing the FRIB SRF development manager since 2012. My photo shows a quarter wave resonator (80.5MHz) and have wave resonator (322MHz) for FRIB.

The main part of a SRF system is the so-called cryomodule and RF system. Figure 1 illustrates the FRIB beta=0.53 half wave resonator cryomodule. Cryomodule consists of a cryostat and SRF cavities included therein. Ionized beam is accelerated by SRF cavities, which is made of superconducting material and cooled by liquid helium at below 4.2K. Cryostat is a kind of Thermos bottle to keep SRF cavities at such a low temperature. Niobium material has been utilized for SR cavities, which has high quality superconducting features: higher superconducting transition temperature Tc=9.25K and higher thermodynamic critical field Hc = 200mT. Niobium has a good forming performance to fabricate cavities. Development of high quality niobium is always a concerned and I have been working on high purity niobium material. My latest concern is single crystalline niobium ingot or other new materials. In RF cavity design it is very important to have an excellent SC cavity performance, which has to be simulated intensively by specific computing cords. I have developed a high gradient SRF cavity shape with an acceleration gradient > 50MV/m and demonstrated the high performance, which is world recorded so far. This activity will applied other new SRF systems.



An example of the SRF systems, FRIB 0.53 half wave resonator cryomodule.

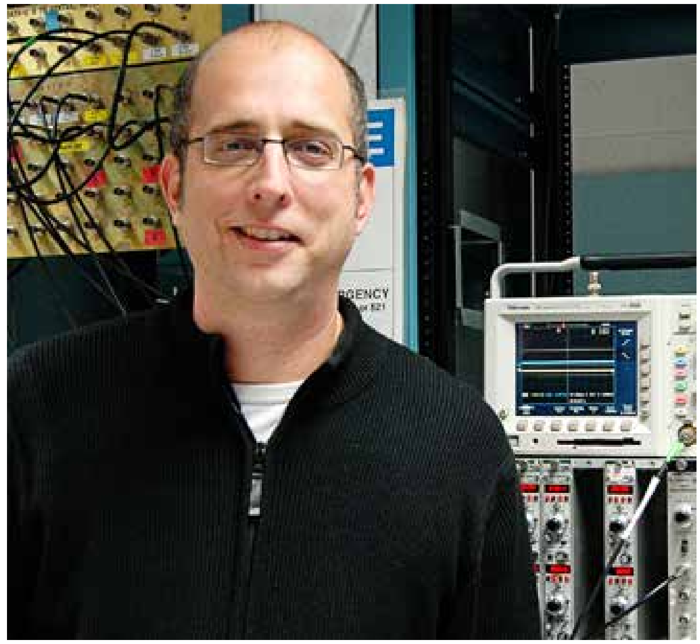
SR cavity performance subjects to very shallow surface characteristics where RF surface current flows. Particle/defect free clean surface is especially crucial. Chemical clean surface preparation and clean assembly technology are key technologies. I have developed electropolishing method for elliptical shaped SRF cavity and confirmed it is the best process for high gradient cavities. This technology will be applied to low beta cavities and push the gradient in order to make SRF system more compact.

Cryostat design includes lots of engineering and material issues. We are investing a lot on this subject in ongoing FRIB cryomodule. The RF system is another exciting place to study. Concerning SRF, high power coupler is an important issue to develop. The design of multipacting free high power coupler structure and cleaning technology, TiN coating technologies, would make for a great theme for a thesis. Thus SRF systems cover various sciences and super-technologies: electromagnetic dynamics, superconducting material science, plastic forming technology, ultra-clean technology, ultra-high vacuum, cryogenics, RF technology, mechanical/electric engineer. SR system is an exciting place to study. Any students from Physics, Chemistry, Materials, and Mechanical/Electric Engineer are acceptable for this subject.

Hendrik Schatz

Professor of Physics
JINA-CEE Department Head

Experimental Nuclear Astrophysics



M.S., Physics,
University of Karlsruhe,
1993

PhD, Physics,
University of
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Joined NSCL in
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Selected Publications

Beta-delayed proton emission in the ^{100}Sn region, G. Lorusso, et. al. Phys. Rev. C, 86, 014313 (2012).

Time-of-Flight Mass Measurements for Nuclear Processes in Neutron Star Crusts, Estrade, A. et al. Phys. Rev. Lett. ***107*** *(2011) 172503 (arXiv:1109.5200)*

Half-lives and branchings for β-delayed neutron emission for neutron-rich Co-Cu isotopes in the r-process, Hosmer, P. et al. Phys. Rev. C ***82*** *(2010) 025806*

Heating in the Accreted Neutron Star Ocean: Implications for Superburst Ignition, S. Gupta, E.F. Brown, H. Schatz, P. Moeller, and K. L. Kratz, Astrophys. J. ***662****, 1188 (2007)*

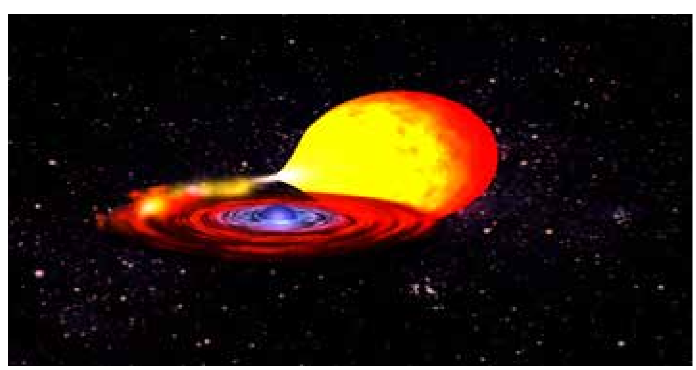
X-ray Binaries, H. Schatz and K.E. Rehm, Nucl. Phys. A ***777****, 601 (2006)*

The goal of our experimental and theoretical research program is to understand the nuclear processes that occur naturally in the cosmos. To that end, we take advantage of the capabilities of NSCL and other laboratories to produce the same exotic isotopes that are created in extreme astrophysical environments such as supernovae, hydrogen explosions on neutron stars and white dwarfs, or the crusts of neutron stars. By measuring the properties of these very short lived isotopes we can address questions such as: What is the origin of the heavy elements in nature made in the rapid neutron capture process (r-process)? Why do current models for this process not work? What powers the frequently observed x-ray bursts and what do observations tell us about the astrophysical site? What are the processes in the crusts of neutron stars that convert ordinary nuclei into exotic isotopes beyond the limits of neutron stability? Why do these processes generate not enough heat to explain observations?

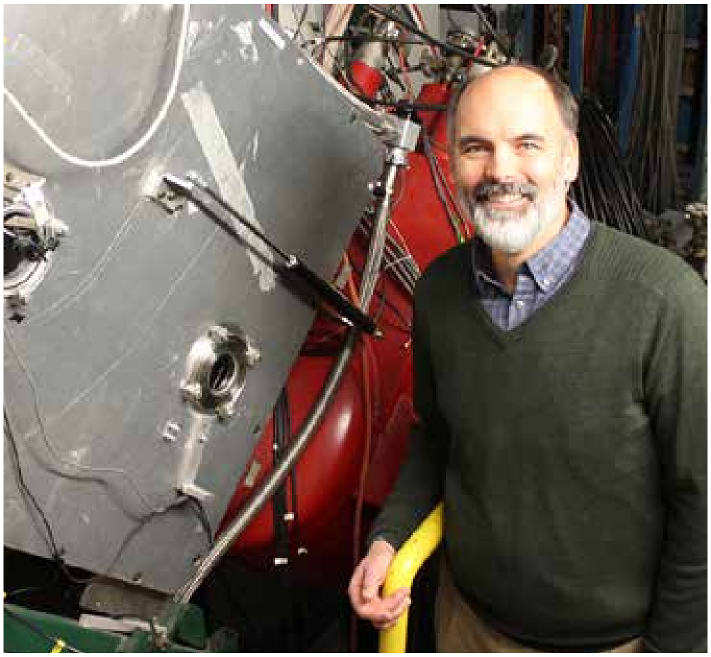
These questions are addressed by carrying out different types of experiments. These include measurements of beta delayed neutron emission with the NERO detector developed by our group, using the new generation gamma ray detector array GRETINA to probe excited states of exotic nuclei that can be used to calculate reactions rates for X-ray bursts, and measuring the masses of very neutron rich nuclei needed in neutron star crust models using the S800 spectrometer and a set of specially developed micro channel plate and fast plastic detectors. A new direction are experiments using the low energy beams that will be provided in 2013 by the new ReA3 facility. Our group is involved in developing a high density gas jet target and a recoil separator system, and we are participating in a number of other projects that will take advantage of these beams. A focus area for the coming years will be to characterize and use the world unique beams provided by ReA3 for nuclear astrophysics research. Thesis projects are available in all these areas.

Our experiments are not performed in isolation but are embedded into a network of astrophysical model calculations and astronomical observations supported by the Joint Institute for Nuclear Astrophysics (JINA) a multi institutional NSF Physics Frontiers Center. Graduate students in our group become part of JINA and participate in all stages of this process. The goal of JINA is to provide a fully interdisciplinary education that is a pre-requisite for a successful career in this field.

While students go through the complete nuclear physics graduate course sequence, their education is complemented by participation in JINA schools (often held internationally), through research stays at JINA collaborating institutions in the US and abroad, and by carrying out astrophysical model calculations as part of their research, for example, to motivate their experiments, or to interpret their experimental results. Our group has a suite of astrophysical models that are available for use and further development at MSU. Alternatively collaborations with JINA partners in theoretical astrophysics can be used to carry out more sophisticated model calculations, such as multi-zone X-ray burst or multi-dimensional supernova simulations. In addition, students will form contacts with other JINA graduate students and postdocs at other institutions, as well with established researchers in nuclear physics, astrophysics, and astronomy.



Artists view of a neutron star that accretes matter from a companion.



Bradley Sherrill

University Distinguished Professor of Physics
Associate Laboratory Director for Users

Experimental Nuclear Physics

Selected Publications

Design of the Advanced Rare Isotope Separator ARIS at FRIB; M. Hausmann, et. al., Nucl. Instruments and Methods B, on-line (2013)

Production cross sections from ^{82}SE fragmentation as indications of shell effects in neutron-rich isotopes close to the drip-line; O.B. Tarasov, et. al., Phys. Rev. C 87, 054612 (2013)

From isotopes to the stars, M. Thoennessen, B.M. Sherrill, Nature 473 (2011) 25.

Evidence for a change in the nuclear mass surface with the discovery of the most neutron-rich nuclei with 17≤Z≤25; O.B. Tarasov, et al, Physical Review Letters **102**, 142501 (2009)

Designer Nuclei, B.M. Sherrill, Science **320** 751 DOI:10.1126/science.1151836 (2008)

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M.S., Physics,
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PhD, Physics,
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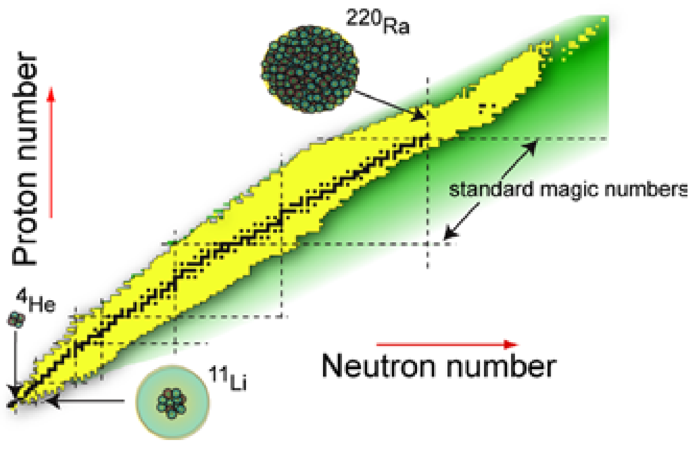
Approximately 270 isotopes are found naturally. However, many more isotopes, nearly 7,000 in total, can be produced by particle accelerators or in nuclear reactors. These isotopes are radioactive and spontaneously decay to more stable forms, and I work to produce and separate new and interesting ones.

There are several reasons why a latent demand exists within the scientific community for new, rare isotopes. One is that the properties of particular isotopes often hold the key to understanding some aspect of nuclear science. Another is that the rate of certain nuclear reactions involving rare isotopes can be important for modeling astronomical objects, such as supernovae. Yet another is that the properties of atomic nuclei can be used to test nature's fundamental symmetries by searches for deviations from known symmetry laws. Finally, the production of isotopes benefits many branches of science and medicine as th isotopes can be used as sensitive probes of biological or physical processes.

The tools for production and separation of rare isotopes gives scientists access to designer nuclei with characteristics that can be adjusted to the research need. For example, super-heavy isotopes of light elements, such as lithium, have a size nearly five times the size of a normal lithium nucleus. The existence of such nuclei allows researchers to study the interaction of neutrons in nearly pure neutron matter, similar to what exists in neutron stars.

For production of new isotopes, the approach that I have helped develop is called in-flight separation; where a heavy ion, such as a uranium nucleus, is broken up at high energy. This produces a cocktail beam of fragments that are filtered by a downstream system of magnets called a fragment separator. The efficiency of this technique can be nearly 100% and we are able to identify a single ion out of 10^{18} other particles. My group develops new techniques for fragment separation, and studies the nuclear reaction mechanisms that are used to product new isotopes. In the process we search for the most exotic isotopes possible in nature.

Research in this area includes study and design of magnetic ion optical devices. learning the various nuclear production mechanisms and improving models to describe them. This background allows one to contribute to science by making new isotopes, but also prepares one for a broad range of careers in academia, government (e.g. national security), and industry.



The rich variety of nuclei is indicated by the depiction of three isotopes ^{4}He, ^{11}Li, and ^{220}Ra overlaid on the chart of nuclides where black squares indicate the combination of neutrons and protons that result in stable isotopes, yellow those produced so far, and green those that might exist. Nuclei like ^{11}Li have very different characteristics, such as a diffuse surface of neutron matter, than do normal nuclei.

Jaideep Taggart Singh

Assistant Professor of Physics

Experimental Atomic & Nuclear Physics

Selected Publications

Measurement of the Hyperfine Quenching Rate of the Clock Transition in ^{171}Yb, C.-Y. Xu, J. Singh et al., Phys. Rev. Lett. 113 033003 (2014)

A magnetically shielded room with ultra low residual field and gradient, I. Altarev et al., Rev. Sci. Instrum. 85 075106 (2014)

The Development of High-Performance Alkali-Hybrid Polarized He-3 Targets for Electron Scattering, Jaideep Singh et al., (submitted to Phys. Rev. C) arXiv:1309.4004 (2013)

Efficient, tightly-confined trapping of ^{226}Ra, R. H. Parker et al., Phys. Rev. C 86 065503 (2012)

B.S. Physics
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2010

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In the Fall of 2014, I will be forming a new group that will apply techniques borrowed from atomic, molecular, & optical physics to problems in nuclear physics. Our research interests include tests of fundamental symmetries, low energy searches of physics beyond the Standard Model, and studies of rare nuclear reactions. A particular emphasis of our group is creating, manipulating, and detecting spin-polarized nuclei.

Why is there something rather than nothing in the Universe? The answer to this question is thought to be closely linked to fundamental interactions between subatomic particles that violate time reversal symmetry. Although it has been known since the late 1960's that the Weak nuclear force slightly violates time reversal, its strength is far too feeble to explain the present day abundance of matter (as opposed to antimatter) in the Universe. The presence of a permanent electric dipole moment (EDM) of a particle is an unambiguous signature of an underlying time reversal symmetry violating interaction. A very sensitive technique to search for an EDM is a clock comparison experiment. In such an experiment, a clock is formed by placing a spin-polarized particle, such as a nucleus, in a very stable and very uniform magnetic field. The clock or spin precession frequency is then observed while an electric field is applied to the particle. An EDM would couple to this electric field causing a very small shift in the observed clock frequency. Over the last sixty years, all searches for an EDM based on this and similar techniques have yielded a null result. Because the observation of a nonzero EDM would have far reaching consequences, there is a world wide effort by many groups to search for an EDM in several different systems.

At the moment, our group is heavily involved in two on-going EDM searches in nuclei. The first involves the rare isotope Radium-225 which, because of its unusual nuclear shape, is expected to have an enhanced sensitivity to new physics which violates time reversal symmetry. Because Radium has a very low vapor pressure, this experiment involves laser cooling and trapping techniques to make efficient use of the small number (thousands) of atoms available.

The Facility for Rare Isotope Beams is expected to provide, among other things, a steady and intense source of Ra-225. This would allow for detailed studies of systematic effects that limit the sensitivity of the Ra-225 EDM search currently underway. The second EDM search involves the stable and abundant isotope Xenon-129, which is a naturally occurring component of air. This experiment involves the production of large Xe magnetizations using a technique called spin exchange optical pumping (SEOP) and very low noise magnetic flux detection using SQUIDs. A key component of this experiment is a state of the art (2.5 m)^3 magnetically shielded room located in Munich, Germany. Our group will contribute to all aspects of these precision measurements providing expertise in ultra-low field NMR, optical pumping, electric field generation & characterization, ultra-high vacuum systems, cryogenic systems, laser manipulation of atoms, and ultra-low noise precision magnetometry.

Our group will also pioneer brand new techniques to capture, detect, and manipulate nuclei embedded in noble gas solids (NGS). NGS provide stable and chemically inert confinement for a wide variety of guest species. Confinement times and atom numbers in NGS exceed those of conventional laser traps by orders of magnitude. Because NGS are transparent at optical wavelengths, the guest atoms can be probed using lasers. Our group aims to demonstrate optical single atom detection in NGS which would provide a new tool for studying rare nuclear reactions. We also plan on performing a search for the permanent EDM of Ytterbium-171 using solid Neon to trap large numbers of Yb atoms. In addition to improving present constraints on the existence of time reversal violating interactions within nuclei, this experiment would provide a testing ground for next generation EDM searches potentially using rare isotopes that will become available when FRIB comes online.

Artemis Spyrou

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Experimental Nuclear Physics

M.S. , Physics,
National Technical
University of Athens,
2003

PhD Physics,
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2007

Joined NSCL in
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Selected Publications

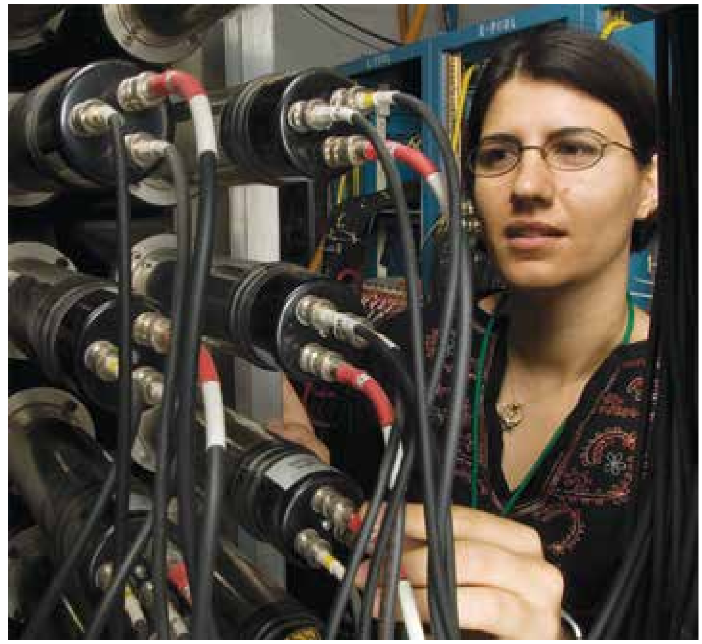
Probing the production mechanism of the light p-nuclei. S.J. Quinn, A. Spyrou, A. Simon, et. al. Physical Review C Rapic Communication, 88 (2013) 011603

Systematic study of (p,y) reactions on Ni isotopes. A. Simon, A. Spyrou, et. al. Physical Review C 87 (2013) 055802

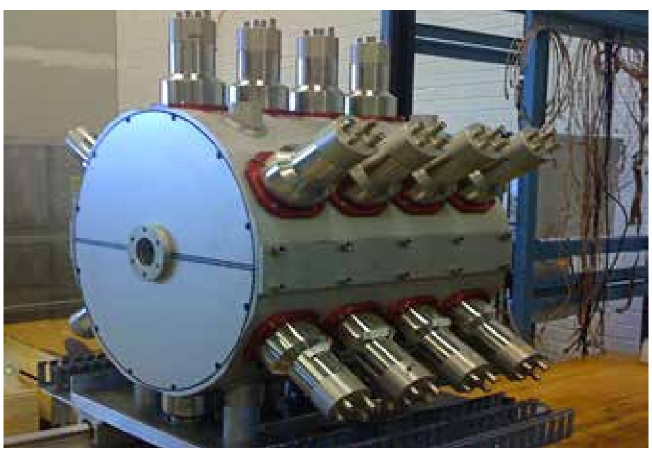
*First Observation of Ground State Dineutron Decay: ^{16}Be, A. Spyrou, Z. Kohley, et al., Physical Review Letters **108** (2012) 102501*

*Nuclear structure experiments along the neutron drip line, T. Baumann, A. Spyrou, M. Thoennessen, Reports on Progress in Physcis, **75** (2012) 036301*

*First evidence for a virtual ^{18}B ground state. A. Spyrou, et al., Physics Letters B **683** (2010) 129.*



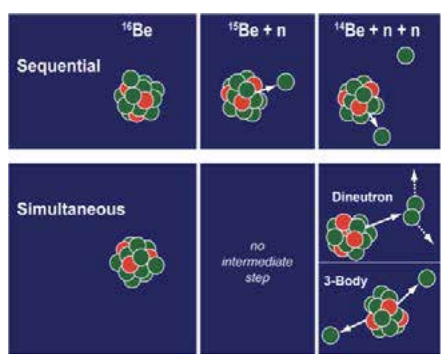
My research interests extend into two fields, both in experimental nuclear physics. For the first one, I study nuclear reactions that take place inside stars and - through different astrophysical processes - are responsible for the synthesis of all known elements. My second field of interest is focused on the structure of light nuclei, which are so neutron-rich that they are beyond the limits of existence.



The SuN detector was constructed at NSCL in 2011 for important astrophysical measurements. http://groups.nscl.msu.edu/SuN/

The elements that we observe today on earth were all created inside stars through different types of nuclear reactions. Starting with hydrogen and helium, the light elements are produced by reaction cycles that burn the existing fuel and slowly build the heavier nuclei up to the region of iron. Above iron, most elements are created through two processes (s- and r-process), which involve neutron-induced reactions together with β-decays. There is also a small group of proton-rich nuclei, called "p-nuclei", which cannot be created by these neutron-processes but rather by a different process called "p process". There are several open questions governing the synthesis of the heavy elements. My work as an experimentalist is to study the nuclear reactions involved in these astrophysical processes. For this purpose, my group developed the SuN detector - a total absorption gamma-ray spectrometer that is used for measuring reaction rates and beta-decay properties involved in the nucleosynthesis and, in particular, related to the r- and p-processes.

At the same time, I'm also a member of the MoNA collaboration, which focuses on experiments to study extremely neutron-rich nuclei along the neutron drip line. These nuclei live for such a small time that no device can capture them to study their properties. In our experiments, we observe the products of their decay, which are a high-energy neutron and the remaining charged nucleus. From these products we can reconstruct the original exotic nucleus and study its structure. The Modular Neutron Array (MoNA) detects the emitted neutrons, providing information about their energy and position. This experimental setup has been used by the MoNA Collaboration to study the properties of nuclei along the neutron drip line with many exciting findings, such as new magic numbers and dineutron decays.



Different possible two-neutron decays. We observed a dineutron decay from the ground state of ^{16}Be, which was the first observation of such a decay. Figure credit T. Baumann.
http://www.cord.edu/dept/physics/mona/

Andreas Stolz

Associate Professor (NSCL)
Operations Department Head
Experimental Nuclear Physics

Selected Publications

Evidence for a Change in the Nuclear Mass Surface with the Discovery of the Most Neutron-Rich Nuclei with 17 ≤ Z ≤ 25, O. B. Tarasov et al., Phys. Rev. Lett. **102**, 142501 (2009)

First observation of two-proton radioactivity in ^{48}Ni, M. Pomorski et al., Phys. Rev. C 83, 061303 (2011).

Discovery of ^{40}Mg and ^{42}Al suggests neutron drip-line slant towards heavier isotopes, T. Baumann et al., Nature **449**, 1022 (2007)

Heteroepitaxial diamond detectors for heavy ion beam tracking, A. Stolz et al., Diamond and Related Materials **15**, 807 (2006)

First observation of ^{60}Ge and ^{64}Se, A. Stolz et al., Phys. Lett. B **627**, 32 (2005)

M.S., Physics, Technological University of Munich 1995

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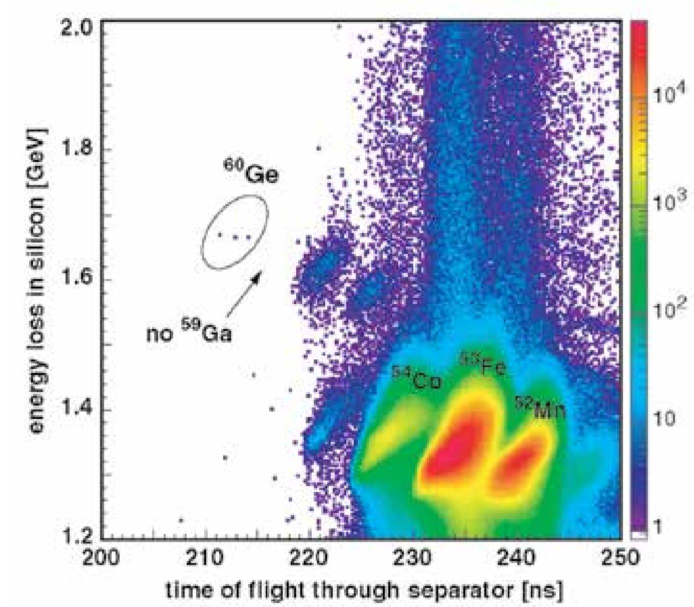
My primary research interest is centered on the production of rare isotope beams with fragment separators and the study of the structure of nuclei at the limits of existence. At NSCL, rare isotope beams are produced by projectile fragmentation. The coupled cyclotrons accelerate stable ions to a velocity up to half the speed of light. The fast ions then impinge on a production target where they break up into fragments of different mass and charges. Most of the fragments are unstable and many of them have an unusual ratio of protons and neutrons. To study their properties, the fragments of interest need to be separated from all other produced particles. The A1900 fragment separator at NSCL filters rare isotopes by their magnetic properties and their energy loss in thin metal foils. Detector systems installed in the path of the beam allow the unambiguous identification of every single isotope transmitted through the device. The large acceptance of the separator together with intense primary beams from the cyclotrons allow access to the most exotic nuclei that exist, some of which were observed for the first time at NSCL. The investigation of the limits of nuclear stability provides a key benchmark for nuclear models and is fundamental to the understanding of the nuclear forces and structure.

Another research area is the development of particle detectors made from diamond produced by chemical vapor. Radioactive beam facilities of the newest generation can produce rare isotope beams with very high intensities. The special properties of diamond allow the development of radiation-hard timing and tracking detectors that can be used at incident particle rates up to 10^8 particles per second. Detectors based on poly-crystalline diamond were built and tested at NSCL and excellent timing properties were achieved. Those detectors have been successfully used as timing detectors in several NSCL experiments. First, detectors based on single-crystal diamond showed superior efficiency and energy resolution. Further development will continue with the investigation of properties of single-crystal diamond detectors and the production of position-sensitive detectors with larger active areas.



Particle identification plot showing the energy loss in a silicon detector as a function of time-of-flight through the A1900 fragment separator. The separator tune was optimized for ^{60}Ge, a rare isotope observed for the first time at NSCL.

Michael Syphers

Professor of Physics

Accelerator Physics

PhD, Physics, University of Illinois at Chicago, 1987

M.S., with Distinction, Physics, De Paul University, Chicago, 1984

B.S. in Ed., Physics, Indiana University, Bloomington, 1979

Joined NSCL in August 2010

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Selected Publications

Status of the Rare Isotope Reaccelerator Facility ReA, D. Leitner, et al., Proc. 2013 Part. Accel. Conf., Anaheim, 1458-1462 (2013)

Accelerator Physics of Colliders, M.J. Syphers and F. Zimmermann; J. Beringer et al. (Particle Data Group), Phys. Rev. D86, 010001 (2013).

Coil Creep and Skew-Quadrupole Field Components in the Tevatron , G.E. Annala, D.J. Harding, M.J. Syphers, Jour. Inst. 7 T03001, 1-16 (2012)

Parameterization of the Driven Betatron Oscillation, R. Miyamoto, et al., Phys. Rev. ST-AB 11, 084002 (2008)

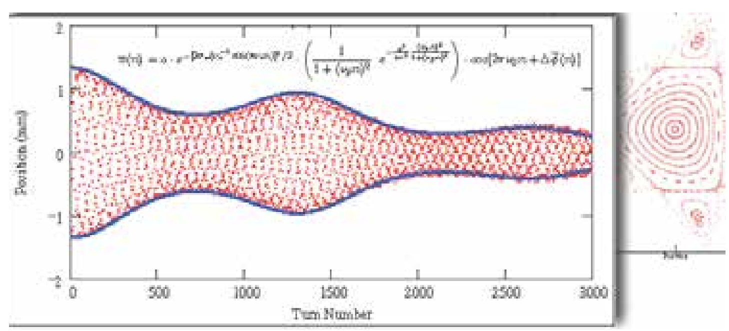
Experimental Test of Coherent Betatron Resonance Excitations, M. Bei, et al., Phys. Rev. E56, 6002 (1997)

The design and development of large-scale particle accelerators, such as the system being pursued at MSU -- the Facility for Rare Isotope Beams (FRIB) -- and the subsequent stability of particle motion within these accelerators have been the focus of my research over the years. Before arriving at MSU in 2010, my career has involved designing, building, commissioning, operating, and experimentally studying large particle accelerators for fundamental physics research, including work on the Main Ring, Tevatron, Main Injector, and other accelerators at Fermilab; the Superconducting Super Collider in Texas (construction halted); Brookhaven National Lab's AGS and RHIC (as a polarized proton collider); and the LHC at CERN. I also have participated in early design studies of the International Linear Collider and Muon Collider concepts.

Particle beam optics and accelerator design, nonlinear particle beam dynamics, and novel uses of beam instrumentation and diagnostics for measuring and monitoring beam and accelerator properties have been the emphasis of my work. New projects at MSU and throughout the world generate demands to the accelerator field in these regards. The wide range of particle species coupled with intense beam power and brightness demanded by modern accelerators pose new challenges to beam intensities, efficiencies, and the need for flexible systems of particle containment, focusing, and optimization.

The MSU Re-accelerator (ReA) is not only a unique system for methodically studying nuclear systems found in astrophysical environments, but it also provides opportunities for research into novel beam diagnostic systems and a test bed for the development of superconducting cavity systems and beam transport systems that can be used in FRIB and other future particle accelerators. Our research group takes advantage of the wide variety of particle beam conditions at ReA to pursue unique and varied opportunities in accelerator and beam research.

Reaching beyond NSCL, I am also engaged in studies of future hadron colliders at the 100 TeV energy scale, as well as the development of storage rings and beam lines that can be used in measurements of anomalous magnetic moments (in particular the muon system) and searches for non-zero electric dipole moments of particles, studies that are important for tests of fundamental symmetries. As a member of the Muon g-2 experiment at Fermilab and the Storage Ring EDM Collaboration, I help investigate particle beam storage and transport systems used in such experiments, involving fundamental design, CPU-intensive computational studies, as well as experimental investigations for verification. Such investigations in turn explore the full potential of accelerator facilities operating at the intensity frontiers of nuclear and high energy physics.



A typical beam position monitor does not resolve individual particles. However, if the beam is intentionally offset from the ideal trajectory it will oscillate due to the focusing fields of the accelerator. An analysis of the resulting signal can give information about the nonlinear properties of the accelerator and of the energy spread of the beam.

Michael Thoennessen

Professor of Physics

Experimental Nuclear Physics

Selected Publications

Current status and future potential of nuclide discoveries, M. Thoennessen, Rep. Prog. Phys. ***76****, 056301 (2013)*

Study of Two-Neutron Radioactivity in the Deacy of ^{26}O, Z. Kohley et al., Phys. Rev. Lett. ***110****, 152501 (2013)*

Novel techniques to search for one- and two-neutron radioactivity, M. Thoennessen et al., Nucl. Instrum. Meth. A ***729****, 207 (2013)*

First observation of ^{15}Be, J. Snyder et al., Phys. Rev. C ***88****, 031303(R) (2013)*

Nuclear Structure at and beyond the neutron dripline, T. Baumann, A. Spyrou, M. Thoennessen, Rep. Prog. Phys. ***75****, 036301 (2012)*

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My research begins where the nuclear chart ends. While normal neutron-rich nuclei decay by converting a neutron into a proton (β decay) on a time scale of milliseconds or longer, nuclei beyond the end of the nuclear chart, or neutron-unbound nuclei, contain so many neutrons that they decay by emitting one or two of the excess neutrons on a time scale of 10-21s.

I am part of the MoNA/Sweeper collaboration which specializes in the study of these neutron-unbound nuclei. The masses and lifetimes of these extremely short-lived nuclei cannot be measured with standard techniques. The availability of fast radioactive ion beams at NSCL gives us the opportunity to create neutron-unbound nuclei and study them by detecting their decay products. For example ^{25}O, the first neutron-unbound oxygen nucleus, was first observed by our group. A primary beam of ^{48}Ca was accelerated to about 50% of the speed of light with the Coupled Cyclotron Facility and a secondary beam of ^{26}F was selected by the A1900 fragment separator. The ^{26}F interacted with a target where we were specifically interested in the one-proton stripping reaction which leads to ^{25}O. Instantaneously, ^{25}O then decays inside the target into ^{24}O and a neutron. Due to the large incoming velocity ^{24}O and the neutron will leave the target at very forward angles so that are possible to detect with high efficiency.

The detection is done with two devices which were specifically designed for these studies. The 4 Tesla superconducting "Sweeper" magnet deflects the charged decay fragment into a set of particle detectors that identify the ^{24}O fragments and measure their energies and angles. The Sweeper magnet was built at the National High Magnetic Field Laboratory at Florida State University in collaboration with NSCL.

The second device is the MoNA-LISA array which is a highly efficient large area neutron detector designed to measure the energy and angle of the emitted neutrons. MoNA and LISA were constructed by a collaboration of primarily undergraduate institutions, and undergraduates continue to participate in the experiments and data analyses. From the energies and angles of the fragments and neutrons, it is possible to reconstruct the mass of the neutron-unbound nuclei. ^{25}O is only one example of the many neutron-unbound nuclei at the limit of nuclear existence, and we have recently expanded our experiments to study even more exotic nuclei which decay by the emission of two neutrons. The combination of MoNA-LISA and the Sweeper with the fast radioactive beams is one of the few facilities in the world where these nuclei can be explored. In addition to discovering more new unbound nuclides, we continuously develop new experimental capabilities, for example we are currently installing a liquid deuterium target for (d,p) reactions and are designing an active target to improve the overall resolution of the setup.

MoNA-LISA: The MOdular Neutron Array and the Large multi-Institutional Scintillator Array.

Betty Tsang

Professor (NSCL)

Nuclear Chemistry

B.S., Mathematics, California State College, 1973

M.S., Chemistry, University of Washington, 1978

PhD, Chemistry, University of Washington, 1980

Joined NSCL in December 1980

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Selected Publications

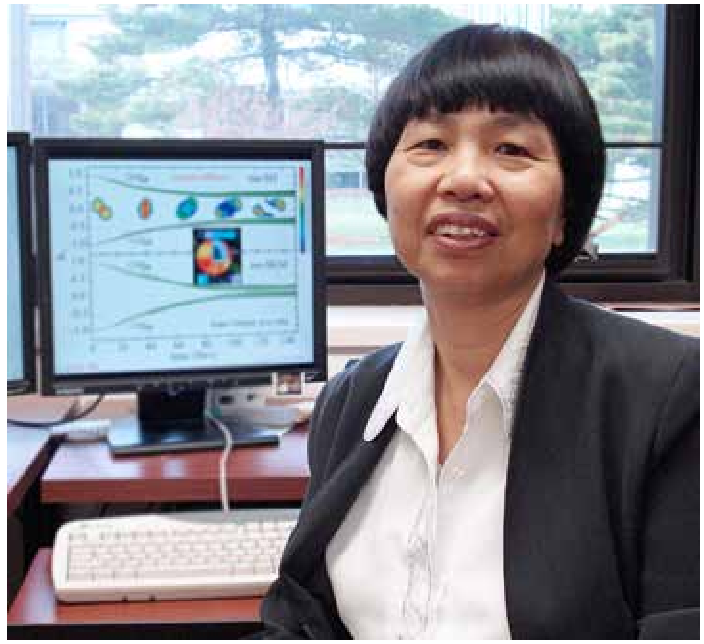
Constraints on the Density Dependence of the Symmetry Energy, M.B. Tsang, Y. Zhang, P. Danielewicz, M. Famiano, Z. Li, W.G. Lynch, A.W. Steiner, Phys. Rev. Lett. ***102****, 122701 (2009)*

Isospin Diffusion in Heavy Ion Reactions, M.B. Tsang et al., Phys. Rev. Lett. ***92****, 062701 (2004).*

Neutron-Proton Asymmetry Dependence of Spectroscopic Factors in Ar Isotopes, Jenny Lee, M.B. Tsang, et al., Phys. Rev. Lett. ***104****, 112701 (2010)*

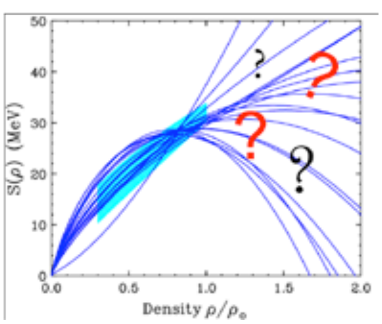
Survey of Excited State Neutron Spectroscopic Factors for Z=8-28 Nuclei, M.B. Tsang, Jenny Lee, S.C. Su, J.. Dai, M. Hori, H. Liu, W.G. Lynch, S. Warren, Phys. Rev. Lett. ***102****, 062501 (2009)*

Constraints on the symmetry energy and neutron skins from experiments and theory, M.B. Tsang et al., Phys. Rev. C ***86****, 015803 (2012)*



As an experimentalist, I study collisions of nuclei at energies at approximately half the speed of light. From the collisions of nuclei, we can create environments that resemble the first moments of the universe after the big bang. Properties of extra-terrestrial objects such as neutron stars can be obtained from studying collisions of a variety of nuclei with different compositions of protons and neutrons. One important research area of current interest is the density dependence of the symmetry energy, which governs the stability as well as other properties of neutron stars. Symmetry energy also determines the degree of stability in nuclei.

We have an active program to study the symmetry energy term in the nuclear equation of state. In a series of experiments at NSCL and in Catania, Italy, we measured the isotope yields from the collisions of different tin isotopes, $^{112}Sn+^{112}Sn$ (light tin systems), $^{124}Sn+^{124}Sn$ (heavy tin systems with more neutrons) as well as the crossed reactions of $^{124}Sn+^{112}Sn$, and $^{112}Sn+^{124}Sn$. We measure isospin diffusions, which is related to the symmetry energy as the degree of isospin transferred in violent encounters of the projectile and target depends on the symmetry energy potentials. In an experiment at MSU, we also measured the neutron to proton ratios that are directly related to the symmetry energy. In addition to experiments, we carry out Transport simulations of nuclear collisions at the super-computing center at Austin, Texas and MSU in our quest to understand the role of symmetry energy in nuclear collisions, nuclear structure and neutron stars.



The curves are the density dependence of the symmetry energy calculated from various phenomenological nucleon interactions. There are large uncertainties below and above the saturation density, r0. The blue shaded region which excludes some of the theoretical calculations have been obtained mainly with NSCL experiments. The next challenge in the quest of understanding symmetry energy is the high density regions.

Through measurements and comparisons to the transport model simulations, we are able to obtain a constraint on the density dependence of the symmetry energy below normal nuclear matter density (which is the density of the nucleus you encounter everyday, $0.26fm^{-3}$ or $2.04x10^{17}$ kg/m^3) as shown in the blue shaded region in the figure. The curves are various theoretical predictions showing the large uncertainties in theory regarding the properties of symmetry energy.

To explore the density region above normal nuclear matter density - marked with question marks in the figure - experiments are planned at NSCL, as well as RIKEN, Japan. Currently, our group is building a Time Projection Chamber that will detect charged particles as well as pions when the TPC is placed inside a dipole magnet. When completed, the TPC will be installed in the SAMURAI magnet in RIKEN, Japan and will allow us to study the symmetry energy at twice of the nuclear matter density.

By studying particles emitted in nuclear collisions, we also gain knowledge about the structure of nuclei. Single nucleon transfer reactions, when either a proton or neutron is transferred from the projectile to the target or vice versa, have been used successfully in the study of nuclear structure. This type of reaction is especially useful in understanding the single particle states in a nucleus, such as 56Ni, which is a double magic nucleus but is unstable. 56NI is a nucleus of astrophysical interest as it is the end product in many astrophysical reactions. Accurate descriptions of single particle states are of fundamental importance to check the validity of the nuclear shell models that predict properties of exotic nuclei relevant in our understanding of nucleosynthesis of elements when the early universe was formed. Our group has an active experimental program in transfer reactions using a state of the art high resolution detector array (HiRA). Experiments are being planned for using radioactive beams at NSCL.

Jie Wei

Professor of Physics
Accelerator Systems Division Director

Accelerator Physics

Selected Publications

FRIB accelerator status and challenges, J. Wei, et al, Proc. Linac Conference, Tel Aviv (2012), pp. 417

*Synchrotrons and accumulators for high-intensity proton beams, J. Wei, Reviews of Modern Physics, **75**, 1383 (2003)*

*The low-energy state of circulating stored ion beam: crystalline beams, J. Wei, X-P. Li, A. M. Sessler, Physical Review Letters, **73**, 3089 (1994)*

*Necessary Conditions for Attaining a Crystalline Beam, J. Wei, H. Okamoto, A.M. Sessler, Physical Review Letters, **80**, 2606 (1998)*

*Theorem on magnet fringe field, J. Wei, R. Talman, Particle Accelerators, **55**, 339 (1996)*

Low-loss design for the high-intensity accumulator ring of the Spallation Neutron Source, J. Wei, et al, Physical Review ST-Accel. Beams, Vol. 3, 080101 (2000)

B.S. Physics, Tsinghua University, China, 1983

Ph. D Physics, Stony Brook University, 1989

Joined NSCL in August 2010

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The accelerators for the Facility of Rare Isotope Beams (FRIB) facility are among the most powerful and technically demanding hadron accelerators in the world. Intense beams of heavy ions up to uranium are produced and accelerated to 200 MeV/u and higher energy with beam powers up to 400 kW to produce rare isotopes. Scientific experiments can be performed with rare isotope beams at velocities similar to the driver linac beam, at near zero velocities after stopping in a gas cell, or at intermediate velocities through reacceleration. The design and development of the FRIB driver accelerator requires the most advanced knowledge in accelerator physics and engineering involving beam dynamics with electron-cyclotron-resonance (ECR) ion sources, radio-frequency quadrupole (RFQ) linac, superconducting RF linac; space charge and beam halo; charge stripping mechanisms based on solid film, liquid film, and gases; mechanisms of beam loss, collimation, and collection; mechanisms of vibration, microphonics, and compensation; and mechanisms of gas dissorption, electron cloud, and mitigations.

Accelerator engineering covers fields of superconducting material and technology; low-temperature cryogenics; permanent and electromagnetic magnets and power supplies; radio-frequency vacuum; beam diagnostics instrumentation and electronics; accelerator controls and machine protection; and beam collimation and shielding. Design, R&D, construction, commissioning, and upgrade of the FRIB accelerator complex involve fascinating and challenging works across multiple disciplines at Michigan State University and in collaboration with major accelerator institutes and laboratories in United States and throughout the world.

During the past 25 years, I have had the opportunity to work on several accelerator projects including the Relativistic Heavy Ion Collider at Brookhaven National Laboratory, the U.S. part of the Large Hadron Collider at CERN, the Spallation Neutron Source at Oak Ridge National Laboratory in collaboration with Lawrence Berkeley, Los Alamos, Thomas Jefferson, Brookhaven, and Argonne National Laboratories, the China Spallation Neutron Source project, and the Compact Pulsed Hadron Source in China. My scientific research involves accelerator physics of high-energy colliders and high-intensity proton accelerators; beam dynamics of non-adiabatic regime and transition crossing in high-intensity rings and proton drivers; magnetic fringe field and nonlinearity correction; electron cloud formation and mitigation in high-intensity rings; intra-beam scattering of heavy-ion beams in colliders; beam cooling and crystallization; development of spallation neutron sources; development of compact pulsed hadron sources; development of hadron therapy facilities; development of accelerator driven sub-critical reactor programs for thorium energy utilization and nuclear waste transmutation; and development of accelerators for rare isotope beams. The field of accelerator physics is uniquely rewarding in that ideas and dreams can be turned into reality through engineering projects, through which one experiences endless learning in physics, technology, teamwork and fostering friendships.

Presently, our team is responsible for the design, prototyping, construction, and commissioning of the driver accelerator complex of the FRIB Project and the commissioning of the ReA3 reaccelerator. Our division contains departments and groups of Accelerator Physics, Superconducting Radio-frequency, Cryogenics, Diagnostics, Controls, Magnet, Front End, Collimation and Beam Dumps, Vacuum and Alignment, ReA3, Mechanical Engineering, and Electrical Engineering. We collaborate closely with major DOE national laboratories in the United States and worldwide with accelerator institutes in Europe and Asia. We are looking forward to more students and young fellows joining us to start their scientific career in the field of accelerator physics and engineering, and joining us in the exciting works of turning FRIB accelerator design into reality.

Gary Westfall

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Experimental Nuclear Physics

B.S., Physics,
University of Texas,
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Austin, 1975

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Selected Publications

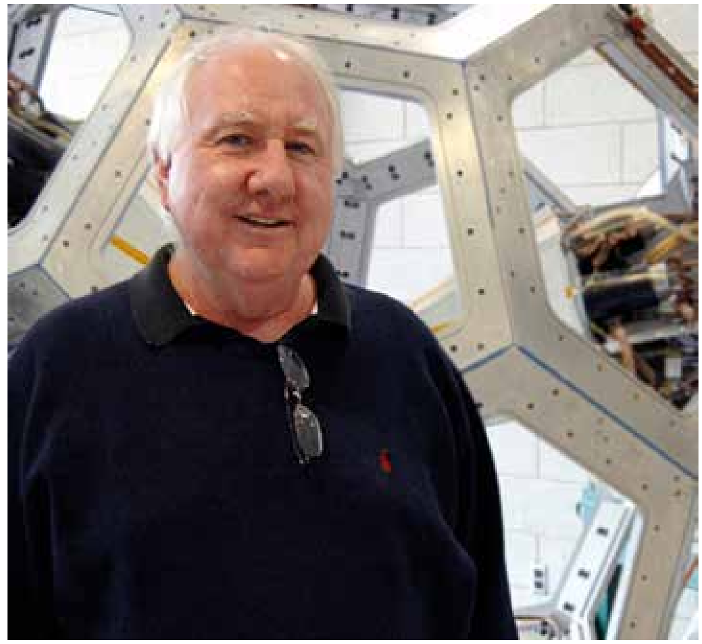
Balance functions from Au+Au, d+Au, and p+p collisions at sqrt(s_{NN}) = 200 GeV, STAR Collaboration, Phys. Rev. C 82, 024905 (2010).

K/ϖ Fluctuations at Relativistic Energies, STAR Collaboration, Phys. Rev. Lett. **103**, 092301 (2009)

Incident Energy Dependence of Correlations at Relativistic Energies, STAR Collaboration, Phys. Rev. C **72**, 044902 (2005)

Fluctuations and Correlations in STAR, G.D. Westfall, J. Phys. G: Nucl. Part. Phys. **30**, S1389 (2004)

Narrowing of the Balance Function with Centrality in Au+Au Collisions at = 130 GeV, STAR Collaboration, Phys. Rev. Lett. **90**, 172301 (2003)



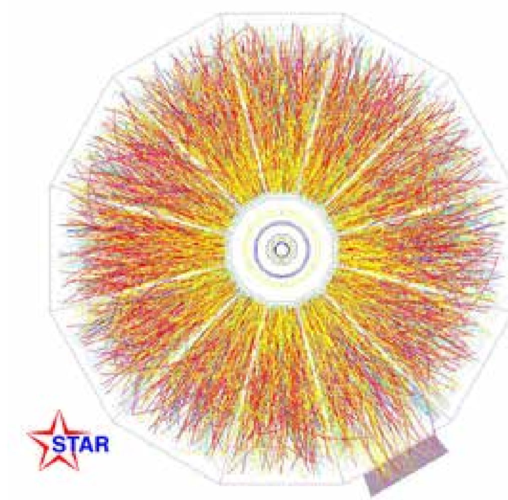
My research focuses on studying the quark-gluon liquid at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory using the STAR detector. At RHIC, we collide gold nuclei at center-of-mass energies of up to 200 GeV per nucleon pair. At this energy, the protons and neutrons in the incident nuclei are transformed into a hot, dense, and strongly interacting liquid of quarks and gluons. This quark-gluon liquid is a nearly perfect liquid, which has nearly zero viscosity as evidenced by the comparison of flow measurements to hydrodynamic calculations. The universe is thought to have existed in this form a few microseconds after the big bang.

The main detector of STAR is its time projection chamber (TPC). This TPC can produce a full three-dimensional picture of the collision of two ultrarelativistic nuclei. A collision of two gold nuclei is shown as measured in the STAR detector. Each line in the picture corresponds to a single particle leaving the collision. Several thousand tracks are observed in this one central collision. The color of the track represents the ionization density of the track. By correlating the curvature of the track and its ionization density, the particles that created the track can be identified.

The three cornerstones of the observation of the quark-gluon liquid at RHIC are thermalization, collective flow and jet suppression. The spectra of particles emitted in gold-gold collisions can be well described by a blast-wave model incorporating a kinetic temperature and an expansion velocity. The relative number of various types of particles can be well described by a thermal model using a chemical temperature and a chemical potential. Collective flow manifests itself in terms of azimuthal anisotropies. The original anisotropy in the overlap region of the two colliding nuclei is translated into momentum correlations in the final state. Central collisions of gold nuclei also show strong jet suppression.

By comparing gold-gold collisions with deuteron-gold and proton-proton collisions, RHIC experimenters were able to show that the quark-gluon liquid originates with the scattering of quark and gluons.

At the top RHIC energies, we observe a smooth transition from the quark gluon plasma to the hadrons observed in STAR. At the lowest RHIC energies, we expect a first order phase transition to occur when the quark gluon plasma hadronizes. The RHIC Beam Energy Scan is designed to provide incident energies at which the critical point may be observed. We are searching for this critical end point using correlation and fluctuation observables. Near the QCD critical point, fluctuations are expected to increase dramatically.



A central collision of two gold nuclei at 130 GeV per nucleon pair as observed in the STAR detector at RHIC. The figure is drawn looking down the beam line of RHIC.

Christopher Wrede

Assistant Professor of Physics

Experimental Nuclear Astrophysics

Selected Publications

The 30P(p, γ)31S reaction in classical novae: progress and prospects, C. Wrede, AIP Advances 4, 041004 (2014)

Classical-Nova Contribution to the Milky Way's 26Al Abundance: Exit Channel of the Key 25Al(p, γ)26Si Resonance, M. B. Bennett, C. Wrede et al., Phys. Rev. Lett. 111, 232503 (2013)

*Electron capture on ^{116}In and implications for nuclear structure related to double-β decay, C. Wrede et al., Phys. Rev. C **87**, 031303(R) (2013)*

*Branches of ^{33}S(p,γ)^{34}Cl at oxygen-neon nova temperatures, B.M. Freeman, C. Wrede, et al., Phys. Rev. C **83**, 048801 (2011)*

*Direct measurements of ^{22}Na(p,γ)^{23}Mg resonances and consequences for ^{22}Na production in classical novae, A. L. Sallaska, C. Wrede, et al., Phys. Rev. Lett. **105**, 152501 (2010)*

M.Sc., Physics,
Simon Fraser University,
2003

M.S., M. Phil., Physics
Yale University
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PhD, Physics,
Yale University,
2008

Joined NSCL in
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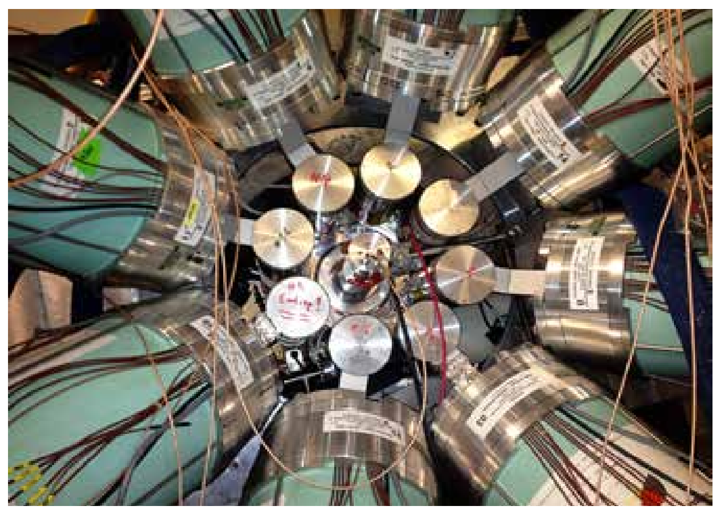
Atomic nuclei play an important role in the evolution of matter in our universe. For many problems in astrophysics, cosmology, and particle physics, the detailed properties of atomic nuclei provide essential inputs to the solutions.

Our group's research focuses on studying nuclei experimentally to probe fundamental questions about our universe. For example, we measure nuclear reactions, decays, and masses in the laboratory to learn about the reactions that power exploding stars or affect their synthesis of chemical elements. Similar experiments can contribute to searches for physics beyond the standard model of particle physics. In some cases we can use these low energy nuclear physics techniques to directly measure the reactions that occur in stars or to directly search for new physics.

In the near future, our group's program at NSCL will be focused on measuring the beta decays of proton-rich nuclides. With these experiments, we hope to constrain the nuclear structure details that are most influential on the explosive burning of hydrogen on the surfaces of accreting compact stars such as white dwarfs and neutron stars. Additionally, these experiments can allow us to better constrain the effects of isospin-symmetry breaking in nuclei on tests of the unitarity of the Cabibbo-Kobayashi-Maskawa matrix, a cornerstone of the standard model.

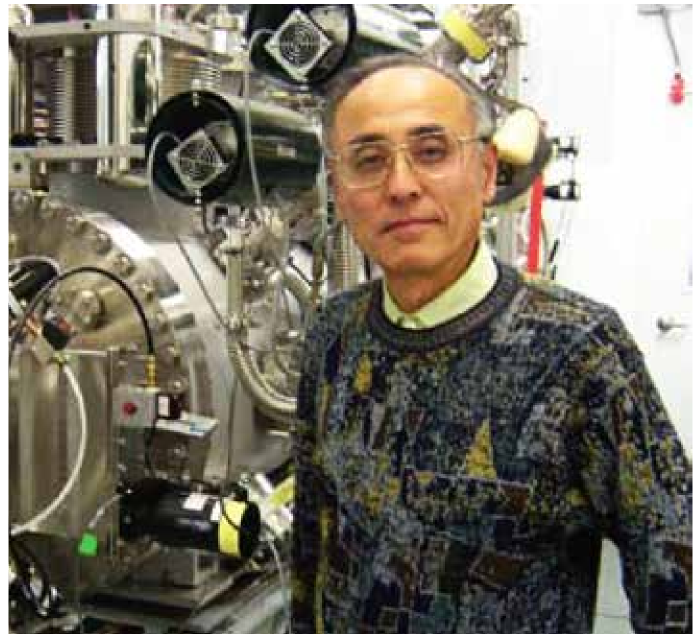
Students in our group have opportunities to propose, prepare, execute, analyze, and interpret nuclear-physics experiments at NSCL, to publish the results in leading scientific journals, and to present the results at national and international conferences.



The SeGA array of germanium gamma-ray detectors arranged for a measurement of the beta delayed gamma decay of ^{26}P in order to determine the amount of ^{26}Al produced in classical nova explosions.

Yoshishige Yamazaki

Professor of Physics
Accelerator Systems Division Deputy Director,
Accelerator Physics



B. E., Applied Physics, University of Tokyo, 1969

M. E., Applied Physics, University of Tokyo, 1971

Ph. D., Physics, University of Tokyo, 1974

Joined NSCL in November 2011

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Selected Publications

Discrepancy between Theory and Experiment in Nuclear Polarization Corrections of Muonic 208Pb. Y. Yamazaki et al., Phys. Rev. Lett. 42, 1470 (1979).

Critical Test of Coupled-Bunch Instability Theory. H. Kobayakawa, et al., Jap. J. Appl. Phys. 25, 864 (1986).

New Field Stabilization Method of a Four-Vane Type RFQ. A. Ueno and Y. Yamazaki, Nucl. Instr. Meth. A300, 15 (1990).

A Three-Cavity System which Suppresses the Coupled-Bunch Instability Associated with the Accelerating Mode. Y. Yamazaki and T. Kageyama, Part. Accel. 44, 107 (1994).

J-PARC Status, Y. Yamazaki, Proc. 2009 Part. Accel. Conf., MO2BCI03 (2009).

Particle accelerators, which were at first invented and developed mainly for studying atomic nuclei and fundamental particles, are nowadays applied to a wide variety of fields, including materials science, life science, cancer therapy, and so forth. Future possible applications may include the transmutation of nuclear waste, which arises from nuclear energy plants. In other words, the development of particle accelerator technology is required not only for studying fundamental particle physics and nuclear physics, but also for other sciences and industrial technology.

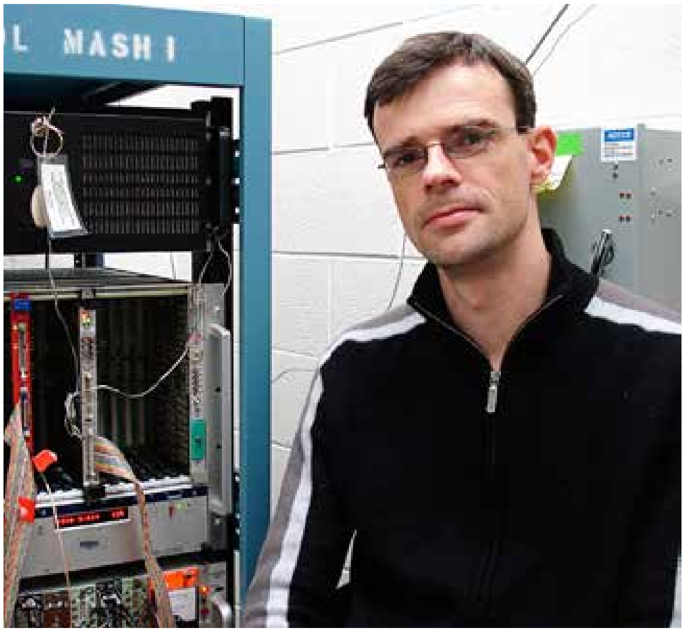
In order to build a world-class particle accelerator, we have to make use of a wide variety of state-of-art technologies. Not only that, in many cases, we have to newly invent and develop some key components, which are themselves applied to other industrial use. In other words, not only accelerators themselves, but also technologies developed for accelerators contribute a lot to the progress in science and technology.

Here, the key word is “world-class”. The linear accelerator in the Facility for Rare Isotope Beams (FRIB) is truly a world-class accelerator. Many species of heavy ions up to uranium are accelerated to 400-MeV/nucleon, generating a beam power of 400 kW (the world-highest uranium beam power). With that amount of power, many rare isotopes will be discovered and studied, opening up a new era for nuclear physics, astrophysics and others. For that purpose, superconducting cavities are entirely used to accelerate the beams from a very front end. The FRIB accelerator, thus innovative, presents many chances for new inventions and developments.

I developed, built and commissioned the RF cavity systems of KEK-PF (Photon Factory, world-highest power synchrotron radiation source, when built) and TRISTAN (world-highest energy electron/positron ring collider, when built) and the RF system of KEKB (B Factory, world-highest luminosity electron/positron ring collider). Before joining NSCL, I have been an accelerator team leader for J-PARC, which generates a world-highest pulse power of neutrons, muons, Kaons and neutrinos. I measured the threshold currents of the coupled-bunch instabilities for the first time and cured the instability for KEK-PF, developed the on-axis coupled accelerating structure for rings for TRISTAN, invented the ARES cavity, for KEKB, invented ϖ-mode stabilizing loops for J-PARC RFQ, and developed the annular-ring coupled structure (ACS) for J-PARC linac. As can be seen from above, I have covered both the beam instability study and the RF technology.

The technology/engineering is nothing but applied science. In other words, deep understanding of physics is really necessary for accelerator physics. On the other hand, accelerator development is a good playground to enjoy physics. I would like to invite many graduate students to enjoy physics by developing, building and commissioning the FRIB accelerator. Here are many chances of invention and innovation, and I can supervise you for those.

Annular-Ring Coupled Structure for 400 MeV upgrade of J-PARC linac developed together with Moscow Meson Factory (MMF), Institute for Nuclear Research (INR)



Remco Zegers

Professor of Physics
Associate Director for Experimental Nuclear Physics and for Education (interim)

Experimental Nuclear Physics

Selected Publications

β+ Gamow-Teller Transition Strengths from 46Ti and Stellar Electron-Capture Rates. S. Noji et al. Phys. Rev. Lett. 112, 252501 (2014)

Probing configuration mixing in 12Be with Gamow-Teller transition strengths, R. Meharchand et. al., Phys. Rev. Lett. 108, 122501 (2012).

Gamow-Teller strengths and electron-capture rates for pf-shell nuclei of relevance for late stellar evolution, A. L. Cole et al., Phys. Rev. C 86, 015809 (2012).

Gamow-Teller Transition Strengths from ^{56}Ni M. Sasano et. al., Phys. Rev. Lett. 107, 202501 (2011), see also K. Langanke, Physics 4, 91 (2011).

The ^{34}P(^{7}Li, ^{7}Be+gamma) Reaction at ^{100}A MeV in inverse kinematics. R.G.T. Zegers et al. Phys. Rev. Lett. 104, 212504 (2010)

M.S., Technical Physics, State University of Groningen, 1995

PhD, Mathematics and Natural Sciences, State University of Groningen, 1999

Joined NSCL in February 2003

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What makes a star explode and ejects its material into space to create planets like earth? What is the mass of the neutrino? And what forces govern the properties of nuclei? These are some of the questions my research group is trying to address in a variety of experiments performed at the NSCL. Although these questions seem rather different in nature, elements of the underlying physics can be studied by using a particular class of nuclear reactions: charge-exchange reactions.

In charge-exchange reactions, a proton in a target nucleus is exchanged for a neutron in the projectile nucleus, or vice-versa, thereby transferring charge between the target and the projectile. Although such reactions are governed by the strong nuclear force, they are closely connected to electron-capture and beta-decay, which are transitions governed by the weak nuclear force. These weak interactions play an important role in the evolution of stars just before they become supernovae and in physics related to neutrinos, such as (neutrinoless) double-beta decay. Charge-exchange reactions are also very useful for probing specific properties of nuclei, especially those related to spin and isospin and are, therefore, used to improve and test our fundamental understanding of nuclear structure.

Currently, my research group is focused on implementing techniques for performing charge-exchange reactions on unstable nuclei. Although such nuclei only exist for a short amount of time, they can play an important role in stellar environments where temperatures and densities are high. In addition, by performing charge-exchange experiments on unstable nuclei, one can probe properties of nuclei that are not (easily) accessible when studying stable nuclei.

Performing charge-exchange studies in which unstable nuclei are probed requires that experiments are performed in inverse kinematics. We have developed a low energy neutron detector array (LENDA) for performing (proton, neutron) charge-exchange reactions in inverse kinematics. Some of our experiments, such as the ones using the (Lithium-7, Beryllium-7) and (Beryllium-10, Boron-10) probes, involve the detection of gamma-rays, either in the Segmented Germanium Array (SeGA) or the Gamma Ray Energy Tracking Array (GRETINA). Both types of experiment use the S800 magnetic spectrograph. Further technical developments will be an important component of future studies on charge-exchange reactions with unstable nuclei at NSCL, but also at the future Facility for Rare Isotope Beams (FRIB).

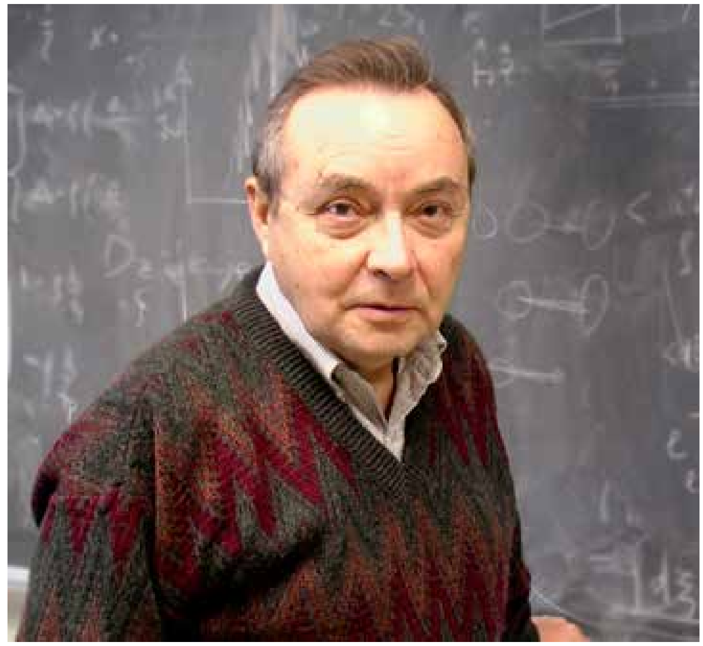
For a variety of purposes, we also perform charge-exchange experiments on stable nuclei and use a reaction in which a hydrogen-3 particle (consisting of 2 neutrons and 1 proton) exchanges a neutron for a proton in a stable target nucleus, thus becoming a helium-3 particle (2 protons and 1 neutron). The hydrogen-3 particles are not stable and are produced as a secondary beam.

The newly-constructed Low-Energy Neutron Detector Array (LENDA) which will be used in (p,n) charge-exchange experiments in inverse kinematics with rare isotope beams.

Vladimir Zelevinsky

Professor of Physics

Theoretical Nuclear Physics



M.S., Physics,
Moscow University, 1960

PhD, Physics,
Budker Institute of Nuclear Physics Novosibirsk, 1964

Joined NSCL in August 1992

2-volume textbook "Quantum Physics" was published by "Wiley" in 2011.

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Selected Publications

Super-radiant dynamics, doorways, and resonances in nuclei and other open mesoscopic systems, N. Auerbach and V. Zelevinsky, Rep. Prog. Phys. {\bf 74}, 106301 (2011) 1-34.

Three-body forces and many-body dynamics. Phys. At. Nucl. **72**, 1107 (2009)

Continuum Shell Model, A. Volya and V. Zelevinsky, Phys. Rev. C **74**, 064314 (2006)

Nuclear structure, random interactions and mesoscopic physics, V. Zelevinsky and A. Volya, Phys. Rep. **391**, 311 (2004)

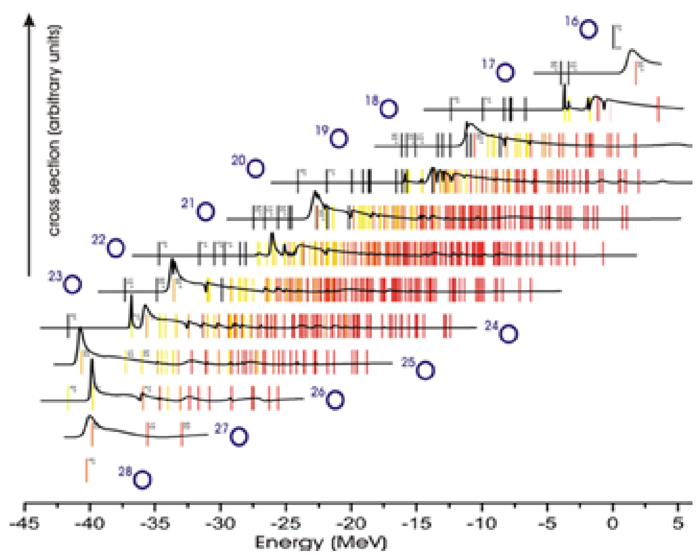
The nuclear shell model as a testing ground for many-body quantum chaos, V. Zelevinsky, B.A. Brown, N. Frazier, and M. Horoi, Phys. Rep. **276**, 85 (1996)

Quantum chaos and complexity in nuclei, V. Zelevinsky, Ann. Rev. Nucl. Part. Sci. **46**, 237 (1996)

My current interest is concentrated on mesoscopic aspects of nuclear physics. The mesoscopic world is intermediate between elementary particles and macroscopic bodies. Mesoscopic systems consist of a relatively small number of particles which still show the noticeable properties of matter. On the other hand, such systems are small enough so that we can study, in theory and in experiments, individual quantum states. Nuclei provide one of the best examples of such arrangement and self-organization. Other mesoscopic systems are complex atoms, molecules (including biological ones), solid state nano-devices and future quantum computers. In all cases, we have certain symmetry, particles, their individual motion in a common field, their interactions, collective excitations (waves, vortices, rotation), coexistence of regularity, complexity and chaos, response to external forces and possible decay.

Loosely bound nuclei are of special interest just because of weak binding. In this situation quantum particles can live far away from the rest of the system in a classically forbidden region forming quantum skins, halos and clusters. Intrinsic structure of such a system is strongly coupled with continuum (or an environment in the context of condensed matter). It is a challenge to learn how one can describe in the same consistent framework intrinsic properties, resonant interaction with external fields and numerous nuclear reactions which give the only available tool to study such exotic systems. Our method of choice (collaboration with A. Volya) is the Continuum Shell Model that combines on equal footing structure and reactions. There are still many unsolved problems in this promising approach. Nuclear reactions have many common features with the signal transmission through a mesoscopic solid state device (quantum dot, quantum wire, quantum computer). Our experience in nuclear physics helps in understanding a more broad class of problems.

Another important theoretical topic is related to symmetries and phase transitions. We still do not have a reliable theory of nuclear shapes and their transformations along the nuclear chart or as a function of excitation energy. The problem is that in mesoscopic systems, frequently the shape is not sharply fixed as, for example, in perfect crystals. Many nuclei are soft and reveal large shape fluctuations. On the other hand, there are reasons to believe that soft modes can enhance some unusual phenomena, such as violation of fundamental symmetries (invariance with respect to coordinate inversion and time reversal). This is a bridge between mesoscopic physics and physics of elementary particles.



For the chain of oxygen isotopes from 16 to 28 we have calculated, in the same approach, bound states, resonances and neutron scattering cross sections. In red we show unstable states with strong color indicating shorter lifetimes.

JINA-CEE

NSCL is a core institution of the Joint Institute for Nuclear Astrophysics Center for Evolution of the Elements (JINA-CEE), a National Science Foundation Physics Frontiers Center dedicated to interdisciplinary research at the interface of nuclear physics and astrophysics.

Currently, nine NSCL faculty members and their groups participate in JINA-CEE together with three faculty members in the Astronomy group at the Department of Physics and Astronomy. JINA-CEE embeds research in nuclear astrophysics carried out at NSCL into a large international research network that includes theorists, other experimenters and astronomers. Experimental results thus can be merged with experimental results from other institutions, implemented in astrophysical models and interpreted together with astronomers.

Success in nuclear astrophysics requires an interdisciplinary research approach. JINA-CEE is dedicated to educate the next generation of nuclear astrophysicists by providing students with cross disciplinary training, networking and research opportunities. Access to locally developed astrophysical model codes, as well as research stays at other institutions in the U.S. or Europe, offer experimental students the opportunity to interpret their results and fully explore the astrophysical and observational work.

JINA-CEE schools and workshops held at various locations around the world, as well as interactions with JINA visitors, provide additional training opportunities. In addition, the constant interaction among the institutions of JINA-CEE provides all of their members many opportunities to meet other researchers with similar interests and network with future colleagues.

The JINA-CEE core institutions are Michigan State University, Arizona State University, University of Notre Dame, and University of Washington. This core institution network is linked to 18 associated institutions, including seven center-to-center partnerships, across six countries. To learn more, visit www.jinaweb.org.

JINA-CEE
Center for the Evolution of the Elements

THE FACILITY FOR RARE ISOTOPE BEAMS

On Dec. 11, 2008, the U.S. Department of Energy Office of Science (DOE-SC) announced that MSU has been selected to design and establish the Facility for Rare Isotope Beams (FRIB), a cutting-edge research facility to advance understanding of rare nuclear isotopes. There are some 300 stable and 3,000 known unstable (rare) isotopes. These and many undiscovered rare isotopes will be produced and made available for research by FRIB. The next generation of scientists will be able to study the properties of these nuclei and use them in applications to address national needs.

The new facilityis currently under construction with completion expected by the end of the decade. At an estimated cost of $730 million, FRIB will provide research opportunities for an international community of approximately 1,300 university and laboratory scientists, postdoctoral associates, and graduate students. By advancing the mission of the Office of Nuclear Physics in the Department of Energy Office of Science—to discover, explore, and understand all possible forms of nuclear matter—FRIB will ensure U.S. leadership in this critical field for decades to come.

FRIB will afford users opportunities with fast, stopped, and reaccelerated beams of rare isotopes. The new facility will adjoin and incorporate the current NSCL facility making effective use of the existing infrastructure. On August 1, 2013, the Department of Energy's Office of Science approved Critical Decision-2 (which formally established the cost and schedule for the FRIB Project) and Critical Decision-3a (which allows the project to proceed with long-lead procurements). Civil construction began in March 2014 and technical construction is slated to begin in October 2014.

More details on FRIB news and updates can be found on the FRIB Project webpage: frib.msu.edu

Features of FRIB design include:

- A superconducting-RF driver linear accelerator that provides 400 kW for all beams with uranium accelerated to 200 MeV per nucleon and lighter ions to higher energy (protons at 600 MeV per nucleon)
- Two electron cyclotron resonance (ECR) ion sources for redundancy with space to add a third ECR ion source
- Space in the linac tunnel and shielding in the production area to allow upgrading the driver linac energy to 400 MeV per nucleon for uranium and 1 GeV for protons without significant interruption of the future science program
- One in-flight production target
- Two rare isotope stopping stations
- Experimental areas (47,000 square feet) for stopped beams, reaccelerated beams, and fast beams
- Upgrade options include doubling the size of the experimental area, adding a neutron scattering facility, or the addition of ISOL or light ion injection
- Opportunity for a pre-FRIB science program using the existing in-flight separated beams from the Coupled Cyclotron Facility and the ReA3 reaccelerator. Users will be able to mount and test equipment and techniques and do science with beams at all energies in-situ so that they are immediately ready for experiments when FRIB is complete; this will allow for a continually evolving science program during the time FRIB is under construction, which will seamlessly merge into the research program at FRIB.
- A User Relations Office during establishment of the FRIB facility to support development of user programs and experimental equipment

An artist's rendering of the finished FRIB facility, scheduled for completion by the end of the decade.

MICHIGAN STATE UNIVERSITY

A Brief History

In 1855, the Michigan State Legislature passed Act 130 which provided for the establishment of the "Agricultural College of the State of Michigan," which came to be known as the Michigan Agricultural College or "MAC." MAC was formally opened and dedicated on May 13, 1857, in what is now East Lansing. MAC was the first agricultural college in the nation, and served as the prototype for the 72 land-grant institutions which were later established under the Federal Land Grant Act of 1862, unofficially known as the "Morrill Act" after its chief sponsor, Senator Justin Morrill of Vermont.

The Campus

The East Lansing campus of MSU is one of the most beautiful in the nation. Early campus architects designed it as a natural arboretum with 7,000 different species of trees, shrubs and vines represented. The Red Cedar River bisects the campus; north of the river's tree-lined banks and grassy slopes is the older, traditional heart of the campus. Some of the existing ivy-covered red-brick buildings found in this part of campus were built before the Civil War. On the south side of the river are the more recent additions to campus — the medical complex, the veterinary medical center, and most of the science and engineering buildings.

Events

The arts have flourished at MSU, especially in the past two decades after our impressive performing arts facility, the Wharton Center for Performing Arts, opened in the Fall of 1982. The Wharton Center's two large concert halls are regularly used for recitals, concerts and theater productions by faculty, student groups, and visiting and touring performing artists. Wharton Center brings to our campus dozens of professional musical and theatrical groups each year. MSU is also home to the Jack Breslin Student Events Center, a 15,000+ seat arena which is home to the MSU Spartan basketball team and also plays host to world-class concerts and attractions.

Two facilities that offer both educational and recreational opportunities are the MSU Museum and the Eli and Edythe Broad Art Museum. The MSU Museum houses documented research collections in Anthropology, Paleontology, Zoology and Folklife, as well as regularly hosting traveling exhibits. The Eli and Edythe Broad Art Museum is the newest campus addition. Dedicated in early November of 2012, the museum is a premier venue for international contemporary art, featuring major exhibitions, and serving as a hub for the cultural life of Michigan State, the local and regional community, as well as international visitors. The building was designed by the world-renowned, Pritzker Prize winning architect, Zaha Hadid. The international exhibition program and wide variety of performances, films, videos, and social actions and art interventions will situate the Broad at the center of the international art dialogue.

MICHIGAN STATE UNIVERSITY

Recreation

Many recreational activities are available on campus and in the Lansing area. Walking and running trails, available extensively throughout the campus, take you through protected natural areas along the Red Cedar River. MSU has two 18-hole golf courses available to students, faculty and staff. There are three fitness centers that provide basketball, handball and squash courts, exercise machine rooms, and aerobic workouts. Two indoor ice skating rinks, an indoor tennis facility, more than thirty outdoor tennis courts, and five swimming pools are accessible as well. In both summer and winter, local state parks such as Rose Lake offer many outdoor activities. In Michigan, snow is not a problem, but an activity, so bring both cross-country and downhill skis. And your snowboards, too!

MSU, which was admitted into the Big Ten in 1948, has a rich tradition in athletics. MSU first competed in conference football in 1953, sharing the title that year with Illinois. Since that time, MSU has enjoyed considerable success in Division I athletics, including NCAA titles in basketball and hockey, and our football team brought home a Rose Bowl Victory in 2014. Graduate students, faculty and staff at NSCL are strong supporters of the athletic programs, which offer opportunities for social interactions outside of the laboratory.

Academics

There are approximately 48,000 students on campus— from every state and more than 120 nations. Of these, approximately 11,000 are in graduate and professional programs. MSU leads all public universities in attracting National Merit Scholars, and is also a leader in the number of students who win National Science Foundation Fellowships. Michigan State was the first university to sponsor National Merit Scholarships.

If students are the lifeblood of a campus, then the faculty is the heart of a great university. The more than 4,500 MSU faculty and academic staff continue to distinguish themselves, and include members in the National Academy of Sciences, and honorees of prestigious fellowships such as the Fullbright, Guggenheim and Danforth.

University-wide research has led to important developments throughout MSU's history. Early research led to important vegetable hybrids and the process for homogenization of milk. More recently, the world's widest-selling and most effective type of anti-cancer drugs (cisplatin and carboplatin) were discovered at MSU.

THE LANSING AREA

Natural Wonders

Situated in the heart of the Great Lakes region of the United States, MSU's East Lansing Campus is centrally located to not only metropolitan areas such as Chicago and Detroit, but to outstanding natural resources and to northern Michigan's world-class summer and winter resorts. Michigan's Upper Peninsula is an undeveloped and unspoiled area of immense natural beauty with a population density of less than twenty persons per square mile. It offers many unique "getaway" opportunities for all seasons. The Lansing area itself provides a variety of recreational opportunities including many golf courses, boating and beach life at Lake Lansing in the summer, and cross-country skiing in the winter. Hunting and fishing opportunities also are found widely throughout the state.

Capital City

Lansing, Michigan's capital city, is centrally located in Michigan's Lower Peninsula. The greater metropolitan area has a population of approximately 464,000 and is home to several large industries. The city offers a variety of restaurants, the Lansing Symphony Orchestra, a number of theater companies and the Lansing Lugnuts baseball team. The Impression 5 Science Museum, the R.E. Olds Transportation Museum and the Michigan Historical Museum attract visitors from throughout the region. Major local employers include MSU, the state government and General Motors. Several high-tech companies are located in the area, including the Michigan Biotechnology Institute, BioPort Corporation and Neogen Corporation.

There is a large scientific community in the Lansing area which, along with MSU, is due in part to the presence of a number of the State of Michigan research laboratories in the area, including the Department of Agriculture, the Department of Natural Resources, the Department of Public Health Laboratories, and the Michigan State Police Crime Laboratories.

In addition to MSU, the Lansing Community College, the Thomas M. Cooley Law School, and Davenport College are all located in the capital city area, and the MSU College of Law is housed on the MSU campus.

East Lansing

Complementing campus life is the city of East Lansing, which surrounds the northern edge of the MSU campus. East Lansing is noted for its congenial atmosphere and tree-lined avenues. Shops, restaurants, bookstores, cafés, malls and places of worship serve the student's needs. East Lansing provides students with a relaxing and stimulating environment for their graduate school experience.

USEFUL LINKS

NSCL website | www.nscl.msu.edu

FRIB website | www.frib.msu.edu

The Graduate School at MSU
www.grad.msu.edu

National Science Foundation
www.nsf.gov

U.S. Department of Energy
www.energy.gov

Statistical Research Center, American Institute of Physics | www.aip.org/statistics

Department of Chemistry at MSU
www.chemistry.msu.edu

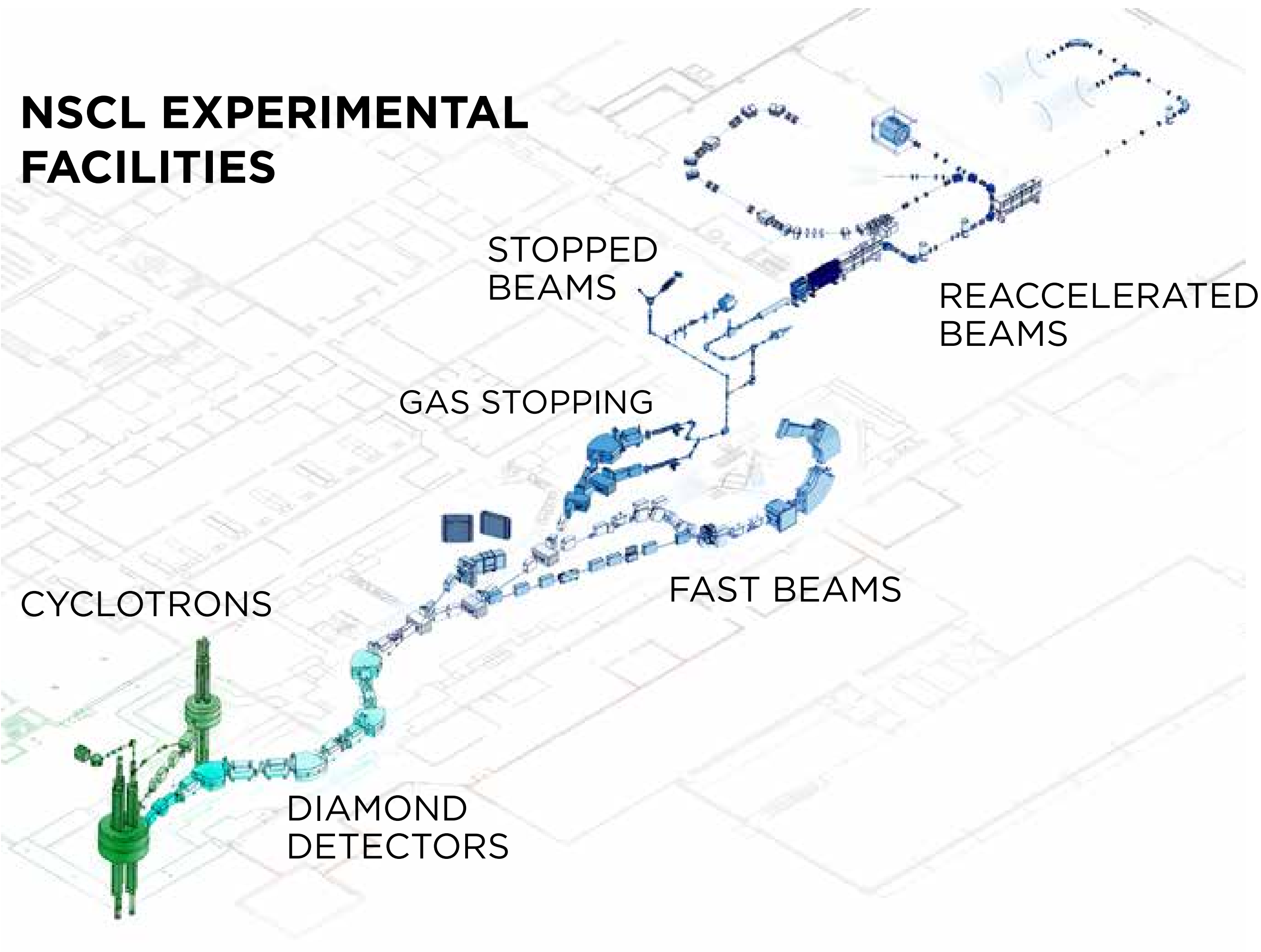
Department of Physics & Astronomy at MSU
www.pa.msu.edu

College of Engineering at MSU
www.egr.msu.edu

MSU General Admissions Information
admissions.msu.edu

Joint Institute for Nuclear Astrophysics (JINA-CEE) | www.jinaweb.org

NSCL EXPERIMENTAL FACILITIES



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