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FRIB Theory Alliance

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1 Introduction

Abstract: Advances in nuclear theory provide the essential underpinning for understanding nuclei and their role in the cosmos. The FRIB Theory Alliance (FRIB-TA), working together with the theory community, has the goal of enhancing theoretical efforts related to the Facility for Rare Isotope Beams (FRIB), across the country. The FRIB-TA has been recognized as a key ingredient for the success of science discovery associated with FRIB [1]. Its national FRIB Theory Fellow program attracts talent to the field. The FRIB Theory Bridge program creates permanent positions in low-energy nuclear theory nationwide. The FRIB Theory Visitors program fosters interdisciplinary collaborations and international initiatives. Finally, FRIB-TA summer schools expand the reach of FRIB science by educating our students and postdocs on the connections with other fields.

1.1 Executive Summary

The realization of the FRIB-TA is the response to the theory initiative recommended in the 2015 Long Range Plan for Nuclear Science *Reaching for the Horizon* [1]: "We recommend the establishment of a national FRIB Theory Alliance. This alliance will enhance the field through the national FRIB Theory Fellow program and tenure-track bridge positions at universities and national laboratories across the U.S."

Faithful to its mission, the FRIB-TA has been devoted since 1st June of 2015 to grow the field and enhance its connections to the experimental program. The multi-pronged strategy includes the FRIB Theory Fellow program, the creation of tenure-track bridge positions, exciting topical programs of relevance to FRIB's science mission, an international partnership with our European colleagues through the EUSTIPEN initiative, and summer schools targeting young scientists (theory and experiment).

In the initial 2-year cycle, the FRIB-TA focused primarily on introducing the national FRIB Theory Fellow program (with the hire of one FRIB theory fellow), while in the subsequent 3-year cycle, the FRIB-TA established the FRIB Theory Bridge Program (with three new faculty hired despite the financial commitment of only two positions), and continued to grow the Fellow program (currently there are three fellows). The faculty bridge positions and the Fellow program attract the best and brightest talent in our field to address important theoretical challenges relevant for the FRIB scientific programs. Detailed descriptions of and updates for the Fellow program and the Bridge program are given in Sections 2.2.1 and 2.2.2.

In the last funding cycle, the FRIB-TA sponsored three successful topical programs. Each program was attended by about 30 theorists and experimentalists for a period of up to three weeks to address issues of relevance to science at FRIB. Consistent with the breadth of FRIB's science mission, the topical programs addressed fundamental problems in nuclear structure and reactions, nuclear astrophysics, and fundamental symmetries (see Section 2.2.3 for a description of the programs and Section 2.3.3 for the resulting science outcomes).

The FRIB-TA also introduced EUSTIPEN, an international initiative with the goal of promoting collaborations between U.S. and European theorists (see Section 2.6). The first year of the EUSTIPEN program was a clear success. During the first half of 2019 alone, a total of 26 applications were funded—with 15 of them submitted by postdoctoral fellows and graduate students. U.S. scientists traveled to the ECT* to attend a variety of topical programs ranging from neutrinos and fundamental symmetries to stellar mergers and the r-process.

Finally, the FRIB-TA introduced a new initiative (which transcends the original mission of the alliance): a yearly summer school that aims to expose graduate students and postdocs in low-energy nuclear physics to exciting new developments in adjacent areas. Two summer schools—"Neutron Star Mergers for Non Experts" (2018) and "Machine Learning Applied to Nuclear Physics" (2019) —ran during this funding cycle and attracted an unexpectedly large number of students from theory and experiment (around 100 participants each). Financial support for both summer schools was provided by the FRIB Laboratory Director to seed this initiative. A full description of the FRIB-TA educational initiatives can be found in Section 2.2.4.

The first five years of the FRIB-TA have been very successful, and it is essential to maintain this good momentum. For the next funding cycle, the FRIB-TA plans to continue to grow the Fellow and Bridge programs to a steady-state total of 6 fellows and 5 bridge faculty/staff positions. Towards this goal, we have already opened a new fellow search and issued a call for a new bridge partner. The FRIB-TA will continue to run topical programs addressing challenges directly relevant for FRIB, enabling a timely response of the theory community to the ever-changing boundary conditions introduced by new discoveries. Due to the enormous interest and positive response of the community, the FRIB-TA plans to run one interdisciplinary summer school every year, following the original format. And, most importantly, the FRIB-TA will continue to explore the best ways to enhance interactions between theory and experiment. In addition to contributing to FRIB Day-1 workshops and participating actively in the low-energy community meetings, we will explore the use of our webpage as a means to provide information to experimental groups regarding theory capabilities, and to facilitate connections between our theory fellows and bridges and the experimental community.

As demonstrated by the scientific accomplishments detailed in Section 2.3, we are already contributing significantly to the FRIB theory needs identified in the beginning of the FRIB-TA. We have important efforts in improving the nucleon-nucleon (NN) forces and their uncertainty quantification, on determining masses and beta-decay rates for light systems, on ab-initio structure of medium mass nuclei as well as shell-model effective interactions and operators constrained by the microscopic forces, on reaction theory for direct and compound transfer and their connection to neutron capture rates, and more. With continued support, we expect to be in a strong position to maximize the impact of the new Facility for Rare Isotope Beams from its early days.

1.2 Personnel

At the time this proposal is submitted, our personnel includes two FRIB theory fellows supported by the grant (Diego Lonardoni and Kevin Fossez), while the third fellow, Gregory Potel, just accepted a staff position at LLNL starting November 2019. We also have two new bridge faculty at WashU (Maria Piarulli and Saori Pastore) with a third bridge faculty (Sebastian König) to start in January 2020 at NCSU. In addition, Gillian Olson has been working half-time for the FRIB-TA, providing assistance with administrative tasks.

Finally, the team responsible for preparing this proposal consists of the FRIB-TA executive board and the FRIB-TA managing director. The executive board, with 12 members elected by the FRIB-TA membership, provides oversight to all FRIB-TA programs and is chaired by the FRIB-TA director (currently Jorge Piekarewicz). In addition, the daily business of the alliance is handled by the FRIB-TA managing director (currently Filomena Nunes). It is important to note that the FRIB-TA grant provides no support for either the director's or the managing director's activities.

2 Narrative

2.1 Our mission and organizational structure

Mission: The mission of the FRIB Theory Alliance (FRIB-TA) is to foster advancements in theory related to diverse areas of FRIB science; optimize the coupling between theory and experiment; and stimulate the field by creating permanent theory positions across the country, attracting and retaining young talent, fostering interdisciplinary collaborations and shepherding international initiatives. Additionally, FRIB-TA will help to improve inclusivity and equity in the community throughout all its activities.

Programs: In order to achieve these goals, the FRIB-TA has a number of programs under its wings. The FRIB Theory Bridge program discussed in Section 2.2.2 provides incentives to universities and national labs to create new permanent positions in FRIB related theory by contributing to the salary of the new hires for the initial years. The FRIB Theory Fellow program (Section 2.2.1) attracts the top postdoctoral level researchers and places them in prestigious 5-year fellowship positions across the U.S. The FRIB-TA topical programs bring into focus theory challenges relevant to FRIB, and enable up to 30 experts to come together for two/three weeks and work towards solving critical problems. The FRIB-TA summer schools provide important opportunities to our community to expand its knowledge into other fields (Section 2.2.4). In addition, the FRIB-TA manages an international initiative that catalyzes collaborations between Europe and the US called EUSTIPEN (Section 2.6).

Organization: The organization of the FRIB-TA is described in its charter (http://www.fribtheoryalliance.org/content/charter.php) ratified on March 2016. The FRIB-TA membership (over 200 scientists from national laboratories, universities, and other institutions) elects members to the FRIB-TA executive board (EB), which oversees all activities of the FRIB-TA. The EB is chaired by the Theory Alliance Director, currently Jorge Piekarewicz, who is elected by board members. In addition to chairing the EB, the Theory Alliance Director represents the FRIB-TA to the broader community and is the liaison with experiment through the FRIB Users Group. The FRIB-TA managing director, appointed by the FRIB director in concurrence with the DOE program officer, takes care of all fiduciary responsibilities associated with maintaining the grants and reporting to the funding agency. The Theory Alliance Director, in coordination with the FRIB-TA managing director, is also responsible for appointing the various committees that conduct the daily business of the Alliance. The committees are:

Organization Committee. Responsible for developing the structure of the Alliance.

Fellow Search Committee. Responsible for the FRIB Theory Fellow program, defining procedures, and conducting searches.

Bridge Committee. Responsible for studying the current possibilities for bridge positions, identifying the optimal cases.

Educational and Topical Programs Committee. Responsible for developing the educational and outreach component of the Theory Alliance.

International Links Committee. Works with current and potential international partners to coordinate and leverage efforts. This committee is responsible for running the EUSTIPEN program and identifying other potential partnerships to strengthen the FRIB-TA initiative.

Broader Impact Committee. Responsible for fostering synergies with other fields of physics.

Webpage Committee. Responsible for maintaining a website serving as a communication vehicle for the FRIB-TA community, promoting and disseminating FRIB-related theory, and engaging in outreach activities.

Personnel reviews and mentoring: All personnel under the FRIB-TA report to the managing director and are reviewed annually. For each FRIB-TA Fellow (see Section 2.2.1), the review is performed jointly, by the FRIB-TA director, FRIB-TA managing director, and the advisor at the partnering institution. The annual performance review letter and reappointment letter for the fellows is the responsibility of the FRIB-TA managing director. For bridge faculty/staff (see Section 2.2.2), the review is primarily the responsibility of the host institution, with input from the FRIB-TA. The administrative assistant is trained to follow FRIB policies and procedures, and is reviewed jointly by the Chief-of-Staff at FRIB and the FRIB-TA managing director.

The FRIB-TA mentoring program matches each fellow/bridge with a senior theorist who serves as their mentor. The mentor meets regularly with the junior researcher to discuss scientific progress, career goals and strategies. The mentor also advocates on behalf of the mentee in the theory community and seeks opportunities to enhance the mentees' visibility in the field. Currently Filomena Nunes is mentoring Diego Lonardoni, Saori Pastore and Maria Piarulli. Kevin Fossez is mentored by Dick Furnstahl.

2.2 FRIB-TA programs

2.2.1 FRIB Theory Fellow program

Fellows are funded 50% through this grant and 50% from the hosting institution. The FRIB Theory Fellowship is a 5-year research position with an annual salary above a 'usual' postdoc position. Each fellow has an independent annual budget for travel and visitors. An initial 2-year appointment is renewed on a yearly basis for an additional maximum of 3 years, depending on performance and the availability of funds. The fellow is expected to develop an ambitious program on important theoretical problems relevant to research within the realm of FRIB. The FRIB theory fellow is expected to advance into an open faculty or permanent staff position in the field within 5 years of the initial appointment.

The FRIB Theory Fellow Search Committee, appointed by the FRIB-TA director in consultation with the executive board, conducts all fellow searches. The searches from 2015–2018 were chaired by Erich Ormand (LLNL) and the ongoing search is being chaired by Charlotte Elster (Ohio U). To ensure continuity, the vice-chair of the Search Committee in a given year becomes chair of the Committee in the following year. Up until the final deliberations, the Search Committee is augmented by one additional member per partner institution.

After the identification of interested partner institutions, an advertisement is shared by email with the FRIB-TA membership, as well as other mailing lists worldwide (e.g. RIKEN, NUSTAR). The ad is also placed on the FRIB and FRIB-TA websites. In addition, members of the search committee and the executive board actively spread the news through their own contacts and encourage promising young individuals to apply, including those from underrepresented communities. This ensures a strong and diverse pool of applicants.

In addition to the standard CV, the applicants are required to submit a research plan proposing research activities over the next five years. The applicant pool is reviewed by the Search Committee,

Table 1: Calendar for fellow hires and moves into permanent positions.

Name	Hosting Institution	Mentor	Years as fellow	Permanent position
Diego Lonardoni	LANL	Nunes	2015–	
Gregory Potel	MSU	Nunes	2016–2019	LLNL
Kevin Fossez	ANL	Furnstahl	2019–	

with the relevance of the proposed research to the scientific program at FRIB being a major selection criterion. A short list of 5 or 6 top candidates are selected by the Search Committee and invited to interviews at FRIB during a one-week period. The Search Committee then ranks the candidates and, with concurrence from the FRIB Laboratory Director and the DOE program director, the FRIB fellow position is offered to the top candidate.

Through feedback from the nuclear theory community, as well as practical experience in the search process, the FRIB-TA Board established a policy for the fellow search process. It is publicly available on the FRIB-TA website, but is attached to this proposal (Section 4) to facilitate the review. This policy aims to ensure transparency and equitability in the search process.

The vision for the FRIB Theory Fellow program is to provide a significant boost of theory efforts relevant to the FRIB science program. So far, the program has proven to be highly competitive and has increased the visibility of low-energy nuclear theory worldwide. Table 1 summarizes the calendar for fellow hires conducted by the FRIB-TA, as well as the respective hosting institution, mentor and the institution where they move onto a permanent position. The fellows' important contributions to FRIB science are highlighted in Section 2.3.1.

In the next cycle, the FRIB-TA proposes to arrive at a steady state of six fellows funded in any given year, with four of these fellows located at partner institutions and two at FRIB. There is an ongoing search for two new fellows and we expect to fill these positions at the start of the renewal grant, one at FRIB and another one at a partner institution. We expect that in the fall of 2020 we will have another fellow search for two more positions reaching the six-fellow target. After 2021, fellow positions will be filled when current fellows transition to permanent positions.

2.2.2 FRIB Theory Bridge program

The daunting list of theoretical developments needed to accomplish the broad scope of science at FRIB requires an increase in theory principal investigators, especially in critical areas identified in Section 2.3. This is the motivation for the FRIB Theory Bridge program: to enhance the opportunities for theory faculty hires at Universities or theory staff hires at National Laboratories. These positions are modeled after those created by the RIKEN/BNL program at RHIC, with 50% of the cost being covered by DOE through the FRIB-TA and 50% by the home institution, until the faculty/staff member is granted tenure over a maximum period of 6 years. A stand-alone document has been developed to provide guidance to units that wish to apply for the program and is readily available at fribtheoryalliance.org/bridge and also attached to this proposal for convenience (Section 4).

Bridge faculty/staff are outstanding junior theorists who develop exceptional theoretical research relevant to rare isotope science. Bridge faculty/staff are 100% employees of their home institution, with all the associated benefits. For bridge positions located at universities, the bridge faculty are expected to build a research group, attract federal funding and have teaching duties,

Table 2: Calendar for bridge hires and home institutions.

Name	Institution	TA mentor	Start year	Tenure year
Saori Pastore	WashU	Nunes	August 2018	
Maria Piarulli	WashU	Nunes	August 2018	
Sebastian König	NCSU	TBD	January 2020	

just as all other faculty at their home institution. Equally, for bridge positions located at national laboratories, the bridge staff is expected to perform at the level of new staff members at national laboratories. In addition, bridge faculty/staff are expected to contribute significantly to the scientific program at FRIB and be spokespersons for FRIB theory, nationally and internationally. They are expected to spend a significant amount of time at FRIB and, for this reason, teaching relief can be negotiated on a case-by-case basis.

The FRIB-TA Bridge committee is responsible for seeking institutional partners for the FRIB Theory Bridge program and making the selection of the institution that will be the home of each bridge position. The criteria and process for bridge positions at universities is summarized here. There are important differences in the process for applications from national laboratories, which are covered in the stand-alone document mentioned above.

In selecting physics departments to carry out the bridge faculty search, the main selection criterion is that the science scope of the search is aligned with FRIB science, as briefly described in the first paragraph of Section 2.3. The committee will select physics departments at research universities using additional criteria including the intellectual environment of the university, the diversity of its physics research program, the institutional record in mentoring young faculty, and the access to good students.

Departments interested in competing for a bridge position prepare a brief proposal (these requirements are appropriately modified for national laboratory applications). The proposal should include:

1. A letter from the dean of the college, with the commitment of a 50% salary match in the event that the institution is selected and a hire is made.
2. A letter from the physics department chair, explaining how this new hire will fit into the long-term vision of the department and indicating the time-scale for advertisement, interviews and hire, in the event that this institution is selected.
3. A letter from the main point of contact, providing background information on the quality of the graduate program and the nuclear physics research program, if one exists. Examples of recently graduated students in nuclear physics should be given, if applicable. Information on junior faculty hiring in the department over the last decade, as well as on the support provided by the department to these junior faculty, should be documented.

Once a partner is identified, the FRIB-TA managing director works closely with the chair of the home physics department (or physics division director) to develop the Memorandum of Understanding that establishes the conditions of the appointment and the various contributions involved (in which the FRIB-TA provides 50% of salary, benefits, and travel).

For the first round, the FRIB-TA Bridge Committee received five applications in response to its call in 2017. These came from Argonne National Laboratory, North Carolina State University, Ohio

University, San Diego State University, and Washington University. The committee felt that all these institutions employ highly accomplished nuclear theorists who can successfully mentor young faculty hired under this program. It was faced with a very difficult selection as it would like to see all these institutions hire junior faculty who would work on FRIB science. The committee picked the Washington University at St. Louis for the first FRIB Theory Bridge Faculty Search. During the search process conducted by Washington University at St. Louis, a strong and diverse short-list was created. The department chose to hire two female candidates identified in the search, Maria Piarulli and Saori Pastore, after negotiations with the FRIB-TA. The FRIB-TA is supporting 25% of the salary of each of the new faculty, as well as travel to FRIB.

For the second round of applications, the FRIB-TA Bridge Committee received five applications in response to its 2018 call. These came from Argonne National Laboratory, Florida State University, Louisiana State University, North Carolina State University, and Ohio University. The situation again was extremely competitive but ultimately the committee picked North Carolina State University for the second FRIB Bridge Faculty Search. The FRIB-TA Bridge Committee encouraged consideration of the remaining four institutions again in the next selection. North Carolina State's short-list was also strong and diverse and the search resulted in hiring Sebastian König.

As in the case of the theory fellows, the bridge faculty are also provided with an FRIB-TA mentor. This is in addition to the mentoring program that is offered by their home institution. Mentors meet regularly with their mentees, discuss progress in research, funding, teaching and other matters, as well as career goals and strategies. Table 2 summarizes the calendar of bridge hires as well as their hosting institution and FRIB-TA mentor. The exciting science projects led by the bridge faculty are described in Section 2.3.2.

In the next funding cycle, the FRIB-TA plans to grow the number of positions to a total of five (note that the FRIB-TA has a funding commitment of only one position at WashU). A new call for bridge partners has been publicized and we expect to add one more position to the bridge list provided in Table 2 by the start of the renewal grant (Summer of 2020). Given the strong interest in the community in partnering with the Bridge program, the plan is to add one more position in Summer 2021 and one in Summer 2022. At that point, a new position will only be added once an existing bridge faculty/staff is promoted/tenured and moves out of the FRIB-TA's funding commitment.

2.2.3 Topical programs and visitors

A key objective of the FRIB-TA is to propel and promote FRIB science in the broadest possible intellectual forum, develop and engage the FRIB community, and facilitate communication between theorists and experimentalists. These goals are achieved in part by FRIB-TA topical programs, meetings, and visitors. Topical program proposals are solicited from members of the FRIB-TA every year, with one program selected per year by the executive board. The topical programs are intensive workshops at FRIB on topics directly related to FRIB science. Each program is required to produce a deliverable in the form of, for example, a white paper or review article. The Alliance grant covers local expenses, while participants are responsible for their travel. From the organization to participation, diverse representation and equity are expected. We have coordinated with the ECT* and the INT on scheduling and program topics, and, where appropriate, partnered with organizations such as JINA-CEE. Below are listed the three topical programs sponsored so far.

- Calvin Johnson (SDSU), Kristina Launey (LSU), Pierre Descouvmont (Université Libre de Bruxelles), Marek Płoszajczak (Ganil), Sofia Quaglioni (LLNL), and Jimmy Rotureau (MSU) organized a topical program on connecting bound state calculations with scattering and reaction theory. This program pulled together experts in scattering and reaction theory, in bound state structure calculations, and especially those working on the boundary, to summarize the state of the art and to identify and lower the technical barriers to move from bound state calculations to the continuum. The program ran from June 11–22, 2018, and had 35 participants (https://indico.fnal.gov/event/16737). The findings and remaining challenges in the field are being written up in a white paper that will be publicly available shortly.

- R. Surman (Notre Dame), A. Aprahamian (Notre Dame), G.C. McLaughlin (NCSU) and A. Frebel (MIT) organized a topical program on implications of the neutron star merger GW170817 and its associated kilonova for rapid-neutron capture, or r-process, nucleosynthesis. This program built upon a previous r-process topical program in 2016 and was especially timely given the extraordinary GW170817 observations. The program ran from July 16–27, 2018 with 48 participants (https://indico.fnal.gov/event/16420). The program featured researchers working on theoretical and experimental aspects of nuclear structure and r-process reaction networks, as well as astronomers and computational nuclear astrophysicists. The participants have compiled a selection of scientific contributions to the program, which are broadly representative of progress in r-process studies since the GW170817 event (https://arxiv.org/abs/1809.00703).

- Andrea Shindler (MSU), Chen-Yu Liu (Indiana), Jaideep Singh (MSU), and Vladimir Zelevinsky (MSU) organized a program on hadronic electric dipole moments (EDM) in the FRIB era. FRIB will provide an unprecedented opportunity for producing rare isotopes useful for searches of permanent electric dipole moments, a signature of CP violation required to explain the observed asymmetry between matter and antimatter. The program ran from August 12–23, 2019, and featured 37 participants with expertise in nuclear structure, physics beyond the Standard Model and effective field theories, experimental methods, atomic and molecular EDMs, and planned future experiments (https://indico.frib.msu.edu/event/13). Writing of the white paper is currently in progress.

In addition to the topical programs, the FRIB-TA also hosts an annual meeting for all members as part of the Low-Energy Community Meeting. This meeting provides an opportunity for FRIB-TA fellows and bridge faculty to present research work, and for the FRIB-TA executive board to gather feedback from the community. The FRIB-TA supports travel for the fellows and bridge faculty to visit FRIB regularly. It also provides visitor office space, discussion areas for collaborative work, and logistical support for all members of the FRIB-TA community visiting FRIB.

2.2.4 Educational program

Training the next generation of researchers will ensure the continued development and vitality of FRIB science for years to come. The FRIB-TA mission therefore emphasizes enabling a broad, modern, and compelling educational curriculum that addresses the nuclear many-body problem and related areas. Since many universities are unable to offer courses in nuclear physics, the FRIB-TA webpage provides access (see https://fribtheoryalliance.org/content/education.php) to introductory nuclear physics online course materials offered at institutions such as Ohio State University and Michigan State University. The FRIB-TA has also started to offer short summer schools on topics that connect FRIB theory and other fields relevant to FRIB science by bringing together students, postdocs, and faculty of diverse backgrounds. This is beyond the existing FRIB-TA budget, and has been made possible through seed funds provided by the FRIB laboratory director.

Summer school proposals are solicited from members of the FRIB-TA every year, with one summer school selected per year by the executive board. The following is a list of recent summer schools:

- Katerina Chatziioanno (CITA), Brian Metzger (Columbia), Charles Horowitz (Indiana), David Radice (Princeton), Luke Roberts (MSU), and Hendrik Schatz (MSU) organized a summer school on neutron star mergers from May 16–18, 2018 (https://indico.fnal.gov/event/15789). The school brought together graduate students, postdoctoral researchers, and senior scientific experts working in nuclear physics, astrophysics, astronomy, and related areas to help our field better connect to the observations of the GW170817 binary neutron star merger and subsequent kilonova. There were a total of 80 participants that attended in person and 20 Zoom connections.
(https://frib.msu.edu/news/2018/merger-school.html)
- Matthew Hirn (MSU), Michelle Kuchera (Davidson), and Morten Hjorth-Jensen (MSU) organized a summer school on the topic of machine learning (https://indico.frib.msu.edu/event/16) from May 20–23, 2019. It provided an introduction to the core concepts and tools of machine learning in a manner that can be applied to nuclear physics. The lecturers covered the basic methods used in supervised learning such as various regression methods before discussing deep-learning methods for both supervised and unsupervised learning. The summer school had 98 participants. (https://frib.msu.edu/news/2019/frib-ss-machine-learning.html)

The FRIB-TA also supports the Training in Advanced Low Energy Nuclear Theory (TALENT) program, which provides in-depth advanced graduate training programs in low-energy nuclear theory. One example of this partnership with the TALENT program is the nuclear reactions summer school held at FRIB in 2019:

- Carl Brune (Ohio), Charlotte Elster (Ohio), and Sofia Quaglioni (LLNL) organized a TALENT summer school from June 3–21, 2019 (https://indico.frib.msu.edu/event/15/overview). In this course students were introduced to modern methods developed to describe nuclear reactions. Students were taught approximation tools used to handle the many-body reaction problem and gained experience working with nuclear reaction data.
(https://frib.msu.edu/news/2019/frib-talent-course-6-summer-school.html)

These summer schools allow us to address emerging topics of importance to FRIB science. Moreover, they provide excellent opportunities for strengthening interdisciplinary connections, improving inclusion and diversity, and building a stronger workforce pipeline.

2.3 Science accomplishments

FRIB science is closely intertwined with the big questions in our field [2], and theory plays a critical role in addressing these questions. Advances in theory are necessary to calculate the properties

Table 3: Theory developments needed for FRIB. The last column references the overarching science questions [2] and the benchmarks from the 2007 NSAC Rare-Isotopes Beam Task Force [3] (B1 shell structure; B2 superheavies; B3 skins; B4 pairing; B5 symmetries; B6 equation of state; B7 r-process; B8 $^{15}O(p,\gamma)$; B9 ^{56}Fe s-process; B10 medicine; B11 stockpile stewardship; B12 atomic electric dipole moment; B13 limits of stability; B14 weakly bound nuclei; B15 mass surface; B16 rp-process; B17 weak interactions). Topics for which there is ongoing effort are indicated in green.

Topic	Theory development needed	Question/Benchmark
T1: Forces	Effective field theory (EFT) constants from LQCD; Improved optimization and uncertainty quantification of chiral forces, with and without Δs; Consistent operators and power counting for chiral EFT.	Q1, Q2, Q3: B1-6, B13-15, B17
T2: Nuclear structure	Connect realistic nuclear forces to shell model and DFT; Microscopic optical potential that incorporates many-body correlations; Proper treatment of collective, cluster and continuum degrees of freedom	Q1, Q2, Q3: B1-6, B8, B13-15, B17-18
	Masses and beta-decay rates, calculated from microscopic approaches and combined with experiment.	Q1: B6-9, B15, B16
T3: Medium-mass nuclei	Properties of nuclei with validated ab-initio techniques; Shell-model effective interactions and operators derived and/or constrained from microscopic interactions, with controlled uncertainties; Unified treatment of structure and reactions.	Q1, Q2, Q3: B1-6, B13-15, B17
T4: Heavy nuclei	DFT constrained by rare isotope data and ab-initio theory; Beyond-DFT treatment of open shell systems; calculations of Schiff and anapole moments.	Q1, Q2, Q3: B1-6, B13-15, B17
	Improved DFT-based adiabatic models of the large-amplitude collective motion; Implementation of TDDFT and multi-reference DFT approaches; Effective field theory for collective nuclear phenomena based on powerful existing phenomenology.	Q2: B1-6, B13-15
	Implementation of proton-neutron, symmetry-projected multi-reference DFT and large-scale shell model to compute nuclear matrix elements for double-beta decay.	Q3: B17
T5: Neutron stars	Controlled calculations of the nuclear equation of state for all relevant densities including extrapolations to high densities with known uncertainties; Improve constraints on nuclear EOS by identifying observables most sensitive to the high-density behavior of the nuclear symmetry energy; Calculate structure in the neutron star crust at various densities (ground state and response functions).	Q1, Q2: B1-6, B13-15
T6: Reactions	Ab-initio reaction theory, consistent with nuclear structure, with quantified uncertainties, adequate for many domains of experimental interest, including radiative capture, transfer, charge-exchange, breakup of dripline nuclei, alpha-induced reactions in intermediate-mass nuclei, and superheavy synthesis to estimate production of nuclei at and beyond the dripline and to extract structural information.	Q1, Q2, Q3, Q4: B1-6, B8, B11, B13-17
	Microscopic theory of spontaneous and neutron-induced fission; Ab-initio theory for light-ion fusion.	Q4: B10,B11
	Reaction theory for compound nucleus formation consistent with structure.	Q2: B2,B14,
	Reliable transport theory with quantified errors, including a quantum formulation with correlations, for heavy-ion reactions from low to intermediate energies.	Q1, Q2: B3,B5,B6
T7: Astrophysics	Advanced simulations of compact objects; supernova, binary neutron star mergers and related explosive phenomena; Nucleosynthesis and chemical evolution simulations with up-to-date nuclear input; Neutrino interactions with nuclei in hot and dense nuclear matter, including neutrino oscillations; Hydrodynamics and neutrino transport in stars; Screening in stellar plasma consistent with reaction theory.	Q1, Q2, Q3: B7-9, B16, B17

of extreme nuclei and nuclear matter to address Q1: How did matter come into being and how does it evolve?; to predict emergent phenomena in nuclei of relevance to exploring Q2: How does subatomic matter organize itself and what phenomena emerge?; and to calculate transitions that connect precision low-energy observables to the fundamental interactions at high energy for Q3: Are the fundamental interactions that are basic to the structure of matter fully understood? The unified theory of nuclear structure and reactions needed to interpret the vast body of experimental data on neutron-rich radioactive isotopes to be measured at FRIB is also key to address, in addition to all of the aforementioned questions, the final question Q4: How can the knowledge and technological progress provided by nuclear physics best be used to benefit society? Table 3 serves as a reminder of the long list of theory developments needed to address these big questions and allow our community to reap the benefits of the variety of FRIB experimental programs, as portrayed through the NSAC Task Force benchmarks [3]. This table was developed by the FRIB-TA board for the 2016 renewal and remains an accurate representation of the FRIB-TA research roadmap.

To address these scientific challenges in a timely manner, the FRIB Theory Alliance has been steadily growing its research portfolio over the past five years – through the fellow program, the bridge program and the topical programs. In this section, we highlight the research accomplishments and plans of our fellows and bridges, and summarize the research outcomes from the FRIB-TA topical programs. Throughout the text, we include cross-references to the topics (T) and questions (Q) listed in Table 3. These highlights demonstrate the high level of innovation introduced by our young talent, the inherent coupling with high-performance computing, and a strong and continuous collaboration with experiment, as we rapidly approach FRIB Day 1.

2.3.1 Highlights from Fellows

At the submission of this proposal, three FRIB Theory Fellows have been supported by the FRIB-TA: Diego Lonardoni (supported since 10/2015, current), Gregory Potel (supported from 5/2016 until 10/2017, now staff at LLNL) and Kevin Fossez (since 3/2019, current).

2.3.1.1 Diego Lonardoni

The research carried out by Lonardoni contributes to building a predictive understanding of nuclear systems characterized by high neutron-to-proton imbalance, from neutron-rich nuclei to neutron stars, grounded in high-quality nuclear forces and ab-initio theory, including a complete assessment of all uncertainties associated with a nuclear many-body calculation (T3 and T5). His results cover a wide range of nuclear properties, with connections to and implications for short-range physics, lepton-nucleon scattering experiments, the physics of strange and neutron-rich systems, the physics of neutron stars, and the overall understanding of the physics of nuclear systems as arising from the underlying baryon-baryon interaction. His results have impact on several FRIB experimental programs as well as other U.S. national laboratories.

Lonardoni, in collaboration with researchers at LANL, Arizona State University, and the TU Darmstadt, has been extending the reach of quantum Monte Carlo (QMC) methods to describe properties of nuclei and nuclear matter with interactions derived from chiral effective field theory (EFT) [11, 12]. This is done in parallel with a comprehensive uncertainty quantification that provides insight into issues in ab-initio nuclear theory. By employing local chiral EFT potentials fit to few-nucleon observables [13, 14, 15, 5] in diffusion Monte Carlo calculations, Lonardoni and collaborators showed that ground-state properties of nuclei up to ^{16}O can be well-reproduced [4, 5] (see Fig. 1), while simultaneously predicting an equation of state of pure neutron matter compatible

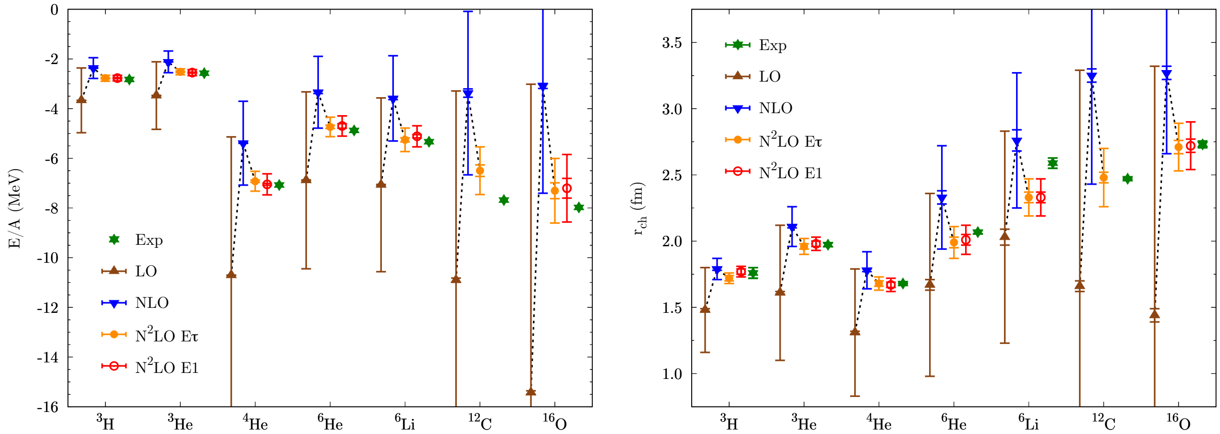

Figure 1: Ground state properties for nuclei with $3 \leq A \leq 16$, calculated using local chiral potentials [4, 5]. Left panel: Binding energy per nucleon. Right panel: Charge radii for selected nuclei. Results at different orders of the chiral expansion and for different parametrizations of the three-nucleon contact term V_E are shown for the coordinate-space cutoff $R_0 = 1.0\,\text{fm}$. Smaller error bars indicate the statistical Monte Carlo uncertainty, while larger error bars are the uncertainties coming from the truncation of the chiral expansion.

with astrophysical observations [15, 16].

The investigation of neutron-rich systems in both terrestrial and astrophysical conditions are part of Lonardoni's research plan, targeting neutron-rich isotopes up to the limits of stability, the equation of state of isospin-asymmetric nuclear matter, and the calculation of the symmetry

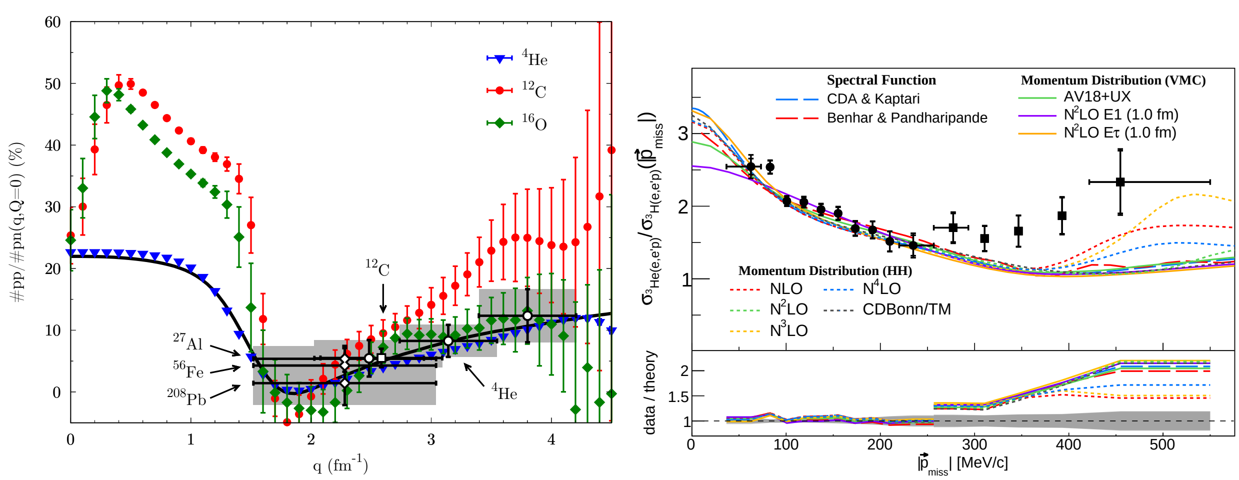

Figure 2: Calculated one- and two-nucleon distributions, compared to experiment. Left panel: pp pairs to pn pairs ratio in $A = 4, 12, 16$ nuclei as a function of the relative momentum q for back-to-back (center-of-mass momentum $Q = 0$) pairs as derived from two-nucleon momentum distributions [6]. Black symbols are extracted from experimental data [7, 8, 9]. Right panel: The measured ^{3}He to ^{3}H cross-section ratio vs. the missing momentum compared with different models for the corresponding momentum distribution ratio [10].

energy. Such studies will deepen our understanding of the nuclear force at neutron-rich extremes and provide strong connections not only to the FRIB experimental program, but also to the LIGO-Virgo collaborations and to the P-REX and C-REX experiments at JLab.

In addition to this core line of nuclear structure research, Lonardoni has also been involved in QMC studies of short-range correlations, in particular their effects as emerging from the underlying microscopic Hamiltonian and the possibility to experimentally probe short-range physics. QMC calculations of single- and two-nucleon distributions in both coordinate and momentum space have been performed for nuclei up to ^{40}Ca using different nuclear potentials (phenomenological and derived from chiral EFT) [17, 6, 18, 19, 10]. Ratios of such quantities have been compared with the large body of information extracted from electron scattering experiments (see selected results in Fig. 2). They have been used to better interpret single- and two-nucleon knockout experiments, highlighting which of such experiments is more sensitive to short-range physics and can thus be more efficiently used to probe such regime of the underlying nuclear force.

2.3.1.2 Gregory Potel

Deuteron-induced transfer reactions are a popular tool in nuclear physics and recent applications of this probe have included exploring the structure of exotic isotopes and using them as an indirect tool for neutron capture processes. The context of Potel's work is tightly connected with many FRIB experimental programs (T6).

The (d, p) formalism developed by Potel and collaborators [20] incorporates, in a transparent, flexible, and modular way, a given structure framework into the calculation of the transfer cross section. Within this context, specific theoretical developments have been necessary in order to address the possible non-locality of the effective neutron-target interactions. These developments have been documented in [21], where the applications include a range of target masses and beam energies. The same developments were essential for the study of the calcium isotopic chain using the coupled cluster ab-initio formalism, and the study of the unbound, exotic neutron rich light nucleus ^{10}Li within an effective field theory approach.

In work on calcium, Potel and collaborators presented, for the first time, a quantitative account of the ab-initio single-particle strength for medium-mass nuclei, as measured through (d, p) reactions. The agreement with experimental results is remarkable (Fig. 3, [22]). In keeping with the excellent reproduction of the data, quantitative predictions are made for (d, p) experiments on ^{52,54}Ca, shedding light on the exotic $N = 34$ shell closure in ^{54}Ca. Potel also studied ^{10}Li in the context of the puzzling experimental result of [23]: the authors of [23] concluded that no S-wave strength was present in the low-lying spectrum of ^{10}Li. By calculating a complete continuum spectroscopy of the low-energy spectrum of ^{10}Li probed with the ^{9}Li(d, p) reaction, Potel reproduced the experimental results, while confirming the need to have a low-lying S-wave in the ^{10}Li spectrum [24].

Concerning the use of $(d, p\gamma)$ as a surrogate method for the measurement of (n, γ) cross sections, Potel was closely involved in the analysis of the benchmark experiment performed on the stable isotope ^{95}Mo [26]. In this experiment, protons and γ–rays were detected in coincidence, after bombarding a ^{95}Mo target with 12.4 MeV deuterons. The observed γ emission was fitted within a Hauser–Feshbach formalism, combined with the predicted spin and parity distribution of the compound ^{96}Mo* produced in the (d, p) reaction. The information of this fit was used to predict (n, γ) cross sections. The (n, γ) cross sections derived from the $(d, p\gamma)$ data are in very good agreement with the existing direct (n, γ) experimental data. Furthermore, in collaboration with

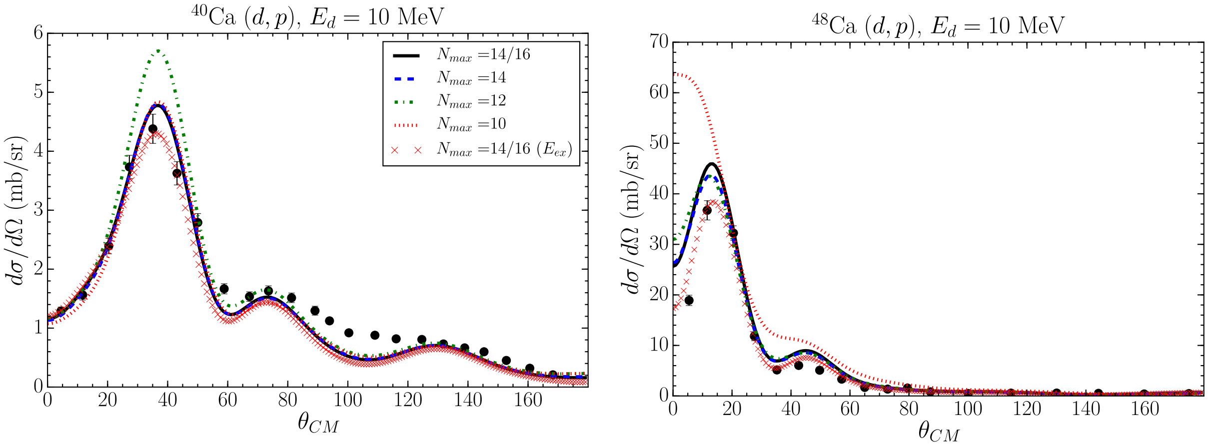

Figure 3: Calculation of the population of the $7/2^-$ ground state of ^{41}Ca in the reaction ^{40}Ca$(d,p)^{49}$Ca and the $3/2^-$ ground state of ^{49}Ca in the reaction ^{48}Ca$(d,p)^{48}$Ca. Theoretical calculations are compared with data from [25]. The curves show the results of coupled cluster calculations with different number of oscillator shells N_{max}. The red crossed curve, labeled $N_{max} = 14/16\,(E_{ex})$, has been obtained within the larger model space (14 and 16 oscillator quanta for 2– and 3–nucleon relative motion, respectively), and adjusting the neutron separation energy to the experimental value (figure taken from [22]).

the Oslo group, Potel is now extending his method to extract gamma strength functions in actinides [27].

The existence and characterization of soft dipole modes (pygmy resonances) in nuclei with neutron excess is a long standing open question, subject to active current research. More specifically, the nature of low-lying dipole strength in light halo nuclei, such as ^{11}Li, is controversial and under heated scientific debate. Recent studies [28, 29] use inelastic reactions to probe the particle-hole components of these vibrations.

Last but not least, Potel contributed to the interpretation of the measurement of the spontaneous proton emission of a nucleus close to the neutron drip line. In a recent experiment [30], in which a ^{11}Be was stopped in an active target time projection chamber, proton emission was observed as a result of the β-decay of ^{11}Be above the proton emission threshold of ^{11}B. The data can only be explained by a narrow proton resonance in ^{11}B.

2.3.1.3 Kevin Fossez

Modern nuclear physics is currently laying the foundations for the exploration of the most exotic nuclei ever created. At the experimental level, FRIB will reveal thousands of new isotopes, mostly neutron-rich and in many instances strongly impacted by continuum couplings. This will require an unprecedented theoretical effort to support and foster this discovery enterprise. Below are three highlights of Fossez's contributions toward this effort (T2 and T3).

At the few-nucleon level, Fossez has contributed to the debate on the existence of the tetranucleon. The recent experimental hint of a resonant four-neutron system (tetraneutron) [31] stimulated the theory community to investigate this exotic system using state-of-the-art ab-initio methods. While a first work generated controversy by supporting the existence of a narrow four-neutron resonance [32], Fossez's proper inclusion of continuum couplings in the density matrix renormalization group (DMRG) approach, combined with a new identification method for resonances, provided a strong case against the existence of such a state [33]. This result was confirmed by other groups [34, 35, 36].

Whether or not there is a parity inversion of the ground state of ^{9}He and what is the structure of ^{10}He are two open questions in nuclear structure. Fossez and collaborators worked with a simplified effective Hamiltonian using the inherent scale separation in neutron-rich helium isotopes to make precise predictions on energy spectra using the DMRG approach in the largest continuum space ever considered [37]. The confirmation of the parity inversion in ^{9}He and the surprising predictions for ^{10}He motivated an experimental proposal to build a tritium target at FRIB to study the reaction $^8\mathrm{He}(t,p)^{10}\mathrm{He}$.

The oxygen chain has provided an important benchmark for ab-initio theories. By combining the Gamow shell model (GSM) [38] and the DMRG [39] approaches, Fossez and collaborators made predictions for the bound and unbound energy spectra of $^{23-28}$O [40]. This opened the door for a theory-experiment collaboration to motivate the re-measurement of ^{25}O spectrum [41].

In the future, Fossez plans to continue his work on the unification of nuclear structure and reactions, which is one of the most challenging problems in nuclear theory. It is especially important to reach a precision for predicted ground- and excited-state energies and decay widths that is comparable with current experimental resolutions, in order to provide theoretical guidance for low-energy nuclear physics experiments at facilities such as FRIB or the Argonne Tandem Linac Accelerator System (ATLAS). This problem can be addressed either by extending ab-initio capabilities to continuum states, to increase predictive power in unknown regions of the nuclear chart, or by developing novel and more precise approaches at lower energy that take into account the existence of emergent phenomena in nuclei while still being properly connected with the more fundamental levels of description. Fossez's plan includes the generalization of the in-medium similarity renormalization group (IM-SRG) approach [42] to continuum states using the Berggren basis; the refactoring and optimization of the DMRG code with computer scientists; and the development of an EFT for the nuclear shell model (SM-EFT) as an alternative to ab-initio calculations of exotic nuclei whose precision is currently too limited.

2.3.2 Highlights from Bridges Faculty/Staff

During the current grant cycle, three bridge positions were established: Maria Piarulli and Saori Pastore started August 2018 at Washington University St. Louis, and Sebastian König plans to start January 2020 at North Carolina State University.

2.3.2.1 Maria Piarulli

The nuclear force is the essential building block for ab-initio theories of the nucleus. Piarulli has been working with collaborators on the formulation of the nuclear force (and associated currents) for use in quantum Monte Carlo (QMC) calculations of nuclear structure and reactions (T1). QMC ab-initio studies have clearly demonstrated how numerous aspects of nuclear structure arise from the underlying nucleon-nucleon (NN) and three-nucleon (3N) forces. The absolute binding energies and excitation spectrum of around 100 states with mass number up to ^{12}C have been accurately reproduced, providing important constraints on the nuclear Hamiltonian [44]. The evaluation of nuclear magnetic moments, electroweak transitions and response has demonstrated the importance of two-body current operators [44]. While these studies are limited to light nuclei, i.e., those with

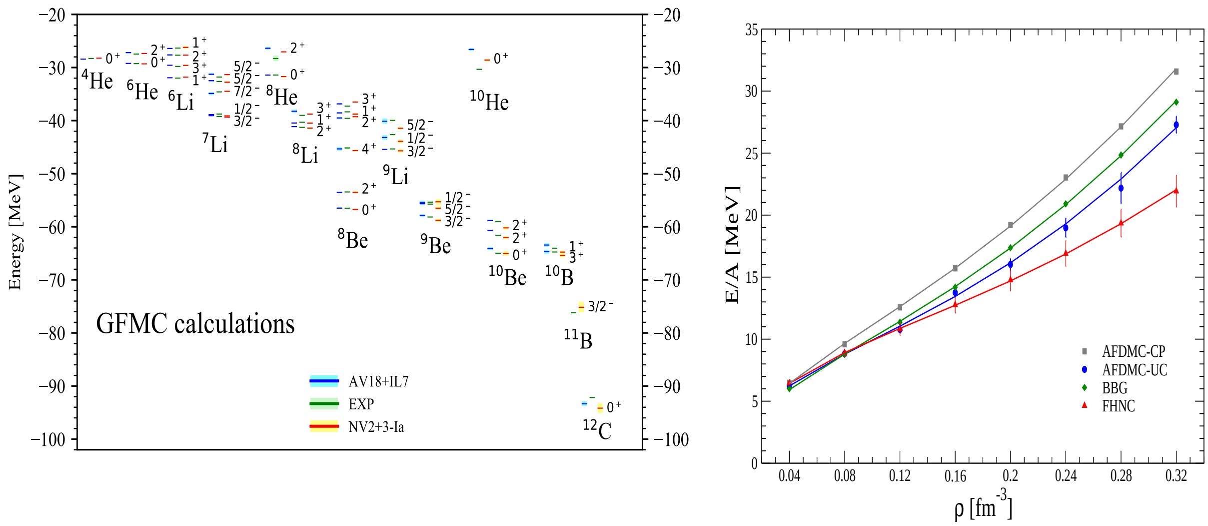

Figure 4: Nuclear properties obtained from QMC calculations using new chiral nuclear interactions (from Ref. [43]). Left panel: Energy spectra of $A = 4$–12 nuclei obtained using Δ-full local chiral interactions compared to experimental data [44]. Also shown are results obtained with the phenomenological AV18+IL7 Hamiltonian [44]. Right panel: Energy per particle of pure neutron matter (PNM) as a function of density calculated with the BBG (green diamonds), FHNC/SOC (red triangles), AFDMC-CP (grey squares) and AFDMC-UC (solid blue points) many-body approaches. The calculations are performed with the two-nucleon Δ-full local chiral interactions.

$A \leq 12$, these ab-initio calculations provide important benchmarks to test other computational methods that can be extended to heavy nuclei, where the treatment of nuclear interactions and currents is much less controlled. For this reason, Piarulli's work is relevant to a large fraction of FRIB's scientific programs.

A major thrust of Piarulli's current work is based on developing models for the nuclear interactions and electroweak operators using chiral effective field theory (χEFT) [45, 46, 47]. During the last two decades, this approach has become popular in the low-energy nuclear physics community because of its deeper connection with the fundamental theory of quantum chromodynamics (QCD), in contrast to the traditional phenomenological approaches adopted in the past [44]. Recently, a high-precision family of chiral nuclear interactions suitable for QMC methods was developed, referred to in the literature as "Δ-full local chiral potentials" [48, 49, 50]. Such models have been implemented in QMC codes and used to perform calculations of the energy levels of $A = 4$–12 nuclei, which are found to be in agreement with the experimental data [43], as shown in the left panel of Fig. 4.

Recently, a benchmark for the energy per particle of pure neutron matter (PNM) as a function of the baryon density using three independent many-body methods was completed. Piarulli and collaborators compare Brueckner-Bethe-Goldstone (BBG), Fermi hypernetted chain/single-operator chain (FHNC/SOC), and auxiliary-field diffusion Monte Carlo (AFDM) [51]. These calculations, displayed in the right panel of Fig. 4, were performed with only two-nucleon interactions because the scope of that work was to quantitatively assess the systematic error of the different many-body approaches and study how this error depends upon the nuclear interaction of choice. Piarulli plans to proceed with a realistic description of the equation of state (EoS) of PNM through the inclusion of many-nucleon forces.

Within the χEFT approach, some of the parameters of the NN and $3N$ chiral potentials also enter the expressions of electroweak currents [52, 53], a fundamental ingredient for describing nuclear properties besides energies calculations. Electroweak currents corresponding to the new Δ-full local chiral interactions have been derived in Refs. [54, 55, 56]. Piarulli collaborates closely with Pastore on the implementation of such currents in the QMC algorithms, to compute nuclear matrix elements relevant for electroweak transitions in light nuclei (details below).

2.3.2.2 Saori Pastore

Understanding the fundamental interactions in nature and their symmetries (Q3) is at the heart of the research being developed by Pastore. She explores the effect of weak interactions in nuclei, using QMC techniques to determine the nuclear structure. Her research connects strongly with the fundamental symmetries program planned for FRIB.

Current and planned experimental programs rely on accurate calculations of nuclear structure and electroweak reactions. For example, neutrinoless double beta decay ($0\nu\beta\beta$) rates depend not only on unknown neutrino properties, but also on $0\nu\beta\beta$ matrix elements. These, lacking experimental data, need to be provided by theory. Calculations for nuclei of experimental interest ($A \geq 48$) are based on computational methods that inevitably adopt approximations to solve the nuclear many-body problem. As a consequence, estimates of $0\nu\beta\beta$ matrix elements may vary by a factor of two when computed using different computational models. Variational and, in particular, Green's function MC computation methods allow one to solve the nuclear many-body problem with an accuracy of $\sim 2\%$ for $A \leqslant 12$ nuclei. Consequently, these light systems are the optimal candidates to study ('exactly') both many-body interactions and electroweak currents.

Recently, Pastore performed Variational Monte Carlo (VMC) calculations of $0\nu\beta\beta$ matrix el-

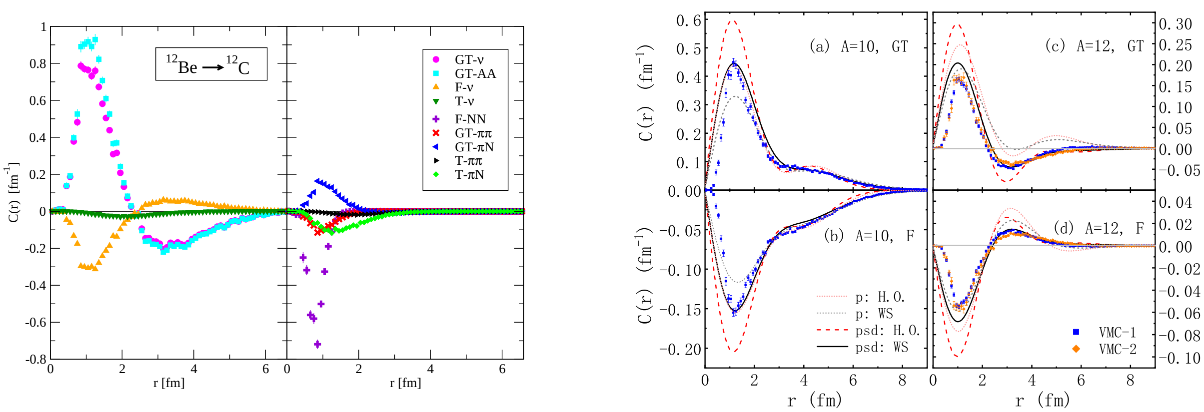

Figure 5: Left panel: The GT-ν, F-ν, GT-$\pi\pi$, and GT-πN distributions in configuration space (r indicates the interparticle distance) for the ^{12}Be$\rightarrow$^{12}C decays (From Ref. [57]). Right panel: Radial distributions of the GT-ν and F-ν operators for A=10 (a-b), and A=12 (c-d) nuclei (From Ref. [58]). The shell model results are for the lowest order $0\hbar\omega$ p-shell calculations and psd-shell calculations with up to four particle excitations, and for two choices of harmonic oscillator and Wood-Saxon radial wave functions. Variational MC results are indicated by 'VMC1' and 'VMC2'.

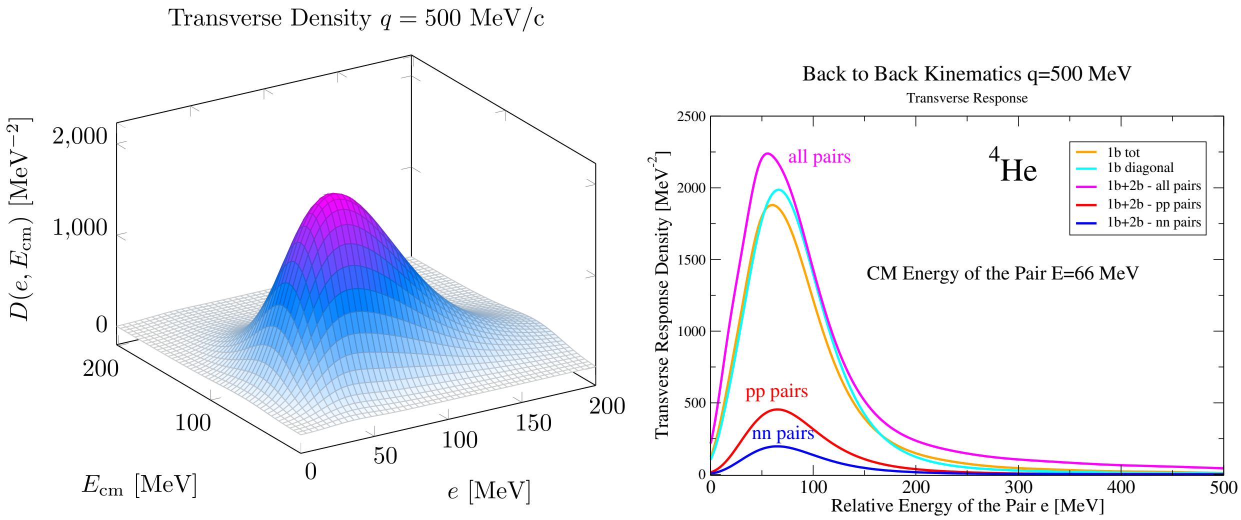

Figure 6: **Left panel**: Electromagnetic transverse response density for the α particle as function of the relative energy e and center of mass energy E_{cm} of the struck nucleon pair. **Right panel:** Electromagnetic transverse response density at fixed back-to-back kinematic. In magenta is shown the total density while responses given by pp and nn pairs are given by the red and blue lines, respectively.

ements in light nuclei [57] with the goal of developing a robust understanding of the dynamics entering these transitions. In particular, $0\nu\beta\beta$ decay induced by Majorana neutrinos, short-range potentials of one- and two-pion range, and contact-like contributions was studied [57, 59]. As an example, the left panel of Fig. 5 shows the transition distributions of the neutrino- and pion-range mechanism inducing the $0\nu\beta\beta$ transition in $A = 12$. The integral over the interparticle distance of the distributions gives the $0\nu\beta\beta$ matrix elements. Together with Wang and collaborators, Pastore performed benchmark calculations of neutrinoless double beta decay matrix elements in $A = 10$ and 12 nuclei [58]. In particular, they compared results from the VMC method [57] with shell-model calculations. These comparisons are shown in the right panel of Fig. 5 and indicate that an agreement between the two computational approaches is reached when a larger model space is utilized in the shell-model calculations. To have a good description of the long range part of the transition density matrix, the Wood-Saxon basis for the shell-model is required. The shell-model calculations displayed in Fig. 5 are obtained without the inclusion of short-range correlations.

Still in the context of Q3 and concurrently with the work on nuclear matrix elements, Pastore is developing the Short-Time Approximation (STA) to evaluate electroweak nuclear responses and response densities induced by lepton scattering from nuclei. The STA retains all the pair correlations and up to two-nucleon currents at the lepton-nucleus interaction vertex. Within the STA, it is possible to calculate response densities representing the nuclear response in terms of the relative and center of mass energy of the struck pair of nucleons. An example for the electromagnetic transverse response density of the α particle is shown in the left panel of Fig. 6. The right panel shows the response density at fixed back-to-back kinematics induced by the whole α-particle and by pp and nn pairs.

2.3.2.3 Sebastian König

König's research has centered around exploring the powerful tool of effective field theories (EFTs) in low energy nuclear theory (T1). In addition, his research plan for the next few years extends to new methods for nuclear structure for a wide range of masses, as well as developments that work toward the unification of structure and reactions (T2,T3). All the new methods here described will be important in the interpretation of a wide range of phenomena that FRIB will cover.

At the lowest energies, it is possible to describe the strong interaction of nucleons with zero-range forces only, not even resolving explicitly the exchange of pions. In this universal regime, EFT links nuclear physics directly to cold atomic gases and weakly bound hadronic molecules. Ref. [60] took this concept to the extreme and expands few-nucleon systems around the so-called "unitarity limit," where the two-body interaction is fixed by reproducing infinite S-wave scattering lengths. This leaves the strength of a three-body force as a single adjustable parameter at leading order, while building up all details as perturbative "fine structure". This work has become part of a greater trend to simplify the nuclear interaction (see Refs. [61, 62, 63] for a few examples). Overall, it directly addresses, through exact calculations of up to four-nucleon systems, the questions how subatomic matter organizes itself and what are the fundamental interactions leading to this organization (Q2).

Along these lines, König, in collaboration with H. Hergert (MSU) and others, is pursing calculations of $A > 4$ nuclei within the unitarity expansion to investigate what is the relevant momentum scale in nuclei (this involves developing a perturbative treatment of higher EFT orders using the IM-SRG [64]). He also plans to explicitly include pion-exchange as in Refs. [60, 65]. These developments are ideally suited to help resolve a long-standing debate on how Chiral EFT should be organized and implemented.

It is well known from the pioneering work of Lüscher [66] that simulating physical systems in a finite volume can be used as a tool to extract physical properties. This technique, based on the fact that the physical S-matrix governs the volume dependencies of energy levels, is widely used for example in Lattice QCD (LQCD). One method for addressing nuclear properties is through finite-volume calculations on a lattice. In Ref. [67], König in collaboration with D. Lee (MSU) derived the volume dependence of bound states with an arbitrary number of constituents. Also, Ref. [67] points out a way to obtain asymptotic normalization constants (ANCs) from the volume dependence of cluster states. An extension of the formalism to include the long-range Coulomb force will be pursued to enable the extraction of a number of relevant ANCs from lattice (EFT) simulations.

Ref. [68] showed that that finite-volume calculations can identify few-body resonance states, manifest as avoided crossings in the volume-dependent energy spectrum. In addition, the "discrete variable representation (DVR)" developed for Ref. [68] offers many interesting applications. For example, it will be possible to investigate α-cluster nuclei based on the effective field theory tailored for the description of such systems (Halo/Cluster EFT). In particular, one can study to what extent the Hoyle state in ^{12}C can be interpreted as a remnant of a universal Efimov trimer. Applications to FRIB relevant nuclei are also planned.

The eigenvector continuation (EC) method was recently introduced into nuclear physics [69]. It enables the extrapolation of parametric dependencies of observables over large domains and even across phase transitions. By exploiting small amounts of information contained in eigenvectors, it is possible to solve problems for which perturbation theory is not applicable, in a manner that is strikingly simple in practice. König is working on extensions of the EC idea in two directions. The first is to use EC to construct accurate and efficient emulators for nuclear observables (emulators evaluate quantities for a large set of parameters in cases where exact calculations are prohibitively expensive). Important applications are the propagation of uncertainties, for example from chiral potentials that depend on many "low-energy constants (LECs)," to final observables, as well as the fitting of these LECs to input data [70]. The second involves the applications of EC to converge otherwise divergent series in many-body perturbation theory (MBPT), providing a reliable alternative to phenomenological resummation techniques. Together with T. Duguet, A. Tichai, and others, König is working to apply this technique to Bogoliubov Many-Body Perturbation Theory (MBPT) [71] calculations of medium-mass open-shell nuclei.

Finally, König is also interested in building a consistent theoretical framework for structure and reactions. Working towards this important science goal [72], König plans to complement existing efforts in two ways. Nuclear-structure calculations based on EFT interactions will always come with an inherent theoretical uncertainty, one which can be accurately determined within EFT. Providing input for reaction calculations, small errors in for example excitation energies can however dramatically influence the result simply because the Q-value of the reaction differs slightly from experiment. König will explore how this can be resolved within a unified EFT framework.

Reactions with heavy nuclei are complicated processes and it is necessary to use another level of effective interactions (optical potentials). König will use existing numerical infrastructure, able to perform exact four-body calculations based on Faddeev-Yakubowsky equations, to systematically study such effective interactions and the approximations involved by comparing results to exact few-body calculations within the same framework. These novel efforts are greatly needed for the FRIB reaction program.

2.3.3 Scientific results from Topical Programs

The last few years have witnessed major breakthroughs and developments in low-energy nuclear theory, including *ab initio* α-α scattering, *ab initio* polarized deuterium-tritium thermonuclear fusion, resolving the discrepancy between experimental and theoretical β-decay rates, effective nucleon-nucleus interactions (optical potentials) rooted in first principles, new insight into charge radii and shell structure in the medium-mass nuclear region, superheavy nuclei, the dramatic expansion of predictive many-body approaches with unprecedented accuracy beyond the light and spherical nuclear species, as well as stronger ties to efforts in astrophysics and probing fundamental symmetries. As collaborations among individual research groups have been critical to this success, the FRIB-TA ran three topical programs between 2017–2019 with the aim to bring scientists together and to prepare the theory needed to address FRIB science, encompassing all the topics (T1-T7) listed in Table 3. The programs have expressed a general consensus that it is imperative to facilitate a close interaction between theorists and experimentalists, as well as among theorists working at different energy scales, with different degrees of freedom, and in inter-disciplinary areas. They reiterated the need for computational time and personnel support to reduce theoretical uncertainties in nuclear physics calculations.

The main goals of the topical program *"Connecting bound-state calculations with the scattering and reaction theory"* (June 2018) were to establish connections among different approaches, especially between few-body approaches (typically applied to nuclear reactions) and many-body approaches (typically applied to nuclear structure), as well as theory to experiment. Low-energy nuclear theory has been invigorated by the introduction and promulgation of novel, rigorous many-body theoretical methods for bound states, allowing for broadly successful *ab initio* calculations.

The low-energy community has also become aware of the need for similarly rigorous calculations for low-energy scattering and reaction theory, particularly for interpreting the results of experiments at FRIB. This program enabled more theorists working in bound-state formalisms to connect to continuum degrees of freedom, and helped develop tools to calculate reaction observables that are directly measured in experiments. It pulled together experts in scattering and reaction theory, in bound-state structure calculations, and especially those working on the boundary, to summarize the state of the art and to identify (and lower) the technical barriers to move from bound-state calculations to the continuum.

The program recognized: 1) the use of localized bases in many bound-state calculations and the need for theoretical advances that use hybrid degrees of freedom; 2) the need to address collectivity, clustering, and non-resonant continuum; 3) the need to replace current statistical methods in cases where reaction rates are dominated by low-lying resonances; 4) the critical need for reliable effective inter-cluster interactions that can be employed in many currently available reaction codes used by theorists and experimentalists; 5) the critical need for an accurate reproduction of thresholds and asymptotic normalization coefficients (ANC); 6) the important support of experiment that can provide measurements on a grid of the nuclear chart allowing for theoretical interpolations, with a focus on masses. The program deliverables include a web site https://indico.fnal.gov/event/16737 that contains all the presentations, and a white paper, which was initiated during the program and is currently being finalized to be submitted to J. Phys. G in 2019. The goal is to provide specific technical resources not only for the next generation of scientists, but also to enable established scientists to apply their work to FRIB science, as well as to summarize the capabilities of current models for the use in experimental analyses.

The timely topical program *"FRIB and the GW170817 kilonova"* (July 2018) closely followed the first discovery of a binary neutron-star merger event by LIGO/Virgo, GW170817. Identifying and understanding the astrophysical site of the formation of the heaviest elements via r-process nucleosynthesis is a primary science focus of FRIB. The recent observation of GW170817 and its associated kilonova provided a dramatic confirmation that at least some r-process elements can be made in such mergers. However, many open questions remain, which were discussed during the program, including the critical astrophysical and nuclear physics uncertainties in the interpretation of the GW170817 kilonova, further insight into the astrophysical site (or sites) of the r-process provided by this event, and the advances in nuclear experiment and theory that are most crucial to pursue in light of the new data.

In particular, the GW170817 kilonova signal is interpreted through comparisons with model signals. Realistic kilonova model signals require state-of-the-art merger simulations to determine the conditions for nucleosynthesis, nuclear network calculations to find the nuclei produced and their associated radioactive heating, and radiation transfer calculations to convert the heating rate into the observed electromagnetic counterpart. Large uncertainties are present in each step, and the reduction of these uncertainties, both from astrophysics and from nuclear physics, is critical to obtain definitive answers. To address this, the program discussed: the uncertainties – astrophysical, atomic, and nuclear – on the kilonova signal; given these uncertainties, the degree of confidence about the nuclei involved and how to connect these estimates to other observational evidence, such as that obtained from metal-poor stars; and the ways nuclear physics can contribute to the interpretation of this signal, with a focus on critical new calculations and measurements needed. A review article that details the scientific accomplishments of the program and important developments is available at arXiv:1809.00703. The program deliverables also include a web site https://indico.fnal.gov/event/16420/ that contains all the presentations.

The topical program *"Hadronic Electric Dipole Moments in the FRIB Era: From the Proton to Protactinium"* (August 2019) addressed the search for permanent electric dipole moments (EDMs), which are among the most sensitive probes of CP-violation beyond the Standard Model (BSM). This, coupled with the unique opportunity afforded by FRIB, represents an enormous discovery potential. In particular, the program discussed the need to clarify how the sources for CP-violation manifest themselves at different energy scales with proper uncertainty quantification from both theory and experiment. The existence of EDMs is closely interlinked with various baryogenesis scenarios as well as BSM physics at or beyond the TeV scale. Historically, neutron EDM placed an extremely stringent limit on CP-violation within the strong interaction through the θ QCD parameter, which lead to the concept of the axion, now a leading cold dark matter candidate. In a contemporary context, EDMs remain one of the few probes of BSM physics that has a reach well beyond the energy scale of current or foreseeable collider experiments. Certain radioactive pear-shaped (octupole-deformed) nuclei such as Protactinium-229 and Radium-225 have exquisite sensitivity to P- and T-violating interactions originating within the nuclear medium. They will be produced in abundance at FRIB. Combined with modern molecular precision measurements techniques developed for electron EDM searches, EDM (and magnetic quadrupole moment) searches using radioactive molecules would have an unprecedented sensitivity to both SM and BSM CP-violation.

The program affirmed: (1) the need for targeted and simultaneous efforts in multiple hadronic systems to disentangle the sources of CP-violation; (2) the critical importance of a robust determination of theory uncertainties across energy scales, which currently plagues the interpretation of EDM limits particularly from the Hg-199 experiment; (3) the strong need for a colinear resonant ionization spectroscopy (CRIS) beamline at FRIB to enable exotic molecules and atoms (EMA) science; (4) the crucial need for nuclear structure theory and measurements of octupole-deformed isotopes such as radium and radon and, in particular, an unambiguous measurement of the energy splitting of the ground state parity doublet of Pa-229, if it exists, which would calibrate the BSM sensitivity of Pa-229; and (5) the significant impact on nuclear physics from precursor experiments such as the determination of nuclear moments including new observables such as anapole moments. The program deliverables include a web site https://indico.frib.msu.edu/event/13/ that contains all the presentations, and a white paper, currently in preparation, with contributions from selected key participants.

2.4 Bringing value to FRIB

The priorities for nuclear physics in the U.S. have been clearly articulated in the 2015 Long Range Plan for Nuclear Science. During the year-long exercise culminating in the plan, the entire nuclear physics community contributed to developing a vision to address the most compelling scientific questions in our field. It was recognized that to fulfill this vision, advances in nuclear theory are essential to meet future challenges and realize the full scientific potential of FRIB and other next-generation experimental facilities. Enabled by a rapid response from the Division of Nuclear Physics of the Office of Science of the Department of Energy, the FRIB theory alliance has been in place for nearly five years, delivering excellent science in support of FRIB's mission.

A strong interplay between theoretical and experimental research is essential for realizing the full potential of FRIB. New measurements will drive new theoretical efforts which, in turn, will uncover new observables of interest and puzzles that will motivate new experimental campaigns. Through collaboration, members of the FRIB-TA play a critical role in the development of the science case for experiments and in the interpretation of new experimental data. The FRIB-TA aims to forge a partnership with our experimental colleagues resulting in a true intellectual exchange in support of the fulfillment of FRIB's science vision. Below is a representative list that illustrates the variety of ways in which this partnership is fostered:

- The FRIB-TA executive board includes, as regular members, an experimentalist voted in by the community (currently Augusto Macchiavelli) and an FRIB representative (currently Alexandra Gade) and, as an ex-officio member, the chair of the FRIB Users organization (currently Heather Crawford). This ensures that our discussions are rooted in experimental reality.
- The FRIB-TA annual board meeting is concurrent with the Low-Energy Community Meeting so that interactions can be maximized. There are ongoing discussions on ways to optimize the interactions with experimentalists during these two days, while still providing an attractive annual meeting to the Theory Alliance membership.
- The FRIB-TA provides updates to the FRIB Science Advisory Committee and receives guidance on best strategies to connect with the experimental program.
- The FRIB-TA was involved in the organization of the FRIB Day-1 workshop at ANL in August 2017. Conveners of the various identified topics consisted of one theorists and one experimentalist that worked together to present the best case for FRIB Day-1 science.
- The FRIB-TA will actively participate in the "FRIB First Experiments Workshop: Proposal Planning" that will take place from May 4-8 2020 at Michigan State University. This will provide the opportunity to get directly engaged in the planning of the early science programs at FRIB.
- The FRIB-TA topical program organizers are encouraged to include experimental colleagues in the organization committee to ensure discussions are contextualized and aligned with the planned FRIB experimental programs.

The FRIB-TA is well positioned to meet the challenges and help realize the full scientific potential of FRIB. With a user program starting in early 2022, the coming years present additional opportunities for an even stronger collaboration between theory and experiment. While theorists and experimentalists will continue to interact through FRIB-TA sponsored topical programs and ECT* workshops, it is essential to strengthen these connections even further. Focused workshops on specific science topics will strengthen the science cases for planned experimental programs and, in turn, will inform the theory community about upcoming opportunities to interpret new results. Furthermore, through the FRIB-TA webpage, we also plan to develop a section dedicated to experimentalists. This will include a current list of theory capabilities as well as FRIB-TA affiliated theorists (fellows and bridges) that an experimentalist can contact if searching for a theory partnership in preparing for PAC proposals.

FRIB will become a treasure trove of new and exciting scientific results that will address the most fundamental questions in nuclear science today. The FRIB-TA is committed to continue to strengthen a successful long-term partnership with our experimental colleagues in our joint quest to answer these fundamental questions.

2.5 Diversity, Equity and Inclusion

We recognize that the nuclear physics community in general is not as diverse as it could be, and that the general practices in the nuclear theory community are not fully inclusive and equitable. Recently, the DOE Office of Science has taken important steps to promote diversity, equity and inclusion (DEI). This is also part of the mission of the FRIB theory alliance: we must help our community progress toward a truly inclusive and equitable environment where all are represented and respected regardless of race, ethnicity, gender, sexual orientation, culture, educational background, etc. Our commitment to providing a safe, inclusive and equitable experience for all requires a multi-level approach, with both internal and external initiatives, as well as specific adjustment in procedures.

- **Code of Conduct:** One first step toward providing a welcoming environment is introducing a code of conduct. To this end, the FRIB-TA endorses the American Physical Society code of conduct: `https://www.aps.org/meetings/policies/code-conduct.cfm`.
- **Equity in fellow searches:** The FRIB-TA will make additional efforts to diversify the pool of applicants. The chair of the theory fellow search will be briefed by FRIB HR on best practices to ensure that all applicants are treated equitably during the search process.
- **DEI in the bridge program:** Bridge searches are the responsibility of the hosting institution however FRIB-TA is responsible for selecting the hosting institution. The FRIB-TA will require that the application package for hosting a bridge position include a diversity, equity and inclusion statement that addresses these issues in the context of the bridge search and the workplace experience of the to-be-hired junior faculty/staff.
- **Representation in Meetings:** The FRIB-TA will require that proposals for topical programs include a diversity plan to ensure broad participation. In addition, the FRIB-TA will collect and make public the demographics of the participants in our topical programs, summer school and EUSTIPEN. Where data reveal issues, the board will discuss and implement specific initiatives to help address those issues.
- **Zero tolerance for Harassment:** FRIB-TA does not tolerate harassment behavior of any kind, sexual or non-sexual, including bullying, intimidation and retaliation. This also includes unwelcoming conduct (verbal, written or physical) based on an individual's race, color, sex, religion, disability, etc. When such behavior is brought to the attention of the FRIB-TA, it will be investigated by the FRIB DEI investigator. If claims are verified, the harasser will be removed from the FRIB-TA membership and will not be granted permission to attend FRIB-TA events.
- **Addressing DEI in the theory community:** A small FRIB-TA taskforce will be set up to consider other ways in which the FRIB-TA can help underrepresented groups feel more welcome and guide our theory community toward becoming truly inclusive.

2.6 International Links and EUSTIPEN

The 2013 report from the comparative research review of nuclear physics for the U.S. Department of Energy [73] states: *"New RIB facilities are under construction in Canada, France, and Asia. With the wider spread of world-leading experimental facilities, international networking will become more* *important in the future. As a first step, DOE has created exchange programs for nuclear theorists with selected countries. These programs should be expanded and include joint graduate education with international partners."* An important goal of the nuclear theory community in the US is to extend its reach beyond its boundaries by creating fruitful collaborations with our colleagues around the world.

There are a number of initiatives already in place that catalyze collaborations between countries. Of particular relevance to the FRIB-TA is the Europe-U.S. Theory Institute for Physics with Exotic Nuclei (EUSTIPEN). Following in the footsteps of similar successful initiatives—JUSTIPEN with Japan [74], FUSTIPEN with France [75], and CUSTIPEN with China [76]—EUSTIPEN was established with the goal of facilitating collaborations between U.S.-based and Europe-based scientists whose main research interest is the physics of exotic nuclei, including nuclear structure and reaction theory, nuclear astrophysics, and fundamental symmetries. EUSTIPEN is being managed by the FRIB-TA with funding provided by the Office of Nuclear Physics of the U. S. Department of Energy. The European portion of its funding comes through the European Nuclear Science and Applications Research Program ENSAR2.

The main purpose of EUSTIPEN is to deliver an international venue for collaborative research on the physics of exotic nuclei. The EUSTIPEN program is intended to fund travel to the European Centre for Theoretical Studies in Nuclear Physics and Related Areas (ECT*) in Trento, Italy for nuclear theorists whose current primary institutional affiliation is with a U.S. university, national laboratory, or other research center. Currently, two kinds of EUSTIPEN grants are supported:

i. Travel support for collaboration meetings at ECT* with Europe-based colleagues;
ii. Travel support for junior scientists and postdocs to attend workshops and training programs at ECT*.

Details can be found in http://fribtheoryalliance.org/content/eustipen.php.

Despite being in its infancy, EUSTIPEN has already been an enormous success. During the first half of 2019 alone, a total of 26 applications were funded—with 15 of them submitted by research associates, postdoctoral fellows, and graduate students. Among the remaining 11 applications, three of them were submitted by Saori Pastore (2) and Maria Piarulli (1)—our two newest colleagues at Washington University who were hired under the FRIB-TA Bridge program. U.S. scientists traveled to the ECT* to attend a variety of topical programs of enormous breadth, ranging from neutrinos and fundamental symmetries to stellar mergers and the r-process. From exit reports by the U.S. attendees, we have learned about the enormous value of the EUSTIPEN program in both fostering new collaborations and keeping the community abreast of exciting new developments. EUSTIPEN is becoming the fourth in a chain of successful partnerships with our international colleagues. As EUSTIPEN moves forward to the next funding cycle, amendments to the policies have taken place to ensure that our priority of supporting junior researchers is implemented effectively.

2.7 Connections with other fields

The FRIB-TA provides an essential vehicle by which the nuclear physics research done at FRIB feeds into the broader physical science research enterprise and the training of young scientists. The FRIB-TA fosters broadly related theoretical research on the frontier of nuclear structure, nuclear reactions, nuclear astrophysics and fundamental symmetries. This work is both complementary to and synergistic with research done in other fields of physics. FRIB-TA research can also provide vital input for other endeavors in the physical sciences, leveraging progress in these fields and identifying synergies with nuclear physics.

An example is research at the interface of high-energy and nuclear physics that uses hadrons and nuclei as probes of fundamental interactions and new physics beyond the Standard Model. It is remarkable that the FRIB experimental program can provide insights about the generation of the baryon asymmetry of the universe by searching for permanent electric dipole moments of specific nuclei, such as Ra-225 and Pa-229. The FRIB-TA, through its current programs, helps develop theoretical methods to motivate and interpret a large number of high-impact nuclear experiments searching for new physics. These include precision nuclear beta decay measurements, searches for neutrinoless double beta decay, neutrino-nucleus scattering essential for the interpretation of oscillation experiments, and dark matter direct detection via nuclear recoils.

Another example of synergy is in astrophysics and cosmology. The discovery of the first neutron star merger, GW170817, in gravitational waves and the identification of its optical counterpart has ushered in a new era in multi-messenger astronomy and nuclear astrophysics. Nuclear processes primarily shape these extreme multi-messenger phenomena such as neutron stars mergers and core-collapse supernovae. Moreover, recent advances in nuclear theory and computational astrophysics suggest that these complex phenomena can be modeled. The FRIB-TA can accelerate progress in these areas, and ensure that we have tools to interpret and correlate gravitational waves, electromagnetic, and neutrino signals from future observations. Remarkably, longstanding fundamental questions about the origin of heavy elements in the universe, the nature of dense nuclear matter and the role of neutrinos and weak interactions are intimately connected through these events and require coordination between nuclear physicists, astrophysicists, gravitational wave physicists, and astronomers to address.

The physics at the intersection of the above areas presents significant technical challenges but also opportunities to address outstanding questions of great interest to the whole physics community. The FRIB-TA addresses these challenges by:

- Facilitating interactions between these diverse communities through workshops, topical programs, and long term visits. The FRIB-TA board and appropriate subcommittees ensures that some topical programs are devoted to "intersections" areas.
- Educating junior scientists to tackle new challenges posed by multi-disciplinary research. A practical vehicle for this is the sponsorship of summer schools that emphasize the broader connections.
- Advocating for a broader scope of the traditional nuclear physics programs at universities and national laboratories. The Theory Fellow and Bridge Faculty programs of the FRIB-TA provide a concrete mechanism to respond to emerging opportunities in areas such as fundamental symmetries, multi-messenger astrophysics, quantum computing, etc.

2.8 Webpage

The FRIB Theory Alliance website serves as a communication tool for the FRIB-TA community, to promote and disseminate FRIB-related theory, and for outreach. The website is primarily managed by Gillian Olson, with support by the FRIB-TA Webpage Committee, and with content supplied by the board members and the FRIB-TA community. Present content includes a range of information on FRIB-TA science and governance, including menu items leading to solicitations and progress reports for FRIB initiatives such as the FRIB-TA Fellows, summer schools, and Topical Programs. There are also links to relevant websites (e.g., theory collaborations and institutes). Recent content development includes the ongoing addition of highlights of FRIB science conducted by fellows and bridge faculty in the form of one-page summary slides.

The website database stores information on the FRIB-TA members. There is a form interface that makes it easy for users to join the FRIB-TA and to modify their information. Membership as of October 2019 is 165 from the United States, from 35 universities (69 faculty members) and 7 national laboratories, with an additional 51 from around the world. The list of FRIB-TA members is directly available from a menu item at fribtheoryalliance.com, where it can be filtered by institution, country, and status (i.e., faculty, laboratory staff, fellow, postdoc, or student). The FRIB-TA leadership can also create internal targeted mailing lists from the member database.

The webpage regularly includes advertisements for important events, pointers to recognitions for FRIB-TA science, and job postings such as for FRIB-TA Bridge positions. These and many other announcements are also distributed to the FRIB-TA membership via email from the automatically generated lists.

A priority upgrade to the website will be information for experimentalists about what FRIB-TA theorists can do. In particular, the fellows and bridge faculty have realized that their expertise is not yet fully exploited. The website will facilitate communication with the experimental community with summaries of capabilities and a linked wiki page for "Theory Support and Capabilities for Experiments".

2.9 Milestones and deliverables

This section on milestones and deliverables reflects our strategy to fulfill the unique mission of the FRIB Theory Alliance. As such, the main goals of the alliance are to foster advancements in theory related to FRIB science; optimize the coupling between theory and experiment; and stimulate the field by creating permanent theory positions. Unlike most proposals, the milestones and deliverables articulated in this section are often repetitive. The aim is to provide a clear path to reach the alliance's ultimate goals that include a steady-state scenario of five FRIB-TA bridge faculty/staff positions and six theory fellows; stimulating yearly summer schools and topical programs; and a long-lasting partnership with our European colleagues through the EUSTIPEN initiative.

FY2020:

- Theory Fellows and Bridge Faculty will continue to develop excellent research relevant for FRIB, spending a significant amount of time at FRIB. Progress toward T1-4 and T6 (Table 1) will occur.
- Two additional fellows will start their positions affiliated with the FRIB-TA.
- The 3rd search for a bridge position will be conducted and the new faculty member will initiate activities with the FRIB-TA.
- The FRIB-TA will actively participate in the workshop *FRIB First Experiments Workshop: Proposal Planning*.
- The FRIB-TA will run another summer school on a topic intersecting FRIB science (possibly in collaboration with JINA).
- An FRIB-TA topical program on a topic of direct relevance to FRIB will take place.

- The FRIB-TA will run its annual meeting concurrent with the Low-Energy Community Meeting.
- EUSTIPEN will continue to fund collaborations between U.S. scientists and European scientists at the ECT*.
- A call for bridge faculty proposals will be sent out and a forth optimal case for a FRIB-TA bridge position will be identified.
- Elections for the replacement of three members of the Board will take place.
- A progress report describing the science achievements, the FRIB-TA's activities, and a work-plan for Year-2 will be produced.

FY2021:

- Theory Fellows and Bridge Faculty will continue to develop excellent research relevant for FRIB. Progress toward many topics in Table 1 will occur.
- The 4th search for a bridge position will be conducted and the new faculty member will initiate activities with the FRIB-TA.
- A call for partners for the fellow program will be sent out and a search for a new national fellow will be conducted.
- The FRIB-TA will run another summer school on a topic intersecting FRIB science in cooperation with INT.
- An FRIB-TA topical program on a topic of direct relevance to FRIB will take place.
- The FRIB-TA will run its annual meeting concurrent with the Low-Energy Community Meeting.
- EUSTIPEN will continue to fund collaborations between U.S. scientists and European scientists at the ECT*.
- Elections for the replacement of another three members of the Board will take place.
- A progress report describing the science achievements, Center's activities, and work-plan for Year-3 will be produced.

FY2022:

- Theory Fellows and Bridge Faculty will continue to develop excellent research relevant for FRIB. Progress toward many topics in Table 1 will occur.
- The sixth fellow will initiate activities with the FRIB-TA.
- The 5th search for a bridge position will be conducted and the new faculty member will initiate activities with the FRIB-TA.
- The FRIB-TA will run another summer school on a topic intersecting FRIB science.

- An FRIB-TA topical program on a topic of direct relevance to FRIB will take place.
- The FRIB-TA will run its annual meeting concurrent with the Low-Energy Community Meeting.
- EUSTIPEN will continue to fund collaborations between U.S. scientists and European scientists at the ECT*.
- Elections for the replacement of another three members of the Board will take place.
- A progress report describing the science achievements, Center's activities, and work-plan for Year-3 will be produced.

FY2023:

- Theory Fellows and Bridge Faculty will continue to develop excellent research relevant for FRIB. Progress toward many topics in Table 1 will occur.
- As theory fellows move on to permanent positions, a call for partners for the fellow program will be sent out and a new fellow search will take place.
- The FRIB-TA will run another summer school on a topic intersecting FRIB science.
- An FRIB-TA topical program on a topic of direct relevance to FRIB will take place.
- The FRIB-TA will run its annual meeting concurrent with the Low-Energy Community Meeting.
- EUSTIPEN will continue to fund collaborations between U.S. scientists and European scientists at the ECT*.
- Elections for the replacement of another three members of the Board will take place.
- A progress report describing the science achievements, Center's activities, and work-plan for Year-3 will be produced.

FY2024:

- Theory Fellows and bridge faculty will continue to develop excellent research relevant for FRIB, spending a significant amount of time at FRIB. Progress toward many topics covered in Table 1 will occur.
- As theory fellows move on to permanent positions, a call for partners for the fellow program will be sent out and a new fellow search will take place.
- As theory bridge faculty/staff get promoted and receive tenure, a call for partners for the bridge program will be sent out and a new bridge search will take place.
- The FRIB-TA will run another summer school on a topic intersecting FRIB science.
- An FRIB-TA topical program on a topic of direct relevance to FRIB will take place.
- EUSTIPEN will continue to fund collaborations between U.S. scientists and European scientists at the ECT*.

- Elections for the replacement of three members of the Board will take place.
- The FRIB-TA will run a decadal meeting, reviewing 10 years of existence and planning for the future.
- A report describing the science achievements and Center's activities in Years 1-5 will be produced.
- The FRIB-TA Board will prepare a renewal proposal to DOE.

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3 Other information

3.1 Scientific products

3.1.1 Publications

Diego Lonardoni:

1. *Scale and Scheme Independence and Position-Momentum Equivalence of Nuclear Short-Range Correlations*, R. Cruz-Torres, D. Lonardoni, R. Weiss, N. Barnea, D. W. Higinbotham, E. Piasetzky, A. Schmidt, L. B. Weinstein, R. B. Wiringa, and O. Hen, under review in Nature Physics, arXiv:1907.03658.

2. *Ab initio short-range-correlation scaling factors from light to medium-mass nuclei*, J. E. Lynn, D. Lonardoni, J. Carlson, J.-W. Chen, W. Detmold, S. Gandolfi, and A. Schwenk, under review in Phys. Rev. C, arXiv:1903.12587.

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4. *Comparing proton momentum distributions in* $A = 2$ *and* 3 *nuclei via* ^{2}H, ^{3}H *and* ^{3}He $(e, e'p)$ *measurements*, R. Cruz-Torres, S. Li, F. Hauenstein, A. Schmidt, D. Nguyen, D. Abrams, H. Albataineh, S. Alsalmi, [...], D. Lonardoni, *et al.* (Jefferson Lab Hall A Tritium Collaboration), Phys. Lett. B 797, 134890 (2019).

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Gregory Potel:

1. F. Barranco, G. Potel, E. Vigezzi, and R. A. Broglia *The $^9Li(d,p)$ reaction, specific probe of ^{10}Li, paradigm of parity–inverted nuclei around $N = 6$ closed shell.* Submitted to Phys. Rev. C.

2. J. Rotureau, G. Potel, W. Li, and F. Nunes *Merging ab initio theory and few-body approach for (d,p) reactions.* Submitted to Phys. Rev. C Rapid Communications.

3. Broglia, R. A. , Barranco, F. , Potel, G. and Vigezzi, E. *Characterization of vorticity in pygmy resonances and soft-dipole modes with two-nucleon transfer reactions.* Accepted for publication in Eur. Phys. Jour. A.

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13. F. Barranco, G. Potel, E. Vigezzi, and R. A. Broglia *The $^{9}Li(d,p)$ reaction, specific probe of ^{10}Li, paradigm of parity–inverted nuclei around $N = 6$ closed shell.* Submitted to Phys. Rev. Lett.

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Maria Piarulli:

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4. *Zemach moments and radii of $^{2,3}H$ and $^{3,4}He$*
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A. Baroni, R. Schiavilla, L.E. Marcucci, L. Girlanda, A. Kievsky, A. Lovato, S. Pastore, M. Piarulli, Steven C. Pieper, M. Viviani, and R.B. Wiringa,
Phys. Rev. C 98, 044003 (2018)

7. *Light-nuclei spectra from chiral dynamics*
M. Piarulli, A. Baroni, L. Girlanda, A. Kievsky, A. Lovato, Ewing Lusk, L.E. Marcucci, Steven C. Pieper, R. Schiavilla, M. Viviani, and R.B. Wiringa,
Phys. Rev. Lett. 120, 052503 (2018)

3.1.2 Presentations

Kevin Fossez

1. *Toward an in-medium effective field theory for the nuclear shell model*, Open Quantum Systems: From atomic nuclei to ultracold atoms and quantum optics, European Centre for Theoretical Studies in Nuclear Physics and Related Areas (ECT*), Villazzano (TN), Italy (2019-10-04).

2. *Toward an in-medium effective field theory for the nuclear shell model*, FRIB Theory Alliance Meeting at the Low Energy Community Meeting, Duke University, Durham, NC (2019-08-08).

3. *Toward an in-medium effective field theory for the nuclear shell model*, Seminar at the Argonne National Laboratory, Lemont, IL (2019-06-25).

4. *Nuclei as open quantum systems*, Theory seminar at the Argonne National Laboratory, Lemont, IL (2019-04-01).

Diego Lonardoni

1. *Quantum Monte Carlo calculations of nuclear charge radii*, Laser spectroscopy as a tool for nuclear theories, CEA, Gif-sur-Yvette, France (2019-10-11).

2. *Ab-initio description of nuclei and nuclear matter*, FRIB Theory Alliance Meeting at the Low Energy Community Meeting, Duke University, Durham, NC (2019-08-08).

3. *Local chiral interactions and quantum Monte Carlo: from nuclei to nuclear matter*, INT Program INT-19-2a - Nuclear Structure at the Crossroads, INT, Seattle, WA (2019-07-17).

4. *Nuclear structure of light and not-so-light nuclei: an ab-initio approach*, Los Alamos National Laboratory (LANL), Los Alamos, NM (2019-07-02).

5. *Quantum Monte Carlo calculations of light nuclei using local chiral interactions*, APS April Meeting 2019, Denver, CO (2019-04-14).

6. *Exploring short-range correlation effects with quantum Monte Carlo*, 2nd Workshop on Quantitative Challenges in SRC and EMC Research, MIT, Cambridge, MA (2019-03-22).

7. *From nuclear structure to neutron stars with quantum Monte Carlo*, First Nuclear and Particle Theory Meeting, Washington University in St. Louis, St. Louis, MO (2019-03-11).

8. *Medium-mass hypernuclei and the nucleon-isospin dependence of the three-body hyperon-nucleon-nucleon force*, Fifth Joint Meeting of the Nuclear Physics Division of the APS and the JPS, Hilton Waikoloa Village, HI (2018-10-23).

9. *Properties of nuclei up to* $A = 16$ *using local chiral interactions*, Ninth International Workshop on Chiral Dynamics, Durham, NC (2018-09-20).

10. *Exploring short-range correlation effects with quantum Monte Carlo and local chiral interactions*, 2018 Center for Frontiers in Nuclear Science (CFNS) Workshop on Short-range Nuclear Correlations at an Electron-Ion Collider, Brookhaven National Laboratory (BNL), Upton, NY (2018-09-06).

11. *Quantum Monte Carlo and local chiral interactions: light and not-so-light nuclei*, INT Program INT-18-2b - Advances in Monte Carlo Techniques for Many-Body Quantum Systems, Institute for Nuclear Theory (INT), Seattle, WA (2018-08-28).

12. *Exploring nuclear properties with quantum Monte Carlo and local chiral interactions*, 2018 Low Energy Community Meeting, Michigan State University (MSU), East Lansing, MI (2018-08-10).

13. *From light to medium-mass nuclei and neutron stars: quantum Monte Carlo and local chiral interactions*, Nuclear Structure 2018, Michigan State University (MSU), East Lansing, MI (2018-08-07).

14. *Strangeness in nuclei and neutron stars: many-body forces and the hyperon puzzle*, The 13th International Conference on Hypernuclear and Strange Particle Physics, Portsmouth, VA (2018-06-29).

15. *Quantum Monte Carlo and local chiral interactions: from light to medium-mass nuclei*, TRIUMF Canada's particle accelerator centre, Vancouver, Canada (2017-09-12).

16. *Towards exact calculations of medium mass nuclei*, Ab initio nuclear structure and electroweak response: current status and future prospects, Thomas Jefferson National Accelerator Facility (JLab), Newport News, VA (2017-08-08).

17. *Towards exact calculations of medium mass nuclei*, 2017 Low Energy Community Meeting, Argonne National Laboratory (ANL), Argonne, IL (2017-08-03).

18. *Quantum Monte Carlo calculations of medium mass nuclei*, INT Program INT-17-2a - Neutrinoless Double-beta Decay, Institute for Nuclear Theory (INT), Seattle, WA (2017-06-26).

19. *The EOS of Neutron Star Matter: Many-Body Forces and Strangeness*, 2017 Gordon Research Conference on Nuclear Chemistry - The Evolution of Nuclear Structure and Reaction Studies in the Era of Rare Isotope Beams, New London, NH (2017-06-19).

20. *Towards exact calculations of medium mass nuclei*, 2017 NUCLEI SciDAC Collaboration Meeting, Santa Fe, NM (2017-06-07).

21. *Towards the exact calculation of medium-heavy nuclei*, Walk on the neutron-rich side, European Centre for Theoretical Studies in Nuclear Physics and Related Areas (ECT*), Villazzano (TN), Italy (2017-04-11).

22. *Chiral forces and quantum Monte Carlo: from nuclei to neutron star matter*, International Workshop on Transport Simulations for Heavy Ion Collisions under Controlled Conditions, Michigan State University (MSU), East Lansing, MI (2017-03-29).

23. *Hyperons in nuclei and neutron stars*, APS April Meeting 2017, Washington, DC 2017-01-29).

24. *Neutron stars: hyperons or no hyperons, that is the puzzle*, International Symposium on Neutron Star Matter, Tohoku University, Sendai, Japan (2016-11-21).

25. *Quantum Monte Carlo for strangeness nuclear physics*, International School for Strangeness Nuclear Physics, Tohoku University, Sendai, Japan (2016-11-18).

26. *Hyperons in nuclei and neutron stars*, Lepton-Nucleus Scattering XIV, Marciana Marina, Elba Island, Italy (2016-06-30).

27. *Progress in AFDMC calculations for nuclei*, 2016 NUCLEI SciDAC Collaboration Meeting, Argonne National Laboratory (ANL), Argonne, IL (2016-06-07).

28. *Progresses in quantum Monte Carlo calculations for nuclear physics*, FRIB Theory Alliance Inaugural Meeting, Michigan State University (MSU), East Lansing, MI (2016-03-31).

29. *AFDMC calculations on medium-heavy hypernuclei*, Hypernuclear Workshop, Thomas Jefferson National Accelerator Facility (JLab), Newport News, VA (2016-03-15).

30. *From hypernuclei to neutron stars: looking for the pieces of the puzzle*, 54th International Winter Meeting on Nuclear Physics, Bormio (SO), Italy (2016-01-28).

31. *A variational Monte Carlo approach for the study of medium-mass nuclei*, Annual Fall Meeting of the APS Division of Nuclear Physics, Santa Fe, NM (2015-10-29).

Saori Pastore

1. *Quantum Monte Carlo Calculations of Lepton-Nucleus Interactions*,
invited talk at the INT Program Nuclear Structure at the Crossroads (INT-19-2a) - INT Seattle, WA - August 2019

2. *Nuclear Corrections from the EFT Perspective*,
invited talk at the Wrokshop Current and Future Status of the First-Row CKM Unitarity, ACFI UMass, Amherst MA, May 2019

3. *Nuclear Structure approaching the Exascale: large scale ab initio calculations*,
invited talk at the APS April Meeting 2019, Denver, CO, April 2019

4. *Quantum Monte Carlo Calculations of Neutrino-Nucleus Interactions*,
invited talk at the 7th LCTP Spring Symposium: Neutrino Physics, UM, Ann Arbor, MI - April 2019

5. *Short Range Correlations and Double Beta Decay*,
invited talk at the 2nd Workshop on Quantitative Challenges in SRC and EMC Research, MIT, Cambridge, MA, March 2019

6. *Lepton-scattering off nuclei in the Short-Time-Approximation*,
contributed talk at the APS April Meeting 2019, Denver, CO, April 2019

7. *Neutrinos and Nuclei*, invited talk at the HEP/NP Dialog, Jefferson Laboratory, Newport News, VA, November 2018

8. *Quantum Monte Carlo Calculations of Beta Decays in Light Nuclei*, invited talk at the Beta Decay as a Probe of New Physics Workshop, ACFI UMass, Amherst MA - Nov 2018

9. *Neutrinos and Nuclei*, HEP/Astro Seminar, University of Cincinnati, Cincinnati, OH, November 2018

10. *Neutrinos and Nuclei*, Colloquium, University of Iowa, Iowa City, IA, November 2018

11. *Neutrinos and Nuclei*, invited talk at the 5th Joint Meeting of the APS Division of Nuclear Physics and the Physical Society of Japan 2014, Waikoloa, HI, October 2018

12. *Neutrinos and Nuclei*, Nuclear and Particle Physics Colloquium, Laboratory for Nuclear Science - MIT, Cambridge, MA, October 2018

13. *The role of chiral dynamics in the electroweak structure of light nuclei and implications for neutrino scattering*, invited plenary talk, 9th International Workshop on Chiral Dynamics, Durham NC, September 2018

14. *A Systematic Theory of the Electroweak Structure of Light Nuclei and Its Implication for Neutrino Scattering* invited talk, Gordon Conference: From Quarks to Nuclei in Photonuclear Reactions, Holderness NH, August 2018

15. *Theory Prospects for Neutrino Nucleus Cross Sections*', invited talk, 51^{st} Annual Fermilab Users Meeting, Batavia IL, June 2018

16. *Neutrinos and nuclei*, invited talk, NUCLEI User Meeting, Knoxville TN, May 2018

Maria Piarulli

1. *Chiral Interactions for Quantum Monte Carlo*, “Bayesian Inference in Subatomic Physics - A Wallenberg Symposium”, Göteborg, Sweden (2019-09-17).

2. *From light-nuclei to neutron stars within chiral dynamics*, “Low Energy Community Meeting 2019”, Durham, NC, USA (2019-08-8).

3. *From light-nuclei to neutron matter within chiral dynamics*, “27th International Nuclear Physics Conference”, Glasgow, UK (2019-07-29).

4. *Structure and Reactions of Light Nuclei within χEFT*, “Progress and Challenges in the Theory of Neutrinoless Double Beta Decay”, ECT* Trento, Italy (2019-07-15).

5. *From light-nuclei to neutron matter within chiral dynamics*, “Neutrini and nuclei, challenges and opportunities for nuclear theory”, ECT* Trento, Italy (2019-05-27), (personal expenses supported by TA-FRIB funds).

6. *From light-nuclei to neutron stars within chiral dynamics*, "Nuclear and Particle Theory for Accelerator Neutrino Experiments collaboration meeting", Batavia, IL, USA (2019-05-10).
7. *The basic model of nuclear theory: from atomic nuclei to infinite matter*, "Colloquium at University of Iowa", Iowa City, IA, USA (2019-04-22).
8. *From light-nuclei to infinite neutron matter within chiral dynamics*, "Ninth International Workshop on Chiral Dynamics" , Durham, NC, USA (2018-09-17).
9. *Local chiral potentials and the structure of light-nuclei*, "2018 Low Energy Community Meeting", East Lansing, MI, USA (2018-08-10).
10. *The basic model of nuclear theory: from atomic nuclei to infinite nuclear matter*, "XXII International Conference on Few-Body Problems in Physics", Caen, France (2018-07-09).
11. *From light nuclei to neutron stars with chiral dynamics*, "New Ideas in Constraining Nuclear Forces", ECT*, Trento, Italy (2018-06-04).
12. *Local chiral potentials and the structure of light-nuclei*, "NUCLEI/SciDac Meeting", Knoxville, TN, USA (2018-05-29).

Gregory Potel

1. Teaching at the Exotic Beam Summer School (EBSS), June 24–29 Oak Ridge National Laboratory, Oak Ridge, Tennessee, US.
2. Invited talk at the *7th Workshop on Nuclear Level Density & Gamma Strength*, May 27–31 2019, Oslo, Norway.
3. Invited seminar at the Laboratori Nazionali di Legnaro-INFN, May 2 2018, Legnaro, Italy.
4. Contributed talk at the *IV International Conference on Nuclear Structure and Dynamics NSD2019*, May 13–17 2019, Venice, Italy.
5. Invited seminar at the Argonne National Laboratory, December 3 2018, Argonne, IL, US.
6. Contributed talk at the 6th *International Workshop on Compound–Nuclear Reactions and Related Topics*, September 24–28 2018, Berkeley, CA US.
7. Invited talk at the 15th *International Conference on Nuclear Reaction Mechanisms*, June 11–15 2018, Varenna, Italy.
8. Invited talk at the *International Conference on Nuclear Structure And Related Topics (NSRT18)*, June 3–9 2018, Burgas, Bulgaria.
9. Invited seminar at the University of Oslo, May 30 2018, Oslo, Norway.
10. 2017-10-16: *Probing Nuclear Correlations with Direct Reactions*, "Conference on Neutrino and Nuclear Physics (CNNP2017)" Catania, Italy.
11. 2017-08-03: *Towards a unified framework for transfer reactions*, "2017 Low Energy Community Meeting" ANL, Argonne, IL, USA.
12. 2017-07-19: *New directions in reaction theory*,"RIBSS Center Retreat", Knoxville, TN, USA.
13. 2017-06-19: *Inclusive Reactions in a 3–Body Model*,"2017 Gordon Research Conference on Nuclear Chemistry", New London, NH, USA.

3.1.3 Experimental and computing proposals

Diego Lonardoni

1. *Quantum Monte Carlo calculations for standard and strange nuclear systems*, proposal for computational resources at NERSC. 10 M CPU-hrs requested for 2020, 6 M CPU-hrs awarded for 2019, 5 M CPU-hrs awarded for 2018, 800 k CPU-hrs awarded for 2017.

2. *The nuclear equation of state in the era of neutron-star mergers*, proposal for 2019/2020 computational resources at LANL (LANL Institutional Computing Program), 30 M CPU-hrs requested in Aug 2019. In collaboration with I. Tews (LANL).

3. *Electroweak response functions from nuclei*, proposal for 2018/2019 computational resources at LANL (LANL Institutional Computing Program), 35 M CPU-hrs awarded in Nov 2018. In collaboration with S. Gandolfi and J. Carlson (LANL).

4. *Electron and neutrino scattering from nuclei*, proposal for 2017/2018 computational resources at LANL (LANL Institutional Computing Program), 30 M CPU-hrs awarded in Nov 2017. In collaboration with S. Gandolfi, J. Carlson, and S. Pastore (LANL).

5. Thomas Jefferson National Accelerator Facility (JLab), experiment E12-15-008, *An isospin dependence study of the* Λ*-N interaction through the high precision spectroscopy of* Λ *hypernuclei with electron beam*, approved by PAC44 in July 2016, scientific rate A, contact person: S. N. Nakamura, Tohoku University, Sendai, Japan.

Saori Pastore

1. 2019 Advanced Scientific Computing Research (ASCR) Leadership Computing Challenge (ALCC)
   Award: computational time on Theta: 0.39 x10^6 Theta-core hours, 40 TB online storage, 150 TB offline storage
   Research Proposal: "Low-energy neutrino-nucleus interactions"
   PI: Saori Pastore
   Award period: 07/2019-07/2020

2. INCITE computational time Sponsor: DOE - Innovative and Novel Computational Impact on Theory and Experiment (INCITE)
   Research Proposal: "Ab-initio Nuclear Structure and Nuclear Reactions"
   PI: Gaute Hagen
   co-PI: Saori Pastore *et al.*
   Award period: 01/01/2019 – 12/31/2019
   Total Award: 4,150,000 node hours on MIRA and Theta at Argonne National Laboratory

Maria Piarulli

1. *Low Energy Neutrino-Nucleus Interactions*, co-author proposal 2019/2020 computational resources ASCR Leadership Computing Challenge (ALCC), awarded for one year with 390,000 Theta node hours at ANL.

2. *Ab-initio Nuclear Structure and Nuclear Reactions*, co-author proposal 2019/2020 INCITE program, awarded for one year with 650,000 Theta node hours and 3,500,000 Mira node hours at ANL.

3.1.4 Organization of meetings

Saori Pastore

- the ECT* Conference "Progress and Challenges in the Theory of Neutrinoless Double Beta Decay", Trento, Italy, July 2019 (personal expenses supported by TA-FRIB funds).
- the Elba Conference 2019 "Lepton Interactions with Nucleons and Nuclei–XV", Elba, Italy, July 2019.
- the Neutrino Theory Network Collaboration Meeting "Nuclear and Particle Theory for Accelerator Neutrino Experiments", Fermi National Laboratory, IL, May 2019.
- the ECT* Conference "Neutrinos and nuclei, challenges and opportunities for nuclear theory", Trento, Italy, May 2019 (personal expenses supported by TA-FRIB funds).
- the "First Nuclear and Particle Theory Meeting", Washington University in St. Louis, MO, March 2019.

Maria Piarulli

- the INT Workshop "Searches for BSM physics with hadrons and nuclei", Seattle, WA, July-August 2020.
- the "2nd Nuclear and Particle Theory Meeting", Washington University in St. Louis, MO, May 2019.
- the Elba Conference 2019 "Lepton Interactions with Nucleons and Nuclei", Elba, Italy, June 2019.
- the "First Nuclear and Particle Theory Meeting", Washington University in St. Louis, MO, March 2019.

3.2 Facilities, equipment and other resources

The FRIB laboratory will contribute to two 1/2-FTE theory fellows, and will provide space, administrative assistance, office computers, software and maintenance. This is addressed in the letter of support of the Laboratory Director. Our space requests include, in addition to the office for the managing director and the office for the administrative assistant, 2 offices to house the FRIB theory fellows stationed at MSU, 2 additional offices for visitors, including bridge faculty, theory fellows at partner institutions and organizers of topical programs. In addition, FRIB will provide meeting space and visitor discussion areas for the participants of topical programs and summer schools.

While the science supported by the FRIB-TA is all FRIB relevant, the impact of the FRIB-TA in low energy nuclear theory is nationwide. It includes partnerships with a large number of institutions. Primary partners are the organizations hosting fellows and bridge faculty (currently ANL, LANL, NCSU and WashU). Furthermore, our collaborative activities include hosting joint programs with the Institute for Nuclear Theory (INT), the Joint Institute for Nuclear Astrophysics Chemical Evolution of the Elements (JINA-CEE) and the Amherst Center for Fundamental Interactions (ACFI). In addition, workshops and collaboration meetings are (or will be) organized with LLNL at the Livermore Valley Open Campus (LVOC/LLNL), the Joint Institute for Nuclear Physics and Astrophysics (JINPA/ORNL), the mid-west theory get-together (MWT/ANL), the LANL T2-Division Nuclear and Particle Physics, Astrophysics and Cosmology (NPAC/LANL), and schools (INT, JINA, NSCL).

High-performance computing is an important component of the cutting-edge research in this field. The ambitious program in computational nuclear physics requires substantial computational resources. Advanced calculations that can resolve the key issues of nuclear physics require leadership computing at the largest scales (capability computing), medium scales (capacity computing), and a software infrastructure to effectively exploit that computing. The theory community involved in the FRIB-TA has aggressively pursued these resources and thereby received substantial allocations on leadership-class facilities such as those under DOE's INCITE and NERSC programs, and programs within the NSF (TeraGrid, NICS), and NNSA. For capacity computing needs at the FRIB-TA, the MSU Institute of Cyber Enable Research (iCER) provides a variety of computational resources. iCER has a number of domain specialists that can assist with HPC users needs.

3.3 Data management plan

Data generated by the scientific activities of the FRIB-TA (associated with fellows and bridge faculty/staff) will be preserved on file-servers and computational facilities already available at the host institutions. Such data will include input, as well as output data from the computations and simulations performed, both of which will be kept and backed up automatically using existing hardware infrastructure. The combination of securely storing both input and output data, will ensure validation of the results at a later time. When data from research projects is published, the data will be made available in an open, machine-readable, and digitally accessible manner to the public by using journals or other means that support such information transfer. Detailed underlying digital research data will be available to the public based on a request to the FRIB-TA managing director. The retention time for sharing and preserving the data generated by the research activity is a minimum of 3 years after the data is officially published.

The FRIB-TA data management will follow law, policies, and procedures concerning confidentiality, personal privacy, Personally Identifiable Information, and U.S. national, homeland, and economic security. It will recognize proprietary interests, business confidential information, and intellectual property rights and avoid significant negative impact on innovation, and U.S. competitiveness, and otherwise be consistent with all applicable laws, regulations, and DOE orders and policies.

3.4 List of principal collaborators for the last four years

Filomena Nunes:
Pierre Capel (Univ. Libre Bruxelles), Pawel Danielewicz (Michigan State), Arnas Deltuva (CFNUL, Lisbon), Wim Dickhoff (Washington University), Charotte Elster (Ohio University), Vasily Eremenko (Ohio University), Jutta Escher (LLNL), Linda Hlophe (Ohio University), Ronald Johnson (Univ. Surrey), Garrett King (Washington University), Amy Lovell (LANL), Witek Nazarewicz (MSU), Leo Neufcourt (MSU, Andreas Nogga (Julich), Gregory Potel (Michigan State), Jimmy Rotureau (Michigan State), Luke Titus (Michigan State), Ian Thompson (Livermore).

Dean Lee:
Jose Manuel Alarcn (Universidad Complutense de Madrid), Andreas Ekstrm (University of Gothenbur), Martin Freer (University of Birmingham), Hans-Werner Hammer (Technical University Darmstadt), Kai Hebeler (Technical University Darmstadt), Hisashi Horiuchi (Osaka University), Yoshiko Kanada-En?yo (Kyoto University), Sebastian Knig (TU Darmstadt), Timo Lhde (Forschungszentrum Jlich), Thomas Luu (Forschungszentrum Jlich / University of Bonn), Ulf-G. Meiner (University of Bonn / Forschungszentrum Jlich), Gautam Rupak (Mississippi State University), Achim Schwenk (Technical University Darmstadt)

4 Attachments

1. Biosketches for the PIs
2. Current and Pending Support for PIs
3. Support letter from FRIB laboratory director
4. FRIB theory fellow searches - guidelines
5. FRIB-TA bridge program - guidelines
6. FRIB-TA topical programs - guidelines

Filomena Nunes

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Education and Training

Instituto Superior Tecnico, Physics Engineering, 1992
University of Surrey, PhD in Theoretical Nuclear Physics, 1995

Research and Professional Experience

Managing Director of FRIB Theory Alliance (2015 -)
Full Professor, Department of Physics and Astronomy and NSCL, MSU (2013 -)
Head of Department of Theoretical Nuclear Science at NSCL (2010 – 2016)
Associate Professor, Department of Physics and Astronomy and NSCL, MSU (2009 – 2013)
Assistant Professor, Department of Physics and Astronomy and NSCL, MSU (2003 – 2009)
Assistant Professor, Physics Department, Instituto Superior Tecnico (IST) (1999 – 2004)
Associate Professor, Universidade Fernando Pessoa, Portugal (1998 – 2003)
Research fellow, CENTRA (Centre for Astrophysics), IST, Portugal (1996 – 1998)
Research fellow, University of Surrey, England (1995 – 1996)

Publications closely related to the proposed project

1. *Direct comparison between Bauesian and Frequentist Uncertainty Quantification in nuclear reactions*, G. King, A. Lovell, L. Neufcourt, F.M. Nunes, Phys. Rev. Lett. 122, 232502 (2019).
2. *Microscopic optical potentials for calcium isotopes,* J. Rotureau, P. Danielewicz, G. Hagen, G.R. Jansen, F.M. Nunes, Phys. Rev. C 97, 064612 (2018).
3. *Deuteron-alpha scattering: separable versus nonseparable Faddeev approach*, L. Hlophe, Jin Lei, Ch. Elster, A. Nogga, F.M. Nunes, D. Jurciukonis and A. Deltuva, Phys. Rev. C 100, 034609 (2019).
4. *Energy dependence of nonlocal optical potentials,* A.E. Lovell, P.-L. Bacq, P. Capel, F.M. Nunes and L. Titus, Phys. Rev. C 96, 051601 (2017)
5. *Transfer reaction code with nonlocal interactions*, L.J. Titus, A. Ross and F.M. Nunes, Comp. Phys. Comm. 207, 499 (2016).

Other selected publications

1. *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, 141101 (2012).
2. *One-neutron halo structure by the ratio method,* P.C. Capel, R.C. Johnson and F.M. Nunes, Phys. Lett. B 705, 112 (2012).
3. *Testing the continuum discretized coupled channel method for deuteron induced reactions,* N.J Upadhyay, F.M. Nunes and A. Deltuva; Phys. Rev. C 85, 054621 (2012).
4. *Adiabatic approximation versus exact Faddeev method for (d,p) and (p,d) reactions, F. M. Nunes and A. Deltuva;* Phys. Rev. C 84, 034607 (2011).
5. *Halo Nucleus ^{11}Be: A Spectroscopic Study via Neutron Transfer, K. T. Schmitt et al.*; Phys. Rev. Lett. 108, 192701 (2012).

Synergistic Activities (selected)

1. National Boards and Committees: Long Range Plan writing group (2014-2015); Nuclear Science Advisory Committee (2014-2017); DNP executive committee (2014-2016); DNP fellowship committee (2017); Training in Advanced Low Energy Nuclear Theory (TALENT) Board member (2015-2021); FRIB users executive committee (2014-2017); FRIB-theory executive committee (2010-2014); FUSTIPEN Board member (2013-); INT National advisory committee (2010-2012).
2. Organize schools/workshops: *FRIB Theory Alliance Inaugural Meeting* (MSU, March/April 2015), *TALENT course, theory for exploring nuclear reaction experiments*, GANIL, July 2013; *Reactions and nuclear properties* (ECT*, Italy 2010); *Interfacing structure and reactions at the centre of the atom* (Queenstown, New Zealand, November 2008); *Women and minorities in science lecture series* at the NSCL (2007-2009); *Direct reactions for exotic beams*, (East Lansing, July 2005).
3. Service to the scientific community: review panels for NSF and DOE; associate editor to Physical Review Letters (2007-2010) and Europhys. J. A (2013-); grant reviewer for NSF, DOE, STFC(UK), and NSERC (Canada), peer reviewer for Physical Review, Nuclear Physics, Europhysics and Journal of Physics.
4. Assisting researchers with *Fresco* (general reaction code) and FaCE (three body Faddeev with core excitation code) that are available for download on the web.

Identification of Potential Conflicts of Interest or Bias in Selection of Reviewers

Graduate and Postdoc Advisors:
Ron Johnson (Univ. Surrey), Ian Thompson (LLNL, Livermore), Raquel Crespo (IST-Lisbon).

Sponsored Graduate students and Postgraduate-Scholar:
Students: Ivan Brida, Jun Hong, Ngoc Nguyen, Luke Titus, Amy Lovell, Terri Poxon-Pearson, Alaina Ross, Michael Quinonez, Nick Cariello.

Postgraduate scholars: Pierre Capel, Antonio Moro, Muslema Pervin, Neil Summers, Neelam Upadhyay, Gregory Potel, Jimmy Rotureau, Linda Hlophe, Weichuan Li.

<u>DEAN LEE</u>

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Education and Training

Harvard University, Cambridge, MA	Physics	A.B.	1988-1992
Harvard University, Cambridge, MA	Physics	Ph.D.	1992-1998

Research and Professional Experience

Professor	FRIB, Michigan State University	2017-present
Professor	North Carolina State University	2012-2017
Associate Professor	North Carolina State University	2007-2012
Assistant Professor	North Carolina State University	2001-2007
Postdoctoral Researcher	University of Massachusetts Amherst	1998-2001

Publications closely related to the proposed project

1. B.-N. Lu, N. Li, S. Elhatisari, D. Lee, E. Epelbaum, U.-G. Meißner, "Essential elements for nuclear binding", Physics Letters **B** 797, 134863 (2019).
2. D. Frame, R. He, I. Ipsen, Da. Lee, De. Lee, E. Rrapaj, "Eigenvector continuation with subspace learning", Phys. Rev. Lett. **121** 032501 (2018).
3. S. Elhatisari, E. Epelbaum, H. Krebs, T. A. Lähde, D. Lee, N. Li, B.-N. Lu, U.-G. Meißner, G. Rupak, "*Ab initio* calculations of the isotopic dependence of nuclear clustering," Phys. Rev. Lett. **119**, 222505 (2017).
4. S. Elhatisari, N. Li, A. Rokash, J. M. Alarcon, D. Du, N. Klein, B.-N. Lu, U.-G. Meißner, E. Epelbaum, H. Krebs, T. A. Lähde, D. Lee, G. Rupak, "Nuclear binding near a quantum phase transition," Phys. Rev. Lett. **117**, 132501 (2016).
5. S. Elhatisari, D. Lee, G. Rupak, E. Epelbaum, H. Krebs, T. A. Lähde, T. Luu and U.-G. Meißner, "*Ab initio* alpha-alpha scattering," Nature **528**, 111 (2015).

Other selected publications

1. M. Freer, H. Horiuchi, Y. Kanada-En'yo, D. Lee, U.-G. Meißner, "Microscopic Clustering in Light Nuclei," Rev. Mod. Phys. **90**, 035004 (2018).
2. E. Epelbaum, H. Krebs, T. A. Lähde, D. Lee, U.-G. Meißner and G. Rupak, "*Ab Initio* Calculation of the Spectrum and Structure of ^{16}O," Phys. Rev. Lett. **112**, 102501 (2014).
3. G. Rupak and D. Lee, "Radiative capture reactions in lattice effective field theory," Phys. Rev. Lett. **111**, no. 3, 032502 (2013).

4. E. Epelbaum, H. Krebs, T. A. Lähde, D. Lee and U.-G. Meißner, "Viability of Carbon-Based Life as a Function of the Light Quark Mass," Phys. Rev. Lett. **110**, 112502 (2013).
5. E. Epelbaum, H. Krebs, T. A. Lähde, D. Lee and U.-G. Meißner, "Structure and rotations of the Hoyle state," Phys. Rev. Lett. **109**, 252501 (2012).

Synergistic Activities

1. Executive Boards and Committees: Vice Chair/Chair-Elect/Chair/Past-Chair APS Topical Group on Few Body Systems and Multiparticle Dynamics (2016-present); INT National Advisory Board (2019-present); FRIB Theory Alliance Executive Committee (2018-present); Executive Committee of APS Topical Group on Few Body Systems and Multiparticle Dynamics (2011-2014).
2. Organizational Activities: Co-organizer of TALENT School "From Quarks to Gluons to Nuclear Forces and Structure" at ECT* (2019); Co-organizer of Proton-Emitting Nuclei Conference at FRIB (2019); Scientific advisor to the Quantum Information Science Workshop at Michigan State University (2018); Co-organizer of Mainz Institute for Theoretical Physics Workshop "Progress in Diagrammatic Monte Carlo Methods for Quantum Field Theories in Particle-, Nuclear-, and Condensed Matter Physics" (2017); Co-organizer of INT Program "Toward Predictive Theories of Nuclear Reactions Across the Isotopic Chart" (2017); Co-organizer of Kavli Institute for Theoretical Physics Program "Frontiers in Nuclear Physics" (2016); Co-organizer of TALENT School on "Nuclear Quantum Monte Carlo Methods" at NC State University (2016); Co-organizer of ECT* Workshop on "Advances in Diagrammatic Monte Carlo for Quantum Field Theory Calculations in Nuclear, Particle, and Condensed Matter Physics" (2015).
3. Service: Manager of the North American Nuclear Theory Jobs Webpage (2012-2017).
4. Outreach: Founder and organizer of the Advanced Studies Gateway at FRIB (2018-present)

Identification of Potential Conflicts of Interest or Bias in Selection of Reviewers

Graduate and Postdoctoral Advisors
Howard Georgi (Harvard University), John Donoghue (University of Massachusetts Amherst), Eugene Golowich (University of Massachusetts Amherst), Barry Holstein (University of Massachusetts Amherst)

Graduate and Postdoctoral Advisees
Joey Bonitati (Michigan State University), Serdar Elhatisari (Karamanoglu Mehmetbey University), Dillon Frame (Forschungszentrum Jülich), Gabriel Given (Michigan State University), Rongzheng He (Michigan State University), Caleb Hicks (Michigan State University), Ning Li (Michigan State University), Bing-Nan Lu (Michigan State University), Avik Sarkar (Michigan State University), Richard Thomson (Alcatel), Jacob Watkins (Michigan State University)

Current and Pending Support

Filomena Nunes

Current

Sponsor:	Department of Energy
Award Number:	DE-SC0013617
Project/Proposal Title:	FRIB Theory Alliance
Total Award Amount:	$2,015,000
Person-Months:	0.12 summer
Total Award Period Covered:	6/1/15 – 5/31/20
Location of Project:	Michigan State University
Brief Description of Project:	Theory Initiative to enhance FRIB related theory.
Overlap with Proposed Research:	none, this proposal is a renewal of this award

Sponsor:	National Science Foundation
Award Number:	PHY-1811815
Project/Proposal Title:	Direct Nuclear Reactions: Theory and Uncertainties
Total Award Amount:	$300,000
Person-Months:	2 summer
Total Award Period Covered:	8/15/18 – 7/31/21
Location of Project:	Michigan State University
Brief Description of Project:	advances in theory for direct reactions with a particular focus on uncertainty quantification.
Overlap with Proposed Research:	none

Sponsor:	Los Alamos National Laboratory
Award Number:	Subcontract No. 332574
Project/Proposal Title:	Facility for Rare Isotope Beam (FRIB) Theory Fellow
Total Award Amount:	$307,109
Person-Months:	0.1 summer
Total Award Period Covered:	8/1/15 – 7/31/20
Location of Project:	Los Alamos National Laboratory
Brief Description of Project:	support for FRIB theory fellow
Overlap with Proposed Research:	This award provides support for 48% of FRIB-TA Diego Lonardoni's effort that is not covered by the FRIB-TA, as described in the budget justification.

Sponsor:	Argonne National Laboratory
Award Number:	Subcontract No. 9F-60106
Project/Proposal Title:	National FRIB theory fellow at Argonne National Laboratory
Total Award Amount:	$148,241

Person-Months:	0.1 summer
Total Award Period Covered:	3/1/19 – 2/28/21
Location of Project:	Argonne National Laboratory
Brief Description of Project:	support for FRIB theory fellow
Overlap with Proposed Research:	This award provides support for 48% of FRIB-TA Kevin Fossez’s effort that is not covered by the FRIB-TA, as described in the budget justification.

Pending

Sponsor:	Department of Energy
Project/Proposal Title:	FRIB Theory Alliance
Total Award Amount:	$6,406,000
Person-Months:	0.12 summer
Total Award Period Covered:	6/1/20 – 5/31/25
Location of Project:	Michigan State University
Brief Description of Project:	Theory Initiative to enhance FRIB related theory.
Overlap with Proposed Research:	this is the proposed project

Sponsor:	National Science Foundation
Project/Proposal Title:	Frameworks: Bayesian Analysis for Nuclei in Diverse Theories
Total Award Amount:	$1,205,350
Person-Months:	1 summer
Total Award Period Covered:	6/1/20 – 5/31/25
Location of Project:	Michigan State University
Brief Description of Project:	multi institutional proposal to develop a CI framework for Bayesian Analysis for Nuclei
Overlap with Proposed Research:	none

Current and Pending Support

Dean Lee

Current

Sponsor:	Department of Energy
Award Number:	DE-SC0018638
Project/Proposal Title:	Nuclear Theory from First Principles to Forefront Experiments
Total Award Amount:	$210,000
Person-Months:	0.12 summer
Total Award Period Covered:	5/15/18 – 5/14/20
Location of Project:	Michigan State University
Brief Description of Project:	Calculations of nuclear structure and reactions from first principles calculations.
Overlap with Proposed Research:	No overlap

Pending

Sponsor:	Department of Energy
Project/Proposal Title:	FRIB Theory Alliance
Total Award Amount:	$6,406,000
Person-Months:	0.12 summer
Total Award Period Covered:	6/1/20 – 5/31/25
Location of Project:	Michigan State University
Brief Description of Project:	Theory Initiative to enhance FRIB related theory.
Overlap with Proposed Research:	this is the proposed project

Sponsor:	MSU (SPG)
Project/Proposal Title:	Quantum Computing for the Nuclear Many-Body Problem
Total Award Amount:	$280,000
Person-Months:	0.12 summer
Total Award Period Covered:	7/1/20 – 6/30/22
Location of Project:	Michigan State University
Brief Description of Project:	MSU Collaboration to design algorithms to solve the nuclear many-body problem using quantum computers.
Overlap with Proposed Research:	No overlap

Sponsor:	Department of Energy
Project/Proposal Title:	From Quarks to Stars; A Quantum Computing Approach to the Nuclear Many-Body Problem
Total Award Amount:	$1,000,000
Person-Months:	0.12 summer
Total Award Period Covered:	10/1/19 – 9/30/22
Location of Project:	Michigan State University

Brief Description of Project:	Collaboration involving MSU and LANL to design algorithms to solve the nuclear many-body problem using quantum computers and training students and postdocs.
Overlap with Proposed Research:	No overlap

MICHIGAN STATE
UNIVERSITY

October 14, 2019

Dr. George Fai
Office of Nuclear Physics-Nuclear Theory
SC-26.1/Germantown Building
U.S. Department of Energy
1000 Independence Ave, SW
Washington, D.C. 20585-1290

Dear George,

I am writing this letter in strong support of the renewal proposal for the FRIB Theory Alliance. The FRIB Theory Alliance plays an important role in delivering FRIB's discovery potential and I am delighted as to how well the low-energy nuclear science theorists have organized themselves.

If the proposal receives the requested funding from your office, the FRIB Laboratory will commit to the following for the three year duration:

1. Support the two ½ FRIB Theory positions
2. Appropriate office space for the two Theory Fellows
3. Appropriate visitor office space for the off-site fellows and bridge faculty to be able to work at FRIB during their stay
4. Meeting space for FRIB-TA activities including summer schools and topical programs, and shared office space for the organizers of the events

The continuing establishment of world-leading effort in connection to FRIB is wise and of seminal importance. We all recognize that funding is extremely tight and that is will take some time to build up the high-quality program we all envision. The proposal delineates a viable and realistic path forward, and I hope that it can be funded at the needed level. The combination of cutting-edge technical capabilities and innovative theoretical breakthroughs will ensure great scientific discoveries.

Sincerely,

Thomas Glasmacher
Laboratory Director

FRIB
Thomas Glasmacher, PhD
University Distinguished Professor and
Laboratory Director

Facility for Rare Isotope Beams

640 S. Shaw Lane
East Lansing, MI 48824

517-908-7710
glasmacher@frib.msu.edu

FRIB Theory Fellows
Guidance for Searches

April 19, 2018

This document provides guidelines for the FRIB theory fellow search procedure.

Description of the theory fellow position

FRIB theory fellows are highly selected individuals who develop high-caliber theoretical research relevant to rare isotope science. Fellows have initial appointments for 2 years, with possible extensions up to a total of 5 years. Fellows can be hosted by MSU or by a partner institution, however, in all cases, they remain 100% MSU employees, and as such enjoy full benefits, including a comprehensive health care plan and a basic retirement plan (www.hr.msu.edu/benefits/summaries.htm). Fellows also administer their own separate travel budget. Fellows are expected to find, within 5 years, a permanent position in nuclear theory. As such, it is important that they develop their own research program and have exposure to university/laboratory administration. These individuals have the freedom to work on problems at the forefront of low energy nuclear physics that connect to the Facility for Rare Isotope Beams (FRIB), either in collaboration with the hosting theory group or leading theorists at other institutions. FRIB fellows have no teaching obligations, but they may participate in committees and graduate student training.

Description of partner institution

Prior to the advertisement for the fellow position, there will be a call for institutions that are interested in partnering with the fellow program. These institutions will contribute with 50% of the funding for the fellow (salary and travel) through a sub-recipient agreement with MSU (subject to MSU off-campus overhead), matched by the FRIB theory alliance 50% contribution. The institution should also identify a senior researcher that will act as the local host for the fellow and that will be the liaison with the FRIB theory alliance in all activities regarding the respective fellow.

No partner institution may host more than one fellow concurrently. A partner institution may not host a fellow if the selected fellow has been in the employ of the partner institution or otherwise stationed at the partner institution for a period longer than two calendar years prior to either the date that the fellow position for the search is posted or the date that the candidate would begin their term as the FRIB Theory fellow. In addition, for partner institutions that have hosted an FRIB Theory Fellow, those partner institutions are excluded from participating as a partner during the next FRIB Theory Fellow search following the termination of their hosted fellow.

Expectation for the fellow

Fellows hosted by MSU are expected to have active involvement in the laboratory and theory group activities. They have their own office, are encouraged to participate in the guidance of young researchers (including graduate students), participate in theory faculty meetings, and are encouraged to organize the theory seminars series. Partner institutions may adjust the arrangements of the theory fellow depending on the conditions of the local group, but need to make the fellows distinct from postdocs, and closer to faculty/staff.

Regardless of their home institution, fellows are expected to: i) spend a significant amount of time at FRIB, ii) contribute to the scientific program of FRIB, and iii) be spokespersons for FRIB theory nationally and internationally.

Calendar for the search

A. The FRIB TA managing director consults with the FRIB TA board to assess if funding permits an FRIB Theory Fellow Search in the calendar year.
B. The FRIB TA managing director notifies the search committee of an upcoming search, who then establish the timeline of the search with guidance from items C-L below.
C. Call for partnership is sent out in May and partners are identified by end of June.
D. The advertisement for fellow position is posted in July and includes explicit mention of possible partners. The deadline for applications is 1st week in September.
E. Reminders are sent out 3 weeks and 1 week prior to deadline.
F. The first list is made by 2nd week of September and reference letters are requested by the chair immediately thereafter. Letter writers are provided one month to respond to the request.
G. The search committee makes the shortlist for interviews in early October and interviews are arranged.
H. The interviews take place in November/December.
I. The recommendations of the search committee are transmitted to the FRIB TA board by early December, with copies to the partner institutions.
J. If FRIB TA accept recommendation, FRIB TA managing director informs FRIB laboratory director, DOE program officer and partner institutions, and negotiates an offer between the top candidate and partner institution in December
K. The results of the search are communicated to FRIB TA membership once the offer is accepted.

Search Committee composition

The search committee will be composed of a subset of members of the FRIB TA assigned by the FRIB TA board (up to five voting members who do not represent a partner institution, except for fellows hosted by MSU). For searches involving a partner institution, one representative from each partner institution will augment the search committee. When MSU is the host, the committee will be augmented by a member appointed by MSU. The FRIB TA board will select the chair of the search committee. Search committee members representing a partner institution are full members of the search committee during the selection process and during the interviews. After the interviews, search committee members representing a partner institution may give their assessment of each candidate to the search committee, but are excluded from the final deliberations and the selection process. Since there is no apparent conflict of interest in the case of an MSU host, the full search committee will participate in the full selection process.

Interviews

The interviews take place at FRIB. Candidates are expected to appear for a one day interview comprised of a seminar, a one-hour meeting with the search committee, and to have one-on-one meetings with various local faculty (experiment and theory). The seminar will be broadcast to the FRIB TA membership. The chair of the search committee is expected to be physically present at MSU during the interviews, but other search committee members may join remotely. For the meeting with the search committee, all candidates will need to respond to a common set of questions, in addition to impromptu discussions.

Following the interviews, the chair of the search committee collects feedback on the candidates and shares with all members of the search committee.

Recommendations by search committee

Following the interviews, the search committee will meet to discuss the candidates and prepare a ranked list. The chair of the search committee will prepare a recommendation to the FRIB TA director that includes the ranked list of the candidates interviewed and considered above threshold for the position, as well as a brief justification for the ranking. The FRIB TA managing director will present the recommendations of the search committee to the FRIB TA board, who will then vote to accept or reject the recommendations of the search committee. If the recommendations of the search committee are not approved by the FRIB TA board, the search committee will reconvene to reconsider the recommendations in concert with the FRIB TA board.

Hiring procedure

Once the FRIB TA board approves the recommendations of the search committee, the FRIB TA managing director informs the FRIB laboratory director and DOE. The FRIB TA managing director then informs the partner institutions of the ranked list and solicits the interest of the partner institutions to host each ranked fellow candidate and confirm their commitments to act as host for any of the candidates. The FRIB TA managing directory then notifies the top-ranked candidate and negotiates between the fellow and partner institutions until mutual acceptance is achieved and a formal offer can be made. In the event that the selected candidate declines the position, the FRIB TA managing director will proceed through the ranked list of acceptable candidates until a formal offer can be made. As an issue of fairness to the participating partner institutions, the FRIB TA managing director should adhere to the commitments obtained from the partner institutions prior to the issuance of the first offer. At any time, partner institutions and candidates may withdraw from the search by notifying the FRIB TA managing director in writing. Once the offer has been accepted and the hire is formalized, the FRIB Theory Fellow is announced to the membership.

FRIB Theory Bridge Program
Guidance for Applications

June 13, 2018

This document provides guidelines for those Universities planning to apply for a bridge faculty position with the FRIB Theory Alliance. The FRIB bridge program contemplates also the existence of staff bridge positions at National Laboratories. However, there are a number of differences in the application process for National Laboratories and, thus, we attach an addendum to address those differences in detail.

Motivation for the FRIB bridge program

The impressive list of theoretical developments needed to accomplish the broad scope of science at the Facility for Rare Isotope Beams (FRIB) requires an increase in Theory Principal Investigators, especially in critical areas identified in the FRIB Theory Alliance (FRIB-TA) proposal. This is the motivation for the FRIB Bridge Program: to enhance the opportunities of Theory Faculty hires at Universities or Theory Staff hires at National Laboratories. These positions will be modeled after those created by the RIKEN/BNL program at RHIC, with 50% of the cost being covered by DOE through the FRIB-TA and 50% by the home institution, over an initial period of up to 6 years or until the faculty member is granted tenure.

Description of the bridge faculty position

Bridge faculty are outstanding young theorists who develop exceptional theoretical research relevant to rare isotope science. Bridge faculty are 100% employees of their home institution, with all the associated benefits. Bridge faculty are expected to build a research group, attract federal funding and have teaching duties, just as all other faculty at their home institution. In addition, bridge faculty are expected to contribute significantly to the scientific program at FRIB and be spokespersons for FRIB theory, nationally and internationally. They must spend a significant amount of time at FRIB and, for this reason, teaching relief could be negotiated on a case-by-case basis.

Selection Process

The FRIB Theory Bridge committee is responsible for seeking institutional partners for the bridge program and making the selection of the institution that will be the home of each bridge position. The FRIB Theory Bridge committee is appointed by the FRIB-TA Board. If several institutions are selected, the committee may attempt to stagger them in time as appropriate.

In selecting physics departments to carry out the bridge faculty search, the main selection criterion will be that the science scope of the search is aligned with FRIB Science. The committee will select physics departments at research universities using additional criteria including the intellectual environment of the university, the diversity of its physics research program, the institutional record in mentoring young faculty and the access to good students.

Guidelines for applications

Departments interested in competing for a bridge position will be asked to prepare a brief proposal. The proposal should contain:

i) A letter from the dean of the college, with the commitment of a 50% salary match in the event that the institution is selected and a hire is made.

ii) A letter from the physics department chair, explaining how this new hire will fit into the long-term vision of the department and indicating the time-scale for advertisement, interviews and hire, in the event that this institution is selected.

iii) A letter from the main point of contact, providing background information on the quality of the graduate program and the nuclear physics research program if one exists. Examples of recently graduated students in nuclear physics should be given, if applicable. Information on junior faculty hiring in the department over the last decade, as well as the support provided by the department to these junior faculty needs to also be documented (see iv).

iv) Supporting information as described in the template attached to the end of this document.

Memorandum of understanding

Once a partner is identified, the FRIB-TA managing director works closely with the chair of the home physics department to develop the MoU that establishes the conditions of the appointment and the various contributions involved (in which the FRIB-TA provides 50% of compensation – salary, benefits and travel). This document is developed before the search takes place.

Recommendation

The home department is responsible for conducting the search process. The short list of interviewees should be communicated to the FRIB-TA through the chair of the bridge program committee. The selected candidate needs to be approved by the FRIB-TA Board. When and if this happens, the FRIB-TA managing director informs the FRIB laboratory director. The home department should inform the chair of the bridge program committee as soon as the selected candidate accepts the position so that it can be promptly announced to the FRIB-TA membership through the FRIB-TA webpage.

Guidance on the timeline for bridge position process

A. Chair of the FRIB Theory Bridge Committee sends out a call for bridge partners in mid-June, with a six week deadline for applications.
B. In early August, the FRIB Theory Bridge Committee studies the applications, rank orders them and provides a recommendation to the FRIB-TA Board.
C. By mid-August, the FRIB-TA Board decides if and how to implement the recommendations of the FRIB Theory Bridge Committee.

D. During the last part of August, the FRIB-TA managing director develops the MoU with the selected home institution.
E. The home institution conducts the search in the Fall: Advertisement is sent out in September, candidates are interviewed early in the next calendar year and a candidate is selected soon after that.
F. Information on the selected candidate is communicated to the FRIB-TA Board, and the Board approves the candidate.
G. The home institution makes the offer to the selected candidate with the possibility of starting in the summer.
H. Immediately after the candidate accepts, the outcome is communicated to FRIB-TA Board, the FRIB laboratory director and the FRIB-TA membership.

Addendum for National Laboratories

October 4, 2016

Due to the important differences in the organization and funding of National Laboratories, an alternative procedure has been developed that enables these laboratories to participate in the FRIB Theory Bridge Program. First, the interested laboratory needs to discuss with the DOE, in order to ensure that the DOE intends to provide long-term laboratory funding after the bridge is complete.

Once there is a good understanding between the National Laboratory and the DOE, a proposal by the National Laboratory is submitted to the FRIB Theory Bridge committee. The proposal should contain the same items discussed in Section "Guidelines for applications" of this document, with the department chair and the dean of the college replaced by the corresponding authority at the National Laboratory.

If a National Laboratory is selected, MSU and this corresponding laboratory develop a MoU establishing that there will be a contribution from the FRIB Theory Alliance to the National Laboratory of up to a total of $500k over the entire bridge period, to support the FRIB theory bridge staff. The National Laboratory sets up the hiring process. If appropriate, the bridge proponents could seek to engage the corresponding Laboratory Fellowship committee in the event that such a fellowship application falls within the conditions and selection criteria outlined by the Laboratory involved. This has the potential of providing additional funds for the process. The laboratory discusses with the FRIB-TA board the parameters for the candidate search and then proceeds with the search.

As for universities, the laboratory must communicate the short list of interviewees to the FRIB-TA and, once the selected candidate is identified, she/he needs to be approved by the FRIB-TA Board. The final funding negotiations will take into consideration potential external funding and will commence among the laboratory, DOE, and MSU as soon as the candidate has been approved.

Supporting information for the FRIB-TA Bridge Program Application

This document is a compilation of relevant data concerning the potential home institution for an FRIB Theory Alliance Bridge position. Note that not having entries in nuclear theory does not exclude an application.

Departmental hiring

1. **Faculty hires.** Provide a table with the list of the Faculty members hired in the last decade by your Department, including the information described in Table 1. This list should contain all Faculty hires from the various areas of physics, and those Faculty members that have since left the unit (for those please include the year of departure).

Faculty	Yr Hired (departed)	Yr Tenure	Research Area	Yrs Funded	Mentor	#Students Total (PhD)(MS)
John Smith	1900(1920)	1906	HEP	1901-1920	Peter Adams	10(5)(5)

Table 1: Table with Faculty Hires in the last decade at the Department of Physics.

2. **Recent start-up packages.** Please describe the start-up packages offered to recent hires in your Department and the start-up package you expect to provide to the bridge faculty hire.

Current students in nuclear physics

3. **Student information.** Please provide a list of current students working in nuclear physics (including experimental physics) at your institution. Include their names, the name of the advisor, the starting year, and the research topic.

Prior nuclear theory activity (if any)

4. **PhDs awarded in nuclear theory.** Please provide a list with all the students that received a PhD from your institution during the last decade. Include name, year of PhD completion, Advisor and Current Position.

5. **Postdoctoral researchers in nuclear theory.** Please provide a complete list of the postdoctoral researchers who have worked in nuclear theory during the last decade at your institution. Provide the name, duration of the postdoctoral contract as well as her/his current position/location. Please include their primary research area.

6. **Nuclear theory visitors.** Please provide a list of visitors working in nuclear theory, that visited your department during the past two years, including sabbatical visits. Please provide their names, year, duration of stay, as well as their permanent affiliation.

FRIB Theory Alliance
Guidance for proposing and organizing Topical Programs

September 1, 2019

Topical programs are meant to address particular issues relevant for the science of the Facility for Rare Isotope Beams. Each program brings together up to 30 theorists and experimentalists, with expertise relevant to the topic, for a period of up to three weeks, and produces a specific deliverable to the community, which can be in the form of a white paper, a review paper, a new code, benchmark calculations, etc. Organizers of topical programs should see themselves as conductors of an orchestra, where they get to pick the musicians and the music. The FRIB-TA provides significant autonomy and flexibility to the organizers, who in turn strive for the best scientific outcome for FRIB.

1. Preparing a Topical Program Proposal

The proposal for topical programs should not exceed 3 pages and should contain a description of the scientific project, covering the scientific motivation, the connection to FRIB (for example through the relevance to particular experiments), and specific deliverables. It should also include the names and affiliations of critical experts who are needed for the effort to be successful and who intend to participate in the program for a significant fraction of time.

1.1 Outcome, Scientific program, Participants

There are essentially three elements for a successful topical program: a well-defined goal, a strong scientific program and a relevant group of participants. Whatever the area of focus for the topical program, it is critical that the organizers have a well-determined outcome in mind. Once the deliverable is set, the organizers should identify steps (themes) needed to achieve the goal, as well as the best researchers to address those steps (as well as potential backup participants). Breaking down the general topical into themes is necessary to construct a strong scientific program. Topical programs can bring together different communities to address the same issue from different perspectives, or just bring expertise on the same topic for benchmarking or to reach agreement on future directions. Topical programs may also need a few days dedicated to input from a larger group, more along the lines of a standard short workshop.

Participants in the topical program are determined by invitation, and therefore local participants should be included in the list generated by the organizers. In general, experimentalists should also be included in the list, as they provide an important realistic perspective to the problems being addressed.

Based on the themes, the organizers generate an outline for the scientific program, particularly identifying which themes are covered on which days. The expertise, required to address each theme, gives rise to a list of participants. From the outline of the scientific program, it becomes clear when participants need to be present.

1.2 Specific information to include in the proposal

Please include the following:

- Organizers: name, institution and email (identify the lead organizer).
- Scientific case for the topical program, including a) the impact of the program to FRIB and to the field of low energy nuclear physics and b) why the program is timely
- Goal of the program and the specific deliverables
- Duration and preferred dates: how many weeks are expected for the program and what is the preferred time to run it (usually within the period of May-August)
- Embedded workshop: if there are plans to run a short workshop during the topical program, provide the reasoning why it is necessary and the expected duration.
- A list of potential participants that intend to participate in case the program is selected (name and institution)

2. Organizing a Topical Program

If your program is selected, it is important to determine the dates for the program by discussing with the organizers and the FRIB-TA managing director. Following that, the organizers need to work on: the budget, the invitations to participants, and the scientific program.

2.1 Budget

Organizers work with Gillian Olson to determine the budget. Gillian prepares a default budget for the event that can be adjusted depending on the specific needs. The standard total budget for a topical program is around $40k provided by the FRIB-TA grant to cover local expenses. Our standard topical programs do not include a registration fee. The organizers should provide to Gillian an estimate of how many people will participate each week, breaking down the total into senior researchers versus student/postdoc. Typically the FRIB-TA covers accommodation and food. For lodging, participants are placed in a nearby hotel (for senior researchers – typical cost $116/night) or a dormitory room on campus (for postdoc and students – typical cost $48/night). The food includes AM+PM coffee breaks (~$30/participant/week), breakfast (usually provided by the hotel, $8 breakfast tickets to the dining hall provided for rooms on campus), lunches (lunch tickets are provided for the dining halls, except for catered lunches at FRIB; ~$60/participant/week). One day a week, there is a social dinner at a pre-arranged restaurant (~$23/participant). For all other days, participants host their own dinners but may be reimbursed later. Note that the typical budget will provide for approximately 24 senior participants who stay for a full two-week program as described above. Larger numbers of participants can be accommodated by, for example, adjusting the composition (student/postdoc/senior) of the program, varying the typical length of stay, or by requesting senior participants bear some percentage of their local expenses, as is the practice at ECT* and the INT. **The budget should be complete and submitted by mid-January.**

2.2 Participants

Researchers have many commitments in the summer and therefore it is critical to get the invitation out to participants as soon as possible. As soon as the budget is prepared and submitted, organizers send out informal invitations to participants to determine their availability. If they can commit, they should block their schedule for the appropriate time. If not, the organizers contact the backup participants to ensure that all the needed expertise will be present at the event. The list of invitees needs to be shared with Gillian so she can proceed with all communication regarding logistics. As soon as the website is ready, invitees will be asked to register. The information provided upon registration enables Gillian to make all the specific arrangements.

In most topical programs, the work developed in each week builds on the work done the previous week. A key function of the organizers is to secure participation in such a way that there is continuity across the weeks of the program.

Remote participation is possible for those exceptional participants that are being used as consultants to a given topic. Therefore, they only need to be consulted for a short period of time (1-2 hours on a given day). However, a normal participant is expected to be physically at FRIB for the duration of the program because long-term remote participation is known to not be effective and is not supported by FRIB IT.

2.3 Talks and discussions

The dynamics of a topical program can contribute significantly for its success. Every topical program contains standard talks (up to 4 a day, often in the morning) and plenty of discussion/working time. Note that the time spent in discussions is considered to be more important than the time spent listening to talks, as it is during that active time that participants move toward the goal and work on the deliverable. The talks should serve only to set the context and the tone for the discussions. Unfortunately, disorganized discussion time can make participants feel that they are wasting their time. Be sure to identify, on a daily basis, key questions to be addressed in the discussion/working time and organize the discussion groups in a manner that is conducive to the desired outcome.

2.4 Space

Topical programs are typically held in FRIB 1221. This room has several projectors and white boards. For the topical programs, the tables in this room are usually arranged in U format to catalyze discussions. In that case, the room accommodates comfortably 30 people. For the duration of the program, the organizers are provided with office space located next to Gillian’s office. In addition, there are several open areas in the theory hall that are well suited for small group discussions. The organizers should encourage participants of the topical programs to utilize these areas to work on tasks related to the topical program.

2.5 Website

Using information provided in the topical program proposal, Gillian prepares a basic website in indico for the event. Organizers are responsible for the scientific content of the website and are given access in order to be able to edit as necessary. Gillian will include additional information as it becomes available: the scientific program, the list of participants, the talks, etc.

2.6 FRIB access and tour

The FRIB building has limited access and all topical program participants will need to carry a visitor badge to enter the building. Before the badge is provided, participants need to be screened for export control, following federal regulations. It is possible that invitees on the participant list are not allowed access unless accompanied by an authorized person. Gillian will work with the organizers to ensure that such situations are handled in timely and sensitive manner.

All participants are encouraged to take a tour of the Facility. The tour will be an integral part of the program and will expose the FRIB-TA members to the most recent technical developments on the accelerator and additional devices on the floor of the Facility for Rare Isotope Beams.

2.7 Timeline

Topical programs are selected at the beginning of the year and typically run in the summer of the same year. This is a fast timescale compared to other organizations such as the ECT* and the INT. It has the advantage that it provides nimbleness. The challenge for the organizers is to act fast to secure the participation of the relevant researchers.

- Goals and outline for the program – December of prior year
- Organizers informed by FRIB-TA about acceptance – first week of January
- Budget submitted - mid-January
- Invitations sent out mid-January with deadline for response by end of January
- Website for event on-line by start of February
- Invitees are contacted to register - beginning of February
- Registration closes – mid-March
- Preliminary participant list – 1st April
- Preliminary detailed agenda – mid-April
- Finalize participant list – four weeks prior to event
- Finalize agenda – three weeks prior to event
- Summary report of the event - late day of the event
- Deliverable – within 6 months of the end of the program