Year	Name	Institution	Brief Description
2019	Martha Constantinou	Temple University	**“EIC Physics from Lattice QCD”** Quantum Chromodynamics (QCD) is the theory of the strong interaction, which binds quarks and gluons to form a spectrum of hadrons, which includes the pions, kaons, and protons. Lattice QCD (LQCD) is an ideal formulation to study the properties and the immensely rich structure of the hadrons with large- scale numerical simulations. The program focuses on LQCD calculations of non-perturbative quantities that encapsulate the dynamics of quarks and gluons within the pions, kaons, and protons, which is necessary for a deeper understanding of nuclear matter. It addresses open questions, such as the origin of the mass and spin decompositions. Both topics were identified as priority science questions in the recent assessment report of the National Academies of Sciences, Engineering, and Medicine, on a future Electron-Ion Collider (EIC). This program supports the science of the EIC with studies of parton distribution functions (PDFs) and generalized parton distributions (GPDs) using two approaches: via their Mellin moments, and via the so-called quasi-distributions. Specific quantities under investigation are form factors and generalized form factors for the unpolarized, helicity and transversity distribution functions. The calculations are based on cutting edge methods for a set of simulations with the quark masses fixed to their physical value. This eliminates a large number of systematic uncertainties, which is crucial for reliable input to experiments, and for comparison to existing measurements.
2019	Zohreh Davoudi	University of Maryland	**“Analog and Digital Quantum Simulations of Strongly Interacting Theories for Applications in Nuclear Physics”** Classical-computing methods have proven extremely successful in obtaining certain

			properties of strongly interacting systems of hadrons and nuclei. Nonetheless, it is known that a number of grand- challenge problems in nuclear physics remain theoretically intractable. These include investigations into the real-time dynamics of matter after the Big Bang, or after the collision of energetic nuclei in the Relativistic Heavy Ion Collider. These also include studies of the properties of dense systems in nature, such as the possibility of exotic phases of matter in the interior of neutron stars. Recent technological advances in scalable quantum-computing platforms provide an exciting possibility in harnessing quantum entanglement to perform highly-parallelized computations of systems in nuclear physics with a large number of correlated degrees of freedom. The overarching goal of this project is to fill in the gap between our classical and quantum approaches to simulating nuclear phenomena from the microscopic theory, i.e., the Standard Model of particle physics at a finer level, and nuclear effective field theories at a coarser level. With a focus on the question of how to map strongly interacting field theories to a quantum-bit (qubit) description, two avenues of research will be pursued. First, novel schemes for analog simulations of simple lattice gauge theories and effective field theories of nuclei will be developed and simultaneously tested on the world's leading Ion Trap quantum-simulation platforms. Second, similar theories will be studied theoretically, and will be benchmarked on available digital quantum computing devices. The benefits and disadvantages of each approach will be studied and quantum-resource estimates will be provided for reaching certain levels of accuracy in obtaining properties of the systems under investigation. This research, while being only a first step toward the ultimate goal of conquering computationally challenging problems in nuclear physics, will pave the way toward leveraging quantum-computing capabilities for research in nuclear physics.
2019	Francois Foucart	University of New Hampshire	**"Nuclear Astrophysics through Simulations of Neutron Star Mergers Using Monte-Carlo Neutrino Radiation Transport"**

			The merger of two neutron stars is a remarkable laboratory for nuclear astrophysics. By observing merging neutron stars, we improve our understanding of dense nuclear matter, the origin of heavy elements likely produced in merger events (e.g. gold, platinum,…), or even the properties of neutrinos. Studies of neutron star mergers thus complement studies of dense matter and heavy nuclei conducted within DOE laboratories. To reliably extract nuclear physics information from merger observations, however, accurate numerical simulations of these events are necessary. Existing simulations have two critical limitations: their resolution is not sufficient to capture important small scale instabilities in the evolution of magnetic fields, and they only approximately evolve neutrinos, despite their crucial role in determining the outcome of nucleosynthesis in mergers. The first objective of this project is to develop an algorithm that truly evolves the equations governing neutrino transport (using Monte-Carlo methods), a long-standing objective that modern computational resources have finally put within our reach. This algorithm will then be implemented in a next-generation open-source code that can leverage upcoming computing facilities to perform high-resolution simulations of neutron star mergers. The second objective of this research is the inclusion of more detailed nuclear physics in the evolution of the matter ejected by mergers, where heavy elements are synthesized. Finally, the last objective of this project is to use these new methods in simulations that can reliably predict the production of heavy elements in neutron star mergers, as well as the impact of the properties of dense matter on the optical and infrared signals that mergers power, thus increasing the payoff of neutron star merger observations for nuclear physics.
2019	Or Hen	Massachusetts Institute of Technology	**“Study of Short-Range Correlations in Nuclei Using Electro-induced Nucleon-knockout Reactions at High Momentum-Transfer”**

			Short-Ranged Correlations (SRC) are pairs of strongly interacting nucleons whose separation is comparable to their radii. Their overlapping quark distributions and strong interaction makes SRC pairs an ideal system to study phenomena that bridge among low-energy nuclear structure, high-density nuclear matter, and high-energy quark distributions. As such, their study has significant consequences for strong- interaction physics, hadronic structure and nuclear astrophysics. This proposal will study SRCs by measuring exclusive high-energy electron scattering reactions at the Thomas Jefferson National Accelerator Facility. High-energy electrons will be used to breakup SRC clusters (pairs and triplets) in various atomic nuclei. Using the CLAS12 spectrometer, the nucleons emitted in the breakup process will be detected and the initial properties of the SRC cluster will be reconstructed. This will allow probing the two- and three-nucleon interaction at short-distances at densities relevant for neutron stars, to test ab-initio many-body nuclear calculations, and to explore the relation between description of atomic nuclei using nucleons and using quarks and gluons.
2019	Ari Palczewski	Thomas Jefferson National Accelerator Facility	**“Developing the Surface Engineering Basis for Next-Generation SRF Accelerator”** Since 2012, expectations of the potential performance of niobium for superconducting radiofrequency (SRF) accelerator applications (SRF cavities) have been dramatically evolving. The discovery that tailored interstitial doping of the radio frequency (RF) surface yields dramatically reduced losses has been transformative (similar to initial advancements in silicon manufacturing). In the case of high-temperature nitrogen doping (HTND); low pressure (~20 mTorr) nitrogen is added at 800°C after a hydrogen de-gassing phase in a vacuum furnace. The nitrogen addition creates a lossy nitride crystal phase on the surface (removed

			through electro-chemistry) and a performance-enhanced nitrided niobium phase below (revealed after electro-chemistry). We seek to develop a predictive model of HTND to transition away from the traditional guess and check method of doping performance. Development of a predictive and tunable model of doping requires a data set built on Scanning Electron Microscope (SEM) for surface morphology and Secondary Ion Mass Spectroscopy (SIMS) for interstitial doping percent. RF cavity tests provide efficiency, maximum performance, and superconducting properties on the doping. The feedback loop provided by the dataset will be used to create a multi-variable predictive mathematical model general enough for use in any application. Unlike previous simplified models, the new model needs to contain the nitride crystal seeding time and material dependencies, time-dependent nitride crystal morphology with/without nitrogen and diffusion coefficients depending crystal structure. Upon completion, this program should allow the modeling and demonstration of specific cavity treatment protocols tailored to any next-generation accelerator, likely making new types of applications economically viable. An even more dramatic expansion of opportunities will open up when HTND technology that simultaneously supports high mid-field Q_0 (high efficiency) and very high gradients (maximum performance) is realized. The new predictive model will be able to calculate the correct doping parameters in advance to achieve such performance.
2019	Richard Saldanha	Pacific Northwest National Laboratory	**“Enhancing the Discovery Potential of the nEXO Neutrinoless Double Beta Decay Experiment”** The particle nature of neutrinos is one of the most interesting open questions in physics today. Neutrinos have the unique possibility of being fundamental Majorana particles, i.e., single particles representing both matter and antimatter states. Discovering that neutrinos are Majorana particles would directly establish physics beyond the current Standard Model and have an immense impact on our understanding of particle physics. The most promising approach to

			experimentally establishing the Majorana nature of neutrinos is to search for neutrinoless double beta decay, an extremely rare nuclear process. The primary experimental challenge for such a search is building a detector that is sensitive to this process above all other naturally occurring radioactive backgrounds. The next-generation Enriched Xenon Observatory (nEXO) experiment aims to search for the neutrinoless double beta decay of xenon-136. The projected sensitivity of nEXO will uncover a large region of unexplored parameter space opening up the possibility of the first detection of neutrinoless double beta decay. This research will develop a comprehensive program to enhance the discovery potential of the experiment by reducing the dominant radioactive backgrounds through two complementary approaches. The first is the development of detector components with extremely low radioactivity levels, while the second involves optimizing the design of the experiment to maximize the rejection of residual backgrounds. These methods are both critical, as they not only significantly increase the sensitivity of the experiment, but also increase the confidence by which a discovery claim could be made.
2019	Jiehang Zhang	New York University	**“Exploring Quantum Many-body Physics with a Trapped Ion Quantum Information Processor”** Quantum many-body physics is notoriously hard to model on classical computers. However, expanding our understanding of these systems will help us gain insight into interesting emergent phenomena, including exotic material properties such as superconductivity, as well as the spectra of complex nuclei, which are composed of quarks and gluons at a fundamental level. In nuclear physics, extensive efforts are devoted to computing the properties of increasingly large interacting systems, which requires an exponential amount of resources on classical computers. With the recent advances of quantum information processors, the potential of controllable quantum systems could be harnessed for simulating these complex

			problems. This work will develop a system consisting of 20~100 singly-charged ions, which are among the leading technologies for quantum computing and simulations. Here, qubits are encoded in the electronic states of the ions, while the ions' shared motional modes are used to create tailored interactions between them. The topics this project will investigate include non-equilibrium phenomena, for example in heavy-ion collisions, where the rapid generation of entanglement could lead to thermalization. Investigating toy models of these mechanisms on a quantum information processor will shine light on their details with high spatial and temporal resolution. Beyond proof-of-principle demonstrations, the scope of this work also focuses on long-term improvements of the qubit quality and quantity, to approach a regime that can no longer be reached using classical computers.