Year	Name	Institution	Brief Description
2021	Corey Adams	Argonne National Laboratory	**"Construction of a Background Free, Normal-Ordering Neutrinoless Double Beta Decay Demonstrator"** The experimental quest for the neutrino's true nature, a search dating back to the earliest days of nuclear and particle physics, is now harnessing experiments, machines, and detectors of high precision and massive scale. Observation of a hypothesized unbelievably rare occurrence – a neutrinoless double beta decay of a nucleus -- would indicate that a neutrino is its own antiparticle, and would help to answer fundamental questions about why there is more matter than antimatter in the Universe. Current and planned experiments will only be able to explore certain theories of neutrinoless double beta decay due to coincidental but rare background (i.e., non-signal) data coming from detectors. To fully resolve whether a nucleus can undergo this as-of-yet undetected reaction will require new breakthroughs in detector technology that can reach the elusive "normal ordering" neutrinoless double beta decay regime by eliminating background events. This research program will unify and incorporate the latest developments in nuclear physics R&D into a novel detector capable of demonstrating background-free searches for neutrinoless double beta decay. Notably, this will include sensors capable of detecting, at the single-ion level, Barium++ ions as they are produced by double beta decay in Xenon. Additionally, this detector will synthesize direct ultraviolet light collection and fast optical cameras to enable high resolution, 3D imaging of neutrinoless double beta decay events. Achieving background-free neutrinoless double beta decay searches will enable the Office of Science's high-priority search for neutrinoless double beta decay to reach unprecedented levels of sensitivity.
2021	Melina Avila Coronado	Argonne National Laboratory	**"Measuring key Nuclear Reactions for the Weak r-process"**

			Where do heavy elements—those heavier than iron, such as gold and europium—come from? For decades, this question has been the subject of intense debate among physicists. The recent first- ever observation of two binary neutron stars colliding and merging suggests that these mergers are responsible for the production of heavy elements via the rapid neutron capture process (r-process). However, observations of ultra-metal-poor stars show that this is not the whole story. Rather, there is strong evidence that there is another r-process site that produces the lightest heavy elements—from strontium to silver—attributable to the r-process. Neutrino-driven winds that follow core-collapse supernova explosions are possible candidates for the production of the weak r-process elements, but unfortunately, none of the relevant reaction rates necessary to constrain astrophysical models are experimentally known. Obtaining direct measurements of these reactions is experimentally challenging because they require unstable neutron-rich beams, which are usually produced at low intensities. The goal of this project is to develop innovative methods of measuring reaction rates important for the production of weak r-process elements, building on a technique recently developed at Argonne National Laboratory's tandem linac accelerator system (ATLAS) for the direct measurement of nuclear reactions using neutron-rich beams. With the development of a powerful active-target detector—a time-projection chamber with three-dimensional tracking and high-rate capabilities—and the implementation of machine learning techniques for data analysis, this research will reduce or remove some of the most important nuclear physics uncertainties associated with the weak r-process and will substantially improve our understanding of nucleosynthesis from neutrino-driven winds in core-collapse supernovae.
2021	Heather Crawford	Lawrence Berkeley National Laboratory	**"In Beam Gamma-Ray Spectroscopy at the Limits of FRIB"**

			An area of great discovery potential at the Facility for Rare Isotope Beams (FRIB) will be at the neutron driplines, the upper mass limit of existence for each isotope on the periodic table. In this region, the imbalance of neutrons and protons in the nucleus results in the evolution of proton and neutron orbitals, the emergence of collective structure, and the potential for changes in nuclear properties due to the proximity of unbound configurations. The study of nuclei close to the neutron dripline is particularly interesting; these nuclei play a strong role in isotope production in stars and their structure also informs nuclear theory. Establishing how and when large neutron-to-proton ratios in a nucleus require new or modified theoretical tools is a major question in nuclear physics that remains largely unanswered. To move the science forward, data as close to the reachable limits of experiment are essential, requiring targeted measurements and new experimental capabilities. The goal of this research is the study of nuclear structure at the limits of existence through a program of strategic measurements at FRIB. Measurements will focus on the most exotic magnesium, calcium and iron nuclei. In parallel, a thick liquid hydrogen target coupled with charged particle detectors for reaction vertex reconstruction will be developed and deployed to maximize sensitivity for spectroscopy measurements at FRIB.
2021	Matthew Durham	Los Alamos National Laboratory	**"Exotic Probes of Dense Nuclear Matter"** Energetic collisions of nuclei produce a unique phase of matter, called the quark-gluon plasma, where normal particles like protons and neutrons melt down into their constituent parts. As this plasma expands and cools, clusters of three quarks can freeze back into more familiar particles, while larger groups of four, five, or more quarks can coalesce into exotic particles that are not well understood. The rate at which exotic particles form is dependent on the properties of the plasma such as its temperature and density, and also

			on the structure of the exotic particles themselves. The LHCb experiment at the Large Hadron Collider is uniquely well suited to measure these exotic particles in a wide range of nuclear environments. This project will use LHCb to measure exotic particles produced in both collider and fixed-target collisions, where they will be exposed to different conditions. These measurements will provide new information on the mechanisms by which quarks combine into particles and the fundamentally allowed configurations of quarks that make up visible matter. In addition, these data will be used to guide projections for future studies of exotic particle interactions at the forthcoming Electron-Ion Collider.
2021	Mengjia Gaowei	Brookhaven National Laboratory	**"Cathode R&D for High Intensity Electron Source in Support of EIC"** The future Electron-Ion Collider (EIC) is a unique high-energy, high-luminosity polarized collider that will be one of the most challenging and exciting accelerator complexes ever built. The EIC will be a discovery machine that collides electrons with protons and nuclei to produce snapshots of those particles' internal structure. It will provide answers to the mysteries of matter related to our understanding the origin of mass, structure, and binding of the atomic nuclei. To maintain a high luminosity in the EIC, it is desirable to cool the hadron beams to improve the collision rate. Electron cooling is a promising technique to achieve this goal. This technique requires an electron source that can continuously produce electron beams with low emittance, high average current and high bunch charge. Multi-alkali antimonide photocathodes have proven to be highly effective in meeting these challenges. This research is aiming at growing nearly perfect crystals of alkali antimonides with assistance of a variety of characterization tools and evaluate the performance of the bulk grown crystals as photocathodes. Further, the effort will test these cathodes alongside traditionally grown cathodes for high current operation, both to evaluate performance and

			to characterize failure mechanisms. These efforts are expected to lead to a dramatic improvement of the material quantum efficiency (QE), with a goal of reproducible production of cathodes with high operational QE and lifetimes at least twice that of traditional cathodes. Furthermore, this research will explore and evaluate the various protective mechanisms brought up by the community in recent years, including 2-D material encapsulation and nano-structure enhancement, under high current operation conditions. The success of this work will yield the ideal photocathode material with better QE and longer lifetime for high current applications for EIC. It has the potential to create both a scientific breakthrough in understanding the properties of photocathode materials, and a technological breakthrough in extending the operational lifetime of cathodes for electron coolers. Ultimately this will improve luminosity and decrease downtime for the flagship machines in nuclear physics.
2021	Andrew Jayich	University of California, Santa Barbara	**“Quantum Logic Spectroscopy of Radioactive molecules for Probing Fundamental Symmetries”** The heavy elements at the bottom of the periodic hold much promise and unique opportunities for basic science and technology. But, the radioactivity of these elements presents challenges. This project aims to use one such element, radium, as the cornerstone for studying and controlling radioactive molecules made with bottom-row elements with both high efficiency and high precision. Trapped radium ions will be used to synthesize trapped radium-based molecules and study their properties with quantum logic spectroscopy, a quantum information technique that was originally developed for optical atomic clocks that has recently been applied to molecules. With radium-based molecules the project will also be able to study properties of the radium nucleus and set the stage for using radioactive molecules to address profound questions centered on time symmetry violation, such as why is the Universe filled with matter, but lacks antimatter? A few

			rare radionuclides have massive octupole shape deformations, e.g. radium- 225 and protactinium-229, which makes them exceptionally sensitive to time symmetry violating or equivalently charge parity violating physics. When these special nuclei are incorporated into a molecule, they can gain a further thousand-fold sensitivity enhancement due to the molecule's intense electric field. The combined nuclear and molecular sensitivities may be exploited to search for a tiny time symmetry violation signal using just a single trapped molecule.
2021	Ben Loer	Pacific Northwest National Laboratory	**"Improving Coherence Times for Quantum Devices Beyond the Next Decade"** Emerging quantum information technologies have the potential to revolutionize many areas in science and computing. It has recently been demonstrated that ionizing radiation contributes to errors in superconducting qubits. If these devices continue their current rate of improvement, ordinary levels of background radiation could become the dominant source of errors within the next decade. The goal of this project is to develop methods to reduce radiation impacts on superconducting quantum devices. The project has three thrusts. First, the response of qubits to a variety of tailored radiation sources will be measured to better understand and model how radiation interacts in these devices at the microscopic level. With this knowledge, new devices may be developed with intrinsically reduced sensitivity to radiation. Second, new types of cryogenic radiation sensors will be developed to better measure the qubit's environment in real time, including a first-of-its-kind hybrid device combining superconducting qubits and microcalorimeter radiation sensors on a single chip. Finally, developing new methods in quantum computing to integrate classical sensor data and detect radiation-induced conditions will enable more accurate quantum calculations with the application of sensor-assisted quantum fault mitigation (Sensor-QFM) concepts. The results of this project will provide a crucial stepping-stone on the path to realizing the full potential of superconducting quantum technologies.

2021	Maria Piarulli	Washington University	**“From Atomic Nuclei to Infinite Nucleonic Matter within Chiral Dynamics”** Emerging quantum information technologies have the potential to revolutionize many areas The quest to describe classes of phenomena that occur in the atomic nucleus lies at the heart of nuclear physics. These quantum mechanical phenomena play a major role in the birth and evolution of the universe, in astrophysical environments, in energy production through fission and fusion reactions, and in industrial and medical applications via use of stable isotopes and radioisotopes. Understanding the structure and dynamics of nuclei and strongly interacting matter is, therefore, the primary focus of many nuclear experimental programs and theoretical efforts. The present research will aim to develop a clear and coherent picture in which microscopic models accurately describe atomic nuclei while simultaneously predicting properties of infinite matter, e.g., pure neutron matter, relevant to the structure and internal composition of neutron stars. It will make use of state-of-the-art computational techniques and high- performance computing to broaden the applicability of variational and Green’s function Monte Carlo methods, currently limited to bound states with mass number $A \leq 12$. The results will directly address some of the fundamental questions at the frontier of nuclear science and will complement the US Department of Energy’s major investments in supporting present and future nuclear physics experiments at low-, medium-, and high-energy.
2021	Srimoyee Sen	Iowa State University of Science and Technology	**“Quantum Materials, Lattice Gauge Theory and QCD”** The confluence of modern scientific ideas from Quantum Chromodynamics (QCD) - the fundamental theory of nuclear interactions, condensed matter physics and particle physics has enabled notable discoveries of exotic phenomena in extreme astrophysical environments as well as in materials in tabletop experiments. This project brings together seminal ideas from lattice quantum field theory

			(QFT), dense-QCD and topological superconductors and insulators, the interrelations of which in two and higher dimensions could reveal novel phase structures of QCD as well as lead to the discovery of new quantum materials. Of great current interest is the realization of anyonic excitations because of their resilience in fault tolerant quantum computing and their ability to exquisitely diagnose topological phases of quantum materials. Advancing our understanding of anyonic excitations in QFT could, in turn, address foundational questions in the study of the QCD phase diagram and nuclear matter.
2021	Chun Shen	Wayne State University	**“Quantitative Characterization of Emerging Quark-Gluon Plasma Properties with Dynamical Fluctuations and Small Systems”** High energy collisions of atomic nuclei create extreme conditions to study the collective property of nuclear matter. Experiments at the Relativistic Heavy Ion Collider (RHIC) in the U.S. and the Large Hadron Collider (LHC) in Europe create a novel state of matter Quark-Gluon Plasma (QGP), which exhibits quarks' and gluons' degrees of freedom at a temperature exceeding 2 trillion degrees Kelvin. The QGP behaves like a nearly perfect fluid from the many-body effects of Quantum Chromodynamics (QCD). This hot and dense soup of elementary particles filled our universe a few microseconds after the Big Bang as the primordial liquid. The emergence of QGP's strongly coupled nature is studied by varying collision energy and system size at RHIC and the LHC. The current Beam Energy Scan (BES) program at RHIC further probes the QCD matter's phase structure, searching for the existence and location of the first order (liquid- vapor) phase boundary between ordinary nuclear matter and QGP terminating at a critical point. This project aims at elucidating QGP properties by understanding the dynamical evolution of stochastic fluctuations in relativistic heavy-ion collisions from large to small systems. This research will provide a quantitative characterization of the QGP properties, how it ripples, flows, and its phase structure by interweaving theoretical many-body nuclear

			physics, high-performance computing, and advanced machine learning techniques. The QGP viscosity and charge diffusion coefficients control how fluctuations of energy, momentum, and charge density dissipate in the system. The presence of a QCD critical point in a heavy-ion collision should lead to enhanced fluctuations and strong correlations of conserved densities. The out-of-equilibrium dynamics of these small ripples under a realistic hydrodynamic flow background elucidate the thermal, critical, and transport properties of the QGP. A new open-source theoretical framework will be developed to decode this information from the measured multi-particle correlations. This framework integrates the state-of-the-art 3D event-by-event QGP dynamics and the evolution of generic fluctuations. By further combining the theoretical framework with advanced statistical analysis, reliable phenomenological constraints on the QGP properties will be delivered when confronting the precision measurements from the RHIC BES program. This research will benefit the current Beam Energy Scan phase II and upcoming SPHENIX programs at RHIC, high luminosity runs at LHC, and the future Electron-Ion Collider (EIC) and Facility for Antiproton and Ion Research (FAIR).