Year	Name	Institution	Brief Description
2023	Philip Adsley	Texas A&M University	**“Probing Nuclear Dipole Responses”** The way that nuclei respond to electromagnetic radiation has profound implications for neutron stars, for the synthesis of heavy elements, for nuclear medicine, and even industrial applications such as the design of nuclear reactors. Of particular importance is the dipole response of nuclei which causes protons and neutrons to oscillate in opposite directions. This response causes one side of the nucleus to have more positive charge than the other. Many contributions to the nuclear dipole response overlap and are hard to isolate. Additionally, isolating the contributions is made more difficult due to deficiencies in past measurements. The present research uses sensitive experimental probes of the nuclear dipole response to resolve these different contributions. This research will also develop independent calibration standards for dipole response measurements to validate modern experimental studies and investigate historical experimental discrepancies. Experiments will be performed at three laboratories with different capabilities: the Texas A&M University Cyclotron Institute, γELBE at Helmholtz-Zentrum Dresden-Rossendorf in Germany, the iThemba Laboratory for Accelerator-Based Science in Cape Town, South Africa. The results from each type of experiment will probe different aspects of the nuclear dipole response.
2023	James Daniel Brandenburg	Ohio State University	**“Nuclear Tomography through Entanglement-Enabled Spin Interference”** Protons and Neutrons are the basic building blocks of almost all visible matter in the Universe. Astonishingly, the rules that govern these basic building blocks dictate the matter formed over 18 orders of magnitude in scale – from tiny atomic nuclei to massive astronomical objects like neutron stars. However, protons and neutrons are not fundamental, but are themselves dynamical quantum objects built from quarks that are ‘glued’ together by gluon particles which mediates the strong nuclear force. A fundamental

			goal of nuclear physics over the last several decades has been to understand the internal structure of protons, neutrons, and nuclei. To this end, one of the primary goals of the future Electron Ion Collider is to construct multi-dimensional maps of the quarks and gluons within large nuclear objects. This project utilizes a recently discovered quantum effect in which entanglement enables wavefunction interference between distinguishable particles. Hidden in these interference patterns is information about the distribution of gluons within protons, neutrons, and large nuclei – enabling a new approach to nuclear tomography. This project undertakes the development of this newfound quantum effect to explore the dynamic properties of gluons within large nuclei and to investigate the details of their quantum spin structure. By developing this novel entanglement-driven technique, this project also aims at providing new opportunities to impact searches for physics beyond the Standard Model and for investigating nuclei as entangled quantum objects.
2023	Maria Laura di Vacri	Pacific Northwest National Laboratory	**“Optimization of the nEXO Detector for Enhanced Sensitivity to Neutrinoless Double Beta Decay of ^{136}Xe”** The experimental observation of neutrinoless double beta decay would have revolutionary implications for neutrino physics, theories beyond the standard model, and cosmology. This work will enhance the prospects of the next Enriched Xenon Observatory (nEXO) experiment by addressing a critical challenge in all experimental searches for neutrinoless double beta decay: material radioactive backgrounds. The project has three objectives. First, this research will improve the nEXO projected sensitivity on the neutrinoless double beta decay half-life of ^{136}Xe by *ca.* 20% by mitigating the most prevalent backgrounds predicted for nEXO: impurities of ^{222}Rn and its progeny in the detector. Second, enhanced control of exposure-based backgrounds will be tackled through improved assay methods, with a focus on radioactivity from dust particulate fallout on detector materials. Finally, this work will develop high-purity Cu-based alloys with yield

			strength significantly larger than pure Cu. In the context of the nEXO detector, increased strength translates into reduced production time, increased performance, and potentially further reduced backgrounds. The nEXO experiment is a major investment in the understanding of neutrinos. While targeted to nEXO, this work will inform the extent to which low-background experiments can reach the greatest sensitivity through mitigation of backgrounds in materials and in the environment into which these experiments are built.
2023	Raghav Kunnawalkam Elayavalli	Vanderbilt University	**“Mapping the Space-time Evolution of Quarks and Gluons at RHIC”** Fundamental building blocks of the observable universe, quarks and gluons, can be studied in relativistic collider experiments as energetic interactions liberate and produce particles which are observed by state-of-the-art particle detectors. One of the biggest unsolved mysteries in nature is in quantifying the mechanism by which quarks/gluons metamorphosize into stable particles such as protons and other hadrons that make up what we see all around us. Such a transition encodes critical features of the theory of strong interaction i.e., quantum chromodynamics (QCD), one of the four fundamental forces. Our group will study relativistic collisions at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL) with the new sPHENIX detector that has just started taking data for the first time in 2023. Heavy ion collisions are a perfect laboratory to study the properties of the early universe as they recreate conditions, high temperature and energy densities, supposed to have existed a few micro-seconds after the big bang. Jets, collections of particles resulting from the fragmentation of highly energetic quarks/gluons, have the right time-scale for probing these conditions. Our results will enable an extraction of the dynamics of quarks/gluons for the first time in high energy nuclear physics. These results satisfy the mission critical need and success of a central goal of BNL and RHIC’s nuclear physics program – studying the production, evolution and eventual

			demise of the emergent Quark-Gluon Plasma (QGP) and its microscopic transport properties.
2023	Norbert M. Linke	Duke University	**“Analog-Digital Hybrid Simulation of Quantum Field Theories with Advanced Ion Traps”** Quantum field theory (QFT) is a powerful theoretical framework that underpins much of modern physics, helping us understand subatomic particles and their interactions. However, computing the dynamics of QFT models can be an immensely challenging task. Quantum computers promise to efficiently simulate such models using qubits, which are computational bits that take advantage of quantum phenomena like entanglement and superpositions to create powerful quantum algorithms. But encoding physical interactions involving photons and other bosonic particles is difficult even for these advanced systems due to the infinite-dimensional state spaces involved. To overcome this challenge, we are developing an analog-digital hybrid quantum simulator based on trapped ions. Linear chains of atomic ions trapped in free space with electric fields offer exceptional qubit properties and are a leading platform for quantum computing. In our scheme, the ion qubits are combined with multiple sets of vibrational modes, represented by the motion of the ion chain in the trap. These modes are a quantum version of the overtones on a guitar-string and provide additional quantum resources. They can not only facilitate discrete, or digital, quantum computational gates by coupling different ions together but also act as bosonic degrees of freedom directly. This follows the idea of analog quantum simulation, where a quantum system is engineered to evolve like another system of interest. Using both digital and analog elements allows for more efficient encoding and simulation of QFT problems. We are constructing a new type of ion trap based

			on micro-fabrication of 3-dimensional glass structures to create the ideal experimental platform for analog-digital hybrid quantum simulations.
2023	Kun Liu	Los Alamos National Laboratory	**“Probing the Emergent Hadron Mass through Pion Structure Measurement at the AMBER Experiment”** Understanding the origin of the hadron mass, which constitutes 99% of our visible universe, is one of the central goals of nuclear physics. The Higgs mechanism, although provides mass for the fundamental building blocks of the matter, can only contribute a very small fraction (~1%) of the nucleon mass by itself. The vast majority of the mass is believed to come from the strong force that tightly binds quarks and gluons together. Therefore, measurement of the quark and gluon structure of the hadron is of utmost importance in understanding how the hadron mass emerges through the strong interaction. Any successful theory needs to reconcile both the heavy proton mass and the very light pion mass simultaneously. In contrast to the abundant experimental measurements of the proton structure, the data on the pion structure is very scarce and outdated. The goal of this research is to provide a comprehensive study of the internal structure of the pion by colliding high-energy pions with a carbon target at the AMBER experiment at CERN. The primary R&D of this study involves the development of a silicon-strip-based vertex detector, which will significantly improve the reconstruction precision of the AMBER spectrometer and consequently leads to the best measurement of the pion structure to date. The result yielded from this study will provide the needed sensitivity to understand and constrain the mechanisms responsible for the emergence of the hadron mass.
2023	Jean-François Paquet	Vanderbilt University	**“Multimessenger Tomography of Ultrarelativistic Nuclear Collisions”** The protons and neutrons that form atomic nuclei are themselves made of smaller constituents

			known as quarks and gluons. When heavy nuclei are accelerated close to the speed of light and made to collide, a hot plasma of these elementary quarks and gluons is produced at the point of impact. The composition and temperature of this plasma are comparable to the state of the Universe microseconds after the Big Bang. The plasma radiates light at different wavelengths in the gamma-ray energy range, which has been measured in experiments at the Relativistic Heavy Ion Collider (RHIC) and the Large Hadron Collider (LHC). The light's energy spectrum and its direction of emission provide a unique window into the properties of the hottest regions of the plasma. In this research project, this electromagnetic radiation will be used to probe the viscosity of the quark-gluon plasma and, critically, study how it changes with the plasma's temperature. This will offer valuable insights into the plasma's transition from a liquid to a gas phase as its temperature increases. Measurements of electromagnetic radiation will be combined with other data sets to obtain state-of-the-art constraints on the plasma's viscosity. Machine learning techniques will be used to accelerate simulations of nuclear collisions and assist the statistical analysis of the data.
2023	Felix Ringer	Old Dominion University	**“Toward a Microscopic Picture of Hadronization and Multi-parton Processes”** Quarks and gluons are the fundamental building blocks of hadrons that make up a large fraction of the visible matter in our universe. Their unique properties and interactions can be studied in detail at collider experiments where they are produced at high energies. Quarks and gluons carry a color charge, described by the theory of quantum chromodynamics (QCD), that leads to their confinement into colorless hadrons shortly after their creation in collider experiments. This transition, which leads to the neutralization of color and the emergence of hadrons, is called hadronization. Despite extensive research, a microscopic picture of the QCD hadronization process has remained elusive due to its nonperturbative nature. Addressing this challenging question is one of the main frontiers

			of the US nuclear physics program, and our limited understanding of the associated multi-parton processes has become a bottleneck in various areas of high-energy nuclear and particle physics. To tackle this question, this project will develop a multi-pronged approach by leveraging three distinct but related methods: 1. Perturbative QCD calculations of observables sensitive to multi-parton dynamics, 2. Quantum simulations of real-time dependent correlation functions that are relevant to understand the complex dynamics of hadronization, and 3. A.I. / Machine learning techniques that will provide new insights into the microscopic picture of hadronization by identifying patterns in collider data. The confluence of these different computational techniques will facilitate a novel and comprehensive approach to studying the QCD hadronization process from multiple perspectives. The research of this project is of direct relevance to the nuclear physics facilities in the US including the ongoing experiments at the Thomas Jefferson National Accelerator Facility and Brookhaven National Laboratory, as well as the future Electron-Ion Collider.
2023	Derong Xu	Brookhaven National Laboratory	**"Luminosity Maximization with Flat Hadron Beams"** The US Electron-Ion Collider (EIC) has been approved by the Department of Energy as the next major scientific facility. The EIC to be built at Brookhaven National Laboratory (BNL) will serve as an ultimate electron microscope to probe the detailed physics inside the nucleus. The success of a collider is measured by its luminosity, which quantifies the number of physics events generated during collisions. The EIC plans to achieve high luminosity by utilizing a flat hadron beam, aligning it with the electron beam to enhance interactions. However, a flat hadron beam has never been demonstrated in a real machine. Maintaining a flat hadron beam presents challenges. The phenomenon of emittance growth and coupling can result in an increase in the vertical size of the beam, ultimately causing the flat hadron beam to become disrupted. This project focuses on investigating factors that can cause emittance

			growth and coupling in a hadron storage ring, specifically looking at intra-beam scattering, magnet non-linearity, and beam-beam interaction. By conducting experiments at the Relativistic Heavy Ion Collider (RHIC) and developing a powerful simulation code, researchers aim to better understand and control these phenomena. The insights gained from this project have the potential to improve the design and operation of future colliders and advance simulation tools for scientific research.