Nuclear Physics

Overview

The mission of the Nuclear Physics (NP) program is to explore the nature of matter: its basic constituents and how they interact to form the elements and the properties we observe. Solving this mystery involves discovering, exploring, and understanding all forms of nuclear matter. This understanding benefits society in numerous fields: energy, climate, commerce, medicine, and national security.

Understanding all forms of nuclear matter requires an enormous range of both theoretical approaches and experimental capabilities. Theoretical approaches to further our understanding are based largely on calculations of the interactions of quarks and gluons described by the theory of Quantum Chromodynamics (QCD). Experimental approaches use large accelerators at scientific user facilities to collide particles at nearly the speed of light, producing short-lived forms of nuclear matter for investigation.

Highlights of the FY 2025 Request

The FY 2025 Request for $833.1 million is an increase of $27.9 million over the FY 2023 Enacted and supports forefront fundamental nuclear physics research; operations, maintenance, and upgrades of scientific user facilities; and projects.

Research

NP is the primary steward of the nation's fundamental nuclear physics research portfolio, providing approximately 95 percent of the U.S. investment in this area. Primary fundamental research thrusts include:

- Characterizing the quark-gluon plasma at the Relativistic Heavy Ion Collider (RHIC) and the Large Hadron Collider (LHC)
- Exploring the fundamental structure of nucleons at the sub-femtometer scale at the Continuous Electron Bean Accelerator Facility (CEBAF) and the future Electron-Ion Collider (EIC)
- Probing the limits of nuclear existence and the process for heavy element production in stars at the Facility for Rare Isotope Beams (FRIB) and the Argonne Tandem Linac Accelerator System (ATLAS)
- Discovery of whether the neutrino is its own anti-particle via neutrino-less double beta decay (NLDBD)
- Research on the strong force in many-body systems leading to precision predictions from QCD of nuclear properties and nuclear reactions via Scientific Discovery Through Advanced Computing (SciDAC)
- Curation of reliable, accurate Nuclear Data for basic nuclear research and nuclear technologies
- Niche capabilities and unique "hands-on" experiences in nuclear science at NP University Centers of Excellence
- Participation in the RENEW and FAIR initiatives to broaden participation and inclusion in NP research

Facility Operations

Funding supports the NP scientific user facilities at roughly 90 percent optimal funding, enabling world-class science:

- RHIC operates 3,100 hours for the super Pioneering High Energy Nuclear Interaction eXperiment (sPHENIX).
- CEBAF operates 3,170 hours for the highest priority 12 GeV experiments.
- ATLAS operates 5,900 hours for compelling research in nuclear structure and astrophysics.
- FRIB operates 3,700 hours discovering and characterizing nuclei at the extremes of the nuclear chart.

Projects

The Request for Construction and Major Items of Equipment (MIEs) includes:

- Preliminary engineering and design (PED) for the EIC, which will provide unprecedented ability to x-ray the proton and discover how the mass of everyday objects is dynamically generated by the interaction of quark and gluon fields inside protons and neutrons. The EIC was the highest priority for facility construction in the 2023 Long Range Plan for Nuclear Physics (LRP) and will maintain U.S. leadership in nuclear physics and accelerator technology.
- Support for management and PED for the Ton Scale NLDBD (TS-NLDBD) program. TS-NLDBD will investigate whether the neutrino is its own anti-particle by searching for a rare nuclear decay predicted to happen once in 10^{28} years and was identified as the highest priority for experiment construction in the 2023 NSAC LRP.
- Continuation of the High Rigidity Spectrometer (HRS) research project at FRIB to maximize the rate of rare neutron-rich nuclei of central importance for understanding the synthesis of heavy elements in cosmic events.

Nuclear Physics
Funding

	(dollars in thousands)			
	FY 2023 Enacted	**FY 2024 Annualized CR**	**FY 2025 Request**	**FY 2025 Request vs FY 2023 Enacted**
Nuclear Physics				
Medium Energy, Research	59,083	50,055	50,592	-8,491
Medium Energy, Operations	149,834	138,620	147,244	-2,590
Total, Medium Energy Physics	**208,917**	**188,675**	**197,836**	**-11,081**
Heavy Ion, Research	46,149	45,474	43,349	-2,800
Heavy Ion, Operations	182,087	166,993	181,126	-961
Heavy Ion, Projects	20,000	2,850	2,850	-17,150
Total, Heavy Ion Physics	**248,236**	**215,317**	**227,325**	**-20,911**
Low Energy, Research	77,651	75,159	72,334	-5,317
Low Energy, Operations	128,579	120,401	135,646	+7,067
Low Energy, Projects	23,940	9,259	5,259	-18,681
Total, Low Energy Physics	**230,170**	**204,819**	**213,239**	**-16,931**
Theory, Research	67,873	67,392	84,691	+16,818
Total, Nuclear Theory	**67,873**	**67,392**	**84,691**	**+16,818**
Subtotal, Nuclear Physics	**755,196**	**676,203**	**723,091**	**-32,105**
Construction				
20-SC-52 Electron Ion Collider (EIC), BNL	50,000	95,000	110,000	+60,000
Subtotal, Construction	**50,000**	**95,000**	**110,000**	**+60,000**
Total, Nuclear Physics	**805,196**	**771,203**	**833,091**	**+27,895**

SBIR/STTR funding:
- FY 2023 Enacted: SBIR $8,336,000 and STTR $1,173,000
- FY 2024 Annualized CR: SBIR $7,061,000 and STTR $993,000
- FY 2025 Request: SBIR $7,378,000 and STTR $1,037,000

Nuclear Physics
Explanation of Major Changes

	(dollars in thousands)
	FY 2025 Request vs FY 2023 Enacted
Medium Energy Physics The Request provides support for the CEBAF accelerator complex to support 3,170 operating hours (89 percent optimal funding). The Request includes support to participate in the SC initiatives for QIS, AI/ML, and Microelectronics.	**-11,081**
Heavy Ion Physics The Request provides funding for the RHIC accelerator complex for a 3,100 hour run (95 percent optimal funding). The Request supports science with sPHENIX, which studies high rate jets of particles at RHIC. Funding supports heavy ion nuclear physics at universities and national laboratories. The Request includes support the SC initiatives for QIS and AI/ML. The Request continues other project costs (OPC) for the EIC, which will enable scientists to play a leading role in R&D and the development of scientific instrumentation and accelerator components for the EIC. The Request also supports EPSCoR implementation grants and early career awards in EPSCoR jurisdictions.	**-20,911**
Low Energy Physics The Request provides support for operations of two low energy user facilities: the ATLAS facility, which operates for 5,900 hours (90 percent optimal funding), and FRIB, which provides beam time for 3,700 hours (90 percent of optimal funding). The Request sustains operations of the 88-Inch Cyclotron for a limited in-house nuclear science program and an electronics irradiation capability. Funding supports nuclear structure and astrophysics at universities and national laboratories. Funding continues for the HRS to exploit the fast beam capabilities at FRIB and for the TSNLDBD experiment.	**-16,931**
Nuclear Theory Funding supports theory research efforts at laboratories and universities, the U.S. Nuclear Data Program, specialized Lattice QCD computing hardware at Thomas Jefferson National Accelerator Facility (TJNAF), and participation in the SciDAC program. The Request supports QIS, quantum computing, and AI/ML. Increased funding supports the RENEW initiative to provide undergraduate and graduate training opportunities for students and academic institutions not currently well represented in the U.S. science and technology (S&T) ecosystem, including a RENEW graduate fellowship. The FAIR initiative increases to provide focused investment on enhancing emerging research institutions, underserved communities, and Historically Black Colleges and Universities (HBCUs), and Minority Serving Institutions (MSIs) communities.	**+16,818**
Construction The Request provides funding for the EIC to continue Project Engineering and Design activities and execute long-lead procurements.	**+60,000**
Total, Nuclear Physics	**+27,895**

Basic and Applied R&D Coordination

The NP mission supports the pursuit of unique opportunities for R&D integration and coordination with other DOE Program Offices, Federal agencies, and non-Federal entities, including coordination on forefront computing resources and technical expertise through the SciDAC projects and Lattice QCD research (ASCR and HEP); cross-section and decay data relevant clean energy initiatives, materials science, and nuclear forensics through the U.S. Nuclear Data Program (Federal Bureau of Investigation [FBI], National Nuclear Security Administration [NNSA], Nuclear Energy [NE], FES and BES); capabilities and techniques to test electronics for radiation sensitivity (NASA and DOD); technological advances relevant to clean energy and the development of advanced fuel cycles for next generation nuclear reactors (NE); advanced cost-effective accelerator technology and particle detection techniques for medical diagnostics and treatment (National Institutes of Health [NIH]); accelerator research and enhancing U.S.-based supply chains for critical accelerator technologies (ARDAP); and research in developing neutron, gamma, and particle beam sources with applications in cargo screening (NNSA, DHS, and the FBI).

Program Accomplishments

Shape-shifting nuclei illuminate nature's whimsy

Using the new Facility for Rare Isotope Beams, researchers have made more than 210 rare-isotope beams for forty-six experiments involving 177 students, across 180 institutions in 50 countries. One exciting example is an isomer of sodium 32 (^{32}Na) —a fleeting variant of the ^{32}Na nucleus with a half-life of only 24 microseconds having the exact same number of protons and neutrons as ^{32}Na — but different internal energy states. Isomers are interesting in general for their potential application in creating nuclear clocks or nuclear batteries. But this isomer is even more interesting because it exists right at the nexus of three nuclear theories which all purport to explain its origin: one theory suggests the ^{32}Na isomer owes its existence to its nature as a shape shifter— a nucleus which can change spontaneously e.g. from being oblate (like a squashed basketball) to prolate (like an American football); one theory predicts that with ten extra neutrons beyond the normal number of eleven neutrons in a stable sodium nucleus (^{22}Na), the shell structure which protons and neutrons ordinarily arrange themselves has become deformed; and one theory suggests this isomer is something altogether different— a highly excited spherical super version of "everyday" ^{32}Na. Discovering which theory comes closest is currently the subject of intense research to systematically uncover the whimsy with which nature allows neutrons and protons to form nuclei, thereby creating new knowledge and technology to advance non-proliferation, nuclear medicine, space exploration, and the discovery of new physics beyond our current understanding.

New tools to discover nature's recipe for quark-gluon soup

It's easy to imagine that when the universe was microseconds old and extremely hot, things looked a bit different. There were no protons and neutrons but only a soup of quarks and gluons now known as a quark-gluon plasma (QGP). Scientists have proven the QGP exists, and they know it exhibits spectacular phenomena. For example, a thin slice of quark-gluon plasma of order a femtometer (.000000000000001 meter) thick can "stop" a quark or gluon attempting to "punch through it" with more than 100 giga-electron-volts of energy. How does that happen? Good question. And one which scientists are now tooled up to answer with the completion and successful commissioning of the sPHENIX detector at RHIC. Unlike previous detectors, advanced strategies for streaming readout and on-the-fly analysis will allow sPHENIX to acquire data on the above phenomenon, known as "jet quenching" at a pace never before achieved, affording unprecedented precision in comparison with "control data" where the QGP is known not to be produced. In addition, scientists have developed new "pop-up thermometers" to tell the precise temperature of the quark-gluon soup under various conditions by observing the sequential dissolution of bound states of bottom & antibottom quarks called the Upsilon family of states. The exciting stage is now set to zero in on precisely how nature does what it does when the temperature gets to be "12 billion Kelvin in the shade".

Mystery of mysteries: the nature of the neutrino

We have all answered the question before, "which one of these does not belong with the others". When it comes to subatomic particles, the answer would have to be the neutrino. Despite the fact there are trillions passing through our bodies every second, we have no idea why its mass is so small compared with other particles. In fact, we know its mass is small but not how small, and beyond that, the fact it has a mass at all is currently not explained by accepted particle theory. Those questions, as well as whether the neutrino is its own anti-particle and might account for why there is more matter than ani-matter in the universe are the target of an ongoing international campaign to search for a rare decay called neutrinoless double beta decay— the decay of a nucleus in which two neutrons transform themselves into two protons and two electrons (charge has to be conserved)—but no neutrinos. That can only happen if the neutrino is its own antiparticle.

Recently, the Majorana Demonstrator experiment carried out at the Sanford Underground Research Facility (SURF) demonstrated that up to a half-life limit of 8.3×10^{25} years, no such decay is observed, setting a new bar for the follow-up global campaign which aims for a limit 1000 times more stringent. One next generation precursor experiment, LEGEND-200, is already underway. It is a collaboration of scientists from Germany, Italy, and the United States urgently focused on demonstrating viability to meet the next challenge.

A New Spin on Deuterium-Tritium Fusion

Scientists at Lawrence Livermore National Laboratory and Institut de Physique Nucléaire d'Orsay (IPN Orsay) in France have recently performed nuclear theory calculations from first principles to predict the rate of nuclear fusion of deuterium and tritium in a spin-polarized plasma. These calculations accurately reproduce the previously measured cross-sections for un-polarized fusion which demonstrates that the theory is accurate. The new calculations have important implications for the exploration of novel avenues to advance the science and commercialization of nuclear fusion energy because, if fusion fuels can be made in a spin-polarized manner, the efficiency of fusion energy systems— a major factor in their viability as a commercial power source—can be made much higher, while simultaneously using less materials to gain the same overall output.

Nuclear Physics
Medium Energy Physics

Description

The Medium Energy Physics subprogram focuses primarily on experimental tests of the theory of the strong interaction, known as Quantum Chromodynamics (QCD). According to QCD, all observed nuclear particles, collectively known as hadrons, arise from the strong interaction of quarks, antiquarks, and gluons. The protons and neutrons inside nuclei are the best-known examples of hadrons. QCD, although difficult to solve computationally, predicts what hadrons exist in nature, and how they interact and decay. Specific questions addressed within this subprogram include:

- What is the internal landscape of the protons and neutrons (collectively known as nucleons)?
- What does QCD predict for the properties of strongly interacting matter?
- What is the role of gluons and gluon self-interactions in nucleons and nuclei?

Scientists use various experimental approaches to determine the distribution of up, down, and strange quarks, their antiquarks, and gluons within protons and neutrons, as well as clarifying the role of gluons in confining the quarks and antiquarks within hadrons. Experiments that scatter electrons off protons, neutrons and nuclei are used to elucidate the effects of the quark and gluon spins within nucleons, and the effect of the nuclear medium on the quarks and gluons. The subprogram also supports experimental searches for higher-mass “excited states” and exotic hadrons predicted by QCD, as well as studies of their various production mechanisms and decay properties.

The Medium Energy subprogram supports research at the Continuous Electron Beam Accelerator Facility (CEBAF) at Thomas Jefferson National Accelerator Facility (TJNAF). In addition, the subprogram provides support for spin physics research at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL), which is the only collider in the world that can provide polarized proton beams.

CEBAF provides high quality beams of polarized electrons that allow scientists to extract information on the quark and gluon structure of protons and neutrons from measurements of how the electrons scatter when they collide with nuclei. CEBAF also uses highly-polarized electrons to make very challenging precision measurements that may reveal processes that violate a fundamental symmetry of nature, called parity, in order to search for physics beyond what is currently described by the Standard Model of particle physics. These capabilities are unique in the world. Research at RHIC using colliding beams of spin-polarized protons, is providing information on the spin of the proton in a kinematic range complementary to that at CEBAF to extend present knowledge beyond the kinematic boundaries accessible at CEBAF alone Complementary, focused experiments that require different capabilities can be conducted at the High Intensity Gamma-Ray Source (HIGS) at the Triangle Universities Nuclear Laboratory (TUNL), a University Center of Excellence; Fermi National Accelerator Laboratory (FNAL); European laboratories; and elsewhere. The Research and Engineering Center (REC) of the Massachusetts Institute of Technology (MIT) has specialized infrastructure used to develop and fabricate advanced instrumentation and accelerator equipment for the nuclear physics community.

A high scientific priority for this community is addressing an outstanding grand challenge question of modern physics: how the fundamental properties of the proton such as its mass and spin are dynamically generated by the extraordinarily strong color fields resulting from dense systems of gluons in nucleons and nuclei. The EIC, to be located at BNL, plans to address this science. Scientists and accelerator physicists from the Medium Energy subprogram are strongly engaged and play significant leadership roles in the development of the scientific agenda and implementation of the EIC.

Transformative accelerator R&D efforts advanced approaches in SRF technology and accelerator science aimed at improving the operations of existing facilities and developing next-generation facilities for nuclear physics. Nuclear physicists participate in activities related to quantum information science (QIS) and quantum computing (QC), in coordination with other SC research programs. NP-specific efforts include R&D on quantum sensors to enable precision NP measurements, development of quantum sensors based on atomic-nuclear interactions, and development of quantum computing algorithms applied to quantum mechanical systems and NP topical problems. Scientists develop cutting-edge techniques based on artificial intelligence and machine learning (AI/ML) of relevance to nuclear science research and accelerator facility operations. Scientists participate in the SC initiative on microelectronics research and development, emphasizing unique microelectronics that survive in cryogenic and high radiation environments.

The Request also continues support for honoraria for awards, including the Enrico Fermi Awards and the Ernest Orlando Lawrence Awards. NP supports RENEW, expanding targeted efforts, including a RENEW graduate fellowship, to broaden participation in underserved communities and advance equity, and inclusion in SC-sponsored research; and FAIR, improving capability in emerging research institutions, HBCUs and MSIs to perform and propose competitive research and building beneficial relationships with DOE national laboratories and facilities.

Research

The Research activity supports high priority research at universities, TJNAF, BNL, ANL, LANL, and LBNL and carries out high priority experiments at CEBAF, RHIC, and elsewhere. Scientists conduct research to advance knowledge and to identify and develop the science opportunities and goals for next generation instrumentation and facilities, primarily for CEBAF and the EIC. Scientists participate in the development and implementation of targeted advanced instrumentation, including state-of-the-art detectors for experiments that may also have application in areas such as medical imaging instrumentation in coordination with NIH and homeland security. Scientists are engaged in experimental QIS research. Researchers participate in the development of scientific and experimental plans for the EIC.

TJNAF scientists and university groups play leadership roles in new experiments in the 12 GeV scientific program, and are engaged in commissioning experiments, instrumentation development, and data taking. Scientists at several national laboratories are engaged in planning for the construction of the EIC and its scientific instrumentation. ANL researchers continue precise measurements of the electric dipole moments of laser-trapped atoms as part of an intensive world-wide effort to set limits on QCD parameters and contribute to the search for possible explanations of the excess of matter over antimatter in the universe. LANL scientists continue to lead an experiment at Fermi lab to study whether anti-quarks are in orbit about the spin axis of the proton. Research groups at BNL and LBNL play leading roles in RHIC data analysis critical for determining the spin structure of the proton. Researchers at TJNAF are developing high current, polarized electron sources for next generation NP facilities.

Accelerator R&D research at universities and laboratories advance technology and core competencies essential for improving operations of the complex user facilities or developing new facilities within the NP program, including the development of transformative technology for the Nation such as, efficient, and cost-effective cryogenic systems, high gradient SRF cavities, and novel in-situ plasma processing of cryomodules. Researchers are also engaged in developing ML techniques focused on improving efficiencies of accelerator operations.

Operations

The Operations activity provides accelerator operations funding for CEBAF, which boasts unique features of continuous wave polarized beam to four experimental halls and serves over 1,800 U.S. and international users. Funding for this activity supports a team of accelerator physicists at TJNAF that operate CEBAF, as well as for power costs of operations and maintenance of the 12 GeV CEBAF. The highest priority investments in cryomodule refurbishment, spares and critical maintenance are supported to address and improve machine performance and reliability. The Request supports high priority accelerator improvements, and high priority capital equipment for research and facility instrumentation. Targeted efforts in developing advances in SRF technology to improve operations of the existing machine continue. The core competency in SRF technology plays a crucial role in supporting DOE projects and facility operations outside of nuclear physics and has broad applications from medicine to homeland security. TJNAF also has developed award-winning cryogenics techniques that have led to more cost-effective operations at TJNAF and several other SC facilities; their cryogenics expertise benefitted several SC superconducting accelerator projects. TJNAF accelerator physicists help train the next generation of accelerator physicists, enabled in part by a close partnership with nearby universities and other institutions with accelerator physics expertise. Accelerator scientists play critical roles in the design development of the EIC. The subprogram provides Experimental Support for scientific and technical staff, as well as for critical materials and supplies needed for the implementation, integration, assembly, and operation of the large and complex CEBAF experiments.

Activities and Explanation of Changes

(dollars in thousands)

FY 2023 Enacted		FY 2025 Request	Explanation of Changes FY 2025 Request vs FY 2023 Enacted
Medium Energy Physics	**$208,917**	**$197,836**	**-$11,081**
Research	$59,083	$50,592	-$8,491
Funding continues to support core research. Scientists, resident at TJNAF, RHIC, universities, and other national laboratories, will participate in high priority experiments to acquire data; develop, implement, and maintain scientific instrumentation; analyze data and publish experimental results; and train students in nuclear science and accelerator science. Funding supports analysis of RHIC polarized proton beam data to learn more about the origin of the proton's spin. Funding supports the development of detector design to be used at the EIC and further develop the scientific program. Funding continues to support researchers to pursue transformative accelerator science to improve operations of current and future NP facilities including applications of AI/ML. Research on Microelectronics is continued to study detector materials, devices, advances in front-end electronics, and integrated sensor/processor architectures. Scientists conduct research on quantum sensors to enable precision NP measurements, development of quantum sensors based on atomic-nuclear interactions. Funding supports the Accelerate Innovations in Emerging Technologies (Accelerate) initiative.		The Request will continue to support core research. Scientists, resident at TJNAF, RHIC, universities, and other national laboratories, will participate in high priority experiments to acquire data; develop, implement, and maintain scientific instrumentation; analyze data and publish experimental results; and train students in nuclear science and accelerator science. The Request will support continued analysis of RHIC polarized proton beam data to learn more about the origin of the proton's spin. The Request will support the development of detector design to be used at the EIC and further develop the scientific program. The Request will continue to support researchers to pursue transformative accelerator science to improve operations of current and future NP facilities including applications of AI/ML. Research on Microelectronics will continue to study detector materials, devices, advances in front-end electronics, and integrated sensor/processor architectures. Scientists will conduct research on quantum sensors to enable precision NP measurements, development of quantum sensors based on atomic-nuclear interactions.	The Request will support high priority core scientific workforce at universities and national laboratories conducting research related to CEBAF, RHIC, EIC, and other facilities.

(dollars in thousands)

FY 2023 Enacted	FY 2025 Request	Explanation of Changes FY 2025 Request vs FY 2023 Enacted
Operations $149,834	$147,244	-$2,590
Funding for operations of the CEBAF facility supports the continuation of the high priority experiments in the 12 GeV science program. Funding provides 4,100 operational hours (96 percent optimal funding) for research, tuning, and beam studies. Funding supports CEBAF operations, including mission readiness of the accelerator, all power and consumables of the site, cryogenics plant, activities to reduce helium consumption, activities to improve accelerator performance and reliability, high priority facility and instrumentation capital equipment, high priority accelerator improvement and GPP projects, and the key computing capabilities for data taking and analysis. Funding supports maintenance of critical core competencies and accelerator scientists, engineers, and technicians, and operations staff. Funding supports targeted facility capital equipment and accelerator improvements to modernize SRF equipment. Lab GPP investments advance the most urgent components of the Campus Strategy for infrastructure. Funding also supports the participation of accelerator scientists in accelerator R&D activities, including those for the EIC.	The Request for operations of the CEBAF facility will support the continuation of the high priority experiments in the 12 GeV science program. The Request will provide 3,170 operational hours (89 percent optimal funding) for research, beam development, and beam studies. The Request will support CEBAF operations, including mission readiness of the accelerator, all power and consumables of the site, cryogenics plant, activities to reduce helium consumption, activities to improve accelerator performance and reliability, high priority facility and instrumentation capital equipment, high priority accelerator improvement and GPP projects, and the key computing capabilities for data taking and analysis. The Request will support maintenance of critical core competencies and accelerator scientists, engineers, and technicians, and operations staff. The Request will support targeted facility capital equipment and accelerator improvements to modernize SRF equipment. Lab GPP investments will advance the most urgent components of the Campus Strategy for infrastructure. The Request will support the participation of accelerator scientists in accelerator R&D activities, including those for the EIC.	The decrease in funding will support the highest priority equipment and efforts to improve CEBAF reliability and performance.

Note:

- *Funding for the subprogram above, includes 3.65 percent of research and development (R&D) funding for the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) Programs, excluding facility operations.*

Nuclear Physics
Heavy Ion Physics

Description
The Heavy Ion Physics subprogram focuses on studies of nuclear matter at extremely high densities and temperatures, directed primarily at answering overarching questions in nuclear physics, including:

- What are the phases of strongly interacting matter, and what roles do they play in the cosmos?
- What governs the transition of quarks and gluons into pions and nucleons?
- What determines the key features of QCD and their relation to the nature of gravity and space-time?

At the Relativistic Heavy Ion Collider (RHIC), scientists continue to pioneer the study of condensed quark-gluon matter at the extreme temperatures, characteristic of the infant universe. With careful measurements, scientists are accumulating data that offer insights into the processes early in the creation of the universe, and how protons, neutrons, and other bits of normal matter developed from that plasma. Important avenues of investigation are directed at learning more about the physical characteristics of the QGP including exploring the energy loss mechanism for quarks and gluons traversing the plasma, determining the speed of sound in the plasma, establishing the threshold conditions (minimum nucleus mass and energy) under which the plasma can be formed, and discovering whether a critical point exists demonstrating a first order phase transition between normal nuclear matter and the QGP. RHIC places heavy ion research at the frontier of discovery in nuclear physics and the facility has roughly 1,000 users. Scientists exploit enhancements to the Solenoid Tracker at RHIC (STAR) detector and the super Pioneering High Energy Nuclear Interaction eXperiment (sPHENIX) detector.

A high scientific priority for the U.S. nuclear science community has been understanding how the fundamental properties of the proton such as its mass and spin are dynamically generated. The answer to this question is key to addressing an outstanding grand challenge problem of modern physics: how QCD, the theory of the strong force that explains all strongly interacting matter in terms of points-like quarks interacting via the exchange of gluons, acts in detail to generate the "macroscopic" properties of protons and neutrons. In 2018, a National Academies study gave a strong endorsement to a U.S.-based EIC, and BNL is partnering with TJNAF to design and establish the EIC at BNL. Scientists and accelerator physicists from the Heavy Ion and the Medium Energy sub-programs are partnering to advance the EIC, both playing significant leadership roles in the development of the scientific agenda and implementation of the EIC.

Over the course of the construction and implementation of the EIC, RHIC operations funding will decrease as scientific staff, engineers and technicians move from RHIC operations to the EIC project. These individuals represent the scientific and technical workforce that are essential to the operations of a complex facility like RHIC and eventually, the EIC. They have critical core competencies in collider operations that cannot easily be replaced; their support is embedded in the EIC total project cost, and they represent the core facility operations force of RHIC and the EIC. Throughout the EIC project, the temporary reprioritization of funds from the collider facility operations budget to the construction budget will reduce the amount of "new funds" needed to implement the EIC, enabling a cost-effective path forward to the implementation of this world-leading facility.

Scientists working in Heavy Ion physics leverage discovery opportunities in sensing, simulation, and computing at the intersections of nuclear physics and QIS. Core competencies exist at NP facilities in the areas of beam and collider physics, hadron beam cooling, high field superconducting magnets, SRF, and ion source technologies. AI/ML applications are pursued to optimize operation of the complex accelerators and detectors at user facilities in the NP program. Accelerator scientists also pursue accelerator science aimed at improving the operations of existing facilities. The objectives of the RENEW and FAIR Initiatives are pursued within the Heavy Ion subprogram.

Collaboration at the LHC at CERN provides U.S. researchers the opportunity to investigate states of matter under substantially different initial conditions than those provided by RHIC. Data collected by the A Large Ion Collider Experiment (ALICE), Compact Muon Solenoid (CMS), and ATLAS detectors confirm that the QGP discovered at RHIC is also seen at the higher energy, and comparisons of results from LHC to those from RHIC have led to important new insights.

Research
This activity supports high priority research at universities and at BNL, LBNL, LANL, and Oak Ridge National Laboratory (ORNL) to participate in efforts at RHIC and the LHC. NP fully supports U.S. commitments to the LHC "common funds," fees based on the level of U.S. scientist participation in the LHC program and the use of LHC computing capabilities. U.S. scientists work with their international peers in developing and implementing upgrades to the LHC scientific instrumentation. One such proposed upgrade is the CMS minimum ionizing particle timing detector (MTD) to enhance particle identification. Heavy Ion research also supports the NQISRCs in partnership with the other SC programs.

The university and national laboratory research groups support personnel and graduate students for taking data within the RHIC heavy ion program, analyzing data, publishing results, developing, and implementing scientific equipment, and planning for future experiments. BNL, LBNL, and ORNL provide computing infrastructure for petabyte-scale data analysis and state-of-the-art facilities for detector and instrument development. Scientists participate in the development of a world-leading scientific program for the future EIC.

Researchers engage in transformative accelerator R&D efforts, including advancements in ion source developments, SRF technology, and hadron beam cooling. Scientists develop cutting-edge techniques based on AI/ML of relevance to nuclear science research, accelerator facility operations and automated machine operations. Additionally, NP is supporting technical development at the intersections between real-time ML and control and the optimization of accelerator systems operations and detector design using AI/ML models.

This subprogram supports the DOE Established Program to Stimulate Competitive Research (EPSCoR), which funds research in states and territories with historically lower levels of Federal academic research funding. In FY 2025, the EPSCoR program will focus on EPSCoR implementation awards for development of research capacity and infrastructure, including equipment, for competitive research in EPSCoR jurisdictions, and continued support of early career awards.

Operations
The Heavy Ion Operations activity supports the operations and power costs of the RHIC accelerator complex at BNL. Staff provides key experimental support, including operation of the scientific equipment associated with the RHIC program. The Request will support high priority capital equipment and accelerator improvement projects at RHIC to promote enhanced and robust operations, such as upgrades to key accelerator infrastructure that will eventually be repurposed for operation of EIC. sPHENIX is the key instrument for the last RHIC data taking campaign and enables scientists to study how the near-perfect QGP liquid arises from the strongly interacting quarks and gluons from which it is formed.

Funding for RHIC operations continues to be reprioritized to EIC as scientific staff and experienced accelerator collider engineers and technicians move from RHIC operations to the EIC project. These individuals represent the scientific and technical workforce that are essential to the operations of a complex facility like RHIC and eventually, the EIC. They have critical core competencies in collider operations that cannot easily be replaced. The temporary reprioritization of funds from the collider facility operations budget to the construction budget will prioritize funding needed to implement the EIC, enabling a cost-effective path forward to the implementation of this world-leading facility.

RHIC operations allow for symbiotic, parallel, cost-effective operations of the Brookhaven Linac Isotope Producer Facility (BLIP), supported by the DOE Isotope Program to produce research and commercial isotopes critically needed by the Nation, and of the NASA Space Radiation Laboratory Program supported by NASA for the study of space radiation effects applicable to human space flight as well as electronics.

Projects
Other project costs (OPC) for the EIC support scientists and accelerator physicists to advance the conceptual design and conduct accelerator and detector R&D. Integration of laboratory core competencies and participation from across the national laboratory complex and universities continues. Accelerator and detector R&D focuses on reduction of technical risks and value engineering.

Activities and Explanation of Changes

(dollars in thousands)

FY 2023 Enacted		FY 2025 Request	Explanation of Changes FY 2025 Request vs FY 2023 Enacted
Heavy Ion Physics	**$248,236**	**$227,325**	**-$20,911**
Research	$46,149	$43,349	-$2,800
Funding supports scientists resident at RHIC, universities, and other national laboratories to develop, fabricate, implement, and maintain scientific instrumentation; participate in experimental runs to acquire data; analyze data and publish experimental results; develop scientific plans and instrumentation for the EIC; and train students in nuclear science. U.S. scientists will participate in the high priority heavy ion efforts and instrumentation upgrades at the international ALICE, CMS, and ATLAS LHC experiments. Funding supports accelerator R&D relevant to NP programmatic needs. Research activities support the NQISRCs and AI/ML aimed at applications of artificial neural networks to nuclear physics research and the optimization of accelerator performance.		The Request will support scientist's resident at RHIC, universities, and other national laboratories to develop, fabricate, implement, and maintain scientific instrumentation; participate in experimental runs to acquire data; analyze data and publish experimental results; develop scientific plans and instrumentation for the EIC; and train students in nuclear science. U.S. scientists will participate in the high priority heavy ion efforts and instrumentation upgrades at the international ALICE, CMS, and ATLAS LHC experiments. The Request will support accelerator R&D relevant to NP programmatic needs. Research activities support the recompetition/renewal of the NQISRCs, and AI/ML aimed at applications of artificial neural networks to nuclear physics research and the optimization of accelerator performance. Funding supports EPSCoR implementation grants and early career awards.	Funding will continue to support high priority core scientific workforce at universities and national laboratories to enhance high priority research at RHIC, the LHC, and for EIC science and detector development. Continued support for research in EPSCoR jurisdictions.

(dollars in thousands)

FY 2023 Enacted	FY 2025 Request	Explanation of Changes FY 2025 Request vs FY 2023 Enacted
Operations $182,087	$181,126	-$961
Funding supports RHIC operations at 2,400 hours (96 percent optimal funding) limited by installation of the new sPHENIX detector. Funding supports the RHIC accelerator complex, including mission readiness and development of the experimental halls and instrumentation, mission readiness of the suite of accelerators, all power and consumables of the site, cryogenics plant, activities to reduce helium consumption, high priority facility and instrumentation capital equipment, high priority accelerator improvement projects, and computing capabilities for data taking and analysis. Support will provide critical core competencies and accelerator scientists, engineers, and technicians, for collider operations. Accelerator scientists conduct research aimed at improving the operations of the RHIC accelerator complex.	The Request will support RHIC operations at 3,100 hours (95 percent optimal funding). The Request will support the RHIC accelerator complex, including mission readiness and development of the experimental halls and instrumentation, mission readiness of the suite of accelerators, all power and consumables of the site, cryogenics plant, activities to reduce helium consumption, high priority facility and instrumentation capital equipment, high priority accelerator improvement projects, and computing capabilities for data taking and analysis. Support will provide critical core competencies and accelerator scientists, engineers, and technicians, for collider operations. Accelerator scientists conduct research aimed at improving the operations of the RHIC accelerator complex.	The Request for RHIC operations will support operations to continue the science programs with STAR and sPHENIX. Reprioritization of effort to support EIC continues.
Projects $20,000	$2,850	-$17,150
The experienced scientists and engineers skilled in collider operations continue to transition from RHIC operations to support EIC activities.	EIC OPC funds will support continued design efforts as well and research and development to increase technical readiness as the project prepares for CD-2.	OPC support of EIC activities will continue at an anticipated lower rate as research and development activities wind down and preliminary design is advanced.

Note:

- *Funding for the subprogram above, includes 3.65 percent of research and development (R&D) funding for the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) Programs, excluding facility operations.*

Nuclear Physics
Nuclear Theory

Description

The Nuclear Theory subprogram provides the theoretical support needed to interpret the wide range of data obtained from the experimental nuclear science subprograms and to advance new ideas and hypotheses that identify potential areas for future experimental investigations. One major theme of theoretical research is the development of an understanding of the mechanisms and effects of quark confinement and deconfinement. A quantitative description of these phenomena through QCD is one of this subprogram's greatest intellectual challenges. New theoretical and computational tools are also being developed by the community to describe nuclear many-body phenomena; these approaches will likely also see important applications in condensed matter physics and in other areas of the physical sciences. Another major research area is nuclear astrophysics, which includes efforts to understand the origins of the elements in the cosmos and what the nature of the neutrino may reveal about the evolution of the early universe.

This subprogram supports the Institute for Nuclear Theory (INT) at the University of Washington and the FRIB Theory Alliance at Michigan State University. It also supports topical collaborations within the university and national laboratory communities to address only the highest priority topics in nuclear theory that merit a concentrated, team-based theoretical effort.

The U.S. Nuclear Data Program (USNDP) aims to provide current, accurate, and authoritative data to workers in basic and applied areas of nuclear science and engineering. It addresses this goal primarily through maintaining and providing public access to extensive nuclear physics databases. These databases are an important national and international resource, and they currently serve approximately five million retrievals of nuclear data annually. The USNDP also addresses important gaps in nuclear data through targeted experiments and the development and use of theoretical models. The program is managed by the National Nuclear Data Center (NNDC) at BNL. The NNDC is designated as an SC Public Reusable Research (PuRe) Data Resource, a designation commensurate with high standards of data management, resource operation, and scientific impact. NP leads an interagency working group including the NNSA, NE, DOE IP, and other federal agencies to coordinate targeted experimental efforts.

Nuclear theorists also conduct research related to QIS and quantum computing (QC), including R&D on quantum sensors to enable precision measurements, development of quantum sensors based on atomic-nuclear interactions, R&D on nuclear physics techniques to enhance qubit coherence times, and development of quantum computing algorithms applied to quantum mechanical systems and NP topical problems. In partnership with other SC programs, NP continues its role in jointly stewarding NQISRCs which focus on building the fundamental tools necessary for the United States to create quantum computers.

Scientists continue to develop cutting-edge techniques based on AI/ML to accelerate discovery in nuclear science research and incorporate next generation AI advances at the nexus of experiment, simulation, and theory.

The Nuclear Theory subprogram supports and leverages lattice quantum chromodynamics (LQCD) calculations that are critical for understanding and interpreting many of the experimental results from RHIC, LHC, and CEBAF. NP supports LQCD computing needs for dedicated computational resources with investments at TJNAF.

The Nuclear Theory subprogram also supports SciDAC, a collaborative program with ASCR that partners scientists and computer experts in research teams to address major scientific challenges that require supercomputer facilities performing at current technological limits.

The Nuclear Theory subprogram supports the RENEW initiative to provide undergraduate and graduate training opportunities for students and academic institutions not currently well represented in the U.S. S&T ecosystem. The Request includes funding for RENEW in the theory subprogram as well as the other NP subprograms with the distribution dependent on peer review results of topical proposals.

Research

This activity supports high priority research at ANL, BNL, LANL, LBNL, Lawrence Livermore National Laboratory (LLNL), ORNL, TJNAF, and universities. This research advances our fundamental understanding of nuclear physics, interpreting the results of experiments carried out under the auspices of the experimental nuclear physics program, and identifies and explores compelling new areas of research. The Request continues support of topical collaborations within available funds to bring together theorists to address specific emerging and high-priority theoretical challenges. NP will prioritize transitioning ECP researchers, software, and technologies into core research efforts and DOE priority research areas as ECP concludes.

The Request supports research related to QIS and QC to provide technological and computational advances relevant to NP and other fields. The Nuclear Science Advisory Committee published a report[a] in October 2019 to articulate further priority areas in QIS/QC where unique opportunities exist for nuclear physics contributions.

Support continues for the fourth year of SciDAC-5 awards initiated in FY 2022. In addition to addressing specific problems relevant for nuclear physics research, SciDAC projects continue to serve as critical research for highly trained scientists who can address national needs. A new round of topical collaborations awarded in FY 2023 is supported for a third year of these efforts.

Funding for AI/ML research continues in FY 2025 to develop cutting-edge techniques based on AI of relevance to nuclear science research.

The Request supports the activities of the USNDP to collect, evaluate, and disseminate nuclear physics data for basic nuclear research and for applied nuclear technologies and their development, providing for world-leading acquisition and dissemination of high-quality data for public consumption. U.S. efforts focus on improving the completeness and reliability of data already archived that is used for industry and for a variety of Federal missions, and the USNDP expands the effort to conduct experiments needed to address gaps in the data archives deemed of high priority and urgency. NP will collaborate with other Federal Agencies, including NNSA, NE, DHS, and DOE IP, that are members of the NP-led Inter-Agency Nuclear Data Working Group, to carry out experimental measurements.

This activity also supports the FAIR initiative which will provide focused investment on building institutional research capacity at HBCUs, MSIs and emerging research institutions.

[a] "*Nuclear Physics and Quantum Information Science*" Nuclear Science Advisory Committee, October 2015 (https://science.osti.gov/~/media/np/nsac/pdf/2015LRP/2015_LRPNS_091815.pdf).

Activities and Explanation of Changes

(dollars in thousands)

FY 2023 Enacted		FY 2025 Request	Explanation of Changes FY 2025 Request vs FY 2023 Enacted
Nuclear Theory	**$67,873**	**$84,691**	**+$16,818**
Research	$67,873	$84,691	+$16,818
Funding supports high priority QIS efforts. LQCD computing investments continue at TJNAF. High priority theoretical research at universities and national laboratories is supported for the interpretation of experimental results obtained at NP facilities, and the exploration of new ideas and hypotheses that identify potential areas for future experimental investigations. Theorists focuses on applying QCD to a wide range of problems from nucleon structure and hadron spectroscopy, through the force between nucleons, to the structure of light nuclei. Advanced dynamic calculations to describe relativistic nuclear collisions and nuclear structure and reactions continues to focus on activities related to the research program at the upgraded 12 GeV CEBAF facility, the research program at FRIB, and ongoing and planned RHIC experiments. Funding supports the second year of SciDAC-5 grants and the first year of theory topical collaborations. Funding supports investments in an initiative to develop cutting-edge AI/ML techniques of relevance to nuclear science research, and accelerator facility operations.		The Request will support high priority QIS efforts. LQCD computing investments continue at TJNAF. Funding will support high priority theoretical research at universities and national laboratories for the interpretation of experimental results obtained at NP facilities, and the exploration of new ideas and hypotheses that identify potential areas for future experimental investigations. Theorists will focus on applying QCD to a wide range of problems from nucleon structure and hadron spectroscopy, through the force between nucleons, to the structure of light nuclei. Advanced dynamic calculations to describe relativistic nuclear collisions and nuclear structure and reactions will continue to focus on activities related to the research program at the upgraded 12 GeV CEBAF facility, the research program at FRIB, and ongoing and planned RHIC experiments. The Request will support the fourth year of SciDAC-5 grants, as well as the third year of theory topical collaborations. Funding will target investments in an initiative to develop cutting-edge AI/ML techniques of relevance to nuclear science research, and accelerator facility operations.	Funding will support the highest priority research in nuclear theory, growth of the FAIR and RENEW initiatives, transition of ECP related activities to core, and DOE priority research areas.

(dollars in thousands)

FY 2023 Enacted	FY 2025 Request	Explanation of Changes FY 2025 Request vs FY 2023 Enacted
This activity also supports the RENEW initiative to provide undergraduate and graduate training opportunities for students and academic institutions not currently well represented in the U.S. S&T ecosystem. Funding also supports the FAIR initiative.	The RENEW initiative expands targeted efforts to increase participation and retention of individuals from underrepresented groups in SC research activities, including a RENEW graduate fellowship. The Request will grow support for the FAIR initiative. Within available resources, NP will prioritize transitioning ECP researchers, software, and technologies into core research efforts and DOE priority research areas as ECP concludes.	
Funding continues the expanded USNDP efforts to collect, evaluate, and disseminate nuclear physics data for basic nuclear research and for applied nuclear technologies and their development initiated in FY 2022.	The Request will continue the expanded USNDP efforts to collect, evaluate, and disseminate nuclear physics data for basic nuclear research and for applied nuclear technologies and their development.	Funding will support nuclear data efforts of the USNDP.

Note:

- *Funding for the subprogram above, includes 3.65 percent of research and development (R&D) funding for the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) Programs, excluding facility operations.*

Nuclear Physics
Low Energy Physics

Description
The Low Energy Physics subprogram includes activities in Nuclear Structure and Nuclear Astrophysics and Fundamental Symmetries.

Nuclear Structure and Nuclear Astrophysics

Questions associated with Nuclear Structure and Nuclear Astrophysics include:

- What is the nature of the nuclear force that binds protons and neutrons into stable nuclei and rare isotopes? What is the origin of simple patterns in complex nuclei? What is the nature of neutron stars and dense nuclear matter?
- What are the origins of the elements in the cosmos? What are the nuclear reactions that drive stars and stellar explosions?

The Nuclear Structure and Nuclear Astrophysics activities address these questions through support of research to develop a comprehensive description of nuclei using beams of stable and rare isotopes to yield new insights and reveal new nuclear phenomena. The activities also measure the cross sections of the nuclear reactions that power stars and lead to spectacular stellar explosions, which are responsible for the synthesis of the elements.

ATLAS at ANL is an SC scientific user facility serving approximately 350 scientists per year. ATLAS is the world's premiere facility for stable beams, providing high-quality beams of all the stable elements up to uranium. Selected beams of short-lived nuclei are produced at ATLAS using the Neutron-generator Upgrade to the Californium Rare Ion Breeder Upgrade (nuCARIBU) ion source. The facility nurtures an expert core competency in scientific instrumentation development and accelerator science, the latter through development of SRF cavities relevant to next generation high-performance linacs. ATLAS stewards the Center for Accelerator Target Science (CATS), a national asset providing critical targets for the community. Investments to increase ATLAS capabilities including a Multi-User Upgrade (MUU) are underway to address high user demand.

FRIB at Michigan State University (MSU), an SC scientific user facility since FY 2020, provides beams of rare isotopes to test the limits of nuclear existence and advance understanding of the atomic nucleus and the evolution of the cosmos. FRIB's reach will be enhanced by the GRETA MIE, which will provide new opportunities to discover and characterize key nuclei for electric dipole moment searches, and open new areas of study in nuclear astrophysics. The High Rigidity Spectrometer (HRS) will exploit FRIB's fast beam capabilities, enabling the most sensitive experiments with the most neutron-rich nuclei. Scientists participate in AI/ML research, conducting R&D targeting automated optimization of accelerator availability, performance, and operation, as well as software development enabling AI/ML-driven discovery. The Low Energy subprogram also supports the objectives of the RENEW and FAIR Initiatives.

Scientists participate in the international effort to discover and characterize new "super heavy" elements in the periodic table. U.S. researchers played a prominent role in the discovery of Elements 115, 117, and 118, and Element 117 was named Tennessine to acknowledge the leadership role of the U.S. in these efforts. Research is ongoing to characterize these new elements and to discover Element 120. NP supports operations of the LBNL 88-Inch Cyclotron for an in-house program studying the properties of newly discovered elements as well as conducting searches for new super-heavy elements. DOD and NASA exploit capabilities at the 88-Inch Cyclotron to develop radiation-resistant electronics for their missions.

Three university Centers of Excellence are supported within the Low Energy subprogram, each with specific goals and unique physics programs: the Cyclotron Institute at Texas A&M University (TAMU), the Triangle Universities Nuclear Laboratory (TUNL) at Duke University, and the Center for Experimental Nuclear Physics and Astrophysics (CENPA) at the University of Washington.

Fundamental Symmetries

Questions related to Fundamental Symmetries of nature addressed in low energy nuclear physics experiments include:

- What is the nature of neutrinos, what are their masses, and what role have they played in creating the imbalance between matter and antimatter in our universe? Is there evidence from the electric-dipole moments of atomic nuclei and the neutron that indicate our current understanding of the fundamental laws governing nuclear physics is incomplete?
- Will precise measurements in electron scattering and the decay of nuclei indicate the existence of forces that were present at the dawn of the universe, and disappeared from view as the universe evolved?

The Fundamental Symmetries activities address these questions through precision studies using neutron and electron beams and decays of nuclei, including beta decay, double-beta decay, and neutrino-less double beta decay (NLDBD). U.S. scientists are world leaders in neutrino science and NP is the SC steward of neutrino mass measurements and NLDBD. Often in partnership with NSF, NP has invested in neutrino experiments, playing critical roles in international experiments that depend on U.S. leadership for their ultimate success: e.g., the Cryogenic Underground Observatory for Rare Events (CUORE), the Karlsruhe Tritium Neutrino Experiment (KATRIN), and Project 8. In partnership with NSF, NP also participates in the international LEGEND-200 experiment. The NSAC 2023 LRP recommended "the United States lead an international consortium that will undertake a neutrinoless double beta decay campaign, featuring the expeditious construction of ton-scale experiments, using different isotopes and complementary techniques." NLDBD can only occur if neutrinos are their own anti-particles. The observation of such events would have profound, game changing consequences for present understanding of the physical universe. NP has invested in R&D on candidate technologies for next–generation ton-scale experiments, including crystals of enriched germanium (LEGEND-1000), liquid xenon (nEXO), and lithium molybdenate crystals (CUPID). The Request will provide support for ton-scale research based on one or more of these technologies to progress toward CD-1, Approve Alternative Selection and Cost Range. The NLDBD MIE received CD-0, Approval of Mission Need, in November 2018.

The MOLLER MIE will measure the parity-violating asymmetry in electron-electron scattering at CEBAF which is uniquely sensitive to the possible existence of new as-yet unforeseen particles. Evidence for electric dipole moments of the neutron and atoms violate time reversal invariance and would shed light on the matter/anti-matter imbalance in the universe. Beams of cold and ultracold neutrons with the dedicated Fundamental Neutron Physics Beamline (FNPB) at the Spallation Neutron Source (SNS) are used to study fundamental properties of neutrons.

Scientists engaged in Fundamental Symmetries research are particularly well positioned with their expertise in rare signal detection, to engage in research on QIS and QC. They contribute to R&D on quantum sensors to enable precision NP measurements, development of quantum sensors based on atomic-nuclear interactions, and development of quantum computing algorithms applied to quantum mechanical systems and NP topical problems.

<u>Nuclear Structure and Nuclear Astrophysics Research</u>
This activity supports high priority research groups at ANL, LBNL, LLNL, and ORNL, and at universities. Scientists develop, fabricate, and use specialized instrumentation at ATLAS, and participate in the acquisition and analysis of data. Scientists design, fabricate, install, and commission instrumentation at FRIB. The Request supports researchers at other facilities to help lead the FRIB scientific mission. Progress continues on the GRETA MIE, although no new funds are requested in FY 2025, as well as the HRS. Scientists participate in research to characterize and discover new super-heavy elements at international facilities and the 88-Inch Cyclotron. The Request supports the university Centers of Excellence at TUNL and TAMU for the conduct of nuclear structure and nuclear astrophysics experiments. Accelerator scientists participate in transformative accelerator R&D, developing next generation SRF cavities and ion sources for accelerators. Scientists utilize AI/ML advances to improve machine performance and reliability and accelerate scientific discovery.

<u>Fundamental Symmetries Research</u>
The activity supports high priority research at BNL, LANL, LBNL, LLNL, ORNL, Pacific Northwest National Laboratory, and SLAC National Accelerator Laboratory, and at universities. R&D continues efforts exploring whether shift moments are an indicator of new physics. Engineering and design efforts continue for international ton-scale NLDBD research, along with

targeted R&D. Progress continues on the MOLLER MIE, although no new funds are requested in FY 2025. Scientists participate in R&D for Project 8 and in the operations of the KATRIN experiment to provide a measurement of the neutrino mass. University Centers of Excellence at TUNL, CENPA, and TAMU with unique capabilities are exploited to advance research in Fundamental Symmetries. Researchers conduct NP research of relevance to QIS, with a focus on novel quantum sensors.

Nuclear Structure and Nuclear Astrophysics Operations

The activity supports facility and operations costs associated with ATLAS, FRIB, and the 88-Inch Cyclotron Funding provides support for the operations and power costs of the ATLAS, and targeted support for high priority accelerator and scientific instrumentation capital equipment, accelerator improvement projects, and experimental support. The ATLAS core competency in accelerator science is maintained. Critical efforts to address facility oversubscription and increase available beam time continue with the implementation of the cost-effective MUU Accelerator Improvement Project.

The Request supports FRIB operations to provide a reliable source of rare isotopes using in-flight production methods. The Request supports beam time for the highest priority experiments, improvements to scientific instrumentation and experimental capabilities, and accelerator enhancements to support progress towards reaching full power.

The Request also sustains operations of the 88-Inch Cyclotron for a focused in-house nuclear physics program which includes characterization and searches for new elements and nuclear data measurements.

Nuclear Physics
Low Energy Physics

Activities and Explanation of Changes

(dollars in thousands)

FY 2023 Enacted		FY 2025 Request	Explanation of Changes FY 2025 Request vs FY 2023 Enacted
Low Energy Physics	**$230,170**	**$213,239**	**-$16,931**
Research	$77,651	$72,334	-$5,317
Funding supports high priority university and laboratory nuclear structure and nuclear astrophysics efforts at ATLAS and installation and commissioning of instrumentation for the FRIB scientific program. Funding targets research for critical FRIB scientific personnel to lead the scientific program at FRIB. Scientists continue to participate in the characterization of recently discovered elements and search for new ones. Research will continue at the university-based Centers of Excellence at TUNL, CENPA, and TAMU. Scientists utilize AI/ML that can promote automated platforms to improve machine performance and reliability and advance detector design and data processing.		The Request will support high priority university and laboratory nuclear structure and nuclear astrophysics efforts at ATLAS and FRIB. Scientists will participate in the characterization of recently discovered elements and search for new ones. Research will continue at the university-based Centers of Excellence at TUNL, CENPA, and TAMU. Scientists utilize AI/ML that can promote automated platforms to improve machine performance and reliability and advance detector design and data processing.	The Request will support the highest priority research efforts and essential workforce at universities and national laboratories, with a focus on conducting experiments at ATLAS and FRIB.
High priority research in NLDBD will continue with a strategic mix of efforts for selection in FY 2023. Funding supports U.S. participation in the operations of the international KATRIN experiment.		High priority research in NLDBD will continue with a strategic mix of efforts for selection in FY 2024. The Request will continue support for U.S. participation in the operations of the international KATRIN experiment.	The Request will support the highest priority research efforts and essential workforce at universities and national laboratories.

(dollars in thousands)

FY 2023 Enacted		FY 2025 Request	Explanation of Changes FY 2025 Request vs FY 2023 Enacted
Operations	$128,579	$135,646	+$7,067
ATLAS operates for 5,950 hours (96 percent of optimal funding). Funding supports operations, staff, maintenance, and high priority accelerator improvement projects and capital equipment for the facility and scientific instrumentation, including the development of a multi-user capability. Funding also supports the second year of operations at FRIB for 3,600 hours (99 percent of optimal funding) to execute the first full year of the scientific program. Funding continues operations of the 88-Inch Cyclotron for high priority experiments studying newly discovered elements.		ATLAS will operate for 5,900 hours (90 percent of optimal funding). The Request will fund operations, staff, maintenance, and high priority accelerator improvement projects and capital equipment for the facility and scientific instrumentation, including the development of a multi-user capability. The Request will also support the second year of operations at FRIB for 3,700 hours (90 percent of optimal funding) to execute the first full year of the scientific program. Funding will sustain operations of the 88-Inch Cyclotron for high priority experiments studying newly discovered elements.	Request will support FRIB, ATLAS, and additional nuclear physics research hours at the 88-Inch Cyclotron for element discovery.
Projects	$23,940	$5,259	-$18,681
Funding continues support for the GRETA MIE, MOLLER MIE, NLDBD MIE, and the HRS research project. The GRETA and MOLLER MIEs received their final funding allocation.		The Request will continue support for the NLDBD MIE and the HRS research project.	The GRETA and MOLLER MIEs complete their baselined and planned funding profiles with the FY 2023 Enacted Appropriations.

Note:

- *Funding for the subprogram above, includes 3.65 percent of research and development (R&D) funding for the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) Programs, excluding facility operations.*

Description

This subprogram supports all line-item construction for the entire NP program. All TECs are funded in this subprogram, including engineering, design, and construction. OPC's are funded in the relevant subprograms. The FY 2025 Request continues the construction effort for the EIC, which will be located at BNL. The estimated TPC range for the EIC project is $1.7 billion to $2.8 billion, with a point estimate of $2.419 billion. BNL has teamed with TJNAF to lead the development and implementation of the EIC. The EIC scope includes an electron injector, rapid cycling synchrotron, an electron storage ring, modifications to one of the two RHIC ion rings, one interaction region with a detector, support buildings, and other infrastructure. Future improvements not part of the project scope would further develop a second interaction region and acquire for it a detector. The project is expected to attract international collaboration and contributions.

<u>20-SC-52, Electron Ion Collider EIC, BNL</u>

The EIC project will increasingly rely on RHIC scientists, engineers, and technicians as RHIC activities ramp down. This workforce with critical core competencies in collider operations remains essential to RHIC now and eventually EIC operations. They cannot easily be replaced. The temporary reprioritization of funds from the collider facility operations budget to the construction budget will supplement funding needed to implement the EIC, enabling a cost-effective path forward to the implementation of this world-leading facility.

Since the release of the 2002 LRP for Nuclear Science, a high priority for the U.S. nuclear science community has been understanding how the fundamental properties of the proton, such as its mass and spin, are dynamically generated by the extraordinarily strong color fields resulting from dense systems of gluons in nucleons and nuclei. The answer to this question is key to addressing an outstanding grand challenge problem of modern physics: how quantum chromodynamics, the theory of the strong force, which explains all strongly interacting matter in terms of points like quarks interacting via the exchange of gluons, acts to generate the "macroscopic" properties of protons and neutrons. The 2023 LRP for Nuclear Science recommended "…the expeditious completion of the EIC as the highest priority for facility construction." A National Academies study, charged to independently assess the impact, uniqueness, and merit of the science that would be enabled by U.S. construction of an electron-ion collider, gave a strong endorsement to a U.S.-based EIC, and recognized its critical role in maintaining U.S. leadership in nuclear science and accelerator R&D. Scientists and accelerator physicists from both the Medium Energy and Heavy Ion subprograms are actively engaged in the development of the scientific agenda, design of the facility and development of scientific instrumentation related to a proposed EIC. Critical Decision-0 (CD-0), Approve Mission Need, was received on December 19, 2019, followed by CD-1, Approve Alternative Selection and Cost Range on June 29, 2021.

Activities and Explanation of Changes

(dollars in thousands)

FY 2023 Enacted		FY 2025 Request	Explanation of Changes FY 2025 Request vs FY 2023 Enacted
Construction	**$50,000**	**$110,000**	**+$60,000**
20-SC-52 Electron Ion Collider (EIC), BNL	$50,000	$110,000	+$60,000
Funding continues TEC support for the EIC. The funds are for engineering and design to reduce technical risk after completion of the conceptual design. RHIC operations includes a “reprioritization” of expert workforce from the RHIC facilities operations budget to support both the EIC OPC and TEC request.		The Request will continue TEC funding for the EIC. The funds will be used for engineering and design to reduce technical risk after completion of the conceptual design and limited long lead procurements. RHIC operations includes a “reprioritization” of expert workforce from the RHIC facilities operations budget to support the EIC OPC and TEC request.	The increased funding will support additional engineering and design efforts and limited long lead procurements. These additional efforts will help align the establishment of the performance baselines and start of construction with the completion of the RHIC science program.

Nuclear Physics
Capital Summary

(dollars in thousands)

	Total	Prior Years	FY 2023 Enacted	FY 2024 Annualized CR	FY 2025 Request	FY 2025 Request vs FY 2023 Enacted
Capital Operating Expenses						
Capital Equipment	N/A	N/A	34,988	20,307	16,307	-18,681
Minor Construction Activities						
General Plant Projects	N/A	N/A	2,642	2,642	1,642	-1,000
Accelerator Improvement Projects	N/A	N/A	5,211	5,211	5,211	–
Total, Capital Operating Expenses	**N/A**	**N/A**	**42,841**	**28,160**	**23,160**	**-19,681**

Capital Equipment

(dollars in thousands)

	Total	Prior Years	FY 2023 Enacted	FY 2024 Annualized CR	FY 2025 Request	FY 2025 Request vs FY 2023 Enacted
Capital Equipment						
Low Energy Physics						
Gamma-Ray Energy Tracking Array (GRETA), LBNL	57,700	42,200	15,500	–	–	-15,500
High Rigidity Spectrometer	122,550	39,080	3,000	6,259	3,259	+259
MOLLER	47,220	43,220	4,000	–	–	-4,000
Ton-Scale Neutrinoless Double Beta Decay (NLDBD) MIE	634,490	10,800	1,440	3,000	2,000	+560
Total, Non-MIE Capital Equipment	N/A	N/A	34,988	20,307	16,307	–
Total, Capital Equipment	**N/A**	**N/A**	**34,988**	**20,307**	**16,307**	**-18,681**

Notes:

- *The Capital Equipment table includes MIEs located at a DOE facility with a Total Estimated Cost (TEC) > $10M and MIEs not located at a DOE facility with a TEC >$2M.*
- *The High Rigidity Spectrometer (HRS) is not an MIE, but a research project supported on a cooperative agreement with Michigan State University.*
- *The current estimated TEC for the GRETA MIE is $57,580,000. In FY 2023 $120,000 was redirected to OPC funding not reflected in this table.*
- *The current estimated TEC for the NLDBD MIE is $633,050,000. In FY 2023 $1,440,000 was redirected to OPC funding not reflected in this table.*

Minor Construction Activities

(dollars in thousands)

	Total	Prior Years	FY 2023 Enacted	FY 2024 Annualized CR	FY 2025 Request	FY 2025 Request vs FY 2023 Enacted
General Plant Projects (GPP)						
GPPs (greater than $5M and $34M or less)						
nEDM Experimental Building 2 (EB-2)	2,000	–	1,000	1,000	–	-1,000
Total GPPs (greater than $5M and $34M or less)	N/A	N/A	1,000	1,000	–	-1,000
Total GPPs $5M or less	N/A	N/A	1,642	1,642	1,642	–
Total, General Plant Projects (GPP)	**N/A**	**N/A**	**2,642**	**2,642**	**1,642**	**-1,000**
Accelerator Improvement Projects (AIP)						
Total AIPs $5M or less	N/A	N/A	5,211	5,211	5,211	–
Total, Accelerator Improvement Projects (AIP)	**N/A**	**N/A**	**5,211**	**5,211**	**5,211**	**–**
Total, Minor Construction Activities	**N/A**	**N/A**	**7,853**	**7,853**	**6,853**	**-1,000**

Notes:

- *GPP activities $5M and less include design and construction for additions and/or improvements to land, buildings, replacements or addition to roads, and general area improvements. AIP activities $5M and less include minor construction at an existing accelerator facility.*
- *Please note that the nEDM experiment was cancelled in the fall of 2023, eliminating the need for the EB-2.*

Nuclear Physics
Major Items of Equipment Description(s)

Low Energy Physics: Nuclear Structure and Nuclear Astrophysics MIE and Research Project:

Gamma-Ray Energy Tracking Array (GRETA) MIE

GRETA directly supports the NP mission by addressing the goal to understand the structure of nuclear matter, the processes of nuclear astrophysics, and the nature of the cosmos. A successful implementation of this detector will represent a major advance in gamma-ray tracking detector technology that will impact nuclear science, as well as detection techniques in homeland security and medicine. GRETA will provide unprecedented gains in detection sensitivity, addressing several high priority scientific topics, including how weak binding and extreme proton-to-neutron asymmetries affect nuclear properties and how the properties of nuclei evolve with changes in excitation energy and angular momentum. GRETA will provide transformational improvements in efficiency, peak-to-total ratio, and higher position resolution than the current generation of detector arrays. In particular, the capability of reconstructing the position of the interaction with millimeter resolution will fully exploit the physics opportunities of FRIB. With GRETA, beam-times necessary for the proposed experiments will be significantly shortened, allowing for some experiments that would otherwise not be feasible at all. GRETA received CD-0 approval on September 15, 2015, and CD-1 approval on October 4, 2017. The project received CD-3A approval for long lead procurements on August 16, 2018, and CD-2/3 on October 7, 2020, with a TPC of $58,300,000. The FY 2023 Enacted appropriation represented the last year of planned funding for the GRETA MIE. CD-4 is scheduled for March 2028.

High Rigidity Spectrometer (HRS) Research Project

The HRS at FRIB will increase the scientific potential of state-of-the-art and community-priority devices, such as GRETA, and other ancillary detectors. FRIB is the world's premier rare-isotope beam facility capable of producing approximately 80 percent of the isotopes predicted to exist. The scientific impact of the FRIB fast beam science program will be enhanced by luminosity gain factors of between two and one hundred for neutron-rich isotopes, with the largest gains for the most neutron-rich species, by construction of the HRS. The HRS will allow experiments with beams of rare isotopes at the maximum production rates for fragmentation or in-flight fission. This enhancement in experimental sensitivity provides access to critical isotopes not available otherwise. The 2023 NSAC LRP recognized that the HRS will push the study of unstable nuclei toward the driplines, increasing the scientific reach of FRIB. The HRS is being funded through a cooperative agreement with MSU and is not a capital asset (MIE). HRS received CD-0 approval in November 2018, and CD-1 in September 2020, with a TPC range of $85,000,000 to $111,400,000. The FY 2025 Request for the HRS of $3,259,000 will support the management team, coordination of collaboration activities and allow preliminary engineering and design work towards future critical decision points.

Low Energy Physics: Fundamental Symmetries MIEs:

Measurement of a Lepton-Lepton Electroweak Reaction (MOLLER) MIE

The MOLLER experiment directly supports the NP mission by measuring the parity-violating asymmetry in polarized electron-electron (Møller) scattering. This extremely small asymmetry is predicted to be on the order of 35 parts per billion (ppb), which requires unprecedented experimental techniques employed for this experiment. CD-0 was approved December 2016. CD-1 was approved in December 2020 with a TPC range of $42,000,000 to $60,100,000. MOLLER achieved CD-3A in Q2 of FY 2023. The project is working on preliminary engineering and design in advance of a combined CD-2/3 planned in Q1 of FY 2024. CD-4 is expected in Q4 of FY2027. The MOLLER experiment is an ultra-precise measurement of the weak mixing angle using Møller scattering which will improve on existing measurements by a factor of five, yielding the most precise measurement of the weak mixing angle at low or high energy anticipated over the next decade. This new result would be sensitive to the interference of the electromagnetic amplitude with new neutral current amplitudes as weak as approximately 10^{-3} G_F (Fermi Factor) from as yet undiscovered dynamics beyond the Standard Model. The resulting reach for scientific discovery is far greater, for at least a decade, than any existing or proposed experiment which searches for new physics signaled by a departure from the expected before vs after conservation of flavor, charge and parity in fundamental particle interactions, and yields a unique window to new physics at MeV and multi-TeV scales, complementary to direct searches at high energy colliders such as the Large Hadron Collider (LHC). The FY 2023 Enacted appropriation represented the last year of planned funding for the MOLLER MIE.

Ton-Scale Neutrino-less Double Beta Decay (NLDBD) Program MIE

The Ton-Scale NLDBD Program, implemented by deploying experiments instrumenting a large volume of a specially selected isotope to detect neutrino-less nuclear beta decays (where within a single nucleus, two neutrons decay into two protons and two electrons with no neutrinos emitted), directly supports NP's mission to explore all forms of nuclear matter. NLDBD can only occur if neutrinos are their own anti-particles and the observation of "lepton number violation" in such neutrino-less beta decay events would have profound consequences for present understanding of the physical universe. For example, one exciting prospect is that the observation of NLDBD would elucidate the mechanism, completely unknown at present, by which the mass of the neutrino is generated. The observation of lepton number violation would also have major implication for the present-day matter/anti-matter asymmetry which has perplexed modern physics for decades. Several demonstrator efforts using smaller volumes of isotopes and various technologies (bolometry in tellurium dioxide crystals, light collection in liquid xenon, charge collection in enriched germanium-76) have been in progress for several years, and all are in the process of delivering new state-of-the-art lifetime limits for neutrino-less double beta decay which are of order a few times 10^{25} years. The goal of the ton-scale program is to reach a lifetime limit of 10^{28} years with high confidence. For reference, the "lifetime limit" discussed is the time one might have to wait to observe neutrino-less double beta decay if observing a single nucleus only. Fortunately, in the ton of isotope planned for the ton-scale neutrino-less double beta decay experiments there are many trillions of nuclei. Thus, such decays, if they exist, should be observable on a much more reasonable timescale (five to ten years) similar to other large modern physics experiments. NLDBD received CD-0 approval in November 2018 with a TPC range of $215,000,000 to $250,000,000. The FY 2025 Request of $2,000,000 will support the management teams, collaboration activities, and preliminary engineering and design.

Nuclear Physics
Construction Projects Summary

(dollars in thousands)

	Total	Prior Years	FY 2023 Enacted	FY 2024 Annualized CR	FY 2025 Request	FY 2025 Request vs FY 2023 Enacted
20-SC-52, Electron Ion Collider (EIC), BNL						
Total Estimated Cost (TEC)	2,126,000	154,240	50,000	95,000	110,000	+60,000
Other Project Cost (OPC)	292,450	69,450	20,000	2,850	2,850	-17,150
Total Project Cost (TPC)	**2,418,450**	**223,690**	**70,000**	**97,850**	**112,850**	**+42,850**
Total, Construction						
Total Estimated Cost (TEC)	**N/A**	**N/A**	**50,000**	**95,000**	**110,000**	**+60,000**
Other Project Cost (OPC)	**N/A**	**N/A**	**20,000**	**2,850**	**2,850**	**-17,150**
Total Project Cost (TPC)	**N/A**	**N/A**	**70,000**	**97,850**	**112,850**	**+42,850**

Nuclear Physics
Scientific User Facility Operations

The treatment of user facilities is distinguished between two types: TYPE A facilities that offer users resources dependent on a single, large-scale machine; TYPE B facilities that offer users a suite of resources that is not dependent on a single, large-scale machine.

(dollars in thousands)

	FY 2023 Enacted	FY 2023 Current	FY 2024 Annualized CR	FY 2025 Request	FY 2025 Request vs FY 2023 Enacted
Scientific User Facilities - Type A					
Relativistic Heavy Ion Collider	**182,087**	**182,045**	**166,993**	**181,126**	**-961**
Number of Users	1,010	1,053	1,010	1,010	–
Achieved Operating Hours	–	1,641	–	–	–
Planned Operating Hours	2,400	2,400	–	3,100	+700
Continuous Electron Beam Accelerator Facility	**149,834**	**147,942**	**138,620**	**147,244**	**-2,590**
Number of Users	1,730	1,904	1,730	1,800	+70
Achieved Operating Hours	–	3,306	–	–	–
Planned Operating Hours	4,100	4,100	2,240	3,170	-930
Facility for Rare Isotope Beams	**98,388**	**98,388**	**90,086**	**103,336**	**+4,948**
Number of Users	650	902	755	755	+105
Achieved Operating Hours	–	3,948	–	–	–
Planned Operating Hours	3,600	3,600	2,142	3,700	+100
Argonne Tandem Linac Accelerator System	**24,350**	**24,350**	**23,464**	**25,110**	**+760**
Number of Users	340	299	340	340	–
Achieved Operating Hours	–	5,769	–	–	–
Planned Operating Hours	5,950	5,950	2,880	5,900	-50
Total, Facilities	**454,659**	**452,725**	**419,163**	**456,816**	**+2,157**
Number of Users	3,730	4,158	3,835	3,905	+175
Achieved Operating Hours	–	14,664	–	–	–

(dollars in thousands)

	FY 2023 Enacted	FY 2023 Current	FY 2024 Annualized CR	FY 2025 Request	FY 2025 Request vs FY 2023 Enacted
Planned Operating Hours	16,050	16,050	7,262	15,870	-180

Notes:
- *Achieved Operating Hours and Unscheduled Downtime Hours will only be reflected in the Congressional budget cycle which provides actuals.*
- *Percent optimal operations defines what is achieved at this funding level. This includes staffing, up-to-date equipment and software, operations and maintenance, and appropriate investments to maintain world leadership.*

Nuclear Physics
Scientific Employment

	FY 2023 Enacted	FY 2024 Annualized CR	FY 2025 Request	FY 2025 Request vs FY 2023 Enacted
Number of Permanent Ph.Ds (FTEs)	856	860	810	-46
Number of Postdoctoral Associates (FTEs)	366	372	355	-11
Number of Graduate Students (FTEs)	524	529	496	-28
Number of Other Scientific Employment (FTEs)	1,023	1,028	1,000	-23
Total Scientific Employment (FTEs)	**2,769**	**2,789**	**2,661**	**-108**

Note:
- *Other Scientific Employment (FTEs) includes technicians, engineers, computer professionals and other support staff.*

20-SC-52 Electron Ion Collider (EIC), BNL
Brookhaven National Laboratory, BNL
Project is for Design and Construction

1. Summary, Significant Changes, and Schedule and Cost History

Summary

The EIC project will acquire facilities, infrastructure, systems, and equipment that will enable scientists to investigate the basic building blocks of nuclei and how quarks and gluons, the particles inside neutrons and protons, interact dynamically via the strong force to generate the fundamental properties of neutrons and protons, such as mass and spin. The FY 2025 Request for the EIC is $110,000,000 of TEC funding and $2,850,000 of OPC funding. The current TPC range is $1,700,000,000 to $2,800,000,000. The preliminary TPC estimate for the project is $2,418,450,000.

Significant Changes

The EIC was initiated in FY 2020. The project most recently received Critical Decision (CD)-1, Approve Alternative Selection and Cost Range, on June 29, 2021. The estimated completion date (CD-4) is 1Q FY 2035 and includes schedule contingency recommended by peer review. In addition, the preliminary TPC in this PDS reflects continued elaboration of the project scope and the point estimate remains within the cost range. The project expects CD-2, Approve Performance Baseline, in Q3 FY 2025.

In FY 2023, the EIC team focused on preliminary design of the infrastructure, collider machine, and detector instrumentation. Research and development to increase technical readiness for certain detector and technical scope and fostering relations with potential in-kind contributors continued. The team developed a list of possible long-lead procurements for a CD-3A, Approve Long Lead Procurement, planned in Q2 FY 2024. Through the Inflation Reduction Act (IRA) the project received $10,000,000 OPC and $128,240,000 TEC at the end of FY 2022. The IRA funds will support architect-engineering services for infrastructure, designs for the collider machine and detector instrumentation, and following a CD-3A, long lead procurements. IRA funds will reduce the peak requests for new funding. FY 2024 activities include completing planning and design for conventional infrastructure and technical systems, research and development to increase technical readiness for certain detector and technical scope, executing approved CD-3A scope, and pursuing agreements with potential in-kind contributors. FY 2025 funding will support final research and development, design, and constructability adjustments, to validate technical assumptions and to reduce project risk, followed by the start of construction.

A Federal Project Director (FPD) has been assigned to this project and has approved this project data sheet. The FPD is certified at Level 3, and the accrual of qualifications for Level 4 certification is in process.

Critical Milestone History

Fiscal Year	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	CD-4
FY 2025	12/19/19	01/12/21	6/29/2021	3Q FY 2025	3Q FY 2025	3Q FY 2025	1Q FY 2035

CD-0 – Approve Mission Need for a construction project with a conceptual scope and cost range; **Conceptual Design Complete** – Actual date the conceptual design was completed (if applicable); **CD-1** – Approve Alternative Selection and Cost Range; **CD-2** – Approve Performance Baseline; **Final Design Complete** – Estimated/Actual date the project design will be/was complete(d); **CD-3** – Approve Start of Construction; **D&D Complete** – Completion of D&D work; **CD-4** – Approve Start of Operations or Project Closeout.

Fiscal Year	Performance Baseline Validation	CD-3A	CD-3B
FY 2025	TBD	3Q FY 2024	1Q FY 2025

CD-3A – Approve Long-Lead Procurements, for specialty materials procurement, including electrical infrastructure, magnets, refrigerators for the satellite cryogenics plant, and components for the injector, radio frequency power amplifier, and the detector.

Project Cost History

(dollars in thousands)

Fiscal Year	TEC, Design	TEC, Construction	TEC, Total	OPC, Except D&D	OPC, Total	TPC
FY 2024	256,000	1,870,000	2,126,000	292,450	292,450	2,418,450
FY 2025	256,000	1,870,000	2,126,000	292,450	292,450	2,418,450

Note:

- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*

2. Project Scope and Justification

Scope

The scope of this project is to design and build the EIC at BNL that will fulfill the scientific gap as identified in the 2023 NSAC LRP. BNL is partnering with TJNAF in the implementation of the EIC. The EIC will have performance parameters that include a high beam polarization of greater than 70 percent from both electrons and light ions, and the capability to accommodate ion beams from deuterons to the heaviest stable nuclei. The EIC will also have variable center of mass energies from 20 to 100 GeV and upgradable to 140 GeV, high collision luminosity from 10^{33} -10^{34} $cm^{-2}s^{-1}$, one detector and one interaction region at project completion, and the capacity to accommodate a second interaction region and a second detector.

The scope also includes a new electron injection system and storage ring while taking full advantage of the existing infrastructure by modifying the existing hadron facility of the RHIC infrastructure at BNL.

The electron system will include a highly polarized room temperature photo-electron gun and a 400 MeV linac to be installed in an existing available straight section of the RHIC tunnel. It will include a transfer line that brings the electrons into the storage ring at the energy of 5 to 18 GeV that will be installed in the existing 2.4-mile circular RHIC tunnel.

Modifications to the existing hadron system include the injection, transfer line and storage ring to increase beam energy to 275 GeV. It will include a strong-hadron-cooling system to reduce and maintain the hadron beam emittance to the level needed to operate with the anticipated luminosity of 10^{33} -10^{34} $cm^{-2}s^{-1}$.

The interaction region will have superconducting final focusing magnets, crab cavities, and spin rotators to provide longitudinally polarized beams for collisions, where the outgoing particles will be collected by one detector.

An enhanced 2 K liquid helium cryogenic plant is provided for the superconducting radiofrequency cavities, with enhanced water-cooling capacity and cooling towers and chillers to stabilize the environment in the existing tunnel. Civil construction will also include electrical systems, service buildings, and access roads.

It is anticipated that non-DOE funding sources such as international collaborators and the State of New York, will contribute $250 million to the EIC Project ($100 million from New York state, and $150 million from international collaborators). The timeframe for commitments by non-DOE contributors will vary throughout the life of the project and become more certain as planning for the project progresses. All non-DOE funding sources will be closely coordinated with the Office of Nuclear Physics and will be incorporated into the project through the change control process once baselined.

Justification

The last four NSAC LRP reports have supported the EIC with recommendations ranging from investing in accelerator research and development (R&D) in the 2002 NSAC LRP, to reducing technical risks in the 2007 NSAC LRP, to the actual construction of a U.S.-based EIC in the 2015 NSAC LRP. The 2023 NSAC LRP for Nuclear Science recommended the EIC as the highest priority for new facility construction. Consistent with that vision, in 2016 NP commissioned a National Academies of Sciences, Engineering, and Medicine study by an independent panel of experts to assess the uniqueness and scientific merit of such a facility. The report, released in July 2018, strongly supports the scientific case for building a U.S. based EIC, documenting that an EIC will advance the understanding of the origins of nucleon mass, the origin of the spin properties of nucleons, and the behavior of gluons.

The project is being conducted in accordance with the project management requirements in DOE Order 413.3B, *Program and Project Management for the Acquisition of Capital Assets.*

Key Performance Parameters (KPPs)

The KPPs are preliminary and may change prior to setting the performance baseline at CD-2. The Threshold KPPs represent the minimum acceptable performance that the project must achieve for success. The Objective KPPs represent the project performance stretch goal. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Approve Project Completion.

Performance Measure	Threshold	Objective
Center-of-Mass	Center-of-mass energy measured in the range of 20 GeV- 100 GeV.	Center-of-mass energy measured in the range of 20 GeV- 140 GeV.
Accelerator	Accelerator installed and capable of delivering beams of protons and a heavy nucleus such as Au.	Ability to deliver a versatile choice of beams from protons and light ions to heavy ions such as Au.
Detector	Detector installed and ready for beam operations.	Inelastic scattering events in the e-p and e-A collisions measured in Detector.
Polarization	Hadron beam polarization of > 50 percent and electron beam polarization of > 40 percent measured at E_{cm} = 100 GeV.	Hadron beam polarization of > 60 percent and electron beam polarization of > 50 percent measured at E_{cm} = 100 GeV.
Luminosity	Luminosity for e-p collisions measured up to $1.0\text{x}10^{32}$ cm^{-2} s^{-1}.	Luminosity greater than $1.0\text{x}10^{33}$ cm^{-2} s^{-1}.

3. Financial Schedule

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs	IRA Supp. Costs
Total Estimated Cost (TEC)				
Design (TEC)				
Prior Years	26,000	26,000	25,500	—
Prior Years - IRA Supp.	70,000	70,000	—	—
FY 2023	50,000	50,000	49,500	50,000
FY 2024	75,000	75,000	74,000	20,000
FY 2025	35,000	35,000	34,000	—
Outyears	—	—	3,000	—
Total, Design (TEC)	**256,000**	**256,000**	**186,000**	**70,000**
Construction (TEC)				
Prior Years - IRA Supp.	58,240	58,240	—	—
FY 2024	20,000	20,000	20,000	58,240
FY 2025	75,000	75,000	70,000	—
Outyears	1,716,760	1,716,760	1,721,760	—
Total, Construction (TEC)	**1,870,000**	**1,870,000**	**1,811,760**	**58,240**
Total Estimated Cost (TEC)				
Prior Years	26,000	26,000	25,500	—
Prior Years - IRA Supp.	128,240	128,240	—	—
FY 2023	50,000	50,000	49,500	50,000
FY 2024	95,000	95,000	94,000	78,240
FY 2025	110,000	110,000	104,000	—
Outyears	1,716,760	1,716,760	1,724,760	—
Total, Total Estimated Cost (TEC)	**2,126,000**	**2,126,000**	**1,997,760**	**128,240**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs	IRA Supp. Costs
Other Project Cost (OPC)				
Prior Years	59,450	59,450	56,500	–
Prior Years - IRA Supp.	10,000	10,000	–	–
FY 2023	20,000	20,000	21,500	10,000
FY 2024	2,850	2,850	2,000	–
FY 2025	2,850	2,850	3,000	–
Outyears	197,300	197,300	199,450	–

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs	IRA Supp. Costs
Other Project Cost (OPC)				
Total, Other Project Cost (OPC)	**292,450**	**292,450**	**282,450**	**10,000**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs	IRA Supp. Costs
Total Project Cost (TPC)				
Prior Years	85,450	85,450	82,000	–
Prior Years - IRA Supp.	138,240	138,240	–	–
FY 2023	70,000	70,000	71,000	60,000
FY 2024	97,850	97,850	96,000	78,240
FY 2025	112,850	112,850	107,000	–
Outyears	1,914,060	1,914,060	1,924,210	–
Total, TPC	**2,418,450**	**2,418,450**	**2,280,210**	**138,240**

4. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design	173,000	173,000	**N/A**
Design - Contingency	83,000	83,000	**N/A**
Total, Design (TEC)	**256,000**	**256,000**	**N/A**
Construction	1,262,000	1,262,000	**N/A**
Construction - Contingency	608,000	608,000	**N/A**
Total, Construction (TEC)	**1,870,000**	**1,870,000**	**N/A**
Total, TEC	**2,126,000**	**2,126,000**	**N/A**
Contingency, TEC	*691,000*	*691,000*	***N/A***
Other Project Cost (OPC)			
R&D	84,150	97,450	**N/A**
Conceptual Design	11,000	11,000	**N/A**
Other OPC Costs	197,300	184,000	**N/A**
Total, Except D&D (OPC)	**292,450**	**292,450**	**N/A**
Total, OPC	**292,450**	**292,450**	**N/A**
Contingency, OPC	***N/A***	*N/A*	***N/A***
Total, TPC	**2,418,450**	**2,418,450**	**N/A**

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total, Contingency (TEC+OPC)	***691,000***	***691,000***	***N/A***

Note:
- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*

5. Schedule of Appropriations Requests

(dollars in thousands)

Fiscal Year	Type	Prior Years	FY 2023	FY 2024	FY 2025	Outyears	Total
FY 2024	TEC	154,240	50,000	95,000	—	1,826,760	2,126,000
	OPC	69,450	20,000	2,850	—	200,150	292,450
	TPC	223,690	70,000	97,850	—	2,026,910	2,418,450
FY 2025	TEC	154,240	50,000	95,000	110,000	1,716,760	2,126,000
	OPC	69,450	20,000	2,850	2,850	197,300	292,450
	TPC	223,690	70,000	97,850	112,850	1,914,060	2,418,450

6. Related Operations and Maintenance Funding Requirements

Over the course of the acquisition of the EIC, experienced RHIC scientists, engineers, and technicians will assume EIC project responsibilities. A gradual transition will balance the need for the scientific experts to continue to support RHIC while ramping up the EIC project. These individuals represent the scientific and technical workforce that are essential to the operations of a complex facility like RHIC and eventually, the EIC. They have critical core competencies in collider operations that cannot easily be replaced, and they represent the core facility operations force of RHIC and the EIC. In the FY 2025 Request, RHIC Operations includes a "reprioritization" of the expert workforce from the RHIC facility operations budget to support the project under the EIC OPC and TEC request. The temporary reprioritization of funds from the facility operations budget to the construction budget will reduce the amount of "new funds" needed to implement the EIC, enabling a cost-effective path forward to the implementation of this world-leading facility. As the EIC nears CD-4 when the machine will be restarted, the scientists, engineers and technicians that are needed to operate the EIC will be transferred back to the facility operations budget.

Start of Operation or Beneficial Occupancy	Q1 FY 2035
Expected Useful Life	50 years
Expected Future Start of D&D of this capital asset	Q1 FY 2085

Related Funding Requirements
(dollars in thousands)

	Annual Costs		Life Cycle Costs	
	Previous Total Estimate	**Current Total Estimate**	**Previous Total Estimate**	**Current Total Estimate**
Operations, Maintenance and Repair	167,000	167,000	13,500,000	13,500,000

7. D&D Information

As part of the upgrade and renovation of the existing accelerator facilities, up to 150,000 square feet of new industrial space will be built as service buildings to house mechanical and electrical equipment. The new area being constructed in this project is not replacing existing facilities.

	Square Feet
New area being constructed by this project at BNL	150,000
Area of D&D in this project at BNL	0
Area at BNL to be transferred, sold, and/or D&D outside the project, including area previously "banked"	N/A
Area of D&D in this project at other sites	N/A
Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked"	N/A
Total area eliminated	0

8. Acquisition Approach

SC selected Brookhaven National Laboratory (BNL) as the site for the EIC on January 9, 2020. NP approved the Acquisition Strategy in conjunction with CD-1. DOE will utilize the expertise of the Management and Operating contractors at BNL and TJNAF to manage the project including the design, fabrication, monitoring cost and schedule, and delivering the technical performance specified in the KPPs. A certified Earned Value Management System based on those that already exist at both laboratories and will evaluate project progress and ensure consistency with DOE Order 413.3B, Program and Project Management for the Acquisition of Capital Assets.