High Energy Physics

Overview

The mission of the High Energy Physics (HEP) program is to understand how the universe works at its most fundamental level by discovering the elementary constituents of matter and energy, probing the interactions between them, and exploring the basic nature of space and time. HEP accomplishes its mission through excellence in scientific discovery in particle physics, and through stewardship of world-class scientific user facilities that enable cutting-edge research and development. HEP continues to deliver major construction projects on time and on budget and provides reliable availability and support to users for operating facilities. HEP's work allows the U.S. to remain a global leader in international particle physics research and collaboration.

Our current understanding of the elementary constituents of matter and energy and the forces that govern them is described by the Standard Model of particle physics. However, experimental measurements suggest that the Standard Model is incomplete, and that new physics may be discovered by future experiments. The May 2014 report of the Particle Physics Project Prioritization Panel (P5), "Building for Discovery: Strategic Plan for U.S. Particle Physics in the Global Context"[a] was unanimously approved by the High Energy Physics Advisory Panel (HEPAP) to serve the U.S. Department of Energy (DOE) and National Science Foundation (NSF) as the ten-year strategic plan for U.S. high energy physics in the context of a 20-year global vision. The P5 report identified five intertwined science drivers of particle physics that provide compelling lines of inquiry with great promise to discover what lies beyond the Standard Model:

- Use the Higgs boson as a new tool for discovery;
- Pursue the physics associated with neutrino mass;
- Identify the new physics of dark matter;
- Understand cosmic acceleration: dark energy and inflation; and
- Explore the unknown: new particles, interactions, and physical principles.

The DOE and NSF charged HEPAP in December 2022 meeting to form a new P5 subpanel to formulate a ten-year plan for the field. The P5 subpanel expects to present its final report at the HEPAP meeting in late 2023.

The HEP program enables scientific discovery and supports cutting edge research and development (R&D):

- Energy Frontier Experimental Physics, where researchers accelerate particles to the highest energies ever made by humanity and collide them to produce and study the fundamental constituents of matter.
- Intensity Frontier Experimental Physics, where researchers use a combination of intense particle beams and highly sensitive detectors to make extremely precise measurements of particle properties, to study some of the rarest interactions predicted by the Standard Model, and to search for new physics.
- Cosmic Frontier Experimental Physics, where researchers use naturally occurring cosmic particles and phenomena to reveal the nature of dark matter, understand the cosmic acceleration caused by dark energy and inflation, infer certain neutrino properties, and explore the unknown.
- Theoretical, Computational, and Interdisciplinary Physics provides the framework to explain experimental observations and gain a deeper understanding of nature.
- The Advanced Technology R&D subprogram fosters fundamental research into particle acceleration and detection techniques and instrumentation.

Innovative research methods and enabling technologies that emerge from R&D into accelerators, instrumentation, quantum information science (QIS), and artificial intelligence/machine learning (AI/ML) will advance scientific knowledge in high energy physics and in a broad range of related fields, advancing DOE's strategic goals for science. Many of the advanced technologies, research tools, and analysis techniques originally developed for high energy physics have proved widely applicable to other scientific disciplines as well as for health services, national security, and the private sector.

Highlights of the FY 2024 Request

The FY 2024 Request of $1,226.3 million focuses resources toward the highest priorities in fundamental research, operation and maintenance of scientific user facilities, facility upgrades, and projects identified in the P5 report.

Key elements in the FY 2024 Request include:

Research

The Request will provide continued support for university and laboratory researchers carrying on critical core competencies, enabling high priority theoretical and experimental activities in pursuit of discovery science. The Request will provide support to foster a diverse, highly skilled, American workforce, and to build R&D capacity and conduct world-leading R&D through the following activities and initiatives:

- Reaching a New Energy Sciences Workforce (RENEW): Expands targeted efforts, including a RENEW graduate fellowship, to broaden participation and advance justice, equity, diversity, and inclusion in Office of Science (SC)-sponsored research.
- Funding for Accelerated, Inclusive Research (FAIR): Improve the capability of Historically Black Colleges and Universities (HBCUs), minority serving institutions (MSIs), and emerging research institutions to propose and perform competitive research; and build beneficial relationships between these institutions and DOE national laboratories and facilities.
- Established Program to Stimulate Competitive Research (EPSCoR): Funding continues support for research in states and territories with historically lower levels of Federal academic research funding.
- Accelerate Initiative: Promotes scientific research to accelerate the transition of science advances to energy technologies.
- QIS: Co-development of quantum information, theory, and technology aligned with HEP science drivers and exploring new capabilities in quantum sensing and computing. HEP will continue support of the Superconducting Quantum Materials and Systems (SQMS) Center led by the Fermi National Accelerator Laboratory (FNAL).
- AI/ML: Tackle the challenges of extracting signals of signature particle physics from HEP experimental and simulated data with increasingly high volumes and complexity; seek solutions for operating accelerators and detectors in real-time and extremely high data rate environments; and address cross-cutting challenges in coordination with DOE investments in AI/ML efforts.
- Accelerator Science and Technology Initiative (ASTI): Mid- to long-term R&D to maintain a leading position in key accelerator technologies that define SC's competitive advantage.
- Microelectronics: Accelerate the advancement of sensor materials, devices, and front-end electronics.
- Advanced Computing: Ensure broad access to exascale computing resources.
- Within available resources, HEP will assist Advanced Scientific Computing Research (ASCR) in transitioning researchers, software, and technologies through the conclusion of the Exascale Computing Project into core research efforts as appropriate for HEP priorities.

Facility Operations

HEP supports two scientific user facilities, the Fermilab Accelerator Complex and the Facility for Advanced Accelerator Experimental Tests II (FACET-II). These facilities will operate 5,200 and 3,300 hours, respectively, while addressing critical upgrades, improvements, and deferred maintenance. HEP also supports laboratory-based accelerator and detector test facilities, and supports the maintenance and operations of large-scale experiments and facilities that are not based at a DOE national laboratory, such as the U.S. A Toroidal LHC Apparatus (ATLAS) and Compact Muon Solenoid (CMS) detectors at the Large Hadron Collider (LHC) at the European Organization for Nuclear Research (CERN) in Geneva, Switzerland; Sanford Underground Research Facility (SURF) in Lead, South Dakota; Vera C. Rubin Observatory in Chile; and Dark Energy Spectroscopic Instrument (DESI) at the Mayall telescope in Kitt Peak, Arizona.

Projects

The Request will continue support for the Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment (LBNF/DUNE) and Proton Improvement Plan II (PIP-II). The Request will also continue four Major Item of Equipment (MIE) projects: 1) Accelerator Controls Operations Research Network (ACORN), 2) Cosmic Microwave Background Stage 4 (CMB-S4), 3) High Luminosity Large Hadron Collider (HL-LHC) ATLAS Detector Upgrade, and 4) HL-LHC CMS Detector Upgrade Projects.

High Energy Physics
Funding

	(dollars in thousands)			
	FY 2022 Enacted	**FY 2023 Enacted**	**FY 2024 Request**	**FY 2024 Request vs FY 2023 Enacted**
High Energy Physics				
Energy Frontier, Research	71,833	76,833	71,833	-5,000
Energy Frontier, Facility Operations and Experimental Support	49,850	54,000	54,000	–
Energy Frontier, Projects	65,000	50,000	35,700	-14,300
Total, Energy Frontier Experimental Physics	**186,683**	**180,833**	**161,533**	**-19,300**
Intensity Frontier, Research	65,994	72,644	68,144	-4,500
Intensity Frontier, Facility Operations and Experimental Support	165,345	194,555	187,898	-6,657
Intensity Frontier, Projects	10,000	6,000	10,199	+4,199
Total, Intensity Frontier Experimental Physics	**241,339**	**273,199**	**266,241**	**-6,958**
Cosmic Frontier, Research	46,012	51,552	49,512	-2,040
Cosmic Frontier, Facility Operations and Experimental Support	38,500	56,550	61,830	+5,280
Cosmic Frontier, Projects	23,000	1,000	9,000	+8,000
Total, Cosmic Frontier Experimental Physics	**107,512**	**109,102**	**120,342**	**+11,240**
Theoretical, Computational, and Interdisciplinary Physics, Research	158,922	171,746	173,746	+2,000
Total, Theoretical, Computational, and Interdisciplinary Physics	**158,922**	**171,746**	**173,746**	**+2,000**
Advanced Technology R&D, Research	75,344	80,871	74,611	-6,260
Advanced Technology R&D, Facility Operations and Experimental Support	40,200	52,249	53,861	+1,612
Total, Advanced Technology R&D	**115,544**	**133,120**	**128,472**	**-4,648**
Subtotal, High Energy Physics	**810,000**	**868,000**	**850,334**	**-17,666**

(dollars in thousands)

	FY 2022 Enacted	FY 2023 Enacted	FY 2024 Request	FY 2024 Request vs FY 2023 Enacted
Construction				
18-SC-42 Proton Improvement Plan II (PIP-II), FNAL	90,000	120,000	125,000	+5,000
11-SC-40 Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment	176,000	176,000	251,000	+75,000
11-SC-41 Muon to Electron Conversion Experiment, FNAL	2,000	2,000	–	-2,000
Subtotal, Construction	**268,000**	**298,000**	**376,000**	**+78,000**
Total, High Energy Physics	**1,078,000**	**1,166,000**	**1,226,334**	**+60,334**

SBIR/STTR funding:

- FY 2022 Enacted: SBIR $22,179,000 and STTR $3,119,000
- FY 2023 Enacted: SBIR $13,911,000 and STTR $1,956,000
- FY 2024 Request: SBIR $13,073,000 and STTR $1,838,000

High Energy Physics
Explanation of Major Changes

	(dollars in thousands) FY 2024 Request vs FY 2023 Enacted
Energy Frontier Experimental Physics The Request will provide reduced funding for the HL-LHC Upgrade projects, as funding from the FY 2022 Inflation Reduction Act (IRA) accelerated planned outyear funding. The HL-LHC Accelerator Upgrade received final planned funding in FY 2023 to support the completion of the project. Within the requested funding, fabrication activities for the HL-LHC ATLAS and CMS Detector Upgrades will continue as planned. Research support will focus on studying high-priority research topics for the LHC.	**-19,300**
Intensity Frontier Experimental Physics The Request will support the Fermilab Accelerator Complex to operate 5,200 hours, and will focus support on expanding user access to detector systems, scientific computing, and experimental data. The Request will increase support for the ACORN MIE, and will prioritize support for SURF operations over SURF infrastructure improvements. Research support will focus on studying high-priority research topics.	**-6,958**
Cosmic Frontier Experimental Physics The Request will increase support for the CMB-S4 MIE and for operations of the Vera C. Rubin Observatory. Research support will focus on exploiting the physics capabilities of new facilities and experiments.	**+11,240**
Theoretical, Computational, and Interdisciplinary Physics The Request will increase support to broaden the RENEW and FAIR initiatives and focus support on new theoretical directions to unlock the mysteries of neutrinos and dark matter. The Request supports EPSCoR State-National Laboratory Partnership awards and early career awards.	**+2,000**
Advanced Technology R&D The Request will support FACET-II to operate 3,300 hours, and will focus support on enhanced cross-cutting advanced technology R&D in coordination with the Office of Science and increased access and utilization of accelerator and detector test facilities at the DOE national laboratories.	**-4,648**
Construction The Request will increase support and enable a subproject tailoring approach to LBNF/DUNE in accordance with DOE Order 413.3B that has been developed to reorganize the project's scope into five independent subprojects for improved planning and management control. Baselining the entire scope of the project at once introduced too many uncertainties and was no longer viewed as being in the best interest of DOE. Support also increases for PIP-II and decreases for Mu2e as the project completes funding in FY 2023.	**+78,000**
Total, High Energy Physics	**+60,334**

Basic and Applied R&D Coordination
The HEP General Accelerator R&D (GARD) research activity within the Advanced Technology R&D subprogram provides the fundamental building blocks of accelerator technology needed for the HEP mission. The GARD activity is based on input from the community, including high-level advice on long term facility goals from HEPAP and P5, and more detailed technical advice developed through a series of Roadmap Workshops. The GARD activity is coordinated with other SC programs and other federal agencies to optimize synergy and foster strong U.S. capability in this key technology area.

The HEP QIS research activity has coordinated partnerships with the Department of Defense's Office of Basic Research as well as the Air Force's Office of Scientific Research on synergistic research connecting foundational theory research with quantum error correction and control systems for sensors, and a partnership with the Department of Commerce's National Institute of Standards and Technology on quantum metrology and quantum sensor development for experimental discovery along HEP science drivers and for improving understanding of fundamental constants. Furthermore, the SC National QIS Research Center (NQISRC) effort is a partnership across all SC programs and engages industry to inform use-inspired research and connect to applied and development activities.

Program Accomplishments
The LUX-ZEPLIN (LZ) dark matter search experiment successfully started operations and delivered its first results as the world's most sensitive dark matter detector (Cosmic Frontier Experimental Physics).
On July 7, 2022, the LZ collaboration announced their first results from the dark matter experiment's first 60 "live days" of testing. These data were collected over a three-and-a-half-month span of initial operations beginning at the end of December. With its initial run, LZ is already the world's most sensitive detector of dark matter—the elusive particles thought to account for most of the matter in the universe. Dark matter particles have never actually been detected, but dark matter's presence and gravitational pull are nonetheless fundamental to our understanding of the universe. For example, the presence of dark matter, shapes the form and movement of galaxies, and it is invoked by researchers to explain what is known about the large-scale structure and expansion of the universe. The LZ experiment is managed by the Lawrence Berkeley National Laboratory (LBNL) and located a mile underground at the Sanford Underground Research Facility in Lead, South Dakota. The heart of the detector is comprised of two nested titanium tanks filled with nearly 10 tons of pure liquid xenon and viewed by two arrays of photomultiplier tubes that can detect faint sources of light due to dark matter particles colliding with xenon nuclei. The full dataset will eventually include about 1000 days of exposure. The LZ experiment is expected to improve on the sensitivity of the previous generation of detectors by a factor of 50.

LHC data enables sensitive studies for detecting extremely rare processes where the Higgs boson is produced in pairs (Energy Frontier Experimental Physics).
Researchers at the LHC are continuously extending our knowledge of the Higgs boson by searching for extremely rare processes that include the Higgs particles being produced in pairs within high energy particle collisions. Such studies can enable an understanding of how the Higgs interacts with itself which is possible when two Higgs bosons are produced instead of just one. This challenging di-Higgs process, including the various decaying particles resulting from each Higgs boson, can be easily confused with other processes that look similar. Therefore, to enhance the sensitivity to detection, the ATLAS and CMS collaborations have each applied AI/ML techniques to help distinguish signal type events from the large backgrounds and thereby scrape away the uninteresting events with increasing precision. Such machine learning algorithms can learn the subtle differences between signal and unwanted backgrounds above and beyond conventional analysis techniques. The present analyses by ATLAS and CMS suggest that an observation will be possible with additional data particularly from that acquired during the future era of the HL-LHC where at least ten times more data is expected. Moreover, these studies, in addition to the entire suite of other precision Higgs boson measurements presently being undertaken at the LHC, continue to demonstrate how the Higgs can be used as a tool for future discoveries of new physics.

Quantum network between two national labs achieves record (Theoretical, Computational, and Interdisciplinary Physics).
A team of researchers with the Illinois-Express Quantum Network (IEQNET) successfully deployed a long-distance quantum network between two DOE laboratories using local fiber optics. The experiment marked the first time that quantum-encoded photons and classical signals were simultaneously delivered across a metropolitan-scale distance with an unprecedented level of synchronization. The IEQNET collaboration includes the DOE's Fermi National Accelerator and Argonne National laboratories, Northwestern University and Caltech. Because they had only two fiber strands between the two labs, the researchers had to send the clock on the same fiber that carried the entangled photons. The way to separate the clock from the quantum signal is to use different wavelengths, but that comes with its own challenge. Ultimately, the two were properly assigned and controlled, and the timing signal and photons were distributed from sources at FNAL. As the photons arrived at each location, measurements were performed and recorded using Argonne's superconducting nanowire single photon detectors. The network was synchronized so accurately that it recorded only a five trillionth of a second time difference in the clocks at each location. Such precision will allow scientists to accurately identify and manipulate entangled photon pairs for supporting quantum network operations over metropolitan distances in real-world conditions. Building on this accomplishment, the IEQNET team is getting ready to perform experiments to demonstrate entanglement swapping. This process enables cross-entanglement between photons from different initially entangled pairs, thus creating longer quantum communication channels.

First demonstration of a new particle beam technology at FNAL (Advanced Technology R&D).
Researchers at the DOE's FNAL have published in *Nature* on their first successful demonstration of a new technique that improves the quality of particle beams. The new technique is called optical stochastic cooling. It was first proposed in the early 1990s, and while significant theoretical progress was made, an experimental demonstration of the technique remained elusive until now. Conventional stochastic cooling, which earned its inventor, Simon van der Meer, a share of the 1984 Nobel Prize, works by using light in the microwave range with wavelengths of several centimeters. In contrast, optical stochastic cooling uses visible and infrared light, which have wavelengths around a millionth of a meter. The shorter wavelength means scientists can sense the particles' activity more precisely and make more accurate corrections. To prepare a particle beam for experiments, accelerator operators send it on several passes through the cooling system. The improved resolution of optical stochastic cooling provides more exact kicks to smaller groups of particles, so fewer laps around the storage ring are needed. With the beam cooled more quickly, researchers can spend more time using those particles to produce experimental data. Scientists at FNAL used the lab's newest storage ring, the Integrable Optics Test Accelerator (IOTA), to demonstrate and explore optical stochastic cooling technology. This first demonstration at IOTA used a medium-energy electron beam and a configuration called "passive cooling," which doesn't amplify the light pulses from the particles. The team successfully observed the effect and achieved about a tenfold increase in cooling rate compared to the natural "radiation damping" that the beam experiences in IOTA. They were also able to control whether the beam cools in one, two or all three dimensions. Finally, scientists also ran experiments studying the cooling of a single electron stored in the accelerator. With the initial experiment completed, the team is developing an improved system at IOTA that will use an optical amplifier to strengthen the light from each particle by about a factor of 1,000 and apply machine learning to add flexibility to the system.

New results from Micro Booster Neutrino Experiment (MicroBooNE) further our understanding of the nature of neutrinos (Intensity Frontier Experimental Physics).
The MicroBooNe collaboration released the results of four complementary analyses that reached the same and notable conclusion: there is no sign of the sterile neutrino, which would be a signal of new physics. Hosted at FNAL, MicroBooNE detector is a 40-foot-long cylindrical container filled with 170 tons of pure liquid argon and has operated since 2015. The MicroBooNE experiment studies interactions of neutrinos, the most abundant fundamental particle with mass. Due to their very weak interactions with normal matter, neutrinos are shrouded with unanswered physics questions: Why are their masses so vanishingly small? Are neutrinos responsible for matter's dominance over antimatter in our universe? This makes neutrinos a unique window into exploring how the universe works at the smallest scales. The sterile neutrino proposed by theorists studied in this experiment has remained a promising explanation for anomalies seen in earlier physics experiments. Finding a new particle would be a major discovery and a radical shift in our understanding of the universe. With sterile neutrinos further disfavored as the explanation for anomalies spotted in neutrino data, scientists are investigating other possibilities. These include light created by other known processes during neutrino collisions, or exotic explanation such as new kinds of dark matter, unexplained physics related to the Higgs boson, or other physics beyond the Standard Model.

High Energy Physics
Energy Frontier Experimental Physics

Description

The Energy Frontier Experimental Physics subprogram's focus is to support the U.S. researchers participating in the LHC program. The LHC hosts two large multi-purpose particle detectors, ATLAS and CMS, which are partially supported by DOE and NSF and are used by large international collaborations of scientists. U.S. researchers, including the next generation of scientists and engineers, participating in the LHC program account for approximately 20 percent and 25 percent of the ATLAS and CMS collaborations, respectively, and play critical leadership roles in all aspects of each experiment. Data collected by ATLAS and CMS are used to address three of the five science drivers as explained below:

- *Use the Higgs boson as a new tool for discovery.*
  In the Standard Model of particle physics, the Higgs boson is a key ingredient responsible for generating the mass for fundamental particles. Experiments at the LHC continue to actively measure the Higgs's properties to establish its exact character and to discover if there are additional effects that are the result of new physics beyond the Standard Model.
- *Explore the unknown: new particles, interactions, and physical principles.*
  Researchers at the LHC probe for evidence of what lies beyond the Standard Model such as supersymmetry, mechanisms for black hole production, extra dimensions, and other exotic phenomena. The upgraded LHC detectors will be increasingly more sensitive to potential deviations from the Standard Model that may be exposed by the highest energy collisions in the world.
- *Identify the new physics of dark matter.*
  LHC collisions may possibly produce dark matter particles, and their general properties may be inferred through the behavior of the accompanying normal matter. This "indirect" detection of dark matter is complementary to the ultra-sensitive direct detection experiments in the Cosmic Frontier and Intensity Frontier Experimental Physics subprograms.

<u>Research</u>

The Energy Frontier Experimental Physics subprogram's Research activity supports groups at U.S. academic and research institutions and national laboratories. These groups, as part of the ATLAS and CMS collaborations, typically have a broad portfolio of responsibilities and leadership roles in support of R&D, experimental design, fabrication, commissioning, operations, and maintenance, and performing scientific simulations and data analyses. This activity also supports Advanced Computing to ensure broad access to exascale computing resources for HEP researchers.

<u>Facility Operations and Experimental Support</u>

U.S. LHC Detector Operations supports the maintenance of U.S.-supplied detector systems for the ATLAS and CMS detectors in the LHC at CERN, and the U.S.-based computer infrastructure used by U.S. physicists to analyze LHC data, including the Tier 1 computing centers at Brookhaven National Laboratory (BNL) and FNAL. The Tier 1 centers provide around-the-clock support for the worldwide LHC Computing Grid; are responsible for storing a portion of raw and processed data; perform large-scale data reprocessing; and store the corresponding output.

<u>Projects</u>

CERN is implementing a major upgrade to the LHC machine to increase the particle collision rate by a factor of at least five, to explore new physics beyond its current reach. Through the HL-LHC Accelerator Upgrade Project, HEP is contributing to this upgrade by constructing and delivering the next-generation of superconducting accelerator components, where U.S. scientists have critical expertise. After the upgrade, the HL-LHC collisions will lead to very challenging conditions in which the ATLAS and CMS detectors must operate. As a result, the HL-LHC ATLAS and HL-LHC CMS Detector Upgrades are critical investments to enable the experiments to operate for an additional decade and collect at least a factor of ten more data.

Activities and Explanation of Changes

(dollars in thousands)

FY 2023 Enacted		FY 2024 Request	Explanation of Changes FY 2024 Request vs FY 2023 Enacted
Energy Frontier Experimental Physics	**$180,833**	**$161,533**	**-$19,300**
Research	$76,833	$71,833	-$5,000
Funding supports the Advanced Computing initiative and continues to support U.S. leadership roles in all aspects of the ATLAS and CMS experimental programs. This includes the analyses of the large physics datasets collected during the LHC run, as well as scientific personnel support for the HL-LHC ATLAS and CMS Detector upgrade activities.		The Request will continue supporting the Advanced Computing initiative and leading roles by U.S. researchers in all aspects of the ATLAS and CMS experimental programs.	Funding will focus on U.S. researchers studying high-profile research topics that search for new physics during the present LHC run, which incorporates upgraded ATLAS and CMS Detectors installed during the last technical stop of the LHC.
Facility Operations and Experimental Support	$54,000	$54,000	$ —
Funding continues to support ATLAS and CMS detector maintenance and operations activities at CERN and the U.S.-based computing infrastructure and resources required to collect, store, and analyze the large volume of LHC data from the LHC run.		The Request will continue supporting ongoing ATLAS and CMS detector maintenance and operations activities at CERN and data taking using the U.S.-based computing infrastructure and resources.	No change.
Projects	$50,000	$35,700	-$14,300
Funding supports the production of quadrupole magnets and crab cavities for the HL-LHC Accelerator Upgrade, and ramp-up of fabrication activities for the HL-LHC ATLAS and CMS Detector Upgrades.		The Request will support fabrication activities for the HL-LHC ATLAS and CMS Detector Upgrades. No funding is requested for the HL-LHC Accelerator Upgrade.	Within the requested funding, the HL-LHC Detector Upgrade projects will continue fabrication activities. The HL-LHC Accelerator Upgrade received its final funding in FY 2023. Funding from the FY 2022 Inflation Reduction Act accelerated outyear funding.

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.*

High Energy Physics
Intensity Frontier Experimental Physics

Description

The Intensity Frontier Experimental Physics subprogram supports the investigation of some of the rarest processes in nature. This HEP subprogram relies on high-power beams or other intense sources such as reactors to make precision measurements of fundamental particle properties. These measurements probe for new phenomena that are not directly observable at the Energy Frontier, because either they occur at much higher energies and their effects may only be indirectly observed, or their interactions are too weak for detection in high-background conditions. Data collected from Intensity Frontier experiments are used to address three of the five science drivers as explained below:

- *Pursue the physics associated with neutrino mass.*
  Of all known particles, neutrinos are perhaps the most enigmatic and elusive. HEP researchers working at U.S. facilities discovered all the three known varieties of neutrinos. HEP supports research into fundamental neutrino properties that may reveal important clues about the unification of forces and the very early history of the universe.
- *Explore the unknown: new particles, interactions, and physical principles.*
  Several observed phenomena are not described by the Standard Model, including the imbalance of matter and antimatter in the universe today. Precision measurements of the properties of known particles may reveal information about what new particles and forces might explain these discrepancies and whether the known forces unify at energies beyond the reach of the LHC.
- *Identify the new physics of dark matter.*
  The lack of experimental evidence from the current generation of dark matter detectors has led to proposed theoretical models with new particles and forces that rarely interact with normal matter. Experiments outfitted with highly-efficient detectors and inserted within intense accelerator beams at national laboratories may offer an opportunity to explore these models.

Research

The Intensity Frontier Experimental Physics subprogram's Research activity supports groups at U.S. academic and research institutions and national laboratories. These groups, as part of scientific collaborations, typically have a broad portfolio of responsibilities and leadership roles in support of R&D, experimental design, fabrication, commissioning, operations, and maintenance, and they perform scientific simulations and physics data analyses. This activity also supports Advanced Computing to ensure broad access to exascale computing resources for HEP researchers.

The largest component of the Intensity Frontier subprogram is the support for research in accelerator-based neutrino physics centered at FNAL with multiple experiments running concurrently in two separate neutrino beams with different beam energies. The Neutrinos at the Main Injector (NuMI) beam is used by the NuMI Off-Axis ν_e Appearance (NOvA) long-baseline neutrino experiment to detect oscillations between different types of neutrinos through 810 km of earth in a far detector in Ash River, Minnesota. The Booster Neutrino Beam is used by the Short-Baseline Neutrino (SBN) program at FNAL to definitively address measurements of additional neutrino types beyond the three currently described in the Standard Model. LBNF/DUNE will be the centerpiece of a U.S. hosted world-leading neutrino research facility, using the world's most intense neutrino beam and large, sensitive underground detectors to make transformative discoveries.

The research activity includes efforts to search for rare physics processes. The Mu2e experiment at FNAL will search for extremely rare muon decays that, if detected, will provide clear evidence of new physics. The Tokai-to-Kamioka (T2K) long-baseline neutrino experiment in Japan is complementary to NOvA, and a combined measurement from these two experiments will offer the best to date available information on neutrino oscillations prior to LBNF/DUNE. At the High Energy Accelerator Research Organization (KEK) in Tsukuba, Japan, the Belle II experiment searches for new physics produced in electron-positron collisions at the SuperKEKB accelerator.

Facility Operations and Experimental Support

The Intensity Frontier Experimental Physics subprogram supports several distinct facility operations and experimental activities, the largest of which is the Fermilab Accelerator Complex User Facility. This activity includes the operations of all accelerators and beamlines at FNAL, the operation of the detectors that use those accelerators, the computing support needed by both the accelerators and detectors, and scientific collaboration support. General Plant Project (GPP) and Accelerator Improvement Project (AIP) funding supports improvements to FNAL facilities.

HEP has a cooperative agreement with the South Dakota Science and Technology Authority (SDSTA), a quasi-state agency created by the State of South Dakota for the operation of the SURF. Experiments supported by DOE, NSF, and other government and private entities are conducted there, including the HEP-supported LZ experiment. SURF will be the home of the DUNE far site detectors being built by the LBNF/DUNE project. The SURF cooperative agreement provides basic services to LBNF/DUNE, and other experiments located at the site and supports critical infrastructure upgrades.

Projects

In support of LBNF/DUNE, a lease with SDSTA provides the framework for DOE and FNAL to construct federally funded buildings and facilities on non-federal land and to establish a long-term (multi-decade) arrangement for DOE and FNAL to use SDSTA space to host the DUNE neutrino detector. Other Project Costs (OPC) have been identified by the LBNF/DUNE project and DOE for the cost of SURF services used by LBNF/DUNE beyond the basic operational support covered by the SURF cooperative agreement mentioned above.

FNAL will upgrade its dated accelerator control system with a modern system, which is maintainable, sustainable, and capable of utilizing advances in AI/ML to create a high-performance accelerator for the future. The Accelerator Controls Operations Research Network (ACORN) MIE is critical as the control system of the Fermilab Accelerator Complex initiates particle beam production; controls beam energy and intensity; steers particle beams to their ultimate destination; measures beam parameters; and monitors beam transport through the complex to ensure safe, reliable, and effective operations.

Activities and Explanation of Changes

(dollars in thousands)

FY 2023 Enacted		FY 2024 Request	Explanation of Changes FY 2024 Request vs FY 2023 Enacted
Intensity Frontier Experimental Physics	**$273,199**	**$266,241**	**-$6,958**
Research	$72,644	$68,144	-$4,500
Funding supports core research efforts in all phases of experiments: data collection, analysis, and dissemination; pre-operations activities for Mu2e, and science planning and development for LBNF/DUNE. Funding also supports the Advancing Computing initiative to support new software and networking technologies, which will be developed to transport and analyze very large neutrino datasets on exascale computers.		The Request will continue to support research activities on NOvA, SBN Program, Belle II, and T2K experiments; researchers participating in commissioning of Mu2e; science planning and development for LBNF/DUNE; design and planning for intermediate neutrino and dark matter concepts; and the Advanced Computing initiative.	Funding will focus support on studying high-profile research topics that search for new physics, preparing for early physics capabilities of the Mu2e experiment, and scientists' contributions to the LBNF/DUNE project.
Facility Operations and Experimental Support	$194,555	$187,898	-$6,657
Funding supports SURF operations and infrastructure improvements, and the continued fabrication and installation of the SBND experiment and operations of ICARUS as part of the SBN program. The Fermilab Accelerator Complex support includes a baseline change request to increase support for a GPP, the Target Systems Integration Building (TSIB). Additional funds are needed to complete the project due to inflation. Support for Special Process Spares are provided for efficient recovery from unexpected downtime.		The Request will continue to support the Fermilab Accelerator Complex including funding for detector and computing operations, scientific collaboration support, and minor GPP; Special Process Spares for efficient recovery from unexpected downtime; and SURF operations.	Funding will focus support on the Fermilab Accelerator Complex by delivering more particle beams at peak power and expanding user access to detector systems, scientific computing, and experimental data. Support for SURF operations will be prioritized over infrastructure improvements.

(dollars in thousands)

FY 2023 Enacted	FY 2024 Request	Explanation of Changes FY 2024 Request vs FY 2023 Enacted
Projects $6,000	$10,199	+$4,199
Funding supports the ACORN MIE system design and other related engineering activities, and OPC execution support costs at SURF for LBNF/DUNE such as electric power for excavation and construction.	The Request will support the ACORN MIE system design and other related engineering activities, as well as OPC execution support costs at SURF for LBNF/DUNE such as electric power for excavation and construction.	Funding will increase to ramp-up ACORN MIE system design activities to prepare for Critical Decision (CD)-1.

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.*

High Energy Physics
Cosmic Frontier Experimental Physics

Description

The Cosmic Frontier Experimental Physics subprogram uses measurements of naturally occurring cosmic particles and observations of the universe to probe fundamental physics questions and offer new insight about the nature of dark matter, cosmic acceleration in the forms of dark energy and inflation, neutrino properties, and other phenomena. The activities in this subprogram use diverse tools and technologies to carry out experiments typically not sited at national laboratories but at ground-based observatories and facilities, space-based missions, and detectors deep underground to address four of the five science drivers as described below:

- *Identify the new physics of dark matter.*
  Experimental evidence reveals that dark matter accounts for five times as much matter in the universe as ordinary matter. A staged series of direct-detection experiments search for the leading theoretical candidate particles using multiple technologies to cover a wide range in mass with increasing sensitivity. Accelerator-based dark matter searches performed in the Intensity Frontier and the Energy Frontier subprograms are complementary to these experiments.
- *Understand cosmic acceleration: dark energy and inflation.*
  The nature of dark energy, which drives the accelerating expansion of the universe, continues as one of the most perplexing questions in science. A staged series of experiments to carry out imaging and spectroscopic surveys of galaxies will determine the nature of dark energy. The cosmic microwave background (CMB), the oldest observable light in the universe, informs researchers about the era of inflation, the rapid expansion in the early universe shortly after the Big Bang. Researchers use measurements of this ancient CMB light and light from distant galaxies to map the acceleration of the universe over time and to unravel the nature of dark energy and inflation.
- *Pursue the physics associated with neutrino mass.*
  The study of the largest physical structures in the Universe may reveal the properties of particles with the smallest known cross section: neutrinos. Experiments studying dark energy and the CMB will put constraints on the number of neutrino species and their masses, complementary to the ultra-sensitive measurements made in the Intensity Frontier.
- *Explore the unknown: new particles, interactions, and physical principles.*
  High-energy cosmic rays and gamma rays probe energy scales well beyond what may be produced with man-made particle accelerators, albeit not in a controlled experimental setting. Searches for new phenomena and indirect signals of dark matter in these surveys may yield surprising discoveries about the fundamental nature of the universe.

<u>Research</u>

The Cosmic Frontier Experimental Physics subprogram's Research activity supports groups at U.S. academic and research institutions and national laboratories. These groups, as part of scientific collaborations, typically have a broad portfolio of responsibilities and leadership roles in support of R&D, experimental design and optimization, fabrication, commissioning, and operations as well as performing scientific simulations and data analyses for these experiments. The research makes use of advanced and high performance computing resources.

Two complementary next-generation, dark energy "Stage 4" experiments provide increased precision in measuring the history of the expansion of the universe. The Dark Energy Spectrographic Instrument (DESI) collaboration is carrying out a five-year survey to make light-spectrum measurements of 40 million galaxies and quasars that span over two-thirds of the history of the universe. The Vera C. Rubin Observatory will carry out a ten-year wide-field, ground-based optical and near-infrared imaging Legacy Survey of Space and Time (LSST) that will be used by the Dark Energy Science Collaboration (DESC). Together the datasets will enable studies on whether acceleration of the expansion of the universe is due to an unknown force, a cosmological constant, or if Einstein's General Theory of Relativity breaks down at large distances.

The next-generation Cosmic Microwave Background Stage 4 (CMB-S4) experiment, with its unprecedented sensitivity and precision, will enable researchers to peer into the inflationary era in the early moments of the universe, at a time scale unreachable by other types of experiments.

Two complementary next-generation, dark matter particle search experiments use complementary technologies to search for weakly interacting massive particles (WIMP) over a wide range of masses, with LZ searching for heavier WIMPs and Super Cryogenic Dark Matter Search at Sudbury Neutrino Observatory Laboratory (SuperCDMS-SNOLAB) sensitive to lighter WIMPs. A third next-generation experiment, Axion Dark Matter Experiment Generation-2 (ADMX-G2), searches for axions, another type of possible dark matter particles. In addition, planning efforts are continuing for potential small projects to use new technologies and search for dark matter in areas not previously investigated.

Facility Operations and Experimental Support

This activity supports the DOE share of expenses necessary to carry out the successful operating phase of Cosmic Frontier experiments, including instrumentation maintenance, operation, data collection, and data processing and serving. Support is provided for the experiments currently operating and for pre-operations activities for the next-generation experiments in the design or fabrication phase. HEP conducts planning reviews to ensure readiness as each experiment transitions from project fabrication to science operations, and periodic reviews during the operations phase.

The DESI instrumentation is mounted on the NSF's Mayall Telescope at Kitt Peak National Observatory with both the instrumentation and telescope operations supported by DOE. DESI started its five-year science survey in May 2021. As of early FY 2023, DESI has made precision measurements of spectra of over 26 million galaxies, more than all other spectroscopic surveys combined.

The Vera C. Rubin Observatory in Chile, using the DOE-provided three billion-pixel LSST camera (LSSTCam), will carry out final commissioning activities and achieve first light in FY 2024. DOE and NSF are full partners in the Rubin facility operations to carry out the ten-year LSST survey. SLAC National Accelerator Laboratory (SLAC) manages the Rubin U.S. Data Facility and the LSSTCam during operations as part of DOE's responsibilities.

The LZ dark matter detector began science operations underground in the Sanford Underground Research Facility (SURF) in Lead, South Dakota in December 2021. Science Run 2 began in FY 2023 and will continue in FY 2024. The SuperCDMS-SNOLAB dark matter detector, located at the Sudbury Neutrino Observatory in Sudbury, Canada starts science operations with its full detector suite in FY 2024. The ADMX-G2 dark matter axion search experiment, located at the University of Washington in Seattle, WA, continues operations in FY 2024.

Projects

The next-generation CMB-S4 project is being planned as a partnership with NSF, with DOE roles led by Lawrence Berkeley National Laboratory. CMB-S4 will consist of an array of small and large telescopes working in concert at two locations, the NSF Amundsen-Scott South Pole Station and the Atacama high desert in Chile. Both arrays are required to reach the full science capabilities. The project is developing a design that will carry out the science goals within the available infrastructure and logistics capabilities at the sites.

High Energy Physics
Cosmic Frontier Experimental Physics

Activities and Explanation of Changes

(dollars in thousands)

FY 2023 Enacted		FY 2024 Request	Explanation of Changes FY 2024 Request vs FY 2023 Enacted
Cosmic Frontier Experimental Physics	**$109,102**	**$120,342**	**+$11,240**
Research	$51,552	$49,512	-$2,040
Funding supports continued research activities on the ADMX-G2, DESI, LZ, and SuperCDMS-SNOLAB experiments, physics preparation for the Vera C. Rubin Observatory, the associated DESC for LSST, and design and planning for new dark matter concepts.		The Request will support continued research activities on the dark matter experiments (ADMX-G2, LZ, and SuperCDMS-SNOLAB), on dark energy science (DESI and Vera C. Rubin Observatory, with its associated DESC) and design and planning for CMB-S4 and the dark matter concepts.	Funding will focus support on research efforts to exploit the new physics capabilities of the Vera C. Rubin Observatory and the SuperCDMS-SNOLAB experiment.
Facility Operations and Experimental Support	$56,550	$61,830	+$5,280
Funding supports continued operations of DESI, LZ, ADMX-G2, and the start of operations for SuperCDMS-SNOLAB. Commissioning and pre-operations planning efforts continue for the Vera C. Rubin Observatory and the DESC planning for the LSST survey.		The Request will support continued operations of DESI, LZ, ADMX-G2, the start of full operations of SuperCDMS-SNOLAB. Final commissioning activities for the Vera C. Rubin Observatory will be carried out in preparation for the start of the science survey in FY 2025.	Funding will increase to support the ramp up in operations needed for the Vera C. Rubin Observatory.
Projects	$1,000	$9,000	+$8,000
Funding supports engineering and design efforts for the CMB-S4 project.		The Request will support engineering and design efforts for the CMB-S4 project.	Funding will increase to ramp up design activities for the CMB-S4.

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.*

High Energy Physics
Theoretical, Computational, and Interdisciplinary Physics

Description

The Theoretical, Computational, and Interdisciplinary Physics subprogram provides the mathematical, phenomenological, computational, and technological framework to understand and extend our knowledge of the dynamics of particles and fields, and the nature of space and time. This research is essential for proper interpretation and understanding of the experimental research activities described in other HEP subprograms, and cuts across all five science drivers and the Energy, Intensity, Cosmic Frontier Experimental Physics, and Advanced Technology R&D subprograms.

Theory

The HEP theory activity supports world-leading Research groups at U.S. academic and research institutions and national laboratories, which play important roles in addressing the leading research areas discussed above. Laboratory groups are typically more focused on data-driven theoretical investigations and precise calculations of experimentally observable quantities. University groups usually focus on building models of physics beyond the Standard Model and studying their phenomenology, as well as on formal and mathematical theory.

This activity supports the Advanced Computing initiative to ensure broad access to exascale computing resources.

Computational HEP

The Computational HEP activity supports advanced simulations and computational science that extends the boundaries of scientific discovery to regions not directly accessible by experiments, observations, or traditional theory. Computation is necessary at all stages of HEP experiments, from planning and constructing accelerators and detectors, to theoretical modeling, to supporting computationally intensive experimental research and large-scale data analysis for scientific discovery in HEP. The multi-laboratory HEP Center for Computational Excellence (CCE) is supported to advance HEP computing by developing common software tools and exploiting the latest architectures in high performance computing platforms and exascale systems. Computational HEP partners with ASCR, including via the Scientific Discovery through Advanced Computing (SciDAC) activity, to optimize the HEP computing ecosystem for the near- and long-term future. Computational traineeships develop the technical expertise of engineers and scientists critical to delivering HEP discovery science.

Quantum Information Science

The HEP QIS activity supports the “science first” approach of the National Quantum Strategy through National QIS Research Centers and individual research grants, applying HEP techniques to QIS and vice versa. Topics include quantum computing; quantum simulation for HEP theory and experiments; and ultrasensitive quantum sensors. The five National QIS Research Centers, jointly supported across SC programs, apply concepts and technology from core research to QIS and foster collaborative partnerships in support of the SC mission. HEP is the lead program supporting the Superconducting Quantum Materials and Systems (SQMS) Center led by the Fermi National Accelerator Laboratory. SQMS is focused on extending the lifetime of quantum states to reduce error rates in quantum computing and enable the construction and deployment of quantum sensors for precision measurements.

Artificial Intelligence and Machine Learning

The HEP AI/ML activity supports research to tackle challenges not possible with more traditional computing due to increasingly high data volumes and complexity or to make connections across the experimental, theoretical and technical HEP frontiers. Priorities include advancing HEP research through development and applications of AI/ML for more efficient processing of large datasets, modeling and mitigation of systematic uncertainties, and improved operations of particle accelerators and detectors. Research also seeks to use unique aspects of HEP such as datasets or theory to improve understanding of fundamental AI/ML techniques and their potential and limitations. This program additionally supports strategic directions in HEP AI/ML that are well aligned with programmatic priorities and includes input from open community workshops and relevant federal advisory committees. The HEP AI/ML research activity is conducted in coordination with DOE and SC programs, other federal agencies, and the private sector.

Broadening Engagement in HEP

This activity will support the RENEW initiative to provide undergraduate and graduate training opportunities for diverse students and academic institutions not currently well represented in the U.S. science and technology ecosystem, including through a RENEW graduate fellowship, and the FAIR initiative to provide focused investment on enhancing research at HBCUs and minority serving institutions and emerging research institutions. The FAIR and RENEW initiatives aim to improve the infrastructure and competitiveness at institutions under-represented in the HEP program, and support research and training activities that broadens engagement in HEP science. RENEW and FAIR are conducted in coordination with DOE SC programs. This activity provides support for the DOE EPSCoR that funds research in states and territories with historically lower levels of Federal academic research funding. In FY 2024, the EPSCoR program will focus on EPSCoR State-National Laboratory Partnership awards to promote single PI and small group interactions with the unique capabilities of the DOE national laboratory system and continued support of early career awards. Funding for EPSCoR within the HEP program provides dedicated support for HEP research conducted at institutions in EPSCoR states, including special-purpose funding opportunities. These activities also broaden engagement and build capabilities in HEP science that reach communities and institutions which are under-represented in the HEP portfolio.

Activities and Explanation of Changes

(dollars in thousands)

FY 2023 Enacted		FY 2024 Request	Explanation of Changes FY 2024 Request vs FY 2023 Enacted
Theoretical, Computational, and Interdisciplinary Physics	**$171,746**	**$173,746**	**+$2,000**
Research	$171,746	$173,746	+$2,000
Theory	*$54,050*	*$50,050*	*-$4,000*
Funding supports world-leading theoretical particle physics research at U.S. universities and national laboratories and the Advanced Computing initiative.		The Request will continue to support the HEP theory activity and the Advanced Computing initiative.	Funding will focus support on theoretical investigations to unlock the mysteries of neutrinos and dark matter.
Computational HEP	*$14,130*	*$14,130*	*$ —*
Funding supports the multi-laboratory HEP CCE, HEP-ASCR SciDAC partnerships, and the Traineeship Program in Computational HEP.		The Request will continue to support HEP CCE, HEP-ASCR SciDAC partnerships, and the Traineeship Program in Computational HEP. Within available resources, HEP will assist ASCR in transitioning researchers, software, and technologies through the conclusion of the Exascale Computing Project into core research efforts as appropriate for HEP priorities.	No changes.
Quantum Information Science	*$50,566*	*$50,566*	*$ —*
Funding supports interdisciplinary HEP-QIS consortia and lab programs for focused research at the intersection of HEP and QIS. Funding also supports SQMS as part of the National QIS Research Centers in partnership with other SC program offices.		The Request will continue to support interdisciplinary HEP QIS consortia and the SQMS National QIS Research Center.	No changes.

(dollars in thousands)

FY 2023 Enacted		FY 2024 Request	Explanation of Changes FY 2024 Request vs FY 2023 Enacted
Artificial Intelligence and Machine Learning	*$40,000*	*$40,000*	*$ —*
Funding supports AI/ML research and development to improve HEP physics and build an AI/ML community around cross-cutting challenges that fulfill the HEP mission, including "seed" awards to explore emerging opportunities.		The Request will support innovation and new opportunities in embedding AI into sensors and experimental design in extreme environments; and developing operations and controls AI/ML techniques for accelerators and open access to HEP datasets.	No changes.
Broadening Engagement in HEP	*$13,000*	*$19,000*	*+$6,000*
Funding supports the RENEW and FAIR initiatives which expand targeted efforts to increase participation and retention of underrepresented individuals and institutions in SC research activities. Dedicated funding for EPSCoR expands participation in HEP research, particularly at historically under-represented institutions.		The Request will continue the HEP participation in the RENEW and FAIR initiatives. Funding supports EPSCoR State-National Laboratory Partnership awards and early career awards in EPSCoR jurisdictions.	Funding will increase support for the RENEW and FAIR initiative activities, including through a RENEW graduate fellowship. Continued support for research in EPSCoR jurisdictions.

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.*

High Energy Physics
Advanced Technology R&D

Description
The Advanced Technology R&D subprogram fosters cutting-edge basic research in the physics of particle beams, accelerator technology R&D, and R&D for particle and radiation detection. These activities are necessary for continued progress in high energy physics.

General Accelerator R&D

The HEP General Accelerator R&D (GARD) activity supports the science underlying the technologies used in particle accelerators and storage rings, as well as the fundamental physics of charged particle beams. Long-term research goals include developing technologies to enable breakthroughs in particle accelerator performance, size, cost, beam intensity, and control. The GARD activity supports groups at U.S. academic and research institutions and national laboratories performing research activities categorized into five areas: 1) accelerator and beam physics; 2) advanced acceleration concepts; 3) particle sources and targetry; 4) radio-frequency acceleration technology; and 5) superconducting magnets and materials. A community study aimed at establishing a technology roadmap for the accelerator and beam physics thrust was conducted in FY 2022; the roadmap report will be published in FY 2023. Community studies for most other HEP GARD thrusts were completed in the past five years.[b] Input on strategic directions from regular, open, community studies as well as future Basic Research Needs workshops, will inform funding decisions in subsequent years.

The state-of-the-art SC facilities attract the world's leading researchers, bringing knowledge and ideas that enhance U.S. science and create high technology jobs. As competing accelerator-based facilities are built abroad, they are beginning to draw away scientific and technical talent. Sustaining world-class accelerator-based SC facilities requires continued, transformative advances in accelerator science and technology, and a workforce capable of performing leading accelerator research for future application. In coordination with the Office of Accelerator R&D and Production, the SC Accelerator Science and Technology Initiative (ASTI) will address these needs by reinforcing high-risk, high-reward accelerator R&D that will invest in SC facilities to stay at the global forefront and develop a world-leading workforce to build and operate future generations of facilities.

The GARD activity supports the highly successful U.S. Particle Accelerator School (USPAS). GARD also supports the Traineeship Program for Accelerator Science and Engineering to revitalize education, training, and innovation in the physics of particle accelerators for the benefit of HEP and other SC programs that rely on these enabling technologies. The Traineeship Program is aimed at university and national laboratory consortia to provide the academic training and research experience needed to meet DOE's anticipated workforce needs. HEP holds a competition for traineeship awards for graduate level students to increase workforce development in areas of critical need. These traineeships leverage existing GARD research activities as well as the capabilities and assets of DOE laboratories.

This activity also supports the Accelerate initiative which will support scientific research to accelerate the transition of science advances to energy technologies.

Detector R&D

The Detector R&D activity supports the development of the next generation instrumentation and particle and radiation detectors necessary to maintain U.S. scientific leadership in a worldwide experimental endeavor that is broadening into new research areas, such as quantum sensors. To meet this challenge, HEP aims to foster an appropriate balance between evolutionary, near-term, low-risk detector R&D and revolutionary, long-term, high-risk detector R&D, while training the next generation of experts. The Detector R&D activity consists of groups at U.S. academic and research institutions and national laboratories performing research into the fundamental physics underlying the interactions of particles and radiation in detector materials. This activity also supports technology development that turns these insights into working detectors. Input on strategic directions from regular, open community studies will inform funding decisions in subsequent years.

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[b] https://science.osti.gov/hep/Community-Resources/Reports

The Detector R&D activity supports the Traineeship Program for HEP Instrumentation to address critical, targeted workforce development in fields of interest to the DOE mission. The program is aimed at university and national laboratory consortia to provide the academic training and research experience needed to meet DOE's anticipated workforce needs. HEP held a competition for traineeship awards for graduate level students to revitalize education, training, and innovation in the physics of particle detectors and next generation instrumentation for the benefit of HEP and other SC and DOE programs that rely on these enabling technologies. These traineeship awards leverage existing Detector R&D research activities as well as the capabilities and assets of DOE laboratories.

SC is in a unique position to both play a critical role in the advancement of microelectronic technologies over the coming decades, and to benefit from the resultant capabilities in detection, computing, and communications. Five SC programs—ASCR, Basic Energy Sciences, Fusion Energy Sciences, HEP, and Nuclear Physics—are working together to advance microelectronics technologies. This activity is focused on establishing the foundational knowledge base for future microelectronics technologies for sensing, communication, and computing that are complementary to quantum computing. Radiation and particle detection specifically will benefit from detector materials R&D, device R&D, advances in front-end electronics, and integrated sensor/processor architectures.

<u>Facility Operations and Experimental Support</u>
This activity supports GARD laboratory experimental and test facilities: Berkeley Lab Laser Accelerator (BELLA), the laser-driven plasma wakefield acceleration facility at Lawrence Berkeley National Laboratory (LBNL); FACET-II, the beam-driven plasma wakefield acceleration facility at SLAC National Accelerator Laboratory (SLAC); Argonne Wakefield Accelerator (AWA) in structure-based advanced acceleration concepts; and superconducting radio-frequency accelerator and magnet facilities at FNAL. This activity also supports detector test beam and fabrication facilities at FNAL.

High Energy Physics
Advanced Technology R&D

Activities and Explanation of Changes

(dollars in thousands)

FY 2023 Enacted		FY 2024 Request	Explanation of Changes FY 2024 Request vs FY 2023 Enacted
Advanced Technology R&D	**$133,120**	**$128,472**	**-$4,648**
Research	$80,871	$74,611	-$6,260
General Accelerator R&D	*$54,342*	*$49,082*	*-$5,260*
Funding supports capitalizing on the science opportunities at the newly completed FACET-II facility and the second beamline at BELLA; other accelerator R&D activities at DOE national laboratories and universities, including ASTI efforts in superconducting magnet and SRF; and the Traineeship Program for Accelerator Science and Technology. The funding also supports the Accelerate initiative.		The Request will support accelerator R&D activities at DOE national laboratories and universities, ASTI and Accelerate initiatives, and the Traineeship Program for Accelerator Science and Engineering.	Funding will focus support on enhanced cross-cutting accelerator R&D themes across the Office of Science, increased access and utilization of accelerator facilities, and broader engagement in scientific training.
Detector R&D	*$26,529*	*$25,529*	*-$1,000*
Funding supports world-leading, innovative Detector R&D; advanced microelectronics technologies and AI/ML implementations; and the Traineeship Program in HEP Instrumentation.		The Request will continue support of world-leading, innovative Detector R&D; advanced microelectronics technologies and AI/ML implementations; and the Traineeship Program in HEP Instrumentation.	Funding will focus support on the highest-priority efforts in the program.

(dollars in thousands)

FY 2023 Enacted	FY 2024 Request	Explanation of Changes FY 2024 Request vs FY 2023 Enacted
Facility Operations and Experimental Support $52,249	$53,861	+$1,612
Funding supports testing and beam time for experiments at the accelerator test facilities at Argonne National Laboratory, FNAL, LBNL and SLAC; and detector and test beam facilities at FNAL. The funding supports facility operations for FACET-II.	The Request will support testing and beam time for experiments at the accelerator and detector test facilities at Argonne National Laboratory, FNAL, LBNL and SLAC including expanded opportunities at the upgraded facilities at FACET-II and BELLA.	Funding will support increased user access to FACET-II at SLAC and to cryogenic, magnet, and SRF testing at FNAL; new two-beam laser wakefield acceleration experiments at LBNL; and modernization of the detector facilities at FNAL.

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.*

High Energy Physics
Construction

Description
This subprogram supports all line-item construction for the entire HEP program. All Total Estimated Costs (TEC) are funded in this subprogram, including engineering, design, and construction.

18-SC-42, Proton Improvement Plan II (PIP-II), FNAL
The PIP-II project will enhance the Fermilab Accelerator Complex to enable it to deliver higher-power proton beams to the neutrino-generating target for groundbreaking discovery in neutrino physics. The project is constructing an 800 megaelectronvolt (MeV) superconducting radio-frequency (SRF) proton linear accelerator and beam transfer line. The PIP-II project is also modifying the existing FNAL Booster, Recycler, and Main Injector synchrotrons downstream from the new linear accelerator to accept the increased beam intensity. Some of the new components and the cryoplant will be provided through international, in-kind contributions. The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-3 (Approve Construction), approved on April 18, 2022, with a Total Project Cost (TPC) of $978,000,000. The CD-4 milestone date is 1Q FY 2033.

11-SC-40, Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment, FNAL
The LBNF/DUNE construction project is a federal, state, private, and international partnership developing and implementing the technologies of particle accelerators and detectors to enable world-leading research into the fundamental physics of neutrinos, which are the most ubiquitous particles in the universe while at the same time among the most mysterious. LBNF/DUNE will study the transformations of muon neutrinos that occur as they travel from FNAL, where they are produced in a high-energy proton beam, to a large detector in South Dakota, 800 miles away from FNAL. The experiment will analyze the rare, flavor-changing transformations of neutrinos in flight, from one lepton flavor to another, which are expected to help explain the fundamental physics of neutrinos and the puzzling imbalance of matter and antimatter that enables our existence in a matter-dominated universe.

The LBNF/DUNE project is a national flagship particle physics initiative and will be the first-ever large-scale, international science facility hosted by the U.S. The LBNF/DUNE project consists of two multinational collaborative efforts. LBNF is responsible for the beamline at FNAL and other experimental and civil infrastructure at FNAL and at the SURF in South Dakota. DUNE is an international scientific collaboration responsible for defining the scientific goals and technical requirements for the beam and detectors, as well as the design, construction and commissioning of the detectors and subsequent research.

DOE's High Energy Physics program manages both activities as a single, line-item construction project—LBNF/DUNE-US. LBNF, with DOE/FNAL leadership and participation by a small number of international partners including CERN, will construct a megawatt-class neutrino source and related facilities at FNAL (the "Near Site"), as well as underground caverns and cryogenic facilities in South Dakota (the "Far Site") needed to house the DUNE detectors. DUNE has international leadership and participation by over 1,400 scientists and engineers from over 200 institutions in over 30 countries. DOE will fund about half of DUNE under the name DUNE-US.

Critical Decision CD-3A, approved on September 1, 2016, allowed for Initial Far Site Construction. Following this approval, excavation and construction for the LBNF Far Site conventional facilities started to mitigate risks and minimize delays for providing a facility ready to accept detectors for installation. DOE conducted an independent project review in July 2022 to evaluate a new cost range and the alternative selection. The most recent DOE Order 413.3B approved CD is CD-1RR (Update cost range, reaffirm the alternative selection, and approve a new tailoring strategy for baselining the project in multiple subprojects), approved on February 16, 2023, with a TPC Point Estimate of $3,277,000,000. This TPC Point Estimate serves for planning purposes and will be refined as the project matures and each subproject is baselined. As each subproject is baselined, the aggregate of the baselined subproject TPCs must be below the upper end of the approved cost range. When the last subproject is baselined, the LBNF/DUNE-U.S. TPC will be the aggregate of all subproject TPCs plus any contingency being held by the parent LBNF/DUNE-U.S. project. The CD-1RR approval reaffirms that the previously selected alternative for an international and more capable deep underground detector is still a reasonable decision based on the matured understanding of factors. The reaffirmed alternative is the best opportunity for the U.S. to host a truly world-leading international neutrino program based upon optimized rate of data collection and unmatched sensitivities and precision. The reaffirmed alternative strengthens the U.S.'s international partnerships in particle physics and allows for future upgrades to the detectors and beam intensity if DOE chooses to do so.

<u>11-SC-41, Muon to Electron Conversion Experiment, FNAL</u>
Mu2e, under construction at FNAL, will search for evidence that a muon can undergo direct (neutrinoless) conversion into an electron, a process that would violate lepton flavor conservation and probe new physics at energy scales beyond the collision energy of the Large Hadron Collider. If observed, this major discovery would signal the existence of new particles or new forces beyond the Standard Model. The Mu2e project completed its technical design phase (CD-3) on July 14, 2016 and moved into full construction at that time. Civil construction of the underground detector housing and the surface building for the experiment were completed in 2017. The funding profile through FY 2019 supported the originally approved TPC of $273,677,000 and the originally approved CD-4 milestone date of 1Q FY 2023.

External factors negatively impacted the performance of the Mu2e project: the COVID-19 pandemic and associated work restrictions at most of the participating institutions; supply chain and workforce disruptions; and vendor delays of critical project components. Mitigating the impacts required additional budget authority and schedule beyond what remained in the authorization for the original performance baseline. Following thorough review and evaluation by an Independent Cost Review and an Independent Project Review, a Baseline Change Proposal for the Mu2e project was approved on December 21, 2022. The new baseline added $42,023,000 to the total project cost and moved the CD-4 milestone date for project completion to January 2028. Funds provided by the FY 2022 Inflation Reduction Act and the FY 2023 Enacted Appropriations completed the funding for this project. No funding is requested in the FY 2024 Request.

Activities and Explanation of Changes

(dollars in thousands)

FY 2023 Enacted		FY 2024 Request		Explanation of Changes FY 2024 Request vs FY 2023 Enacted
Construction	**$298,000**		**$376,000**	**+$78,000**
18-SC-42, Proton Improvement Plan II (PIP-II), FNAL	$120,000		$125,000	+$5,000
Funding supports initiation of civil construction for the balance of the linear accelerator facilities as well as continuation of procurement and fabrication of technical systems.		The Request will support continuation of civil construction and fabrication of technical systems.		Funding will increase and support a ramp-up of construction for the linear accelerator facilities.
11-SC-40, Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment, FNAL	$176,000		$251,000	+$75,000
Funding supports continuation of the Far Site civil construction activities for excavation of the underground equipment caverns and connecting drifts (tunnels). Design activities will be completed for the far site detectors and cryogenics systems and the beamline design will be finalized.		The Request will support continued excavation of the far detector caverns; execution of the Far Site Conventional Facilities Building and Site Infrastructure, and Far Detectors and Cryogenic Infrastructure subprojects; and design and planning for the Near Site Conventional Facilities and Beamline, and Near Detector subprojects to prepare for baseline and approval of construction.		Funding will increase and support all five of the subprojects.
11-SC-41, Muon to Electron Conversion Experiment, FNAL	$2,000		$ —	-$2,000
Funding supports continued implementation of corrective actions due to schedule delays caused by pandemic response at FNAL and collaborating universities, and by fabrication delays for the tracking detector and two superconducting magnets being fabricated by a vendor.		No funding is requested for this activity.		The Mu2e project received final funding in FY 2023.

High Energy Physics
Capital Summary

	(dollars in thousands)						
	Total	**Prior Years**	**FY 2022 Enacted**	**FY 2022 IRA Supp.**	**FY 2023 Enacted**	**FY 2024 Request**	**FY 2024 Request vs FY 2023 Enacted**
Capital Operating Expenses							
Capital Equipment	N/A	N/A	107,915	105,740	73,620	58,200	-15,420
Minor Construction Activities							
General Plant Projects	N/A	N/A	–	–	4,000	4,200	+200
Total, Capital Operating Expenses	**N/A**	**N/A**	**107,915**	**105,740**	**77,620**	**62,400**	**-15,220**

High Energy Physics
Capital Equipment

(dollars in thousands)

	Total	Prior Years	FY 2022 Enacted	FY 2022 IRA Supp.	FY 2023 Enacted	FY 2024 Request	FY 2024 Request vs FY 2023 Enacted
Capital Equipment							
Major Items of Equipment							
Energy Frontier Experimental Physics							
High Luminosity Large Hadron Collider Accelerator Upgrade Project	259,952	166,597	25,000	38,355	30,000	–	-30,000
High Luminosity Large Hadron Collider ATLAS Upgrade Project	183,485	68,000	20,000	32,785	10,000	16,200	+6,200
High Luminosity Large Hadron Collider CMS Upgrade Project	158,550	48,238	20,000	34,600	10,000	19,500	+9,500
Intensity Frontier Experimental Physics							
Accelerator Controls Operations Research Network	121,201	–	500	–	–	5,000	+5,000
Cosmic Frontier Experimental Physics							
Cosmic Microwave Background - Stage 4	354,000	1,000	–	–	–	9,000	+9,000
Lunar Surface Electromagnetics Experiment Night	14,000	–	14,000	–	–	–	–
Total, MIEs	N/A	N/A	79,500	105,740	50,000	49,700	-300
Total, Non-MIE Capital Equipment	N/A	N/A	28,415	–	23,620	8,500	-15,120
Total, Capital Equipment	**N/A**	**N/A**	**107,915**	**105,740**	**73,620**	**58,200**	**-15,420**

Note:
- *The Capital Equipment table includes MIEs located at a DOE facility with a Total Estimated Cost (TEC) > $5M and MIEs not located at a DOE facility with a TEC >$2M.*

High Energy Physics
Minor Construction Activities

(dollars in thousands)

	Total	Prior Years	FY 2022 Enacted	FY 2023 Enacted	FY 2024 Request	FY 2024 Request vs FY 2023 Enacted
General Plant Projects (GPP)						
GPPs (greater than or equal to $5M and less than $30M)						
Target Systems Integration Building	5,500	1,500	–	4,000	–	-4,000
Total GPPs (greater than or equal to $5M and less than $30M)	N/A	N/A	–	4,000	–	-4,000
Total GPPs less than $5M	N/A	N/A	–	–	4,200	+4,200
Total, General Plant Projects (GPP)	**N/A**	**N/A**	**–**	**4,000**	**4,200**	**+200**
Total, Minor Construction Activities	**N/A**	**N/A**	**–**	**4,000**	**4,200**	**+200**

Note:

- *GPP activities less than $5M include design and construction for additions and/or improvements to land, buildings, replacements or addition to roads, and general area improvements. AIP activities less than $5M include minor construction at an existing accelerator facility.*
- *The Target Systems Integration Building includes $11,400,000 obligated in FY 2022 that brings the total project amount to $16,900,000 pending a baseline change approval.*

High Energy Physics
Major Items of Equipment Description(s)

<u>Energy Frontier Experimental Physics MIEs:</u>
High-Luminosity Large Hadron Collider Accelerator Upgrade Project (HL-LHC Accelerator Upgrade Project)
The HL-LHC Accelerator Upgrade Project received CD-3 approval on December 21, 2020. Following the major upgrade, the CERN LHC machine will further increase the particle collision rate by at least a factor of five to explore new physics beyond its current reach. This project is delivering components for which U.S. scientists have critical expertise: interaction region focusing quadrupole magnets, and special superconducting radiofrequency cavities that can generate transverse electric fields. The magnets are being assembled at LBNL, BNL, and FNAL, exploiting special expertise and unique capabilities at each laboratory. The project was stalled by shutdowns at the national laboratories due to COVID-19 and has seen increased costs as a result. In all other respects the project is performing well. A rebaseline review of the project was held December 13-15, 2022, which supports a new Total Estimated Cost (TEC) of $259,952,000 with the Baseline Change Proposal approval scheduled for March 2023. Due to the $38,355,000 provided in the FY 2022 Inflation Reduction Act, and the project receiving final funding needed in FY 2023 Enacted Appropriation, no additional funding is requested in FY 2024.

High-Luminosity Large Hadron Collider ATLAS Detector Upgrade Project (HL-LHC ATLAS)
The HL-LHC ATLAS Detector Upgrade Project received CD-2/3 approval on January 31, 2023, with a TPC of $200,000,000. The ATLAS detector will integrate a higher amount of data per run by at least a factor of ten compared to the period prior to the HL-LHC upgrades, making the physical conditions in which the detectors run very challenging. To operate for an additional decade in these new conditions, the ATLAS detector requires upgrades to the silicon pixel and strip tracker detectors, the muon detector systems, the calorimeter detectors and associated electronics, as well as the trigger and data acquisition systems. The National Science Foundation (NSF) approved support for a Major Research Equipment and Facility Construction (MREFC) project in FY 2020 to provide different scope to the HL-LHC ATLAS detector upgrade. DOE and NSF are coordinating their contributions to avoid duplication. The FY 2024 Request for TEC funding of $16,200,000 will focus on completion of the final design and ramp-up of fabrication activities.

High-Luminosity Large Hadron Collider CMS Detector Upgrade Project (HL-LHC CMS)
The HL-LHC CMS project received CD-1 approval on December 19, 2019, and CD-3B approval on June 24, 2022. A CD-2/3 review of the project was held January 24-27, 2023. The proposed TPC shown at the review was $200,000,000. CD-2/3 approval is planned for 2Q of FY 2023. The CMS detector will integrate a higher amount of data per run by at least a factor of ten compared to the period prior to the HL-LHC upgrades, making the physical conditions in which the detectors run very challenging. To operate for an additional decade in these new conditions, the CMS detector requires upgrades to the silicon pixel tracker detectors, the outer tracker detector, the muon detector systems, the calorimeter detectors and associated electronics, the trigger and data acquisition systems, and the addition of a novel timing detector. NSF approved support for a MREFC Project in FY 2020 to provide different scope to the HL-LHC CMS detector upgrade. DOE and NSF are coordinating their contributions to avoid duplication. The FY 2024 Request for TEC funding of $19,500,000 will focus on completion of the final design and ramp-up of fabrication activities.

<u>Intensity Frontier Experimental Physics MIE:</u>
Accelerator Controls Operations Research Network (ACORN)
The ACORN project received CD-0 approval on August 28, 2020, with an estimated cost range of $100,000,000 to $142,000,000. This project will replace FNAL's dated accelerator control system with a modern system which is maintainable, sustainable, and capable of utilizing advances in Artificial Intelligence and Machine Learning to create a high-performance accelerator for the future. The control system of the Fermilab Accelerator Complex initiates particle beam production; controls beam energy and intensity; steers particle beams to their ultimate destination; measures beam parameters; and monitors beam transport through the complex to ensure safe, reliable, and effective operations. ACORN will provide FNAL with an accelerator control system that will be compatible with PIP-II. FNAL plans to collaborate with other national labs that have experience with accelerator control systems. This project is expected to receive CD-1 approval in FY 2024. The FY 2024 Request for TEC funding of $5,000,000 will fund system design and other related engineering activities.

Cosmic Frontier Experimental Physics MIE:

Cosmic Microwave Background Stage 4 (CMB-S4)

The CMB-S4 project received CD-0 approval on July 25, 2019, with an estimated cost range of $320,000,000 to $395,000,000. The project is expected to be carried out as a partnership with NSF, with DOE as the lead agency and a distribution of scope planned to be determined by the end of FY 2023. The project consists of fabricating an array of small and large telescopes at two locations: the NSF Amundsen-Scott South Pole Station and the Atacama high desert in Chile. LBNL was selected in August 2020 to lead the efforts in providing the DOE scope for the project. The FY 2024 Request for TEC funding of $9,000,000 will support engineering and design efforts.

Lunar Surface Electromagnetics Experiment Night (LuSEE-Night)

The LuSEE-Night MIE is a BNL managed project that follows the BNL Standards-Based Management System in which Project Decision (PD) reviews are analogous to DOE CD reviews. LuSEE-Night received PD-1 approval on May 16, 2022, with a TPC of $15,000,000. LuSEE-Night is an experiment on the far side of the moon to study fundamental physics in the early universe. LuSEE's radio spectrometer will make the most precise measurements of the low-frequency radio sky, which is inaccessible from Earth, seeking to detect the fossil radiation emitted 100 million years after the Big Bang when the first structures were forming. LuSEE-Night is a collaboration between NASA and DOE. The mission is led by NASA-funded Space Sciences Laboratory at the University of California, Berkeley. NASA provides for the delivery to the Moon via the Commercial Lunar Payload Services program. DOE LuSEE-Night MIE responsibilities are for the science antennae and preamplifiers, the inner electronics box including the spectrometer, the communication system, and the power management. The FY 2022 Enacted Appropriation provided full funding to complete all DOE deliverables.

High Energy Physics
Construction Projects Summary

(dollars in thousands)

	Total	Prior Years	FY 2022 Enacted	FY 2022 IRA Supp.	FY 2023 Enacted	FY 2024 Request	FY 2024 Request vs FY 2023 Enacted
18-SC-42, Proton Improvement Plan II							
Total Estimated Cost (TEC)	891,200	160,000	90,000	10,000	120,000	125,000	+5,000
Other Project Cost (OPC)	86,800	73,594	–	–	–	–	–
Total Project Cost (TPC)	**978,000**	**233,594**	**90,000**	**10,000**	**120,000**	**125,000**	**+5,000**
11-SC-40, Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment							
Total Estimated Cost (TEC)	3,167,335	678,781	176,000	125,000	176,000	251,000	+75,000
Other Project Cost (OPC)	109,665	93,625	8,000	–	4,000	4,000	–
Total Project Cost (TPC)	**3,277,000**	**772,406**	**184,000**	**125,000**	**180,000**	**255,000**	**+75,000**
11-SC-41, Muon to Electron Conversion Experiment							
Total Estimated Cost (TEC)	292,023	252,000	2,000	36,023	2,000	–	-2,000
Other Project Cost (OPC)	23,677	23,677	–	–	–	–	–
Total Project Cost (TPC)	**315,700**	**275,677**	**2,000**	**36,023**	**2,000**	**–**	**-2,000**
Total, Construction							
Total Estimated Cost (TEC)	**N/A**	**N/A**	**268,000**	**171,023**	**298,000**	**376,000**	**+78,000**
Other Project Cost (OPC)	**N/A**	**N/A**	**8,000**	**–**	**4,000**	**4,000**	**–**
Total Project Cost (TPC)	**N/A**	**N/A**	**276,000**	**171,023**	**302,000**	**380,000**	**+78,000**

High Energy 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 2022 Enacted	FY 2022 Current	FY 2023 Enacted	FY 2024 Request	FY 2024 Request vs FY 2023 Enacted
Scientific User Facilities - Type A					
Fermilab Accelerator Complex	**131,500**	**129,754**	**152,984**	**150,630**	**-2,354**
Number of Users	2,300	2,095	2,700	2,700	–
Achieved Operating Hours	–	5,154	–	–	–
Planned Operating Hours	5,180	5,180	5,740	5,200	-540
Unscheduled Down Time Hours	–	1,880	–	–	–
Facility for Advanced Accelerator Experimental Tests II (FACET II)	**13,000**	**13,152**	**15,500**	**15,572**	**+72**
Number of Users	225	120	120	125	+5
Achieved Operating Hours	–	3,969	–	–	–
Planned Operating Hours	2,700	2,700	3,300	3,300	–
Unscheduled Down Time Hours	–	600	–	–	–
Total, Facilities	**144,500**	**142,906**	**168,484**	**166,202**	**-2,282**
Number of Users	2,525	2,215	2,820	2,825	+5
Achieved Operating Hours	–	9,123	–	–	–
Planned Operating Hours	7,880	7,880	9,040	8,500	-540
Unscheduled Down Time Hours	–	2,480	–	–	–

Note:
- *Achieved Operating Hours and Unscheduled Downtime Hours will only be reflected in the Congressional budget cycle which provides actuals.*

High Energy Physics
Scientific Employment

	FY 2022 Enacted	FY 2023 Enacted	FY 2024 Request	FY 2024 Request vs FY 2023 Enacted
Number of Permanent Ph.Ds (FTEs)	775	785	785	–
Number of Postdoctoral Associates (FTEs)	388	400	380	-20
Number of Graduate Students (FTEs)	500	530	540	+10
Number of Other Scientific Employment (FTEs)	1,560	1,635	1,540	-95
Total Scientific Employment (FTEs)	**3,223**	**3,350**	**3,245**	**-105**

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

18-SC-42, Proton Improvement Plan II (PIP-II), FNAL
Fermi National Accelerator Laboratory, FNAL
Project is for Design and Construction

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

Summary

The FY 2024 Request for the Proton Improvement Project II (PIP-II) is $125,000,000 of Total Estimated Cost (TEC) funding. The project has an approved Total Project Cost (TPC) of $978,000,000.

The PIP-II project will enhance the Fermilab Accelerator Complex to enable it to deliver higher-power proton beams to the neutrino-generating target for groundbreaking discovery in neutrino physics. The project will design and construct an 800 megaelectronvolt (MeV) superconducting radio frequency (SRF) proton linear accelerator and beam transfer line. The PIP-II project also will modify the existing Fermi National Accelerator Laboratory (FNAL) Booster, Recycler, and Main Injector synchrotrons downstream from the new linear accelerator to accept the increased beam intensity. Some of the new components and the cryo-plant will be provided through international, in-kind contributions.

Significant Changes

This project was initiated in FY 2018. The most recent DOE Order 413.3B Critical Decision (CD) is CD-3 (Approve Construction), approved on April 18, 2022. The planned date for CD-4, Project Completion, is 1Q FY 2033.

Anticipated in-kind technical contributions from international partners total $330,000,000 (equivalent to DOE costing). Legally binding agreements with all countries but France have been signed to cover the planned work. The legally binding agreement with France has been drafted and signatures are expected by the end of 2023. Non-binding Project Planning Documents (PPDs) that provide additional technical details beyond those provided in the legally binding agreements are being signed by the international partners; so far PPDs have been signed with Italian, Polish, and UK partner institutions. The PPD, with the India's Department of Atomic Energy laboratories, is expected to be signed in 2023.

The FY 2022 Enacted Appropriations supported continuation of construction of the Early Conventional Facilities (ECF) cryo-plant building, site preparation for the linear accelerator complex, completion of design for CD-3, and initiation of preconstruction procurement for the accelerator's technical systems as designs are completed.

The design was completed ahead of schedule during FY 2022 and, consequently, savings of previously estimated 'design' cost were redirected to offset cost increases and risk-based contingency estimates for 'construction' procurements, including civil construction and technical equipment and specialized materials and processes (such as niobium and superconducting RF cavities), due to inflation and supply chain issues.

The Inflation Reduction Act provided $10,000,000 for PIP-II to advance the project's procurements to reduce schedule risk.

The FY 2023 Enacted Appropriations support initiation of civil construction for the linear accelerator complex as well as initiation of procurement and fabrication for the accelerator's technical systems.

The FY 2024 Request will support continuation of construction of the conventional facilities as well as continuation of procurement and fabrication for the technical systems.

A Federal Project Director (FPD) has been assigned to this project and has approved this construction project datasheet. The FPD has a Level III certification.

Critical Milestone History

Fiscal Year	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	CD-4
FY 2024	11/12/15	7/23/18	7/23/18	12/14/20	4/18/22	4/18/22	1Q FY 2033

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
FY 2024	12/14/20	3/16/21

CD-3A – Approve long-lead procurement of niobium for superconducting radio frequency (SRF) cavities and other long lead components for SRF cryomodules

Project Cost History

(dollars in thousands)

Fiscal Year	TEC, Design	TEC, Construction	TEC, Total	OPC, Except D&D	OPC, Total	TPC
FY 2023	177,000	714,200	891,200	86,800	86,800	978,000
FY 2024	135,895	755,305	891,200	86,800	86,800	978,000

2. Project Scope and Justification

Scope

Specific scope elements of the PIP-II project include construction of (a) the superconducting radio frequency (SRF) Linac, (b) cryoplant to support SRF operation, (c) beam transfer line, (d) modifications to the Booster, Recycler and Main Injector synchrotrons, and (e) conventional facilities:

a) 800-MeV Superconducting H^- Linac consisting of a 2.1 MeV warm (normal-conducting) front-end injector and five types of SRF cryomodules that are continuous wave capable but operating initially in pulsed mode. The cryomodules include Half Wave Resonator cavities (HWR) at 162.5 MHz, two types of Single Spoke Resonator cavities (SSR1 and SSR2) at 325 MHz, Low-Beta and High-Beta elliptical cavities at 650 MHz (LB-650 and HB-650). The warm front-end injector consists of an H^- ion source, Low Energy Beam Transport (LEBT), Radiofrequency Quadrupole (RFQ) and Medium Energy Beam Transport (MEBT) that prepare the beam for injection into the SRF cryomodules. The scope includes the associated electronic power sources, instrumentation, and controls to support Linac operation.

   The PIP-II Injector Test Facility at FNAL is an R&D prototype for the low-energy proton injector at the front-end of the Linac, consisting of H^- ion source, LEBT, RFQ, MEBT, HWR, and one SSR1 cryomodule. It was developed to reduce technical risks for the project, with participation and in-kind contributions from the India Department of Atomic Energy (DAE) Labs. The Test Facility has successfully completed its program and has been converted to a cryomodule test stand for testing the cryomodules for the project.

b) Cryoplant with storage and distribution system to support SRF Linac operation. The cryoplant is an in-kind contribution by the India DAE Labs that is similar to the cryoplant being designed and constructed for a high-intensity superconducting proton accelerator project in India.[c]
c) Beam Transfer Line from the Linac to the Booster Synchrotron, including accommodation of a beam dump and future delivery of beam to the FNAL Muon Campus.
d) Modification of the Booster, Recycler and Main Injector synchrotrons to accommodate a 50 percent increase in beam intensity and construction of a new injection area in the Booster to accommodate 800-megaelectronvolt (MeV) injection.
e) Civil construction of conventional facilities, including housings, service buildings, roads, access points and utilities with the special capabilities required for the linac and beam transport line. A portion of the civil construction scope comprises the ECF subproject. That subproject scope includes the cryogenics plant building and site work. ECF subproject total estimated cost is $36,000,000; $8,000,000 in FY 2020, $22,000,000 in FY 2021 and $6,000,000 in FY 2022. The ECF subproject's building and site work will be completed in FY 2023. If the ECF subproject is completed for less than its full budget, DOE may authorize redistribution of those funds to remaining PIP-II project scope.

Significant pieces of the Linac and cryogenic scope (a and b above) will be delivered as in-kind international contributions not funded by DOE. These include assembly and/or fabrication of Linac SRF components and the cryoplant. The rationale or motivation behind these contributions are institutional and/or industrial technical capability, and interest in SRF technology, as well as interest in LBNF/DUNE. The construction phase scope of in-kind contributions is divided between U.S. DOE national laboratories, India Department of Atomic Energy (DAE) Labs, Italy National Institute for Nuclear Physics (INFN) Labs, French Atomic Energy Commission (CEA) and National Center for Scientific Research (CNRS)-National Institute of Nuclear and Particle Physics (IN2P3) Labs, UK Science & Technology Facilities Council (STFC) Labs, and Wroclaw University of Science and Technology in Poland, tentatively as indicated in the following table of Scope Responsibilities for PIP-II.

Construction-phase Scope Responsibilities for PIP-II Linac RF Components

Components	Quan-tity	Freq. (MHz)	SRF Cavities	Responsibility for Cavity Fabrication	Responsibility for Module Assembly	Responsibility for RF Amplifiers	Cryogenic Cooling Source and Distribution System
RFQ	1	162.5	N/A	N/A	U.S. DOE (LBNL)	U.S. DOE (FNAL)	N/A
HWR Cryomodule	1	162.5	8	U.S. DOE (ANL)	U.S. DOE (ANL)	U.S. DOE (FNAL)	India DAE Labs, Poland WUST
SSR1 Cryomodule	2	325	16	U.S. DOE (FNAL), India DAE Labs	U.S. DOE (FNAL)	India DAE Labs	India DAE Labs, Poland WUST
SSR2 Cryomodule	7	325	35	France CNRS (IN2P3 Lab)	U.S. DOE (FNAL)	India DAE Labs	India DAE Labs, Poland WUST
LB-650 Cryomodule	9	650	36	Italy INFN (LASA)	France CEA (Saclay Lab)	India DAE Labs	India DAE Labs, Poland WUST
HB-650 Cryomodule	4	650	24	UK STFC Labs	UK STFC Labs, U.S. DOE (FNAL)	India DAE Labs	India DAE Labs, Poland WUST

Justification

The PIP-II project will enhance the Fermilab Accelerator Complex by providing the capability to deliver higher-power proton beams to the neutrino-generating target that serves the LBNF/DUNE program for groundbreaking discovery in neutrino physics, a major field of fundamental research in high energy particle physics. Increasing the neutrino beam intensity requires increasing the proton beam power on target. PIP-II will raise the proton beam power from 800 kW to 1,200 kW over an energy range of 60-120 GeV and will enable the eventual increase to 2,400 kW with upgrades to the Booster accelerator. The PIP-II project will provide more flexibility for future science-driven upgrades to the entire accelerator complex and increase the system's overall reliability by addressing some of the accelerator complex's elements that are far beyond their design life.

[c] See Section 8.

PIP-II was identified as one of the highest priorities in the 10-year strategic plan for U.S. High Energy Physics developed by the High Energy Physics Program Prioritization Panel (P5) and unanimously approved by the High Energy Physics Advisory Panel (HEPAP), advising DOE and NSF, in 2014.[d]

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 Threshold KPPs represent the minimum acceptable performance that the project must achieve. The Objective KPPs represent the desired project performance. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion.

Performance Measure	Threshold	Objective
Linac Beam Energy	H- beam will be accelerated to 600 MeV.	H- beam will be accelerated to 700 MeV. Linac systems required for 800 MeV will be installed and tested.
Linac Beam Intensity	H- beam will be delivered to the beam absorber at the end of the linac.	H- beam with intensity of 1.3×10^{12} particles per pulse at 20 Hz pulse-repetition rate will be delivered to the Beam Transfer Line absorber.
Booster, Recycler and Main Injector Synchrotron Upgrades	Upgrades of the Booster, Recycler and Main Injector Synchrotrons, required to support delivery of 1.2 MW onto the LBNF target, will be installed and tested without beam.	Linac beam will be injected into and circulated in the Booster.

[d] "Building for Discovery: Strategic Plan for U.S. Particle Physics in the Global Context," HEPAP, 2014.

3. Financial Schedule

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs	IRA Supp. Costs
Total Estimated Cost (TEC)				
Design (TEC)				
Prior Years	125,000	125,000	99,945	–
FY 2022	10,895	10,895	35,950	–
Total, Design (TEC)	**135,895**	**135,895**	**135,895**	**–**
Construction (TEC)				
Prior Years	35,000	35,000	17,194	–
FY 2022	79,105	79,105	20,104	–
FY 2022 - IRA Supp.	10,000	10,000	–	–
FY 2023	120,000	120,000	110,000	10,000
FY 2024	125,000	125,000	125,000	–
Outyears	386,200	386,200	473,007	–
Total, Construction (TEC)	**755,305**	**755,305**	**745,305**	**10,000**
Total Estimated Cost (TEC)				
Prior Years	160,000	160,000	117,139	–
FY 2022	90,000	90,000	56,054	–
FY 2022 - IRA Supp.	10,000	10,000	–	–
FY 2023	120,000	120,000	110,000	10,000
FY 2024	125,000	125,000	125,000	–
Outyears	386,200	386,200	473,007	–
Total, TEC	**891,200**	**891,200**	**881,200**	**10,000**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs	IRA Supp. Costs
Other Project Cost (OPC)				
Prior Years	73,594	73,594	73,410	–
FY 2022	–	–	9	–
FY 2023	–	–	175	–
Outyears	13,206	13,206	13,206	–
Total, OPC	**86,800**	**86,800**	**86,800**	**–**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs	IRA Supp. Costs
Total Project Cost (TPC)				
Prior Years	233,594	233,594	190,549	–
FY 2022	90,000	90,000	56,063	–
FY 2022 - IRA Supp.	10,000	10,000	–	–
FY 2023	120,000	120,000	110,175	10,000
FY 2024	125,000	125,000	125,000	–
Outyears	399,406	399,406	486,213	–
Total, TPC	**978,000**	**978,000**	**968,000**	**10,000**

Note:
- *Prior Years and FY 2022 reflect actual costs; remaining years are cost estimates.*

4. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design	135,895	146,314	146,314
Design - Contingency	N/A	30,686	30,686
Total, Design (TEC)	**135,895**	**177,000**	**177,000**
Construction	151,000	124,009	124,009
Site Preparation	13,000	12,783	12,783
Equipment	433,905	378,705	378,705
Construction - Contingency	157,400	198,703	198,703
Total, Construction (TEC)	**755,305**	**714,200**	**714,200**
Total, TEC	**891,200**	**891,200**	**891,200**
Contingency, TEC	*157,400*	*229,389*	*229,389*
Other Project Cost (OPC)			
R&D	67,117	67,117	67,117
Conceptual Planning	8,324	8,324	8,324
Conceptual Design	2,855	2,855	2,855
OPC - Contingency	8,504	8,504	8,504
Total, Except D&D (OPC)	**86,800**	**86,800**	**86,800**
Total, OPC	**86,800**	**86,800**	**86,800**
Contingency, OPC	*8,504*	*8,504*	*8,504*
Total, TPC	**978,000**	**978,000**	**978,000**
Total, Contingency (TEC+OPC)	***165,904***	***237,893***	***237,893***

5. Schedule of Appropriations Requests

(dollars in thousands)

Fiscal Year	Type	Prior Years	FY 2022	FY 2022 IRA Supp.	FY 2023	FY 2024	Outyears	Total
FY 2023	TEC	160,000	90,000	—	120,000	—	521,200	891,200
	OPC	73,594	—	—	—	—	13,206	86,800
	TPC	233,594	90,000	—	120,000	—	534,406	978,000
FY 2024	TEC	160,000	90,000	10,000	120,000	125,000	386,200	891,200
	OPC	73,594	—	—	—	—	13,206	86,800
	TPC	233,594	90,000	10,000	120,000	125,000	399,406	978,000

6. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy	1Q FY 2033
Expected Useful Life	20 years
Expected Future Start of D&D of this capital asset	1Q FY 2053

FNAL will operate the PIP-II Linac as an integral part of the entire Fermilab Accelerator Complex. Related funding estimates for operations, utilities, maintenance, and repairs are incremental to the balance of the FNAL accelerator complex for which the present cost of operation, utilities, maintenance, and repairs is approximately $100,000,000 annually.

Related Funding Requirements
(dollars in thousands)

	Annual Costs		Life Cycle Costs	
	Previous Total Estimate	**Current Total Estimate**	**Previous Total Estimate**	**Current Total Estimate**
Operations	4,000	4,000	80,000	80,000
Utilities	3,000	3,000	60,000	60,000
Maintenance and Repair	2,000	2,000	40,000	40,000
Total, Operations and Maintenance	9,000	9,000	180,000	180,000

7. D&D Information

The new area being constructed in this project is not replacing existing facilities.

	Square Feet
New area being constructed by this project at FNAL	127,676
Area of D&D in this project at FNAL	—
Area at FNAL to be transferred, sold, and/or D&D outside the project, including area previously "banked"	—
Area of D&D in this project at other sites	—
Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked"	127,676
Total area eliminated	—

The one-for-one replacement will be met through banked space. A waiver from the one-for-one requirement to eliminate excess space at FNAL to offset PIP-II and other projects was approved by DOE Headquarters on November 12, 2009. The waiver identified and transferred to FNAL 575,104 square feet of excess space to accommodate new facilities including Mu2e, LBNF, DUNE, and other facilities, as-yet unbuilt, from space that was banked at other DOE facilities. The PIP-II Project is following all current DOE procedures for tracking and reporting space utilization.

8. Acquisition Approach

DOE is acquiring the PIP-II project through Fermi Research Alliance (FRA), the Management and Operating (M&O) contractor responsible for FNAL, rather than have the DOE compete a contract for fabrication to a third party. FRA has a strong relationship with the high energy physics community and its leadership, including many FNAL scientists and engineers. This arrangement will facilitate close cooperation and coordination for PIP-II with an experienced team of project leaders managed by FRA, which will have primary responsibility for oversight of all subcontracts required to execute the project. The arrangement is expected to include subcontracts for the purchase of components from third party vendors as well as delivery of in-kind contributions from non-DOE partners.

Project partners will deliver significant pieces of scope as in-kind international contributions, not funded by U.S. DOE. The rationale or motivation behind these contributions are institutional and/or industrial technical capability, long-standing collaborations in the physics programs at FNAL that PIP-II will support, and interest in SRF technology. Scientific institutions from several countries, tabulated below, are engaged in discussion of potential PIP-II scope contributions within the framework of international, government-to-government science and technology agreements.

Scientific Agencies and Institutions Discussing Potential Contributions of Scope for PIP-II

Country	Funding Agency	Institutions
U.S.	Department of Energy	Fermi National Accelerator Laboratory; Lawrence Berkeley National Laboratory; Argonne National Laboratory
India	Department of Atomic Energy	Bhabha Atomic Research Centre, Mumbai; Inter University Accelerator Centre, New Delhi; Raja Ramanna Centre for Advanced Technology, Indore; Variable Energy Cyclotron Centre, Kolkata
Italy	National Institute for Nuclear Physics	Laboratory for Accelerators and Applied Superconductivity, Milan
France	Atomic Energy Commission National Center for Scientific Research	Saclay Nuclear Research Center; National Institute of Nuclear & Particle Physics, Paris
UK	Science & Technology Facilities Council	Daresbury Laboratory
Poland	Wroclaw University of Science and Technology	Wroclaw University of Science and Technology

For example, joint participation by U.S. DOE and the India DAE in the development and construction of high intensity superconducting proton accelerator projects at FNAL and in India is codified in Annex I to the “Implementing Agreement between DOE and Indian Department of Atomic Energy in the Area of Accelerator and Particle Detector Research and Development for Discovery Science for High Intensity Proton Accelerators,” signed in January 2015 by the U.S. Secretary of Energy and the India Chairman of DAE. FNAL and DAE Labs subsequently developed a “Joint R&D Document” outlining the specific roles and goals of the collaborators during the R&D phase of the PIP-II project. This R&D agreement is expected to lead to a similar agreement for the construction phase, describing roles and in-kind contributions. DOE and FNAL are developing similar agreements with Italy, France, and the UK for PIP-II.

SC is putting mechanisms into place to facilitate joint consultation between the partnering funding agencies, such that coordinated oversight and actions will ensure the success of the overall program. SC is successfully employing similar mechanisms for international partnering for the DOE LBNF/DUNE project and for DOE participation in LHC-related projects hosted by CERN.

Domestic engineering and construction subcontractors will perform the civil construction at FNAL. FNAL is utilizing a firm fixed-price contract for architectural-engineering services to complete all remaining designs for conventional facilities with an option for construction support. The general construction subcontract will be placed on a firm-fixed-price basis.

All subcontracts will be competitively bid and awarded based on best value to the government. Fermi Site Office provides contract oversight for FRA’s plans and performance. Project performance metrics for FRA are included in the M&O contractor’s annual performance evaluation and measurement plan.

11-SC-40, Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment, FNAL
Fermi National Accelerator Laboratory, FNAL
Project is for Design and Construction

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

Summary
The FY 2024 Request for Long Baseline Neutrino Facility (LBNF)/Deep Underground Neutrino Experiment (DUNE) is $251,000,000 of Total Estimated Cost (TEC) funding and $4,000,000 in Other Project Cost (OPC) funding.

Significant Changes
In November 2015, a preliminary cost and schedule was approved with Critical Decision (CD)-1, replacing an earlier CD-1 approval and including enhanced scope recommended by P5. The approved cost range was $1,260,000,000 to $1,860,000,000. Cost increases from a number of factors, including a lack of experience with working underground, overoptimistic estimates of international contributions, and delays due to COVID-19, supply chain, and funding profiles, led to the TPC exceeding 50 percent above the CD-1 range which required a new CD-1 cost and schedule range as part of a CD-1 Reaffirmation (CD-1RR). Lessons learned were developed around these issues to ensure the new cost estimate would be more reliable. The CD-1RR was approved on February 16, 2023, and established a cost range of $3,160,000,000 to $3,677,000,000.

At the time of CD-1RR approval, the Total Project Cost (TPC) Point Estimate is $3,277,000,000. This TPC Point Estimate is for planning purposes and will be refined as the project matures and each subproject is baselined. The aggregate of the new baselined subproject TPCs must be below the upper end of the approved cost range. When the last subproject is baselined, the LBNF/DUNE-U.S. TPC will be the aggregate of all subproject TPCs plus any contingency being held by the parent LBNF/DUNE-U.S. project. The CD-1RR approval reaffirmed that the previously selected alternative for an international and more capable deep underground detector is still a reasonable decision based on the matured understanding of factors. The reaffirmed alternative is the best opportunity for the U.S. to host a truly world-leading international neutrino program based upon optimized rate of data collection and unmatched sensitivities and precision. The reaffirmed alternative strengthens the U.S.'s international partnerships in particle physics and allows for future upgrades to the detectors and beam intensity if DOE chooses to do so.

The Inflation Reduction Act provided $125,000,000 for LBNF/DUNE. These funds will be used for the Far Site Conventional Facilities—Buildings and Site Infrastructure subproject, which is described below. The TPC estimate is not changed. The funding profile is advanced, but the schedule remains unchanged. The project has allocated contingency earlier in the project as recommended in an Office of Science peer review of the project in order to reduce schedule risk.

The scale of LBNF/DUNE and various other factors, including annual funding levels and research and development needs, resulted in the major scope elements of the project maturing at different rates. Baselining the entire scope of the project at once introduced too many uncertainties and was no longer viewed as being in the best interest of DOE. Therefore, a subproject tailoring approach in accordance with DOE Order 413.3B has been developed to reorganize the project's scope into several independent subprojects for improved planning and management control.

The five subprojects are:
- Far Site Conventional Facilities – Excavation (FSCF-EXC)
- Far Site Conventional Facilities – Buildings and Site Infrastructure (FSCF-BSI)
- Far Detectors and Cryogenic Infrastructure (FDC)
- Near Site Conventional Facilities and Beamline (NSCF+B)
- Near Detector (ND)

The approach to managing subprojects was approved at CD-1RR. The first subproject to be baselined authorizes the completion of cavern excavation at the Far Site. The FSCF-EXC subproject was approved for baseline and start of construction in August 2022. The FSCF-BSI and FDC subprojects will be baselined in FY 2023 and FY 2024, respectively.

FY 2023 Enacted Appropriations funding support continued excavation of the far detector caverns; long-lead procurement items for FDC and NSCF+B; site preparation activities for NSCF+B including site clearing and grading activities in advance of CD-3; initiate construction of FSCF-BSI infrastructure including HVAC, electric, plumbing, etc.; and design and other planning efforts for FDC, NSCF+B and ND in preparation for baseline and approval of construction.

The FY 2024 Request will complete excavation of the far detector caverns; continue construction of FSCF-BSI; begin installation of far detector components for FDC; continue design and other planning efforts for NSCF+B and ND; and continue site preparation of the conventional facilities of NSCF+B.

A Federal Project Director with a certification level 4 is assigned to this project and has approved this CPDS.

Critical Milestone History

	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	CD-4
LBNF/DUNE-Overall	1/8/10	11/5/15	11/5/15	3Q FY 2025	4Q FY 2026	1Q FY 2027	1Q FY 2035
Far Site Conventional Facilities-Excavation	–	–	–	8/19/22	12/31/20	8/19/22	1Q FY 2027
Far Site Conventional Facilities-Buildings and Site Infrastructure	–	–	–	2Q FY 2024	11/20/20	2Q FY 2024	4Q FY 2028
Far Detectors and Cryogenic Infrastructure	–	–	–	4Q FY 2024	4Q FY 2024	4Q FY 2024	1Q FY 2033
Near Site Conventional Facilities and Beamline	–	–	–	2Q FY 2025	2Q FY 2025	2Q FY 2025	2Q FY 2033
Near Detector	–	–	–	3Q FY 2025	4Q FY 2026	1Q FY 2027	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.

	Performance Baseline Validation	CD-1R	CD-1RR	CD-3A
LBNF/DUNE-Overall	3Q FY 2025	11/5/15	2/16/23	1Q FY 2026
Far Site Conventional Facilities-Excavation	8/19/22	—	2/16/23	10/27/21
Far Site Conventional Facilities-Buildings and Site Infrastructure	2Q FY 2024	—	2/16/23	–
Far Detectors and Cryogenic Infrastructure	4Q FY 2024	—	2/16/23	2/21/23
Near Site Conventional Facilities and Beamline	2Q FY 2025	—	2/16/23	2Q FY 2024
Near Detector	3Q FY 2025	—	2/16/23	1Q FY 2026

CD-1R – Refresh of CD-1 approval for the new Conceptual Design.

CD-1RR – Update cost range, reaffirm the alternative selection, and approve a new tailoring strategy for baselining the project in multiple subprojects.
CD-3A – Approve initial construction and long lead procurements in order to mitigate risks and avoid delays. The CD-3A scope for the Far Detectors and Cryogenic Infrastructure subproject is long-lead procurement of certain components of the detector electronics, photon detectors, and the anode plane assemblies. The CD-3A scope for the Near Site Conventional Facilities and Beamline subproject is long-lead procurement of shielding and accelerator kicker components, early fabrication of magnetic horn components, and wetlands work that must be completed before the corresponding USACE permit expires. The CD-3A scope for the Near Detector is currently under development.

Project Cost History

(dollars in thousands)

Fiscal Year	TEC, Design	TEC, Construction	TEC, Total	OPC, Except D&D	OPC, Total	TPC
FY 2023	455,464	2,410,911	2,866,375	133,625	133,625	3,000,000
FY 2024	550,447	2,616,888	3,167,335	109,665	109,665	3,277,000

Notes:
- *The project is Pre-CD-2 for most subprojects. All estimates are preliminary. The preliminary TPC range for CD-1RR is $3,160,000,000 to $3,677,000,000.*
- *No construction, other than site preparation and approved civil construction or long-lead procurement, will be performed prior to validation of the Performance Baseline and approval of CD-3 for each subproject.*

2. Project Scope and Justification

Scope
LBNF/DUNE will be composed of a neutrino beam created by new construction as well as modifications to the existing Fermilab Accelerator Complex, massive neutrino detectors (up to 40,000 tons in total) and associated cryogenics infrastructure located in one or more large underground caverns to be excavated at least 800 miles “downstream” from the neutrino source, and a much smaller neutrino detector at FNAL for monitoring the neutrino beam near its source. A primary beam of protons will produce a neutrino beam directed into a target for converting the protons into a secondary beam of particles (pions and muons) that decay into neutrinos, followed by a decay tunnel hundreds of meters long where the decay neutrinos will emerge and travel through the earth to the massive detector. The Neutrinos at the Main Injector (NuMI)

beam at FNAL is an existing example of this type of configuration for a neutrino beam facility. The new LBNF beam line will provide a neutrino beam of lower energy and greater intensity than the NuMI beam and would point to far detector modules at a greater distance than is used with NuMI experiments.[e]

For the LBNF/DUNE project, FNAL will be responsible for design, construction and operation of the major components of facilities which enable the DUNE research program (LBNF) including: the primary proton beam, neutrino production target, focusing structures, decay pipe, absorbers and corresponding beam instrumentation; the conventional facilities and experiment infrastructure on the FNAL site required for the near detector; and the conventional facilities and experiment infrastructure at SURF for the large detectors including the cryostats and cryogenics systems.

Justification

Recent international progress in neutrino physics, celebrated by the Nobel Prizes for Physics in 1988, 1995, 2002, and 2015, provides the basis for further discovery opportunities. Determining relative masses and mass ordering of the three known neutrinos will give guidance and constraints to theories beyond the Standard Model of particle physics. The study and observation of the different behavior of neutrinos and antineutrinos will offer insight into the dominance of matter over antimatter in our universe and, therefore, the very structure of our universe. The only other source of the matter-antimatter asymmetry, in the quark sector, is too small to account for the observed matter dominance.

The LBNF/DUNE construction project is a federal, state, private, and international partnership developing and implementing the technologies of particle accelerators and detectors to enable world-leading research into the fundamental physics of neutrinos, which are the most ubiquitous particles in the universe while at the same time among the most mysterious. Neutrinos are intimately involved in nuclear decay processes and high energy nuclear reactions. LBNF/DUNE will study the transformations of muon neutrinos into electron neutrinos, which occur as they travel to large detectors in South Dakota, 800 miles away from FNAL, where they are produced in a high-energy beam. The experiment will analyze the rare, flavor-changing transformations of neutrinos in flight, from one lepton flavor to another, which are expected to help explain the fundamental physics of neutrinos and the puzzling matter-antimatter asymmetry that enables our existence in a matter-dominated universe.

The LBNF/DUNE project comprises a national flagship particle physics initiative. LBNF/DUNE will be the first-ever large-scale international science facility hosted by the United States. As part of implementation of High Energy Physics Advisory Panel (HEPAP)-Particle Physics Project Prioritization Panel (P5) recommendations, the LBNF/DUNE project consists of two multinational collaborative efforts:

- LBNF is responsible for the beamline and other experimental and civil infrastructure at FNAL and at the Sanford Underground Research Facility (SURF) in South Dakota. It is currently operated by the South Dakota Science and Technology Authority (SDSTA), an agency of the State of South Dakota, and hosts experiments supported by DOE, the National Science Foundation, and major research universities.

- DUNE is an international scientific collaboration responsible for defining the scientific goals and technical requirements for the beam and detectors, as well as the design, fabrication of detector components and subsequent research program.

DOE's High Energy Physics program manages both activities as a single, line-item construction project—LBNF/DUNE. LBNF, with DOE/FNAL leadership and minority participation by international partners including CERN, will construct a megawatt-class neutrino source and related facilities at FNAL (the "Near Site"), as well as underground caverns and cryogenic facilities in South Dakota (the "Far Site") needed to house the DUNE detectors. DUNE has international leadership and participation of over 1,400 scientists and engineers from over 200 institutions in over 30 countries. DOE will fund approximately one half of the DUNE detectors. This excludes the cryostats that hold the detectors. The cryostats will be provided by CERN. The

[e] Detailed analyses of alternatives compared the NuMI beam to a new, lower-energy neutrino beam directed toward SURF in South Dakota, and also compared different neutrino detection technologies for the DUNE detector.

project continues to refine the development of the design and cost estimates as the U.S. DOE contributions to the multinational effort now are better understood. The cost estimate for DOE contributions will be updated as planning continues in preparation for baselining the various subprojects.

FNAL and DOE have confirmed contributions to LBNF documented in international agreements from CERN, the UK, India, Poland, and Brazil. Discussions are ongoing with several other countries for additional contributions, including significant additional contributions from CERN that are in the process of being finalized. For the DUNE detectors, the collaboration put in place a process to complete a technical design of the detectors and divide the work of building the detectors between the collaborating institutions. The review of the detector design with a complete set of funding responsibilities by the Long Baseline Neutrino Committee began in 2019, and development of the set of funding responsibilities has made significant progress and continues to advance. New commitments for detector contributions are being finalized now. SC will manage all DOE contributions to the facility and the detectors according to DOE Order 413.3B, and FNAL will provide unified project management reporting.

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 will be finalized and approved with each subproject.

The Threshold KPPs represent the minimum acceptable performance that the project must achieve. The Objective KPPs represent the desired project performance. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion.

Performance Measure	Threshold	Objective
Far Site Conventional Facilities – Excavation (FSCF-EXC)	1) Provide power capacity at the 4850L capable of supporting 10 MW demand. 2) Provide a ventilation route capable of exhausting 200,000 CFM though the spray chamber. 3) Complete the Ross Shaft brow enlargement and the excavation of all ancillary spaces and access drifts to create a minimum of 71,500 GSF. 4) Complete the excavation of three caverns with the following volumes including all required ground support, shotcrete placement and networked geotechnical monitoring system: a. North cavern (102,000 CY) b. South cavern (102,000 CY) c. Central utility cavern (46,800 CY) 5) Provide a minimum of 170,000 GSF of concrete floor.	All Threshold KPPs

Performance Measure	Threshold	Objective
Far Site Conventional Facilities – Buildings and Site Infrastructure (FSCF-BSI)	1) 1200A at 12.47kV power capacity installed in the CUC (sufficient to support four cryostats/detectors). 2) Power distribution at 120/240V, 480V, and 4160V installed at the 4850L to support two detectors, along with all general use power installed at the 4850L and 4910L. 3) Heat rejection cooling tower installed with 2,000-ton (7 MW) rejection capacity (sufficient to support four detectors. 4) 1,600 ton (5.6 MW) chilled water capacity installed to support two detectors and all general cooling loads at the 4850L.	Expanded power distribution and chilled water systems installed to support four cryostats/detectors. This adds 400 tons (1.4 MW) for a total of 2000 tons (7 MW) of chilled water capacity and transformers/power distribution specific to detectors 3 and 4.
FDC Subproject: Far Site Cryogenic Infrastructure	1) Nitrogen System engineered to support 4 cryostat / detector modules (400 kW). 2) Nitrogen System for two cryostats/detectors installed and commissioned: confirmation of delivery of 300 kW of refrigeration at end of distribution to Argon Condensers. 3) Surface receiving facilities installed, tested and ready to accept cryogens. 4) Argon purification, regeneration and circulation and Argon condensers system for two cryostats/detectors installed and tested. 5) Process controls for two cryostats/detectors installed and tested. 6) All cryogenics systems reviewed and approved for filling two cryostats with liquid Argon (LAr). 7) First Cryostat reviewed and approved for cryostat filling with LAr. 8) Set up contract with options to procure Argon for multiple detectors and buy Argon for first detector. 9) Second Cryostat reviewed and approved for cryostat filling with LAr. 10) Buy Argon for second detector.	All Threshold KPPs and 1) Successfully filled first cryostat/detector with LAr. 2) Fill second cryostat to 30 percent level with liquid argon.

Performance Measure	Threshold	Objective
FDC Subproject: Far Detector – Horizontal Drift Detector	Using parts and components provided by both the project and in kind by international partners: 1) Fabricate and deliver to SURF anode plane assemblies, high voltage field cage structures and cathode planes; Time Projection Chamber (TPC) electronics; components of the photon detector system; part of the DAQ servers; and purity monitors for one horizontal-drift LAr TPC according to specifications. 2) Install in the cryostat anode plane assemblies; high voltage field cage structures and cathode planes; TPC electronics; components of the photon detector system; and purity monitors for one horizontal-drift LAr TPC according to specifications. Install the corresponding detector parts and services on top of the cryostat. 3) Prior to the final closure of the cryostat, demonstrate continuous readout of the TPC electronics and of the photon detector system through the data acquisition system for one week with a live time of at least 50 percent and a minimum of 96 percent fully functional electronic readout channels, prior to the final closure of the cryostat. *Note that threshold KPPs can be satisfied without filling the cryostat.	All threshold KPPs, with the minimum number of functional channels increased to 98 percent at room temperature. *one cryostat/detector module is equivalent to 17-kiloton detector mass
FDC Subproject: Far Detector – Vertical Drift Detector	Using parts and components provided by both the project and in kind by international partners: 1) Fabricate and deliver to SURF charge readout planes for the bottom drift volume, high voltage field cage; electronics for the readout of the bottom charge readout planes; components of the photon detector system; part of the DAQ servers; and purity monitors for one vertical-drift LAr TPC according to specification. 2) Install in the cryostat high voltage field cage structures and cathode modules; electronics for the bottom charge readout planes; and components of the photon detector system for one vertical-drift LAr Time Projection Chamber (TPC) according to specifications. Install the corresponding detector parts on top of the cryostat. 3) Prior to the final closure of the cryostat, demonstrate continuous readout of the electronics for the bottom charge readout planes through the data acquisition system for one week with a live time of at least 50 percent and a minimum of 96 percent fully functional electronic readout channels, prior to the final closure of the cryostat. *Note that threshold KPPs can be satisfied without filling the cryostat.	All threshold KPPs, with the minimum number of functional channels increased to 98 percent at room temperature. *one cryostat/detector module is equivalent to 17-kiloton detector mass

Performance Measure	Threshold	Objective
FDC Subproject: Far Detector Far Site Integration	Achieve the threshold KPPs for both the Horizontal and Vertical Drift Detectors. The threshold KPPs in both cases can be satisfied without filling the cryostats.	1) Once the first cryostat is completely full, observe cosmic ray tracks with the charge and light detection systems. 2) Once the second cryostat is filled at the 30 percent level, demonstrate that all the readout channels that can be operated at that point in liquid Argon are fully functional with a minimum number of 94 percent of the total number of channels. *Note that objective KPPs do require a completely filled cryostat for one of the two detectors, and a partially filled cryostat for the second one.
Near Site Conventional Facilities and Beamline (NSCF+B)	1) Primary Beamline: • Conventional facilities and beamline constructed to be capable of 2.4MW operation • Beamline under vacuum with all magnets ramped on 120 GeV operations cycle 2) Neutrino Beamline: • Conventional facilities constructed to support 2.4MW proton beam • Target Hall to support a three-horn focusing system optimized for oscillation science • Decay Region minimum 635 ft in length • Shielding and absorber constructed to support 2.4MW operation • Horns, target, radioactive water system, and beam windows fabricated for 1.2 MW proton beam • Operation of target pile, decay pipe, horn, and absorber cooling systems • Two-horn focusing system pulsed in situ to 240kA • Target cooling system flow demonstrated in situ • Target shield pile sealed to outside air 3) ND Complex: • Cavern space with minimum volume of 700,000 cubic ft • Power infrastructure has a capacity of 2,700kVA running load • Cooling infrastructure includes a minimum of 650 tons of chiller capacity	1) Primary Beamline: • 120GeV protons delivered to the absorber with the target removed 2) Neutrino Beamline: • Three horns pulsed in situ to 300kA • Muons observed downstream of absorber 3) Near Detector Complex • All threshold KPPs

Performance Measure	Threshold	Objective
Near Detector	Hardware installed for a neutrino beam monitor capable of detecting a 1 percent shift in the horn current within a period of one week of nominal 1.2MW exposure with performance verified by simulation.	1) All Threshold KPPs 2) Using parts and components provided by both the project and in-kind by international partners: • Deliver a LAr Time Projection Chamber (TPC) detector system capable of measuring neutrino interactions in argon at the near site with similar performance as specified for the Far Detector to directly support long-baseline physics measurements in the DUNE FD • Ability to move the LAr TPC near detector system to an off-axis location • Ability to monitor the on-axis neutrino beam when the LAr TPC near detector system is off-axis

3. Financial Schedule

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs	IRA Supp. Costs
Total Estimated Cost (TEC)				
Design (TEC)				
Prior Years	374,464	374,464	329,701	–
FY 2022	81,000	81,000	61,987	–
FY 2023	67,743	67,743	128,189	–
FY 2024	24,710	24,710	27,400	–
Outyears	2,530	2,530	3,170	–
Total, Design (TEC)	**550,447**	**550,447**	**550,447**	**–**
Construction (TEC)				
Prior Years	304,317	304,317	172,526	–
FY 2022	95,000	95,000	93,374	–
FY 2022 - IRA Supp.	125,000	125,000	–	–
FY 2023	108,257	108,257	188,835	13,000
FY 2024	226,290	226,290	212,100	104,750
Outyears	1,758,024	1,758,024	1,825,053	7,250
Total, Construction (TEC)	**2,616,888**	**2,616,888**	**2,491,888**	**125,000**
Total Estimated Cost (TEC)				
Prior Years	678,781	678,781	502,227	–
FY 2022	176,000	176,000	155,361	–
FY 2022 - IRA Supp.	125,000	125,000	–	–
FY 2023	176,000	176,000	317,024	13,000
FY 2024	251,000	251,000	239,500	104,750
Outyears	1,760,554	1,760,554	1,828,223	7,250
Total, TEC	**3,167,335**	**3,167,335**	**3,042,335**	**125,000**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs	IRA Supp. Costs
Other Project Cost (OPC)				
Prior Years	93,625	93,625	91,696	–
FY 2022	8,000	8,000	785	–
FY 2023	4,000	4,000	3,757	–
FY 2024	4,000	4,000	2,500	–
Outyears	40	40	10,927	–
Total, OPC	**109,665**	**109,665**	**109,665**	**–**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs	IRA Supp. Costs
Total Project Cost (TPC)				
Prior Years	772,406	772,406	593,923	–
FY 2022	184,000	184,000	156,146	–
FY 2022 - IRA Supp.	125,000	125,000	–	–
FY 2023	180,000	180,000	320,781	13,000
FY 2024	255,000	255,000	242,000	104,750
Outyears	1,760,594	1,760,594	1,839,150	7,250
Total, TPC	**3,277,000**	**3,277,000**	**3,152,000**	**125,000**

Note:

- *Prior years and FY 2022 reflect actual costs; remaining years are cost estimates.*

4. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design	528,377	397,568	**N/A**
Design - Contingency	22,070	57,896	**N/A**
Total, Design (TEC)	**550,447**	**455,464**	**N/A**
Construction	1,344,860	1,134,000	**N/A**
Equipment	571,488	700,000	**N/A**
Construction - Contingency	700,540	576,911	**N/A**
Total, Construction (TEC)	**2,616,888**	**2,410,911**	**N/A**
Total, TEC	**3,167,335**	**2,866,375**	**N/A**
Contingency, TEC	*722,610*	*634,807*	***N/A***
Other Project Cost (OPC)			
R&D	16,000	20,625	**N/A**
Conceptual Planning	44,958	30,000	**N/A**
Conceptual Design	31,977	35,000	**N/A**
Other OPC Costs	13,540	27,625	**N/A**
OPC - Contingency	3,190	20,375	**N/A**
Total, Except D&D (OPC)	**109,665**	**133,625**	**N/A**
Total, OPC	**109,665**	**133,625**	**N/A**
Contingency, OPC	*3,190*	*20,375*	***N/A***
Total, TPC	**3,277,000**	**3,000,000**	**N/A**
Total, Contingency (TEC+OPC)	***725,800***	***655,182***	***N/A***

Notes:
- *The validated baseline does not occur until all subprojects reach CD-2.*
- *Construction involves excavation of caverns at SURF, 4850 ft. below the surface, for technical equipment including particle detectors and cryogenic systems and construction of the housing for the neutrino-production beam line and the near detector.*
- *Technical equipment in the DOE scope, estimated here, will be supplemented by in-kind contributions of additional technical equipment, for the accelerator beam and particle detectors, from non-DOE partners as described in Section 2.*
- *"Other OPC Costs" include execution support costs including electrical power for construction* and equipment installation.

5. Schedule of Appropriations Requests

(dollars in thousands)

Fiscal Year	Type	Prior Years	FY 2022	FY 2022 IRA Supp.	FY 2023	FY 2024	Outyears	Total
FY 2023	TEC	678,781	176,000	—	176,000	—	1,835,594	2,866,375
	OPC	93,625	4,000	—	4,000	—	32,000	133,625
	TPC	772,406	180,000	—	180,000	—	1,867,594	3,000,000
FY 2024	TEC	678,781	176,000	125,000	176,000	251,000	1,760,554	3,167,335
	OPC	93,625	8,000	—	4,000	4,000	40	109,665
	TPC	772,406	184,000	125,000	180,000	255,000	1,760,594	3,277,000

Note:

- *All estimates are preliminary.*

6. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy	1Q FY 2035
Expected Useful Life	20 years
Expected Future Start of D&D of this capital asset	1Q FY 2055

Operations and maintenance funding of this experiment will become part of the existing Fermilab Accelerator Complex. Annual related funding estimates include the incremental cost of 20 years of full operation, utilities, maintenance, and repairs with the accelerator beam on. The estimates also include operations and maintenance for the remote site of the large detector. New operations and maintenance estimates were developed in 2022 based on a new study and detailed estimating. Current estimate represents an average annual cost in FY 2022 dollars.

Related Funding Requirements
(dollars in thousands)

	Annual Costs		Life Cycle Costs	
	Previous Total Estimate	**Current Total Estimate**	**Previous Total Estimate**	**Current Total Estimate**
Operations	9,000	22,000	180,000	440,000
Utilities	8,000	6,000	160,000	120,000
Maintenance and Repair	1,000	14,000	20,000	280,000
Total, Operations and Maintenance	18,000	42,000	360,000	840,000

7. D&D Information

The new area being constructed in this project is replacing existing facilities.

	Square Feet
New area being constructed by this project at FNAL	79,100
New area being constructed by this project at Sanford Underground Research Facility (SURF)	185,700
Area of D&D in this project at FNAL	—
Area at FNAL to be transferred, sold, and/or D&D outside the project, including area previously "banked"	79,100
Area of D&D in this project at other sites	—
Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked"	185,700
Total area eliminated	—

The new facility square footage estimates are based on the current design and updating the calculation to be consistent with DOE's real estate guidance. New facilities information will be identified and reported in accordance with DOE guidance.

8. Acquisition Approach

The Acquisition Strategy, approved as part of CD-1, documents the acquisition approach. DOE is acquiring design, construction, fabrication, and operation of LBNF through the M&O contractor responsible for FNAL, Fermi Research Alliance (FRA). FRA and FNAL, through the LBNF Project based at FNAL, is responsible to DOE to manage and complete construction of LBNF at both the near and remote site locations. FRA and FNAL are assigned oversight and management responsibility for execution of the international DUNE project, to include management of the DOE contributions to DUNE. The basis for this choice and strategy is that:

- FNAL is the site of the only existing neutrino beam facility in the U.S. and, in addition to these facilities, provides a source of existing staff and expertise to be utilized for beamline and detector construction.
- FNAL can best ensure that the design, construction, and installation of key LBNF and DUNE components are coordinated effectively and efficiently with other research activities at FNAL.
- FNAL has a DOE-approved procurement system with established processes and acquisition expertise needed to obtain the necessary components and services to build the scientific hardware, equipment and conventional facilities for the accelerator beamline, and detectors for LBNF and DUNE.
- FNAL has extensive experience in managing complex construction, fabrication, and installation projects involving multiple national laboratories, universities, and other partner institutions, building facilities both on-site and at remote off-site locations.
- FNAL, through the LBNF Project, has established a close working relationship with SURF and the SDSTA, organizations that manage and operate the remote site for the far detector in Lead, SD.
- FNAL has extensive experience with management and participation in international projects and international collaborations, including most recently the LHC and CMS projects at CERN, as well as in the increasingly international neutrino experiments and program.

The LBNF/DUNE construction project is a federal, state, private and international partnership. Leading the LBNF/DUNE Project, FNAL will collaborate and work with many institutions, including other DOE national laboratories (e.g. BNL, LBNL and SLAC), dozens of universities, foreign research institutions, and the SDSTA. FNAL will be responsible for overall project management, Near Site conventional facilities, and the beamline. FNAL will work with SDSTA to complete the conventional facilities construction at the remote site needed to house and outfit the DUNE far detector. With the DUNE collaboration, FNAL is also responsible for technical and resource coordination to support the DUNE far and near detector design and construction. DOE will be providing in-kind contributions to the DUNE collaboration for detector systems, as agreed upon with the international DUNE collaboration.

International participation in the design, construction, and operation of LBNF and DUNE will be of essential importance because the field of High Energy Physics is international by nature; necessary talent and expertise are globally distributed, and DOE does not have the procurement or technical resources to self-perform all of the required construction and fabrication work. Contributions from other nations will be predominantly through the delivery of components built in their own countries by their own researchers. DOE will negotiate agreements in cooperation with the Department of State on a bilateral basis with all contributing nations to specify their expected contributions and the working relationships during the construction and operation of the experiment.

DOE will provide funding for the LBNF/DUNE Project directly to FNAL and collaborating DOE national laboratories via approved financial plans, and under management control of the LBNF/DUNE Project Office at FNAL, which will also manage and control DOE funding to the combination of university subcontracts and direct fixed-price vendor procurements that are anticipated for the design, fabrication, and installation of LBNF and DUNE technical components. All actions will perform in accordance with DOE approved procurement policies and procedures.

FNAL staff, or by subcontract, temporary staff working directly with FNAL personnel will perform much of the neutrino beamline component design, fabrication, assembly, and installation. The acquisition approach includes both new procurements based on existing designs, and re-purposed equipment from the Fermilab Accelerator Complex. For some highly specialized components, FNAL will have the Rutherford Appleton Laboratory (RAL) in the United Kingdom design and fabricate the components. RAL is a long-standing FNAL collaborator who has proven experience with such components.

FNAL has chosen the Construction Manager/General Contractor (CM/GC) model to execute the delivery of LBNF conventional facilities at the SURF Far Site. The Laboratory contracted with an architect/engineer (A/E) firm for design of LBNF Far Site conventional facilities at SURF and with a CM/GC subcontractor to manage the construction of LBNF Far Site facilities. FNAL selected this strategy to reduce risk, enhance quality and safety performance, provide a more collaborative approach to construction, and offer the opportunity for reduced cost and shortened construction schedules, via options for the CM/GC to self-perform or competitively bid subcontract award packages. FNAL determined that excavation scope should be openly competed as provided by the subcontract. An excavation subcontract was awarded within budget and excavation construction activities began in FY 2021.

For the LBNF Near Site conventional facilities at FNAL, the laboratory will subcontract with an A/E firm for design and plan to utilize a traditional design-bid-build construction method supported by additional procurements for preconstruction and construction phase services from a professional construction management firm.

For the LBNF Far Site conventional facilities at SURF, DOE entered into a land lease with SDSTA on May 20, 2016, covering the area on which the DOE-funded facilities housing and supporting the LBNF and DUNE detector will be built. The lease and related realty actions provides the framework for DOE and FNAL to construct federally-funded buildings and facilities on non-federal land, and to establish a long-term (multi-decade) arrangement for DOE and FNAL to use SDSTA space to host the DUNE experiment. Modifications, repairs, and improvements to the SDSTA infrastructure to support the LBNF/DUNE project are costed to the project. Repairs and improvements for the overall facility are costed to the cooperative agreement between HEP and SDSTA for operation of the facility. Protections for DOE’s real property interests in these infrastructure tasks are acquired through the lease with SDSTA, contracts and other agreements such as easements. DOE plans for FNAL to have responsibility for managing and operating the LBNF and DUNE far detector and facilities for a useful lifetime of 20 years and may contract with SDSTA for day-to-day management and maintenance services. At the end of useful life, federal regulations permit transfer of ownership to SDSTA, which is willing to accept ownership as a condition for the lease. FNAL developed an appropriate decommissioning plan prior to lease signing.