High Energy Physics

Overview

The High Energy Physics (HEP) program's mission 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 (R&D). HEP continues to deliver major construction projects on time and on budget and provides users with reliably available 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] continues to guide 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 2014 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.

In December 2022, DOE and NSF charged the High Energy Physics Advisory Panel (HEPAP) to assemble a new P5 subpanel to formulate a ten-year plan for the field. At the December 2023 HEPAP meeting, the subpanel presented the new 2023 P5 report, "Exploring the Quantum Universe: Pathways to Innovation and Discovery in Particle Physics," which HEPAP then unanimously approved. The 2023 report was released too late in the year to impact FY 2025 formulation. However, the first Recommendation of the report strongly reiterates the importance of completing major HEP projects initiated over the previous decade, which are supported in the FY 2025 Request. DOE is studying the 2023 P5 report and will prepare a response to the recommendations and develop an implementation plan.

The HEP program enables scientific discovery and supports cutting edge R&D in five focused subprograms:

- 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 artificial intelligence/machine learning (AI/ML), quantum information science (QIS), microelectronics, accelerators, and instrumentation will advance scientific

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[a] https://science.osti.gov/~/media/hep/hepap/pdf/May-2014/FINAL_P5_Report_053014.pdf

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.[b]

Highlights of the FY 2025 Request

The FY 2025 Request of $1,230.8 million is an increase of $64.8 million over the FY 2023 Enacted, and will focus resources on the highest priorities in fundamental research, operation and maintenance of scientific user facilities, facility upgrades, and projects identified in the 2014 P5 report.

Research

The Request will provide continued support for HEP core competencies in theoretical and experimental activities and world-leading advanced technology R&D in pursuit of discovery science. Through continued funding for the Established Program to Stimulate Competitive Research (EPSCoR) program and the Reaching a New Energy Sciences Workforce (RENEW) and Funding for Accelerated, Inclusive Research (FAIR) initiatives, HEP will build stronger programs with underserved communities and regions, as well as emerging research institutions, Historically Black Colleges and Universities (HBCUs) and Minority Serving Institutions (MSIs), investing in a more diverse and inclusive workforce. Funding will shift from the Accelerate initiative to other priority cross-cutting initiatives across the Office of Science (SC):

- AI/ML: Tackle the challenges of extracting particle signatures 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.
- 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 support the recompetition/renewal of the Superconducting Quantum Materials and Systems (SQMS) Center led by the Fermi National Accelerator Laboratory (FNAL), one of SC's National QIS Research Centers.
- Microelectronics: Accelerate R&D into sensor materials, detector devices, advances in front-end electronics, and integrated sensor/processor architectures, including adaptation to high-radiation, or cryogenic temperature, or low radioactive background environments.
- Accelerator Science and Technology Initiative (ASTI): Longer-term R&D focused on future facilities and capabilities, to maintain a leading position in key accelerator technologies that define SC's competitive advantage.
- Advanced Computing: Enable broader access to exascale computing resources by providing support for researchers to develop and adapt scientific codes for high performance on modern computing architectures.

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 5,180 and 3,120 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 increase support for the Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment (LBNF/DUNE-US) and Proton Improvement Plan II (PIP-II) construction projects. The Request will also increase support for 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.

[b] https://science.osti.gov/hep/-/media/hep/pdf/files/pdfs/hep_benefits_v2.pdf

High Energy Physics
Funding

(dollars in thousands)

	FY 2023 Enacted	FY 2024 Annualized CR	FY 2025 Request	FY 2025 Request vs FY 2023 Enacted
High Energy Physics				
Energy Frontier, Research	76,833	67,848	59,283	-17,550
Energy Frontier, Facility Operations and Experimental Support	54,000	52,800	57,285	+3,285
Energy Frontier, Projects	50,000	35,700	33,700	-16,300
Total, Energy Frontier Experimental Physics	**180,833**	**156,348**	**150,268**	**-30,565**
Intensity Frontier, Research	72,644	64,394	55,679	-16,965
Intensity Frontier, Facility Operations and Experimental Support	194,555	188,411	209,530	+14,975
Intensity Frontier, Projects	6,000	10,199	10,000	+4,000
Total, Intensity Frontier Experimental Physics	**273,199**	**263,004**	**275,209**	**+2,010**
Cosmic Frontier, Research	51,552	47,512	36,301	-15,251
Cosmic Frontier, Facility Operations and Experimental Support	56,550	57,056	57,210	+660
Cosmic Frontier, Projects	1,000	9,000	4,500	+3,500
Total, Cosmic Frontier Experimental Physics	**109,102**	**113,568**	**98,011**	**-11,091**
Theoretical, Computational, and Interdisciplinary Physics, Research	171,746	166,246	186,714	+14,968
Total, Theoretical, Computational, and Interdisciplinary Physics	**171,746**	**166,246**	**186,714**	**+14,968**
Advanced Technology R&D, Research	80,871	68,861	57,856	-23,015
Advanced Technology R&D, Facility Operations and Experimental Support	52,249	52,274	57,710	+5,461
Total, Advanced Technology R&D	**133,120**	**121,135**	**115,566**	**-17,554**
Subtotal, High Energy Physics	**868,000**	**820,301**	**825,768**	**-42,232**
Construction				
18-SC-42 Proton Improvement Plan II (PIP-II), FNAL	120,000	125,000	125,000	+5,000

(dollars in thousands)

	FY 2023 Enacted	FY 2024 Annualized CR	FY 2025 Request	FY 2025 Request vs FY 2023 Enacted
11-SC-40 Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment	176,000	251,000	280,000	+104,000
11-SC-41 Muon to Electron Conversion Experiment, FNAL	2,000	–	–	-2,000
Subtotal, Construction	**298,000**	**376,000**	**405,000**	**+107,000**
Total, High Energy Physics	**1,166,000**	**1,196,301**	**1,230,768**	**+64,768**

SBIR/STTR funding:

- FY 2023 Enacted: SBIR $13,911,000 and STTR $1,956,000
- FY 2024 Annualized CR: SBIR $12,450,000 and STTR $1,751,000
- FY 2025 Request: SBIR $11,831,000 and STTR $1,664,000

High Energy Physics
Explanation of Major Changes

	(dollars in thousands) FY 2025 Request vs FY 2023 Enacted
Energy Frontier Experimental Physics The Request will emphasize research that focuses on high-priority topics that search for new physics, refresh U.S.-based computing infrastructure, and continue fabrication activities for the HL-LHC ATLAS and CMS Detector Upgrade projects, as planned. The HL-LHC Accelerator Upgrade Project received final planned funding in FY 2023, which results in decreased funding for the HL-LHC Upgrade projects in this Request.	**-30,565**
Intensity Frontier Experimental Physics The Request will increase support for the Fermilab Accelerator Complex to operate 5,180 hours, while expanding user access, reducing deferred maintenance, and advancing modernization efforts. The Request will increase support for the ACORN MIE. Research support will focus on early physics results from the Short-Baseline Neutrino (SBN) program and high-priority topics that search for new physics.	**+2,010**
Cosmic Frontier Experimental Physics The Request will support the CMB-S4 MIE and provide operations funding for the Vera C. Rubin Observatory. Research support will fund the highest priorities of the Administration and SC focused on exploiting the physics capabilities of new facilities and experiments.	**-11,091**
Theoretical, Computational, and Interdisciplinary Physics The Request will increase support to broaden the RENEW and FAIR initiatives, to develop and retain AI/ML scientific workforce at the national laboratories, and to build AI/ML capacity and computational infrastructure for the broader HEP community.	**+14,968**
Advanced Technology R&D The Request will support FACET-II to operate 3,120 hours. Research support will fund the highest priorities of the Administration and SC focused on cross-cutting advanced technology R&D in coordination with other SC programs and increased access and utilization of accelerator and detector test facilities at the DOE national laboratories.	**-17,554**
Construction The Request will increase support and continue the approach to LBNF/DUNE-US in accordance with DOE Order 413.3B which reorganized the project's scope into five independent subprojects for improved planning and management control. Support increases for PIP-II, and decreases for Mu2e as the project completes funding in FY 2023.	**+107,000**
Total, High Energy Physics	**+64,768**

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, as well as those of several other SC programs. 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. As a source of innovation for many new scientific capabilities with broader applications, 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

Most precise measurements of the muon magnetic anomaly from the g-2 experiment (Intensity Frontier Experimental Physics)

Muons have a quantum mechanical property called spin, which causes them to act like a tiny magnet. When placed in a magnetic field, the muon's internal magnet processes, much like the wobble of a spinning top. The speed of this wobble is determined by a quantity known as the magnetic moment, which scientists represent with the letter "g". At the simplest level of our theoretical understanding, g equals 2. However, the value of g is sensitive to all known (and unknown) elementary particles that can pop in and out of existence for a short moment of time and lead to a small deviation from 2, hence the name g-2. The Muon g-2 collaboration revealed its second result for g-2, which bolsters the first result published by the collaboration in 2021. The new result is based on data taken in 2019 and 2020 and improves the precision by more than a factor of 2 compared to the first result. Both the total statistical and systematic uncertainties improved by factors of 2.2. This leads to a total uncertainty of the experimental average for the muon magnetic anomaly of 190 parts-per-billion (ppb). This is the world's most precise measurement ever made at a particle accelerator. While the statistical uncertainty will continue to significantly improve with plenty more data to be analyzed in the upcoming years, the total systematic uncertainty of 70 ppb has already surpassed the original proposal goal of 100 ppb—a major achievement for the experiment.

LBNF/DUNE-US project team gets approval for next phase of construction in South Dakota (Construction)

The FNAL-hosted LBNF/DUNE is an enormous international scientific effort to address some of the most pressing questions in particle physics today including the matter-antimatter asymmetry in our universe. The LBNF/DUNE-US project represents a new model of international partnership and support for large scientific efforts. Over the past year the project made significant progress, achieving five DOE critical decision approvals to proceed to the next stages of construction, including baselining the first two of five subprojects and receiving long-lead procurement authority for the third and fourth subprojects. The DUNE experiment will send the world's most intense high-energy neutrino and anti-neutrino beams from FNAL in Batavia, Illinois, to huge underground particle detectors, 800 miles away at the Sanford Underground Research Facility (SURF) in Lead, South Dakota. More than 1,400 scientists and engineers at over 200 institutions in 37 countries are working on the preparations for the experiment.

U.S. achieves major milestone with the delivery of quadrupole magnets to CERN (Energy Frontier Experimental Physics)

In coordination with the international community, including the U.S., CERN is upgrading LHC in Switzerland to increase the particle collision rate, or luminosity, by a factor of at least five to precisely measure the Higgs boson and explore new physics beyond its current reach. DOE is contributing to the high-luminosity accelerator upgrade project (HL-LHC AUP), hosted at FNAL, by designing, fabricating, and delivering ten high-field quadrupole focusing magnets that will allow particle beams to collide at higher intensities at the upgraded machine's interaction points. The U.S. is the world leader in this high-field accelerator technology and these magnets are the culmination of over ten years of R&D. The first of these magnet elements made its transatlantic voyage to CERN in November 2023, thereby achieving a major milestone in the DOE-supported HL-LHC AUP.

Advances in dark energy studies were made in spectroscopic and imaging next-generation experiments (Cosmic Frontier Experimental Physics)
The Dark Energy Spectroscopic Instrument (DESI) experiment released its first detection of the baryon acoustic oscillation (BAO) signal in 2023. Dark energy, discovered in the late 1990's, causing the acceleration of the expansion of the universe, is one of the big unsolved questions in physics and cosmology. Data from the first two months of the survey, including all four object types, were used to study the evolution of large-scale structure. The BAO peak was detected at 5σ confidence in the luminous red galaxy sample, which is comparable to the one from the precursor BOSS experiment's full 5-year data sample. DOE's DESI, managed by the Lawrence Berkeley National Laboratory, is the world's premier multi-object spectrograph and the first Stage IV dark energy project to take data, DESI is installed and operating on the National Science Foundation's (NSF) Mayall telescope at Kitt Peak National Observatory near Tucson, AZ.

Gordon Bell Prize awarded to international team for particle-in-cell simulations on exascale-class supercomputers (Advanced Technology R&D)
The Association for Computing Machinery (ACM) named a 16-member team drawn from French, Japanese, and U.S. institutions, including Lawrence Berkeley National Laboratory, as recipient of the 2022 ACM Gordon Bell Prize for their project, "Pushing the Frontier in the Design of Laser-Based Electron Accelerators with Groundbreaking Mesh-Refined Particle-In-Cell Simulations on Exascale-Class Supercomputers." Particle-in-Cell (PIC) simulation is a technique within high-performance computing used to model the motion of charged particles, or plasma. PIC has applications in many areas, including nuclear fusion, accelerators, space physics, and astrophysics. The very recent introduction of exascale-class computers has expanded the horizons of PIC simulations and makes this year's winning project especially exciting. The team used a first-of-kind mesh-refined (MR) massively parallel PIC code for kinetic plasma simulations optimized on SC's Frontier, Summit, and Perlmutter supercomputers. The major improvements in their PIC code over existing state-of-the-art approaches included a groundbreaking mesh refinement capability that provides between 1.5x to 4x savings in computing requirements, which is a significant step towards a new era in the modelling of laser-plasma interactions.

FNAL particle accelerator achieves world record beam power (Intensity Frontier Experimental Physics)
The Fermilab Accelerator Complex produces and delivers particle beams to various particle physics experiments for scientists to learn more about neutrinos, muons, and other building blocks of nature. Over many years they collect large data sets that provide information on the nature of the universe. With more data, the potential for discovery increases. The size of the data sets depends on the total beam delivery to each experiment. Scientists maximize beam delivery by operating particle accelerators around the clock at the highest beam intensity possible and delivering the largest number of beam pulses with the highest number of protons per second. On May 22, 2023, FNAL accelerator experts set a beam power record of 0.96 megawatts (MW). This one-hour beam power record achieved was 7 percent higher than the previous record, as a result of increasing the rate of beam delivery. The cycle time of the Fermilab Main Injector for delivery of 120 GeV beam was reduced from 1.2 seconds to 1.13 seconds by exploiting the capabilities of the existing system and improving beam manipulation techniques. Increasing Fermilab beam power is critical to achieving the ultimate science objectives of the LBNF/DUNE program.

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 international 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 participating in the LHC program, including the next generation of scientists and engineers, are one of the largest collaborating groups at the LHC and account for approximately 20 percent and 25 percent of the ATLAS and CMS collaborations, respectively. Correspondingly, they 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 advance the development of capabilities for exascale computing used by HEP researchers for data analyses.

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

The 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 that, in the longer-term, can lead to developing innovative technologies for future proposed accelerator facilities. 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 2025 Request	Explanation of Changes FY 2025 Request vs FY 2023 Enacted
Energy Frontier Experimental Physics	**$180,833**	**$150,268**	**-$30,565**
Research	$76,833	$59,283	-$17,550
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 leading roles and key contributions by U.S. researchers in all aspects of the ATLAS and CMS experimental programs. The Request will support the Advanced Computing initiative to transition data-intensive simulations and analyses to SC high-performance computing.	Funding will prioritize support on high-priority research topics that search for new physics during the present LHC run, key contributions to the HL-LHC detector upgrades, and critical U.S. commitments to the ATLAS and CMS experiments.
Facility Operations and Experimental Support	$54,000	$57,285	+$3,285
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.	Funding will increase to support the critically needed refreshment of U.S.-based computing infrastructure and resources to continue efficiently collecting, storing, and analyzing the large volume of data from the ongoing LHC run.
Projects	$50,000	$33,700	-$16,300
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 the HL-LHC CMS Detector Upgrades.	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.

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

Description

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 offer an opportunity to explore these models in a controlled laboratory setting.

Research

This 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 Muon g-2 experiment at FNAL studies the anomalous magnetic moment of the muon, which is very sensitive to new physics beyond the standard model. 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

This Activity 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, as well as 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 outdated 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 2025 Request	Explanation of Changes FY 2025 Request vs FY 2023 Enacted
Intensity Frontier Experimental Physics $273,199	**$275,209**	**+$2,010**
Research $72,644	$55,679	-$16,965
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 supporting the leading roles and key contributions by U.S. researchers on ongoing experiments (NOvA, SBN program, Belle II, and T2K), on future projects (Mu2e and DUNE), and design and planning for dark matter concepts. The Request will support the Advanced Computing initiative to transition data-intensive simulations and analyses to SC high-performance computing.	Funding will prioritize support on analyzing early research results from the SBN Program, high-priority research topics that search for new physics from ongoing experiments, and critical U.S. commitments to Mu2e and DUNE.
Facility Operations and Experimental Support $194,555	$209,530	+$14,975
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 supporting the Fermilab Accelerator Complex including funding for detector and computing operations, scientific collaboration support, and minor GPPs; Special Process Spares for efficient recovery from unexpected downtime; and SURF operations and infrastructure improvements.	Funding will increase to support the Fermilab Accelerator Complex to deliver more particle beams at peak power; to expand user access to detector systems, scientific computing, and experimental data; to reduce deferred maintenance; and to advance modernization efforts.

(dollars in thousands)

FY 2023 Enacted	FY 2025 Request	Explanation of Changes FY 2025 Request vs FY 2023 Enacted
Projects $6,000	$10,000	+$4,000
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 required to reach CD-2.	Funding will increase to support ACORN MIE power supply systems design and the integration of AI/ML into the control system. The LBNF/DUNE OPC for support costs at SURF is reduced as planned.

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 signal 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 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 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.

The Lunar Surface Electromagnetics Experiment Night (LuSEE-Night) is a pathfinder space mission for studies of the Cosmic Dark Ages, which is the period in the universe after the CMB and when stars and galaxies start to form. It will measure the long wavelength radio signal from the far side of the moon during the lunar night and place the most sensitive constraints to date and potentially discover the Cosmic Dark Ages signal.

Two 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 experiment, the 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 project concepts that 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. 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 Mayall Telescope at Kitt Peak National Observatory with both the instrumentation and telescope operations supported by DOE. The Vera C. Rubin Observatory is located in Chile, using the DOE-provided three billion-pixel LSST camera (LSSTCam). DOE and NSF are full partners in the Rubin facility operations. 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, SuperCDMS-SNOLAB, and ADMX-G2 dark matter experiment are located 1.5 km underground in the SURF in Lead, South Dakota; 2 km underground at the Sudbury Neutrino Observatory in Sudbury, Canada; and at the University of Washington in Seattle, WA, respectively.

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 full science capabilities. The project is developing a design that will carry out the science goals within the available infrastructure and logistics capabilities at these sites.

High Energy Physics
Cosmic Frontier Experimental Physics

Activities and Explanation of Changes

(dollars in thousands)

FY 2023 Enacted		FY 2025 Request	Explanation of Changes FY 2025 Request vs FY 2023 Enacted
Cosmic Frontier Experimental Physics	**$109,102**	**$98,011**	**-$11,091**
Research	$51,552	$36,301	-$15,251
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 continue supporting the leading roles and key contributions by U.S. researchers on the dark matter experiments (ADMX-G2, LZ, and SuperCDMS-SNOLAB), on dark energy science (DESI and Vera C. Rubin Observatory), and design and planning for CMB-S4 and the dark matter concepts.	Funding will prioritize support on analyzing early research results from Vera C. Rubin Observatory and the SuperCDMS-SNOLAB experiment, high-profile research topics that search for new physics from ongoing experiments, and critical U.S. commitments to CMB-S4.
Facility Operations and Experimental Support	$56,550	$57,210	+$660
Funding supports continued operations of DESI, LZ, ADMX-G2, and the start of operations for SuperCDMS-SNOLAB. Commissioning and preoperations 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. Vera C. Rubin Observatory final commissioning activities and the start of the science survey will be carried out FY 2025. LuSEE-Night final commissioning activities will be carried out.	Funding will increase to ramp up to full operations of the Vera C. Rubin Observatory, support full operations for SuperCDMS SNOLAB experiment and LZ experiments, and continue support for DESI and ADMX-G2 operations.
Projects	$1,000	$4,500	+$3,500
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.

<u>Theory</u>
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.

<u>Computational HEP</u>
The Computational HEP activity supports advanced computing research and development (R&D) targeting challenges that extend the boundaries of scientific discovery to regions not otherwise accessible by experiments, observations, or traditional theory. Computation is necessary at all stages of HEP science, from planning and constructing accelerators and detectors, to theoretical modeling, to supporting computationally intensive experimental research and large-scale data analysis for scientific discovery. The activity supports the multi-laboratory HEP Center for Computational Excellence (CCE) to advance HEP computing by developing common software tools and enabling HEP science on the latest architectures in high performance computing platforms and exascale systems. Computational HEP partners with ASCR, including 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. University participation and Computational HEP Traineeships ensure technical expertise needed to deliver HEP scientific discoveries. This activity supports the Advanced Computing initiative to enable broader access to exascale computing resources by providing support for researchers to develop and adapt scientific codes for high performance on modern computing architectures.

<u>Quantum Information Science</u>
The HEP QIS activity supports the National Quantum Strategy's science first policy through the National QIS Research Centers and individual research grants, applying HEP techniques to QIS and vice versa. The objectives are to support QIS research and technology development that extends the scientific reach of existing HEP programs beyond currently achievable, or uses HEP experimental and theoretical techniques to improve the understanding of the theoretical and practical capabilities and limitations of complex quantum systems. 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 and composed of over 400 collaborators from national laboratories, academia, and industry. 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.

<u>Artificial Intelligence and Machine Learning</u>
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. The Activity also supports research that 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. HEP supports the development of an advanced AI/ML workforce through these university and lab-based research programs that provide students with experience developing and using cutting edge AI/ML techniques to conduct HEP discovery science. The HEP

AI/ML research activity is conducted in coordination with DOE and SC programs, other federal agencies, and the private sector.

<u>Broadening Engagement in HEP</u>
This activity supports:

- Reaching a New Energy Sciences Workforce (RENEW) initiative, expanding targeted efforts, including a RENEW graduate fellowship, to broaden participation in underserved communities and advance equity and inclusion in SC-sponsored research.
- Funding for Accelerated, Inclusive Research (FAIR), improving capability in emerging research institutions, underserved communities, HBCUs and MSIs to perform and propose competitive research and building beneficial relationships with DOE national laboratories and facilities.
- DOE Established Program to Stimulate Competitive Research (EPSCoR), which strengthen investments in U.S. states and territories that do not historically have large federally-supported academic research programs, and reach communities and institutions which are under-represented in the HEP portfolio. Funding for EPSCoR within the HEP 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.
- Other activities that broaden engagement with DOE national laboratories including:
  - Science Accelerating Girls' Engagement (SAGE) Journey internships, which provide hands-on experiences working with teams of engineers, scientists, and other professional staff at the DOE national laboratories.
  - Veteran Applied Laboratory Occupational Retraining, which provides Junior Reserve Officer Training Corps high school cadets and veterans, who are starting their civilian careers valuable, hands-on training experiences and full-time technical career placement at the DOE national laboratories.
  - African School of Fundamental Physics and Application (African School of Physics). The primary goals of the African School of Physics increase the number of African students who pursue careers in physics and build an international collaborative network consisting of African and international researchers. The African School of Physics also provides hands-on experience working with scientists on research projects at the DOE national laboratories.

Activities and Explanation of Changes

(dollars in thousands)

FY 2023 Enacted		FY 2025 Request	Explanation of Changes FY 2025 Request vs FY 2023 Enacted
Theoretical, Computational, and Interdisciplinary Physics	**$171,746**	**$186,714**	**+$14,968**
Research	$171,746	$186,714	+$14,968
Theory	*$54,050*	*$36,170*	*-$17,880*
Funding supports world-leading theoretical particle physics research at U.S. universities and national laboratories and the Advanced Computing initiative.		The Request will continue supporting world-leading theoretical particle physics research at U.S. universities and national laboratories.	Funding will prioritize support for theoretical investigations to unlock the mysteries of neutrinos and dark matter.
Computational HEP	*$14,130*	*$15,026*	*+$896*
Funding supports the multi-laboratory HEP CCE, HEP-ASCR SciDAC partnerships, and the Traineeship Program in Computational HEP.		The Request will continue supporting advanced computing R&D for HEP scientific discovery, in partnership with ASCR SciDAC, and the Traineeship Program in Computational HEP. The Request will also support the Advanced Computing initiative.	Funding increase will provide support for the Advanced Computing initiative and prioritize support for university research and training, and on enabling HEP scientists to carry out their research on high performance computing platforms and exascale systems.
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 supporting interdisciplinary HEP QIS consortia and the recompetition/renewal of the SQMS National QIS Research Center.	No changes.

(dollars in thousands)

FY 2023 Enacted		FY 2025 Request	Explanation of Changes FY 2025 Request vs FY 2023 Enacted
Artificial Intelligence and Machine Learning	*$40,000*	*$63,952*	*+$23,952*
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 continue supporting AI/ML research into ambitious applications of advanced methods through multi-institutional, interdisciplinary collaborations and into improved understanding of fundamental techniques for effective user facility operations and interpretation of massive data sets. The Request will support investments in the HEP AI ecosystem to broaden participation in HEP research.	The increase will provide support to develop and retain AI/ML scientific workforce at the national laboratories and to build AI/ML capacity and computational infrastructure for the broader HEP community.
Broadening Engagement in HEP	*$13,000*	*$21,000*	*+$8,000*
Funding supports the RENEW and FAIR initiatives which expand targeted efforts to increase participation and retention of under-represented 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 supporting the HEP participation in the RENEW and FAIR initiatives. The Request will support EPSCoR Implementation awards, larger multiple investigator teams that develop research capabilities, including investment in instrumentation, in EPSCoR jurisdictions; SAGE Journey Internships; and Veteran Applied Laboratory Occupational Retraining.	The increase will support the RENEW and FAIR initiatives.

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, colliders, 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 energy, 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. DOE published a report in early 2023 from a community study establishing a technology roadmap for the accelerator and beam physics thrust.[c]

SC's state-of-the-art 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 graduate 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 partnerships to provide the academic training and research experience needed to meet DOE's anticipated workforce needs, including the highly successful U.S. Particle Accelerator School. 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.

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, utilizing emerging technologies such as quantum sensors and real-time AI/ML in the front-end electronics. To meet this challenge, HEP aims to foster an appropriate balance between incremental, near-term, low-risk detector R&D and transformative, long-term, high-risk detector R&D, while training the next generation of instrumentation 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 cutting-edge detectors.

The Detector R&D activity supports the graduate 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 partnerships to provide the academic training and research experience needed to meet DOE's anticipated workforce needs to include emerging research institutions and underserved communities. 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.

[c] https://science.osti.gov/hep/-/media/hep/pdf/2022/ABP_Roadmap_2023_final.pdf

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, edge 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, computing, and communication 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.

Facility Operations and Experimental Support

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 and the microsystems laboratory at LBNL.

High Energy Physics
Advanced Technology R&D

Activities and Explanation of Changes

(dollars in thousands)

FY 2023 Enacted		FY 2025 Request	Explanation of Changes FY 2025 Request vs FY 2023 Enacted
Advanced Technology R&D	**$133,120**	**$115,566**	**-$17,554**
Research	$80,871	$57,856	-$23,015
General Accelerator R&D	*$54,342*	*$35,327*	*-$19,015*
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 continue supporting world-leading accelerator R&D activities at DOE national laboratories and universities, the ASTI initiative, and the Traineeship Program for Accelerator Science and Engineering.	Funding will prioritize support in key strategic research topics recommended by the community technology roadmaps, and on increasing participation in accelerator science training. Funding will shift from the Accelerate initiative to other priority cross-cutting initiatives while maintaining support for priority accelerator R&D themes across the Office of Science.
Detector R&D	*$26,529*	*$22,529*	*-$4,000*
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 supporting world-leading, innovative Detector R&D, advanced microelectronics technologies and AI/ML implementations, and the Traineeship Program in HEP Instrumentation.	Funding will prioritize support for developing emerging and potentially transformative technologies and on increasing participation in scientific instrumentation training.
Facility Operations and Experimental Support	$52,249	$57,710	+$5,461
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.*

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. PIP-II received Critical Decision (CD)-3 approval 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-US 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-US 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-US 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 of these efforts as a single, line-item construction project—LBNF/DUNE-US. The 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.

The LBNF/DUNE-US project received approval for CD-1RR (Update cost range, reaffirm the alternative selection, and approve a new tailoring strategy for baselining the project in five subprojects) on February 16, 2023, with a TPC Point Estimate of $3,277,000,000. 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 TPC Point Estimate 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-US TPC will be the aggregate of all subproject TPCs plus any contingency being held by the parent LBNF/DUNE-US project.

11-SC-41, Muon to Electron Conversion Experiment, FNAL

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 civil construction of the underground detector housing and the surface building for the experiment in 2017. External factors negatively impacted the performance of the Mu2e project and through a 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, which supported a new TPC of $315,700,000. The CD-4 milestone date for project completion is January 2028. The FY 2022 Inflation Reduction Act provided $40,023,000 and the project received its final funding in the FY 2023 Enacted Appropriation.

Activities and Explanation of Changes

(dollars in thousands)

FY 2023 Enacted		FY 2025 Request	Explanation of Changes FY 2025 Request vs FY 2023 Enacted
Construction	**$298,000**	**$405,000**	**+$107,000**
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 construction of the linac building and the fabrication and testing of production RF cavities, cryomodules, and other 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	$280,000	+$104,000
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 continue the construction of FSCF-BSI; continue installation of far detector components at FDC; and continue design and prototyping activities for NSCF+B and ND. NSCF+B activities will also include preparations to award construction subcontracts for the facilities. NSCF+B site preparation work will continue to provide a temporary construction entrance to the FNAL site	Funding will increase to 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 2023 Enacted	FY 2024 Annualized CR	FY 2025 Request	FY 2025 Request vs FY 2023 Enacted
Capital Operating Expenses						
Capital Equipment	N/A	N/A	73,620	58,200	56,700	-16,920
Minor Construction Activities						
General Plant Projects	N/A	N/A	4,000	4,200	7,640	+3,640
Total, Capital Operating Expenses	**N/A**	**N/A**	**77,620**	**62,400**	**64,340**	**-13,280**

High Energy Physics
Capital Equipment

(dollars in thousands)

	Total	Prior Years	FY 2023 Enacted	FY 2024 Annualized CR	FY 2025 Request	FY 2025 Request vs FY 2023 Enacted
Capital Equipment						
Major Items of Equipment						
Energy Frontier Experimental Physics						
High Luminosity Large Hadron Collider Accelerator Upgrade Project	259,952	229,952	30,000	–	–	-30,000
High Luminosity Large Hadron Collider ATLAS Upgrade Project	183,485	120,785	10,000	16,200	16,200	+6,200
High Luminosity Large Hadron Collider CMS Upgrade Project	158,550	102,838	10,000	19,500	17,500	+7,500
Intensity Frontier Experimental Physics						
Accelerator Controls Operations Research Network	113,000	–	–	5,000	10,000	+10,000
Cosmic Frontier Experimental Physics						
Cosmic Microwave Background - Stage 4	349,000	–	–	9,000	4,500	+4,500
Total, MIEs	N/A	N/A	50,000	49,700	48,200	-1,800
Total, Non-MIE Capital Equipment	N/A	N/A	23,620	8,500	8,500	-15,120
Total, Capital Equipment	**N/A**	**N/A**	**73,620**	**58,200**	**56,700**	**-16,920**

Note:
- *The Capital Equipment table includes MIEs located at a DOE facility with a Total Estimated Cost (TEC) > $10M and MIEs not located at a DOE facility with a TEC >$2M.*

High Energy Physics
Minor Construction Activities

(dollars in thousands)

	Total	Prior Years	FY 2023 Enacted	FY 2024 Annualized CR	FY 2025 Request	FY 2025 Request vs FY 2023 Enacted
General Plant Projects (GPP)						
GPPs (greater than $5M and $34M or less)						
Target Systems Integration Building	6,900	2,900	4,000	–	–	-4,000
Total GPPs (greater than $5M and $34M or less)	N/A	N/A	4,000	–	–	-4,000
Total GPPs $5M or less	N/A	N/A	–	4,200	7,640	+7,640
Total, General Plant Projects (GPP)	**N/A**	**N/A**	**4,000**	**4,200**	**7,640**	**+3,640**
Total, Minor Construction Activities	**N/A**	**N/A**	**4,000**	**4,200**	**7,640**	**+3,640**

Note:
- *GPP activities $5M and less include design and construction for additions and/or improvements to land, buildings, replacements or addition to roads, and general area improvements. AIP activities $5M and less include minor construction at an existing accelerator facility.*
- *The Target Systems Integration Building includes $10,000,000 of redirected funds obligated in FY 2022 that brings the total project amount to $16,900,000 consistent with the baseline change approval.*

High Energy Physics
Major Items of Equipment Description(s)

Energy Frontier Experimental Physics MIEs:

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 increased costs, which resulted in a rebaseline review of the project. The new Total Estimated Cost (TEC) of $259,952,000 was approved on March 20, 2023. Due to the $38,355,000 provided in the FY 2022 Inflation Reduction Act, and the project receiving its final funding in the FY 2023 Enacted Appropriation, the FY 2025 Request includes no additional funding for the project.

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 ATLAS and CMS detectors are technically configured similarly but largely differ in the type of tracker subsystem, calorimeter, muon detector subsystem, and trigger employed by each experiment. 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 2025 Request for TEC funding of $16,200,000 will focus on ramping up fabrication activities of U.S.-built deliverables for the project.

High-Luminosity Large Hadron Collider CMS Detector Upgrade Project (HL-LHC CMS)

The HL-LHC CMS project received CD-2/3c approval on April 4, 2023, with a TPC of $200,000,000. 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. The ATLAS and CMS detectors are technically configured similarly but largely differ in the type of tracker subsystem, calorimeter, muon detector subsystem, and trigger employed by each experiment. 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 2025 Request for TEC funding of $17,500,000 will focus on ramping up fabrication activities of U.S.-built deliverables for the project.

Intensity Frontier Experimental Physics MIE:

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 outdated 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 2025 Request for TEC funding of $10,000,000 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. The distribution of scope is under discussion. 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 2025 Request for TEC funding of $4,500,000 will support engineering and design efforts.

High Energy Physics
Construction Projects Summary

(dollars in thousands)

	Total	Prior Years	FY 2023 Enacted	FY 2024 Annualized CR	FY 2025 Request	FY 2025 Request vs FY 2023 Enacted
18-SC-42, Proton Improvement Plan II (PIP-II), FNAL						
Total Estimated Cost (TEC)	891,200	260,000	120,000	125,000	125,000	+5,000
Other Project Cost (OPC)	86,800	73,594	-	-	-	-
Total Project Cost (TPC)	**978,000**	**333,594**	**120,000**	**125,000**	**125,000**	**+5,000**
11-SC-40, Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment						
Total Estimated Cost (TEC)	3,163,335	979,781	176,000	251,000	280,000	+104,000
Other Project Cost (OPC)	113,665	101,625	4,000	4,000	-	-4,000
Total Project Cost (TPC)	**3,277,000**	**1,081,406**	**180,000**	**255,000**	**280,000**	**+100,000**
11-SC-41, Muon to Electron Conversion Experiment, FNAL						
Total Estimated Cost (TEC)	292,023	290,023	2,000	-	-	-2,000
Other Project Cost (OPC)	23,677	23,677	-	-	-	-
Total Project Cost (TPC)	**315,700**	**313,700**	**2,000**	**-**	**-**	**-2,000**
Total, Construction						
Total Estimated Cost (TEC)	**N/A**	**N/A**	**298,000**	**376,000**	**405,000**	**+107,000**
Other Project Cost (OPC)	**N/A**	**N/A**	**4,000**	**4,000**	**-**	**-4,000**
Total Project Cost (TPC)	**N/A**	**N/A**	**302,000**	**380,000**	**405,000**	**+103,000**

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 2023 Enacted	FY 2023 Current	FY 2024 Annualized CR	FY 2025 Request	FY 2025 Request vs FY 2023 Enacted
Scientific User Facilities - Type A					
Fermilab Accelerator Complex	**152,984**	**145,376**	**146,232**	**166,850**	**+13,866**
Number of Users	2,700	2,395	2,395	2,800	+100
Achieved Operating Hours	–	2,486	–	–	–
Planned Operating Hours	5,740	5,320	2,940	5,180	-560
Unscheduled Down Time Hours	–	3,567	–	–	–
Facility for Advanced Accelerator Experimental Tests II (FACET II)	**15,500**	**15,500**	**14,155**	**17,640**	**+2,140**
Number of Users	120	144	144	144	+24
Achieved Operating Hours	–	1,596	–	–	–
Planned Operating Hours	3,300	3,360	3,120	3,120	-180
Unscheduled Down Time Hours	–	2,414	–	–	–
Total, Facilities	**168,484**	**160,876**	**160,387**	**184,490**	**+16,006**
Number of Users	2,820	2,539	2,539	2,944	+124
Achieved Operating Hours	–	4,082	–	–	–
Planned Operating Hours	9,040	8,680	6,060	8,300	-740
Unscheduled Down Time Hours	–	5,981	–	–	–

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

High Energy Physics
Scientific Employment

	FY 2023 Enacted	FY 2024 Annualized CR	FY 2025 Request	FY 2025 Request vs FY 2023 Enacted
Number of Permanent Ph.Ds (FTEs)	785	785	707	-78
Number of Postdoctoral Associates (FTEs)	400	380	335	-65
Number of Graduate Students (FTEs)	530	540	424	-106
Number of Other Scientific Employment (FTEs)	1,635	1,540	1,570	-65
Total Scientific Employment (FTEs)	**3,350**	**3,245**	**3,036**	**-314**

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 2025 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 in 2024. 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. As of January 2022, 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 late 2024.

Civil construction costs and the construction contingency estimate increased relative to previous estimates due to market conditions whereas increase in the total cost was offset by refinement of the technical equipment estimate.

The FY 2023 Enacted Appropriations supported initiation of civil construction as well as developing prototypes of superconducting RF cavities, cryomodules, and the accelerator’s other technical systems. The FY 2024 Request supports the completion of the cryogenic plant building, the continuation of the linac building civil construction, and the continued development of prototypes of the superconducting RF cavities and the cryomodules that hold them. The FY 2025 Request will support continuation of construction of the linac building and the fabrication and testing of production RF cavities, cryomodules, and other technical systems.

A civil construction injury accident in May 2023 delayed linac civil construction until December 2023 for investigations and strengthening of the hazard identification and mitigation processes, consuming several months of schedule contingency and $2,000,000,000 of cost contingency. Civil construction is now on the project’s critical path; the CD-4 milestone date has not changed. An Independent Project Review (IPR) planned in spring 2024 will reassess the contingencies and remaining risks.

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 2025	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 2025	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 2024	135,895	755,305	891,200	86,800	86,800	978,000
FY 2025	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.[d]
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. The ECF subproject total estimated cost is $36,000,000; it was initiated in FY 2020 and will be completed in FY 2024. If the ECF subproject is completed for less than its full budget, DOE may authorize redistribution of subproject funds to the PIP-II project contingency for remaining project risks.

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.

[d] 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.[e]

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.

3. Financial Schedule

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs	IRA Supp. Costs
Total Estimated Cost (TEC)				
Design (TEC)				
Prior Years	135,895	135,895	135,895	—
Total, Design (TEC)	**135,895**	**135,895**	**135,895**	**—**
Construction (TEC)				
Prior Years	114,105	114,105	37,298	—
Prior Years - IRA Supp.	10,000	10,000	—	—
FY 2023	120,000	120,000	58,668	1,293
FY 2024	125,000	125,000	125,000	8,707
FY 2025	125,000	125,000	125,000	—
Outyears	261,200	261,200	399,339	—
Total, Construction (TEC)	**755,305**	**755,305**	**745,305**	**10,000**
Total Estimated Cost (TEC)				

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

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs	IRA Supp. Costs
Total Estimated Cost (TEC)				
Prior Years	250,000	250,000	173,193	—
Prior Years - IRA Supp.	10,000	10,000	—	—
FY 2023	120,000	120,000	58,668	1,293
FY 2024	125,000	125,000	125,000	8,707
FY 2025	125,000	125,000	125,000	—
Outyears	261,200	261,200	399,339	—
Total, Total Estimated Cost (TEC)	**891,200**	**891,200**	**881,200**	**10,000**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Other Project Cost (OPC)			
Prior Years	73,594	73,594	73,419
FY 2023	–	–	1
FY 2024	–	–	174
Outyears	13,206	13,206	13,206
Total, Other Project Cost (OPC)	**86,800**	**86,800**	**86,800**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs	IRA Supp. Costs
Total Project Cost (TPC)				
Prior Years	323,594	323,594	246,612	–
Prior Years - IRA Supp.	10,000	10,000	–	–
FY 2023	120,000	120,000	58,669	1,293
FY 2024	125,000	125,000	125,174	8,707
FY 2025	125,000	125,000	125,000	–
Outyears	274,406	274,406	412,545	–
Total, TPC	**978,000**	**978,000**	**968,000**	**10,000**

Note:
- *Prior Years and FY 2023 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	135,895	146,314
Design - Contingency	N/A	N/A	30,686
Total, Design (TEC)	**135,895**	**135,895**	**177,000**
Construction	177,000	151,000	124,009
Site Preparation	13,000	13,000	12,783
Equipment	403,760	433,905	378,705
Construction - Contingency	161,545	157,400	198,703
Total, Construction (TEC)	**755,305**	**755,305**	**714,200**
Total, TEC	**891,200**	**891,200**	**891,200**
Contingency, TEC	*161,545*	*157,400*	*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)	***170,049***	***165,904***	***237,893***

5. Schedule of Appropriations Requests

(dollars in thousands)

Fiscal Year	Type	Prior Years	FY 2023	FY 2024	FY 2025	Outyears	Total
FY 2024	TEC	260,000	120,000	125,000	—	386,200	891,200
	OPC	73,594	—	—	—	13,206	86,800
	TPC	333,594	120,000	125,000	—	399,406	978,000
FY 2025	TEC	260,000	120,000	125,000	125,000	261,200	891,200
	OPC	73,594	—	—	—	13,206	86,800
	TPC	333,594	120,000	125,000	125,000	274,406	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, planned or anticipated for future experiments, 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-US 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 has been placed on a firm-fixed-price basis, and work has begun at the laboratory.

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 2025 Request for Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment (LBNF/DUNE-US) is $280,000,000 of Total Estimated Cost (TEC) funding.

The LBNF/DUNE-US scope is organized into five 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)

Significant Changes
The CD-1 Reaffirmation (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 was $3,277,000,000. This TPC Point Estimate was 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-US TPC will be the aggregate of all subproject TPCs plus any contingency being held by the parent LBNF/DUNE-US project.

The FSCF-EXC subproject was the first subproject to be approved for baseline and start of construction (CD-2/3) in August 2022. The FSCF-BSI achieved CD-2/3 approval in March 2023. The FDC subproject, which obtained CD-3a approval in February 2023, is expected to achieve CD-2/3 approval in FY 2024. In addition, NSCF+B subproject achieved CD-3a approval in March 2023 with a combined CD-2/3 approval planned for FY 2025. The Near Detector Subproject is expected to be the last subproject to be baselined.

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

The FY 2024 Request will support activities that include completing excavation of the far detector caverns; construction of FSCF-BSI; beginning installation of far detector components for FDC and manufacturing of components; continuing design and other planning efforts for NSCF+B and ND; and continuing site preparation of the conventional facilities of NSCF+B.

The FY 2025 Request will continue to support the construction of FSCF-BSI, the installation of far detector components at FDC, and the design and prototyping activities for NSCF+B and ND. NSCF+B activities will also include preparations to award construction subcontracts for the facilities. NSCF+B site preparation work will continue to provide a temporary construction entrance to the FNAL site.

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	2Q FY 2026	4Q FY 2026	3Q FY 2027	4Q 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	–	–	–	3/25/23	11/20/20	3/25/23	4Q FY 2028
Far Detectors and Cryogenic Infrastructure	–	–	–	4Q FY 2024	8/10/23	4Q FY 2024	2Q FY 2033
Near Site Conventional Facilities and Beamline	–	–	–	1Q FY 2026	3Q FY 2026	1Q FY 2026	1Q FY 2034
Near Detector	–	–	–	2Q FY 2026	4Q FY 2026	3Q FY 2027	4Q 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	CD-3B
LBNF/DUNE-Overall	4Q 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	3/25/23	—	2/16/23	–	–
Far Detectors and Cryogenic Infrastructure	4Q FY 2024	—	2/16/23	2/21/23	2Q FY 2024
Near Site Conventional Facilities and Beamline	3Q FY 2025	—	2/16/23	3/25/23	1Q FY 2025
Near Detector	4Q FY 2025	—	2/16/23	–	–

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.

Project Cost History

(dollars in thousands)

Fiscal Year	TEC, Design	TEC, Construction	TEC, Total	OPC, Except D&D	OPC, Total	TPC
FY 2024	550,447	2,616,888	3,167,335	109,665	109,665	3,277,000
FY 2025	569,694	2,593,641	3,163,335	113,665	113,665	3,277,000

Notes:
- *The project is Pre-CD-2 for some subprojects. All estimates are preliminary. The approved TPC range for CD-1RR is $3,160,000,000 to $3,677,000,000.*
- *No construction, other than site preparation and approved 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
The LBNF/DUNE-US 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 and among the most mysterious particles in the universe. 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 muon neutrinos 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 transformations of neutrinos in flight 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.

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 at the SURF. A much smaller neutrino detector will be installed 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 greater intensity than the NuMI beam and would point to far detector modules at a greater distance than is used with NuMI experiments.

For the LBNF/DUNE-US project, FNAL will be responsible for design, construction, and operation of the major components of facilities which enable the DUNE research program 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. LBNF/DUNE-US provides detector components for the DUNE research program and supports the installation and integration of detector components provided by international partners.

Justification

As part of implementation of High Energy Physics Advisory Panel (HEPAP)-Particle Physics Project Prioritization Panel (P5) recommendations the LBNF/DUNE-US project comprises a national flagship particle physics initiative and consists of two multinational collaborative efforts:

- LBNF is responsible for the beamline and other experimental and civil infrastructure at FNAL and at SURF in South Dakota. SURF 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, NSF, 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. The U.S. contributes to DUNE along with other international funding agencies. DOE and FNAL host the international DUNE research program.

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 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 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 each subprojects.

FNAL and DOE have confirmed contributions to LBNF documented in international agreements from CERN, the UK, and other international partners. Discussions are ongoing with other countries for additional contributions. 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. Commitments for detector contributions and associated planning are being finalized in advance of each relevant subproject. 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. KPPs for each subproject are finalized with the approval of relevant subproject CD-2.

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 Cubic Feet per Minute though the spray chamber.	All Threshold KPPs

Performance Measure	Threshold	Objective
	3) Complete the Ross Shaft brow enlargement and the excavation of all ancillary spaces and access drifts to create a minimum of 71,500 Gross Square Feet (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 Cubic Yards (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.	
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.
Far Detector – Horizontal Drift Detector Components	Fabricate, deliver to SURF, and install the deliverables as specified in the detailed FDC subproject Threshold KPPs for the Horizontal Drift detector providing coverage for at least 95 percent of the detector volume. This includes: the 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 Liquid Argon (LAr) TPC. Deliver and install the corresponding detector parts, DAQ servers and services outside the cryostat.	Fabricate, deliver to SURF, and install the deliverables as specified in the detailed FDC subproject Objective KPPs for the Horizontal Drift Detector providing full (100 percent) coverage.
Far Detector – Vertical Drift Detector Components	Fabricate, deliver to SURF, and install the deliverables as specified in the detailed FDC subproject threshold KPPs for the Vertical Drift Detector providing coverage for at least 95 percent of the detector volume. This includes: the Charge Readout Planes for the bottom drift volume, High Voltage field cage structures; electronics for the readout of the bottom charge readout planes; components of the Photon Detector System; and purity monitors for one vertical-drift LAr TPC. Deliver and install the corresponding detector parts, DAQ servers and services outside the cryostat.	Fabricate, deliver to SURF, and install the deliverables specified in the detailed FDC subproject Objective KPPs for the Vertical Drift Detector providing full (100 percent) coverage.

Performance Measure	Threshold	Objective
Far Site Cryogenic Infrastructure	1) Design, procure, install and commission the Nitrogen refrigeration system capable of providing 300 kW cooling capacity to the detector modules. 2) Install and commission the surface receiving facilities for the cryogenic liquids. 3) Install and commission the Argon purification, circulation, regeneration and Argon condensers system for two cryostat detectors. 4) Install and test internal cryogenics for Gaseous Argon/LAr distribution. 5) Provide operational readiness clearance for the operation of the cryogenic systems and for filling with LAr the first two cryostats. 6) Set up the contract with options to procure the necessary amount of LAr for each of the Far Detectors (Horizontal and Vertical drift) LAr TPC modules per FDC Requirements. Commit funds for the procurement of 30 percent of the LAr for each of the two far detectors.	In addition to the threshold KPPs: 1) Commit the funds for the procurement of the remaining 70 percent of the LAr for the two Far detectors. 2) Procure the required Liquid Xenon (10 ppm) required to improve light collection efficiency for the Vertical Drift Detector.

Performance Measure	Threshold	Objective
Far Site Far Detector Integration* *Note that the KPPs defined for Far Detector Horizontal and Vertical Detector Components and the Cryogenic Infrastructure are pre-requisites to the KPPs for the Far Detector Integration.	1) Prior to the final closure of the cryostat, demonstrate, at room temperature, 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 95 percent fully functional electronic readout channels. 2) Close both cryostats in preparation for purging/filling Purge and fill both cryostats to minimum level (30 percent) and demonstrate LAr recirculation and purification.	1) Prior to the final closure of the two cryostats, demonstrate, at room temperature, 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 90 percent and a minimum of 99 percent fully functional electronic readout channels. 2) Purge and fill both cryostats to maximum level (100 percent) and demonstrate LAr recirculation and purification. 3) Establish an electrical field in the drift volume of at least 250 V/cm with a live time of at least 80 percent. 4) Demonstrate that all the channels can continue to be read out in each detector module after the cryostats are filled. Observe signals from cosmic ray tracks with the charge and light detection systems. Demonstrate coincidences between TPC and photon detector signals. Perform measurements of the electron lifetime in LAr using the purity monitors for each of the two cryostats.

Performance Measure	Threshold	Objective
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
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.	Using parts and components provided by both the project and in-kind by international partners: 1) 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 2) Ability to move the LAr TPC near detector system to an off-axis location 3) 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	443,713	443,713	391,688	—
FY 2023	107,501	107,501	61,004	—
FY 2024	9,570	9,570	106,852	—
FY 2025	8,910	8,910	10,150	—
Total, Design (TEC)	**569,694**	**569,694**	**569,694**	**—**
Construction (TEC)				
Prior Years	411,068	411,068	265,900	—
Prior Years - IRA Supp.	125,000	125,000	—	—
FY 2023	68,499	68,499	108,156	2,563
FY 2024	241,430	241,430	313,873	122,437
FY 2025	271,090	271,090	248,329	—
Outyears	1,476,554	1,476,554	1,532,383	—
Total, Construction (TEC)	**2,593,641**	**2,593,641**	**2,468,641**	**125,000**
Total Estimated Cost (TEC)				
Prior Years	854,781	854,781	657,588	—
Prior Years - IRA Supp.	125,000	125,000	—	—
FY 2023	176,000	176,000	169,160	2,563
FY 2024	251,000	251,000	420,725	122,437
FY 2025	280,000	280,000	258,479	—
Outyears	1,476,554	1,476,554	1,532,383	—
Total, Total Estimated Cost (TEC)	**3,163,335**	**3,163,335**	**3,038,335**	**125,000**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Other Project Cost (OPC)			
Prior Years	101,625	101,625	92,481
FY 2023	4,000	4,000	993
FY 2024	4,000	4,000	9,264
FY 2025	–	–	2,497
Outyears	4,040	4,040	8,430

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Other Project Cost (OPC)			
Total, Other Project Cost (OPC)	**113,665**	**113,665**	**113,665**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs	IRA Supp. Costs
Total Project Cost (TPC)				
Prior Years	956,406	956,406	750,069	–
Prior Years - IRA Supp.	125,000	125,000	–	–
FY 2023	180,000	180,000	170,153	2,563
FY 2024	255,000	255,000	429,989	122,437
FY 2025	280,000	280,000	260,976	–
Outyears	1,480,594	1,480,594	1,540,813	–
Total, TPC	**3,277,000**	**3,277,000**	**3,152,000**	**125,000**

Note:
- *Prior years and FY 2023 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	555,102	528,377	**N/A**
Design - Contingency	14,592	22,070	**N/A**
Total, Design (TEC)	**569,694**	**550,447**	**N/A**
Construction	1,362,798	1,344,860	**N/A**
Equipment	571,488	571,488	**N/A**
Construction - Contingency	659,355	700,540	**N/A**
Total, Construction (TEC)	**2,593,641**	**2,616,888**	**N/A**
Total, TEC	**3,163,335**	**3,167,335**	**N/A**
Contingency, TEC	*673,947*	*722,610*	***N/A***
Other Project Cost (OPC)			
R&D	16,000	16,000	**N/A**
Conceptual Planning	44,958	44,958	**N/A**
Conceptual Design	31,977	31,977	**N/A**

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Other OPC Costs	17,840	13,540	**N/A**
OPC - Contingency	2,890	3,190	**N/A**
Total, Except D&D (OPC)	**113,665**	**109,665**	**N/A**
Total, OPC	**113,665**	**109,665**	**N/A**
Contingency, OPC	*2,890*	*3,190*	***N/A***
Total, TPC	**3,277,000**	**3,277,000**	**N/A**
Total, Contingency (TEC+OPC)	***676,837***	***725,800***	***N/A***

Notes:

- *Each subproject will have a validated baseline at the time of each subproject's CD-2 approval.*
- *Construction involves excavation of caverns at SURF, 4,850 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 2023	FY 2024	FY 2025	Outyears	Total
FY 2024	TEC	979,781	176,000	251,000	—	1,760,554	3,167,335
	OPC	101,625	4,000	4,000	—	40	109,665
	TPC	1,081,406	180,000	255,000	—	1,760,594	3,277,000
FY 2025	TEC	979,781	176,000	251,000	280,000	1,476,554	3,163,335
	OPC	101,625	4,000	4,000	—	4,040	113,665
	TPC	1,081,406	180,000	255,000	280,000	1,480,594	3,277,000

Note:

- *All estimates are preliminary.*

6. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy	4Q FY 2035
Expected Useful Life	20 years
Expected Future Start of D&D of this capital asset	4Q FY 2055

Operations and maintenance funding of this experiment will become part of the existing Fermilab Accelerator Complex Users Facility. 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	22,000	22,000	440,000	440,000
Utilities	6,000	6,000	120,000	120,000
Maintenance and Repair	14,000	14,000	280,000	280,000
Total, Operations and Maintenance	42,000	42,000	840,000	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-RR, documents the acquisition approach. DOE is acquiring design, construction, fabrication, and operation of LBNF through FRA, the M&O contractor responsible for FNAL. 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 research program, 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, South Dakota.

- 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-US construction project is a federal, state, private and international partnership. Leading the LBNF/DUNE-US 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 SURF 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 essential 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 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 negotiates 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 provides funding for the LBNF/DUNE-US Project directly to FNAL and collaborating DOE national laboratories via approved financial plans, and under management control of the LBNF/DUNE-US 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 provide 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 and improvements to the SDSTA infrastructure to support the LBNF/DUNE-US project are costed to the project. Repairs and improvements for the overall facility are costed to the cooperative agreement between HEP and SDSTA for general 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.