High Energy Physics

Overview

The High Energy Physics (HEP) program 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 supports individual investigators and small-scale collaborations, as well as very large international collaborations, chosen for their scientific merit and potential for significant impact. More than 20 HEP-supported physicists have received the Nobel Prize. Moreover, many of the advanced technologies and research tools originally developed for high energy physics have proved widely applicable to other scientific disciplines as well as industry, medicine, and national security.

Our current understanding of the elementary constituents of matter and energy is captured in what is called the Standard Model of particle physics. It describes the elementary particles that comprise ordinary matter and the forces that govern them with very high precision. However, recent observations that are not explained by the Standard Model suggest that it is incomplete and new physics may be discovered by future experiments. Astronomical observations indicate that ordinary matter makes up only about 5% of the universe, the remainder being 70% dark energy and 25% dark matter, both “dark” because they are either nonluminous or unknown. The observation of very small but non-zero masses of the elementary particles known as neutrinos provides further hints of new physics beyond the Standard Model.

A world-wide program of particle physics research is underway to discover what lies beyond the Standard Model. Five intertwined science drivers of particle physics provide compelling lines of inquiry that show great promise for discovery:

- 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
- Explore the unknown: new particles, interactions and physical principles

The HEP program enables scientific discovery through a strategy organized along three frontiers of particle physics:

- Energy Frontier, where researchers accelerate particles to the highest energies ever made by humanity and collide them to produce and study the fundamental constituents of matter. This requires some of the largest machines ever built. The Large Hadron Collider (LHC), 17 miles in circumference, accelerates and collides high-energy protons while sophisticated detectors, some the size of apartment buildings, observe newly produced particles that provide insight into fundamental forces of nature and the conditions of the early universe.
- Intensity Frontier, where researchers use a combination of intense particle beams and highly sensitive detectors to make extremely precise measurements of particle properties, study some of the rarest particle interactions predicted by the Standard Model of particle physics, and search for new physics. Measurements of the mass and other properties of neutrinos may have profound consequences for understanding the evolution and ultimate fate of the universe.
- Cosmic Frontier, where researchers seek to reveal the nature of dark matter and dark energy by using naturally occurring particles to explore new phenomena. The highest-energy particles ever observed have come from cosmic sources, and the ancient light from distant galaxies allows the distribution of dark matter to be mapped and perhaps the nature of dark energy to be unraveled. Ultra-sensitive detectors deep underground may glimpse the dark matter passing through Earth. Observations of the cosmic frontier reveal a universe far stranger than ever thought possible.

These three frontiers are supported by the Theoretical and Computational Physics and the Advanced Technology R&D subprograms. Theoretical and Computational Physics provides the framework to explain experimental observations and gain a deeper understanding of nature. A thriving theory program is essential to support current experiments and identify new directions for the field. Theoretical physicists take the lead in the interpretation of a broad range of experimental results and synthesize new ideas as they search for deep connections and develop testable models. Advanced computing tools are necessary for designing, operating, and interpreting experiments while performing the computational science and simulations that enable discovery research in the three frontiers. Advanced Technology R&D fosters fundamental research into particle acceleration and detection techniques and instrumentation. These in turn provide the enabling technologies and new research

methods that can advance scientific knowledge in high energy physics and a broad range of related fields, advancing the DOE's strategic goals for science.
The Accelerator Stewardship subprogram supports R&D efforts that are synergistic with the HEP mission but also impact activities outside the traditional HEP boundaries. The activities of the Stewardship subprogram include: improving access to Office of Science (SC) accelerator R&D infrastructure for industrial and other users; near-term translational R&D to adapt HEP accelerator technology for potential uses in medical, industrial, security, defense, energy and environmental applications; and long-term R&D for science and technology needed to build future generations of accelerators, with a focus on transformational opportunities.

Highlights of the FY 2017 Budget Request

In September 2013, the DOE and the National Science Foundation (NSF) charged the High Energy Physics Advisory Panel (HEPAP) to convene a Particle Physics Project Prioritization Panel (P5) in order to develop a ten-year strategic plan for U.S. high energy physics in the context of a 20-year global vision. The panel was charged to respond to three realistic budget scenarios provided by the funding agencies. In May 2014, HEPAP unanimously approved the P5 report and its recommendations. The report provides a practical, long-term strategy that enables discovery and maintains the U.S. position as a global leader in particle physics. The DOE accepted the recommendations in the P5 report and is committed to implementing a successful program based on this new vision.

The FY 2017 Budget Request continues implementation of the recommendations contained in the P5 report. The Request supports full operation of existing major HEP facilities and experiments; the planned construction funding profile for the Muon to Electron Conversion Experiment (Mu2e), and fabrication for recent major items of equipment (MIEs) for the Large Underground Xenon (LUX)–ZonEd Proportional scintillation in LIquid Noble gases (ZEPLIN) experiment (LZ) and the Super Cryogenic Dark Matter Search at Sudbury Neutrino Observatory Laboratory (SuperCDMS-SNOLab) experiment. The Request includes capital equipment funding to continue support of the planned funding profiles for the camera for the Large Synoptic Survey Telescope (LSSTcam) project, the Dark Energy Spectroscopic Instrument (DESI) project, the Muon g-2 Experiment, and the U.S. contributions to the LHC ATLAS (A Toroidal LHC Apparatus) Detector Upgrade, and the LHC Compact Muon Solenoid (CMS) Detector Upgrade. The Muon g-2 Experiment and LHC detector upgrades complete their funding profiles in FY 2017.

HEP's implementation of the P5 recommendation to reformulate the long baseline neutrino program in an international context has resulted in the formation of two multi-national efforts: the Long Baseline Neutrino Facility (LBNF), which will be responsible for the beamline at the Fermi National Accelerator Laboratory (Fermilab) and other experimental and civil infrastructure at Fermilab and Sanford Underground Research Facility (SURF); and the Deep Underground Neutrino Experiment (DUNE), an international experimental collaboration responsible for defining the scientific goals and technical requirements for the detectors and beamline as well as design, construction, commissioning of the detectors and subsequent research program. HEP proposes to manage both activities as a single project to be known as LBNF/DUNE. There has been significant progress in the development of these international partnerships in the past year, and the new DUNE science collaboration is moving forward expeditiously to implement an optimized detector design. HEP continues to pursue the development of this world-leading long-baseline neutrino experiment by recruiting additional partners and coordinating plans for the international facility that enables it.

In the FY 2017 Budget Request, most funding for the Working Capital Fund (WCF) is transferred to Program Direction to establish a consolidated source of funding for goods and services provided by the WCF. CyberOne is still funded through program dollars in the SC Safeguards and Security Program. In FY 2016 and prior years, WCF costs were shared by SC research programs and Program Direction.

<u>Energy Frontier Experimental Physics</u>
The LHC resumed operations in 2015 at collision energies of 13 TeV, a substantial increase from 8 TeV in the previous run that enabled the discovery of the Higgs boson. Higher energies will increase the reach of the LHC into the search for new physics, particularly in high-impact topics such as supersymmetry, dark matter candidates, and evidence for extra space-time dimensions. Physics results from this higher-energy data became available in 2015 and will continue well into 2017, critically informing future HEP research directions and opportunities. Investments are made for U.S. contributions to planned LHC detector upgrades that will exploit the full physics potential of LHC with much higher luminosities.

Intensity Frontier Experimental Physics

FY 2017 will feature full operations for the Neutrinos at the Main Injector (NuMI) Off-axis Electron Neutrino Appearance Experiment (NOvA) detector in the world's most intense neutrino beam from Fermilab. The physics goals of this experiment include improved measurements of neutrino mixing, first results on the neutrino mass hierarchy, and the search for matter-antimatter asymmetry in the neutrino sector. The MicroBooNE neutrino experiment will be in full operation in the Fermilab Booster Neutrino Beam (BNB), with a goal of resolving certain anomalies seen in several previous accelerator-based neutrino experiments. MicroBooNE is the first experiment in the Fermilab Short Baseline Neutrino (SBN) program, a coordinated set of liquid argon neutrino detector experiments that will advance neutrino science and serve as an international R&D platform for LBNF/DUNE. The SBN program will also include the Short Baseline Neutrino Detector (SBND) and the Imaging Cosmic and Rare Underground Signals (ICARUS) detector, which is being moved from Italy to Fermilab. Both detectors are scheduled to begin data taking in FY 2018.

The Muon g-2 MIE will complete fabrication, installation and commissioning in FY 2017 and the first data-taking run of the Muon g-2 Experiment will begin. Both experiments will probe energy scales beyond the LHC through the study of rare processes and precision measurements. The SuperKEKB electron-positron collider, located at the Japanese High Energy Accelerator Research Organization (KEK) laboratory in Tsukuba, Japan, will begin sending beam to the Belle II detector in FY 2017. The Belle II experiment will have unprecedented sensitivity to search for new physics and study rare decays in heavy quarks and tau leptons.

The FY 2017 Request includes funding for Other Project Costs (OPC) for the Proton Improvement Plan II (PIP-II) project. The original Proton Improvement Plan (PIP) included a series of equipment replacements and refurbishments necessary to keep the nearly 50 year old accelerator complex running efficiently. Fermilab is currently completing this work. In order to meet the currently foreseen goals of the HEP program, however, it will be necessary to go beyond the modest PIP improvements and replace the entire front end of the accelerator complex. This upgrade to the linac to increase the beam power and the energy is referred to as PIP-II. Unlike its predecessor, PIP-II will be a line item construction project once construction funding is requested. In FY 2017, only OPC funding is requested to support conceptual design activities.

Cosmic Frontier Experimental Physics

The Cosmic Frontier Experimental Physics program will continue a coordinated program of studies of the nature of dark energy and searches for dark matter particles. The program also includes experiments studying high energy cosmic rays, gamma rays, and the study of the cosmic microwave background (CMB) in order to gain insight into the nature of inflation in the early universe. Projects that will carry out the next generation imaging and spectroscopic dark energy studies, LSSTcam and DESI, will be in their fabrication phases in FY 2017. There are three second generation direct detection dark matter projects that will use a variety of technologies to provide complementary searches for dark matter particles. The Axion Dark Matter Search Generation 2 (ADMX-G2) is a series of small experiments that will search for axions, a proposed dark matter candidate, over different mass ranges. The LZ and SuperCDMS-SNOLab experiments will search for a different type of proposed dark matter candidate, Weakly Interacting Massive Particles (WIMPs), using complementary technologies to search over a broad range of masses. The LZ project will use liquid xenon in the SURF and will enter its fabrication phase in FY 2017. The SuperCDMS-SNOLab project will use cryogenic semi-conductor detectors in SNOLab and will be baselined and enter its final design phase in FY 2017. Planning for a large-scale Cosmic Microwave Background (CMB) experiment, which will be used to study the nature of inflation in the early universe, will continue in FY 2017, along with a suite of operating experiments and R&D efforts addressing priority science areas identified in the P5 report.

Theoretical and Computational Physics

The current high priority thrusts of the Theoretical Physics subprogram are to understand the LHC data and develop new search strategies that can be used at the LHC in the future; to develop new models of dark matter; and to suggest new experimental probes that can reveal physics beyond the Standard Model. The Computational Physics effort supports research and operations on computation, simulation, data tools, and software that cut across all HEP programs, and provides partnership opportunities with SC's Advanced Scientific Computing Research (ASCR) program as well as other agencies to develop innovative data and computational tools to address HEP computational and data challenges for the future.

Advanced Technology R&D

The General Accelerator R&D (GARD) activity supports the vibrant advanced plasma accelerator research at BELLA (Berkeley Lab Laser Accelerator) at LBNL and FACET (Facility for Advanced Accelerator Experimental Tests) at SLAC. BELLA set a new world record for laser-driven plasma wakefield accelerator technology in FY 2015, producing an energy gradient of 4.25 GeV over 9 cm. FACET is the first to accelerate positrons by multi-gigaelectronvolts (GeV) in energy with a narrow energy spread in a long plasma channel. Also, in collaboration with and using techniques developed in university research supported by GARD, FACET became the first to image the beam driven wakefield.

FACET will shut down in FY 2016 to make way for the Linac Coherent Light Source (LCLS)-II. A new and more capable facility, the FACET-II MIE project, will be in its fabrication phase in FY 2017 using the kilometer linac section between LCLS and LCLS-II, to continue the very successful electron-beam-driven plasma wakefield accelerator program. Operations of the BELLA facility continue in FY 2017.

The LHC Accelerator Research Program (LARP) develops powerful focusing magnets made from niobium-tin superconductors that have higher magnetic fields than those currently used in the LHC. Successful development of these new magnets will allow the U.S. to make a unique and critical contribution to the upgrade of the LHC to produce more particle collisions per second, which in turn will provide more data for the researchers. Funding for this effort is increased in FY 2017 to meet the schedule for delivery of prototype magnets. Following external technical reviews and recommendations in the P5 report, the Muon Accelerator Program (MAP) is being ramped down, and FY 2017 is the final year of funding for MAP. Key elements of MAP with broad applications will be redirected into GARD.

<u>Accelerator Stewardship</u>
The Brookhaven National Laboratory's (BNL) Accelerator Test Facility (ATF) was formally designated an SC User Facility in FY 2015, and its charter broadened to support the Accelerator Stewardship mission. The ATF provides a unique combination of high quality electron and infrared laser beams in a well-controlled user-friendly environment. The ATF will continue to support user operations in FY 2017.

<u>Construction</u>
Two construction projects are underway to support Intensity Frontier Physics. Mu2e completes its design phase in FY 2016 and proceeds with construction. LBNF/DUNE will continue its design phase and site preparation in FY 2016 and will commence underground excavation in FY 2017.

High Energy Physics
Funding ($K)

	FY 2015 Enacted	FY 2015 Current[a]	FY 2016 Enacted	FY 2017 Request[b]	FY 2017 vs. FY 2016
Energy Frontier Experimental Physics					
Research	78,782	84,387	77,270	76,811	-459
Facility Operations and Experimental Support	53,802	53,670	54,453	55,220	+767
Projects	15,000	7,983	19,000	18,967	-33
Total, Energy Frontier Experimental Physics	**147,584**	**146,040**	**150,723**	**150,998**	**+275**
Intensity Frontier Experimental Physics					
Research	55,181	54,122	56,104	56,509	+405
Facility Operations and Experimental Support	165,073	158,658	151,317	153,066	+1,749
Projects	43,970	46,970	35,700	24,569	-11,131
Total, Intensity Frontier Experimental Physics	**264,224**	**259,750**	**243,121**	**234,144**	**-8,977**
Cosmic Frontier Experimental Physics					
Research	49,310	48,777	49,910	49,934	+24
Facility Operations and Experimental Support	11,832	11,327	13,837	9,935	-3,902
Projects	45,728	46,403	66,835	70,200	+3,365
Total, Cosmic Frontier Experimental Physics	**106,870**	**106,507**	**130,582**	**130,069**	**-513**
Theoretical and Computational Physics					
Research					
Theory	50,224	52,323	48,465	49,620	+1,155
Computational HEP	8,050	8,525	8,618	8,036	-582
Total, Research	58,274	60,848	57,083	57,656	+573
Projects	1,000	1,000	2,000	2,000	0
Total, Theoretical and Computational Physics	**59,274**	**61,848**	**59,083**	**59,656**	**+573**

[a] Reflects the transfer of Small Business Innovation/Technology Transfer Research (SBIR/STTR) funds within the Office of Science.
[b] A transfer of $1,704,000 to Science Program Direction is to consolidate all Working Capital Funds in one program.

	FY 2015 Enacted	FY 2015 Current[a]	FY 2016 Enacted	FY 2017 Request[b]	FY 2017 vs. FY 2016
Advanced Technology R&D					
Research					
HEP General Accelerator R&D	45,452	45,903	46,722	44,510	-2,212
HEP Directed Accelerator R&D	22,570	23,000	20,640	21,500	+860
Detector R&D	21,914	19,314	16,282	17,350	+1,068
Total, Research	89,936	88,217	83,644	83,360	-284
Facility Operations and Experimental Support	30,318	35,870	29,750	26,925	-2,825
Projects	0	0	2,100	8,000	+5,900
Total, Advanced Technology R&D	**120,254**	**124,087**	**115,494**	**118,285**	**+2,791**
Accelerator Stewardship					
Research	5,900	4,891	3,378	6,853	+3,475
Facility Operations and Experimental Support	4,100	5,109	5,622	6,891	+1,269
Total, Accelerator Stewardship	**10,000**	**10,000**	**9,000**	**13,744**	**+4,744**
SBIR/STTR	**20,794**	**0**	**20,897**	**22,580**	**+1,683**
Subtotal, High Energy Physics	**729,000**	**708,232**	**728,900**	**729,476**	**+576**
Construction					
11-SC-40, Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment	12,000	12,000	26,000	45,021	+19,021
11-SC-41, Muon to Electron Conversion Experiment	25,000	25,000	40,100	43,500	+3,400
Total, Construction	**37,000**	**37,000**	**66,100**	**88,521**	**+22,421**
Total, High Energy Physics	**766,000**	**745,232**	**795,000**	**817,997**	**+22,997**

SBIR/STTR:

- FY 2015 Transferred: SBIR: $18,251,000; STTR: $2,517,000
- FY 2016 Projected: SBIR: $18,171,000; STTR: $2,726,000
- FY 2017 Request: SBIR: $19,796,000; STTR: $2,784,000

[a] Reflects the transfer of Small Business Innovation/Technology Transfer Research (SBIR/STTR) funds within the Office of Science.
[a] A transfer of $1,704,000 to Science Program Direction is to consolidate all Working Capital Funds in one program.

High Energy Physics
Explanation of Major Changes ($K)

	FY 2017 vs. FY 2016 Enacted
Energy Frontier Experimental Physics: Funding continues for the LHC detector upgrade fabrication activities that are scheduled to complete their planned funding in FY 2017. Initial investments are made to support subsequent LHC detector upgrade activities for longer-term operations at much higher luminosities, in accordance with the P5 report. Research efforts are slightly reduced in order to provide additional support for experimental support activities.	**+275**
Intensity Frontier Experimental Physics: Completion of the Muon Campus AIP and GPP items account for the bulk of the funding reduction in this area. Future project R&D for the development of a new superconducting proton linac to replace the more than 40-year-old existing linac is completed in FY 2016. In FY 2017 continuing efforts will be funded as PIP-II OPC. Optimal operations of the upgraded NuMI beamline for NOvA continue, as do refurbishment of the oldest portions of the Fermilab accelerator complex, including a modernization of the front-end linac. The Short Baseline Neutrino (SBN) program at Fermilab will perform R&D and fabrication of liquid argon TPC detectors to address the observed anomalies in previous neutrino experiments while advancing the R&D necessary for LBNF/DUNE, as recommended in the P5 report. Research efforts are increased in order to maintain support for data analysis of operating experiments and ramp up support for physics studies and R&D for next-generation experiments.	**-8,977**
Cosmic Frontier Experimental Physics: Funding increases caused by the ramp-up of the MIE projects, which increase according to their planned funding profiles, are offset by several first generation dark matter experiments that end operations funding in FY 2016. These MIE projects include the next generation dark energy projects using complementary techniques of imaging (LSSTcam) and spectroscopic (DESI) surveys and measurements and the second generation direct detection dark matter experiments (LZ and SuperCDMS-SNOLab) that use complementary technologies and search in different mass ranges. The funding for these projects is in accordance with the P5 report.	**-513**
Theoretical and Computational Physics: Overall research increases slightly, with an increase in support for theory offsetting a slight reduction in computational research.	**+573**
Advanced Technology R&D: LARP increases to complete large scale prototypes of niobium-tin superconducting quadrupole magnets needed for the upgrade of the LHC. FY 2017 is the last year of funding for the MAP as deliverables for the Muon Ionization Cooling Experiment in England are completed. FACET does not run in FY 2017 and its funding is redirected to the FACET-II MIE.	**+2,791**
Accelerator Stewardship: Funding for research is increased to support targeted R&D efforts to develop new uses of accelerator technology with broad applicability. Facilities funding is increased as the relocation of BNL ATF reaches the peak years of activity.	**+4,744**
SBIR/STTR: Funding is provided in accordance with the legislatively directed percentage of HEP operating budgets.	**+1,683**

	FY 2017 vs. FY 2016 Enacted
Construction: Funding is provided according to the planned profile for construction of Mu2e. Funding for engineering design, site preparation and underground excavation for LBNF/DUNE is requested.	**+22,421**
Total, High Energy Physics	**+22,997**

Basic and Applied R&D Coordination
HEP developed the Accelerator Stewardship subprogram based on input from accelerator R&D experts drawn from universities, national laboratories, and industry to help identify specific research areas and infrastructure gaps where HEP investments could have significant impacts beyond the SC research mission. This program is closely coordinated with the SC's Basic Energy Sciences (BES) and Nuclear Physics (NP) programs and partner agencies[a] to ensure all federal stakeholders have input in crafting funding opportunity announcements, reviewing applications, and evaluating the efficacy and impact of funded activities.

More broadly, HEP coordinates its program with other offices and agencies with related programs and missions. The U.S. LHC program is supported by the HEP and the NSF Division of Physics (NSF-PHY), and overseen by a Joint Oversight Group (JOG). Dark matter research is also jointly sponsored by these agencies, which are coordinating their activities on the next generation projects. Both HEP and NSF-PHY use HEPAP as part of their advisory structure. HEP also coordinates with NSF Division of Astronomical Sciences on the Dark Energy Survey (DES) experiment and the LSST and the DESI projects, each of which is overseen by a JOG. Both agencies as well as NASA receive advice from the Astronomy and Astrophysics Advisory Committee on areas of overlap and joint interest. HEP also coordinates with other SC programs to identify common scientific interests and to prevent duplication.

Program Accomplishments
Significant discoveries, substantial sensitivity improvements, and world-record achievements moved the frontiers of particle physics forward in FY 2015.

DOE, NSF, and CERN signed a new international cooperation agreement on May 7, 2015. This agreement was a vital component of the HEP strategic plan that called for a global vision of particle physics. The U.S. will continue to participate in the LHC program with accelerator and detector contributions for the High Luminosity LHC, and CERN will support the participation of European particle physicists in Deep Underground Neutrino Experiment through contributions to the Long Baseline Neutrino Facility being built by Fermilab. How CERN and the U.S. will work together under the international agreement has been detailed in four protocols on U.S. contributions to experiments at the LHC, U.S. contributions to the accelerator to raise its luminosity, CERN contributions to LBNF, and joint U.S.-CERN studies on new higher energy colliders that were signed on December 18, 2015. The value of the contributions being made under these protocols will be documented in addenda that are still being negotiated.

The NuMI Off-Axis ν_e Appearance (NOvA) experiment, the highest-intensity and longest-baseline neutrino oscillation experiment in the world, took its first science data in FY 2015 and has measured both muon disappearance and electron appearance neutrino oscillations (Intensity Frontier). The global scientific community recognized the importance of neutrino oscillation science with the awarding of the 2015 Nobel Prize in Physics to Takaaki Kajita and Arthur B. McDonald for the discovery of neutrino oscillations and the 2016 Breakthrough Prize in Fundamental Physics to five experiments investigating neutrino oscillations. All of the experiments recognized through these prizes received HEP support. The P5 report recommendations outline a plan to continue the highly successful pursuit of neutrino science with NOvA and the future U.S.-hosted international Deep Underground Neutrino Experiment (DUNE). The NOvA detector was completed in November 2014 and currently receives the highest intensity neutrino beam in the world, generated 500 miles away at Fermilab. Initial physics results from early data were announced in the summer of 2015. NOvA will run for another six years, increasing its statistics to improve the precision of oscillation measurements, study the neutrino mass hierarchy, and search for the source of matter-antimatter asymmetry in the universe.

Dedicated astronomical surveys usher in an era of precision measurement in cosmology (Cosmic Frontier). The Baryon Oscillation Spectroscopic Survey (BOSS) measured the scale of the universe at a time 5 billion years ago to a precision of 1% and the rate of cosmic structure growth to 10%, using the full data set from its successful five year survey of 1.5 million galaxies and quasars. David J. Schlegel (Lawrence Berkeley National Laboratory), principal investigator for BOSS, was awarded the 2014 Ernest Orlando Lawrence Award exceptional leadership of major projects making the largest two-dimensional and three-dimensional maps of the universe. The Dark Energy Survey (DES) completed its second year of a five-year survey using precision imaging observations, providing complementary measurements to BOSS data. In FY 2015, DES released the largest map to date of the dark matter distribution in the universe, measured by gravitational lensing. DES also discovered 17 new dwarf galaxies, satellites of our Milky

[a] Partner agencies for the Accelerator Stewardship program's initial two years are: the National Institutes of Health's National Cancer Institute, the Department of Defense's Office of Naval Research and Air Force Office of Scientific Research, and the NSF's Physics Division and Chemical, Bioengineering, Environmental, and Transport Systems Division.

Way galaxy, that provide excellent laboratories to explore the physics of dark matter. Jointly with the Fermi Gamma-ray Space Telescope (FGST), the DES dwarf galaxy measurements were used to place tight limits on dark matter properties.

An experiment at the Facility for Advanced Accelerator Experimental Tests (FACET) demonstrated the acceleration of positrons, the antiparticle of the electron, in a beam-driven plasma wakefield accelerator for the first time (Advanced Technology R&D). Plasma wakefield particle acceleration is an advanced technology that could boost the energy and shrink the size of future linear particle accelerators and have broad impact within the DOE Office of Science. Electron plasma wakefield acceleration has been previously demonstrated at FACET using two beam pulses, a drive pulse of electrons that generate a plasma wake and a trailing pulse that is accelerated by “surfing” on the plasma wake. FACET has the unique capability to use positrons in a plasma wakefield accelerator and has successfully demonstrated a new technique for accelerating them. Within a single pulse of positrons, the front of the positron bunch generated a plasma wake that accelerated the trailing positrons. The acceleration of positrons in addition to electrons is needed to implement this technology in a future Energy Frontier collider.

High Energy Physics
Energy Frontier Experimental Physics

Description

The Energy Frontier Experimental Physics subprogram supports research at the LHC with the goal of determining to what extent the Standard Model correctly describes the natural world. Exploring new physics at the highest energies and new dynamics of already discovered elementary particles are now the foundation for much of the LHC research program.

Research activities at the Energy Frontier in FY 2017 will be focused on the LHC, which resumed operations in FY 2015 after a planned shutdown that began in FY 2013 to bring the collider to its full design energy of at least 13 TeV. Data collected during this period will be used to address at least three of the five primary science drivers identified by the P5 report:

- *Use the Higgs boson as a new tool for discovery*
  In the Standard Model of particle physics, the Higgs boson is responsible for generating the mass for all fundamental particles. In July 2012, CERN announced the discovery of a new particle consistent, within the limited statistical accuracy, with being the Standard Model Higgs boson. Since the discovery, experiments at the LHC have continued to actively measure the particle's properties and results thus far have strongly indicated consistency of the Higgs boson with the Standard Model picture. However, more data are required to precisely measure its properties. Through such studies, scientists will be able to establish the particle's exact character and 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 hope to find evidence of what lies beyond the Standard Model or significantly constrain postulated modifications to it, such as supersymmetry, mechanisms for black hole production, extra dimensions, and other exotic phenomena. As the second run continues in FY 2017, the LHC detectors will be increasingly more sensitive to potential deviations from the Standard Model that may be exposed by the increase in collision energy from 8 TeV to at least 13 TeV.
- *Identify the new physics of dark matter.*
  If dark matter particles are light enough, they can be produced in LHC collisions and their general properties measured by inference (since they interact only weakly with normal matter). This "indirect" detection of dark matter is complementary to, and a powerful cross-check on, the ultra-sensitive "direct" detection experiments on the Cosmic Frontier where one tries to observe the very faint signal of ambient cosmic dark matter particles colliding with nuclei. Limits on dark matter production set by the LHC experiments already significantly constrain many theoretical models.

The LHC hosts two large multi-purpose particle detectors, CMS and ATLAS, which are partially supported by DOE and the NSF and used by large international collaborations of scientists. U.S. researchers make up approximately 20% of the ATLAS collaboration and approximately 30% of the CMS collaboration and play critical leadership roles in all aspects of each experiment.

The Energy Frontier Experimental Physics subprogram also supports the LHC detector operations program, which covers the maintenance of U.S. supplied detector systems for the ATLAS and CMS detectors at the LHC and the U.S. based computer infrastructure for the analysis of LHC data by U.S. physicists.

Research

University-based Energy Frontier research is carried out by groups at over 65 institutions performing experiments at the LHC. Grant-supported scientists typically constitute about 50–75% of the personnel needed to create, run, and analyze an experiment, usually working in collaboration with other university and laboratory groups. Grant-based research efforts are selected based on external competitive peer review, and funding allocations take into account the quality and scientific priority of the research proposed. Energy Frontier research also supports physicists from five national laboratories. These are typically large groups that also have significant responsibilities for detector operations, maintenance, and upgrades, particularly at the laboratories that host large computing and analysis-support centers as well as maintain unique instrumentation facilities. HEP conducted an external peer review of laboratory research groups in this activity in 2015, and findings from this review are being used to inform the funding decisions in subsequent years. HEP plans to review this activity again in 2018 and evaluate progress.

Facility Operations and Experimental Support

U.S. LHC Detector Operations funding supports the maintenance of U.S. supplied detector systems for the CMS and ATLAS detectors at the LHC and for the U.S.-based computer infrastructure used by U.S. physicists to analyze LHC data, including Tier 1 computing centers at Fermilab and at BNL. There are 13 LHC Tier 1 computing centers around the world. The Tier 1 centers provide round-the-clock support for the LHC Computing Grid and are responsible for storing a proportional share of raw and reconstructed data, as well as performing large-scale data reprocessing and storing the corresponding output. This program also supports investments in R&D activities aimed at improvements to the LHC detectors so they can operate in the long-term at higher luminosities.

Projects

CERN is upgrading the LHC machine to produce two to three times the particle collision rate (instantaneous luminosity) currently delivered. This work motivates upgrades to the ATLAS and CMS detectors in order to enable each experiment to fully exploit the physics opportunities offered by the LHC for exploration of new physics and to make precision measurements of properties of known phenomena. Project activities will therefore continue to support the fabrication of major items of equipment (MIE) for these two detector upgrades within the Energy Frontier subprogram. Upgrade fabrication efforts are planned to start ramping down in 2017 in preparation for installation of U.S.-delivered detector systems in their respective experimental collision halls during a planned shutdown in 2019-2020.

The ATLAS Detector Upgrade Project was baselined (CD-2) and approved for a fabrication start (CD-3) in FY 2015. Upgrades are needed to the Muon Subsystem, the Liquid Argon Calorimeter Detector, and Trigger and Data Acquisition System to take advantage of the increased luminosity. The last production readiness reviews will be completed in early FY 2017 and full production will continue in FY 2018.

The CMS Detector Upgrade Project was baselined (CD-2) and approved for a fabrication start (CD-3) in FY 2015. Upgrades are needed to the Pixelated Inner Tracking Detector, the Hadron Calorimeter Detector, and Trigger System to take advantage of the increased luminosity. The U.S. contributions to forward pixel detector subsystem and the trigger subsystem are planned to be completed in FY 2017.

During the period that spans the next two decades, CERN plans a major upgrade to the LHC machine to further increase the instantaneous luminosity by a factor of ten times its design value to explore new physics beyond the reach of the current LHC program, which will provide physicists insights to elementary particles and their interactions at unprecedented levels. Activities for the High Luminosity (HL)-LHC ATLAS and CMS Detector Upgrade projects are planned to begin in 2016 and are due to be completed by 2024. Based on recommendations in the P5 report, Mission Need Statements for these upgrades are expected to be approved in early 2016.

Energy Frontier Experimental Physics

Activities and Explanation of Changes

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs. FY 2016
Energy Frontier Experimental Physics $150,723,000	**$150,998,000**	**+$275,000**
Research $77,270,000	**$76,811,000**	**-$459,000**
U.S. university and laboratory scientists begin analyzing the newly acquired data from LHC's second run that began in early-2015. Research activities focus on addressing key areas within the five science drivers outlined in the P5 report, which include using the Higgs boson as a new tool for discovery and exploring new particles and their interactions.	U.S. university and laboratory scientists will focus on continuing research activities during LHC's second run at collision energies of at least 13 TeV, pursuing new physics such as supersymmetry, dark matter candidates and evidence of extra space-time dimensions, and conducting high-profile studies such as precision measurements of the Higgs boson. U.S scientists will work on the preliminary design for the HL-LHC detector upgrades.	SC will reduce funding for the Energy Frontier research due to overall programmatic reductions in research activities to support current and future experimental capabilities. Some research staff previously supported under Research will be redirected to complete the fabrication of U.S. supplied detector systems for the LHC Detector Upgrade projects and to begin leading the HL-LHC ATLAS and CMS Detector Upgrade projects.
Facility Operations and Experimental Support $54,453,000	**$55,220,000**	**+$767,000**
Funding supports the operation of the LHC ATLAS and CMS detectors during LHC's second run. Major activities include continuing the routine maintenance and calibration of the detectors as well as the processing of newly acquired data. Initial investments support critical R&D activities for longer-term operations of the LHC detectors at higher luminosities.	The Request will continue to support maintenance and operational activities of the LHC ATLAS and CMS detectors during LHC's second run. Critical R&D activities will be completed in order to begin prototyping LHC detector systems for planned upgrades of the detectors at higher luminosities.	Increased funding supports ATLAS and CMS detector maintenance and operations during the LHC's second run and the critical R&D activities that will support prototyping for the HL-LHC detector upgrades.
Projects $19,000,000	**$18,967,000**	**-$33,000**
The LHC ATLAS and CMS Detector Upgrade projects were baselined in FY 2015 and fabrication activities continue into FY 2016.	Fabrication activities for the LHC ATLAS Detector Upgrade and the LHC CMS Detector Upgrade projects will be completed in FY 2017. The Request provides OPC funding for the HL-LHC ATLAS and CMS Detector Upgrades in order to take advantage of the increased LHC luminosity during the next decade. Mission Need (CD-0) for these upgrades is planned for early 2016.	The reduction in funding aligns with the approved profiles for the LHC ATLAS Detector Upgrade and the LHC CMS Detector Upgrade projects. Initial OPC funding for the HL-LHC ATLAS and CMS Detector Upgrades is provided.

High Energy Physics
Intensity Frontier Experimental Physics

Description

The Intensity Frontier Experimental Physics subprogram investigates some of the rarest processes in nature including unusual interactions of fundamental particles or subtle effects requiring large data sets to observe and measure. This subprogram in particular shares some deep intellectual connections with NP. Generally, this HEP subprogram focuses on using high-power particle beams or other intense particle sources to make precision measurements of fundamental particle properties. These measurements in turn probe for new phenomena that cannot be directly observed at the Energy Frontier, either because they occur at much higher energies and their effects can only be seen indirectly or because they are due to interactions that are too weak to be detected in a high-background environment such as the LHC.

Activities at the Intensity Frontier will be focused primarily on operating new and existing facilities while continuing investments that maintain a world-leading program into the future and establish the scientific foundation for the future U.S.-hosted international LBNF/DUNE. These facilities and investments are concentrated primarily in the areas of neutrino and muon physics and primarily based at Fermilab. The Fermilab SBN program, established in response to the P5 report, will continue to advance neutrino physics while serving as an international platform for many of the research and development activities necessary to establish LBNF/DUNE. The MicroBooNE experiment will continue taking data as research and development activities continue for its SBN partners, SBND and ICARUS, that are scheduled to begin data taking in FY 2018.

The NOvA neutrino detector was completed in FY 2014 and will be in its third year of operations. NOvA is currently the world's longest-baseline neutrino experiment and studies neutrinos from the world's most powerful neutrino beam, the upgraded NuMI beam at Fermilab. NOvA may switch to antineutrino mode in FY 2017 based on physics results from its first two years of operation.

Operation of the Daya Bay Reactor Neutrino Experiment (Daya Bay) in China will conclude in FY 2017. Physics analyses on the very large Daya Bay experimental dataset will continue through 2021 with a focus on extracting high-precision measurements on neutrino parameters and searching for new physics. Fabrication funding for the Fermilab Muon g-2 Experiment concludes in FY 2017. Physics commissioning of the Muon g-2 detector continues, and first data taking for the Muon g-2 Experiment will begin in FY 2017. Mu2e will continue its construction phase.

Data collected from the supported Intensity Frontier experiments during this period will be used to address at least three of the five key science drivers identified by the P5 report:

- *Pursue the physics associated with neutrino mass.*
  Of all known particles, neutrinos are perhaps the most enigmatic and certainly the most elusive. The three known varieties of neutrinos were all discovered by HEP researchers working at U.S. facilities. 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.
- *Identify the new physics of dark matter.*
  The lack of experimental evidence from current generation dark matter detectors has led some to propose theoretical models with new "dark" particles and forces which have ultra-weak couplings to normal matter. These particles and forces are effectively invisible to conventional experiments, but could be connected to the cosmic dark matter. Using intense accelerator beams at U.S. national laboratories outfitted with highly capable high-rate detectors allows for probes of these models via subtle quantum mechanical mixing effects. These experiments complement the searches for dark matter performed in Cosmic Frontier and Energy Frontier experiments.
- *Explore the unknown, new particles, interactions, and physical principles.*
  Prominent in this category are experiments addressing the poorly understood large scale absence of antimatter in the universe and the puzzling three generation family structure of the fundamental constituents of matter.

<u>Research</u>

The HEP experimental research activity at the Intensity Frontier consists of groups at over 50 academic institutions and physicists from eight national laboratories, performing experiments at a variety of locations. These groups, as part of scientific collaborations, typically have a broad portfolio of significant responsibilities and leadership roles including R&D, experimental design, fabrication, commissioning, operations, and maintenance, as well as scientific simulations, computing, and data analysis on the experiments in the subprogram. Research efforts are selected based on a competitive peer-review process in order to maintain activities with the highest scientific merit and potential impact. HEP conducted an external peer review of all laboratory research groups in this subprogram in 2013 and the next review will be in 2017. These findings will be used to inform the funding decisions in subsequent years.

Facility Operations and Experimental Support

There are several distinct facility operations and experimental support efforts in the Intensity Frontier subprogram. The largest is the Fermilab Accelerator Complex User Facility. The operation of the accelerator, detectors, and computing are included in this activity. Improvements to the facility are supported via General Plant Project (GPP) and Accelerator Improvement Project (AIP) funding. Refurbishment of the oldest parts of the complex including the Linac and the BNB continues in FY 2017 in order to maintain the reliability and efficiency of the complex. The major experimental efforts will be the NOvA and MicroBooNE experiments using the NuMI and BNB. In addition, the Muon g-2 experiment will begin physics data taking in 2017. Operations support for the LUX and Majorana demonstrator experiments at the Homestake Mine is also provided under this activity.

Projects

This activity supports the fabrication of major items of equipment for the Intensity Frontier subprogram. It also covers preconceptual R&D and design for proposed new Intensity Frontier efforts and the other project costs (OPC) of line item construction for the Intensity Frontier. This effort also includes subsystems integration and infrastructure needed for the SBN program, such as cryogenics, electronics and data acquisition.

The Muon g-2 project is an MIE to provide equipment needed to adapt an existing muon storage ring from BNL to utilize the higher intensity proton beam at Fermilab. In FY 2015, the project completed critical tests of the storage ring's superconducting, and in FY 2016 and FY 2017, it will fabricate new detectors, a muon production target, and a muon beam transport.
The FY 2017 Request funds the engineering design, site preparation, and long-lead construction activities for LBNF/DUNE. It also provides funding for Future Project R&D funding for the short baseline neutrino experiments. These experiments are much smaller than NOvA and LBNF/DUNE and address other issues in neutrino physics, such as the possibility of a new type of neutrino that does interact with charged particles. For more complete information on the LBNF/DUNE project, please see the Construction section.

Future Project R&D funding is ending and funding for Other Project Costs is provided for the PIP-II upgrade to the front-end of the Fermilab Accelerator complex. The front-end is the oldest part of the complex and needs to be replaced to improve reliability and to produce higher intensity muon and neutrino beams. The P5 report recommended an increase in power for the Fermilab accelerator complex so that it could provide a 1.2 megawatt beam to LBNF/DUNE, which is higher than the 0.7 megawatt beam planned for NOvA. Critical Decision 0 was approved on October 20, 2015, which identified and defined the mission need to increase the beam power needed for neutrino and muon experiments and maintain the efficiency of the Fermilab accelerator complex. Fermilab has supported R&D on this concept for several years with some of the R&D activities in partnership with institutions in India. An international agreement between DOE and the Department of Atomic Energy of India will provide contributions from India worth approximately $60,000,000 towards the development of this project. Additional funds will become available after successful completion of the design phase.

Intensity Frontier Experimental Physics

Activities and Explanation of Changes

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs. FY 2016
Intensity Frontier Experimental Physics $243,121,000	**$234,144,000**	**-$8,977,000**
Research $56,104,000	**$56,509,000**	**+$405,000**
Physics analyses leading to first published results from the NOvA and MicroBooNE experiments occur. The Main Injector Neutrino Oscillation Search (MINOS+) experiment at Fermilab concludes in FY 2016; physics analyses on the very large MINOS+ experimental dataset will continue through 2020 with a focus on extracting precision measurements on neutrino parameters and searching for sterile neutrinos. LBNF/DUNE physics studies and optimization continue under the umbrella of a new, fully internationalized program. New research and development activities for the Fermilab SBN program are underway, following the P5 report. Other proposed small-scale efforts may be supported depending on the outcomes of peer review. Physics studies to optimize the operation of the under construction Mu2e experiment continue. Muon g-2 physics commissioning efforts ramp up in preparation for first data in FY 2017. Commissioning of the Belle II detector at KEK begins.	The neutrino program will see new and more precise results from the NOvA experiment. These results will inform possible switch from a neutrino beam to an antineutrino beam in FY 2017. The Fermilab SBN program will continue to advance as MicroBooNE produces new physics results. ICARUS, a 600 ton liquid argon detector, will arrive from Italy, after refurbishment at CERN in FY 2017. It will enhance the SBN program by being larger and at a greater distance from the neutrino source than MicroBooNE. These two experiments will take data together to study anomalies in the neutrino sector. Operations support for Daya Bay will ramp down to its planned completion. The Fermilab Muon g-2 experiment will begin physics data taking. R&D, physics studies and optimization will continue for Mu2e and LBNF/DUNE. Other proposed small-scale efforts may be supported depending on the outcomes of peer review. Physics commissioning of the Belle II detector is completed and will be followed by initial data taking.	Funding for the Intensity Frontier research increases to support current and future experimental capabilities. Some research staff previously supported under Research will be redirected to lead the internationalization of LBNF/DUNE or towards development of the Fermilab SBN program.

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs. FY 2016
Facility Operations and Experimental Support **$151,317,000**	**$153,066,000**	**+$1,749,000**
The Fermilab Accelerator complex ($129,282,000) continues to operate to support neutrino physics. FY 2016 is an important funding year for two AIPs that provide enhancements for the future operations program: the delivery ring AIP, which modifies the antiproton accumulator to store protons for the muon program, and the Recycler RF AIP, which upgrade the RF power in the recycler to handle high intensity proton beams for both the muon program and the short baseline neutrino program at Fermilab. Funding for the SBN Far Hall GPP is completed. Operational Support at Homestake Mine ($15,300,000) continues as LUX completes its data-taking and the Majorana demonstrator continues.	The Fermilab Accelerator complex ($130,781,000) will continue to operate to support neutrino physics. FY 2017 is the last year for AIP funding for the Muon Campus (MC). The refurbishment of the Linac and BNB continues in FY 2017. Construction of an addition to the Industrial Center Building is planned as GPP in FY 2017. This addition will provide high bay space needed for the assembly of large equipment like superconducting magnets, SRF cryomodules, and detectors. Operational support at Homestake Mine ($15,000,000) is for the Majorana demonstrator activities and preparations begin supporting the LZ experiment and LBNF/DUNE construction.	Increased funding supports refurbishments to the Fermilab Accelerator Complex to support the Intensity Frontier program.
Projects $35,700,000	**$24,569,000**	**-$11,131,000**
Funding for the Muon g-2 MIE project ($10,200,000) will continue accelerator modifications and fabrication of the beamline and detectors. A combination of Other Project Cost funding ($18,015,000) and preconceptual R&D funding supports the development of PIP-II, a new superconducting proton linac to replace the more than 40-year-old existing front-end linac at Fermilab. The goal of this development is to significantly increase the beam power of the entire complex and improve its reliability. This improvement to make the Fermilab neutrino and muon programs sustainable through the next decade was recommended in the P5 report. Funding for the SBN program supports subsystems integration and infrastructure needed for the program.	Funding for the Muon g-2 MIE project ($6,349,000) will continue accelerator modifications and fabrication of the beamline and detectors. Funding ($15,220,000) supports the Other Project Costs for the PIP-II project including the conceptual design for a new superconducting proton linac to replace the more than 40 year-old existing linac. The goal of this development is to increase the beam power of the entire complex and improve its reliability. This improvement to make the Fermilab neutrino and muon programs sustainable through the next decade was recommended in the P5 report. Funding for SBN program supports subsystems integration and infrastructure needed for the program.	The reduction in funding is dominated by the ramp down of funding for Muon g-2 and the end of funding for preconceptual R&D for Fermilab linac upgrade.

High Energy Physics
Cosmic Frontier Experimental Physics

Description

The Cosmic Frontier Experimental Physics subprogram supports the study of high energy physics through measurements of naturally occurring cosmic particles and observations of the universe. The activities in this subprogram use diverse tools and technologies, from ground-based telescopes and space-based experiments to large detectors deep underground, to probe fundamental physics questions and offer new insight about the nature of dark matter, dark energy, inflation in the early universe and other phenomena. In FY 2017, a varied suite of complementary, staged experiments are planned that will lead to measurements with greater precision as the operations and analysis of current experiments continues, while the next generation of experiments are being planned and built. The program includes investments in projects for the future in accordance with the P5 report.

Experiments in this subprogram can be classified into four main categories: direct-detection searches for dark matter; studies of the nature of dark energy; measurements of the cosmic microwave background (CMB) to study the inflationary epoch in the early universe and provide constraints on neutrino masses; and measurements of high-energy cosmic and gamma rays. Data collected will be used to address at least three of the five key science drivers identified in the P5 report:

- *Understand cosmic acceleration: dark energy and inflation*
  Since the Nobel Prize in Physics in 2011 was awarded for the discovery of the acceleration of the expansion of the universe, steady progress has been made in studying the nature of dark energy. BOSS has measured galactic distances to a precision of 1% and growth rates through galaxy clustering. DES has produced the largest area maps of dark matter, whose evolution reveals the behavior of dark energy. DES operations are ongoing and the final release of DES maps will cover 30 times the current sky area. Inflation, a period of rapid expansion in the universe at extremely high energy shortly after the Big Bang, is the target of the increasing sensitivity of operating and planned CMB experiments seeking direct detection of its quantum fluctuations in spacetime.
- *Identify the new physics of dark matter*
  Measurements of motions within galaxies, the cosmic web of structure, weighing the universe as a whole, and the primordial abundance of elements all show that dark matter, which is not explained by the Standard Model, accounts for five times as much of the universe as ordinary matter. Direct-detection experiments in the laboratory provide the primary method to search for cosmic dark matter particles' rare interactions with atomic nuclei, while indirect-detection observatories search for the products of dark matter annihilation in the core of galaxies. The first generation of direct detection experiments have significantly tightened the limits on dark matter properties, and the second generation will soon be operational, aiming to measure the signature of dark matter interaction. These experiments are complemented by the searches for dark matter performed in Intensity Frontier and Energy Frontier experiments.
- *Explore the unknown: new particles, interactions, and physical principles*
  High-energy cosmic and gamma rays can probe energy scales well beyond what can be produced with man-made particle accelerators, albeit not in a controlled experimental environment. These experiments allow searches for indirect signals of dark matter, and the presence of primordial antimatter. Searches for new phenomena in high-energy cosmic surveys may yield surprising discoveries about the fundamental nature of the universe.

<u>Research</u>

The Cosmic Frontier experimental research program consists of groups at over 45 academic and research institutions and 8 national laboratories performing experiments at a wide variety of locations. These groups, as part of scientific collaborations, typically have a broad portfolio of significant responsibilities and leadership roles including R&D, experimental design, fabrication, commissioning, operations, and maintenance, as well as scientific simulations, computing, and data analysis on the experiments in the subprogram. Research efforts are selected based on a competitive peer-review process in order to maintain activities with the highest scientific merit and potential impact. A competitive review is conducted annually for new or renewal grant proposals. HEP conducted an external peer review of all laboratory research groups in this subprogram in 2013 and the next review will be in 2016. The findings from these reviews are used to inform the funding decisions in subsequent years. Research efforts are supported for operating or recently completed experiments. Research activities are continuing on dark energy experiments using imaging and spectroscopic surveys, including the Dark Energy Survey (DES) and the extended Baryon Oscillation Spectroscopic Survey (eBOSS) experiments, and the space-based Alpha Magnetic Spectrometer II (AMS-II) and the Fermi Gamma-ray Space Telescope (FGST). It also includes operations of the South Pole Telescope Generation 3 (SPT-3G) CMB experiment, the High Altitude Water Cherenkov (HAWC) gamma ray experiment, and the ADMX-G2 dark matter search experiment. HEP-funded final data analyses will be completed on the suite of first generation dark matter direct detection (DM-G1) experiments, the Pierre Auger cosmic-ray observatory, and on the VERITAS gamma ray observatory.

Research activities continue to support design, fabrication, and science planning for next generation dark energy, direct-detection dark matter, and CMB experiments, including LSST, DESI, LZ, and SuperCDMS-SNOLab. Support for R&D and science planning of possible future experiments in the program, such as the large-scale CMB experiment, is also included.

Facility Operations and Experimental Support

This activity supports the DOE share of personnel, data processing, and other expenses necessary for the successful maintenance, operations, and data production of Cosmic Frontier experiments. These experiments are typically not sited at DOE facilities. They are located at telescopes, in space, or underground. Many experiments have large multi-national collaborations and DOE's fraction of the support cost is based on the magnitude of U.S. roles and responsibilities. In addition, there are DOE-only experiments and partnerships with NSF and NASA. Support is provided for the experiments currently operating as listed above as well as early operations planning for the next generation experiments currently in the design or fabrication phase. HEP conducted a scientific peer review of Cosmic Frontier operations in early FY 2015 and findings from this review are being used to monitor the experiments, and inform decisions concerning the level of operations support needed and whether to continue specific activities in subsequent years. DOE support for operations of Auger, VERITAS, and the first generation dark matter direct detection experiments is planned to be completed in FY 2016 and final data analyses will continue in FY 2017.

Projects

This activity supports design and fabrication of Cosmic Frontier projects, including major items of equipment (MIEs) as well as development of small experiments and R&D for future experiments. The FY 2017 Budget Request supports the continued MIE fabrication efforts on the three billion pixel precision camera for the Large Synoptic Survey Telescope (LSSTcam) project, which is the DOE contribution to the NSF-led LSST Project, and design and fabrication efforts on the Dark Energy Spectroscopic Instrument (DESI), which is being done in coordination with NSF. These dark energy projects will provide complementary techniques using imaging (LSST) and spectroscopic (DESI) measurements to study the nature of dark energy. The FY 2017 Budget Request also supports the DM-G2 MIE projects selected in FY 2014: LZ, which is in its fabrication phase, and SuperCDMS-SNOLab, which is in its final design phase in FY 2017. These will provide second generation searches for dark matter using complementary techniques to search for WIMPs in different mass ranges. Support for fabrication of the small-scale ADMX-G2 dark matter experiment and the SPT-3G CMB experiment ends in FY 2016 and will move to their operations phase in FY 2017.

Cosmic Frontier Experimental Physics

Activities and Explanation of Changes

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs. FY 2016
Cosmic Frontier Experimental Physics $130,582,000	**$130,069,000**	**-$513,000**
Research $49,910,000	**$49,934,000**	**+$24,000**
Research efforts support the currently operating or recently-completed suite of cosmic-ray and high-energy gamma-ray telescope experiments, the suite of DM-G1 experiments, and dark energy experiments including DES, and eBOSS. Research activities continue to support design, fabrication and science planning for the next generation of dark energy, dark matter and CMB experiments, as well as R&D and science planning of possible future experiments.	The FY 2017 Budget Request supports research efforts for data analyses on the currently operating or recently completed experiments, as described above. Research activities will continue to support design, fabrication and science planning for the next generation of dark energy, dark matter and CMB experiments, as well as R&D and science planning of possible future projects and experiments.	Research efforts continue at a slightly increased level to support the planning for calibration, simulation, science planning, and operation of new projects and data analyses for operating or recently completed experiments.
Facility Operations and Experimental Support $13,837,000	**$9,935,000**	**-$3,902,000**
Operations support continues for experiments that are in the data-taking phase, including the AMS-II cosmic-ray experiment, the FGST and HAWC gamma-ray experiments, and for imaging and spectroscopic dark energy experiments including DES and eBOSS. Final data processing efforts continue while analyses are completed on experiments that have finished their science mission, including DM-G1 experiments, the VERITAS gamma-ray experiment and the Pierre Auger cosmic ray experiment.	Operations support will continue for experiments that are in the data-taking phase, including AMS-II, HAWC, FGST, DES, and eBOSS. SPT-3G and ADMX-G2 start operations in FY 2017. Funding will support the experiments currently operating as listed above as well as early planning for the next generation experiments currently in the fabrication phase.	Support for the operation of several first generation dark matter experiments ends in FY 2016. Other Facilities activities decrease for Working Capital Fund to SC Program Direction, which are offset by increased funding to support transitions to early operations planning activities for future experiments, particularly LSST.

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs. FY 2016
Projects $66,835,000	**$70,200,000**	**+$3,365,000**
Funding is provided for LSSTcam according to its approved baseline funding profile. The DESI and LZ MIEs to study dark energy and dark matter, respectively, are expected to be baselined in FY 2016. The SuperCDMS-SNOLab MIE, to complement LZ in the study of dark matter, will support design work towards project baseline. Small projects below MIE thresholds are also included.	Fabrication activities will continue on the dark energy MIE projects, including a ramp up on LSSTcam and the DESI funding profile as planned. These projects will provide complementary next-generation techniques for studying dark energy. SuperCDMS-SNOLab is expected to be baselined in FY 2017 and will enter its final design phase. LZ will continue fabrication. The program will also support a small effort on R&D and development efforts for future experiments.	The increase will support final design for the SuperCDMS-SNOLab MIE and fabrication for the MIE projects, LSSTcam, DESI, and LZ, according to their planned profiles. Fabrication activities on the small projects ADMX-G2 and SPT-3G were completed in FY 2016. The increase will also support a small effort on R&D and development efforts for future experiments.

High Energy Physics
Theoretical and Computational Physics

Description

The Theoretical and Computational Physics subprogram provides the mathematical, phenomenological, and computational framework to understand and extend our knowledge of the dynamics of particles and forces, 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.

Major research thrusts focus on the central science drivers for HEP as identified by the P5 report, intertwining the physics of the Higgs boson, neutrino mass, and the dark universe along with exploring the unknown. Theory and computation cross-cut the science drivers and the energy, intensity, and cosmic experimental frontiers.

This subprogram supports theoretical research ranging from detailed calculations of the predictions of the Standard Model to the formulation and exploration of possible theories of new phenomena such as dark matter and dark energy and the identification of experimental signatures that would validate these new ideas. This subprogram also supports computational approaches to advance understanding of fundamental physical laws describing the elementary constituents of matter and energy, including computational science and simulations for scientific discovery and computing and software tools to enable and advance experimental and theoretical research at the three High Energy Physics frontiers.

Theory

The HEP theory research activity supports groups at over 70 academic and research institutions supported by research grants and seven national laboratory research groups. Both university and laboratory research groups play important roles in addressing the leading research areas discussed above, with laboratory groups typically more focused on data-driven theoretical investigations and model-building and university groups additionally focusing on formal or mathematical theory. Research efforts are selected based on competitive peer review to maintain the activities with the highest scientific impact and potential. Laboratory research groups are generally reviewed every three to four years. The most recent review in this subprogram was held in 2014, and findings from this review are being used to inform the funding decisions in subsequent years.

Computational HEP

Computation is necessary at all stages of HEP experiments—from planning and constructing accelerators and detectors, to theoretical modeling, to supporting computationally intensive experimental research and large-scale data analysis. In addition, scientific simulation and advanced computing help extend the boundaries of scientific discovery to regions not directly accessible by experiments, observations, or traditional theory. Computational HEP partners with the ASCR program on projects that focus on HEP topics that benefit most strongly from advanced computational techniques, such as Scientific Discovery through Advanced Computing (SciDAC) and the National Strategic Computing Initiative (NSCI). Computational HEP also supports directed efforts to develop and maintain operations and R&D for some HEP specific computational tools and supports forward-looking HEP computational research to address the challenges of evolving computer architectures and massive increases in scientific data.

Projects

The Projects activity currently funds acquisition and operation of dedicated hardware for the Lattice Quantum Chromodynamics (LQCD) computing effort. Since lattice techniques can address both nuclear and high energy physics topics, this program is managed in partnership with NP in order to avoid any duplication of effort. The LQCD Project provides dedicated computer hardware for the simulation of the strong interaction of gluons and quarks in bound states. Within the HEP program, its goals are most directly applicable to the Intensity and Energy Frontiers, and the results generated by its users are critical for the interpretation of data from the HEP experimental program in these Frontiers. Based on strong peer reviews and following recommendations in the P5 report, the LQCD project was extended in FY 2015 for a five-year period.

Theoretical and Computational Physics

Activities and Explanation of Changes

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs. FY 2016
Theoretical and Computational Physics $59,083,000	**$59,656,000**	**+$573,000**
Theory $48,465,000	**$49,620,000**	**+$1,155,000**
This activity funds research for university and laboratory groups as well as the Particle Data Group. Research proposals in the general topic areas described above are selected based on peer review by technical experts.	This activity will fund research for university and laboratory groups as well as the Particle Data Group. Research proposals in the general topic areas described above are selected based on peer review by technical experts.	Slight increase to maintain a thriving theory program as recommended in the P5 report.
Computational HEP $8,618,000	**$8,036,000**	**-$582,000**
This activity supports the research, development, and operation of computational tools that enable scientific advances in the HEP program. SciDAC projects selected in FY 2015 will continue in FY 2016. Other ongoing projects continue at approximately the same funding level.	This activity supports the research, development, and operation of computational tools that enable scientific advances in the HEP program. SciDAC will be re-competed in FY 2017 in partnership with ASCR.	HEP is expanding its cooperation with ASCR on multiple computational projects and will rely less on the SciDAC program. This results in a lower level of funding for SciDAC within a slightly reduced overall budget.
Projects $2,000,000	**$2,000,000**	**$0**
FY 2016 funding plan includes acquisition of new hardware as well as continued operations of the LQCD.	FY 2017 funding plan includes acquisition of new hardware as well as continued operations.	Funding is provided according to the planned profile.

High Energy Physics
Advanced Technology R&D

Description

The Advanced Technology Research and Development (R&D) subprogram fosters cutting-edge research in the physics of particle beams, accelerator R&D, and particle detection—all of which are necessary for continued progress in high energy physics. New developments are stimulated and supported through peer reviewed research. This subprogram supports and advances research at all three experimental Frontiers.

Advanced Technology R&D includes particle accelerator, detector, and beam physics areas. Long-term multi-purpose accelerator research, applicable to fields beyond HEP, is carried out under the Accelerator Stewardship subprogram.

HEP General Accelerator R&D

HEP General Accelerator R&D (GARD) focuses on understanding the science underlying the technologies used in particle accelerators and storage rings, as well as the fundamental physics of charged particle beams. Long-term research goals include developing technologies to enable breakthroughs in particle accelerator size, cost, beam intensity, and control.

Research activity is categorized into five thrust areas: accelerator and beam physics; advanced acceleration concepts; particle sources and targetry; radiofrequency acceleration technology; and superconducting magnet and materials. GARD supports research at seven DOE national laboratories and about 30 academic or other research institutions. Research topics are prioritized based on input from recent HEPAP subpanels and funding is awarded based on external competitive peer reviews. The program also trains new accelerator physicists with approximately 50 graduate students supported per year through research grants. Graduate level training for students and laboratory staff in areas of accelerator physics and technology is supported in this program.

In the past six years, two accelerator R&D test facilities (BELLA at LBNL and FACET at SLAC) have been built and operated under this subprogram to support research using plasmas to accelerate charged particles much more effectively than conventional electromagnetic cavities. These techniques hold the promise of reducing the size of particle accelerators by approximately 90%, making them considerably less expensive to build. The energy to drive the plasma can come either from lasers (as in BELLA) or electron beams (as in FACET). Both techniques have successfully accelerated beams while maintaining good beam quality.

FACET will complete operations in FY 2016 to make way for LCLS-II. A new and more capable facility, FACET-II, will be in its fabrication phase in FY 2017 using the kilometer linac section between LCLS and LCLS-II. FACET-II will continue the very successful electron beam driven plasma accelerator program. Operations of the BELLA facility will continue in FY 2017.

In FY 2017, GARD will launch a new activity to revitalize education and innovation in the physics of particle accelerators for the benefit of HEP and other SC programs that rely on these enabling technologies. A component of this program will allow graduate students to participate in mentored accelerator research and technology development and enable leveraging the capabilities and assets of DOE laboratories. HEP will hold a competition for a traineeship program to support the projected workforce shortage. This will be aimed at a university/national laboratory consortium in order to provide the academic training and research experience needed to meet DOE’s anticipated workforce needs.

HEP Directed Accelerator R&D

HEP Directed Accelerator R&D supports strategic investments in innovative technologies for possible future HEP accelerator projects, with proof-of-principle demonstrations, prototype component development, and advancing technical readiness. This includes R&D and prototyping to bring new concepts to a stage of engineering readiness where they can be incorporated into existing facilities or be applied to the design of new facilities. Research efforts within this activity are generally limited in time and have concrete milestones associated with specific future accelerator facilities or technologies. The current components of the HEP Directed Accelerator R&D activity are the LHC Accelerator Research Program (LARP) and the Muon Accelerator Program (MAP).

LARP is carrying out R&D needed to produce prototypes for U.S. deliverables to the High Luminosity LHC (HL-LHC) that CERN is planning to begin building late in this decade. The MAP program was created to carry out R&D on the feasibility of creating and accelerating muon beams for either the production of neutrinos or a very high energy lepton collider. Following the P5 report, these applications are now seen as less scientifically compelling at this time. The Muon Accelerator Program is being ramped down, with FY 2017 being the last year of funding for this activity; some key elements with broad applications will be redirected into General Accelerator R&D.

Detector R&D

Detector R&D addresses the need for continuing development of the next generation instrumentation and detectors at the Energy, Intensity, and Cosmic Frontiers in order to maintain scientific leadership in a worldwide experimental program that is broadening into new research areas. In order to meet this challenge, HEP maintains a program appropriately balanced between evolutionary, near-term, low-risk detector R&D and revolutionary, long-term, high-risk detector R&D, while training the next generation of experts. The program supports research into the fundamental physics underlying the interactions of particles and radiation in detector materials as well as the development of technologies that turn these insights into working detectors. This activity supports research programs at five DOE national laboratories and about 20 academic research institutions, as well as extensive test and fabrication facilities at three laboratories. Research efforts are selected based on competitive peer review to maintain the activities with the highest scientific impact and potential. All laboratory research groups are reviewed every three years. HEP conducted an external peer review of all laboratory research groups in this subprogram in 2012 and the next review is planned for 2016.

Facility Operations and Experimental Support

This activity generally provides operations funding for proposal-driven accelerator R&D facilities like FACET at SLAC, as well as other laboratory experimental and test facilities, including BELLA at LBNL and superconducting RF and magnet facilities at Fermilab. The SRF facilities are centralized at Fermilab due to the cost to build and operate them.

FACET, and its planned successor, FACET-II, provide very high energy beams of electrons and positrons for testing wakefield acceleration and radiation production. BELLA provides the world's highest repetition rate high-power laser for experiments in laser plasma acceleration and the interaction of ultra-intense light with matter. Experiments at both BELLA and FACET have shown increases in both acceleration gradients and precision of the beam control over the last several years.

The current priorities for the Fermilab accelerator test facilities are the programs to develop higher field magnets for the LHC (LARP), LCLS-II cryomodule production and testing, and R&D on a future upgrade of the Fermilab Accelerator Complex front end linac.

HEP also supports test beams at SLAC and Fermilab for the testing of new detector concepts as well as detector fabrication facilities like the Microsystem System Laboratory at LBNL and Silicon Detector (SiDET) Facility at Fermilab.

Projects

In FY 2017, initial equipment funding for the FACET-II MIE project is requested. A new shield wall in Sector 10 will be constructed to allow for FACET-II commissioning and operation during LCLS-II construction in Sectors 0-10.

Advanced Technology R&D

Activities and Explanation of Changes

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs. FY 2016
Advanced Technology R&D $115,494,000	**$118,285,000**	**+$2,791,000**
HEP General Accelerator R&D $46,722,000	**$44,510,000**	**-$2,212,000**
The general portfolio of topics described in the narrative above continues to be supported, but the program adjusts the emphasis on each topic based on the detailed recommendation from the HEPAP Accelerator R&D Subpanel (report issued in April 2015[a]) to optimize alignment with the P5 report.	The program will adjust research topics based on the recommendations from the HEPAP Accelerator R&D Subpanel (report issued in April 2015) to optimize alignment with the P5 report. A new traineeship activity will revitalize education and innovation in the physics of particle accelerators for the benefit of HEP and other SC programs that rely on these enabling technologies.	The program receives $1,000,000 to initiate a new traineeship activity in the physics of particle accelerators, but overall funding is down as priority goes to P5 recommended projects.
HEP Directed Accelerator R&D $20,640,000	**$21,500,000**	**+$860,000**
LARP increases effort to develop a prototype superconducting quadrupole magnets with the large apertures needed to increase luminosity at the LHC. MAP effort will be ramping down as recommended by P5 according to a detailed ramp-down plan which was developed in FY 2015.	LARP will increase efforts to develop a prototype superconducting quadrupole magnets with the large apertures needed to increase luminosity at the LHC. MAP effort will ramp down as recommended by P5 according to a detailed ramp-down plan which was developed in FY 2015.	Reductions due to the ramp down of MAP effort are offset by an increase in LARP superconducting magnet effort to meet schedule for delivery of magnet prototypes.
Detector R&D $16,282,000	**$17,350,000**	**+$1,068,000**
Research activities continue at U.S. universities and national laboratories, with resources continuing to shift towards near-term requirements of the high-priority efforts and towards strengthening the university activities, as recommended in the P5 report.	Research activities will continue at U.S. universities and national laboratories, with resources shifted towards near-term requirements of the high-priority efforts and towards strengthening the university efforts, as recommended in the P5 report.	Detector research activities will receive modest support while focus remains on the high priority activities recommended in the P5 report.
Facility Operations and Experimental Support $29,750,000	**$26,925,000**	**-$2,825,000**
Support for operation of BELLA and SRF Infrastructure continues. This program provides support for superconducting magnet fabrication and test facilities. FACET is supported at a reduced level due to a shorter run dictated by a shutdown for LCLS-II construction.	Support for operation of BELLA, SC magnet test facility and SRF test facilities continues. FACET ceased operation in FY 2016 due to LCLS-II construction removing part of the linac used by FACET.	The reduction is dominated by the end of funding for the operation of FACET.

[a] http://science.energy.gov/~/media/hep/hepap/pdf/Reports/Accelerator_RD_Subpanel_Report.pdf

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs. FY 2016
Projects $2,100,000	**$8,000,000**	**+$5,900,000**
Mission Need (CD-0) for the FACET-II MIE project was approved in September 2015, and the project will begin receiving funding for Other Project Costs in FY 2016.	The FACET-II project will begin fabrication with $5,000,000 of equipment funding and $3,000,000 for other project costs. FACET-II will continue the very successful program started by FACET. The larger and higher priority LCLS-II project sponsored by BES is taking over the first third of the SLAC linac. FACET-II will be designed to use only the middle third of the SLAC linac.	Increase supports the FACET-II project.

Description

This subprogram stewards accelerator science & technology through three principal activities: improving access to SC accelerator R&D infrastructure for industrial and other users; near-term translational R&D to adapt accelerator technology for medical, industrial, security, defense, energy and environmental applications; and long-term R&D for the science and technology needed to build future generations of accelerators. HEP manages this program in close consultation with other SC programs, including NP and BES, and in consultation with other federal stakeholders of accelerator technology, most notably NSF, the Department of Defense, and the National Institutes of Health.

Accelerator Stewardship pursues targeted R&D to develop new uses of accelerator technology with broad applicability. Initial workshops and a request for information identified three target application areas with broad impact: accelerator technologies for ion beam therapy of cancer, laser technologies for accelerators, and energy and environmental applications of accelerators. As the program evolves, new cross-cutting areas of research will be identified based on input from the federal stakeholders, R&D performers, and U.S. industry.

HEP and other SC programs will continue to conduct programmatic near- and mid-term R&D on accelerator and beam physics issues related to the scientific facilities they operate. This subprogram will not replace or duplicate those R&D efforts, which are driven by specific science goals and program priorities.

Research

Research funding supports activities that have been identified for applications in areas broader than just HEP. Research is conducted at national laboratories, universities, and in industry. The stewardship program supports both near-term translational R&D and long-term basic accelerator R&D.

Near-term R&D funding is structured to produce practical prototypes of new applications in five to seven years. The needs for applications chosen for this category have been specifically identified by federal stakeholders and developed further by workshops. Near-term R&D funding opportunities are specifically structured to strengthen academic-industrial collaboration. Long-term R&D funding is targeted at scientific innovations enabling breakthroughs in particle accelerator size, cost, beam intensity, and control.

Facility Operations and Experimental Support

The Accelerator R&D Stewardship subprogram supports facility operations through two mechanisms: a dedicated Accelerator Stewardship facility (the BNL ATF) and the Accelerator Stewardship Test Facility Pilot Program, which provides seed funding to engage a broader user community, including industry users, at SC national laboratories.

The BNL ATF is a low-power electron and laser test facility dedicated to accelerator studies. Experiments at the BNL ATF study the interactions of high power electromagnetic radiation and high brightness electron beams, including free-electron lasers and laser acceleration of electrons and the development of electron beams with extremely high brightness, photo-injectors, electron beam and radiation diagnostics and computer controls. Beam time at the BNL ATF is awarded based on a merit-based peer review process. The BNL ATF was formally designated as an SC User Facility in FY 2015.

The Accelerator Stewardship Test Facility Pilot Program was launched in FY 2015 and provides operations support for non-traditional users to access accelerator test infrastructure at DOE's SC national laboratories. Unlike the SC user facilities, this class of SC assets is frequently unseen and underexploited by the broader community. A public portal[a] has been created, and public outreach events held at six national laboratories in the winter/spring of 2015 reached more than 450 participants. The broader community was made aware of these facilities, and laboratories subsequently submitted seed-funding proposals for limited-scale use of these facilities. Experience from the pilot program will inform the implementation of a long-term mechanism for making the SC's unique accelerator test facilities more available.

[a] www.acceleratoramerica.org

Accelerator Stewardship

Activities and Explanation of Changes

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs. FY 2016
Accelerator Stewardship $9,000,000	**$13,744,000**	**+$4,744,000**
Research $3,378,000	**$6,853,000**	**+$3,475,000**
Research activities continue at laboratories, universities, and in industry. As funds allow, the program initiates research support for selected technology areas such as energy & environmental applications of accelerators, as identified by SC workshops.	The Request will continue to support research activities at laboratories, universities, and in industry for technology R&D areas such as laser, ion-beam therapy, and accelerator technology for energy and environmental applications.	Research funding increases to support targeted R&D efforts to develop new uses of accelerator technology with broad applicability.
Facility Operations and Experimental Support $5,622,000	**$6,891,000**	**+$1,269,000**
Support continues for ATF operations, continuation of the Accelerator Test Facility Pilot Program, and the completion of the relocation of the ATF to a larger building.	The Request will support ATF user facility operations and the continuation of the Accelerator Stewardship Test Facility Pilot Program.	The facilities request in FY 2017 increases as the BNL-ATF relocation to a larger building reaches a peak year of activity. The Accelerator Stewardship Test Facility Pilot Program is expanded.

High Energy Physics
SBIR/STTR

Description

The SBIR/STTR amount is adjusted to mandated percentages for non-capital funding.

Activities and Explanation Changes

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs. FY 2016
SBIR/STTR $20,897,000	**$22,580,000**	**+$1,683,000**
In FY 2016, SBIR/STTR funding is set at 3.45% of non-capital funding.	In FY 2017, SBIR/STTR funding is set at 3.65% of non-capital funding.	The SBIR/STTR amount is adjusted to mandated percentages for non-capital funding.

High Energy Physics
Construction

Description

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

Mu2e, under construction at Fermilab, will be an important component of the Intensity Frontier subprogram. It will utilize a proton beam to produce muons and determine whether those muons, on rare occasions, can transform into electrons in apparent violation of lepton flavor symmetry. Evidence of muon to electron flavor change would further probe physics beyond the Standard Model at very high energy scales.

The project received approval for its performance baseline (Critical Decision CD-2) and for civil construction and long-lead procurement of the most challenging superconducting solenoid magnets (Critical Decision CD-3B) on March 4, 2015. Civil construction was initiated shortly thereafter. The Mu2e Project will complete its technical design phase in FY 2016 and move into full construction at that time. FY 2017 construction funds will be used to modify the Fermilab accelerator complex to deliver muons to Mu2e, to fabricate the two remaining superconducting solenoid magnets, and to fabricate the particle detection systems for Mu2e.

The Long Baseline Neutrino Facility and its associated Deep Underground Neutrino Experiment (LBNF/DUNE) will study the transformations of muon neutrinos that occur as they travel to a large detector in South Dakota, 800 miles away from Fermilab where they are produced in a high-energy beam. The experiment will analyze the rare, flavor-changing transformations of neutrinos in flight, from one lepton flavor to another, which are expected to help explain the fundamental physics of neutrinos and the matter-antimatter asymmetry of the universe.

DOE implemented the recommendations from the P5 report during FY 2015 by assessing and evaluating opportunities to incorporate in-kind contributions from international collaborators. The non-DOE scope is expected to focus on modular components of the accelerator beam and neutrino detectors. DOE scope is expected to incorporate all civil construction activities including excavation for large modular neutrino detectors, as well as integration and operation of the accelerator beam and detectors. The reformulated, international program is now identified jointly as LBNF/DUNE.

HEP proposes to use the successful management model of the LHC in delivering the long baseline neutrino program. Fermilab would lead the construction of the LBNF project and will be responsible for design, construction, and operation of the LBNF beamline; design, construction, and operation of the conventional facilities and experiment infrastructure on the Fermilab site required for the near detector; and design, construction, and operation of the conventional facilities and experiment infrastructure at SURF, including the cryostats and cryogenics systems, required for the far detector.

The Deep Underground Neutrino Experiment (DUNE) is a new international collaboration that has formed to carry out the neutrino experiment enabled by the LBNF facility. The DUNE collaboration will be responsible for: the definition of the scientific goals; the design, construction, commissioning, and operation of the near detector at Fermilab and the far detectors at the SURF; and the scientific research program conducted with the DUNE detectors. The DUNE collaboration currently consists of about 750 physicists from nearly 150 institutes from 26 different countries. Each of the collaborating institutions will be responsible for delivering in-kind detector components that they have proven to have the expertise to build and install. Presently, the DOE contribution to the detectors will be a minority portion of the scope.

All DOE contributions to LBNF/DUNE will be managed according to the SC's implementation of DOE O413.3B. Fermilab, in its role as the host, will oversee all LBNF/DUNE construction. Fermilab's oversight of the neutrino detectors includes technical coordination to ensure the various pieces will fit and operate together and arrive on time. The technical coordination group will document all work scope assignments, maintain a schedule, and provide design, production readiness, and operational readiness reviews in cooperation with the collaboration. This process follows the practice, systems, and procedures at CERN for the LHC detectors.

The reformulated and integrated project plan for the LBNF/DUNE project was reviewed successfully in July 2015 by a DOE Independent Cost Review (ICR) and a DOE Independent Project Review (IPR). The DOE ESAAB refreshed the approval for CD-1 on November 5, 2015, with a revised TPC cost range of $1,255,000,000 to $1,727,000,000 and a TPC point estimate of

$1,500,000,000 based on the new conceptual design. The revised scope and outyear funding projections have pushed the CD-4 date to FY 2030.

The critical path item for LBNF/DUNE is excavation of the equipment caverns. Installation of the cryogenic systems and detectors cannot start until the caverns are ready. Before excavation can begin, critical site preparations are needed such as safety and reliability refurbishments for the underground infrastructure as well as a waste-rock handling system. This work will start with funding received in FY 2016. The FY 2017 Request would support continuing these site preparation activities as well as initiating civil construction for excavation of the underground equipment caverns beginning in late FY 2017.

Approval of a new Critical Decision, CD-3A, is needed for the excavation work planned for a FY 2017 start. Approval is anticipated in FY 2016 based on strong positive recommendations from a DOE ICR and an IPR, both of which were convened simultaneously at SURF on December 2-4, 2015.

Construction

Activities and Explanation of Changes

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs. FY 2016
Construction $66,100,000	**$88,521,000**	**+$22,421,000**
11-SC-40, Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment $26,000,000	**$45,021,000**	**+$19,021,000**
Total Estimated Cost (TEC) funding supports the following: civil and geotechnical engineering design of the detector cavern in South Dakota; technical design of the neutrino-production beam line and related facilities at Fermilab; site preparation; and modifications to the technical design of the experimental facility, infrastructure, and detectors in light of the new international participation.	TEC funding is requested to continue technical design of the facility and the experiment. The design of cryogenic infrastructure is the next part of the facility design that needs to be completed. The Request includes funding to continue site preparation and initiation of underground excavation of the large caverns for the neutrino detectors.	The increased TEC funding will support continued site preparation and the start of the excavation of caverns for the neutrino detectors and cryogenic infrastructure.
11-SC-41, Muon to Electron Conversion Experiment $40,100,000	**$43,500,000**	**+$3,400,000**
Construction funding continues for the civil construction and initiate accelerator modifications and fabrication of technical components (solenoid magnets and particle detectors).	The Request includes funding to finish civil construction and continue accelerator modifications and fabrication of technical components (solenoid magnets and particle detectors).	Funding is increased according to the planned funding profile as construction continues.

High Energy Physics
Performance Measures

In accordance with the GPRA Modernization Act of 2010, the Department sets performance targets for, and tracks progress toward, achieving performance goals for each program. The following table shows the performance targets for FY 2015 through FY 2017. Details on the Annual Performance Report can be found at http://energy.gov/cfo/reports/annual-performance-reports.

	2015	2016	2017
Performance Goal (Measure)	**HEP Facility Operations—Average achieved operation time of HEP user facilities as a percentage of total scheduled annual operation time**		
Target	≥ 80%	≥ 80%	≥ 80%
Result	Met	TBD	TBD
Endpoint Target	Many of the research projects that are undertaken at the SC's scientific user facilities take a great deal of time, money, and effort to prepare and regularly have a very short window of opportunity to run. If the facility is not operating as expected the experiment could be ruined or critically setback. In addition, taxpayers have invested millions or even hundreds of millions of dollars in these facilities. The greater the period of reliable operations, the greater the return on the taxpayers' investment.		
Performance Goal (Measure)	**HEP Construction/MIE Cost & Schedule— Cost-weighted mean percentage variance from established cost and schedule baselines for major construction, upgrade, or equipment procurement projects**		
Target	< 10%	< 10%	< 10%
Result	Met	TBD	TBD
Endpoint Target	Adhering to the cost and schedule baselines for a complex, large scale, science project is critical to meeting the scientific requirements for the project and for being good stewards of the taxpayers' investment in the project.		
Performance Goal (Measure)	**HEP Neutrino Model—Carry out series of experiments to test the standard 3-neutrino model of mixing**		
Target	Physics analyses results from the first year of data taking with the full detector were presented by the NOvA and MicroBooNE experimental collaborations at the FY 2015 summer conferences.	Physics analyses results of data taking with the full detector will be presented by the NOvA and MicroBooNE experimental collaborations at the FY 2016 summer conferences.	Determine based on the data taken with NOvA, whether it is appropriate to switch to taking antineutrino data. This should be based on a proposal from the NOvA Collaboration and evaluated by the Fermilab Program Advisory Committee.
Result	Not Met	TBD	TBD
Endpoint Target	Similar to quarks, the mixing between neutrinos is postulated to be described by a unitary matrix. Measuring the independent parameters of this matrix in different ways and with adequate precision will demonstrate whether this model of neutrinos is correct. Such a model is needed to correctly extract evidence for matter-antimatter asymmetry in the neutrino sector.		

High Energy Physics
Capital Summary ($K)

	Total	Prior Years	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs. FY 2016
Capital Operating Expenses Summary							
Capital equipment	n/a	n/a	74,452	61,455	104,325	99,046	-5,279
General plant projects (GPP)	n/a	n/a	12,463	12,463	9,160	7,400	-1,760
Accelerator improvement projects (AIP) (<$5M)	n/a	n/a	12,750	12,400	9,700	4,400	-5,300
Total, Capital Operating Expenses	**n/a**	**n/a**	**99,665**	**86,318**	**123,185**	**110,846**	**-12,339**
Capital Equipment							
Major items of equipment[a]							
Energy Frontier Experimental Physics							
LHC ATLAS Detector Upgrades[b]	20,821	0	7,500	2,821	9,500	8,500	-1,000
LHC CMS Detector Upgrades[c]	22,629	0	7,500	5,162	9,500	7,967	-1,533
Intensity Frontier Experimental Physics							
Belle II[d]	8,870	7,900	970	970	0	0	0
Muon g-2 Experiment[e]	27,549	2,000	8,000	9,000	10,200	6,349	-3,851
Cosmic Frontier Experimental Physics							
Large Synoptic Survey Telescope Camera (LSSTcam)[f]	150,300	19,700	35,000	35,000	40,800	45,000	+4,200
Dark Energy Spectroscopic Instrument[g] (DESI)	46,137	0	250	500	9,800	9,000	-800
LUX-ZEPLIN[h] (LZ)	46,550	0	250	500	10,500	10,500	0
SuperCDMS-SNOlab[i]	14,725	0	250	0	2,375	4,000	+1,625
Advanced Technology R&D							
FACET II	41,500	0	0	0	0	5,000	+5,000
Total MIEs	n/a	n/a	59,720	53,953	92,675	96,316	+3,641

[a] Each MIE located at a DOE facility Total Estimated Cost (TEC) > $5M and each MIE not located at a DOE facility TEC > $2M
[b] Critical Decisions CD-2 and 3 for the LHC ATLAS Detector Upgrade Project were approved on November 12, 2014. The TPC is $33,250,000.
[c] Critical Decisions CD-2 and 3 for the LHC CMS Detector Upgrade Project were approved on November 12, 2014. The TPC is $33,217,000.
[d] Critical Decision CD-2 and 3 for Belle II were approved on April 23, 2014. The TPC is $15,000,000.
[e] Critical Decision CD-2 and 3 for Muon g-2 Experiment were approved August 20, 2015. The TPC is $46,400,000.
[f] Critical Decision CD-3 for the LSSTcam project was approved on August 27, 2015. The TPC is $168,000,000.
[g] Critical Decision CD-2 for DESI project was approved on September 17, 2015. The TPC is $56,328,000. Approval of Critical Decision CD-3 is expected in FY 2016.
[h] The LZ project MIE was one of two MIEs selected to meet the Dark Matter Second Generation Mission Need. CD-1 and -3A were approved April 24, 2015. The project is expected to be baselined in FY 2016. The estimated cost range at CD-1 was $46,000,000-$59,000,000.
[i] The SuperCDMS-SNOlab MIE was one of two MIEs selected to meet the Dark Matter Second Generation Mission Need. CD-1 was approved on December 21, 2015. The estimated cost range at CD-1 was $16,000,000–$21,500,000. The project expects to be baselined in 2017.

	Total	Prior Years	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs. FY 2016
Total Non-MIE Capital Equipment	n/a	n/a	14,732	7,502	11,650	2,730	-8,920
Total, Capital equipment	**n/a**	**n/a**	**74,452**	**61,455**	**104,325**	**99,046**	**-5,279**
General Plant Projects (GPP)							
MC-1 Building	9,500	9,000	500	500	0	0	0
Muon Campus Beamline Enclosure	8,700	4,100	4,600	4,600	0	0	0
Short Baseline Neutrino Far Hall	9,800	1,000[a]	6,287	5,298	3,502	0	-3,502
Short Baseline Neutrino Near Hall	5,350	0	0	2,050	3,300	0	-3,300
Industrial Center Building addition	7,513	0	0	0	0	6,750	+6,750
Other projects under $5 million TEC	n/a	n/a	1,076	15	2,358	650	-1,708
Total, Plant Project (GPP)	**n/a**	**n/a**	**12,463**	**12,463**	**9,160**	**7,400**	**-1,760**
Accelerator Improvement Projects (AIP)							
Muon Campus Cryogenics	9,600	6,200	1,300	1,300	700	1,400	+700
Recycler RF Upgrades	9,200	1,400	3,800	3,800	4,000	0	-4,000
Beam Transport	6,500	2,700	3,700	3,700	100	0	-100
Delivery Ring	9,100	1,900	3,300	3,300	3,900	0	-3,900
ATF-II Upgrade	5,000	2,200	650	300	1,000	1,500	+500
ATF-II Experimental Area	8,500	0	0	0	0	1,500	+1,500
Other projects under $5 million TEC	n/a	n/a	0	0	0	0	0
Total, Accelerator Improvement Projects	**n/a**	**n/a**	**12,750**	**12,400**	**9,700**	**4,400**	**-5,300**

[a] Updated information is consistent with the project profile.

Major Items of Equipment Descriptions

Energy Frontier Experimental Physics MIEs:

The *ATLAS Detector Upgrade Project* started as a new MIE in FY 2015 and subsequent ramp-up of fabrication activities for U.S. built detectors systems is planned in FY 2016. The U.S. scope includes upgrades to the muon subsystem, the liquid argon calorimeter detector, and the trigger and data acquisition system to take advantage of the increased LHC luminosity. The LHC ATLAS Detector Upgrade Project received CD-1, Approve Alternative Selection and Cost Range, on October 17, 2013, with an estimated cost range of $32,200,000 to $34,500,000. The project was baselined (CD-2) and approved for a fabrication start (CD-3) on November 12, 2014, with a total project cost of $33,250,000 and planned completion date (CD-4) in FY 2019. The FY 2017 Request of TEC funding for the ATLAS Detector Upgrade Project is $8,500,000, which is $1,000,000 lower than the FY 2016 Enacted level of $9,500,000 and consistent with the approved baseline funding profile.

The *CMS Detector Upgrade Project* started as a new MIE in FY 2015 and subsequent ramp up of fabrication activities for U.S. built detector systems is planned in FY 2016. The planned U.S. scope includes upgrades to the pixelated Inner tracking detector, the hadron calorimeter detector, and trigger system to take advantage of the increased LHC luminosity. The LHC CMS Detector Upgrade Project received CD-1, Approve Alternative Selections and Cost Range on October 17, 2013, with an estimated cost range of $29,200,000 to $35,900,000. The project was baselined (CD-2) and approved for a fabrication start (CD-3) on November 12, 2014, with a total project cost of $33,217,000 and planned completion date (CD-4) in FY 2020. The FY 2017 Request of TEC funding for the CMS Detector Upgrade Project is $7,967,000, which is $1,533,000 lower than the FY 2016 Enacted level of $9,500,000 and consistent with the approved baseline funding profile.

Intensity Frontier Experimental Physics MIEs:

The *Belle II* project is fabricating detector subsystems for the upgraded Belle detector located at the Japanese B-Factory, which is currently being upgraded to deliver much higher luminosity. U.S. groups are making key contributions to the particle identification systems. CD-2/3 was approved April 23, 2014 with a TPC of $15,000,000 and a project completion date of September 30, 2016. No fabrication funding is requested for Belle II in FY 2017.

The *Muon g-2* project will fabricate an experiment that seeks to improve the measurement of the muon anomalous magnet moment, which is sensitive to new physical interactions such as supersymmetry. The project will repurpose a storage ring from a previous experiment at BNL with upgraded detectors located at Fermilab in order to utilize the high intensity proton beam available there to produce the needed muons. CD-1 was approved on December 19, 2013, with a TPC range of $43,000,000 to $50,100,000. The Muon g-2 Project was baselined and CD-2 & 3 were approved August 20, 2015, with a TPC of $46,400,000 and planned completion date (CD-4) in FY 2019. Transfer of the BNL storage ring to Fermilab occurred in FY 2013. New instrumentation for the storage ring will be provided, in part, by in-kind contributions from non-DOE sources including NSF. The FY 2017 Request of TEC funding for Muon g-2 is $6,349,000, which is $3,851,000 lower than the FY 2016 Enacted level of $10,200,000 and consistent with the approved baseline funding profile.

Cosmic Frontier Experimental Physics MIEs:

The *Large Synoptic Survey Telescope Camera (LSSTcam*) project fabricates a state-of-the-art three billion pixel digital camera for a next-generation, wide-field, ground-based optical and near-infrared LSST observatory, located in Chile, and is designed to provide deep images of half the sky every few nights. The project is carried out in collaboration with NSF, which leads the project, along with private and foreign contributions. DOE will provide the camera for the facility. CD-2 for the LSSTcam project was approved January 7, 2015, with a DOE TPC of $168,000,000 and a completion date of FY 2022. CD-3 was approved on August 27, 2015. The FY 2017 Request of TEC funding for the LSSTcam is $45,000,000, which is $4,200,000 higher than the FY 2016 Enacted level of $40,800,000 and consistent with the approved baseline funding profile.

The *Dark Energy Spectroscopic Instrument (DESI)* project started fabrication in FY 2015. The project is fabricating an instrument that will measure the effect of dark energy on the expansion of the universe using spectroscopic measurements. The DESI survey will provide different, complementary measurements to those of the LSST survey. The instrument will be mounted on NSF's Mayall 4-meter telescope at Kitt Peak National Observatory in Arizona, with operations of the telescope supported by DOE. CD-2 was approved on September 17, 2015 with a TPC of $56,328,000, and a completion date of FY 2021. A review in preparation for CD-3 is scheduled for May 2016. The FY 2017 Request of TEC funding for DESI is $9,000,000, which is $800,000 lower than the FY 2016 Enacted level of $9,800,000 and consistent with the approved baseline funding profile.

The LUX-ZEPLIN (LZ) project started MIE fabrication in FY 2015. This MIE is one of two selected to meet the Dark Matter Second Generation Mission Need and the concept for the experiment was developed by a merger of the LUX and ZEPLIN collaborations from the U.S. and the U.K. respectively. The project will fabricate a detector using seven tons of liquid xenon inside a Time Projection Chamber (TPC) to search for xenon nuclei that recoil in response to collisions with an impinging flux of dark matter particles known as Weakly Interacting Massive Particles (WIMPs). The detector will be located 4,850 feet deep in the Sanford Underground Research Facility (SURF) in Lead, South Dakota. CD-1 was approved in April 28, 2015, together with CD-3a for long-lead procurement of photomultiplier tubes. CD-2 and CD-3b are planned for Q3 of FY 2016 with project completion (CD-4) in FY 2021. The FY 2017 Request of TEC funding for LZ is $10,500,000, which is flat with the FY 2016 Enacted level and consistent with the preliminary baseline funding profile.

The *Super Cryogenic Dark Matter Search at Sudbury Neutrino Observatory Laboratory (SuperCDMS-SNOLab)* project is a new MIE fabrication start in FY 2016. This MIE is one of two selected to meet the Dark Matter Second Generation Mission Need. The project will fabricate an instrument that uses ultra-clean, cryogenically-cooled silicon (Si) and germanium (Ge) detectors to search for Si or Ge nuclei recoiling in response to collisions with WIMPs. The detector will be located 2 km deep in the SNOLab facility in Sudbury, Ontario, Canada. CD-0 was approved in August 2012. CD-1 was approved on December, 21, 2015, and CD-2 is planned for FY 2017. SuperCDMS will be optimized to detect low mass WIMPs and will cover a range of WIMP mass that LZ is not sensitive to. The FY 2017 Request of TEC funding for SuperCDMS-SNOLab is $4,000,000, which is $1,625,000 higher than the FY 2016 Enacted level of $2,375,000 and consistent with the preliminary baseline funding profile.

Advanced Technology R&D MIE:
The *Facility for ACcelerator and Experimental Tests II (FACET-II)* is a new MIE fabrication start in FY 2017. It will succeed FACET as the world's premier beam driven plasma wakefield facility and provide intense ultra-short electron beams for other applications in accelerator and related sciences. The successful FACET program is ending due to the construction of the Linac Coherent Light Source II in a portion of the SLAC tunnel used by FACET. FACET-II will be designed to deliver the needed beams using only one third of the linac. The Mission Need Statement was signed August 24, 2015, and CD-0 was approved September 18, 2015. CD-1 was approved December 21, 2015. The FY 2017 Request of TEC funding for FACET-II is $5,000,000, which is consistent with the proposed funding profile.

High Energy Physics Construction Project Summary ($K)

	Total	Prior Years	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs. FY 2016
11-SC-40, Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment							
TEC	1,414,461	23,781	12,000	12,000	26,000	45,021	+19,021
OPC	85,539	75,539	10,000	10,000	0	0	0
TPC	1,500,000	99,320	22,000	22,000	26,000	45,021	+19,021
11-SC-41, Muon to Electron Conversion Experiment							
TEC	250,000	67,000	25,000	25,000	40,100	43,500	+3,400
OPC	23,677	23,677	0	0	0	0	0
TPC	273,677	90,677	25,000	25,000	40,100	43,500	+3,400
Total, Construction							
TEC	n/a	n/a	37,000	37,000	66,100	88,521	+22,421
OPC	n/a	n/a	10,000	10,000	0	0	0
TPC	n/a	n/a	47,000	47,000	66,100	88,521	+22,421

Funding Summary ($K)

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs. FY 2016
Research	358,177	334,225	348,286	353,703	+5,417
Facilities Operations					
Scientific User Facilities Operations	150,798	144,173	138,882	136,472	-2,410
Other Facilities	114,327	120,461	116,097	115,565	-532
Total, Facilities Operations	**265,125**	**264,634**	**254,979**	**252,037**	**-2,942**
Projects					
Major Items of Equipment[a]	72,373	73,148	95,900	102,816	+6,916
Other Projects	23,325	26,225	11,720	5,700	-6,020
Construction[a]	47,000	47,000	84,115	103,741	+19,626
Total, Projects	**142,698**	**146,373**	**191,735**	**212,257**	**+20,522**
Total, High Energy Physics	**766,000**	**745,232**	**795,000**	**817,997**	**+22,997**

[a] Includes Other Project Costs.

Scientific User Facility Operations ($K)

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.

Definitions:
Achieved Operating Hours – The amount of time (in hours) the facility was available for users.

Planned Operating Hours –
- For Past Fiscal Year (PY), the amount of time (in hours) the facility was planned to be available for users.
- For Current Fiscal Year (CY), the amount of time (in hours) the facility is planned to be available for users.
- For the Budget Fiscal Year (BY), based on the proposed Budget Request the amount of time (in hours) the facility is anticipated to be available for users.

Optimal Hours – The amount of time (in hours) a facility would be available to satisfy the needs of the user community if unconstrained by funding levels.

Percent of Optimal Hours – An indication of utilization effectiveness in the context of available funding; it is not a direct indication of scientific or facility productivity.
- For BY and CY, Planned Operating Hours divided by Optimal Hours expressed as a percentage.
- For PY, Achieved Operating Hours divided by Optimal Hours.

Unscheduled Downtime Hours - The amount of time (in hours) the facility was unavailable to users due to unscheduled events. NOTE: For type "A" facilities, zero Unscheduled Downtime Hours indicates Achieved Operating Hours equals Planned Operating Hours.

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs. FY 2016
TYPE A FACILITIES					
Fermilab Accelerator Complex	**$141,738**	**$134,613**	**$129,282**	**$130,781**	**+$1,499**
Number of Users	2,200	1,925	2,310	2,310	0
Achieved operating hours	TBD	4,866	N/A	N/A	N/A
Planned operating hours	4,200	4,200	4,800	4,800	0
Optimal hours	4,200	4,200	4,800	4,800	0
Percent optimal hours	100.0%	115.9%	100.0%	100.0%	N/A
Unscheduled downtime hours	TBD	882	N/A	N/A	N/A

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs. FY 2016
FACET (SLAC)	**$9,060**	**$9,560**	**$5,100**	**$0**	**-$5,100**
Number of Users	155	155	52	0	-52
Achieved operating hours	TBD	3,439	N/A	N/A	N/A
Planned operating hours	5,176	5,176	1,482	0	-1,482
Optimal hours	5,176	5,176	4,448	0	-4,448
Percent optimal hours	100.0%	66.4%	33.3%	N/A	N/A
Unscheduled downtime hours	TBD	530	N/A	N/A	N/A
Accelerator Test Facility (BNL)	**$0**	**$0**	**$4,500**	**$5,691**	**+$1,191**
Number of Users	0	0	50	52	+2
Achieved operating hours	N/A	N/A	N/A	N/A	N/A
Planned operating hours	N/A	N/A	2,400	1,800	-600
Optimal hours	N/A	N/A	2,500	1,825	-675
Percent optimal hours	N/A	N/A	96.0%	98.6%	+2.6%
Unscheduled downtime hours	N/A	N/A	N/A	N/A	N/A
Total Facilities	**$150,798**	**$144,173**	**$138,882**	**$136,472**	**-$2,410**
Number of Users	2,355	2,080	2,412	2,362	-50
Achieved operating hours	TBD	8,305	N/A	N/A	N/A
Planned operating hours	9,376	9,376	8,682	6,600	-2,082
Optimal hours	9,376	9,376	11,748	6,625	-5,123
Percent of optimal hours[a]	100.0%	112.6%	97.4%	99.9%	+2.5%
Unscheduled downtime hours	TBD	1,412	N/A	N/A	N/A

[a] For total facilities only, this is a "funding weighted" calculation FOR ONLY TYPE A facilities: $\frac{\sum_1^n[(\%OH\ for\ facility\ n)\times(funding\ for\ facility\ n\ operations)]}{Total\ funding\ for\ all\ facility\ operations}$

Scientific Employment

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Estimate	FY 2017 vs. FY 2016
Number of permanent Ph.D.'s (FTEs)	905	915	900	900	0
Number of postdoctoral associates (FTEs)	370	375	365	375	+10
Number of graduate students (FTEs)	485	500	475	480	+5
Other[a]	1,880	1,805	1,915	1,895	-20

[a] Includes technicians, engineers, computer professionals, and other support staff.

11-SC-40, Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment (LBNF/DUNE), Fermi National Accelerator Laboratory, Batavia, Illinois Project is for Design and Construction

1. Significant Changes and Summary

Significant Changes

This Construction Project Data Sheet (CPDS) is an update of the FY 2016 CPDS and does not include a new start for FY 2017. The Project 11-SC-40, the Long Baseline Neutrino Facility (LBNF), is being renamed as the Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment (LBNF/DUNE). The FY 2017 Request for LBNF/DUNE is $45,021,000, $19,021,000 more than the FY 2016 Enacted level of $26,000,000 and consistent with the preliminary cost profile approved at the CD-1 refresh.

The Particle Physics Project Prioritization Panel (P5) of the High Energy Physics Advisory Panel (HEPAP), in its 2014 *Strategic Plan for U.S. Particle Physics in the Global Context* report, recommended:

> *"The [LBNF] should be reformulated under the auspices of a new international collaboration, with Fermilab as host. There should be international participation in defining the program's scope and capabilities. The experiment should be designed, constructed, and operated by the international collaboration. The goal should be to achieve, and even exceed if physics eventually demands, the target requirements through the broadest possible international participation."*

HEP's implementation of the P5 recommendation to reformulate the long baseline neutrino program in an international context has resulted in the formation of two multinational, collaborative efforts—LBNF, which will construct the beamline at Fermilab and other experimental and civil infrastructure at Fermilab and at the Sanford Underground Research Facility (SURF); and the Deep Underground Neutrino Experiment (DUNE), an international experimental collaboration that is defining and implementing the scientific goals and technical requirements for the beamline, detectors and research program to be conducted at the LBNF facility. HEP proposes to manage both activities as a single project—LBNF/DUNE – and will use the successful Large Hadron Collider (LHC) management model for the collaborations.

LBNF, the host facility that will produce the neutrinos and house the experimental apparatus (neutrino detectors), will be built by Fermilab and a small number of international partners. The experimental apparatus, DUNE, will be built jointly by a large international collaboration (currently from 144 institutions in 26 countries). The DOE contributions to LBNF and DUNE together comprise a single project in terms of DOE Order 413.3B. Consequently, the DOE project's name has been expanded to the "Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment" (LBNF/DUNE). As host of the LBNF facility, DOE will provide the *majority* contribution to the LBNF facility and will provide a *minority* contribution to the DUNE international detector apparatus.

This management arrangement where a host facility provides by a major laboratory and detectors are provided by large collaborations is a very close match to the highly successful LHC model and its massive particle detectors at CERN. As the lead laboratory in the U.S., Fermilab was a major partner to CERN, providing key components to the LHC facility and detectors. U.S. scientists and engineers held key management and technical positions at CERN over the many years leading up to the Higgs discovery. Analogously, the construction of LBNF will be led by Fermilab, while the construction of the detectors will led by an international collaboration, supported by CERN, with Fermilab providing oversight and coordination. There will be two distinct management organizations to ensure effective execution by the partners in each. All DOE contributions to the facility and the detectors will be managed according to DOE Order 413.3B, and Fermilab will provide unified project reporting on both facets of the project.

Fermilab will be responsible for the design, construction, and operation of the major aspects of the LBNF facility: the neutrino beam, conventional civil facilities (including buildings and underground caverns), and technical infrastructure (including conventional civil construction, cryostats and cryogenic systems) required for the detectors.

Fermilab will oversee the new international DUNE experimental collaboration that has been formed to build the necessary detectors. The DUNE collaboration will be responsible for: the definition of the scientific goals and corresponding scientific and technical requirements on the detector systems and neutrino beamline; the design, construction, commissioning, and operation of the near detector at Fermilab and the far detectors at SURF; and the scientific research program conducted with the DUNE detectors.

The DUNE collaboration is led by elected co-spokespersons, currently one from the United Kingdom and the other from Switzerland. The collaboration has organized the development of the detector conceptual designs and is assigning the work scope among the collaboration members based on each collaborating institution's ability to carry it out. Each of the collaborating institutions will be responsible for delivering in-kind detector components and installing them in the detector. Presently the DOE contribution to the detectors is assumed to be less than a third of the total cost of the detectors.

Fermilab, in its role as the host, will oversee all LBNF and DUNE construction. Fermilab's oversight of the neutrino detectors includes technical coordination to ensure the various pieces will fit and operate together and arrive on time. The technical coordination group will document all work scope assignments, maintain a schedule, and provide design, production readiness, and operational readiness reviews in cooperation with the collaboration. This process follows the practice, systems, and procedures at CERN for the LHC detectors.

Unlike DUNE with its many international participants, only a few international partners are expected to provide in-kind contributions to LBNF. For example, CERN is proposing to provide cryogenic infrastructure needed to support the detectors. CERN currently runs the largest cryogenic system in the world. HEP and Fermilab continue to recruit other partners that can similarly contribute their expertise as well as their financial resources. The international contributions to LBNF will be developed by Fermilab and its partner institutions under the oversight of DOE and other funding agencies. DOE will be responsible for developing any needed international agreements for LBNF.

The reformulated and integrated project plan for the LBNF/DUNE project was reviewed successfully in July 2015 by a DOE Independent Cost Review (ICR) panel and by a DOE Independent Project Review (IPR) panel, convened simultaneously at Fermilab in July 2015. Based on the recommendations of these panel reviews, the DOE ESAAB approved the revised CD-1 on November 5, 2015 with a TPC cost range of $1,260,000,000 to $1,860,000,000 and a TPC point estimate of $1,500,000,000 based on the new conceptual design. The revised scope and outyear funding projections have pushed the CD-4 date to FY 2030.

The FY 2016 funding for LBNF supports: civil and geotechnical engineering design of the detector cavern in South Dakota; technical design of the neutrino-production beam line and related facilities at Fermilab; site preparation; and for support of modifications to the technical design of the experimental facility, infrastructure and detectors. Site preparation begins with maintenance activities to mine shaft, hoists, ventilation systems, and general support infrastructure to allow for safe and reliable work once construction begins. Site preparation also includes development of a waste rock handling system needed to support excavation.

The FY 2017 Request will support the completion of site preparation activities as well as initiating the procurement of civil construction for excavation of the underground equipment caverns beginning in late FY 2017. Approval of a new Critical Decision, CD-3A, will be needed before excavation work can start. The approval is anticipated in FY 2016 based on strong positive recommendations from a DOE ICR and an IPR. The DOE ESAAB for CD-3A is planned for Spring 2016.

Summary

The LBNF facility collaboration and DUNE experimental collaboration will create the premier facility and experiment for long-baseline neutrino science world-wide. DUNE will analyze transformations of muon neutrinos in a beam from Fermilab to a large detector in South Dakota, 800 miles away. The experiment will analyze the rare, flavor-changing transformations of neutrinos in flight, from one lepton flavor to another, that are expected to help elucidate the fundamental physics of neutrinos and perhaps explain the puzzling matter-antimatter asymmetry observed in the universe.

The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-1R, which was approved November 5, 2015 with a preliminary TPC cost range of $1,260,000,000 to $1,860,000,000, a TPC point estimate of $1,500,000,000, and a CD-4 date of FY 2030. This includes the full cost of the LBNF host facility excluding foreign contributions, as well as the full cost of the DOE contribution to the DUNE experimental apparatus.

Contributions from the international partners are currently being negotiated. For the DUNE detector the process is being driven from the principal investigator level up to the funding agencies as was done for the LHC. Proposals are under review by the other funding agencies. CERN has put funding into its medium-term budget plan for one detector cryostat worth $90 million in U.S. accounting. An addendum to the U.S. CERN agreement will document this commitment and others currently being negotiated.

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

2. Critical Milestone History

(fiscal quarter or date)

	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	D&D Complete	CD-4
FY 2011	1/8/2010		1Q FY 2011	TBD	4Q FY 2013	TBD	TBD	TBD
FY 2012	1/8/2010		2Q FY 2012	TBD	2Q FY 2015	TBD	TBD	TBD
FY 2016 [a]	1/8/2010	12/10/2012	12/10/2012	4Q FY 2017	4Q FY 2019	4Q FY 2019	N/A	4Q FY 2027
FY 2017	1/8/2010	11/5/2015 [b]	11/5/2015 [b]	1Q FY 2020	1Q FY 2020	1Q FY 2020	N/A	4Q FY 2030

CD-0 – Approve Mission Need
Conceptual Design Complete – Actual date the conceptual design was completed
CD-1 – Approve Design Scope and Project Cost and Schedule Ranges
CD-2 – Approve Project Performance Baseline
Final Design Complete – Estimated date the project design will complete
CD-3 – Approve Start of Construction
D&D Complete – Completion of D&D work (see section 9)
CD-4 – Approve Start of Operations or Project Closeout

(fiscal quarter or date)

	CD-1R	CD-3A	CD-3B	CD-3C	Performance Baseline Validation
FY 2017	11/5/2015	2Q FY 2016	3Q FY 2018	1Q FY 2020	1Q FY 2020

CD-1R – Refresh of CD-1 approval for the new Conceptual Design.
CD-3A – Approval for initiating excavation of the equipment caverns at the Far Site.
CD-3B – Approval for procurement of cryogenic system technical infrastructure at the Far Site, as well as for initiation of civil construction of an embankment for the neutrino-production beam line at Fermilab.
CD-3C – Approval for all project fabrication and construction (same as CD-3).

[a] No CPDS was submitted for FY 2013, FY 2014 or FY 2015 because no TEC funds were requested; however, design funds were provided in each year's appropriation.
[b] Critical Decision CD-1 was approved for the new conceptual design by an ESAAB approval (CD-1R) on November 5, 2015.

3. Project Cost History

(dollars in thousands)

	TEC, Design	TEC, Construction	TEC, Total	OPC Except D&D	OPC, D&D	OPC, Total	TPC
FY 2011	102,000	TBD	TBD	22,180	TBD	TBD	TBD
FY 2012	133,000	TBD	TBD	42,621	TBD	TBD	TBD
FY 2016[a]	127,781	655,612	783,393	89,539	N/A	89,539	872,932
FY 2017[b]	123,781	1,290,680	1,414,461	85,539	N/A	85,539	1,500,000[c]

4. Project Scope and Justification

Scope

LBNF/DUNE will be composed of a neutrino beam created by new construction as well as modifications to the existing Fermilab accelerator complex, massive neutrino detectors (at least 40,000 tons in total) and associated cryogenics infrastructure located in one or more large underground caverns to be excavated at least 800 miles "downstream" from the neutrino source, and a much smaller neutrino detector at Fermilab for monitoring the neutrino beam near its source. The neutrino beam will be produced by a primary beam of protons directed into a target for converting the protons into a secondary beam of particles (pi mesons 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 Fermilab is an existing example of this type of configuration for a neutrino beam facility. The new LBNF beam line will provide a neutrino beam of lower energy and greater intensity than the NuMI beam, and would point to a far detector at a greater distance than is used with NuMI experiments in order to provide the distance needed for the study of neutrino oscillations.

For the LBNF/DUNE project, Fermilab will be responsible for design, construction and operation of the major components of the LBNF facility 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 Fermilab site required for the near detector; and the conventional facilities and experiment infrastructure at SURF for the large detector including the cryostats and cryogenics systems.

Justification

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

Among the technical issues addressed in the alternatives analysis were the preferred detector technology and the neutrino beamline design. After a thorough study, both technologies were found to be capable of meeting the performance requirements if located underground, only liquid argon could work on the surface, and is less expensive. A low energy

[a] No CPDS was submitted for FY 2013, FY 2014 or FY 2015 because no TEC funds were requested; however, design funds were provided in each year's appropriation.

[b] The project is Pre-CD-2 and has not been baselined. All estimates are preliminary. The TPC point estimate is $1,500,000,000. The preliminary TPC range at CD-1 is $1,260,000,000 to $1,860,000,000.

[c] No construction, other than site preparation, approved civil construction or long-lead procurement will be performed prior to validation of the Performance Baseline and approval of CD-3.

neutrino beam to the Homestake mine and the current NuMI beam were compared. The new beam with its lower energy and longer distance to the detector was shown to be superior.

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

The preliminary Key Performance Parameters (KPPs) for project completion that were approved by CD-1 in FY 2015 include the primary beam and neutrino beam production systems as well as underground caverns excavated for four separate, 10 kton detector modules (of liquid-argon, time-projection detectors) at the SURF site, 1000-1500 km from the neutrino source. The DOE contribution for DUNE will include technical components for two of the four detector modules, which will be installed and tested with cosmic rays, and components of the cryogenic systems for the detectors, which will be installed and pressure tested. The KPPs will be finalized at CD-2.

Preliminary Key Performance Parameters

Scope	Threshold KPP	Objective KPP
Primary Beam to produce neutrinos directed to the far detector site	Beamline hardware commissioning complete and demonstration of protons delivered to the target	In addition to Threshold KPPs, system enhancements to maximize neutrino flux, enable tunability in neutrino energy spectrum or to improve neutrino beam capability
Far Site-Conventional Facilities	Caverns excavated for 40 kiloton fiducial detector mass[a]; beneficial occupancy granted for cavern space to house 20 kiloton fiducial detector mass[a]	In addition to Threshold KPPs, Beneficial Occupancy granted for remaining cavern space
Detector Cryogenic Infrastructure	DOE-provided components for Cryogenic subsystems installed and pressure tested for 20 kiloton fiducial detector mass[a]	In addition to Threshold KPPs, additional DOE contributions to cryogenic subsystems installed and pressure tested for additional 20 kiloton fiducial detector mass[a]; DOE contributions to cryostats

[a] Fiducial detector mass pertains to the mass of the interior volume of the detection medium (liquid argon) that excludes the external portion of the detection medium where most background events would occur.

Scope	Threshold KPP	Objective KPP
Long-Baseline Distance between neutrino source and far detector	1,000-1,500 kilometers	
Far Detector	DOE-provided components installed in cryostats to support 20 kiloton fiducial detector mass[a], with cosmic ray interactions detected in each detector module	In addition to Threshold KPPs, additional DOE contributions to support up to 40 kiloton fiducial detector mass[a]

5. Financial Schedule[b]

	(dollars in thousands)			
	Appropriations	Obligations	Recovery Act Costs	Costs[c]
Total Estimated Cost (TEC)				
Design Only				
FY 2012	4,000	4,000	0	0[d]
FY 2013	3,781	3,781	0	801
FY 2014	16,000	16,000	0	7,109
FY 2015	12,000	12,000	0	15,791
FY 2016	0	0	0	12,080
Subtotal, Design Only	35,781	35,781	0	35,781
Design (Design and Construction)				
FY 2016	N/A	N/A	0	26,000
FY 2017	N/A	N/A	0	18,000
Outyears	N/A	N/A	0	44,000
Subtotal, Design (Design and Construction)	N/A	N/A	0	88,000
Total, Design	N/A	N/A	0	123,781

[a] Fiducial detector mass pertains to the mass of the interior volume of the detection medium (liquid argon) that excludes the external portion of the detection medium where most background events would occur.
[b] The project is Pre-CD-2 and has not been baselined. All estimates are preliminary. The TPC point estimate is $1,500,000,000. The preliminary TPC range at CD-1 is $1,260,000,000 to $1,860,000,000. Design and international collaboration plans are currently being developed; outyears are preliminary.
[c] Costs through FY 2015 reflect actual costs; costs for FY 2016 and the outyears are estimates.
[d]$1,078,000 was erroneously costed to this project in FY 2012, the accounting records were adjusted in early FY 2013.

(dollars in thousands)	Appropriations	Obligations	Recovery Act Costs	Costs[a]
Construction[b]				
FY 2016	N/A	N/A	0	0
FY 2017	N/A	N/A	0	14,000[c]
Outyears	N/A	N/A	0	1,276,680
Total, Construction	N/A	N/A	0	1,290,680
TEC[b]				
FY 2012	4,000	4,000	0	0
FY 2013	3,781	3,781	0	801
FY 2014	16,000	16,000	0	7,109
FY 2015	12,000	12,000	0	15,791
FY 2016	26,000[d]	26,000[d]	0	38,080[d]
FY 2017	45,021[c]	45,021[c]	0	32,000[c]
Outyears	1,307,659	1,307,659		1,320,680
Total, TEC	1,414,461	1,414,461	0	1,414,461
Other Project Cost (OPC)				
OPC except D&D				
FY 2009 Recovery Act	12,486[e]	12,486	0	0
FY 2010	14,178	14,178	4,696	6,336
FY 2011	7,768	7,750	7,233	11,321
FY 2012	17,000	17,018[f]	557[g]	17,940
FY 2013	14,107	14,107	0	13,022
FY 2014	10,000	10,000	0	11,505
FY 2015	10,000	10,000	0	10,079
FY 2016	0	0	0	2,850
Total, OPC	85,539	85,539	12,486	73,053

[a] Costs through FY 2015 reflect actual costs; costs for FY 2016 and the outyears are estimates.

[b] The project is Pre-CD-2 and has not been baselined. All estimates are preliminary. The TPC point estimate is $1,500,000,000. The preliminary TPC range at CD-1 is $1,260,000,000 to $1,860,000,000. Design and international collaboration plans are currently being developed; outyears are preliminary.

[c] Estimated costs are for initiating excavation of the equipment caverns at the Far Site, to be approved by CD-3A.

[d] Estimated costs are for Far Site preparation including procurement of the waste-rock handling system and for safety and reliability refurbishment of the underground infrastructure, which are needed prior to initiating excavation of the equipment caverns.

[e] $13,000,000 of Recovery Act funding was originally planned for the conceptual design; the difference of $512,000 relates to pre-conceptual design activities needed prior to approval of mission need (CD-0).

[f] $18,000 of FY 2011 funding was attributed towards the Other Project Costs activities in FY 2012.

[g] During FY 2012, $1,000 of Recovery Act funding was recategorized from pre-conceptual design and so became part of the OPC. $3,000 was deobligated and expired because Recovery Act funds are no longer available for obligation.

	(dollars in thousands)			
	Appropriations	Obligations	Recovery Act Costs	Costs[a]
Total Project Cost (TPC)[b]				
FY 2009 Recovery Act	12,486	12,486	0	0
FY 2010	14,178	14,178	4,696	6,336
FY 2011	7,768	7,750	7,233	11,321
FY 2012	21,000	21,018	557	17,940
FY 2013	17,888	17,888	0	13,823
FY 2014	26,000	26,000	0	18,614
FY 2015	22,000	22,000	0	25,870
FY 2016	26,000	26,000	0	40,930
FY 2017	45,021	45,021	0	32,000
Outyears	1,307,659	1,307,659	0	1,320,680
Total, TPC	1,500,000	1,500,000	12,486	1,487,514

6. Details of Project Cost Estimate[c]

	(dollars in thousands)		
	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design			
Design	100,000	100,000	N/A
Contingency	23,781	27,781	N/A
Total, Design	123,781	127,781	N/A
Construction			
Site Preparation[d]	20,000	20,000	N/A
Far Site Civil Construction[e]	300,000	400,000	N/A
Fermilab Site Civil Construction[f]	270,000	N/A	N/A
Far Site Technical Infrastructure[g]	110,000	75,000	N/A

[a] Costs through FY 2015 reflect actual costs; costs for FY 2016 and the outyears are estimates.

[b] The project is Pre-CD-2 and has not been baselined. All estimates are preliminary. The TPC point estimate is $1,500,000,000. The preliminary TPC range at CD-1 is $1,260,000,000 to $1,860,000,000. Design and international collaboration plans are currently being developed; outyears are preliminary.

[c] The project is Pre-CD-2 and has not been baselined. All estimates are preliminary. The TPC point estimate is $1,500,000,000. The preliminary TPC range at CD-1 was $1,260,000,000 to $1,860,000,000.

[d] Site Preparation involves procurement of the waste-rock handling system and refurbishment of the existing underground infrastructure for improved safety and reliability at the Far Site, as well as for preparation of the Fermilab Site for construction.

[e] Far Site civil construction involves excavation of caverns at SURF, 4850 ft below the surface, for technical equipment including particle detectors and cryogenic systems.

[f] Fermilab Site civil construction involves construction of the housing for the neutrino-production beam line and the near detector.

[g] 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 1.

	(dollars in thousands)		
	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Fermilab Site Beamline[a]	130,000	75,000	N/A
DUNE Detectors	120,000	N/A	N/A
Contingency	340,680	160,612	N/A
Total, Construction	1,290,680	655,612	N/A
Total, TEC	1,414,461	783,393	N/A
Contingency, TEC	364,461	188,393	N/A
Other Project Cost (OPC)			
OPC except D&D			
R&D	18,000	16,000	N/A
Conceptual Planning	30,000	30,000	N/A
Conceptual Design	36,689	34,000	N/A
Contingency	850	9,539	N/A
Total, OPC	85,539	89,539	N/A
Contingency, OPC	850	9,539	N/A
Total, TPC	1,500,000	872,932	N/A
Total, Contingency	365,311	197,932	N/A

7. Schedule of Appropriation Requests[b]

Request Year		Prior Years	FY 2015	FY 2016	FY 2017	Outyears	Total
		(dollars in thousands)					
FY 2011	TEC	102,000	0	0	0	0	102,000
	OPC	22,180	0	0	0	0	22,180
	TPC	124,180	0	0	0	0	124,180
FY 2012	TEC	91,000	42,000	0	0	0	133,000
	OPC	42,621	0	0	0	0	42,621
	TPC	133,621	42,000	0	0	0	175,621
FY 2016	TEC	23,781	12,000	16,000	TBD	TBD	783,393
	OPC	75,539	10,000	4,000	TBD	TBD	89,539
	TPC	99,320	22,000	20,000	TBD	TBD	872,932
FY 2017[c]	TEC	23,781	12,000	26,000	45,021	1,307,659	1,414,461
	OPC	75,539	10,000	0	0	0	85,539
	TPC	99,320	22,000	26,000	45,021	1,307,659	1,500,000

8. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy	FY 2030
Expected Useful Life	20 years
Expected Future Start of D&D of this capital asset	FY 2050

[a] 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 1.
[b] Design and international collaboration plans are currently being developed; outyears are preliminary.
[c] The project is Pre-CD-2 and has not been baselined. All estimates are preliminary. The TPC point estimate is $1,500,000,000. The preliminary TPC range at CD-1 was $1,260,000,000 to $1,860,000,000.

Operations and maintenance funding of this experiment will become part of the existing Fermilab accelerator 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.

(Related Funding Requirements)

(dollars in thousands)

	Annual Costs		Life Cycle Costs	
	Current Total Estimate	Previous Total Estimate	Current Total Estimate	Previous Total Estimate
Operations	9,000	9,000	180,000	180,000
Utilities	8,000	8,000	160,000	160,000
Maintenance & Repair	1,000	1,000	20,000	20,000
Total	18,000	18,000	360,000	360,000

9. Required D&D Information

	Square Feet
Area of new construction	142,000 SF
Area of existing facility being replaced and D&D'd by this project	0
Area of other D&D outside the project	0
Area of any additional D&D space to meet the "one-for-one" requirement taken from the banked area.	142,000 SF

The one-for-one replacement has been met through banked space. A waiver from the one-for-one requirement to eliminate excess space at Fermilab to offset the LBNF/DUNE project was approved by DOE Headquarters on November 12, 2009. The waiver identified and transferred to Fermilab 575,104 square feet of excess space to accommodate the new LBNF facilities and other as yet unbuilt facilities from space that was banked at other DOE facilities.

10. Acquisition Approach

The LBNF and the DUNE detector apparatus comprise a unique, geographically distributed, complex system of scientific equipment consisting of a beam source at Fermilab and particle detectors both nearby at Fermilab and at a remote site 800 miles away in Lead, South Dakota. The overall DOE Project defined for delivery of LBNF and DUNE is referred to as LBNF/DUNE. The acquisition approach is documented in the Acquisition Strategy approved as part of CD-1. DOE is acquiring design, construction, fabrication and operation of LBNF through the M&O contractor responsible for Fermilab, Fermi Research Alliance (FRA). FRA and Fermilab, through the LBNF Project based at Fermilab, is responsible to DOE to manage and complete construction of the LBNF facility at both the near and remote site locations. FRA and Fermilab are assigned oversight and management responsibility for execution of the international DUNE project, to include management of the DOE contributions to DUNE. The basis for this choice and strategy is that:

- Fermilab 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.
- Fermilab 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 Fermilab.
- Fermilab 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.
- Fermilab 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.

- Fermilab, through the LBNF Project, has established a close working relationship with the Sanford Underground Research Facility (SURF) and the South Dakota Science and Technology Authority (SDSTA), organizations that manage and operate the remote site for the far detector in Lead, SD; Fermilab will work through SDSTA to award and manage contracts needed to complete the LBNF and DUNE work at the remote site.
- Fermilab 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.

In leading the LBNF/DUNE Project, Fermilab will collaborate and work with many institutions, including several DOE National Laboratories (BNL, LBNL and LANL), dozens of universities, foreign research institutions, SURF, and the SDSTA. Fermilab will be responsible for overall project management, near site conventional facilities, and the beamline. Fermilab will work through SDSTA/SURF to complete the conventional facilities construction at the remote site needed to house and outfit the DUNE far detector. With the DUNE collaboration, Fermilab is also responsible for technical and resource coordination to support the DUNE far and near detector design and construction. DOE will be providing in-kind contributions to the DUNE collaboration for detector systems, as agreed upon with the international DUNE collaboration. International participation in the design, construction, and operation of LBNF and DUNE will be of essential importance because the field of High Energy Physics is international by nature; necessary talent and expertise are globally distributed, and DOE does not have the procurement or technical resources to self-perform all of the required construction and fabrication work. Contributions from other nations will be predominantly through the delivery of components built in their own countries by their own researchers. DOE will negotiate agreements in cooperation with the Department of State on a bilateral basis with all contributing nations to specify their expected contributions and the working relationships during the construction and operation of the experiment. For the DUNE detector, the process of developing in-kind contributions is being driven by the principal investigators and being reviewed by their funding agencies.

DOE funding for the LBNF Project will be provided directly to Fermilab and collaborating DOE National Laboratories via approved financial plans, and under management control of the LBNF Project Office. The LBNF Project Office will also manage and control DOE funding to the other LBNF institutions contributing to detector design and construction. In addition to the work performed by DOE National Laboratories, a combination of university subcontracts and direct fixed-price purchases with vendors is anticipated to design, fabricate, and install the LBNF and DUNE technical components. The DUNE-U.S. Project Office at Fermilab will manage and control DOE funding to the other U.S. institutions contributing to DUNE detector design and construction. All actions will be in accordance with the DOE approved procurement policies and procedures.

Much of the neutrino beamline component design, fabrication, assembly, and installation will be done by Fermilab staff or by subcontract temporary staff working directly with Fermilab personnel. The acquisition approach includes both new procurements based on existing designs, and re-purposed equipment from the Fermilab accelerator complex. Some highly specialized components will be designed and fabricated by or in consultation with long-standing Fermilab collaborators having proven experience with such components.

Delivery of LBNF conventional facilities at the Fermilab near site and SURF far site will be via the Construction Manager/General Contractor (CM/GC) model. This strategy was chosen to reduce reduced risk, enhance quality and safety performance, provide a more collaborative approach to construction, and offer the opportunity for reduced cost and shortened construction schedules.

For the LBNF near site conventional facilities at Fermilab, procurement is through existing Fermilab master subcontracts with national architect/engineering companies for design services and contracts will be incrementally phase-funded since they will span multiple years.

For the LBNF far site conventional facilities at SURF, Fermilab will work with SDSTA, the owner of the site and land, which has been donated to SDSTA by the Homestake Mining Company for the sole purpose of facilitating scientific and technological research and development. Fermilab will contract directly with SDSTA to provide pre-construction services and design of LBNF far site conventional facilities at SURF. Fermilab will solicit bids for CM/GC services to manage the construction of LBNF far site facilities. The CM/GC subcontractor will furnish all labor, equipment and materials for far site conventional facilities construction management. Work includes pre-construction construction management services and an option for executing the construction and management of the construction. The CM/GC subcontractor staff will have proven experience in the area of construction management and construction of industrial and heavy construction projects. The CM/GC firm will provide support services to the LBNF and A/E teams, including input regarding the selection of materials, building systems and equipment, construction feasibility, value engineering, and factors related to construction, plus cost estimates and schedules, including estimates of alternative designs or materials. The CM/GC will also provide recommendations of actions designed to minimize adverse effects of labor or material shortages, time requirements for procurement and installation and construction completion.

The overall approach to both near and far site enables Fermilab to gain construction management expertise early in the design phase to produce well-integrated designs and well understood constructability, with potential cost and management efficiencies and reduced construction risk as a result.

Prior to the start of far-site conventional facilities construction, DOE plans to enter into a land lease with SDSTA covering the area on which the DOE funded facilities housing and supporting the LBNF and DUNE detector will be built. The lease provides the framework for DOE and Fermilab to construct federally funded buildings and facilities on non-federal land, and to establish a long-term (multi-decade) arrangement for DOE and Fermilab to use SDSTA space to host the DUNE experiment. DOE plans for Fermilab to have responsibility for managing and operating the LBNF and DUNE far detector and facilities for a useful lifetime of 20 year duration, 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. An appropriate decommissioning plan will be developed prior to lease signing.

11-SC-41, Muon to Electron Conversion Experiment (Mu2e), Fermi National Accelerator Laboratory, Batavia, Illinois
Project is for Design and Construction

1. Significant Changes and Summary

Significant Changes
This Construction Project Data Sheet (CPDS) is an update of the FY 2016 CPDS and does not include a new start for FY 2017.

Summary
The FY 2017 Request for the Muon to Electron Conversion Experiment (Mu2e) is $43,500,000, $3,400,000 more than the FY 2016 Enacted level of $40,100,000 and consistent with the approved baseline funding profile. The most recent DOE Order 413.3B approved Critical Decisions (CDs) are CD-2 (Approve Performance Baseline) and CD-3B (Approve Long-Lead Procurement), both approved on March 4, 2015. CD-2 established the scope, cost, and schedule baseline and CD-3B initiated civil construction and long-lead procurement of the Transport Solenoid modules. A new milestone, CD-3C, was established concurrent with completion of final design, which is anticipated to be in 3Q FY 2016. Total Project Cost was approved at $273,677,000. The funding profile supports this TPC. The CD-4 milestone is 1Q FY 2023.

A Federal Project Director (FPD) with Certification Level 2 has been assigned to this project and has approved this CPDS. The FPD will complete the Level-3 Certification requirements in FY 2016.

The Mu2e project provides the accelerator beam and experimental apparatus to identify unambiguously neutrinoless muon-to-electron conversion events. The conversion of a muon to an electron in the field of a nucleus would probe new physics for discovery at mass scales far beyond the reach of any existing or proposed experiment. Civil construction has started and long-lead procurement for the Transport Solenoid system began in 4Q FY 2015. In FY 2016, the long-lead procurement activities and civil construction will continue, and final design and prototyping for accelerator, beamline and particle detector systems will be completed. Fabrication of the accelerator, beamline and detector technical systems will be initiated in 4Q FY 2016, following Critical Decision CD-3C, and will continue throughout FY 2017.

2. Critical Milestone History

(fiscal quarter or date)

	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	D&D Complete	CD-4
FY 2011	11/24/2009		4Q FY 2010	TBD	4Q FY 2012	TBD	TBD	TBD
FY 2012	11/24/2009		4Q FY 2011	TBD	4Q FY 2013	TBD	TBD	TBD
FY 2013	11/24/2009		4Q FY 2012	4Q FY 2013	4Q FY 2014	4Q FY 2014	N/A	4Q FY 2018
FY 2014	11/24/2009		7/11/2012	2Q FY 2014	2Q FY 2015	4Q FY 2015	N/A	2Q FY 2021
FY 2013 Repro-gramming	11/24/2009		7/11/2012	2Q FY 2014	2Q FY 2015	4Q FY 2015	N/A	2Q FY 2021
FY 2015	11/24/2009		7/11/2012	4Q FY 2014	2Q FY 2015	4Q FY 2014	N/A	2Q FY 2021
FY 2016	11/24/2009	7/11/2012	7/11/2012	2Q FY 2015	3Q FY 2016	3Q FY 2016	N/A	1Q FY 2023
FY 2017 PB	11/24/2009	7/11/2012	7/11/2012	3/4/2015	3Q FY 2016	3Q FY 2016	N/A	1Q FY 2023

CD-0 – Approve Mission Need
Conceptual Design Complete – Actual date the conceptual design was completed
CD-1 – Approve Design Scope and Project Cost and Schedule Ranges
CD-2 – Approve Project Performance Baseline
Final Design Complete – Estimated/Actual date the project design will be/was completed
CD-3 – Approve Start of Construction
D&D Complete – Completion of D&D work (see section 9)
CD-4 – Approve Start of Operations or Project Closeout
PB – Indicates the Performance Baseline

	Performance Baseline Validation	CD-3A	CD-3B	CD-3C
FY 2014		3Q FY 2013		
FY 2013 Reprogram-ming		3Q FY 2013		
FY 2015		3Q FY 2014		
FY 2016	2Q FY 2015	7/10/2014	2Q FY 2015	3Q FY 2016
FY 2017 PB	3/4/2015	7/10/2014	3/4/2015	3Q FY 2016

CD-3A – Approve Long-Lead Procurement of superconducting wire for the magnet systems.
CD-3B – Approve Long-Lead Procurement for superconducting solenoid magnet modules and for construction of the detector hall.
CD-3C – Approve All Construction and Fabrication (same as CD-3)

3. Project Cost History

(dollars in thousands)

	TEC, Design	TEC, Construction	TEC, Total	OPC Except D&D	OPC, D&D	OPC, Total	TPC
FY 2011	35,000	TBD	TBD	10,000	TBD	TBD	TBD
FY 2012	36,500	TBD	TBD	18,777	TBD	TBD	TBD
FY 2013	44,000	N/A	N/A	24,177	0	24,177	68,177
FY 2014	61,000	162,000	223,000	26,177	0	26,177	249,177
FY 2013 Reprogram-ming	49,000	162,000	211,000	23,677	0	23,677	234,677
FY 2015	47,000	162,900	209,900	23,677	0	23,677	233,577
FY 2016	57,000	193,000	250,000	23,677	N/A	23,677	273,677
FY 2017 PB	57,000	193,000	250,000	23,677	N/A	23,677	273,677[a]

4. Project Scope and Justification

Scope

The Mu2e project includes accelerator modifications, fabrication of superconducting magnets and particle detector systems, and construction of a civil facility with the special capabilities necessary for the experiment. The scope of work in the Project Data Sheet has not changed. The muon beam for the Mu2e experiment will be produced by an intense 8-GeV proton beam, extracted from the Fermilab Booster accelerator, striking a tungsten target. The Mu2e project will modify the existing Fermilab accelerator complex (Booster, Recycler and Debuncher Rings) to deliver the primary proton beam to a muon production target, and efficiently collect and transport the produced muons to a stopping target. The stopping target is surrounded by the Mu2e detector system that can identify muon-to-electron conversions and reject background contamination.

The project will design and construct the detector system (consisting of a tracker, calorimeter, cosmic ray veto and data acquisition subsystem), a new beam line from the Debuncher Ring to the detector system, and three superconducting solenoid magnets (a Production Solenoid, Transport Solenoid and Detector Solenoid) that will serve as the beam transport channel for collecting the muons and transporting them into the detector system.

[a] No construction, other than approved long-lead procurement and detector hall civil construction, will be performed until CD-3 has been approved.

The project will design and construct a 25,000 square foot civil facility with the special capabilities required to house the primary beam target and transport systems for producing the muons and stopping them in the detector system. The civil construction consists of an underground detector enclosure and a surface building, for containing the necessary equipment and infrastructure that can be accessed while the multikilowatt proton beam is being delivered to the experiment. The building includes radiation shielding and design features for safe operation of the beam line and experimental apparatus.

Justification

The conversion of a muon to an electron in the field of a nucleus provides a unique window for discovery of charged lepton flavor symmetry violation and allows access to new physics at very high mass scales. In 2008, the Particle Physics Project Prioritization Panel (P5), a subpanel of the High Energy Physics Advisory Panel (HEPAP), recommended this type of experiment for the Intensity Frontier of particle physics. The most recent P5 Subpanel reiterated this recommendation in its 2014 report. This project provides accelerator beam and experimental apparatus to identify unambiguously neutrinoless muon-to-electron conversion events.

Key Performance Parameters

System	Threshold Performance	Objective Performance
Accelerator		
	Accelerator components are acceptance tested at nominal voltages and currents. Components necessary for single-turn extraction installed. Shielding designed for 1.5 kW operation delivered to Fermilab and ready for installation. All target station components are complete, delivered to Fermilab and tested. Heat and Radiation Shield is installed in Production Solenoid. Other components are ready to be installed after field mapping.	Protons are delivered to the diagnostic absorber in the M4 beamline. Shielding designed for 8 kW operation delivered to Fermilab and ready for installation.
Superconducting Solenoid Magnets		
	The Production, Transport and Detector Solenoids have been cooled and powered to the settings necessary to take physics data.	The Production, Transport and Detector Solenoids have been cooled and powered to their nominal field settings.
Detector Components		
	Cosmic Ray Tracks are observed in the Tracker, Calorimeter and a subset of the Cosmic Ray Veto and acquired by the Data Acquisition System after they are installed in the garage position behind the Detector Solenoid. The balance of the Cosmic Ray Veto counters are at Fermilab and ready for installation.	The cosmic ray data in the detectors is acquired by the Data Acquisition System, reconstructed in the online processors, visualized in the event display and stored on disk.

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

5. Financial Schedule

	(dollars in thousands)		
	Appropriations	Obligations	Costs[a]
Total Estimated Cost (TEC)			
Design			
FY 2013	N/A	N/A	14,653
FY 2014	N/A	N/A	15,404

[a] Costs through FY 2015 reflect actual costs; costs for FY 2016 and the outyears are estimates.

	(dollars in thousands)		
	Appropriations	Obligations	Costs[a]
FY 2015	N/A	N/A	16,892
FY 2016	N/A	N/A	10,051
Total, Design	N/A	N/A	57,000
Construction			
FY 2014	N/A	N/A	0
FY 2015	N/A	N/A	9,907
FY 2016	N/A	N/A	59,000
FY 2017	N/A	N/A	30,000
FY 2018	N/A	N/A	30,000
FY 2019	N/A	N/A	30,000
FY 2020	N/A	N/A	20,000
FY 2021	N/A	N/A	10,000
FY 2022	N/A	N/A	4,093
Total, Construction	N/A	N/A	193,000
TEC			
FY 2012	24,000	24,000	0
FY 2013	8,000[b]	8,000	14,653
FY 2014	35,000[c]	35,000	15,404
FY 2015	25,000[d]	25,000	26,799
FY 2016	40,100	40,100	69,051
FY 2017	43,500	43,500	30,000
FY 2018	44,400	44,400	30,000
FY 2019	30,000	30,000	30,000
FY 2020	0	0	20,000
FY 2021	0	0	10,000
FY 2022	0	0	4,093
Total, TEC	250,000	250,000	250,000
Other Project Costs (OPC)			
OPC except D&D			
FY 2010	4,777	4,777	3,769
FY 2011	8,400	8,400	8,940
FY 2012	8,000	8,000	6,740
FY 2013	2,500	2,500	1,020
FY 2014	0	0	2,136
FY 2015	0	0	159
FY 2016	0	0	913
Total, OPC	23,677	23,677	23,677
Total Project Cost (TPC)			
FY 2010	4,777	4,777	3,769
FY 2011	8,400	8,400	8,940
FY 2012	32,000	32,000	6,740

[a] Costs through FY 2015 reflect actual costs; costs for FY 2016 and the outyears are estimates.
[b] Congress approved a reprogramming that reduced the FY 2013 funding to $8,000,000 from the $22,685,000 that was originally appropriated.
[c] $5,162,907 was for long-lead procurements of superconducting wire for the magnet systems.
[d] $25,000,000 was for long-lead procurements for the superconducting solenoid magnet modules and for civil construction of the detector hall.

	(dollars in thousands)		
	Appropriations	Obligations	Costs[a]
FY 2013	10,500	10,500	15,673
FY 2014	35,000	35,000	17,540
FY 2015	25,000	25,000	26,958
FY 2016	40,100	40,100	69,964
FY 2017	43,500	43,500	30,000
FY 2018	44,400	44,400	30,000
FY 2019	30,000	30,000	30,000
FY 2020	0	0	20,000
FY 2021	0	0	10,000
FY 2022	0	0	4,093
Total, TPC	273,677	273,677	273,677

6. Details of Project Cost Estimate

	(dollars in thousands)		
	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design			
Design	52,000	55,000	49,000
Contingency	5,000	2,000	8,000
Total, Design	57,000	57,000	57,000
Construction			
Site Work	2,000	2,000	2,000
Construction	13,000	19,000	13,000
Equipment	133,000	119,000	133,000
Contingency	45,000	53,000	45,000
Total, Construction	193,000	193,000	193,000
Total, TEC	250,000	250,000	250,000
Contingency, TEC	50,000	55,000	53,000
Other Project Cost (OPC)			
OPC except D&D			
R&D	8,200	6,600	8,200
Conceptual Planning	2,300	4,350	2,300
Conceptual Design	13,177	12,727	13,177
Total, OPC	23,677	23,677	23,677
Total, TPC	273,677	273,677	273,677
Total, Contingency	50,000	55,000	53,000

[a] Costs through FY 2015 reflect actual costs; costs for FY 2016 and the outyears are estimates.

7. Schedule of Appropriation Requests

(dollars in thousands)

Request Year		Prior Years	FY 2012	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019	Total
FY 2011	TEC	5,000	30,000	0	0	0	0	0	0	0	35,000
	OPC	10,000	0	0	0	0	0	0	0	0	10,000
	TPC	15,000	30,000	0	0	0	0	0	0	0	45,000
FY 2012	TEC	0	24,000	12,500	0	0	0	0	0	0	36,500
	OPC	12,777	6,000	0	0	0	0	0	0	0	18,777
	TPC	12,777	30,000	12,500	0	0	0	0	0	0	55,277
FY 2013	TEC	0	24,000	20,000	0	0	0	0	0	0	44,000
	OPC	13,177	6,000	5,000	0	0	0	0	0	0	24,177
	TPC	13,177	30,000	25,000	0	0	0	0	0	0	68,177
FY 2014	TEC	0	24,000	24,147	35,000	32,000	44,000	45,000	23,000	0	223,000
	OPC	13,177	8,000	8,049	0	0	0	0	0	0	26,177
	TPC	13,177	32,000	32,196[a]	35,000	32,000	44,000	45,000	23,000	0	249,177
FY 2013 Repro-gram-ming	TEC	0	24,000	8,000[b]	35,000	32,000	44,000	45,000	23,000	0	211,000
	OPC	13,177	8,000	2,500	0	0	0	0	0	0	23,677
	TPC	13,177	32,000	10,500	35,000	32,000	44,000	45,000	23,000	0	234,677
FY 2015	TEC	0	24,000	8,000	35,000	25,000	42,000	43,000	32,900	0	209,900
	OPC	13,177	8,000	2,500	0	0	0	0	0	0	23,677
	TPC	13,177	32,000	10,500	35,000	25,000	42,000	43,000	32,900	0	233,577
FY 2016	TEC	0	24,000	8,000	35,000	25,000	40,100	43,500	44,400	30,000	250,000
	OPC	13,177	8,000	2,500	0	0	0	0	0	0	23,677
	TPC	13,177	32,000	10,500	35,000	25,000	40,100	43,500	44,400	30,000	273,677
FY 2017 PB	TEC	0	24,000	8,000	35,000	25,000	40,100	43,500	44,400	30,000	250,000
	OPC	13,177	8,000	2,500	0	0	0	0	0	0	23,677
	TPC	13,177	32,000	10,500	35,000	25,000	40,100	43,500	44,400	30,000	273,677

8. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy	FY 2023
Expected Useful Life	10 years
Expected Future Start of D&D of this capital asset	FY 2033

Operations and maintenance of this experiment will become part of the existing Fermilab accelerator facility. Annual related funding estimates are for the incremental cost of five years of full operation, utilities, maintenance and repairs with the accelerator beam on. Five subsequent years are planned for further analysis of the data while the detector and beam line are maintained in a minimal maintenance state (with annual cost of approximately 3% of full operations) to preserve availability for future usage with much smaller annual cost.

[a] The FY 2013 amount shown reflected the P.L. 112-175 continuing resolution level annualized to a full year. The TEC, OPC, and TPC total and outyear appropriation assumptions were not adjusted to reflect the final FY 2013 level; the FY 2013 Request level of $25,000,000 ($20,000,000 TEC and $5,000,000 OPC) were assumed instead.
[b] Congress approved a reprogramming that reduced the FY 2013 funding to $8,000,000 from the $22,685,000 that was originally appropriated.

(Related Funding Requirements)

	(dollars in thousands)			
	Annual Costs		Life Cycle Costs	
	Current Total Estimate	Previous Total Estimate	Current Total Estimate	Previous Total Estimate
Operations	3,100	3,100	16,000	16,000
Utilities	2,400	2,400	12,400	12,400
Maintenance & Repair	100	100	600	600
Total	5,600	5,600	29,000	29,000

9. Required D&D Information

	Square Feet
Area of new construction	~25,000
Area of existing facility being replaced and D&D'd by this project.............................	0
Area of other D&D outside the project	0
Area of any additional D&D space to meet the "one-for-one" requirement taken from the banked area.	~25,000

The one-for-one replacement has been met through banked space. A waiver from the one-for-one requirement to eliminate excess space at Fermilab to offset the Mu2e project was approved by DOE Headquarters on November 12, 2009. The waiver identified and transferred to Fermilab 575,104 square feet of excess space to accommodate the new Mu2e facilities and other as yet unbuilt facilities from space that was banked at other DOE facilities.

10. Acquisition Approach

The acquisition approach is fully documented in the Acquisition Strategy approved as part of CD-1. This is a high-level summary of material from that document.

DOE has awarded the prime contract for the Mu2e project to the Fermi Research Alliance (FRA), the Fermilab Management and Operating (M&O) contractor, 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 Fermilab scientists and engineers. This arrangement will facilitate close cooperation and coordination between the Mu2e scientific collaboration and an experienced team of project leaders managed by FRA. FRA will have primary responsibility for oversight of all subcontracts required to execute the project. These subcontracts are expected to include the purchase of components from third party vendors as well as subcontracts with university groups to fabricate detector subsystems.

The largest procurements will be the magnet systems and the civil construction. The superconducting solenoid magnets are divided into three systems that could be procured independently but which must ultimately perform as a single integrated magnetic system. Two of the systems are similar to systems that have been successfully built in private industry, so the engineering design and fabrication for two of the solenoids may be subcontracted to third party vendors, if a planned study of industrial vendor capabilities confirms that the technical risks are acceptable. The third solenoid is relatively unique, and no good industrial analog exists. This solenoid will be designed and fabricated at Fermilab, though most of the parts will be procured from third party vendors.

There are two major subcontracts for the civil construction for Mu2e. An architecture and engineering (A&E) contract was placed on a firm-fixed-price basis for Preliminary (Title I) Design, and Final (Title II) Design with an option for construction (Title III) support. The general construction subcontract was placed on a firm-fixed-price basis.

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