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 offers research opportunities for 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 proven 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 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 tradition 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 2016 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 2016 budget request implements the recommendations contained in the P5 report. Support is requested for 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 Super Cryogenic Dark Matter Search at the new Sudbury Neutrino Observatory laboratory (SuperCDMS-SNOLab), the Large Underground Xenon (LUX) –ZonEd Proportional scintillation in LIquid Noble gases (ZEPLIN) experiment (LZ), and the Dark Energy Spectroscopic Instrument (DESI) projects. Capital equipment funding is requested to continue support of the planned funding profiles for the camera for the Large Synoptic Survey Telescope (LSSTcam) project, the Muon g-2 Experiment, and the U.S. contributions to the Large Hadron Collider (LHC) A Toroidal LHC Apparatus (ATLAS) Detector Upgrade, and the LHC Compact Muon Solenoid (CMS) Detector Upgrade. The internationalization and re-scoping of the Long Baseline Neutrino Experiment to optimize science impact is a major recommendation from P5. HEP will pursue the development of a more capable long baseline experiment by recruiting international partners. To recognize this change, P5 suggested a name change to Long Baseline Neutrino Facility (LBNF), and the name has been adopted here.

<u>Energy Frontier Experimental Physics</u>

The LHC will resume operations in 2015 at collision energies of at least 13 TeV, a substantial increase from 8 TeV in the last run. This 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. Investments are made for U.S. contributions to future planned LHC detector upgrades that will exploit the full physics potential of the higher luminosities.

<u>Intensity Frontier Experimental Physics</u>

FY 2016 will feature full operations for the NOvA detector in the world's most intense neutrino beam from Fermilab. The physics goals of this experiment include improved measurements of neutrino mixing and first results on the neutrino mass hierarchy and the search for Charge Parity (CP) violation in the neutrino sector. The MicroBooNE detector will be in full operation in the Fermilab Booster Neutrino Beam, with a goal of resolving certain anomalies seen in several previous accelerator based neutrino experiments.

The Mu2e construction project and the Muon g-2 major item of equipment will be in the fabrication phase; physics studies and simulations will continue to optimize the physics output of these experiments. These experiments will probe energy scales beyond the LHC through the study of rare processes and precision measurements. U.S. contributions to the Belle II detector upgrade will be complete in FY 2015. The Belle II detector is located at a particle accelerator facility in Tsukuba, Japan and will study rare decays and CP violation in the heavy quark systems.

Cosmic Frontier Experimental Physics

A coordinated program of dark energy science will continue in FY 2016: the Dark Energy Survey enters its fourth year of operations; next generation imaging and spectroscopic experiments enter fabrication, specifically the Large Synoptic Survey Telescope's digital camera, the LSSTcam; and the Dark Energy Spectroscopic Instrument (DESI) project will be baselined. Three second generation experiments were selected in 2014 to directly detect dark matter, including the small-scale Axion Dark Matter Search Generation 2 (ADMX-G2), which completes its development phase in FY 2016. The LZ and SuperCDMS-SNOLab projects were selected and are expected to be baselined in FY 2016. Community 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 2016, 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 on computation, simulation, data tools, and software that cut across all HEP programs. It provides partnership opportunities with other Office of Science programs as well as other agencies.

Advanced Technology R&D

In the past five years, HEP built two accelerator R&D test facilities (BELLA, Berkeley Lab Laser Accelerator, at LBNL; and FACET, Facility for Advanced Accelerator Experimental Tests, at SLAC) to support research using plasmas to accelerate charged particles much more effectively than conventional electromagnetic cavities. Both are supported for continued operations and research in this budget request. 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 or electron beams. Both techniques have successfully accelerated beams while maintaining good beam quality. These discoveries are being followed with research programs in FY 2016 to determine if practical particle accelerators can be built with these techniques, and which possible scientific applications of these new devices are most promising.

The LHC Accelerator Research Program 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 2016 to meet the schedule for delivery of prototype magnets. Following HEPAP recommendations and external technical reviews, the Muon Accelerator Program is being ramped down; some key elements with broad applications will be redirected into General Accelerator R&D.

Accelerator Stewardship

The first call for Accelerator Stewardship proposals in 2014 emphasized applications identified by a technical working group in 2012, which were further developed in cross-disciplinary community workshops in 2013. These applications include accelerator technology to enable ion-beam therapy of cancer; and R&D for high-power ultrafast lasers, a supporting technology that has grown steadily in importance to accelerators and science in general. This call also solicited proposals for accelerator R&D with the potential to significantly increase accelerator performance and decrease cost. Applications funded in the initial call for proposals will be ongoing in FY 2016. The pilot program to open DOE national laboratory accelerator test facilities to industry users, scheduled to begin in 2015, is also planned to continue.

The main accelerator test facility that supports this subprogram, the Brookhaven Accelerator Test Facility (ATF), is undergoing relocation and expansion in FY 2016 to accommodate more users.

The FY 2016 funding request provides support for a new research thrust in energy and environmental applications of accelerators and expands the open test facilities effort. The energy and environment topic was also identified by the 2012 technical working group report, and in response to a subsequent broadly-based Request for Information in 2014. Cross-disciplinary community workshops planned for 2015 will identify targeted R&D areas appropriate for a new Stewardship funding opportunity announcement.

Construction

Two construction projects are underway to support Intensity Frontier Physics. The Muon to Electron Conversion Experiment (Mu2e), which will search for violation of charged lepton flavor conservation, completes its design phase and proceeds with construction in FY 2015. The LBNF will continue its design phase in FY 2016. Following recommendations of the P5 report, LBNF design efforts will be optimized to support a reconfigured international Long Baseline Neutrino Facility. International in-kind contributions are actively being sought, and will be incorporated into a revised project as the overall baseline cost and technical scope are developed over the next few years.

High Energy Physics
Funding ($K)

	FY 2014 Enacted	FY 2014 Current[1]	FY 2015 Enacted	FY 2016 Request	FY 2016 vs. FY 2015
Energy Frontier Experimental Physics					
Research	94,987	94,987	78,782	78,837	+55
Facility Operations and Experimental Support	57,399	57,399	53,802	56,718	+2,916
Projects	0	0	15,000	19,000	+4,000
Total, Energy Frontier Experimental Physics	**152,386**	**152,386**	**147,584**	**154,555**	**+6,971**
Intensity Frontier Experimental Physics					
Research	56,401	56,401	55,181	55,924	+743
Facility Operations and Experimental Support	157,186	157,186	165,073	157,572	-7,501
Projects	37,400	37,400	43,970	33,700	-10,270
Total, Intensity Frontier Experimental Physics	**250,987**	**250,987**	**264,224**	**247,196**	**-17,028**
Cosmic Frontier Experimental Physics					
Research	52,712	52,712	49,310	50,079	+769
Facility Operations and Experimental Support	13,510	13,510	11,832	10,545	-1,287
Projects	30,705	30,705	45,728	58,701	+12,973
Total, Cosmic Frontier Experimental Physics	**96,927**	**96,927**	**106,870**	**119,325**	**+12,455**
Theoretical and Computational Physics					
Research					
Theory	52,613	52,613	50,224	50,182	-42
Computational HEP	8,462	8,462	8,050	8,135	+85
Total, Research	61,075	61,075	58,274	58,317	+43
Projects	3,200	3,200	1,000	2,000	+1,000
Total, Theoretical and Computational Physics	**64,275**	**64,275**	**59,274**	**60,317**	**+1,043**

[1] Funding reflects the transfer of SBIR/STTR to the Office of Science.

	FY 2014 Enacted	FY 2014 Current[1]	FY 2015 Enacted	FY 2016 Request	FY 2016 vs. FY 2015
Advanced Technology R&D					
Research					
HEP General Accelerator R&D	55,617	55,617	45,452	39,924	-5,528
HEP Directed Accelerator R&D	25,463	25,463	22,570	21,500	-1,070
Detector R&D	24,402	24,402	21,914	21,922	+8
Total, Research	105,482	105,482	89,936	83,346	-6,590
Facility Operations and Experimental Support	44,788	44,788	30,318	32,023	+1,705
Total, Advanced Technology R&D	**150,270**	**150,270**	**120,254**	**115,369**	**-4,885**
Accelerator Stewardship					
Research	3,275	3,275	5,900	8,200	+2,300
Facility Operations and Experimental Support	5,800	5,800	4,100	5,800	+1,700
Total, Accelerator Stewardship	**9,075**	**9,075**	**10,000**	**14,000**	**+4,000**
SBIR/STTR	21,601	0	20,794	21,138	+344
Subtotal, High Energy Physics	**745,521**	**723,920**	**729,000**	**731,900**	**+2,900**
Construction					
11-SC-40, Long Baseline Neutrino Facility	16,000	16,000	12,000	16,000	+4,000
11-SC-41, Muon to Electron Conversion Experiment	35,000	35,000	25,000	40,100	+15,100
Total, Construction	**51,000**	**51,000**	**37,000**	**56,100**	**+19,100**
Total, High Energy Physics	**796,521**	**774,920**	**766,000**	**788,000**	**+22,000**

SBIR/STTR:

- FY 2014 Transferred: SBIR: $18,901,000; STTR: $2,700,000
- FY 2015 Projected: SBIR: $18,273,000; STTR: $2,521,000
- FY 2016 Request: SBIR: $18,381,000; STTR: $2,757,000

High Energy Physics
Explanation of Major Changes ($K)

	FY 2016 vs. FY 2015
Energy Frontier Experimental Physics: Increased funding continues LHC detector upgrade fabrication activities, scheduled for completion by 2018. Research efforts are maintained at approximately FY 2015 levels to support continuing analysis and interpretation of LHC data as well as exploratory physics studies. Initial investments are made to support R&D activities for longer-term operations of the LHC detectors at higher luminosities, in accordance with the long-term strategic plan for particle physics recommended by HEPAP.	+6,971
Intensity Frontier Experimental Physics: Reductions are primarily from moving Facility Operations, particularly the continued operation of facilities for testing of, and R&D on, superconducting radiofrequency acceleration (RF) cavities to Advanced Technology Facility Operations, which is more appropriate for an R&D-driven activity. Project R&D efforts funded as LBNF Other Project Cost (OPC) also ramp-down as that project moves into the engineering design phase. 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; and support for R&D and fabrication of current and future experiments, including a new short baseline neutrino program at Fermilab, as recommended in the HEPAP strategic plan. Research efforts are slightly increased in order to maintain support for data analysis of current experiments as well as physics studies for next-generation experiments.	-17,028
Cosmic Frontier Experimental Physics: Funding increases are dominated by the ramp-up of the LSSTcam MIE according to its planned profile and proceeding with MIE fabrication phases for recent, next-generation dark energy (DESI) and dark matter (LZ and SuperCDMS-SNOLab) experiments, in accordance with the long-term strategic plan for particle physics recommended by HEPAP. Some operations support of current experiments is redirected to support R&D and fabrication efforts for these new experiments. Research efforts are slightly increased in order to maintain support for data analysis of current experiments as well as physics studies for next-generation experiments.	+12,455
Theoretical and Computational Physics: The Lattice QCD project increases by $1,000,000 according to its profile. Research efforts are slightly increased in order to maintain support for analysis and interpretation of data as well as exploratory physics studies.	+1,043
Advanced Technology R&D: Research activities are reduced to shift towards higher priority R&D activities aligned with the HEPAP strategic plan. In particular, funding for the Muon Accelerator Program is reduced further with the last year of funding in FY 2017.	-4,885
Accelerator Stewardship: Research activities are increased to provide support for new stewardship research topics and expand the open test facilities effort. Increases in Facility Operations will allow completion of the BNL Accelerator Test Facility (ATF) relocation, which will accommodate more users.	+4,000
SBIR/STTR: Funding provided in accordance with the legislatively directed percentage of HEP operating budgets.	+344
Construction: Funding is provided according to the planned profile for construction of the Muon to Electron Conversion Experiment. Funding for engineering and design of the LBNF is requested, in accordance with the P5 recommendation.	+19,100
Total, High Energy Physics	**+22,000**

Basic and Applied R&D Coordination

HEP funded research has frequently resulted in unanticipated technology applications. Although it has been recognized that many of these technology developments have transformative impacts in the areas of national security, medicine, energy and environment, industry, and discovery science (including accelerator science), there has been no systematic way of enhancing technology transfer to these other fields.

HEP developed the Accelerator Stewardship subprogram based on input from accelerator R&D and experts in this field 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 and Nuclear Physics programs and partner agencies 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 National Science Foundation's (NSF) Physics Division, and overseen by a Joint Oversight Group (JOG). Dark matter research is also jointly sponsored by these agencies, which are coordinating their planning on next generation experiments. Both HEP and NSF Physics use the High Energy Physics Advisory Panel (HEPAP) as part of their advisory structure. HEP also coordinates with NSF Astronomy on the Dark Energy Survey and the Large Synoptic Survey Telescope, 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 joint interest. HEP also coordinates with other offices with the Office of Science 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 2014.

LHC experiments confirm the Standard Model Higgs boson has been found (Energy Frontier). François Englert and Peter Higgs were awarded the 2013 Nobel Prize in Physics for their contributions to our understanding of the origin of mass, confirmed by the discovery of the Higgs boson in 2012 by the ATLAS and CMS experiments at CERN's Large Hadron Collider. Additional data published during 2013- 2014 made the signal for the Higgs boson indisputable and provided additional measurements of its fundamental properties consistent with the predictions of the Standard Model. U.S. HEP research groups have made leading contributions to both the discovery and the confirmation of the Higgs.

First results from the Large Underground Xenon (LUX) dark matter direct detection experiment set the world's most stringent limits (Cosmic Frontier). With 350 kg of xenon mass, LUX is currently the world's largest operating dual-phase liquid xenon detector. The new limits are based on the initial 110 days of data recorded with the experiment installed 4,850 feet underground at the Sanford Underground Research Facility (SURF). LUX continues to take data in parallel with the development of LUX-ZEPLIN (LZ), a second-generation dark matter direct detection experiment that will use seven tons of active liquid xenon to significantly improve sensitivity.

The *Baryon Oscillation Spectroscopic Survey (BOSS) measured the scale of the universe to an accuracy of one percent (Cosmic Frontier).* Dark energy is believed to be the force driving the accelerating expansion of the universe, but to verify this theory one needs precise measurements of distance scales in the universe at different epochs. The BOSS measurement and future data at this level of precision are the keys to determining the nature of dark energy. The Dark Energy Survey (DES) experiment completed its first full year of a five year survey using imaging observations, which will provide complementary precision measurements to BOSS in understanding the nature of dark energy.

The Berkeley Lab Laser Accelerator (BELLA) set a new world record for laser-driven plasma wakefield acceleration (Advanced Technology R&D). Research in plasma wakefield acceleration aims to create compact and cost-effective acceleration technology for future particle accelerators. BELLA accelerated electrons to 4.25 GeV using a 9 cm plasma channel created by a 390 TW laser pulse. Today's technology would require a 200 meter long accelerator to achieve the same energy.

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 2016 will be focused on the LHC, which will resume operations in FY 2015 after a planned shutdown that began in FY 2013 to bring the collider to the 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 recent P5 strategic plan:

- *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. During their second run in FY 2016, the LHC detectors will be equipped to be much 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 collaborations of international 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.

<u>Research</u>

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 2012, and findings from this review are being used to inform the funding decisions in subsequent years. HEP will review this activity again in late FY 2015 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 Fermi National Accelerator Laboratory (Fermilab) and the Brookhaven National Laboratory (BNL). There are 11 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

This activity will support the fabrication of major items of equipment (MIE) for the Energy Frontier subprogram, namely upgrades to the ATLAS and CMS detectors.

CERN plans to upgrade the LHC machine to produce two to three times the instantaneous luminosity currently delivered. This work is planned to be completed in 2018. The objective of the two detector upgrade projects is 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.

The ATLAS Detector Upgrade Project was a new MIE start in FY 2015. The 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 CMS Detector Upgrade Project was a new MIE start in FY 2015. The 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.

Energy Frontier Experimental Physics

Activities and Explanation of Changes

FY 2015 Enacted	FY 2016 Request	Explanation of Changes FY 2016 vs. FY 2015
Energy Frontier Experimental Physics $147,584,000	**$154,555,000**	**+$6,971,000**
Research ($78,782,000)	**Research ($78,837,000)**	**Research (+$55,000)**
U.S. university and laboratory scientists focus on continuing research activities in conducting high-profile studies, including precision measurements of the recently discovered Higgs boson and search for new physics.	U.S. university and laboratory scientists will begin analyzing the newly acquired data from LHC's second run that begins in early-2015. Research activities will focus on addressing key areas within the five science drivers outlined in the long-range strategic plan for particle physics, which include using the Higgs boson as a new tool for discovery and exploring new particles and their interactions.	Funding for the Energy Frontier research is maintained at a constant level to support U.S. scientists continuing research activities in high-profile analyses topics during LHC's second run.
Facility Operations and Experimental Support ($53,802,000)	**Facility Operations and Experimental Support ($56,718,000)**	**Facility Operations and Experimental Support (+$2,916,000)**
The LHC resumes full operations in mid FY 2015, and activities supported shift to routine maintenance and calibration of the detectors. The computing centers will process the newly acquired data in addition to supporting data analysis and simulation.	Operation of the LHC ATLAS and CMS detectors will be supported 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 will be made to support critical R&D activities for longer-term operations of the LHC detectors at higher luminosities.	FY 2016 will be the first year of full operations after an extended shutdown ends in mid FY 2015 and funding is increased to meet the increased operational expenses.
Projects ($15,000,000)	**Projects ($19,000,000)**	**Projects (+$4,000,000)**
In order to take advantage of the increased LHC luminosity, two new MIEs are initiated. The LHC ATLAS Detector Upgrade provides upgrades to the Muon Subsystem, the Liquid Argon Calorimeter Detector, and Trigger and Data Acquisition System.	The LHC ATLAS and CMS Detector Upgrade projects were baselined in FY 2015 and fabrication activities will continue into FY 2016.	Increased funds are provided to support the ramp up of fabrication activities for the two LHC Detector Upgrades according to funding profiles approved at CD-2.

FY 2015 Enacted	FY 2016 Request	Explanation of Changes FY 2016 vs. FY 2015
The CMS Detector Upgrade provides upgrades to the Pixelated Inner Tracking Detector, the Hadron Calorimeter Detector, and Trigger System.		

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 Nuclear Physics. 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. These facilities and investments are concentrated primarily in the areas of neutrino and muon physics at Fermilab. The NOvA neutrino detector was completed in FY 2014 and will have a full run in FY 2015 with the upgraded NuMI beam, the world's most powerful neutrino beam. Operation of the Daya Bay Reactor Neutrino Experiment in China will continue in FY 2016. Fabrication funding also continues for the Muon g-2 Experiment. Data collected during this period will be used to address at least three of the five key science drivers identified by the recent 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 that 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[a].

Research

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. The laboratory groups typically have a portfolio of significant responsibilities ranging from detector operations and maintenance to computing and data analysis. 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 findings from this review will be used to inform the funding decisions in subsequent years. The next laboratory research review is planned for 2016.

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

[a] www.particleadventure.org/three_gen.html

included in this activity. Improvements to the facility are supported via General Plant Project (GPP) and Accelerator Improvement Project (AIP) funding. The major experimental efforts will be the NOvA and MicroBooNE experiments using the NuMI and Booster neutrino beams. Operation 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 for proposed new Intensity Frontier efforts and the other project costs (OPC) of line item construction for the Intensity Frontier.

The Muon g-2 project is an MIE to provide equipment needed to adapt an existing muon storage ring from Brookhaven National Laboratory (BNL) to utilize the higher intensity proton beam at Fermilab. The storage ring was successfully moved from BNL to Fermilab in FY 2013. Critical tests of the storage ring’s superconducting magnets will be completed in FY 2015. New detectors, a muon production target, and muon beam transport will be fabricated.

Other Project Costs for LBNF are funded to support efforts to develop international partnerships in response to recommendations of P5. A more complete discussion of LBNF can found in the Construction section. Future Project R&D funding is provided for R&D on an 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 provide higher intensity muon and neutrino beams. The current R&D plan is concentrated on superconducting RF technology because of its ability to handle the higher beam power needed for the future Intensity Frontier subprogram.

Intensity Frontier Experimental Physics

Activities and Explanation of Changes

FY 2015 Enacted	FY 2016 Request	Explanation of Changes FY 2016 vs. FY 2015
Intensity Frontier Experimental Physics $264,224,000	**$247,196,000**	**-$17,028,000**
Research ($55,181,000)	**Research ($55,924,000)**	**Research (+$743,000)**
Commissioning of the Belle II detector, datataking and physics analysis with the ongoing experiments of NOvA, MicroBooNE, T2K, MINOS+ and MINERvA; research and development for the future experiments of Muon g-2, Mu2e are all supported. Support for research to enhance the development of LBNF in cooperation with international partners is provided.	Commissioning of the Belle II detector will be completed followed by initial data taking. Physics analysis leading to first results from the NOvA and MicroBooNE experiments will occur. The MINOS+ program will finish and pursue final data analyses. LBNF physics studies and optimization will continue under the umbrella of a new, fully internationalized Long Baseline Neutrino Facility. Research activities for the Daya Bay Reactor Neutrino experiment will continue to ramp down. Research and development efforts for the Fermilab Muon g-2 and Mu2e experiments will continue. New research and development activities for a Fermilab Short Baseline Neutrino program will be underway, following the P5 recommendations. Other proposed small-scale efforts may be supported depending on the outcomes of peer review.	Funding for the Intensity Frontier research is maintained to support current and future experimental capabilities. Some research staff previously supported under Research will be redirected to lead the internationalization of LBNF or develop other elements of the Fermilab neutrino program. Support for Daya Bay and BaBar research is ramped down as analyses are completed.

FY 2015 Enacted	FY 2016 Request	Explanation of Changes FY 2016 vs. FY 2015
Facility Operations and Experimental Support ($165,073,000)	**Facility Operations and Experimental Support ($157,572,000)**	**Facility Operations and Experimental Support (-$7,501,000)**
The Fermilab Accelerator complex *($141,738,000)* continues to operate to support neutrino physics. In addition there are specific infrastructure and machine enhancements to support the muon and neutrino physics programs. There are two GPP projects in the Muon Campus (MC) complex in FY 2015 (Beamline Enclosure and MC Infrastructure) whose funding is planned at $5,100,000. Another GPP project to support the neutrino program, Short Baseline Neutrino Far Hall is included at $6,287,000. In addition, there are four AIP projects in the Muon Campus in FY 2015 (Cryogenics, Recycler RF, Beam Transport and Delivery Ring) whose aggregate funding is planned at $12,100,000. Operational support ($15,000,000) is provided to the LUX and Majorana demonstrator experiments at the Homestake Mine.	The Fermilab Accelerator complex *($135,100,000)* will continue 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 will modify the antiproton accumulator to store protons for the muon program, and the Recycler RF AIP, which will 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 Short Baseline Neutrino Far Hall GPP Project ($2,302,000) will be completed. Operational Support at Homestake Mine ($15,000,000) will be continued as LUX completes its data-taking and the Majorana demonstrator continues.	The reduction in funding is primarily due to the rampdown of funding for the GPP and AIP projects according to their profiles.
Projects ($43,970,000)	**Projects ($33,700,000)**	**Projects (-$10,270,000)**
FY 2015 is the final year of funding for the Belle II detector upgrade. Funding for the Muon g-2 MIE project provides the critical test of the superconducting magnet and accelerator modifications necessary for the project to begin.	Funding for the Muon g-2 MIE project ($10,200,000) will continue accelerator modifications and fabrication of the beamline and detectors.	Other projects (Muon g-2 and Belle II) follow their planned profiles.
Other Project Costs for LBNF are included.	Funding is provided for Other Project Costs for the LBNF ($4,000,000) to support the development of an international collaboration.	Funding for LBNF OPC is reduced (-$6,000,000) as PED funding in the Construction program is increased to support the LBNF design work.

FY 2015 Enacted	FY 2016 Request	Explanation of Changes FY 2016 vs. FY 2015
Preconceptual R&D for a possible upgrade of the front-end of the Fermilab Accelerator Complex is included.	Future project R&D funding ($19,500,000) will support the development of a new superconducting proton linac to replace the more than 40-year-old existing linac. The goal of this development is to significantly increase the beam power of the entire complex and improve its reliability. P5 recommended this improvement to make the Fermilab neutrino and muon programs sustainable through the next decade.	Funding for the development of Fermilab linac replacement with a superconducting RF linac is continued.

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 2016, as the operations and analysis of current experiments continues, a varied suite of complementary, staged experiments are planned that will lead to measurements with greater precision. The program includes investments in projects for the future in accordance with the long-term strategic plan in particle physics.

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 measurements of high-energy cosmic and gamma rays to search for indirect signals of dark matter, the presence of primordial antimatter and other fundamental phenomena. Data collected will be used to address at least three of the five key science drivers identified by the recent P5 report:

- *Understand cosmic acceleration: dark energy and inflation*

  Observations of supernovae suggest that, for approximately the last six billion years, the universe has been expanding at an accelerating rate due to a mysterious "dark energy" that appears to overcome gravitational attraction. The Nobel Prize in Physics in 2011 was awarded for the discovery of the acceleration of the expansion of the universe. In addition, theoretical cosmological models have postulated a period of rapid expansion in the universe shortly after the Big Bang, a phenomenon known as "inflation", and some recent experimental results have suggested this epoch can now be observed in CMB data.

- *Identify the new physics of dark matter.*

  A wide variety of astronomical data suggest that there could be large quantities of matter in the universe that the Standard Model does not explain. This dark matter, so-called because it does not emit electromagnetic radiation that we cannotcan notcannot yet detect, played a dominant role in the formation of structures in the Universe. Direct-detection experiments search for cosmic dark matter particles' rare interactions with atomic nuclei, while indirect-detection observatories search for dark matter signatures in the interactions of high-energy cosmic particles. These experiments complement 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. Searches for new phenomena in high-energy cosmic surveys may yield surprising discoveries about the fundamental nature of the universe.

Research

The Cosmic Frontier experimental research program consists of groups at about 40 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. HEP conducted an external peer review of all laboratory research groups in this subprogram in 2013, and findings from this review are being used to inform the funding decisions in subsequent years. A follow-on review is being planned for 2016.

Research efforts are supported for operating or recently completed experiments including the suite of first generation dark matter direct detection experiments, and dark energy experiments using imaging and spectroscopic surveys, including the Dark Energy Survey (DES) and Baryon Oscillation Spectroscopic Survey (BOSS). Research activities are also supported for the space-based Alpha Magnetic Spectrometer II (AMS-II) and the Fermi Gamma-ray Space Telescope (FGST); and the High Altitude Water Cherenkov (HAWC) detector array.

Research activities continue to support design, fabrication and science planning for anticipated next generation experiments for direct-detection of dark energy and dark matter (DM-G2), and CMB experiments, including the Large Synoptic Survey Telescope (LSST), the Dark Energy Spectroscopic Instrument (DESI), Axion Dark Matter Search Generation 2 (ADMX-G2), the Large Underground Xenon (LUX) – ZEPLIN experiment (LZ), the Super Cryogenic Dark Matter Search at the Sudbury Neutrino Observatory Laboratory (SuperCDMS-SNOLab), and the South Pole Telescope generation 3 (SPT-3G). Support for R&D and science planning of possible future experiments in the program, such as community planning for a 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. 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. HEP conducted a scientific peer review of Cosmic Frontier operations in 2012 and a follow-on review was held in early FY 2015. Findings from this review are being used to monitor the experiments and inform decisions concerning the continuation of specific activities in subsequent years.

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 2016 Request supports the continued fabrication of the three billion pixel precision camera for the Large Synoptic Survey Telescope (LSSTcam), which is the DOE contribution to the NSF-led LSST Project. It also supports fabrication for the DM-G2 projects selected in FY 2014, LZ and SuperCDMS-SNOLab; and the design and baselining of the DESI project which will provide complementary Stage IV techniques to LSST for studying dark energy. Support for fabrication of the small-scale ADMX-G2 dark matter experiment is also included.

Cosmic Frontier Experimental Physics

Activities and Explanation of Changes

FY 2015 Enacted	FY 2016 Request	Explanation of Changes FY 2016 vs. FY 2015
Cosmic Frontier Experimental Physics $106,870,000	**$119,325,000**	**+$12,455,000**
Research ($49,310,000)	**Research ($50,079,000)**	**Research (+$769,000)**
Research activities continue on the operating experiments including DES, AMS-II, and FGST. Data analysis continues on BOSS, which completed its survey in FY 2014. Research activities continue to support design, fabrication and science planning for planned next generation dark energy, dark matter (DM-G2) direct detection, and CMB experiments.	The FY 2016 request supports research efforts on 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 BOSS, which completed operations in FY 2014. 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 experiments.	Research efforts are increased as P5-recommended initiatives in dark matter and dark energy are pursued with high priority.
Facility Operations and Experimental Support ($11,832,000)	**Facility Operations and Experimental Support ($10,545,000)**	**Facility Operations and Experimental Support (-$1,287,000)**
Dark matter searches currently underway complete operations in FY 2015, with data processing and analysis expected to continue for another year. Operations are supported for AMS-II, DES, and the FGST.	Operations support will continue 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 the Dark Energy Survey. 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.	Funding for operations decreases as the operations and data processing efforts for experiments completed in recent years begin to ramp down.

FY 2015 Enacted	FY 2016 Request	Explanation of Changes FY 2016 vs. FY 2015
Projects ($45,728,000)	**Projects ($58,701,000)**	**Projects (+$12,973,000)**
There are four MIE projects supported with $43,403,000. LSSTcam fabrication activities continue ($35,000,000). Three new MIE projects, LZ, SuperCDMS-SNOLab, and DESI, are started in FY 2015 with $8,403,000 (TEC and OPC funding). Small projects below MIE thresholds and future project R&D are funded at $2,325,000.	Funding is provided for LSSTcam according to its approved baseline funding profile ($40,800,000). The three smaller MIEs to study dark energy or dark matter started in FY 2015 are expected to be baselined in FY 2016: DESI ($5,300,000), LZ ($9,000,000), and SuperCDMS-SNOLab ($2,000,000). Small projects below MIE thresholds are funded at $1,601,000.	Funding increases support the MIE projects.

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 recently 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 7 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 typically focused on more formal or mathematical theory. 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 and the 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 a HEP experiment—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 supports partnership projects such as SciDAC with the Advanced Scientific Computing Research program that focus on HEP topics that benefit most strongly from advanced computational techniques. Examples of previous SciDAC projects include accelerator modeling, cosmological simulations, and directed efforts to develop and maintain and HEP specific computational tools.

Projects

The Projects activity currently funds acquisition and operation of dedicated hardware for the Lattice Quantum Chromodynamics (LQCD) computing effort. These techniques can address both nuclear and high energy physics topics, and to avoid any duplication of effort, this program is managed in partnership with the Office of Nuclear Physics (NP). 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 programmatic endorsement from HEPAP in 2014, the LQCD project will be extended in FY 2015 for a five-year period. Coordination with NP on LQCD ensures that the research results are productively used by both communities and ensure efforts are not duplicated.

Theoretical and Computational Physics

Activities and Explanation of Changes

FY 2015 Enacted	FY 2016 Request	Explanation of Changes FY 2016 vs. FY 2015
Theoretical and Computational Physics $59,274,000	**$60,317,000**	**+$1,043,000**
Theory ($50,224,000)	**Theory ($50,182,000)**	**Theory (-$42,000)**
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 will be selected based on peer review by technical experts.	Funding is slightly reduced for HEP research activities.
Computational HEP ($8,050,000)	**Computational HEP ($8,135,000)**	**Computational HEP (+$85,000)**
HEP is currently planning a new SciDAC solicitation for FY 2015 in partnership with ASCR.	SciDAC projects selected in FY 2015 will be continued in FY 2016. Other ongoing projects and directed funding will continue at approximately the same funding level.	Funding is held nearly constant.
Projects ($1,000,000)	**Projects ($2,000,000)**	**Projects (+$1,000,000)**
Funds are supplied to continue operation of the existing LQCD hardware, while planning for the acquisition of new hardware is carried out.	FY 2016 funding plan includes acquisition of new hardware as well as continued operations of the LQCD.	Funding is provided according to the planned profile.

High Energy Physics
Advanced Technology R&D

Description

The Advanced Technology R&D subprogram fosters cutting-edge research in the physics of particle beams, accelerator research and development (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 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.

This activity supports research at 8 DOE national laboratories and about 30 academic or other research institutions. 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.

HEP Directed Accelerator R&D

HEP Directed Accelerator R&D supports 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. 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 for possible U.S. deliverables to the High Luminosity LHC (HL-LHC) that CERN is planning to begin building late in this decade. LARP is investigating how to build niobium-tin superconducting magnets to decrease the size of the beam, “crab” cavities that causes the beam to meet head on rather than at an angle, and feedback systems to keep the intense beams in a compact configuration. 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 HEPAP strategic plan recommendations, these applications are now seen as less scientifically compelling. The Muon Accelerator Program is being ramped down, and 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. New instrumentation and detectors must be developed with increased capabilities while keeping the cost and schedule from conception to operation at a minimum. To meet these challenges, HEP actively supports investments in innovative, generic instrumentation and detector research with the potential for wide applicability and/or high payoff. This activity supports research at 5 DOE national laboratories and about 20 academic or other research institutions.

Facility Operations and Experimental Support

Facility Operations and Experimental Support provides operations funding for proposal-driven user facilities like the Facility for Advanced Accelerator Experimental Tests (FACET) at SLAC, as well as laboratory experimental and test facilities, including the Berkeley Lab Laser Accelerator (BELLA) facility at LBNL. HEP supports the maintenance and operation of fabrication and test facilities for superconducting magnets and superconducting RF. These facilities are centralized at Fermilab due to the cost to build and operate them. The current priorities for these facilities are the programs to develop higher field magnets for the LHC (LARP), the LCLS-II cryomodule production and testing, and the R&D on a future upgrade of the Fermilab accelerator frontend. BELLA, FACET, and the superconducting magnet facility and SRF infrastructure at Fermilab are all in operation.

Advanced Technology R&D

Activities and Explanation of Changes

FY 2015 Enacted	FY 2016 Request	Explanation of Changes FY 2016 vs. FY 2015
Advanced Technology R&D $120,254,000	**$115,369,000**	**-$4,885,000**
HEP General Accelerator R&D ($45,452,000)	**HEP General Accelerator R&D ($39,924,000)**	**HEP General Accelerator R&D (-$5,528,000)**
The general portfolio of topics described above continue to be supported, but there is a shift in emphasis as some of the accelerator personnel with expertise in superconducting magnets, beam simulations, and beam physics are being redirected to support HEP Directed Accelerator R&D.	The general portfolio of topics described above will continue to be supported, but the emphasis on each will be adjusted based on the detailed recommendation from the HEPAP Accelerator R&D Subpanel (planned to report in March 2015) to optimize alignment with the HEPAP strategic plan.	Research activities are reduced and shifted towards higher priority R&D activities as recommended in the HEPAP strategic plan.
HEP Directed Accelerator R&D ($22,570,000)	**HEP Directed Accelerator R&D ($21,500,000)**	**HEP Directed Accelerator R&D (-$1,070,000)**
LARP develops a prototype superconducting quadrupole magnet with the large apertures needed to increase luminosity at the LHC. MAP commissions the Muon Ionization Cooling Experiment (MICE) that will demonstrate critical technologies for the collection of muons.	LARP will increase 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 will be developed in FY 2015.	Reductions are due to the ramp down of MAP effort, partially offset by an increase in LARP superconducting magnet effort to meet schedule for delivery of magnet prototypes.
Detector R&D ($21,914,000)	**Detector R&D ($21,922,000)**	**Detector R&D (+$8,000)**
Research activities continue at U.S. universities and national laboratories. HEP programmatic decisions informed by community input and the P5 report have been a factor in setting priorities in detector development at a time of budget constraints, with increased emphasis on R&D support for near-term projects.	Research activities will 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.	Support for detector research activities is held constant.

FY 2015 Enacted	FY 2016 Request	Explanation of Changes FY 2016 vs. FY 2015
Facility Operations and Experimental Support ($30,318,000)	**Facility Operations and Experimental Support ($32,023,000)**	**Facility Operations and Experimental Support (+$1,705,000)**
Support for activities at FACET, BELLA and SRF Infrastructure continues.	Support for operation of BELLA and SRF Infrastructure will continue. Superconducting magnet fabrication and test facilities support will be provided in this area. FACET will be supported at a reduced level.	The primary changes are that superconducting magnet test facilities are included under this activity which increase funding (+$5,668,000) and FACET running is reduced providing some savings (-$3,963,000).

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 Office of Science programs, including Nuclear Physics and Basic Energy Sciences, and in consultation with other federal stakeholders of accelerator technology, most notably DOD, NSF, and NIH.

Accelerator Stewardship pursues targeted R&D to develop new uses of accelerator technology with broad applicability. Initial workshops and a request for information in 2014 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

This research 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 supports both near-term translational R&D and long-term 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. This activity in FY 2014 supported 10 university grants in broadly applicable areas of advanced accelerator science, beam physics, and related technologies.

Facility Operations and Experimental Support

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

The Brookhaven ATF is a low-power electron and laser test facility dedicated to accelerator studies. Experiments at 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 ATF is awarded based on a merit-based peer review process.

The Accelerator Test Facility Pilot Program will launch in FY 2015, and provide operations support for non-traditional users to access accelerator test infrastructure at seven of DOE's national laboratories (ANL, BNL, Fermilab, LBNL, ORNL, SLAC, and TJNAF). 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 events will be held to make the broad community aware of these facilities, encourage proposals to be submitted for limited-scale engagements to use these facilities, and seed-fund the

[a] www.acceleratorsamerica.org

operation of the test facilities for a few test cases. Based on experience from the pilot program, a long-term mechanism for making SC's unique accelerator test facilities more available will be formulated.

Accelerator Stewardship

Activities and Explanation of Changes

FY 2015 Enacted	FY 2016 Request	Explanation of Changes FY 2016 vs. FY 2015
Accelerator Stewardship $10,000,000	**$14,000,000**	**+$4,000,000**
Research ($5,900,000)	**Research ($8,200,000)**	**Research (+$2,300,000)**
Continue to support research activities at laboratories and universities. Initiate research support for selected technology areas including laser development for accelerators, ion-beam therapy and green RF sources, which have been identified through Office of Science led workshops. The best research proposals in these areas are selected based on peer review by technical experts.	Will continue to support research activities at laboratories, universities, and in industry. As funds allow, will initiate research support for selected technology areas such as energy & environmental applications of accelerators, as identified by SC workshops.	Additional research funding is requested to initiate support for accelerator R&D for energy and environmental applications.
Facility Operations and Experimental Support ($4,100,000)	**Facility Operations and Experimental Support ($5,800,000)**	**Facility Operations and Experimental Support (+$1,700,000)**
Supports facility operation of the ATF for a broad program of long-term accelerator research. Provides continued support for relocation of the ATF to a larger building. Initiate the Accelerator Test Facility Pilot Program, to enable wider use of SC accelerator test infrastructure.	Will support continued ATF operations, continuation of the Accelerator Test Facility Pilot Program, and the completion of the relocation of the ATF to a larger building.	Additional facility operations funding is requested to complete the ATF relocation to a larger building.

High Energy Physics
SBIR/STTR

Description

SBIR/STTR funding is provided in accordance with the Small Business Innovation Development Act and subsequent related legislation.

Activities and Explanation Changes

FY 2015 Enacted	FY 2016 Request	Explanation of Changes FY 2016 vs. FY 2015
SBIR/STTR $20,794,000	**$21,138,000**	**+$344,000**
In FY 2015, SBIR/STTR funding is set at 3.3% of non-capital funding.	In FY 2016, SBIR/STTR funding is set at 3.45% of non-capital funding.	The SBIR/STTR amount is adjusted to mandated percentages for non-capital funding.

Description

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

The Muon to Electron Conversion Experiment (Mu2e) will be built at Fermilab and is an important component of the Intensity Frontier subprogram. It will utilize a proton beam to produce muons and determine if those muons can undergo a quantum flavor conversion into electrons. There is no known mechanism for such interactions of charged leptons in the Standard Model, but similar processes have been observed in neutrinos. Evidence of muon to electron flavor change would further probe physics beyond the Standard Model at very high energy scales.

The Mu2e CD-1 was approved on July 11, 2012. Funds appropriated in FY 2013 and 2014 were used to complete the preliminary engineering design and establish the performance baseline. Construction funds in FY 2014 are being used to initiate long-lead procurement of technical materials in order to reduce cost and schedule risk. The project baseline will be approved (CD-2) in FY 2015 and civil construction will be initiated in FY 2015.

The Long Baseline Neutrino Facility (LBNF) 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 explain the fundamental physics of neutrinos and the matter-antimatter asymmetry of the universe.

The new national strategic plan for U.S. Particle Physics, developed by P5 and approved by HEPAP in May 2014, recommended "a change in approach for the LBNE Project through reformulation under the auspices of a new international collaboration, as an internationally coordinated and funded program, with Fermilab as host and international participation in defining the program's scope and capabilities."[a]

The HEP Program is responding to the recommendation by modifying the preliminary design in order to facilitate international participation, with the goal of achieving enhanced scientific capability through non-DOE contributions to the construction project and the experiment. HEP has begun discussions with foreign funding agencies on successful management models for large science projects. The LHC model where all contributions are provided as in-kind to a host laboratory that has responsibility to coordinate and integrate the contributions has been shown to succeed and will be emulated. All DOE project activities will be managed under DOE Order 413.3B and Office of Science oversight.

DOE is now assessing and evaluating the opportunities to incorporate contributions from international collaborators. The FY 2016 request includes design funding to support modifying the preliminary design in order to facilitate international participation with the goal of achieving enhanced scientific capability through non-DOE contributions. Operating funds for LBNF Other Project Cost (OPC) are requested under the Intensity Frontier subprogram to enable international collaborative activities.

[a] P5 Report, "*Building for Discovery: Strategic Plan for U.S. Particle Physics in the Global Context*," May 2014. Available at http://science.energy.gov/~/media/hep/hepap/pdf/May%202014/FINAL_P5_Report_Interactive_060214.pdf

Construction

Activities and Explanation of Changes

FY 2015 Enacted	FY 2016 Request	Explanation of Changes FY 2016 vs. FY 2015
Construction $37,000,000	**$56,100,000**	**+$19,100,000**
11-SC-40, Long Baseline Neutrino Facility ($12,000,000)	**11-SC-40, Long Baseline Neutrino Facility ($16,000,000)**	**11-SC-40, Long Baseline Neutrino Facility (+$4,000,000)**
Design funds will be used to modify the preliminary design in order to facilitate international participation with the goal of achieving enhanced scientific capability through non-DOE contributions.	Funds are requested to continue the development of an internationally supported project.	Funding is increased in accordance with the P5 recommendation.
11-SC-41, Muon to Electron Conversion Experiment ($25,000,000)	**11-SC-41, Muon to Electron Conversion Experiment ($40,100,000)**	**11-SC-41, Muon to Electron Conversion Experiment (+$15,100,000)**
Funds are for final design work, construction of the detector hall, and fabrication of the accelerator beamline and detector components.	Construction funds are requested to continue civil construction and initiate fabrication of technical components (solenoid magnets and particle detectors).	Funding is increased according to the planned funding profile.

High Energy Physics
Performance Measures

In accordance with the GPRA Modernization Act of 2010, the Department sets targets for, and tracks progress toward, achieving performance goals for each program. The following table shows the targets for FY 2014 through FY 2016.

	2014	2015	2016
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	85%	TBD	TBD
Endpoint Target	Many of the research projects that are undertaken at the Office of Science'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	4%	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	Begin operation of full NOvA detector using neutrino beam from Fermilab for purpose of measuring mixing angle between muon neutrinos and electron neutrinos ($\sin^2(2\theta_{13})$) using the appearance of electron neutrinos.	Physics analyses results from the first year of datataking with the full detector will be presented by the NOvA and MicroBooNE experimental collaborations at the FY 2015 summer conferences.	Physics analyses results from datataking will be presented by the NOvA and MicroBooNE experimental collaborations at the FY 2016 summer conferences.
Result	Operation of the detector has been successfully started.	TBD	TBD

	2014	2015	2016
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 CP violation in the neutrino sector.		

High Energy Physics
Capital Summary ($K)

	Total	Prior Years	FY 2014 Enacted	FY 2014 Current	FY 2015 Enacted	FY 2016 Request	FY 2016 vs. FY 2015
Capital Operating Expenses Summary							
Capital equipment	n/a	n/a	41,152	41,152	74,452	101,797	+27,345
General plant projects (GPP)	n/a	n/a	13,558	13,558	12,463	7,100	-5,363
Accelerator improvement projects (AIP)	n/a	n/a	11,700	11,700	12,750	10,300	-2,450
Total, Capital Operating Expenses	**n/a**	**n/a**	**66,410**	**66,410**	**99,665**	**119,197**	**+19,532**
Capital Equipment							
Major items of equipment							
Energy Frontier Experimental Physics							
LHC ATLAS Detector Upgrades[a]	25,500	0	0	0	7,500	9,500	+2,000
LHC CMS Detector Upgrades[b]	24,967	0	0	0	7,500	9,500	+2,000
Intensity Frontier Experimental Physics							
Belle II[c]	8,870	0	7,900	7,900	970	0	-970
Muon g-2 Experiment[d]	26,400	0	2,000	2,000	8,000	10,200	+2,200
Cosmic Frontier Experimental Physics							
Large Synoptic Survey Telescope Camera (LSSTcam)[e]	150,300	0	19,700	19,700	35,000	40,800	+5,800
Dark Energy Spectroscopic Instrument (DESI)[f]	44,783	0	0	0	250	4,800	+4,550
LUX-ZEPLIN[g] (LZ)	36,250	0	0	0	250	9,000	+8,750
SuperCDMS-SNOLab[h]	11,950	0	0	0	250	2,000	+1,750
Total MIEs	n/a	n/a	29,600	29,600	59,720	85,800	+26,080

[a] Critical Decision CD-2/3 for the LHC ATLAS Detector Upgrade Project was approved on November 12, 2014. The TPC is $33,250,000.
[b] Critical Decision CD-2/3 for the LHC CMS Detector Upgrade Project was approved on November 12, 2014. The TPC is $33,217,000.
[c] Critical Decision CD-2/3 was approved on April 23, 2014. The TPC is $15,000,000.
[d] Critical Decision CD-1 for the Muon g–2 Project was approved on December 19, 2013. The TPC range is $43,000,000 to $50,100,000.
[e] Critical Decision CD-2 for the Large Synoptic Survey Telescope Camera was approved on January 7, 2015. The TPC is $168,000,000.
[f] This project is not yet baselined. This project received CD-0 on September 12, 2012 with a cost range of $25,000,000 to $42,000,000.
[g] This MIE was one of two MIEs selected to meet the Dark Matter Second Generation Mission Need. The project is not yet baselined.
[h] This MIE was one of two MIEs selected to meet the Dark Matter Second Generation Mission Need. The project is not yet baselined.

	Total	Prior Years	FY 2014 Enacted	FY 2014 Current	FY 2015 Enacted	FY 2016 Request	FY 2016 vs. FY 2015
Other capital equipment projects under $2 million TEC	n/a	n/a	11,552	11,552	14,732	15,997	+1,265
Total, Capital equipment	**n/a**	**n/a**	**41,152**	**41,152**	**74,452**	**101,797**	**+27,345**
General Plant Projects (GPP)							
MC-1 Building	9,500	8,000	1,000	1,000	500	0	-500
Muon Campus Beamline Enclosure	8,700	400	3,700	3,700	4,600	0	-4,600
Short Baseline Neutrino Far Hall	9,800	0	1,211	1,211	6,287	2,302	-3,985
Other projects under $5 million TEC	n/a	n/a	7,647	7,647	1,076	4,798	+3,722
Total, Plant Project (GPP)	**n/a**	**n/a**	**13,558**	**13,558**	**12,463**	**7,100**	**-5,363**
Accelerator Improvement Projects (AIP)							
Muon Campus Cryogenics	9,700	1,100	5,100	5,100	1,300	800	-500
Recycler RF Upgrades	8,600	400	1,000	1,000	3,800	3,400	-400
Beam Transport	6,700	300	2,400	2,400	3,700	300	-3,400
Delivery Ring	9,500	200	1,700	1,700	3,300	4,300	+1,000
Other projects under $5 million TEC	n/a	n/a	1,500	1,500	650	1,500	+850
Total, Accelerator Improvement Projects	**n/a**	**n/a**	**11,700**	**11,700**	**12,750**	**10,300**	**-2,450**

Major Items of Equipment Descriptions

Energy Frontier Experimental Physics MIEs:

By 2019, CERN plans to increase the LHC luminosity by 100–200% compared to its 2015–2017 running period. The increase will result in higher particle rates and densities as well as a large increase in the number of overlapping collisions, leading to more rapid radiation damage to individual detector subsystems, larger volumes of data, and challenging event conditions. In order to cope with these effects and continue to fully exploit the physics opportunities offered at the LHC, the detectors will need upgrades. DOE supported part of the original construction of two of the four LHC detectors (CMS and ATLAS), and proposes to support the upgrade of those detectors to maintain their capabilities at the higher luminosity LHC. The HEPAP strategic plan identifies the LHC upgrades their highest priority near term projects.

The *ATLAS Detector Upgrade Project* started as a new MIE in FY 2015 and ramp up of fabrication activities for U.S. built detectors systems are planned in FY 2016. The planned 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 luminosity. The LHC ATLAS Detector Upgrade Project received CD-2, Approve Performance Baseline, and CD-3, Approve Start of Construction, on November 12, 2014, with a total project cost of $33,250,000 and completion date of FY 2018.

The *CMS Detector Upgrade Project* started as a new MIE in FY 2015 and ramp up of fabrication activities for U.S. built detector systems are 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 luminosity. The LHC CMS Detector Upgrade Project received CD-2, Approve Performance Baseline, and CD-3, Approve Start of Construction on November 12, 2014, with a total project cost of $33,217,000 and completion date of FY 2018.

Intensity Frontier Experimental Physics MIEs:

The *Belle II* project will fabricate 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 in April 2014 with a TPC of $15,000,000 and a project completion date in FY 2016.

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 Brookhaven National Laboratory with upgraded detectors to be 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. Transfer of the BNL storage ring to Fermilab occurred in FY 2013. The Muon g-2 Project plans for CD-2 in FY 2015. New instrumentation for the storage ring will be provided, in part, by in-kind contributions from non-DOE sources including NSF. The Muon g−2 experiment offers a strategic opportunity to search for new physics that may be inaccessible to the LHC. P5 recommended completing muon g-2 as an immediate target of opportunity for searching new physics and identifying future directions for the field.

Cosmic Frontier Experimental Physics MIEs:

The *Large Synoptic Survey Telescope Camera (LSSTcam*) was a new MIE start in FY 2014. It is a 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-3A for long-lead procurement of camera sensors was approved in June 2014. CD-2 for the LSSTcam project was approved on January 7, 2015, with a TPC of $168,000,000 and completion date of FY 2022. P5 reiterated the importance of LSST to the Cosmic Frontier program in its 2014 report.

The *Dark Energy Spectroscopic Instrument (DESI)* project is a new MIE in FY 2015. The project will fabricate an instrument that will measure the effect of dark energy on the expansion of the universe using the baryon acoustic oscillation and other techniques that rely on spectroscopic measurements. DESI will provide measurements complementary to the LSST survey. The instrument will be mounted on the Mayall 4-meter telescope at Kitt Peak National Observatory in Arizona. The DESI survey will obtain optical spectra for tens of millions of galaxies and quasars to construct a 3-dimensional map spanning the nearby universe and to a distance of 10 billion light years. CD-0 was approved September 12, 2012 with an estimated Total Project Cost of $25,000,000–$42,000,000. CD-1 is planned for FY 2015 and CD-2 for FY 2016. P5 recommended building DESI as part of a program of dark energy studies that also includes LSST since the two projects study dark energy using different methods.

The LUX- ZEPLIN (LZ) project is a new MIE in FY 2015. This MIE was one of two MIEs 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 United Kingdom 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 4850-foot deep the Sanford Underground Research Facility (SURF) in Lead, South Dakota. CD-1 is planned for FY 2015 and CD-2 for FY 2016. P5 identified the search for dark matter as a science driver and recommended a program of dark matter searches that would maximize the probability of successfully discovering.

The *Super Cryogenic Dark Matter Search at Sudbury Neutrino Observatory Laboratory (SuperCDMS-SNOLab)* project is a new MIE in FY 2015. This MIE was one of two MIEs selected to meet the Dark Matter Second Generation Mission Need. The project will fabricate an instrument that utilizes 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 in Sudbury, Ontario, Canada. SuperCDMS will be optimized to detect low mass WIMPS. This will cover a range of WIMP mass that LZ is not sensitive to. This is in response to the P5 recommendation to develop a comprehensive dark matter search program CD-1 is planned for FY 2015 and CD-2 for FY 2016.

High Energy Physics Construction Project Summary ($K)

	Total	Prior Years	FY 2014 Enacted	FY 2014 Current	FY 2015 Enacted	FY 2016 Request	FY 2016 vs. FY 2015
11-SC-40, Long Baseline Neutrino Facility							
TEC	783,393	7,781	16,000	16,000	12,000	16,000	+4,000
OPC	89,539	65,539	10,000	10,000	10,000	4,000	-6,000
TPC	872,932	73,320	26,000	26,000	22,000	20,000	-2,000
11-SC-41, Muon to Electron Conversion Experiment							
TEC	250,000	32,000	35,000	35,000	25,000	40,100	+15,100
OPC	23,677	23,677	0	0	0	0	0
TPC	273,677	55,677	35,000	35,000	25,000	40,100	+15,100
Total, Construction							
TEC	n/a	n/a	51,000	51,000	37,000	56,100	+19,100
OPC	n/a	n/a	10,000	10,000	10,000	4,000	-6,000
TPC	n/a	n/a	61,000	61,000	47,000	60,100	+13,100

Funding Summary ($K)

	FY 2014 Enacted	FY 2014 Current	FY 2015 Enacted	FY 2016 Request	FY 2016 vs. FY 2015
Research	382,533	360,932	358,177	355,841	-2,336
Facilities Operations[a]					
Scientific User Facilities Operations	144,121	144,121	150,798	140,197	-10,601
Other Facilities	134,562	134,562	114,327	122,461	+8,134
Total, Facilities Operations	**278,683**	**278,683**	**265,125**	**262,658**	**-2,467**

[a] In previous budget submissions, B-Factory and LHC were included in Scientific User Facility Operations; these activities are now captured under Other Facilities.

	FY 2014 Enacted	FY 2014 Current	FY 2015 Enacted	FY 2016 Request	FY 2016 vs. FY 2015
Projects					
Major Items of Equipment	54,300	54,300	72,373	86,300	+13,927
Other Projects	20,005	20,005	23,325	23,101	-224
Construction[a]	61,000	61,000	47,000	60,100	+13,100
Total, Projects	**135,305**	**135,305**	**142,698**	**169,501**	**+26,803**
Total, High Energy Physics	**796,521**	**774,920**	**766,000**	**788,000**	**+22,000**

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.

[a] Includes Other Project Costs funding for LBNF.

	FY 2014 Enacted	FY 2014 Current	FY 2015 Enacted	FY 2016 Request	FY 2016 vs. FY 2015
TYPE A FACILITIES					
Fermilab Accelerator Complex	**$135,173**	**$135,173**	**$141,738**	**$135,100**	**-$6,638**
Number of Users	2,097	2,097	2,200	2,310	+110
Achieved operating hours	6,455	6,455	N/A	N/A	N/A
Planned operating hours	5,760	5,760	4,200	4,800	+600
Optimal hours	5,760	5,760	4,200	4,800	+600
Percent optimal hours	112.1%	112.1%	100.0%	100.0%	N/A
Unscheduled downtime hours	N/A	N/A	N/A	N/A	N/A
FACET	**$8,948**	**$8,948**	**$9,060**	**$5,097**	**-$3,963**
Number of Users	150	150	155	52	-103
Achieved operating hours	4,215	4,215	N/A	N/A	N/A
Planned operating hours	3,502	3,502	5,176	1,482	-3,694
Optimal hours	3,502	3,502	5,176	4,448	-728
Percent optimal hours	120.4%	120.4%	100.0%	33.3%	N/A
Unscheduled downtime hours	N/A	N/A	N/A	N/A	N/A
Total Facilities[a]	**$144,121**	**$144,121**	**$150,798**	**$140,197**	**-$10,601**
Number of Users	2,247	2,247	2,355	2,362	+7
Achieved operating hours	10,670	10,670	N/A	N/A	N/A
Planned operating hours	9,262	9,262	9,376	6,282	-3,094
Optimal hours	9,262	9,262	9,376	9,248	-128
Percent of optimal hours[b]	112.6%	112.6%	100.0%	97.6%	N/A
Unscheduled downtime hours	N/A	N/A	N/A	N/A	N/A

[a] In previous budget submissions, B-Factory and LHC were included in Scientific User Facility Operations; these activities are now captured under Other Facilities.

[b] 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 2014 Enacted	FY 2014 Current	FY 2015 Estimate	FY 2016 Estimate	FY 2016 vs. FY 2015
Number of permanent Ph.D.'s (FTEs)	950	950	905	905	0
Number of postdoctoral associates (FTEs)	405	405	370	370	0
Number of graduate students (FTEs)	480	480	485	485	0
Other[a]	1,990	1,990	1,880	1,920	+40

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

11-SC-40, Long Baseline Neutrino Facility (LBNF), 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 2012 CPDS and does not include a new start for the budget year. 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. The title is changed to Long Baseline Neutrino Facility following recommendation of the Particle Physics Project Prioritization Panel and endorsed by OMB. The scope of the full LBNF project has not changed. The original CPDS submitted for the FY 2011 request covered only the design stage; in order to accurately reflect the full cost and schedule of the project, the scope of the CPDS has been adjusted to capture both design and construction.

Summary

The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-1, which was approved December 10, 2012 with a preliminary cost range of $805,000,000 to $1,110,000,000 and CD-4 of FY 2025. The CD-4 date has been revised to FY 2027 reflecting new outyear funding projections since the CD-1 approval. The current Total Project Cost point estimate is $872,932,000.

A Federal Project Director has been assigned to this project and has approved this CPDS.

The Long Baseline Neutrino Facility (LBNF) 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.

LBNF was originally envisioned as a joint DOE-NSF project with NSF providing the Deep Underground Science and Engineering Laboratory (DUSEL) as a site for the LBNF far detector. However, the National Science Board terminated NSF's DUSEL project in December 2010. Due to the broad interest in this physics around the world and the significant cost, the new HEP strategic plan developed by the Particle Physics Project Prioritization Panel and endorsed by the High Energy Physics Advisory Panel recommended that DOE seek international partners to participate while the technical, cost, and schedule baseline is being developed over the next several years. The planned funding for the design phase has been spread over several years so that non-DOE partners can engage in and contribute to the design, construction and operation of the experiment.

The TEC funds requested for FY 2016 will be used for civil and geotechnical engineering design for the detector cavern in South Dakota, for technical design of the neutrino-production beam line and related facilities at Fermilab, for site preparation, and to support modification of the technical design of the experimental facility, infrastructure, and detectors.

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	1/8/2010	12/10/2012	12/10/2012	4Q FY 2017[a]	4Q FY 2019	4Q FY 2019[a]	N/A	4Q FY 2027[a]

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
PB – Indicates Performance Baseline

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[b]	127,781	655,612	783,393	89,539	N/A	89,539	872,932

4. Project Scope and Justification

Scope

The Long Baseline Neutrino Facility (LBNF) will be composed of a neutrino beamline, a large neutrino detector located underground at least 800 miles "downstream" from the neutrino source, and a smaller neutrino detector for monitoring the neutrino beam near its source. A neutrino beam aimed through the earth will begin in a tunnel holding the proton beamline, followed by a target for converting the protons into particles that decay into neutrinos, and a long empty tunnel where the particles decay into neutrinos. The neutrinos will pass through the earth to the far 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 LBNF new beam line would 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.

[a] CD dates beyond CD-1 reflect outyear funding projections revised since CD-1 approval.
[b] The project is Pre-CD-2 and has not been baselined. All estimates are preliminary. The TPC point estimate is $872,932,000. The preliminary TPC range is $805,000,000 to $1,110,000,000.

Justification

The recent progress in neutrino physics has laid the basis for new 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 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.

5. Financial Schedule[a]

(dollars in thousands)

	Appropriations	Obligations	Recovery Act Costs	Costs
Total Estimated Cost (TEC)				
Design Only				
FY 2012	4,000	4,000	0	0[b]
FY 2013	3,781	3,781	0	801
FY 2014	16,000	16,000	0	7,109
FY 2015	12,000	12,000	0	18,000
FY 2016	0	0	0	9,871
Total, Design Only	35,781	35,781	0	35,781
Design (Design and Construction)				
FY 2016	N/A	N/A	0	16,000
FY 2017-FY 2019	TBD	TBD	0	TBD
Total, Design (Design and Construction)	TBD	TBD	0	TBD

[a] Design and international collaboration plans are currently being developed; outyear appropriation levels will be determined at a later date.

[b]$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
Total, Design[a]	TBD	TBD	0	TBD
Construction				
FY 2020- FY 2027	TBD	TBD	0	TBD
Total, Construction[a]	TBD	TBD	0	TBD
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	18,000
FY 2016	16,000	16,000	0	25,871
FY 2017-FY 2027	TBD	TBD	0	TBD
Total, TEC[a]	TBD	TBD	0	TBD

[a] The project is Pre-CD-2 and has not been baselined. All estimates are preliminary. The TPC point estimate is $872,932,000. The preliminary TPC range is $805,000,000 to $1,110,000,000.
[b] Design and international collaboration plans are currently being developed; outyear appropriation levels will be determined at a later date.

(dollars in thousands)

	Appropriations	Obligations	Recovery Act Costs	Costs
Other Project Cost (OPC)				
OPC except D&D				
FY 2009 Recovery Act	12,486[a]	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[b]	557[c]	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	11,000
FY 2016	4,000	4,000	0	5,929
Total, OPC	89,539	89,539	12,486	77,053
Total Project Cost (TPC)[d]				
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	29,000
FY 2016	20,000	20,000	0	31,800
FY 2017-FY 2027	TBD	TBD	0	TBD
Total, TPC[e]	TBD	TBD	12,486	TBD

[a] $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).
[b] $18,000 of FY 2011 funding was attributed towards the Other Project Costs activities in FY 2012.
[c] 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.
[d] Design and international collaboration plans are currently being developed; outyear appropriation levels will be determined at a later date.
[e] The project is Pre-CD-2 and has not been baselined. All estimates are preliminary. The TPC point estimate is $872,932,000. The preliminary TPC range is $805,000,000 to $1,110,000,000.

6. Details of Project Cost Estimate[a]

	(dollars in thousands)		
	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design			
Design	100,000	101,000	N/A
Contingency	27,781	32,000	N/A
Total, Design	127,781	133,000	N/A
Construction[b]			
Site Work	20,000	N/A	N/A
Civil Construction	400,000	N/A	N/A
Technical Equipment[c]	75,000	N/A	N/A
Contingency	160,612	N/A	N/A
Total, Construction	655,612	N/A	N/A
Total, TEC	783,393	133,000	N/A
Contingency, TEC	188,393	32,000	N/A

[a] The project is Pre-CD-2 and has not been baselined. All estimates are preliminary. The TPC point estimate is $872,932,000. The preliminary TPC range is $805,000,000 to $1,110,000,000.

[b] This project is not yet baselined and all construction costs are derived from the middle of the cost range approved with CD-1. The cost reflects the current SC outyear budget plan, post CD-1.

[c] 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
Other Project Cost (OPC)			
OPC except D&D			
R&D	16,000	6,000	N/A
Conceptual Planning	30,000	13,000	N/A
Conceptual Design	34,000	15,000	N/A
Contingency	9,539	8,621	N/A
Total, OPC	89,539	42,621	N/A
Contingency, OPC	9,539	8,621	N/A
Total, TPC	872,932	175,621	N/A
Total, Contingency	197,932	40,621	N/A

7. Schedule of Appropriation Requests[a]

Request Year		Prior Years	FY 2013	FY 2014	FY 2015	FY 2016	Out-years	Total
FY 2011	TEC	47,000	55,000	0	0	0	0	102,000
	OPC	22,180	0	0	0	0	0	22,180
	TPC	69,180	55,000	0	0	0	0	124,180
FY 2012	TEC	17,000	36,000	38,000	42,000	0	0	133,000
	OPC	42,621	0	0	0	0	0	42,621
	TPC	59,621	36,000	38,000	42,000	0	0	175,621
FY 2016[b]	TEC	4,000	3,781	16,000	12,000	16,000	TBD	783,393
	OPC	51,432	14,107	10,000	10,000	4,000	TBD	89,539
	TPC	55,432	17,888	26,000	22,000	20,000	TBD	872,932

8. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy	FY 2026
Expected Useful Life	20 years

[a] Design and international collaboration plans are currently being developed; outyear appropriation levels will be determined at a later date.
[b] The project is Pre-CD-2 and has not been baselined. All estimates are preliminary. The TPC point estimate is $872,932,000. The preliminary TPC range is $805,000,000 to $1,110,000,000.

Expected Future Start of D&D of this capital asset	FY 2046

Operations and maintenance 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	N/A	180,000	N/A
Utilities	8,000	N/A	160,000	N/A
Maintenance & Repair	1,000	N/A	20,000	N/A
Recapitalization	0	N/A	0	N/A
Total	18,000	N/A	360,000	N/A

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 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 apparatus is 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 South Dakota. 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 and detector configuration at both the near and remote site locations. 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 the design; construction and installation of key LBNF 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.

- Fermilab has extensive experience in managing complex construction, fabrication and installation projects involving multiple National Laboratory, University 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 work at the remote site.

In leading the LBNF 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 is also responsible for the Far Detector (FD) design and construction, with BNL assuming responsibility for acquisition and procurement of select FD subsystems. Fermilab will work through SDSTA/SURF to complete the conventional facilities construction at the remote site needed to house and outfit the FD.

International participation in the design, construction and operation of LBNF will be of essential importance because 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 construction and fabrication work needed. Contributions from other nations will be predominantly through the delivery of components built in their own countries by their own researchers. DOE will negotiate agreements in cooperation with the Department of State on a bilateral basis with all contributing nations to specify their expected contributions and the working relationships during the construction and operation of the experiment.

DOE 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 Project Office also manages and controls 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 technical components. 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 Fermilab will be responsibility of the laboratory. 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.

Delivery of LBNF conventional facilities at SURF will be responsibility of Fermilab working 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 plans to enter into sole-source contracts with the SDSTA to include one for professional design and construction management (CM) preconstruction services, and one for construction of LBNF facilities. During the design phase, the CM will be responsible for independent estimates, design constructability review and reconciliation, developing construction sequencing schedule and acquisition plans, and integration support to project staff to integrate cost, schedule and risk for the major design contracts. The CM contract will be structured with an option to provide staff to augment the SDSTA staff through construction.

The contract for construction of LBNF far-site facilities will involve SDSTA executing multiple construction sub-tier contracts on behalf of LBNF and will also allow SDSTA to self-perform some construction work including items such as electrical distribution to the site. Construction sub-tier contract values would be added to the SDSTA subcontract as those sub-tier contracts are bid and awarded. LBNF and SDSTA would participate in the selection of construction contractors. These selections will include participation from procurement and engineering management in the LBNF Project and Fermilab since LBNF, through Fermilab, will fund these activities and will be ultimately responsible to DOE for their completion.

Prior to the start of far-site conventional facilities construction, it is planned for DOE to enter into a land lease with SDSTA covering the area on which the DOE funded facilities to house and support the LBNF detector will be built. Under the land lease SDSTA will maintain control of the far site facilities until the facilities are turned over to DOE for beneficial occupancy. It is planned that Fermilab will have responsibility for managing and operating the LBNF 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 2015 CPDS and does not include a new start for the budget year. The Independent Project Review held in October 2014 made several recommendations to improve the quality of the baseline and these will be implemented before approving the baseline. Critical Decisions CD-2 and CD-3B are planned for establishing the scope, cost and schedule baseline and for initiating civil construction in 2Q FY 2015. CD-2 date was adjusted by two quarters. CD-3C was established concurrent with completion of final design. CD-4 was extended to 1Q FY 2023 with the application of schedule contingency to mitigate risk.

Development of the preliminary design during FY 2014 refined the baseline scope definition and construction cost estimates by incorporating lessons learned from the NOvA Project at Fermilab relevant to the technical labor effort, risk mitigation and appropriate cost contingency. Consequently the projected Total Project Cost grew from $233,577,000 to $273,677,000, which is well within the Total Project Cost range of $200,000,000–$310,000,000. The funding profile was changed to support this new cost estimate.

The new national strategic plan for U.S. Particle Physics, released by the High Energy Physics Advisory Panel in May 2014, recommends completion of the Mu2e experiment at Fermilab in the near term because it could reveal the presence of new particles with masses up to a million times heavier than that of a proton, well beyond the reach of the Large Hadron Collider (LHC) at CERN.

Summary

The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-3A – Approve Long-Lead Procurement that was approved on 7/10/2014. The preliminary cost range of $200,000,000–$310,000,000 was approved at CD-1 on 7/11/2012. The current CD-4 milestone is 1Q FY 2023.

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

The preliminary design was completed and is being reviewed in preparation for establishing the performance baseline in 2Q FY 2015. Later in FY 2015, civil construction and long-lead procurement for the Transport Solenoid system will start, and the project will initiate the final design and prototyping for technical components. In FY 2016, civil construction activities will continue and fabrication of the solenoid magnets and particle detector systems will be initiated.

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

(fiscal quarter or date)

	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	D&D Complete	CD-4
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[a]	3Q FY 2016[a]	3Q FY 2016[a]	N/A	1Q FY 2023[a]

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 complete/d
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

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 (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

[a] Schedule estimates are preliminary since this project has not received CD-2 approval.

(dollars in thousands)

	TEC, Design	TEC, Construction	TEC, Total	OPC Except D&D	OPC, D&D	OPC, Total	TPC
FY 2016	57,000	193,000	250,000	23,677	N/A	23,677	273,677[a]

4. Project Scope and Justification

Scope

Project will modify existing and construct new proton beam lines for muon production and muon transport into the experimental detector, construct an experimental hall, fabricate three superconducting solenoid magnet systems (the Production Solenoid, Transport Solenoid and Detector Solenoid), and fabricate detector systems including a tracker, electromagnetic calorimeter, cosmic ray veto, trigger and data acquisition subsystems.

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 HEPAP, recommended this type of experiment for the Intensity Frontier of particle physics. The most recent P5 report repeated this recommendation in their 2014 report. This project provides accelerator beam and experimental apparatus to identify unambiguously neutrinoless muon-to-electron conversion events.

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
Total Estimated Cost (TEC)			
Design			
FY 2013	N/A	N/A	14,653
FY 2014	N/A	N/A	15,404
FY 2015	N/A	N/A	18,000
FY 2016	N/A	N/A	8,943
Total, Design	N/A	N/A	57,000
Construction			
FY 2014	N/A	N/A	0
FY 2015	N/A	N/A	20,000
FY 2016	N/A	N/A	30,000
FY 2017	N/A	N/A	40,000
FY 2018	N/A	N/A	40,000
FY 2019	N/A	N/A	32,000
FY 2020	N/A	N/A	25,000

[a] This project has not received CD-2 approval. No construction, other than long-lead procurement, will be performed until the project performance baseline has been validated and CD-3 has been approved.

	(dollars in thousands)		
	Appropriations	Obligations	Costs
FY 2021	N/A	N/A	6,000
Total, Construction	N/A	N/A	193,000
TEC			
FY 2012	24,000	24,000	0
FY 2013	8,000[a]	8,000	14,653
FY 2014	35,000[b]	35,000	15,404
FY 2015	25,000[c]	25,000	38,000
FY 2016	40,100	40,100	38,943
FY 2017	43,500	43,500	40,000
FY 2018	44,400	44,400	40,000
FY 2019	30,000	30,000	32,000
FY 2020	0	0	25,000
FY 2021	0	0	6,000
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	1,072
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
FY 2013	10,500	10,500	15,673
FY 2014	35,000	35,000	17,540
FY 2015	25,000	25,000	39,072
FY 2016	40,100	40,100	38,943
FY 2017	43,500	43,500	40,000
FY 2018	44,400	44,400	40,000

[a] Congress approved a reprogramming that reduced the FY 2013 funding to $8,000,000 from the $22,685,000 that was originally appropriated.
[b] $5,162,907 is for long-lead procurements of superconducting wire for the magnet systems.
[c] $25,000,000 is for long-lead procurements for the superconducting solenoid magnet modules and for construction of the detector hall.

(dollars in thousands)

	Appropriations	Obligations	Costs
FY 2019	30,000	30,000	32,000
FY 2020	0	0	25,000
FY 2021	0	0	6,000
Total, TPC	273,677[a]	273,677[a]	273,677[a]

6. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design			
Design	55,000	40,000	N/A
Contingency	2,000	7,000	N/A
Total, Design	57,000	47,000	N/A
Construction			
Site Work	2,000	2,000	N/A
Construction	19,000	17,000	N/A
Equipment	119,000	99,000	N/A
Contingency	53,000	44,900	N/A
Total, Construction	193,000	162,900	N/A
Total, TEC	250,000	209,900	N/A
Contingency, TEC	55,000	51,900	N/A
Other Project Cost (OPC)			
OPC except D&D			
R&D	6,600	6,600	N/A
Conceptual Planning	4,350	4,350	N/A
Conceptual Design	12,727	12,727	N/A
Contingency	0	0	N/A
Total, OPC	23,677	23,677	N/A
Contingency, OPC	0	0	N/A
Total, TPC	273,677	233,577	N/A
Total, Contingency	55,000	51,900	N/A

[a] This project has not yet received CD-2 approval.

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-	TEC	0	24,000	8,000	35,000	32,000	44,000	45,000	23,000	0	211,000
gram-	OPC	13,177	8,000	2,500	0	0	0	0	0	0	23,677
ming	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

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 been 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.

(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
Recapitalization	0	0	0	0
Total	5,600	5,600	29,000	29,000

9. Required D&D Information

	Square Feet
Area of new construction	Approximately 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.	Approximately 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 will be two major subcontracts for the civil construction for Mu2e. An architecture and engineering (A&E) contract will be 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 will be placed on a firm-fixed-price basis. It is expected that the design specifications will be sufficiently detailed to allow prospective constructors to formulate firm-fixed-price offers without excessive contingency and allowances.

All subcontracts will be competitively bid and awarded based on best value to the government. Chicago 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.