# High Energy Physics

## Funding Profile by Subprogram

(dollars in thousands)

| | FY 2009 Current Appropriation | FY 2009 Current Recovery Act Appropriation[a] | FY 2010 Current Appropriation | FY 2011 Request |
|---|---|---|---|---|
| High Energy Physics | | | | |
| Proton Accelerator-Based Physics | 401,368 | +107,990 | 434,167 | 439,262 |
| Electron Accelerator-Based Physics | 32,030 | +1,400 | 27,427 | 24,707 |
| Non-Accelerator Physics | 101,138 | +4,445 | 99,625 | 88,539 |
| Theoretical Physics | 66,148 | +5,975 | 66,962 | 69,524 |
| Advanced Technology R&D | 175,184 | +112,580 | 182,302 | 189,968 |
| Subtotal, High Energy Physics | 775,868 | +232,390 | 810,483 | 812,000 |
| Construction | 0 | 0 | 0 | 17,000 |
| Total, High Energy Physics | 775,868[b] | +232,390 | 810,483 | 829,000 |

**Public Law Authorizations:**
Public Law 95–91, "Department of Energy Organization Act", 1977
Public Law 109–58, "Energy Policy Act of 2005"
Public Law 110–69, "America COMPETES Act of 2007"

## Program Overview

### Mission

The High Energy Physics (HEP) program's mission is to understand how the universe works at its most fundamental level, which is done by discovering the elementary constituents of matter and energy, probing the interactions between them, and exploring the basic nature of space and time.

### Background

Research in high energy physics, often called particle physics, has led to a profound understanding of the physical laws that govern matter, energy, space, and time. This understanding has been formulated in the Standard Model of particle physics, first established in the 1970s, which successfully describes all known behavior of particles and forces, often to very high precision. Nevertheless, the Standard Model is understood to be incomplete. The model fails at extremely high energies—energies just now being created in particle accelerators—and describes only a small fraction of the matter and energy filling the universe. Data have revealed that only about 5% of the universe is made of the normal, visible matter described by the Standard Model. The remaining 95% of the universe consists of matter and energy whose fundamental nature remains a mystery.

A world-wide program of particle physics research is underway to explore what lies beyond the Standard Model. To this end, the HEP supports a program focused on three scientific frontiers:

[a] The Recovery Act Current Appropriation column reflects the allocation of funding as of September 30, 2009.
[b] Total is reduced by $19,858,000: $17,730,000 of which was transferred to the Small Business Innovation Research (SBIR) program and $2,128,000 of which was transferred to the Small Business Technology Transfer (STTR) program.

- *The Energy Frontier,* where powerful accelerators are used to create new particles, reveal their interactions, and investigate fundamental forces;
- *The Intensity Frontier,* where intense particle beams and highly sensitive detectors are used to pursue alternate pathways to investigate fundamental forces and particle interactions by studying events that occur rarely in nature; and
- *The Cosmic Frontier,* where ground and space-based experiments and telescopes are used to make measurements that will offer new insight and information about the nature of dark matter and dark energy to understand fundamental particle properties and discover new phenomena.

Together, these three interrelated and complementary discovery frontiers offer the opportunity to answer some of the most basic questions about the world around us, such as:

- *Are there undiscovered principles of nature, such as new symmetries or new physical laws?*

  The laws of quantum physics that describe elementary particles and forces are based on underlying symmetries of nature. Some of these prevail only at very high energies. A possible and theoretically well motivated new symmetry, called supersymmetry, relates particles and forces. It predicts a superpartner for every particle we know. If such superparticles exist, it may be possible to produce the lightest of them with accelerators that operate at the Energy Frontier or infer their existence from rare decays or new phenomena at the Intensity or Cosmic Frontiers.

- *How can we solve the mystery of dark energy?*

  The structure of the universe today is a result of two opposing forces: gravitational attraction and cosmic expansion. For approximately the last six billion years, the universe has been expanding at an accelerating rate due to a mysterious dark energy that overcame gravitational attraction. This energy, which permeates empty space, must have a quantum (or particle) explanation. Dark energy was first discovered in 1998 by HEP-supported researchers (among others); more and other types of data, gathered from the Cosmic Frontier, along with new theoretical ideas, are necessary to make progress in understanding its fundamental nature.

- *Are there extra dimensions of space?*

  String theory is an attempt to unify physics by explaining particles and forces as the vibrations of sub-microscopic strings. String theory requires extra dimensions of space and generally supersymmetry. Accelerators at the Energy Frontier may find evidence for extra dimensions, requiring a completely new paradigm for thinking about the structure of space and time.

- *Do all the forces become one?*

  All the basic forces in the universe could be various manifestations of a single unified force. Unification was Einstein's great, unrealized dream, and advances in string theory give hope of achieving it. The discovery of superpartners or extra dimensions at Energy Frontier accelerators, or hints of them at the Intensity or Cosmic Frontiers, would lend strong support to current ideas about unification.

- *Why are there so many kinds of particles?*

  Three different pairings or "families" of quarks and leptons have been discovered—most of these at DOE national laboratories. Does nature somehow require that there are only three, or are there more? Moreover, the various quarks and leptons have widely different masses and force couplings. These differences suggest there may be an undiscovered explanation that unifies quarks and leptons, just as the discovery of quarks simplified the zoo of composite particle states discovered in the

1960s. Detailed studies that employ Energy Frontier accelerators, as well as precision measurements made at Intensity Frontier facilities, may provide the dramatic insights into this complex puzzle.

- *What is dark matter? How can we make it in the laboratory?*

  Most of the matter in the universe is invisible. We can detect its existence only through its gravitational interactions with normal matter. This dark matter is thought to consist of exotic particles (relics) that have survived since the Big Bang. Experiments are being mounted to try to directly detect these exotic particles, via observations of relic dark matter at the Cosmic Frontier or by producing them at Energy Frontier accelerators that briefly recreate the conditions of the Big Bang.

- *What are neutrinos telling us?*

  Of all the 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. Trillions pass through the Earth every second with little or no interaction. Their detection requires intense neutrino sources and large detectors. HEP supports research into fundamental neutrino properties because they can reveal important clues to the unification of forces and the very early history of the universe. Naturally occurring neutrinos are produced by cosmic ray interactions with the Earth's atmosphere, by supernovae, and in the interior of stars. These can be studied at the Cosmic Frontier. They can also be studied at the Intensity Frontier using intense neutrino sources such as nuclear reactors and advanced accelerators.

- *How did the present universe come to be?*

  The universe began with a massive explosion known as the Big Bang, followed by a burst of expansion of space itself. The universe then expanded more slowly and cooled, which allowed the formation of stars, galaxies, and ultimately life. Understanding the very early evolution of the universe will require a breakthrough in physics: the theoretical reconciliation of quantum mechanics with gravity.

- *What happened to the antimatter?*

  The universe appears to contain very little antimatter. Antimatter is continually produced by naturally occurring nuclear reactions only to undergo near immediate annihilation. The Big Bang, however, should have produced equal amounts of both matter and antimatter. This has, to date, been borne out by the study of high-energy collisions in the laboratory. Precise Energy and Intensity Frontier accelerator-based measurements of the subtle asymmetries present in the weak nuclear interaction may shed light on how the present day matter-antimatter asymmetry arose.

Because of the strong connections between the key questions in each area, successfully addressing these questions requires coordinated initiatives at each of the frontiers. The HEP program invents new technologies to answer these questions and to meet the challenges of research at the frontiers. It supports theoretical and experimental studies by individual investigators and large collaborative teams—some who gather and analyze data from accelerator facilities in the U.S. and around the world, and others who develop and deploy ultra-sensitive instruments to detect particles from space and observe astrophysical phenomena that advance our understanding of fundamental particle properties.

### Subprograms

The High Energy Physics program is divided into five subprograms that are organized around the tools and facilities they employ (e.g., an electron accelerator or cosmic ray detector) and/or the knowledge and technology they develop (e.g., superconducting radio frequency cavities or computational capabilities):

- The *Proton Accelerator-Based Physics subprogram* exploits two major applications of proton accelerators. Due to the high energy of the collisions at the Tevatron Collider (2 TeV) and the Large Hadron Collider (LHC, 14 TeV), the composite nature of the protons (which are like bean bags full of quarks and gluons), and the fact that the particles interact differently at different energies, these facilities can be used to study a wide variety of scientific issues. Proton accelerators are also capable of producing, by colliding intense proton beams into fixed targets, large samples of other particles (e.g., antiprotons, K mesons, muons, and neutrinos) which can be formed into beams for experiments. The proposed Intensity Frontier program utilizes the high-power proton beam at Fermi National Accelerator Laboratory (Fermilab) to produce intense secondary beams of neutrinos and muons for world-leading experiments.
- The *Electron Accelerator-Based Physics subprogram* utilizes accelerators with high-intensity and ultra-precise electron beams to create and investigate matter at its most basic level. Since electrons are light, point-like particles (unlike protons) they are well-suited to precision measurements of particle properties and exacting beam control. The next-generation Energy Frontier accelerator after the LHC is likely to be a high-energy lepton (electron or perhaps muon) facility that can probe LHC discoveries in detail.
- The *Non-Accelerator Physics subprogram* provides U.S. leadership in the study of those topics in particle physics that cannot be investigated with accelerators, or are best studied by other means. These activities have provided experimental data, new ideas, and techniques complementary to those provided by accelerator-based research. Scientists in this subprogram investigate topics such as dark matter, dark energy, neutrino properties, proton decay, the highest energy gamma rays, and primordial antimatter. Some of the non-accelerator particle sources used in this research are cosmic rays, gamma rays, and neutrinos from astrophysical sources, and neutrinos from commercial nuclear power reactors.
- The *Theoretical Physics subprogram* provides the vision and mathematical framework for understanding and extending the knowledge of particles, forces, space-time, and the universe. This program supports activities that range from detailed calculations of the predictions of the Standard Model to advanced computation and simulations to solve otherwise intractable problems. Theoretical physicists play key roles in determining which experiments to perform and explaining experimental results in terms of underlying theories that describe the interactions of matter, energy, and space-time.
- The *Advanced Technology R&D subprogram* develops the next generation of particle accelerator and detector technologies for the future advancement of high energy physics and other sciences, supporting world-leading research in the physics of particle beams, fundamental advances in particle detection, and R&D on new technologies and research methods appropriate for a broad range of scientific disciplines.

## Benefits

Seeking answers to big questions drives basic research. It appeals to our deepest human nature. However, the new technologies created to answer the questions that high energy physicists seek to answer, and the knowledge acquired in their pursuit, also yield substantial benefits of a more tangible nature for society as a whole. The continuous improvement of accelerator and detector technology necessary to pursue high energy physics as well as the scale of the science itself, have had transformative impacts on the Nation's economy, security, and society. HEP, as steward of accelerator science and advanced accelerator technology R&D in the Office of Science, has developed the knowledge and technologies that are the basis for all of the Office of Science major accelerator user facilities. HEP's contributions to the underlying technologies now used in medicine, science, industry, homeland and national security, as well as for workforce training, are also well known. (For more information, visit http://www.science.doe.gov/hep/benefits.)

Looking to the future, HEP's ongoing and future development of accelerator, detector, electronics, and magnet technologies is anticipated to have significant impact in a number of areas: medical treatment and diagnosis—where new, more cost-efficient particle accelerators, detectors, and magnets for cancer treatment and diagnosis should emerge; homeland and national security—where particle accelerators and detectors developed for high energy physics research have the potential for hazardous material detection and non-proliferation verification; industry—where, for example, superconducting cables being developed for next generation magnets for high energy physics research could be used to transmit, with minimal power losses, far more electricity than conventional cables; internet grid development—where the developments of the international grid capability for data analysis of the large detectors at the LHC may result in a paradigm change in the handling of huge data sets; and other scientific fields—where HEP's development of the science and technologies needed for next-generation particle accelerator and detector applications will be transferred and exploited.

An important benefit to the Nation provided by the HEP program is the recruitment and training of a highly motivated, highly trained scientific and technical work force. In particle physics, roughly two thirds of those completing doctoral degrees ultimately pursue careers in diverse sectors of the national economy such as industry, national defense, information technology, medical instrumentation, electronics, communications, and biophysics—where the workforce requires highly developed analytical and technical skills, the ability to work in large teams on complex projects, and the ability to think creatively to solve unique problems.

## Program Planning and Management

- *Advisory and Consultative Activities*

  To ensure that resources are allocated to the most scientifically promising experiments, DOE and its national laboratories actively seek external input using a variety of advisory bodies. The High Energy Physics Advisory Panel (HEPAP), jointly chartered by DOE and NSF, provides advice regarding the scientific opportunities and priorities of the national high energy physics research program. HEPAP or one of its subpanels undertakes special studies and planning exercises in response to specific charges from the funding agencies.

  A HEPAP subpanel called the Particle Physics Project Prioritization Panel (P5) was formed to assess and prioritize scientific opportunities and proposed projects. HEPAP subpanels are also convened to review progress and/or future plans in particular research areas or elements of the HEP program. In 2007, P5 was charged to examine the options for mounting a world-class U.S. particle physics program at various funding levels. This HEPAP report[a] was submitted in June 2008 and has provided important input for setting programmatic priorities for the HEP program. Many of the recommendations contained in the report have been implemented, and this budget request in particular emphasizes implementation of the P5 roadmap for the Intensity Frontier.

[a] The full HEPAP report is available at http://www.science.doe.gov/hep/files/pdfs/P5_Report%2006022008.pdf.

The Astronomy and Astrophysics Advisory Committee (AAAC) now reports on a continuing basis to DOE, as well as to NSF and the National Aeronautics and Space Administration (NASA), with advice on the direction and management of the national astronomy and astrophysics research programs. The AAAC operates similarly to HEPAP and the two advisory bodies have been charged to form joint task forces or subpanels to address research issues at the intersection of high energy physics, astrophysics and astronomy, such as dark energy and dark matter, and the study of high energy cosmic and gamma rays.

The HEP program also instituted a Committee of Visitors (COV) that provides an independent review of its responses to proposals and its research management process, as well as an evaluation of the quality, performance, and relevance of the research portfolio and an assessment of its breadth and balance. The second triennial HEP COV review took place in summer 2007. The 2007 COV report[a] had 18 specific recommendations relating primarily to staffing, grants review and processing, and project management. HEP has completed seven of the recommendations, particularly in regard to staffing; six recommendations are in-process and five are on-going.

- *Review and Oversight*

  The HEP program office reviews and provides oversight for its research portfolio. All university research proposals are subject to a review process to ensure high quality research and relevance to achieving the goals of the national program. Proposals to DOE for grant support are peer-reviewed by external technical experts, following the guidelines established by 10 CFR Part 605.

  Following recommendations of the 2007 COV, HEP implemented a new review process for high energy physics research and basic technology R&D efforts at DOE laboratories. Laboratory high energy physics research or technology R&D groups are peer-reviewed triennially on a rotating basis, using the same criteria established for the university reviews. This is a comparative review that assesses the relative strengths and weaknesses of the various laboratory groups in particular research subfields. In FY 2011, the Accelerator Science and Theoretical Physics subprograms will be reviewed. Laboratory proposals involving significant new research scope are also subject to peer-review by external experts on an *ad hoc* basis.

### Basic and Applied R&D Coordination

Many of the broader applications of technology originally developed for HEP research have been serendipitous. In order to provide a more direct connection between fundamental accelerator technology and applications, the HEP program sponsored a workshop in October 2009 to identify the R&D needs of the various users of accelerators who would benefit from future technology R&D initiatives. The workshop focused on the role of accelerators in the nation's efforts in science, medicine, national security, and industry; the opportunities and research challenges for next generation accelerators; the most promising avenues for new or enhanced R&D efforts; and a path forward to stronger coordination between basic and applied research. HEP will use this report to develop a strategic plan for accelerator technology R&D that recognizes its broader societal impacts.

### Budget Overview

The HEP program addresses fundamental questions about the nature of the universe by balancing the scientific priorities of the research community with the constraints of the facilities, tools, and resources available. Research facilities for high energy physics generally require significant investments over

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[a] The 2007 COV report and HEP's response are available at http://www.science.doe.gov/SC-2/COV-HEP/HEP_Reviews.htm.

many years and the coordinated efforts of international teams of scientists and engineers to realize accelerators and detectors that push the frontiers of Energy, Intensity, and Cosmic exploration.

The HEP program, with input from the scientific community, has developed a long-range plan which maintains a leadership role for the U.S. within this global context. In this plan there is a continuing shift of focus from the operation of the facilities built at the end of the 1990s to the design and construction of new research capabilities, while maintaining a world-leading scientific program and identifying targeted long-range R&D for the future. This strategic plan allows the Nation to play an important role at all three frontiers of particle physics.

**The Energy Frontier:** The Tevatron Collider at Fermilab continues operations in FY 2011. Its record-breaking performance in delivering data over the last few years means that it will remain competitive with the LHC for significant discoveries during the first few years of LHC operations. The primary scientific goals of the HEP program over the next five years are to enable these discoveries—for example, the Higgs boson and supersymmetric particles—either at the Tevatron or the LHC. First beam collisions at the LHC occurred at the end of 2009 and the first physics run will begin in February 2010. Support for LHC detector operations, maintenance, computing, and R&D is necessary to maintain a U.S. leadership role in the LHC program.

The HEP strategic plan includes U.S. participation in the first phase of the anticipated LHC accelerator and detector upgrades to improve performance and reliability and provide a two-fold increase in the LHC luminosity (a measure of the number of physics interactions per second), which will significantly lower statistical uncertainties and improve the chances of observing rare events. Data from the first phase will guide the choice of the most promising physics to pursue in any future enhancement of LHC accelerator and detector capabilities. Physics results from the LHC will also help guide research and development for a potential next-generation lepton collider.

**The Intensity Frontier:** The Neutrinos at the Main Injector (NuMI) beamline at Fermilab will operate in its current configuration through FY 2011 for ongoing neutrino experiments and then will be subject to a year-long upgrade from approximately 400 kW to 700 kW of beam power for the NuMI Off-Axis Neutrino Appearance (NOνA) experiment. The NOνA project will enable key measurements of neutrino properties; it is under construction and will be in full operation in 2014. In FY 2011, project engineering and design (PED) funding is provided to initiate the Long Baseline Neutrino Experiment (LBNE) and the Muon to Electron Conversion Experiment (Mu2e) that will use the NuMI beam and other auxiliary beamlines before the end of the next decade. The HEP program is developing the LBNE project in coordination with NSF, which is proposing to construct a Deep Underground Science and Engineering Laboratory (DUSEL) in an old gold mine in South Dakota; DUSEL may be an attractive site for the large LBNE neutrino detector.

**The Cosmic Frontier:** DOE is partnering with NASA and NSF in world class, space-based and ground-based particle astrophysics observatories for exploration of the Cosmic Frontier. HEP and NASA are presently jointly supporting analysis of data from NASA's Fermi Gamma-ray Space Telescope that detects gamma-rays emanating from astrophysical sources, and HEP continues support for commissioning and integration activities for the Alpha Magnetic Spectrometer experiment which is on NASA's Space Shuttle manifest for launch in 2010. HEP is collaborating with NSF on experiments using ground-based observatories, including the Baryon Oscillation Spectroscopic Survey, which is currently operating, and the Dark Energy Survey, currently in fabrication, and on R&D aimed at developing large, next-generation telescopes that can significantly advance our knowledge of dark energy. HEP and NASA continue to work together to develop a space-based Joint Dark Energy Mission that will complement and extend the ground-based measurements. HEP will also continue to collaborate with NSF on a phased program of research and technology development that is designed to directly detect dark matter particles (rather than indirectly observe their effects on normal matter) using ultra-sensitive detectors located underground.

**Significant Program Shifts**

Following the recommendations of HEPAP, a continued leadership role for the U.S. HEP program requires investments in new facilities to exploit the scientific opportunities at the research frontiers. In this budget request, there is funding to begin project engineering and design (PED) for the Long Baseline Neutrino Experiment (LBNE) and Muon to Electron Conversion Experiment (Mu2e) to enable future discoveries.

**Annual Performance Results and Targets**

**Secretarial Priority**: Innovation: Lead the world in science, technology, and engineering.

**GPRA Unit Program Goal**: High Energy Physics Program Goal: Explore the Fundamental Interactions of Energy, Matter, Time, and Space—Understand the unification of fundamental particles and forces, and the mysterious forms of unseen energy and matter that dominate the universe; search for possible new dimensions of space; and investigate the nature of time itself.

**Annual Performance Measure**: Deliver within 20% of baseline estimate a total integrated amount of data (in inverse picobarns [$pb^{-1}$]) to the CDF and D-Zero detectors at the Tevatron[a].

| | |
|---|---|
| **FY 2006** | T: Baseline is 675, so within 20% of baseline is 540 $pb^{-1}$.<br>A: Goal met |
| **FY 2007** | T: Baseline is 800 $pb^{-1}$, so within 20% of baseline is 640 $pb^{-1}$.<br>A: Goal met |
| **FY 2008** | T: Baseline is 1,000 $pb^{-1}$, so within 20% of baseline is 800 $pb^{-1}$.<br>A: Goal met |
| **FY 2009** | T: Baseline is 1,684 $pb^{-1}$, so within 20% of baseline is 1,347 $pb^{-1}$.<br>A: Met |
| **FY 2010** | T: Total is 1,700 $pb^{-1}$, within 20% is 1360 $pb^{-1}$<br>A: TBD |
| **FY 2011** | T: Total is 1,700 $pb^{-1}$, within 20% is 1,360 $pb^{-1}$.<br>A: TBD |
| **FY 2012** | T: Completed/Discontinued |

**Annual Performance Measure**: Achieve less than 10% for both the cost-weighted mean percentage variance from established cost and schedule baselines for major construction, upgrade, or equipment procurement projects.

| | |
|---|---|
| **FY 2006** | T: Less than 10% variance from established cost and schedule baselines<br>A: Goal met |

[a] FY 2011 is the last planned year of operations of the CDF and D-Zero detectors.

| | |
|---|---|
| **FY 2007** | T: Less than 10% variance from established cost and schedule baselines<br>A: Goal met |
| **FY 2008** | T: Less than 10% variance from established cost and schedule baselines<br>A: Goal met |
| **FY 2009** | T: Less than 10% variance from established cost and schedule baselines<br>A: Goal met |
| **FY 2010 - 2015** | T: Less than 10% variance from established cost and schedule baselines<br>A: TBD |

**Annual Performance Measure**: Achieve greater than 80% average operation time of the scientific user facilities (the Fermilab Tevatron) as a percentage of the total scheduled annual operating time.

| | |
|---|---|
| **FY 2006** | T: 80% of scheduled operating time<br>A: Goal not met |
| **FY 2007** | T: 80% of scheduled operating time<br>A: Goal met |
| **FY 2008** | T: 80% of scheduled operating time<br>A: Goal met |
| **FY 2009** | T: 80% of scheduled operating time<br>A: Goal met |
| **FY 2010** | T: 80% of scheduled operating time<br>A: TBD |
| **FY 2011** | T: 80% of scheduled operating time<br>A: TBD |
| **FY 2012** | T: None[a]<br>A: TBD |
| **FY 2013 - 2015** | T: 80% of scheduled operating time<br>A: TBD |

[a] The Tevatron complex is shut down in FY 2012 for the installation of the upgrades to the proton accelerator complex for the NOνA project.

**Annual Performance Measure:** Measure within 20% of the total integrated amount of data (in protons on-target) delivered to the MINOS (or NOvA) detector using the NuMI facility.[a]

| | |
|---|---|
| **FY 2006** | T: N/A[b]<br>A: |
| **FY 2007** | T: Baseline is 1.5 x $10^{20}$ protons-on-target to MINOS, so within 20% of baseline is 1.2 x $10^{20}$ protons-on-target.<br>A: Goal met |
| **FY 2008** | T: Baseline is 2.0 x $10^{20}$ protons-on-target to MINOS, so within 20% of baseline is 1.6 x $10^{20}$ protons-on-target.<br>A: Goal met |
| **FY 2009** | T: Baseline is 2.2 x $10^{20}$ protons-on-target to MINOS; goal will be met if total integrated amount of data measured is greater than or equal to 1.8 x $10^{20}$ protons-on-target.<br>A: Goal met |
| **FY 2010** | T: 2.7 x$10^{20}$ protons on target to the MINOS. (80% is 2.2 x $10^{20}$)<br>A: TBD |
| **FY 2011** | T: 2.7 x$10^{20}$ protons on target to the MINOS. (80% is 2.2 x $10^{20}$)<br>A: TBD |
| **FY 2012** | T: None.<br>A: TBD |
| **FY 2013** | T: 1.0 x$10^{20}$ protons on target for NOvA. (80% is 0.8 x $10^{20}$)<br>A: TBD |
| **FY 2014** | T: 2.5 x$10^{20}$ protons on target for NOvA. (80% is 2.0 x $10^{20}$)<br>A: TBD |
| **FY 2015** | T: 3.5 x$10^{20}$ protons on target for NOvA. (80% is 2.8 x $10^{20}$)<br>A: TBD |

[a] FY 2011 is the last planned year of operations of the MINOS detector, operations of the NOvA detector are planned to start in FY 2013.
[b] NuMI performance measure established in 2007.

## Proton Accelerator-Based Physics

### Funding Schedule by Activity

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2009 | FY 2010 | FY 2011 |
| Proton Accelerator-Based Physics | | | |
| Research | 126,405 | 125,436 | 130,299 |
| Facilities | 274,963 | 308,731 | 308,963 |
| Total, Proton Accelerator-Based Physics | 401,368 | 434,167 | 439,262 |

## Description

The Proton Accelerator-Based Physics subprogram exploits the application of proton accelerators at two of the scientific frontiers. At the Energy Frontier, experiments at the Tevatron and LHC it will be used to determine whether the Standard Model correctly predicts the mechanism that generates mass for all fundamental particles and will search for the first clear evidence of new physics beyond the Standard Model. At the Intensity Frontier, experiments using the beams from NuMI will make precise, controlled measurements of basic neutrino properties and will provide important clues and constraints on the new world of matter and energy beyond the Standard Model, which is a primary goal of HEP-supported neutrino research.

### Selected FY 2009 Accomplishments

- For the first time since the Large Electron-Positron (LEP) collider at CERN last operated in 2000, researchers are again treading on unexplored Higgs territory with the Tevatron Collider experiments at Fermilab. Recently, combined results from the Tevatron Collider experiments have started to exclude a region of Higgs mass between 170 and 181 times the mass of the proton. As more data is collected at the Tevatron, either this exclusion region will expand or the first possible hints of the Higgs boson will appear.

- The Tevatron Collider experiments, CDF and D-Zero, have observed rare Standard Model processes such as double Z boson production, simultaneous W and Z boson production, and single top quark production. The observation of these rare processes is a necessary precursor for the discovery of the Higgs boson. In addition, the Tevatron has also recently produced the most precise measurements of top quark and W boson parameters, which are used to further constrain new physics theories. The innovative analysis methods employed by CDF and D-Zero scientists and the thorough understanding of detector performance and backgrounds displayed in these results also support future discoveries.

- A groundbreaking ceremony was held in May 2009 at the site of the NOνA neutrino detector in northern Minnesota. The NOνA project will fabricate the NuMI Off-Axis Electron Neutrino Appearance (NOνA) detector near the Ash River, about 40 miles southeast of International Falls. This 14,000-ton particle detector is optimized to identify electron-type neutrinos and, using the NuMI beam from Fermilab, will observe for the first time the transformation of muon-type neutrinos into electron-type neutrinos. Fabrication of the NOνA detector was initiated in 2007, and is planned to be complete in FY 2014. Operations are planned to begin with a partially completed detector in 2013.

- Operations of the Large Hadron Collider (LHC) began in late 2009 after a year-long shutdown to repair electrical problems discovered in its initial start-up. The energy of the machine was ramped up to a center-of-mass energy of 2.36 TeV, surpassing the Tevatron Collider as the world's highest energy accelerator, although initial luminosity is very low as the machine is being carefully commissioned. Both the ATLAS and CMS large detectors have observed events and are taking data with fully functional detectors. The LHC is expected to increase its energy and accumulate much more data in 2010 with its first physics run.

## Detailed Justification

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2009 | FY 2010 | FY 2011 |
| **Research** | **126,405** | **125,436** | **130,299** |

The major research activities under the Proton Accelerator-Based Physics subprogram are the research programs using the CDF and D-Zero detectors at the Tevatron at Fermilab, the neutrino research program using the NuMI/MINOS detectors located at Fermilab and at the Soudan Mine site in Minnesota, and the research programs of ATLAS and CMS at the LHC at CERN.

The research program using the Tevatron Collider at Fermilab is being carried out by a collaboration composed of 1,400 scientists from Fermilab, Argonne National Laboratory (ANL), Brookhaven National Laboratory (BNL), 56 U.S. universities, and institutions in over 20 foreign countries. The major effort in FY 2011 is the collection of data with the CDF and D-Zero detectors. The physics issues to be addressed include searches for the Higgs boson, supersymmetry, or other new phenomena; B meson studies including charge-parity (CP) violation; and precision measurements of the top quark and the W boson properties. In particular, the direct experimental searches for a Standard Model Higgs boson with a mass in the range expected (based on other indirect experimental data) will require the entire Tevatron data set. The Tevatron Collider will continue operations in FY 2011 to provide the two detectors access to the entire region of the expected Higgs mass range.

The research program using the NuMI/MINOS facilities at Fermilab and the Soudan Mine is being carried out by a collaboration that includes 250 scientists from Fermilab, ANL, BNL, 16 U.S. universities, and institutions in five foreign countries. The major effort in FY 2011 will be data collection and analysis, along with optimizing accelerator performance to improve beam intensity for higher statistics measurements. The experiment is planned to complete its data taking in FY 2011 to achieve its ultimate sensitivity, approximately a factor of two improvement over its current result, and will search for the as-yet unseen oscillation of muon neutrinos to electron neutrinos.

In FY 2011, U.S. researchers will play a leadership role in the physics discoveries at the high energies enabled by the LHC. Achieving this goal requires effective integration of U.S. researchers in the LHC detector calibration and data analysis efforts, and implementation and optimization of the U.S. data handling and computing capabilities needed for full participation in the LHC research program. Maintenance of U.S.-supplied detector elements for LHC experiments at CERN will continue.

| | | | |
|---|---|---|---|
| ▪ **Grants Research** | **59,550** | **59,546** | **61,253** |

The grant-based HEP experimental research program consists of groups at more than 60 universities performing experiments at proton accelerator facilities. Grant-supported scientists typically constitute about 50–75% of the personnel needed to create, run, and analyze an experiment, and they usually work in collaboration with other university and laboratory groups. Grant-based research efforts are selected based on peer review, and funded at levels commensurate with the effort needed to carry out the experiments.

In FY 2011, the grant research effort is increased above the FY 2010 level, in order to fully support LHC research activities while maintaining participation in the Tevatron Collider and growing strong neutrino physics programs. Active participation of university physicists is needed to carry out both the collider and neutrino programs at the Tevatron during FY 2011. There will be healthy scientific competition between completion of Run II of the Tevatron Collider program and commencement of the LHC experiments, although the level of this competition will depend on how quickly the LHC will be brought into full operation. Some migration of U.S. university researchers from the LHC back to the Tevatron Collider program has been observed in 2009 due to the delayed startup of the LHC. At the same time, university groups are expected to take important roles in developing the design, physics optimization, and analysis techniques for the planned neutrino initiatives, such as NOνA, Main Injector Experiment ν-A (MINERνA), and LBNE. U.S. university groups also have leadership roles in the Tokai-to-Kamioka (T2K) neutrino oscillation experiment that complements and extends the physics reach of NOνA. The detailed funding allocations will take into account the quality and scientific priority of the research proposed.

| | FY 2009 | FY 2010 | FY 2011 |
|---|---|---|---|
| ▪ **National Laboratory Research** | **65,857** | **64,956** | **68,108** |

Proton accelerator research activities concentrate on experiments at the Tevatron complex (collider and neutrino physics programs) at Fermilab and the LHC at CERN. The HEP program conducted a comparative peer review of laboratory research groups in this subprogram in 2009, and findings from this review have been used to inform the funding decisions in the FY 2011 request.

In FY 2011, U.S. laboratory physicists will continue to play important roles in A Large Toroidal LHC ApparatuS (ATLAS) and Compact Muon Solenoid (CMS) experiments, as LHC operations and data analysis move past the commissioning phase into steady-state operations. Strong involvement of physicists from the national laboratories will also be needed to carry out the research program at the Tevatron during FY 2011. The HEP program will monitor progress in these areas and balance resources in order to optimize the national program.

The Fermilab research program includes data collection and analysis of the CDF, D-Zero, and MINOS experiments; the CMS research and computing program; and research related to the NOνA, MINERνA, MicroBooNE, and LBNE experiments. Research at LBNL consists of a large and active group in the ATLAS research program. The BNL research group will focus on the ATLAS research and computing program, with a small effort on D-Zero and an enhanced effort related to future neutrino initiatives, in particular detector design for LBNE. The research group at ANL will be working primarily on the ATLAS research and computing program, analysis of the MINOS data, and research on NOνA. The relatively new research group from SLAC on the ATLAS experiment has taken on important roles in LHC research and data analysis.

| | FY 2009 | FY 2010 | FY 2011 |
|---|---|---|---|
| ▪ **University Service Accounts** | **998** | **934** | **938** |

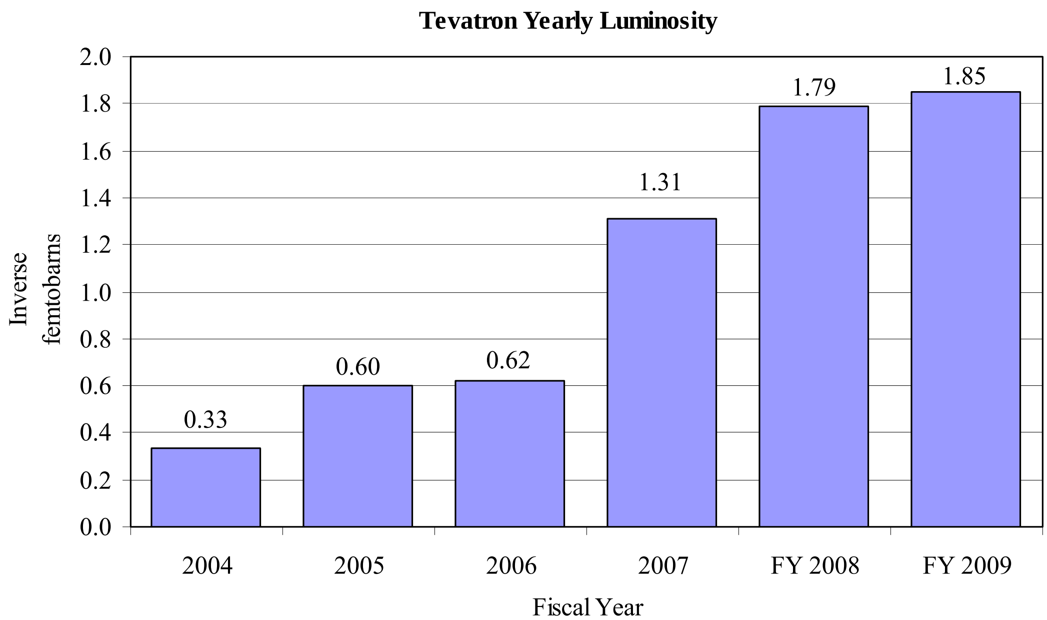
University Service Accounts facilitate the support of university groups working at accelerator facilities. This activity provides funding for these groups to purchase needed equipment and services from the laboratories with a minimum of time and cost overhead. Currently, 45 university groups

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2009 | FY 2010 | FY 2011 |

maintain service accounts at Fermilab and at BNL. Funding for these university service accounts reflects the anticipated need.

| | | | |
|---|---|---|---|
| **Facilities** | **274,963** | **308,731** | **308,963** |
| ▪ **Proton Accelerator Complex Operations** | **129,585** | **123,985** | **123,215** |

Fermilab operations include running the Tevatron accelerator complex for both collider and neutrino physics programs comprising two collider detectors and several neutrino experiments, respectively. The performance of the Tevatron collider has continued to improve as the laboratory staff has learned to effectively exploit the upgrades that were completed in FY 2006. Tevatron performance improved significantly in FY 2007 and FY 2008 and reached a steady state of high performance in FY 2009. The plot below shows the annual integrated luminosity delivered to the experiments.




Some of the increase in luminosity in FY 2008 was due to additional running time that was scheduled to maximize the integrated luminosity before the first beam collisions at the LHC. Performance in FY 2009 improved and the yearly total was slightly higher than FY 2008 with a normal length run. Performance in FY 2010 and FY 2011 should plateau around two inverse femtobarns per year, so the total delivered luminosity for Run II at the end of FY 2011 should be about twice as large as the total recorded by the end of FY 2009.

In FY 2011, the flat funding in this category reflects the fact that stable running has been achieved and that fewer personnel are needed to run the accelerator. Increased automation of data collection with the CDF and D-Zero detectors has also reduced personnel required for detector operations.

Operations of the Tevatron complex include simultaneous provision of beam for fixed target and collider programs. This dual running mode is necessary for the MINOS and the MINERνA experiments that use neutrinos from the NuMI beamline. The small MINERνA experiment in the MINOS near detector hall at Fermilab is measuring the rates of neutrino interactions with ordinary matter. Its results are important for interpreting the data from MINOS and other neutrino experiments, including NOνA.

| | FY 2009 | FY 2010 | FY 2011 |
|---|---|---|---|
| Proton Accelerator Complex[a] | | | |
| Achieved Operating Hours | 5,333 | N/A | N/A |
| Planned Operating Hours | 5,040 | 5,400 | 5,400 |
| Optimal hours (estimated) | 5,400 | 5,400 | 5,400 |
| Percent of Optimal Hours | 99% | 100% | 100% |
| Unscheduled Downtime | 16% | N/A | N/A |
| Total Number of Users | 2,160 | 2,000 | 1,800 |

- **Proton Accelerator Complex Support** **18,892** **14,161** **16,617**

  This category includes funding for accelerator improvements, experimental computing expansion, and other detector support, as well as funds for general plant projects (GPP) and other infrastructure improvements at Fermilab. A backlog of GPP projects was addressed with 2009 Recovery Act funding, reducing the need for GPP funds in FY 2010. GPP funding in FY 2011 is increased to the level needed to adequately maintain site infrastructure over the long term.

- **Proton Accelerator Facility Projects** **46,958** **80,173** **74,463**

  - **Current Facility Projects** **32,666** **61,843** **59,220**

    After the completion of Tevatron Collider Run II, it will be possible to adapt portions of the existing collider complex to support operations of the NuMI beam-line at even higher intensity. Reconfiguration of the recycler, which currently serves as a storage ring for antiprotons, can raise the beam power to the NuMI target from 400 kW to 700 kW. Improvements to the cooling, shielding, and power supplies in the booster, main injector, and NuMI beam-line would also be done to support the higher beam intensity.

    Since the increase in neutrino intensity that can be achieved with this reconfiguration will be very important to support the physics goals of the NOνA detector, this collection of upgrades and improvements has been included as part of the scope of the NOνA project in order to ensure appropriate project management oversight and integration.

    The NOνA detector is optimized to identify electron-type neutrinos and, using the NuMI beam from Fermilab, it will observe for the first time the transformation of muon-type neutrinos into electron-type neutrinos. It will also make important indirect measurements from which we may be able to determine the mass hierarchy of the three known neutrino types (e.g., whether there are two light and one heavier type neutrinos or vice versa). This will be a key piece of information that will help determine the currently unknown masses of neutrinos. The project includes the very large far detector (approximately five stories high with a football-field size

[a] Tevatron and NuMI operations run in parallel.

|  | FY 2009 | FY 2010 | FY 2011 |
|---|---|---|---|

(dollars in thousands)

footprint), the far detector enclosure, its associated electronics and data acquisition system, and a small near detector on the Fermilab site. The project baseline was approved in September 2008, and detector fabrication made significant progress in 2009, using FY 2009 and Recovery Act funds. In FY 2011, TEC funding has decreased from the peak in FY 2010. Fabrication will be completed in FY 2014, but the experiment can start taking data with a partially completed detector in FY 2013.

Funding in FY 2011 includes $8,000,000 to begin fabrication of the MicroBooNE experiment. This is a new Major Item of Equipment (MIE) project that will fabricate a liquid argon neutrino detector to be used in the Booster neutrino beam at Fermilab for the measurement of low energy neutrino cross-sections. These cross sections will be measured at lower neutrino energy than the work planned for MINERνA and will be important for interpreting data from T2K and the proposed Long Baseline Neutrino Experiment (LBNE).

| | | | |
|---|---|---|---|
| • **Future Facility Projects R&D** | **14,292** | **18,330** | **15,243** |

Pre-conceptual R&D for possible future projects that utilize the Fermilab facility is funded in this category. Specifically, pre-conceptual R&D directed toward detector concepts tied to future facilities, and for a superconducting GeV linac, is supported in FY 2011. This linac would provide the beam power needed to continue high intensity experiments using the Fermilab accelerator complex. It would replace the current linac and booster accelerators at Fermilab, which are over 35 years old, and upgrade the beam power approximately 2–3 times beyond the upgrades planned for NOνA.

| | | | |
|---|---|---|---|
| ▪ **Large Hadron Collider Support** | **71,897** | **80,161** | **84,033** |

U.S. involvement in the LHC has been regularly endorsed by HEPAP and by a National Academies report (EPP 2010[a]). The overall U.S. LHC effort is jointly supported by DOE and NSF and is one of HEP's highest priorities. HEP resources will be used for LHC software and computing, as well as operations and maintenance of the U.S.-built systems that are part of the LHC detectors. The U.S. also participates in accelerator commissioning and accelerator physics studies that use the LHC, along with R&D for potential future upgrades to both the accelerator and its detectors.

| | | | |
|---|---|---|---|
| • **LHC Accelerator Research** | **13,000** | **12,390** | **12,409** |

The U.S. LHC Accelerator Research Program (LARP) is supported solely by DOE. It will continue to focus its R&D effort on the production of full-scale, accelerator-quality magnets that sustain the highest possible magnetic fields. This R&D effort will provide important technical data to CERN for management decisions on possible future LHC accelerator upgrades to increase luminosity. In late 2009, full-size prototype upgraded high-field LHC interaction region magnets composed of niobium-tin ($Nb_3Sn$) superconductor material, were demonstrated by the U.S. groups developing this technology. The development of these magnets is in preparation for possible U.S. participation in a second phase of upgrades to LHC. Special instrumentation such as LHC beam collimation and monitoring systems is also being developed under the LARP

[a] "Revealing the Hidden Nature of Space and Time: Charting the Course for Elementary Particle Physics" is available at http://www.nap.edu/catalog.php?record_id=11641.

| | (dollars in thousands) | |
|---|---|---|
| FY 2009 | FY 2010 | FY 2011 |

program. These instruments will play an important role in improving and achieving reliable LHC accelerator operations.

| | FY 2009 | FY 2010 | FY 2011 |
|---|---|---|---|
| • **LHC Detector Support** | **56,397** | **58,771** | **62,374** |

Funding is provided for operations and maintenance of the U.S.-built detector subsystems. These detectors were commissioned with cosmic ray data until the first LHC beam collisions occurred late in 2009. This effort will support the continuing development and deployment of tools and procedures required to collect the detector data at high efficiency and develop the calibration and alignment procedures required in order to understand the detector performance at the level necessary for physics analysis. Support is also provided for technical coordination and program management.

To date, U.S. detector support efforts have focused on hardware commissioning and on the infrastructure needed for full analysis of simulated and cosmic ray data using professional-quality software. Grid computing solutions are integrated into the experiment computing models, building on the tools provided by the Scientific Discovery through Advanced Computing (SciDAC) Open Science Grid project. The grid provides U.S. researchers the access and computing power needed to analyze the large and complex data sets. For FY 2011, computing hardware facilities running grid computing interfaces are essential to enable a rapid development cycle for processing and analyzing the data and improving analysis algorithms as the rate of physics data is expected to increase as accelerator operations become standardized.

Support is also provided for detector R&D, with specific focus on detector technologies needed to accommodate the proposed LHC upgrade in luminosity. Pre-conceptual studies for long-term replacements of major elements of the detectors are ongoing, with proposals expected by the end of 2010. The proposals are expected to cover the two planned phases for LHC upgrades (targeted towards installation in the middle and near the end of the decade, respectively) and will emphasize areas where U.S. groups have particular expertise and technical capability. In FY 2011, funding for LHC upgrade-related detector R&D increases in preparation for possible U.S. participation in these upgrades.

| | FY 2009 | FY 2010 | FY 2011 |
|---|---|---|---|
| • **LHC Upgrades** | **2,500** | **9,000** | **9,250** |

Fabrication of the Accelerator Project for the Upgrade of the LHC (APUL) will be initiated in FY 2010. The project will construct components needed for the planned increase of the luminosity of the LHC by a factor of two to three. The Mission Need (CD-0) was approved October 2008 and conceptual design has been completed. The scope of the project includes the design and fabrication of magnets, replacing those near ATLAS and CMS whose apertures limit the luminosity, and their associated cold powering and feedboxes. The intent is to have these components built by BNL and Fermilab and delivered to CERN for installation in the LHC by FY 2013. The U.S. scope has been coordinated with CERN management and takes advantage of U.S. expertise in the particular technical areas.

| | FY 2009 | FY 2010 | FY 2011 |
|---|---|---|---|
| ▪ **Other Facilities** | **7,631** | **10,251** | **10,635** |

This category includes funding for long-term D&D of the Alternating Gradient Synchrotron (AGS) facility at BNL, where operations as a HEP user facility were terminated at the end of FY 2002. Funding for private institutions, government laboratories, and foundations that participate in high

| | FY 2009 | FY 2010 | FY 2011 |
|---|---|---|---|
| energy physics research is also included, as well as recurring contributions to general program operations activities, such as the federal laboratory consortium, financial auditing, support for internal and external program and project reviews, personnel support under the Intergovernmental Personnel Act, and technical consultation on programmatic issues. This category also includes funding to respond to new opportunities and unexpected changes in facilities operations and support. | | | |
| **Total, Proton Accelerator-Based Physics** | **401,368** | **434,167** | **439,262** |

(dollars in thousands)

### Explanation of Funding Changes

| | FY 2011 vs. FY 2010 ($000) |
|---|---|
| **Research** | |
| ▪ **Grants Research** | |
| Funding for the core grants research program will fully support LHC and Tevatron collider research while growing a strong neutrino physics program to exploit future facilities. | +1,707 |
| ▪ **National Laboratory Research** | |
| Funding will fully support LHC and Tevatron collider research programs and enhance efforts in the neutrino physics program. | +3,152 |
| • **University Service Accounts** | |
| Funding maintains the support needed for university groups working primarily on research programs at Fermilab and BNL. | +4 |
| **Total, Research** | **+4,863** |
| **Facilities** | |
| ▪ **Proton Accelerator Complex Operations** | |
| Funding for Proton Accelerator Complex Operations is decreased in FY 2011 due to somewhat reduced personnel needs as Tevatron Collider operations continue. Standardized running procedures and increased automation allow efficient and high performance operation with fewer personnel. | -770 |
| ▪ **Proton Accelerator Complex Support** | |
| Proton Accelerator Complex Support funding increases overall, primarily due to enhancement of GPP funding to the level needed to maintain Fermilab site infrastructure over the long term. | +2,456 |

| | FY 2011 vs. FY 2010 ($000) |
|---|---|
| ▪ **Proton Accelerator Facility Projects** | |
| • **Current Facility Projects** | |
| Net funding for Current Facility Projects decreases according to the planned project profiles. Funding decreases for NOvA ($-12,780,000) and MINERvA ($-800,000), offset by increases in funding for MicroBooNE ($+5,957,000) and the other project costs for the new Mu2e project ($+5,000,000). | -2,623 |
| • **Future Facility Projects R&D** | |
| Funding decreases ($-11,962,000) as the R&D support in FY 2010 for LBNE and Mu2e has shifted out of this category as these efforts become approved projects, offset by increases in funding for pre-conceptual R&D for a superconducting GeV linac, and for specific detector concepts that would make use of possible future Fermilab accelerator facilties ($+8,875,000). | -3,087 |
| **Total, Proton Accelerator Facility Projects** | **-5,710** |
| ▪ **Large Hadron Collider Support** | |
| LHC Support increases for pre-conceptual R&D on technologies relevant to the proposed LHC Detector upgrades. ATLAS and CMS operations and support are maintained at about FY 2010 effort levels. LARP and LHC upgrade project (APUL) are continued at FY 2010 levels. | +3,872 |
| ▪ **Other Facilities** | |
| Funding provides for continued service and support in FY 2011 at approximately the same level of effort as FY 2010. | +384 |
| **Total, Facilities** | **+232** |
| **Total Funding Change, Proton Accelerator-Based Physics** | **+5,095** |

## Electron Accelerator-Based Physics

## Funding Schedule by Activity

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2009 | FY 2010 | FY 2011 |
| Electron Accelerator-Based Physics | | | |
| Research | 16,699 | 15,353 | 14,927 |
| Facilities | 15,331 | 12,074 | 9,780 |
| Total, Electron Accelerator-Based Physics | 32,030 | 27,427 | 24,707 |

### Description

The Electron Accelerator-Based Physics subprogram utilizes accelerators with high-intensity and ultra-precise beams to create and investigate matter at its most basic level. Over the last decade, the electron B-factory at SLAC led investigations at the Intensity Frontier, providing precision measurements of different behavior of matter and antimatter observed in the decay products of B-mesons. Physicists consider this asymmetric behavior, called charge-parity (CP) violation, to be vital to understanding the apparent predominance of matter over antimatter, one of the greatest puzzles in comprehending the structure of the universe. There are currently proposals in Italy and Japan for next-generation Intensity Frontier electron-positron colliders, so-called “Super-B Factories” because they are successors to the B-factory at SLAC, whose goal is to fully understand CP violation in B-mesons and hopefully find evidence for unexpected new phenomena.

### Selected FY 2009 Accomplishment

Over the past several years, the B-factories in the U.S. and Japan have discovered several unexpected new particles which contain a charm quark and a charm antiquark. However, the masses and decay patterns of these new states do not fit within the theoretical expectations from Quantum ChromoDynamics (QCD) for standard strongly bound quark-antiquark states, and the evidence for some of these new states is controversial and in need of independent confirmation. These recently discovered exotic particles may be hybrid quark-antiquark-gluon states, loosely bound “molecules” of conventional charmed mesons, or four quark states. The exploration of this unforeseen new spectroscopy is an essential step towards fully understanding QCD. Studies of these exotic hadrons with the full B-factory datasets are ongoing.

## Detailed Justification

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2009 | FY 2010 | FY 2011 |
| **Research** | **16,699** | **15,353** | **14,927** |

The research program at the B-factory/BaBar Facility at SLAC will continue analysis of the 557 $fb^{-1}$ data set that has been accumulated over the nine-year operational life of the facility. The number of physicists involved in this effort is expected to fall to approximately 300 over the course of the year as analysis is completed on portions of the data. Physicists from approximately 30 universities, three national laboratories (LLNL, LBNL, and SLAC), and seven foreign countries have been actively involved in the data analysis. The physics issues to be addressed include expanding our understanding of CP violation in many particle decay modes and the investigation of the many heavy quark states predicted by QCD.

The research program at other electron accelerator facilities complements the B-factory/BaBar efforts and consists of a group of experimental research activities using the Cornell Electron Storage Ring (CESR) accelerator at Cornell University, the KEK-B electron accelerator facilities in Japan, and recently upgraded electron accelerator facilities in China. A total of four U.S. university groups work at KEK-B, four groups work at the Beijing Electron-Positron Collider (BEPC), and 22 U.S. university groups work at CESR. CESR, operated by NSF, also completed running in FY 2008. There are also small R&D efforts aimed at designing detectors for a possible next-generation "Super-B factory" in Italy or Japan.

| | FY 2009 | FY 2010 | FY 2011 |
|---|---|---|---|
| ▪ **Grants Research** | **6,872** | **6,511** | **6,337** |

Grant-supported scientists typically constitute about 50–75% of the personnel needed to create, run, and analyze an experiment, and they usually work in collaboration with other university and laboratory groups. Grant-based research efforts are funded based on peer review and at levels commensurate with the effort needed to carry out the experiments.

In FY 2011, funding continues at a reduced level of effort to complete analysis of physics data from BaBar and the CLEO-c experiment at CESR. Smaller efforts devoted to operations of the Belle detector at KEK B, and the Beijing Spectrometer at BEPC and the analysis of data taken there are supported. Also supported is a small research program devoted to physics studies of a much higher performance, higher intensity B-factory. The Italian government is supporting pre-conceptual R&D aimed at developing a proposal for such a facility. The detailed funding allocations will take into account the quality and scientific priority of the research proposed.

| | FY 2009 | FY 2010 | FY 2011 |
|---|---|---|---|
| ▪ **National Laboratory Research** | **9,817** | **8,816** | **8,565** |

The national laboratory research program consists of groups at four laboratories participating in experiments at electron accelerator facilities with a physics program similar to the grant program described above. Electron accelerator research activities concentrate on experiments at the SLAC B-factory. HEP will conduct a comparative peer review of laboratory research groups in this subprogram in FY 2010.

In FY 2011, laboratory-based research in this subprogram continues at about the same level of effort to complete data analysis from BaBar and CLEO-c. SLAC will continue to maintain strong participation in the B-factory research program, which will be completing a period of intense analysis of the entire B-factory data set and will be focused on final archival analyses. Research groups at LBNL and LLNL have mostly transitioned to other activities. A small research program at Fermilab and SLAC devoted to physics studies of the International Linear Collider is also supported.

| | FY 2009 | FY 2010 | FY 2011 |
|---|---|---|---|
| ▪ **University Service Accounts** | **10** | **26** | **25** |

University Service Accounts facilitate the support of university groups working at accelerator facilities by providing funds for these groups to purchase needed supplies and services from the laboratories with minimum time and cost overhead. Currently 12 university groups maintain service accounts at SLAC.

| | FY 2009 | FY 2010 | FY 2011 |
|---|---|---|---|
| | (dollars in thousands) | | |
| **Facilities** | **15,331** | **12,074** | **9,780** |
| ▪ **Electron Accelerator Complex Operations** | **10,951** | **11,194** | **8,880** |

B-factory operations ended in FY 2008. Funding in this category supports the transition of the B-factory accelerator complex to a safe and stable maintenance mode and decommissioning and decontamination (D&D) activities. The funding category also supports ongoing BaBar computing operations and data analysis.

| | | | |
|---|---|---|---|
| ▪ **Electron Accelerator Complex Support** | **4,380** | **880** | **900** |

Funding is provided for the necessary maintenance and operation of computing capabilities in order to support the timely analysis of the B-factory data.

| | | | |
|---|---|---|---|
| **Total, Electron Accelerator-Based Physics** | **32,030** | **27,427** | **24,707** |

## Explanation of Funding Changes

| | FY 2011 vs. FY 2010 ($000) |
|---|---|
| **Research** | |
| Funding for electron accelerator-based experimental research is reduced to a level necessary to complete analysis of physics data from BaBar and CLEO-c. Analysis of the final archival results from BaBar and CLEO-c data is planned to be completed in 2011. | -426 |
| **Facilities** | |
| ▪ **Electron Accelerator Complex Operations** | |
| Funding for B-factory Operations is reduced to support the planned profile for safe dismantling and decommissioning of the BaBar detector and putting the accelerator into a minimum maintenance configuration. | -2,314 |
| ▪ **Electron Accelerator Complex Support** | |
| Funding is increased slightly to maintain the computing capabilities needed to finish BaBar data analysis. | +20 |
| **Total, Facilities** | **-2,294** |
| **Total Funding Change, Electron Accelerator-Based Physics** | **-2,720** |

## Non-Accelerator Physics

## Funding Schedule by Activity

(dollars in thousands)

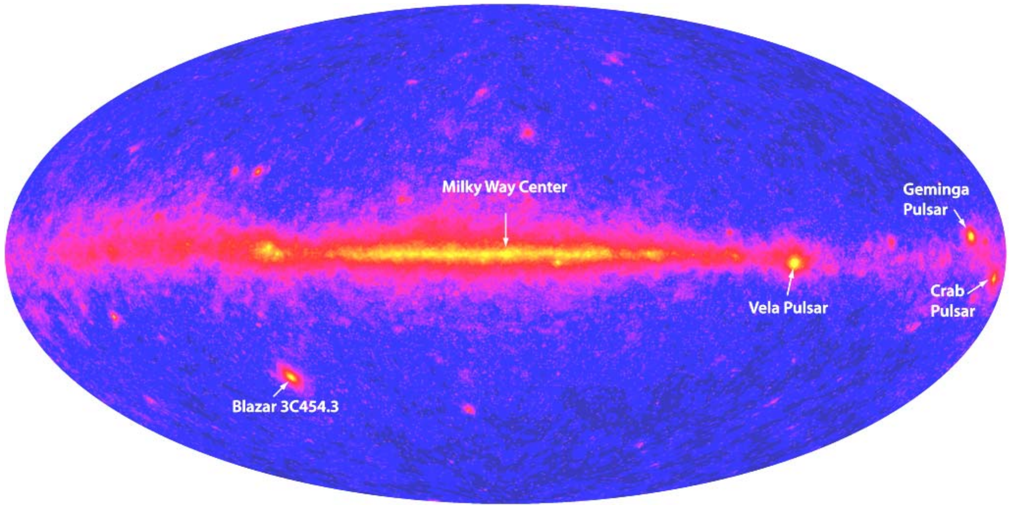
| | FY 2009 | FY 2010 | FY 2011 |
|---|---|---|---|
| Non-Accelerator Physics | | | |
| Grants Research | 22,215 | 21,753 | 22,556 |
| National Laboratory Research | 40,181 | 40,813 | 43,923 |
| Projects | 35,542 | 37,059 | 22,060 |
| Other | 3,200 | 0 | 0 |
| Total, Non-Accelerator Physics | 101,138 | 99,625 | 88,539 |

### Description

The Non-Accelerator Physics subprogram provides U.S. leadership in the study of those topics in particle physics that cannot be investigated with accelerators or are best studied by other means. For example, some of the earliest discoveries in particle physics were due to the production of previously unobserved particles in high-energy cosmic rays. Non-Accelerator Physics studies play an important role in the HEP program, using ever more sophisticated techniques to probe fundamental physics questions with naturally occurring particles and phenomena. Scientists in this subprogram investigate topics central to both the Intensity and Cosmic Frontiers, such as understanding the nature of dark matter and dark energy; precision measurements of neutrino properties that will illuminate their role in the history of the universe; and searches for new phenomena such as proton decay and primordial antimatter. These areas of research probe well beyond the Standard Model of particle physics and offer possibilities for discovery of significant new physics.

### Selected FY 2009 Accomplishments

- In FY 2009, the Large Area Telescope (LAT), the primary instrument on NASA's Fermi Gamma-ray Space Telescope (FGST) mission, performed outstandingly delivering data that has resulted in over 35 peer reviewed publications and motivated a week-long workshop to present and discuss what these results mean for astronomy, astrophysics, and particle physics. The initial results from FGST were selected by the editors of *Science* magazine as the runner-up "Breakthrough of the Year" for 2009, noting, "The Fermi Telescope has … revealed, with unprecedented detail, a very restless high-energy universe, and it is solving old mysteries while making new, unexpected discoveries." The international LAT collaboration released an all-sky survey which shows the universe as seen in high-energy gamma rays (see the figure below). The LAT was a joint DOE and NASA project. SLAC led the DOE participation in the fabrication of the LAT and operates the instrument science operations center while data are taken.




Fermi Gamma-ray Space Telescope image of the night sky as seen in high-energy gamma rays

- The Cryogenic Dark Matter Search (CDMS) experiment announced in late 2009 the final results of the first phase of their experiment, based on several years of data taking with a few kilograms of ultra-sensitive silicon and germanium detectors that can detect extremely rare dark matter interactions. They found two events in their signal region, but this could be a statistical fluctuation of the expected background due to naturally-occuring radioactivity. An upgraded 15 kg detector with improved background rejection is in fabrication (SuperCDMS) and will be installed and operated in 2010 to confirm or deny the tantalizing initial results. Other experiments using different techniques are also actively exploring this region.

## Detailed Justification

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2009 | FY 2010 | FY 2011 |
| **Grants Research** | **22,215** | **21,753** | **22,556** |

The grant-based program supports research groups at more than 35 universities that perform experiments at non-accelerator-based physics facilities. This program also funds private institutions, government laboratories, and foundations that participate in non-accelerator-based physics research. This subprogram is carried out in collaboration with physicists supported by other government agencies and institutes; among them NSF, NASA, and the Smithsonian Astrophysical Observatory. The selection of research efforts supported is based on peer review. The amount of funding a grant receives takes into account the discovery potential of the proposed research.

In FY 2011, the Non-Accelerator Physics grants program will support research on experiments that are now engaged in data collection, as well as preparations for future experiments. The operating experiments include the Very Energetic Radiation Imaging Telescope Array System, a ground-based gamma ray experiment at the Whipple Observatory in Arizona; the Pierre Auger Observatory in Argentina; and the LAT gamma-ray survey on NASA’s FGST space-based mission. Other active research efforts include searches for dark matter using the upgraded “Super” Cryogenic Dark Matter Search (SuperCDMS) at the Soudan Mine in Minnesota and the Axion Dark Matter eXperiment (ADMX) at LLNL, as well as other dark matter searches using different techniques. Studies of dark

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2009 | FY 2010 | FY 2011 |

energy use data from the Baryon Oscillation Spectroscopic Survey (BOSS) experiment on the Sloan Digital Sky Survey telescope in New Mexico. Research also continues with Super-Kamiokande, a proton decay and neutrino detector located in the Kamioka Underground Laboratory in Japan and the Enriched Xenon Observatory (EXO), which is searching for neutrino-less double beta decay at the DOE Waste Isolation Pilot Plant facility in New Mexico.

These groups also participate in the research and planning for the Reactor Neutrino Detector at Daya Bay in China, the Dark Energy Survey (DES) experiment in Chile, the proposed space-based Joint Dark Energy Mission (JDEM), and the proposed ground-based Large Synoptic Survey Telescope (LSST); the latter two will both be used to study dark energy. DOE-supported university groups also lead the commissioning and integration for NASA's Alpha Magnetic Spectrometer (AMS) experiment which is on the Space Shuttle manifest for launch in 2010 and will begin taking data in FY 2011.

HEP also supports research groups participating in the design and R&D efforts for next-generation dark matter experiments and a next-generation neutrino-less double beta decay experiment.

| | | | |
|---|---|---|---|
| **National Laboratory Research** | **40,181** | **40,813** | **43,923** |

Groups at several national laboratories (ANL, BNL, Fermilab, LBNL, LLNL, LANL, and SLAC) currently participate in non-accelerator-based physics experiments. With strong laboratory technical resources, the laboratory groups provide invaluable and unique service to the research program in terms of experiment management, design, construction, and operations. Laboratory scientists are also involved in the research. The HEP program will conduct a comparative peer-review of the laboratory research efforts in this subprogram in 2010.

In FY 2011, the laboratory research program in non-accelerator physics will continue to support research and operations for ongoing experiments such as the Pierre Auger Observatory, SuperCDMS, the Chicagoland Observatory for Underground Particle Physics 60 kg (COUPP-60) experiment, ADMX, BOSS, EXO, and the LAT gamma-ray survey on NASA's FGST. SLAC runs the instrument science operations center for the LAT. Laboratory groups also lead the operations and research for various dark energy surveys that use existing telescope facilities.

Laboratory groups participate in the research planning for future experiments completing their fabrication phase such as DES. The laboratory groups also focus on the R&D and design efforts for other future projects such as the COUPP-500kg, other next generation dark matter experiments, and the proposed JDEM and LSST experiments to study dark energy.

| | | | |
|---|---|---|---|
| **Projects** | **35,542** | **37,059** | **22,060** |
| ▪ **Current Projects** | **24,700** | **21,110** | **6,060** |

Funding for the fabrication of the Reactor Neutrino Detector MIE continues in FY 2011. DOE and the Chinese Institute for High Energy Physics are partners for this experiment, which will be located at a site near several commercial nuclear reactors in Daya Bay, China. This experiment will measure and compare the number of neutrinos observed by a detector close to a reactor (the near detector) with the number observed in a far detector about 10 km away. From this data, a crucial neutrino oscillation parameter can be extracted. The U.S. collaboration is led by groups from BNL and LBNL. The project is expected to be completed in FY 2013.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2009 | FY 2010 | FY 2011 |
| Final funding for the DES MIE is provided in FY 2011, with final project completion to occur one year later. DOE is supporting the fabrication of a new camera to be installed and operated on the existing Blanco four-meter telescope at the Cerro Tololo Inter-American Observatory (CTIO) in Chile. The DES project is a partnership between DOE, NSF, which operates the telescope, and international participants. The data management system and upgrades to the telescope facility are supported by NSF. | | | |
| ▪ **Future Projects R&D** | **10,842** | **15,949** | **16,000** |
| This category provides support for R&D and pre-conceptual design activities for promising proposed future experiments. In FY 2011, this includes R&D on technical issues related to DOE's proposed contribution for the JDEM and LSST projects. DOE, NASA, and NSF await input from the community on the scientific priority given to these projects in the National Academies' Decadal Survey for Astronomy and Astrophysics. This report is due in summer 2010. | | | |
| **Other** | **3,200** | **0** | **0** |
| FY 2009 funding provided for completion of EXO-200 experiment at the Waste Isolation Pilot Plant. | | | |
| **Total, Non-Accelerator Physics** | **101,138** | **99,625** | **88,539** |

## Explanation of Funding Changes

| | FY 2011 vs. FY 2010 ($000) |
|---|---|
| **Grants Research** | |
| Funding for grant-based research continues at a constant level of effort in order to support experiments that are currently active in commissioning, operations, and/or data analysis and to respond to new research proposals. | +803 |
| **National Laboratory Research** | |
| Funding for laboratory-based research is enhanced to provide support for pre-operations, operations, and commissioning for projects that have reached or will soon reach completion (SuperCDMS, DES). | +3,110 |
| **Projects** | |
| ▪ **Current Projects** | |
| Following the planned project profiles, funding decreases for Reactor Neutrino Detector ($-8,940,000), DES ($-4,610,000), and SuperCDMS ($-1,500,000). | -15,050 |

| | FY 2011 vs. FY 2010 ($000) |
|---|---|
| ▪ **Future Projects R&D** | |
| R&D funding is provided for proposed ground-based and satellite-based dark energy, dark matter, and other particle astrophysics experiments. This funding is maintained at approximately the FY 2010 level. Allocated funding will utilize guidance from the community on the priority given to these projects in the National Academies' Decadal Survey. | +51 |
| **Total, Projects** | **-14,999** |
| **Total Funding Change, Non-Accelerator Physics** | **-11,086** |

## Theoretical Physics

## Funding Schedule by Activity

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2009 | FY 2010 | FY 2011 |
| Theoretical Physics | | | |
| Grants Research | 26,801 | 26,801 | 27,555 |
| National Laboratory Research | 24,549 | 25,105 | 26,290 |
| Computational HEP | 11,280 | 10,000 | 10,400 |
| Other | 3,518 | 5,056 | 5,279 |
| Total, Theoretical Physics | 66,148 | 66,962 | 69,524 |

### Description

The Theoretical Physics subprogram provides the vision and mathematical framework for understanding and extending the knowledge of particles, forces, space-time, and the universe. This program supports activities that range from detailed calculations of the predictions of the Standard Model to the extrapolation of current knowledge to a new level of understanding and the identification of the means to experimentally search for them. Symmetries play a major role in the current understanding of the subatomic world: discovering how particle symmetries are realized (or broken) in nature has provided many fundamental breakthroughs in the development of the Standard Model. This subprogram supports and advances research at all three high energy physics Frontiers.

### Selected FY 2009 Accomplishments

- The 2008 Nobel Prize in Physics, announced in October 2008, was shared by Yoichiro Nambu for his theoretical work discovering how symmetry breaking can manifest itself in nature. His work was supported by HEP.
- High precision numerical simulations of the strong interactions of quarks and gluons, Quantum Chromodynamics (QCD), are producing accurate and reliable predictions of strong interaction decay constants and mass differences. These results, which use supercomputer simulations of QCD, include the important but difficult to calculate "virtual quark" effects in the underlying field theory. In some important cases, the agreement between the theoretical and experimental values has reached the level of the experimental uncertainty itself. This is a major success of the theory of strong interactions and is an improvement by nearly an order of magnitude over previous calculations. These breakthroughs have been accomplished by the application of new, highly efficient algorithms combined with the use of today's supercomputers and dedicated clusters of personal computers. The support for these research breakthroughs has come from ongoing efforts in the core HEP theory research program, as well as the SciDAC program for high-performance software, and investments in dedicated computing hardware to enable fast and reliable calculations.

## Detailed Justification

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2009 | FY 2010 | FY 2011 |
| **Grants Research** | **26,801** | **26,801** | **27,555** |

This program consists of research groups at approximately 70 colleges and universities. It includes funding for private institutions, universities, and foundations that participate in theoretical physics. As part of their research efforts, the university groups train graduate students and postdoctoral researchers. Physicists in this theoretical research area often work in collaboration with other university and laboratory groups. Research efforts are selected based on a peer review process.

The grants program addresses topics across the full range of theoretical physics research. A particularly interesting topic considers additional space-time dimensions that are normally hidden. This is motivated by the effort to unify Einstein's theory of gravity with quantum mechanics in a consistent way. Some of these extra dimensions and their consequences may be accessible to experimental investigation and may manifest themselves at the LHC as so-called Kaluza-Klein excitations, named after the physicists who first suggested in the 1920s that we live in a 5-dimensional universe. Another topic of current research interest is the nature of dark matter and dark energy in the context of high energy physics. University research groups play leading roles in addressing these research areas.

In FY 2011, the Theoretical Physics Grants program supports enhanced efforts focused on the analysis of current and previous experiments and in the design and optimization of new experiments, so that these experiments can fulfill their maximum potential. It will also support theorists who explore new ideas of physics at all three particle physics Frontiers.

| | | | |
|---|---|---|---|
| **National Laboratory Research** | **24,549** | **25,105** | **26,290** |

The national laboratory theoretical research program currently consists of groups at seven DOE laboratories (Fermilab, SLAC, BNL, ANL, LBNL, LLNL, and LANL). The laboratory theory groups are a resource for the national research program, with a particular emphasis on collaborations with experimental scientists and data interpretation to provide a clear understanding of the significance of measurements from ongoing experiments and to help shape and develop the laboratories' experimental programs. HEP conducted a comparative peer-review of the laboratory research efforts in this subfield in 2008 whose findings have been used to inform the funding decisions in this budget request; in particular there are targeted increases to support laboratory research programs which reviewed well. HEP will review these programs again in 2011.

In FY 2011, the laboratory theoretical research groups will address topics across the full range of theoretical physics, including the analysis and interpretation of the new data expected from the Tevatron Collider detectors and forthcoming data from the LHC. There are also efforts to understand properties of neutrinos through reactor, accelerator, and non-accelerator neutrino experiments. As data from the LHC becomes available, an increased effort will be made to identify the most promising and sensitive methods for finding signs of new phenomena in these data.

| | | | |
|---|---|---|---|
| **Computational HEP** | **11,280** | **10,000** | **10,400** |

This budget category provides for specific high energy physics research activities that require extensive or customized computational resources including R&D, design, fabrication, procurement, maintenance, and operation of computational software and hardware that is not associated with specific high energy physics experiments or research facilities. Current activities in this category include the Scientific

| | FY 2009 | FY 2010 | FY 2011 |
|---|---|---|---|

(dollars in thousands)

Discovery through Advanced Computing (SciDAC) program, the Lattice QCD (LQCD) computing initiative, support for dedicated transatlantic networking, and U.S. contributions to experiment-independent computer codes required for HEP's program.

| | | | |
|---|---|---|---|
| ▪ **SciDAC** | **6,100** | **6,000** | **5,600** |

All HEP-supported SciDAC projects had mid-term continuation reviews in FY 2009 and are planned to be re-competed in FY 2011. The SciDAC program is managed and cooperatively funded by the SC program offices, including the Advanced Scientific Computing Research program. There are four principal HEP-supported SciDAC efforts: Type Ia supernova simulations, to better understand the thermonuclear explosions that create supernovae and to generate supernova light curves appropriate for dark energy measurements, a joint effort with Nuclear Physics (NP) and the National Nuclear Security Administration; platform-independent software to facilitate large-scale QCD calculations (see also the LQCD computing initiative below), a joint effort with NP; very large scale, fault-tolerant data handling and distributed grid computing which will allow physicists in the U.S. to analyze petabytes of data produced in Europe at the LHC, a joint effort with NP and NSF; and large-scale computational infrastructure for accelerator modeling and optimization, to support design and operations of complex accelerator systems throughout the SC complex, a joint effort with NP and the Basic Energy Sciences program.

| | | | |
|---|---|---|---|
| ▪ **Computational QCD and Network Support** | **5,180** | **4,000** | **4,800** |

The understanding of many HEP experimental results has been limited by a lack of precision in QCD calculations which describe the underlying physics; these calculations are in turn limited by a lack of computational power. This activity includes funding for the LQCD computing initiative that is a coordinated effort with the NP program aimed toward the development, procurement, and operation of a multi-teraflop computer capability for dedicated LQCD simulations. During FY 2009, the first phase of this joint effort was completed and provides on average about 13 teraflops of capacity. This investment is coordinated with the SciDAC QCD effort described above to ensure that the software codes developed can be run on a variety of available hardware platforms and used by a wide community of researchers. There is a follow-on proposal to deploy approximately 100 teraflops of dedicated capacity for QCD computing, which is currently under review.

This category also includes funding for the HEP-related transatlantic network requirements between the U.S., CERN, and HEP-related computing facilities in Europe. These requirements are dictated by the unprecedented size of the LHC data set. The dedicated network paths are known as the U.S. LHC Net. In FY 2009, the U.S. LHC Net provided 40 gigabits per second of connectivity between CERN and points of presence in Chicago and New York and is being upgraded to 60 gigabits per second. U.S. LHC Net is closely integrated with the DOE Energy Science Network, which connects the U.S. LHC Net transatlantic bridge to the main U.S. research network backbone.

| | | | |
|---|---|---|---|
| **Other** | **3,518** | **5,056** | **5,279** |

This activity includes funding for education and outreach activities, compilations of high energy physics data, reviews of data by the Particle Data Group at LBNL, conferences, studies, workshops, funding for theoretical physics research activities to be determined by peer review, and for responding to new and unexpected physics opportunities. This category also includes funding for the QuarkNet education project. This project takes place in QuarkNet centers which are set up at universities and laboratories

| | FY 2009 | FY 2010 | FY 2011 |
|---|---|---|---|
| around the country. The purpose of each center is to engage high school physics teachers in the analysis of real data from an active high energy physics experiment (such as at the Tevatron Collider or LHC). The experience these teachers garner is taken back to their classrooms in order to expose high school students to the world of high energy physics. The project began in 1999. | | | |
| **Total, Theoretical Physics** | **66,148** | **66,962** | **69,524** |

(dollars in thousands)

## Explanation of Funding Changes

| | FY 2011 vs. FY 2010 ($000) |
|---|---|
| **Grants Research** | |
| The Theoretical Physics Grants program is supported at a constant level of effort that will support the analysis of current and previous experiments, and in the design and optimization of new experiments. | +754 |
| **National Laboratory Research** | |
| The National Laboratory Research program is increased above a constant level of effort to provide additional support for the laboratory research groups which performed well in the HEP comparative review in 2008. | +1,185 |
| **Computational HEP** | |
| The final allocation of funding among the activities in this category (SciDAC, LQCD, and Network Support) will depend upon peer-review of proposed activities, identified scientific priorities, and program needs and will provide for a constant level of support compared to FY 2010 funding levels. | +400 |
| **Other** | |
| The increase maintains approximately a constant effort in education and outreach activities, and the data compilations and summaries provided by the Particle Data Group at LBNL. | +223 |
| **Total Funding Change, Theoretical Physics** | **+2,562** |

## Advanced Technology R&D

## Funding Schedule by Activity

(dollars in thousands)

| | FY 2009 | FY 2010 | FY 2011 |
|---|---|---|---|
| Advanced Technology R&D | | | |
| Accelerator Science | 51,999 | 47,324 | 52,135 |
| Accelerator Development | 98,520 | 90,501 | 91,611 |
| Other Technology R&D | 24,665 | 24,819 | 26,195 |
| SBIR/STTR | 0 | 19,658 | 20,027 |
| Total, Advanced Technology R&D | 175,184 | 182,302 | 189,968 |

### Description

The Advanced Technology R&D subprogram fosters world-leading research in the physics of particle beams, accelerator research and development, and particle detection—all necessary for continued progress in high energy physics. High energy physics research relies on the use of high energy and high intensity particle beams generated with charged particle accelerators, storage rings, and their associated tracking and identification detectors. New developments are stimulated and supported through proposal driven, peer reviewed research. Ultimately, these new technological developments are incorporated into construction projects sponsored by HEP. This subprogram supports and advances research at all three high energy physics Frontiers. Advanced Technology R&D also provides new technologies and research methods appropriate for a broad range of scientific disciplines, thereby enhancing DOE's broader strategic goals for science.

### Selected FY 2009 Accomplishments

- A collaboration of laboratories, universities, and small businesses has significantly advanced the state of the art for accelerating gradients in normal-conducting accelerating cavities, which is approximately 50 MeV per meter. This effort is directed towards reducing the size and cost of future TeV-scale lepton colliders. At ANL, an intense pulse of electrons was used to excite a microwave field of 100 MeV per meter in a dielectric-loaded accelerating structure. An MIT-designed photonic band-gap accelerating structure also achieved 100 MeV per meter. SLAC has demonstrated 150 MeV per meter in a single-cell, standing-wave copper structure.
- An example of a novel detector technology that was recently developed with DOE support is a large-area single photon sensor with extremely low radioactivity. These new photodetectors will enable cost-effective scale-up of highly sensitive photon detectors (such as dark matter detectors) that require large active volumes along with extremely low backgrounds from naturally-occurring radioactivity. This technology has a patent application pending and is being commercialized.

## Detailed Justification

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2009 | FY 2010 | FY 2011 |
| **Accelerator Science** | **51,999** | **47,324** | **52,135** |

This activity 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. Funding in this category includes costs for operating university and laboratory-based accelerator R&D test facilities.

| | | | |
|---|---|---|---|
| ▪ **Grants Research** | **9,060** | **9,060** | **9,725** |

The FY 2011 budget will continue support for a broad research program in advanced accelerator physics and related technologies. Funding is increased above a constant level of effort to support increased university participation in experiments at new accelerator R&D facilities (BELLA and FACET, see below). Funding is included for private institutions, universities, industry, and federal research centers that participate in fundamental accelerator physics. As part of their research efforts, these groups train graduate students and postdoctoral researchers. Physicists in this research area often work in collaboration with other university and laboratory groups. For example, university groups are leading the development and execution of the proposals for the experimental program at FACET. Research efforts are selected based on a peer review process.

The grant-based research program will continue to investigate novel acceleration concepts, such as the use of plasmas and lasers to accelerate charged particles; theoretical studies in advanced beam dynamics, including the study of non-linear optics and space-charge dominated beams; studies of accelerating gradient limits in normal conducting accelerators; development of advanced particle beam sources and instrumentation; and accelerator R&D into the fundamental issues associated with the ionization cooling of muon beams.

| | | | |
|---|---|---|---|
| ▪ **National Laboratory Research** | **34,939** | **38,264** | **42,410** |

This activity supports accelerator R&D efforts and operations of test facilities at ANL, BNL, Fermilab, LBNL and SLAC, and theoretical studies of space-charge dominated beams at the Princeton Plasma Physics Laboratory. HEP conducted a comparative peer-review of the laboratory research efforts in this subfield in 2008, whose findings have been used to inform the funding decisions in this budget request; in particular there are targeted increases to support laboratory research programs which reviewed well. HEP will review these programs again in 2011.

The national laboratory accelerator science program explores advanced methods to accelerate charged particles with the goal of more efficient, compact, and inexpensive particle accelerators. Efforts in FY 2011 will focus on the development of new accelerating structures and techniques needed to achieve accelerating gradients in excess of 100 MeV/m. This work currently occurs primarily at the Argonne Wakefield Accelerator, the Laser Optical Accelerator Systems Integrated Studies (LOASIS) test facility at LBNL, and the new Facility for Accelerator Science and Experimental Test Beams (FACET) at SLAC. The new BErkeley Lab Laser Accelerator project (BELLA, see Projects below) will be in full fabrication in FY 2011 with completion planned for FY 2012. In FY 2011, the first round of experiments will begin at the new FACET facility where an electron bunch (the beam is not a continuous stream of electrons but structured in discrete bunches) is accelerated by plasma wakefields. The goal of this effort will be a demonstration of efficient,

| | (dollars in thousands) | |
|---|---|---|
| FY 2009 | FY 2010 | FY 2011 |

full-length accelerating structures with gradients well above 1 GeV per meter. Funding for FACET operations is included in this category.

The national laboratory groups are also involved in a significant long-range R&D effort to demonstrate the advanced technologies needed to realize muon-based accelerators; this is a global R&D program with major U.S. participation at Fermilab and BNL. A five-year R&D plan for muon-based accelerators, with milestones and deliverables, has been submitted by U.S. research institutions and will be reviewed by HEP in 2010.

BNL is also the home of the very successful Accelerator Test Facility. The facility supports HEP-funded research at universities as well as through the Small Business Innovation Research (SBIR) program, based on proposal-driven, peer-reviewed research in accelerator concepts and beam physics. In FY 2011, the facility will continue a program to test advanced accelerator concepts, develop new instrumentation, and further next-generation, high-brightness electron sources that are based on laser-driven photocathodes.

| | FY 2009 | FY 2010 | FY 2011 |
|---|---|---|---|
| ▪ **Projects** | **8,000** | **0** | **0** |

Funding was provided in the FY 2009 Appropriation and in the FY 2009 Recovery Act for the BELLA Project. BELLA will further advance the world-leading laser-driven plasma acceleration program, with a focus on exploring concepts for cascading GeV wakefield accelerating modules, a promising path to higher gradients and energies. LOASIS has already accelerated high-quality electron beams to energy exceeding 1 GeV in a 3 centimeter long structure. BELLA will initially improve this by a factor of ten, to 10 GeV in a one meter long structure. BELLA is planned to be complete in FY 2012.

| | FY 2009 | FY 2010 | FY 2011 |
|---|---|---|---|
| **Accelerator Development** | **98,520** | **90,501** | **91,611** |

The task of this activity is to demonstrate the feasibility of concepts and technical approaches on an engineering scale. This includes R&D and prototyping to bring new concepts to a stage of engineering readiness where they can be incorporated into existing facilities, upgrade existing facilities, or applied to the design of new facilities. Carrying out development of advanced high-technology components at this level often requires significant investments in research infrastructure. Major thrusts in this activity are superconducting radio frequency (RF) infrastructure development, studies of very high intensity proton sources for potential application in neutrino physics research, and R&D relevant to the proposed International Linear Collider.

| | FY 2009 | FY 2010 | FY 2011 |
|---|---|---|---|
| ▪ **General Accelerator Development** | **39,520** | **33,501** | **34,171** |

This activity focuses on R&D that can be widely applied to a range of accelerator facilities. The work is primarily done at Fermilab, LBNL, SLAC, and BNL. The major areas of R&D are superconducting magnet and related materials technology; high-powered RF acceleration systems; instrumentation; beam dynamics, both linear and nonlinear; and development of large simulation programs. The latter effort is coordinated with the SciDAC accelerator simulation project.

The R&D program on high-power RF systems is led by SLAC, including simulation codes for modeling RF system components and high-powered microwave tubes. This program also builds custom high-power RF sources for HEP and other scientific applications.

|  | (dollars in thousands) |  |  |
|---|---|---|---|
|  | FY 2009 | FY 2010 | FY 2011 |

Fermilab leads the R&D for a future high-intensity neutrino beam facility, in particular developing very high intensity proton sources for neutrino physics research.

The R&D program on superconducting magnets and materials includes efforts at BNL, Fermilab, and LBNL, focusing on demonstrating very high field superconducting magnets using advanced superconducting materials, and an industrially-based program to develop these materials, particularly niobium-tin.

| | | | |
|---|---|---|---|
| ▪ **Superconducting RF R&D** | **24,000** | **22,000** | **22,440** |

Superconducting Radio Frequency (SRF) technology is applicable to a variety of future accelerator projects central to the HEP scientific strategy. Centered at Fermilab, the program supports development of the infrastructure necessary for SRF development and includes equipment and facilities for accelerator cavity processing, assembly, and testing and for cryomodule assembly and testing. The infrastructure will be utilized to improve cavity and cryomodule performance and prototype cryomodules for future projects. Information on processing and construction will be of use to a broad spectrum of projects throughout the Office of Science. Completion of this essential technology infrastructure was accelerated in FY 2009 using Recovery Act funding.

In FY 2011, this effort will provide funds for procurement of components and equipment support necessary to develop prototype multi-cavity cryomodules. It also enables continued development of U.S. capabilities for testing individual bare cavities, dressed cavities with all power components attached, and cryomodules. Fermilab is the lead U.S. laboratory and coordinates the national R&D program in this area. FY 2011 funding will also be used to support a fundamental research effort in SRF cavity design that aims to enhance the performance capability, gradient, production yield, reliability, lifetime, and cost of the fundamental RF accelerating structures.

Funding in FY 2011 includes $3,200,000 of capital equipment to procure an electron beam welder as an MIE project. The electron beam welder will be located at Fermilab and will be used to assemble and repair niobium superconducting cavities.

| | | | |
|---|---|---|---|
| ▪ **International Linear Collider R&D** | **35,000** | **35,000** | **35,000** |

A TeV-scale linear electron-positron collider iswidely considered by the international high energy physics community to be a likely successor to the LHC, though the data from the LHC may indicate that an even higher energy accelerator (such as a muon collider) is needed to understand the new physics that emerges at this energy scale. In FY 2007, the International Linear Collider (ILC) collaboration under the auspices of the ILC Steering Group and the direction of the Global Design Effort (GDE) completed a detailed review of the R&D to be accomplished worldwide with milestones and priorities for that work. In FY 2008, the GDE initiated a five-year program to develop a Technical Design Report (TDR) that will address outstanding R&D issues, complete a baseline design, and provide a project implementation plan. Completion of the TDR in 2012 is consistent with worldwide resources currently available for the ILC R&D and coincident with first physics results from the LHC (necessary to finalize operating parameters for a TeV-scale linear collider).

In FY 2011, the ILC R&D program will continue to support an important, leading U.S. role in the comprehensive and coordinated international R&D program. Accordingly, efforts will focus on R&D for systems associated with the generation and maintenance of very bright particle beams, such as electron sources, damping rings, beam dynamics development, and beam delivery systems. Support

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2009 | FY 2010 | FY 2011 |

will also be provided for development and prototyping of high level RF equipment and components associated with the main linac accelerator, including ILC cryomodules. These R&D efforts also have wider applicability to other projects supported by the Office of Science.

| | | | |
|---|---|---|---|
| **Other Technology R&D** | **24,665** | **24,819** | **26,195** |

This category includes R&D on new particle detector technologies, addressing fundamental scientific problems to foster new technologies in particle detection, measurement, and data processing; and providing support for prototyping and detector systems development to bring the technologies to the maturity where they can be incorporated into future particle physics experiments.

| | | | |
|---|---|---|---|
| ▪ **Detector Development, Grants Research** | **3,492** | **3,568** | **3,688** |

The grants-based R&D program provides support for university physicists to develop new detector technologies or advance technologies that have broad applicability to a wide range of high energy physics experiments. This support includes maintaining university infrastructure to enable state-of-the-art R&D into new detector technologies. Technologies targeted for development are selected based on anticipated applications that require further technological improvements before deployment, and specific proposals are selected based on peer-review. Final funding levels depend on the number and quality of proposals received. Current areas of investigation include liquid noble gas detectors, silicon photomultipliers, large area photodetectors, and picosecond timing techniques. This activity was called Advanced Detector Research in past budget submissions.

| | | | |
|---|---|---|---|
| ▪ **Detector Development, National Laboratory Research** | **21,173** | **21,251** | **22,507** |

This activity supports detector R&D efforts and operations of test facilities at ANL, BNL, Fermilab, LBNL and SLAC. HEP conducted a comparative peer-review of the laboratory research efforts in this subfield in 2009, whose findings have been used to inform the funding decisions in this budget request.

The FY 2011 request will maintain R&D efforts directed toward developing new detectors, including prototyping and in-beam studies. A diverse program will continue, including efforts on particle flow calorimeters, very low-mass trackers, advanced charged-coupled devices, and radiation resistant, fast readout electronics. Prototype detector systems will be operated in the Fermilab test beam, providing a major test of particle flow algorithms and detector construction techniques. Since the Fermilab test beam is over-subscribed, a reconfiguration of an old experimental beam line at SLAC into a dedicated test beam for detectors to meet this demand is being supported.

This activity was called Detector Development in past budget submissions.

| | | | |
|---|---|---|---|
| **SBIR/STTR** | **0** | **19,658** | **20,027** |

In FY 2009 $17,730,000 and $2,128,000 was transferred to the congressionally mandated Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs, respectively. The FY 2010 and FY 2011 amounts are estimated requirements for the continuation of these programs.

| | | | |
|---|---|---|---|
| **Total, Advanced Technology R&D** | **175,184** | **182,302** | **189,968** |

## Explanation of Funding Changes

| | FY 2011 vs. FY 2010 ($000) |
|---|---|
| **Accelerator Science** | |
| ▪ **Grants Research** | |
| Funding for grant-based research increases relative to the FY 2010 level-of-effort to support university participation in experiments at new accelerator R&D facilities. | +665 |
| ▪ **National Laboratory Research** | |
| Funding for the core research program at the laboratories is increased to support enhanced research at newly completed accelerator facilities including FACET. | +4,146 |
| **Total, Accelerator Science** | **+4,811** |
| **Accelerator Development** | |
| ▪ **General Accelerator Development** | |
| Funding for General Accelerator Development activities maintains about a constant level of effort. | +670 |
| ▪ **Superconducting RF R&D** | |
| Funding for Superconducting RF development supports the planned implementation of capabilities at Fermilab and about a constant level of effort for supporting R&D efforts. | +440 |
| **Total, Accelerator Development** | **+1,110** |
| **Other Technology R&D** | |
| Funding for Other Technology R&D maintains about a constant level of effort after the funding for the test beam is taken into account. | +1,376 |
| **SBIR/STTR** | |
| SBIR/STTR programs are funded at the mandated level. | +369 |
| **Total Funding Change, Advanced Technology R&D** | **+7,666** |

## Construction

### Funding Schedule by Activity

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2009 | FY 2010 | FY 2011 |
| Construction | | | |
| 11-SC-40, Long Baseline Neutrino Experiment, PED | 0 | 0 | 12,000 |
| 11-SC-41, Muon to Electron Conversion Experiment, PED | 0 | 0 | 5,000 |
| Total, Construction | 0 | 0 | 17,000 |

### Description

This subprogram provides for the Construction and Project Engineering and Design that is needed to meet overall objectives of the High Energy Physics program.

### Detailed Justification

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2009 | FY 2010 | FY 2011 |
| **11-SC-40, Long Baseline Neutrino Experiment, PED** | **0** | **0** | **12,000** |

The Long Baseline Neutrino Experiment will be composed of a neutrino beamline, small (near) detector located near to the neutrino beamline, and a large (far) neutrino detector located a long distance from the neutrino source. In order to build a neutrino beam that passes through the earth, a beam of protons must be transported through a tunnel that points into the ground. At the end of the tunnel the protons hit a target producing neutrinos that then travel through the earth. An existing neutrino beam of this type is the Neutrino at the Main Injector (NuMI) beam at Fermilab. The new LBNE beamline would provide low-energy neutrinos, a more intense beam, and point in a different direction from NuMI in order to provide the needed longer distance to the detector to extend the study of neutrino oscillations.

It is expected that the far detector will also need to be located underground to reduce the background from cosmic rays to a manageable level. The scope of work currently being developed includes a neutrino beamline, a small near detector, one or more large far neutrino detectors, the large underground cavern(s) needed to house the far detector(s), and the infrastructure needed to support the construction and operation of the large detector if housed underground.

| | | | |
|---|---|---|---|
| **11-SC-41, Muon to Electron Conversion Experiment, PED** | **0** | **0** | **5,000** |

The conversion of a muon to an electron in the field of a nucleus provides a unique window on the structure of potential new physics discoveries and allows access to new physics at very high mass scales. The Particle Physics Project Prioritization Panel (P5) identified this opportunity as a top priority for the Intensity Frontier of particle physics.

| | FY 2009 | FY 2010 | FY 2011 |
|---|---|---|---|
| This project will construct a new beamline to take protons from the existing 8 GeV Booster synchrotron at Fermilab to a muon production target, a beamline to transport those muons to the detector, a low-mass magnetic spectrometer, which can measure the electron momentum with a resolution of order 0.15%, and a new experimental hall to house the muon production target, muon beamline, and the detector. | | | |
| **Total, Construction** | **0** | **0** | **17,000** |

(dollars in thousands)

### Explanation of Funding Changes

| | FY 2011 vs. FY 2010 ($000) |
|---|---|
| **11-SC-40, Long Baseline Neutrino Experiment, PED** | |
| Funding is provided to initiate PED activities. | +12,000 |
| **11-SC-41, Muon to Electron Conversion Experiment, PED** | |
| Funding is provided to initiate PED activities. | +5,000 |
| **Total, Construction** | **+17,000** |

## Supporting Information

## Operating Expenses, Capital Equipment and Construction Summary

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2009 | FY 2010 | FY 2011 |
| Operating Expenses | 679,244 | 702,203 | 714,333 |
| Capital Equipment | 87,167 | 103,908 | 90,131 |
| General Plant Projects | 4,417 | 2,952 | 7,536 |
| Accelerator Improvement Projects | 5,040 | 1,420 | 0 |
| Construction | 0 | 0 | 17,000 |
| Total, High Energy Physics | 775,868 | 810,483 | 829,000 |

## Funding Summary

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2009 | FY 2010 | FY 2011 |
| Research | 451,674 | 448,910 | 463,970 |
| Scientific User Facilities Operations | 247,497 | 239,711 | 239,638 |
| Projects | | | |
| Major Items of Equipment | 69,066 | 91,953 | 72,730 |
| Construction | 0 | 0 | 22,000 |
| Total, Projects | 69,066 | 91,953 | 94,730 |
| Other | 7,631 | 29,909 | 30,662 |
| Total, High Energy Physics | 775,868 | 810,483 | 829,000 |

## Scientific User Facilities Operations

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2009 | FY 2010 | FY 2011 |
| Tevatron | 162,769 | 156,476 | 155,075 |
| B-factory | 15,331 | 12,074 | 9,780 |
| LHC Detector Support and Operations | 69,397 | 71,161 | 74,783 |
| Total, Scientific User Facilities Operations | 247,497 | 239,711 | 239,638 |

## Total Facility Hours and Users

| | FY 2009 | FY 2010 | FY 2011 |
|---|---|---|---|
| Proton Accelerator Complex[a] | | | |
| Achieved Operating Hours | 5,333 | N/A | N/A |
| Planned Operating Hours | 5,040 | 5,400 | 5,400 |
| Optimal hours (estimated) | 5,400 | 5,400 | 5,400 |
| Percent of Optimal Hours | 99% | 100% | 100% |
| Unscheduled Downtime | 16% | N/A | N/A |
| Total Number of Users | 2,160 | 2,000 | 1,800 |
| SLAC B-factory | | | |
| Total Number of Users | 800 | 600 | 300 |
| Total Facilities | | | |
| Achieved Operating Hours | 5,333 | N/A | N/A |
| Planned Operating hours | 5,040 | 5,400 | 5,400 |
| Optimal hours (estimated) | 5,400 | 5,400 | 5,400 |
| Percent of Optimal Hours | 99% | 100% | 100% |
| Unscheduled Downtime | 16% | N/A | N/A |
| Total Number of Users | 2,960 | 2,600 | 2,100 |

## Major Items of Equipment (MIE)

(dollars in thousands)

| | Prior Years | FY 2009 | FY 2009 Recovery Act | FY 2010 | FY 2011 | Outyears | Total |
|---|---|---|---|---|---|---|---|
| **Proton Accelerator-Based Physics** | | | | | | | |
| MINERνA | | | | | | | |
| Total Estimated Costs (TEC) | 5,000 | 4,900 | 0 | 800 | 0 | 0 | 10,700 |
| Other Project Costs (OPC) | 6,100 | 0 | 0 | 0 | 0 | 0 | 6,100 |
| Total Project Costs (TPC) | 11,100 | 4,900 | 0 | 800 | 0 | 0 | 16,800 |

[a] Tevatron and NuMI operations run in parallel.

(dollars in thousands)

| | Prior Years | FY 2009 | FY 2009 Recovery Act | FY 2010 | FY 2011 | Outyears | Total |
|---|---|---|---|---|---|---|---|
| NOνA | | | | | | | |
| TEC | 550 | 15,542 | 14,936 | 59,000 | 46,220 | 60,720 | 196,968 |
| OPC | 28,744 | 12,224 | 40,064 | 0 | 0 | 0 | 81,032 |
| TPC | 29,294 | 27,766 | 55,000 | 59,000 | 46,220 | 60,720 | 278,000 |
| T2K | | | | | | | |
| TEC | 1,848 | 1,000 | 0 | 0 | 0 | 0 | 2,848 |
| OPC | 1,860 | 0 | 0 | 0 | 0 | 0 | 1,860 |
| TPC | 3,708 | 1,000 | 0 | 0 | 0 | 0 | 4,708 |
| Accelerator Project for the Upgrade of the LHC | | | | | | | |
| TEC | 0 | 0 | 0 | TBD[a] | 9,250 | 8,250 | 17,500 |
| OPC | 0 | 2,500 | 0 | 9,000[a] | 0 | 0 | 11,500 |
| TPC | 0 | 2,500 | 0 | 9,000 | 9,250 | 8,250 | 29,000 |
| MicroBooNE[b] | | | | | | | |
| TEC | 0 | 0 | 0 | 0 | 8,000 | 8,957 | 16,957 |
| OPC | 0 | 0 | 0 | 2,043 | 0 | 0 | 2,043 |
| TPC | 0 | 0 | 0 | 2,043 | 8,000 | 8,957 | 19,000 |
| **Non-Accelerator Physics** | | | | | | | |
| Reactor Neutrino Detector | | | | | | | |
| TEC | 5,460 | 14,000 | 0 | 11,000 | 1,960 | 500 | 32,920 |
| OPC | 2,480 | 0 | 0 | 0 | 100 | 0 | 2,580 |
| TPC[c] | 7,940 | 14,000 | 0 | 11,000 | 2,060 | 500 | 35,500 |

[a] This MIE is not yet baselined, and therefore the TEC and OPC have not been determined. Mission Need (CD-0) was approved on November 20, 2008, with an estimated cost range of $25,000,000–$27,000,000. FY 2010 funding is for engineering design only. Engineering design may include limited fabrication and testing of design concepts. Fund for full fabrication will be requested after approval of the Performance Baseline, CD-2.
[b] This MIE is not yet baselined, and therefore the TEC and OPC have not yet been determined. The Mission Need (CD-0) was approved September 2009. The estimated cost range is $17,000,000–$19,000,000.
[c] A baseline change increasing the TPC from $34,000,000 to $35,500,000 with a planned completion date of April 2013 was approved by the Secretarial Acquisition Executive on January 11, 2010. This baseline change was needed to accommodate delays in the civil construction being performed by our Chinese partners.

(dollars in thousands)

| | Prior Years | FY 2009 | FY 2009 Recovery Act | FY 2010 | FY 2011 | Outyears | Total |
|---|---|---|---|---|---|---|---|
| Dark Energy Survey | | | | | | | |
| TEC | 1,650 | 8,990 | 0 | 8,610 | 4,000 | 0 | 23,250 |
| OPC | 10,990 | 910 | 0 | 0 | 0 | 0 | 11,900 |
| TPC | 12,640 | 9,900 | 0 | 8,610 | 4,000 | 0 | 35,150 |
| SuperCDMS at Soudan | | | | | | | |
| TEC/TPC | 0 | 1,000 | 0 | 1,500 | 0 | 0 | 2,500 |
| **Advanced Technology R&D** | | | | | | | |
| Advanced Accelerator R&D Test Facility[a] | | | | | | | |
| BELLA | | | | | | | |
| TEC | 0 | 8,000 | 18,718 | 0 | 0 | 0 | 26,718 |
| OPC | 0 | 0 | 2,000 | 0 | 0 | 0 | 2,000 |
| TPC | 0 | 8,000 | 20,718 | 0 | 0 | 0 | 28,718 |
| FACET | | | | | | | |
| TEC | 0 | 0 | 11,000 | 0 | 0 | 0 | 11,000 |
| OPC | 0 | 0 | 2,000 | 0 | 0 | 0 | 2,000 |
| TPC | 0 | 0 | 13,000 | 0 | 0 | 0 | 13,000 |
| Electron Beam Welder | | | | | | | |
| TEC/TPC | 0 | 0 | 0 | 0 | 3,200 | 0 | 3,200 |

[a] Two proposals, Berkeley Lab Laser Accelerator (BELLA) Project and the Facility for Accelerator Science and Experimental Test Beams (FACET) were reviewed as candidates for this facility. Both received excellent reviews and using Recovery Act funds, both are proceeding. FACET received only Recovery Act funds and BELLA received both FY 2009 funds and Recovery Act funds. Neither project is baselined yet, so the split between TEC and OPC funds is not yet determined. Mission Need (CD-0) was approved on February 27, 2008 with an estimated cost range of $32,000,000–$37,000,000 for both projects. This early estimate did not explicitly include OPC costs.

(dollars in thousands)

| | Prior Years | FY 2009 | FY 2009 Recovery Act | FY 2010 | FY 2011 | Outyears | Total |
|---|---|---|---|---|---|---|---|
| Total MIEs | | | | | | | |
| TEC | | 53,432 | 44,654 | 80,910 | 72,630 | | |
| OPC | | 15,634 | 44,064 | 11,043 | 100 | | |
| TPC | | 69,066 | 88,718 | 91,953 | 72,730 | | |

**Proton Accelerator-Based Physics MIEs:**

*Main Injector Experiment ν-A (MINERνA)* will make precision measurements of neutrino interaction rates in the NuMI beam, an important input to analyze data from neutrino oscillation experiments (such as MINOS and NOνA). The planned completion for this project is in FY 2010.

*NuMI Off-axis Neutrino Appearance (NOνA) Detector* will use the NuMI beam from Fermilab to directly observe and measure the transformation of muon neutrinos into electron neutrinos over a distance of 700 km. The project also includes improvements to the proton source to increase the intensity of the NuMI beam. The occurrence of these particular neutrino "flavor" changes is expected to be much rarer than the phenomenon under study with MINOS. The baseline was approved in September 2008 with a TPC of $278,000,000. A total of $55,000,000 was provided under the Recovery Act to advance the project. Funding planned for the outyears was reduced to maintain the same TPC. Work is ongoing to update the schedule to reflect the advanced funding profile. As of now, the planned completion for this project is still in 2014, but it is expected to be advanced.

*Tokai-to-Kamioka (T2K) Near Detector* is a new accelerator-based neutrino oscillation experiment in Japan. This experiment utilizes neutrino beams from the Japanese proton accelerator facility, measured both in a nearby detector and in the Super-Kamiokande detector approximately 300 km away, to study neutrino oscillations in a manner complementary to NOνA. This project was completed in FY 2009.

*Accelerator Project for the Upgrade of the LHC (APUL)* is a new MIE planned to begin fabrication in FY 2010. The scope of the project is to design and construct selected magnets, power systems, and beam instrumentation needed for increasing the LHC luminosity by a factor of two to three. The Mission Need was approved October 2008 and conceptual design is underway, funded under Other Project Costs. Brookhaven National Laboratory and Fermilab are expected to fabricate components and deliver them to CERN for installation in the LHC.

*MicroBooNE* is a new MIE planned to begin fabrication in FY 2011. The scope of the project is build a liquid argon neutrino detector to be used in the Booster neutrino beam at Fermilab for the measurement of low energy neutrino cross-sections. These cross sections will be measured at lower neutrino energy than the work planned for MINERνA and will be important for future neutrino oscillation experiments such as T2K and the proposed long baseline neutrino experiment for which PED funds are requested in FY 2011. This experiment will also be an important demonstration of efficacy of liquid argon time projection chambers as neutrino detectors.

**Non-Accelerator Physics MIEs:**

*Reactor Neutrino Detector*, located in Daya Bay, China, is being fabricated in partnership with research institutes in China. This experiment will use anti-neutrinos produced by commercial power reactors to precisely measure a fundamental parameter that will help resolve ambiguities in neutrino properties and will be input to setting future directions of neutrino research. A baseline change increasing the TPC from $34,000,000 to $35,500,000 with a planned completion date of April 2013 was approved January 2010. This baseline change was needed to accommodate delays in the civil construction being performed by our Chinese partners.

*Dark Energy Survey (DES) project* will provide the next step beyond the discovery of dark energy by making more detailed studies using several different observational methods. DOE is supporting the fabrication of a new camera to be installed and operated on the existing Blanco four-meter Telescope at the Cerro Tololo Inter-American Observatory (CTIO) in Chile. This project is a partnership between DOE and the NSF, which operates the telescope, along with international participation. The planned completion of this project is in FY 2011.

*Super Cryogenic Dark Matter Survey (SuperCDMS) at Soudan* is an upgrade of an existing dark matter search experiment (CDMS) to increase sensitivity for direct detection of dark matter over current experiments by a factor of three. The ultra-cold, supersensitive superconducting germanium detectors will be manufactured at Stanford University and tested at various U.S. institutions before being installed at the Soudan Underground Laboratory in Minnesota. This project has been reduced in size compared to the FY 2009 budget request in order to complete the experiment more quickly and maintain scientific competitiveness with other dark matter detection technologies.

**Advanced Technology R&D MIEs:**

*Advanced Accelerator R&D Test Facility* was initiated in FY 2009. Two proposals, Berkeley Lab Laser Accelerator (BELLA) Project at LBNL and the Facility for Accelerator Science and Experimental Test Beams (FACET) at SLAC were reviewed as candidates for this facility. Both received excellent reviews and using Recovery Act funds, both projects are proceeding. FACET received only Recovery Act funds and BELLA is funded with both FY 2009 funds and Recovery Act funds. FACET will fabricate equipment to be installed in the portion of the SLAC linac not utilized by Linac Coherent Light Source. It will support experiments on plasma wakefield acceleration of electrons, a technique that exploits the field created by one electron bunch moving through a plasma to accelerate a second bunch following in the wake of the first. The BELLA Project will utilize a 1 petawatt laser to produce the wakefields in the plasma, instead of a beam of electrons. The goal of the project is to produce 10 GeV electron beams in less than 1 meter of plasma. Both projects received CD-1 in September 2009. BELLA also received CD-2A/3A to approve procurement of the 1 petawatt laser.

*Electron Beam Welder* is a new MIE in FY 2011. This is a single procurement for a large piece of equipment needed in the processing of niobium superconducting RF cavities. Electron beam welding is the preferred method of welding niobium due to its very high melting point, approximately 4500° F, and the minimal size of the heat affected zone. The electron beam welder for Fermilab will be used to assemble and repair niobium superconducting cavities.

## Construction Projects

(dollars in thousands)

| | Prior Years | FY 2009 | FY 2009 Recovery Act | FY 2010 | FY 2011 | Outyears | Total |
|---|---|---|---|---|---|---|---|
| Long Baseline Neutrino Experiment (PED) | | | | | | | |
| TEC | 0 | 0 | 0 | 0 | 12,000 | 90,000 | 102,000 |
| OPC | 0 | 0 | 13,000 | 9,180 | 0 | 0 | 22,180 |
| TPC | 0 | 0 | 13,000 | 9,180 | 12,000 | 90,000 | 124,180 |
| Muon to Electron Conversion Experiment (PED) | | | | | | | |
| TEC | 0 | 0 | 0 | 0 | 5,000 | 30,000 | 35,000 |
| OPC | 0 | 0 | 0 | 5,000 | 5,000 | 0 | 10,000 |
| TPC | 0 | 0 | 0 | 5,000 | 10,000 | 30,000 | 45,000 |

| | FY 2009 | FY 2009 Recovery Act | FY 2010 | FY 2011 |
|---|---|---|---|---|
| Total Construction | | | | |
| TEC | 0 | 0 | 0 | 17,000 |
| OPC | 0 | 13,000 | 14,180[a] | 5,000 |
| TPC | 0 | 13,000 | 14,180 | 22,000 |

## Scientific Employment

| | FY 2009 estimate | FY 2010 estimate | FY 2011 estimate |
|---|---|---|---|
| # University Grants | 200 | 200 | 200 |
| # Laboratory Groups | 45 | 45 | 45 |
| # Permanent Ph.D.'s (FTEs) | 1,150 | 1,140 | 1,140 |
| # Postdoctoral Associates (FTEs) | 600 | 550 | 550 |
| # Graduate Students (FTEs) | 605 | 595 | 595 |
| # Ph.D.'s awarded | 110 | 110 | 110 |

[a] Other Project Costs for planned Construction activities in FY 2010 reflects the budget plan in the Mission Need statements for these projects. Critical Decision documentation was recently approved and the funding will be provided in the 2nd Quarter of FY 2010.

**11-SC-40, Long Baseline Neutrino Experiment (LBNE), Fermi National Accelerator Laboratory, Batavia, Illinois**
**Project Data Sheet is for PED**

## 1. Significant Changes

The most recent DOE O 413.3A approved Critical Decision (CD) is CD-0 that was approved January 8, 2010.

A Federal Project Director (FPD) has not been assigned to this project, but an FPD will be assigned by CD-1.

This PDS is new for PED. The FY 2011 request is for PED only.

## 2. Design, Construction, and D&D Schedule[a]

(fiscal quarter or date)

| | CD-0 | CD-1 | PED Complete | CD-2 | CD-3 | CD-4 | D&D Start | D&D Complete |
|---|---|---|---|---|---|---|---|---|
| FY 2011 | 1/8/2010 | 1Q FY 2011 | 4Q FY 2013 | TBD | TBD | TBD | TBD | TBD |

CD-0 – Approve Mission Need
CD-1 – Approve Alternative Selection and Cost Range
CD-2 – Approve Performance Baseline
CD-3 – Approve Start of Construction
CD-4 – Approve Start of Operations or Project Closeout
D&D Start – Start of Demolition & Decontamination (D&D) work
D&D Complete – Completion of D&D work

## 3. Baseline and Validation Status[b]

(dollars in thousands)

| | TEC, PED | TEC, Construction | TEC, Total | OPC Except D&D | OPC, D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|---|
| FY 2011 | 102,000[c] | TBD | TBD | 22,180[d] | TBD | TBD | TBD |

## 4. Project Description, Justification, and Scope

The Long Baseline Neutrino Experiment (LBNE) will be composed of a neutrino beamline, a small near detector, and a large neutrino detector located a long distance from the neutrino beam. A neutrino beam designed to pass through earth is built in a downward sloping tunnel, like the Neutrinos at the Main Injector (NuMI) beam, and therefore requires the construction of an underground tunnel. This new beamline would provide low-energy neutrinos, a more intense beam, and point in a different direction from NuMI in order to provide the longer distance to the detector needed for the study of neutrino oscillations.

[a] This project does not have CD-2 approval and is not requesting construction funds.
[b] This project is not yet baselined.
[c] This is a preliminary estimate for the planned PED over FY 2011–FY 2013.
[d] This is a preliminary estimate for Other Project Costs (OPC) including R&D, conceptual design, but not commissioning, and pre-operations.

Depending on the technology used, the detector may also need to be located underground to reduce the background from cosmic rays to a manageable level. The scope of work currently being developed includes: a neutrino beamline, one or more large neutrino detectors, the large underground cavern(s) needed to house the detector(s), and the infrastructure needed to support the construction and operation of the large detector underground.

The Particle Physics Project Prioritization Panel saw the Deep Underground Science and Engineering Laboratory (DUSEL), proposed by the National Science Foundation (NSF) to be a good match to the needs of a long baseline neutrino experiment. The Office of High Energy Physics (HEP) has been in discussions with the NSF Physics Division on cooperating during the development of these two initiatives, but will not commit to the DUSEL location for the long baseline neutrino experiment until the DOE alternatives analysis is completed, which is estimated to be early in FY 2011. Among the technical issues that need to be addressed in the alternatives analysis is the preferred detector technology. Two technologies are presently being considered: water Cerenkov and liquid argon time projection chamber. Water Cerenkov is a well established technology with more than 20 years of use, while liquid argon is a highly promising technology that could prove to be less expensive. Funding will be provided for R&D to answer a number of questions about liquid argon that will allow for a better comparison of the technologies.

The project is being conducted in accordance with the project management requirements in DOE O 413.3A, Program and Project Management for the Acquisition of Capital Assets, and all appropriate project management requirements have been met.

## 5. Financial Schedule

(dollars in thousands)

| | Appropriations | Obligations | Recovery Act Costs | Costs |
|---|---|---|---|---|
| Total Estimated Cost (TEC) | | | | |
| PED | | | | |
| FY 2011 | 12,000 | 12,000 | 0 | 10,000 |
| FY 2012 | 35,000 | 35,000 | 0 | 34,000 |
| FY 2013 | 55,000 | 55,000 | 0 | 50,000 |
| FY 2014 | 0 | 0 | 0 | 8,000 |
| Total, PED | 102,000 | 102,000 | 0 | 102,000 |
| | | | | |
| Other Project Cost (OPC) | | | | |
| OPC except D&D | | | | |
| FY 2009 Recovery Act | 13,000 | 13,000 | 0 | 0 |
| FY 2010 | 9,180 | 9,180 | 13,000 | 7,000 |
| FY 2011 | 0 | 0 | 0 | 2,180 |
| Total, OPC except D&D | 22,180 | 22,180 | 13,000 | 9,180 |
| | | | | |
| Total Project Cost (TPC) | | | | |
| FY 2009 Recovery Act | 13,000 | 13,000 | 0 | 0 |
| FY 2010 | 9,180 | 9,180 | 13,000 | 7,000 |

(dollars in thousands)

| | Appropriations | Obligations | Recovery Act Costs | Costs |
|---|---|---|---|---|
| FY 2011 | 12,000 | 12,000 | 0 | 12,180 |
| FY 2012 | 35,000 | 35,000 | 0 | 34,000 |
| FY 2013 | 55,000 | 55,000 | 0 | 50,000 |
| FY 2014 | 0 | 0 | 0 | 8,000 |
| Total, TPC | 124,180 | 124,180 | 13,000 | 111,180 |

## 6. Details of Project Cost Estimate

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| Total Estimated Cost (TEC) | | | |
| Design (PED) | | | |
| Design | 75,000 | N/A | N/A |
| Contingency | 27,000 | N/A | N/A |
| Total, PED | 102,000 | N/A | N/A |
| | | | |
| Total, TEC | 102,000 | N/A | N/A |
| Contingency, TEC | 27,000 | N/A | N/A |
| | | | |
| Other Project Cost (OPC) | | | |
| OPC except D&D | | | |
| R&D | 2,000 | N/A | N/A |
| Conceptual Planning | 7,000 | N/A | N/A |
| Conceptual Design | 9,000 | N/A | N/A |
| Contingency | 4,180 | N/A | N/A |
| Total, OPC except D&D | 22,180 | N/A | N/A |
| Contingency, OPC | 4,180 | N/A | N/A |
| | | | |
| Total, TPC | 124,180 | N/A | N/A |
| Total, Contingency | 31,180 | N/A | N/A |

## 7. Funding Profile History

(dollars in thousands)

| Request Year | | Prior Years | FY 2009 | FY 2009 Recovery Act | FY 2010 | FY 2011 | FY 2012 | FY 2013 | FY 2014 | FY 2015 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| FY 2011[a] | TEC | 0 | 0 | 0 | 0 | 12,000 | 35,000 | 55,000 | 0 | 0 | 102,000 |
| | OPC | 0 | 0 | 13,000 | 9,180 | 0 | 0 | 0 | 0 | 0 | 22,180 |
| | TPC | 0 | 0 | 13,000 | 9,180 | 12,000 | 35,000 | 55,000 | 0 | 0 | 124,180 |

## 8. Related Operations and Maintenance Funding Requirements

Not applicable for PED.

## 9. Required D&D Information

Not applicable for PED.

## 10. Acquisition Approach

The conceptual design and study of alternatives is being led by Fermi National Accelerator Laboratory with the assistance of Brookhaven National Laboratory. This work will be used to develop an Acquistion Strategy that will be approved as part of CD-1. At this time it is expected that a new neutrino beamline and neutrino detector will be needed. The technical expertise needed to design and build these components is very specialzed and will limit the acquisition approaches.

[a] This project has not yet received CD-2 approval and this is the first request for PED funds. Only PED and OPC excluding D&D are shown.

## 11-SC-41, Muon to Electron Conversion Experiment (Mu2e), Fermi National Accelerator Laboratory, Batavia, Illinois
## Project Data Sheet is for PED

### 1. Significant Changes

The most recent DOE O 413.3A approved Critical Decision (CD) is CD-0 was approved November 24, 2009.

A Federal Project Director has not yet been assigned to this project, but will be by CD-1.

This PDS is new for PED. The FY 2011 request is for PED only.

### 2. Design, Construction, and D&D Schedule[a]

(fiscal quarter or date)

| | CD-0 | CD-1 | PED Complete | CD-2 | CD-3 | CD-4 | D&D Start | D&D Complete |
|---|---|---|---|---|---|---|---|---|
| FY 2011 | 11/24/2009 | 4Q FY 2010 | 4Q FY 2012 | TBD | TBD | TBD | TBD | TBD |

CD-0 – Approve Mission Need
CD-1 – Approve Alternative Selection and Cost Range
CD-2 – Approve Performance Baseline
CD-3 – Approve Start of Construction
CD-4 – Approve Start of Operations or Project Closeout
D&D Start – Start of Demolition & Decontamination (D&D) work
D&D Complete –Completion of D&D work

### 3. Baseline and Validation Status[b]

(dollars in thousands)

| | TEC, PED | TEC, Construction | TEC, Total | OPC Except D&D | OPC, D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|---|
| FY 2011 | 35,000[c] | TBD | TBD | 10,000[d] | TBD | TBD | TBD |

### 4. Project Description, Justification, and Scope

The conversion of a muon to an electron (Mu2e) in the field of a nucleus provides a unique window on the structure of potential new physics discoveries and allows access to new physics at very high mass scales. The Particle Physics Project Prioritization Panel (P5) identified this opportunity as a top priority for the Intensity Frontier of particle physics.

This project will construct a new beamline to take protons from the existing 8 GeV Booster synchrotron at Fermilab to a muon production target, a beamline to transport those muons to the detector, a low-mass magnetic spectrometer, which can measure the electron momentum with a resolution of order 0.15%, and a new experimental hall to house the muon production target, muon beamline, and the detector.

[a] This project does not have CD-2 approval and is not requesting construction funds.
[b] This project is not yet baselined.
[c] This is a preliminary estimate for the planned PED in FY 2011 and FY 2012.
[d] This is a preliminary estimate for the OPC including R&D, conceptual design, but not commissioning, and pre-operations.

This project is very close to being completely ready technically for construction. The only needed R&D that has been identified is work on heating of the muon production target with an estimated cost of $150,000.

The project is being conducted in accordance with the project management requirements in DOE O 413.3A, Program and Project Management for the Acquisition of Capital Assets, and all appropriate project management requirements have been met.

## 5. Financial Schedule

| | (dollars in thousands) | | |
|---|---|---|---|
| | Appropriations | Obligations | Costs |
| Total Estimated Cost (TEC) | | | |
| PED | | | |
| FY 2011 | 5,000 | 5,000 | 4,500 |
| FY 2012 | 30,000 | 30,000 | 20,000 |
| FY 2013 | 0 | 0 | 10,500 |
| Total, PED | 35,000 | 35,000 | 35,000 |
| Other Project Cost (OPC) | | | |
| OPC except D&D | | | |
| FY 2010 | 5,000 | 5,000 | 4,500 |
| FY 2011 | 5,000 | 5,000 | 5,500 |
| Total, OPC except D&D | 10,000 | 10,000 | 10,000 |
| Total Project Cost (TPC) | | | |
| FY 2010 | 5,000 | 5,000 | 4,500 |
| FY 2011 | 10,000 | 10,000 | 10,000 |
| FY 2012 | 30,000 | 30,000 | 20,000 |
| FY 2013 | 0 | 0 | 10,500 |
| Total, TPC | 45,000 | 45,000 | 45,000 |

## 6. Details of Project Cost Estimate

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| Total Estimated Cost (TEC) | | | |
| Design (PED) | | | |
| Design | 28,000 | N/A | N/A |
| Contingency | 7,000 | N/A | N/A |
| Total, PED | 35,000 | N/A | N/A |
| | | | |
| Total, TEC | 35,000 | N/A | N/A |
| Contingency, TEC | 7,000 | N/A | N/A |
| | | | |
| Other Project Cost (OPC) | | | |
| OPC except D&D | | | |
| R&D | 150 | N/A | N/A |
| Conceptual Planning | 3,850 | N/A | N/A |
| Conceptual Design | 4,000 | N/A | N/A |
| Contingency | 2,000 | N/A | N/A |
| Total, OPC except D&D | 10,000 | N/A | N/A |
| Contingency, OPC | 2,000 | N/A | N/A |
| | | | |
| Total, TPC | 45,000 | N/A | N/A |
| Total, Contingency | 9,000 | N/A | N/A |

## 7. Funding Profile History

(dollars in thousands)

| Request Year | | Prior Years | FY 2009 | FY 2010 | FY 2011 | FY 2012 | FY 2013 | FY 2014 | FY 2015 | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| FY 2011[a] | TEC | 0 | 0 | 0 | 5,000 | 30,000 | 0 | 0 | 0 | 35,000 |
| | OPC | 0 | 0 | 5,000 | 5,000 | 0 | 0 | 0 | 0 | 10,000 |
| | TPC | 0 | 0 | 5,000 | 10,000 | 30,000 | 0 | 0 | 0 | TBD |

## 8. Related Operations and Maintenance Funding Requirements

Not applicable for PED.

## 9. Required D&D Information

Not applicable for PED.

[a] This project has not yet received CD-2 approval and this is the first request for PED funds. Only PED and OPC excluding D&D are shown.

## 10. Acquisition Approach

The conceptual design is being peformed by Fermilab, and it will inform the acquisition approach that will be documented in the Acquistion Strategy required for CD-1. It is already known that beamlines, detectors, and an experimental hall will be needed, and that the specialized expertise in those areas will be limit the range of acquisition options.