High Energy Physics

Funding Profile by Subprogram

(dollars in thousands)

	FY 2007 Current Appropriation	FY 2008 Original Appropriation	FY 2008 Adjustments	FY 2008 Current Appropriation	FY 2009 Request
High Energy Physics					
Proton Accelerator-Based Physics	343,633	376,702	-7,877[abc]	368,825	419,577
Electron Accelerator-Based Physics	101,284	78,763	-13,169[ab]	65,594	48,772
Non-Accelerator Physics	60,655	61,800	+12,399[ab]	74,199	86,482
Theoretical Physics	59,955	56,909	+3,325[ab]	60,234	63,036
Advanced Technology R&D	166,907	120,464	+15[ab]	120,479	187,093
Total, High Energy Physics	732,434[d]	694,638	-5,307[a]	689,331	804,960
Stanford Linear Accelerator Center (SLAC) Linac Operations (non-add)[e]	(51,300)	(20,000)	(-183)[a]	(19,817)	(—)
High Energy Physics, excluding SLAC Linac Operations (non-add)[e]	(681,134)	(674,638)	(-5,124)[a]	(669,514)	(804,960)

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"

Mission

The mission of the High Energy Physics (HEP) program is to understand how our universe works at its most fundamental level. We do this by discovering the most elementary constituents of matter and energy, probing the interactions between them, and exploring the basic nature of space and time itself. These fundamental ideas are the foundation of our understanding of the universe, its origins, and its destiny. To enable these discoveries, HEP supports theoretical and experimental research in both elementary particle physics and fundamental accelerator science and other supporting technology. HEP underpins and advances the Department of Energy (DOE) missions and objectives through this research,

[a] Reflects a reduction for the 0.91% rescission in P.L. 110–161, the Energy and Water Development and Related Agencies Appropriations Act, 2008, as follows: Proton Accelerator-Based Physics ($-3,428,000), Electron Accelerator-Based Physics ($-717,000); Non-Accelerator Physics ($-562,000); Theoretical Physics ($-518,000); and Advanced Technology R&D ($-1,096,000).
[b] Reflects a reallocation of funding in accordance with the Energy and Water Development Conference Report, as follows: Proton Accelerator-Based Physics ($-5,463,000), Electron Accelerator-Based Physics ($-12,452,000); Non-Accelerator Physics ($+12,961,000); Theoretical Physics ($+3,843,000); and Advanced Technology R&D ($+1,111,000).
[c] Reflects an approved reprogramming from prior year balances of $1,014,000.
[d] Total is reduced by $19,352,000: $17,279,000 of which was transferred to the Small Business Innovative Research (SBIR) program and $2,073,000 of which was transferred to the Small Business Technology Transfer (STTR) program.
[e] The SLAC linear accelerator (linac) supports operations of the B-factory (funded by HEP) and will also support operations of the Linac Coherent Light Source (currently under construction and funded by Basic Energy Sciences (BES)). With the completion of B-factory operations in FY 2008, SC has been transitioning funding of the SLAC linac from HEP to BES, with FY 2008 representing the third and final year of joint funding with BES. HEP totals without SLAC linac funding are presented to display program growth exclusive of this functional transfer.

and by the development of key technologies and trained manpower needed to work at the cutting edge of science.

Description

What is the nature of the universe and what is it made of?

What are matter, energy, space, and time?

We have been asking basic questions like these throughout human history. Today, many of these questions are addressed scientifically through research in high energy physics, also known as particle physics. The DOE and its predecessors have supported research into these fundamental questions for more than five decades.

This research has led to a profound understanding of the physical laws that govern matter, energy, space, and time. This understanding is encompassed in a "Standard Model," first established in the 1970's, which predicts the behavior of particles and forces. The model has been subjected to countless experimental tests since then and its predictions have consistently been verified. The Standard Model is one of the great scientific triumphs of the 20th century and the discoveries that led to it have been recognized with more than a dozen Nobel Prizes.

Nevertheless, the Standard Model is understood to be incomplete. Startling new data have revealed that only about 5% of the universe is made of the normal, visible matter described by the Standard Model. The other 95% of the universe consists of matter and energy whose fundamental nature is a mystery. The Standard Model's orderly and elegant view of the universe must somehow be incorporated into a broader and deeper theory where these new phenomena take their natural places. The new phenomena beyond it should appear at the energy scale accessed by new facilities.

A revolution in particle physics, and in our understanding of the universe in which we live, is coming.

Questions and the Quest for Answers

A world-wide program of particle physics research is underway to explore the new scientific landscape. The long-term plan for the U.S. HEP program prepared by the National Academy of Sciences ("Revealing the Hidden Nature of Space and Time") recommends the thoughtful pursuit of a high-risk, high-reward strategy to explore the energy frontier, called the "Terascale". At Terascale (meaning 10^{12} electron volts, or TeV for short) energies, questions in cosmology and particle physics are closely connected: the history, nature, and ultimate fate of the universe depend intimately on elementary particles and their interactions.

Here are some of the key questions the HEP program is addressing, and how we are seeking the answers:

- Are there undiscovered principles of nature: new symmetries, 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 particle energies. One possible and well motivated new symmetry, called supersymmetry, relates particles and forces. It predicts a "superpartner" for every particle we know, the lightest of which should be produced and observed at accelerators operating at the Terascale.

- How can we solve the mystery of dark energy?

  The "dark energy" that permeates empty space and accelerates the expansion of the universe must have a quantum explanation, in the same way that the quantum theory of light and the atom explained mysterious atomic spectra. More precise experimental data on dark energy, along with new theoretical ideas, are necessary to make progress on this fundamental problem.

- Are there extra dimensions of space?

  "String theory" is an attempt to unify physics by explaining particles and forces as the vibrations of tiny strings. String theory requires supersymmetry and seven extra dimensions of space. Evidence of such extra dimensions which support string theory could be seen at Terascale accelerators.

- 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 recent advances in string theory give hope of achieving it. The discovery of superpartners or extra dimensions at Terascale accelerators would lend strong support to current ideas about unification.

- Why are there so many kinds of particles?

  Three different "families" of quarks and leptons have been discovered. Moreover, quarks and leptons have widely different masses and force couplings. These variations suggest there may be undiscovered simplifying principles that connect quarks and leptons, just as the discovery of quarks simplified the "zoo" of composite particle states discovered in the 1960's. Detailed studies at accelerators will provide the clearest 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 and interacts very rarely with normal matter. This "dark matter" is thought to consist of exotic particles that have survived since the Big Bang. They may be reproduced and studied at Terascale accelerators, or detected in cosmic rays by using ultra-sensitive detectors.

- What are neutrinos telling us?

  Of all the known particles, neutrinos are perhaps the most mysterious. They played an essential role in the evolution of the universe, and flood otherwise empty space, but most pass right through the Earth undeflected and void of interaction. Their tiny masses may imply new physics and provide important clues to the unification of forces. Neutrinos are produced by cosmic rays, where they can be studied, as well as with experiments at accelerators and nuclear reactors.

- How did the universe come to be?

  The Big Bang (our universe) began with a singular disturbance of space-time, followed by a burst of inflationary expansion of space itself. The universe then expanded more slowly and cooled, allowing 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?

  By all observation the universe appears to contain very little antimatter, although the Big Bang should have produced equal amounts of matter and antimatter, a fact that is supported by high-energy collisions in the laboratory. Precise accelerator-based measurements of the subtle asymmetries present in the weak nuclear interaction may shed light on how this asymmetry arose.

All these questions are addressed at some level by the existing and planned HEP program described in this budget request. Theoretical research, development of new and enabling technologies, and a wide variety of experimental approaches are working hand-in-hand to provide new opportunities for further discoveries about the fundamental nature of the universe.

While exploration of the scientific opportunities of the energy frontier at the Terascale is identified as a priority, it is also critical to maintain a diverse portfolio of activities in particle physics, from theory to accelerator R&D to construction and support of new experimental facilities. A central challenge for the U.S. and international high energy physics community is defining and executing a robust and balanced scientific program that includes provision for a new research collider at the energy frontier. The International Linear Collider (ILC), which is widely viewed as that collider, is a complex, technologically challenging multi-billion dollar investment requiring international commitments and years of R&D and design work before it might become a reality. The physics case and some design parameters for the ILC depend on physics results from the Large Hadron Collider (LHC) at CERN that will probably not be available for at least a few years. Recognizing the strong endorsement of the ILC from the U.S. and international HEP communities and from the National Academy of Sciences, we support a U.S. role in the global ILC R&D effort, in the context of an appropriately balanced HEP program that will enable the U.S. to play a leadership role in targeted research areas, both in the LHC era and whatever comes next.

In order to maintain this balance, the U.S. involvement in the global ILC R&D effort is focused on areas where the U.S. is the acknowledged leader. This becomes part of an overall strategy for accelerator R&D that has both near- and long-term components, and it provides the U.S. options over the next decade to exploit the most scientifically compelling accelerator facilities. With the Fermi National Accelerator Laboratory (Fermilab) Tevatron Collider nearing the end of its scientific program, investments must be made to develop the capabilities and infrastructure for a next generation of experimental tools.

The HEP program supported by this request allows the U.S. to continue its leadership at the energy frontier with the Tevatron as long as possible and play a strong role in the LHC program; to pursue an internationally coordinated, staged program in neutrino physics that will establish a U.S. leadership role in this area in the next decade; and to address compelling non-accelerator scientific opportunities and in particular, to expand the program in particle astrophysics.

- FY 2009 funding is provided to operate the Tevatron for its planned 42 week (5,040 hours) schedule. The luminosity improvements of the Tevatron Collider have been successfully carried out, enabling the Tevatron to open a window of discovery for the long-sought Higgs particle in advance of significant data from the LHC. The possibility of Tevatron operations for an addition year in FY 2010 will be revisited in FY 2008 when more Tevatron data have been analyzed and the LHC turn-on schedule is better understood.
- As the LHC accelerator nears its turn-on date in 2008, U.S. activities related to fabrication of detector components are complete and new activities related to commissioning and pre-operations of these detectors, along with software and computing activities needed to analyze the data, are being ramped-up. Support of an effective role for U.S. research groups in LHC discoveries will continue to be a high priority of the HEP program. R&D to explore possible options for upgrades to the LHC accelerator and detectors is supported.
- Increased funding is provided in FY 2009 for targeted areas in accelerator R&D, in accordance with recommendations from High-Energy Physics Advisory Panel (HEPAP) and external program reviews, to begin implementation of a strategic plan for technology R&D in the HEP program. These increases are directed at four distinct areas: (1) short-term R&D focused on addressing the issues associated with the development of a high intensity proton source for an enhanced neutrino program at Fermilab; (2) mid-term R&D directed at developing superconducting radiofrequency technologies

and infrastructure for the HEP program and the U.S.; (3) mid-term R&D directed towards the proposed ILC that is focused on areas where the U.S. is acknowledged expert, and that is internationally coordinated; and (4) long-term R&D directed at advanced accelerator technologies with the promise of transformational changes. Overall funding for technology R&D activities is actually below the FY 2007 level-of-effort but is better aligned with programmatic priorities.

- Funding is provided for the Dark Energy Survey (DES), Reactor Neutrino Detector (Daya Bay) and Cold Dark Matter Search (CDMS) Major Items of Equipment (MIEs) and for R&D for a Joint Dark Energy Mission (JDEM). Each of these has the potential for shedding new information and insight on the mysteries of dark matter and energy.

Strategic and GPRA Unit Program Goals

The Department's Strategic Plan identifies five Strategic Themes (one each for nuclear, energy, science, management, and environmental aspects of the mission) plus 16 Strategic Goals that tie to the Strategic Themes. The High Energy Physics program supports the following goals:

Strategic Theme 3, Scientific Discovery & Innovation

- Strategic Goal 3.1, Scientific Breakthroughs: Achieve the major scientific discoveries that will drive U.S. competitiveness; inspire America; and revolutionize our approaches to the Nation's energy, national security, and environmental quality challenges.
- Strategic Goal 3.2, Foundations of Science: Deliver the scientific facilities, train the next generation of scientists and engineers, and provide the laboratory infrastructure required for U.S. scientific primacy.

The HEP program has one GPRA Unit Program Goal which contributes to Strategic Goals 3.1 and 3.2 in the "goal cascade."

GPRA Unit Program Goal 3.1/2.46.00: 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.

Contribution to GPRA Unit Program Goal 3.1/2.46.00, Explore the Fundamental Interactions of Energy, Matter, Time and Space

The HEP program contributes to this goal by advancing our understanding of the basic constituents of matter and the forces between them, deeper symmetries in the laws of nature at high energies, and mysterious phenomena that pervade the universe, such as dark energy and dark matter. HEP uses particle accelerators and very sensitive detectors to study fundamental particle interactions at the highest possible energies. Because particle physics is deeply connected to the origin and evolution of the universe itself, the HEP program also supports non-accelerator studies of cosmic particles and phenomena including experiments conducted deep underground, on mountains, or in space. This research at the frontier of science may discover new particles, forces, or undiscovered dimensions of space and time; explain how matter came to have mass; and reveal the underlying nature of the universe. In particular, the HEP program seeks to identify the mysterious dark matter that holds galaxies together and the even more mysterious dark energy that is stretching space apart; explain why there is any matter in the universe at all; and show how the tiniest constituents of the universe play a leading role in shaping its birth, growth, and ultimate fate. Our goals in FY 2009 address all of these questions.

The FY 2009 budget request places high priority on operations, upgrades, and infrastructure for the two major HEP user facilities: the Tevatron Collider and Neutrinos at the Main Injector (NuMI) at Fermilab, to produce maximum scientific data to address these fundamental questions. FY 2008 is the final year of operations for the B-factory at the Stanford Linear Accelerator Center (SLAC); in FY 2009 the SLAC facility operation completes its transition to the Basic Energy Sciences (BES) program.

In 2004, the HEPAP established the following indicators for specific long-term (10 year) goals in scientific advancement to which the HEP program is committed. They do not necessarily represent the research goals of individual experiments in the field. The order of the indicators corresponds roughly to current research priorities, and is meant to be representative of the program, not comprehensive.

- Measure the properties and interactions of the heaviest known particle (the top quark) in order to understand its particular role in the Standard Model, our current theory of particles and interactions.
- Measure the matter-antimatter asymmetry in many particle decay modes with high precision.
- Discover or rule out the Standard Model Higgs particle, thought to be responsible for generating the mass of elementary particles.
- Determine the pattern of the neutrino masses and the details of their mixing parameters.
- Confirm the existence of new supersymmetric (SUSY) particles or rule out the minimal SUSY Standard Model of new physics.
- Directly discover or rule out new particles that could explain the cosmological "dark matter."

Funding by Strategic and GPRA Unit Program Goal

(dollars in thousands)

	FY 2007	FY 2008	FY 2009
Strategic Goals 3.1, Scientific Breakthroughs and 3.2, Foundations of Science			
GPRA Unit Program Goal 3.1/2.46.00, Explore the Fundamental Interactions of Energy, Matter, Time and Space			
High Energy Physics	732,434	689,331	804,960

Annual Performance Results and Targets

FY 2004 Results	FY 2005 Results	FY 2006 Results	FY 2007 Results	FY 2008 Targets	FY 2009 Targets
GPRA Unit Program Goal 3.1/2.46.00—Explore the Fundamental Interactions of Energy, Matter, Time and Space					
All HEP Facilities					
Maintained and operated HEP facilities such that unscheduled downtime was on average less than 20% of the total scheduled operating time. [Met Goal]	Maintained and operated HEP facilities such that unscheduled downtime was on average less than 20% of the total scheduled operating time. [Met Goal]	Maintained and operated HEP facilities such that unscheduled downtime was on average less than 20% of the total scheduled operating time. [Goal Not Met]	Maintained and operated HEP facilities such that unscheduled downtime was on average less than 20% of the total scheduled operating time. [Met Goal]	Achieve greater than 80% average operation time of the scientific user facilities (the Fermilab Tevatron and the Stanford Linear Accelerator (SLAC) B-factory) as a percentage of the total scheduled annual operating time.	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.
Proton Accelerator-Based Physics/Facilities					
Delivered data as planned within 20% of the baseline estimate (240 pb^{-1}) to CDF and D-Zero detectors at the Tevatron. [Met Goal]	Delivered data as planned within 20% of the baseline estimate (390 pb^{-1}) to CDF and D-Zero detectors at the Tevatron. [Met Goal]	Delivered data as planned within 20% of the baseline estimate (675 pb^{-1}) to CDF and D-Zero detectors at the Tevatron.[Met Goal]	Delivered data as planned within 20% of the baseline estimate (800 pb^{-1}) to CDF and D-Zero detectors at the Tevatron. [Met Goal]	Deliver within 20% of baseline estimate a total integrated amount of data (800 pb^{-1}) to CDF and D-Zero detectors at the Tevatron.	Deliver within 20% of baseline estimate a total integrated amount of data (1200 pb^{-1}) to CDF and D-Zero detectors at the Tevatron.
		Delivered data as planned within 20% of the baseline estimate ($1x10^{20}$ protons on target) for the MINOS experiment using the NuMI facility.[Met Goal]	Delivered data as planned within 20% of the baseline estimate ($1.5\ x10^{20}$ protons on target) for the MINOS experiment using the NuMI facility. [Met Goal]	Measure within 20% of the total integrated amount of data ($2.0\ x10^{20}$ protons on target) delivered to the MINOS detector using the NuMI facility.	Measure within 20% of the total integrated amount of data ($2.7\ x10^{20}$ protons on target) delivered to the MINOS detector using the NuMI facility.
Electron Accelerator-Based Physics/Facilities					
Delivered data as planned within 20% of baseline estimate (45 fb^{-1}) to the BaBar detector at the SLAC B-factory. [Met Goal]	Delivered data as planned within 20% of baseline estimate (50 fb^{-1}) to the BaBar detector at the SLAC B-factory. [Met Goal]	Delivered data as planned within 20% of the baseline estimate (100 fb^{-1}) to the BaBar detector at the SLAC B-factory.[Met Goal]	Delivered data as planned within 20% of the baseline estimate (150 fb^{-1}) to the BaBar detector at the SLAC B-factory. [Goal Not Met]	Deliver within 20% of the baseline estimate a total integrated amount of data (220 fb^{-1}) delivered to the BaBar detector at the Stanford Linear Accelerator (SLAC) B-factory.	
Construction/Major Items of Equipment					
Maintained cost and schedule milestones for upgrades and new major construction projects within 10% of baseline estimates. [Met Goal]	Maintained cost and schedule milestones for upgrades and new major construction projects within 10% of baseline estimates. [Met Goal]	Maintained cost and schedule milestones for upgrades and new major construction projects within 10% of baseline estimates. [Met Goal]	Maintained cost and schedule milestones for major items of equipment and new construction projects within 10% of baseline estimates. [Met Goal]	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.	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.

Means and Strategies

The HEP program will use various means and strategies to achieve its program goals. However, various external factors may impact the ability to achieve these goals.

The HEP program supports fundamental, innovative, peer-reviewed research to create new knowledge in areas important to the HEP mission, i.e., in experimental and theoretical particle physics, particle astrophysics, cosmology, accelerator science and technology R&D. HEP also plays a critical role in constructing and operating a wide array of scientific user facilities for the Nation's researchers. All research projects undergo regular peer review and merit evaluation based on procedures in Office of Science Regulation 10 CFR 605 for the extramural grant program, and under a similar process for the laboratory programs and scientific user facilities. New projects are selected through peer review and merit evaluation.

External factors that affect the programs and performance include: (1) changing mission needs as described by the DOE and Office of Science (SC) mission statements and strategic plans; (2) evolving scientific opportunities that sometimes emerge in a way that revolutionizes disciplines; (3) results of external program reviews and international benchmarking activities of entire fields or sub fields, such as those performed by the National Academy of Sciences; (4) unanticipated failures, for example, in critical components of scientific user facilities, which cannot be mitigated in a timely manner; and (5) strategic and programmatic decisions made by other Federal agencies and by international entities.

The HEP program in fundamental science is closely coordinated with the activities of other federal agencies, including the National Science Foundation (NSF) and the National Aeronautics and Space Administration (NASA). HEP also promotes the transfer of the results of its basic research to contribute to DOE missions in areas of nuclear physics research and facilities; basic energy sciences facilities, (contributing to research in materials science, molecular biology, physical chemistry, and environmental sciences); and mathematical and computational sciences.

Validation and Verification

Progress against established plans is evaluated by periodic internal and external performance reviews. These reviews provide an opportunity to validate and verify performance. Quarterly, semiannual, and annual reviews consistent with specific program management plans are held to ensure technical progress, cost and schedule adherence, and responsiveness to program requirements.

Program Assessment Rating Tool (PART)

The Department has implemented a tool to evaluate selected programs. PART was developed by the Office of Management and Budget (OMB) to provide a standardized way to assess the effectiveness of the Federal Government’s portfolio of programs. The structured framework of the PART provides a means through which programs can assess their activities differently than through traditional reviews. The HEP program has incorporated feedback from OMB into the FY 2009 Budget Request and has taken or will take the necessary steps to continue to improve performance.

The HEPAP reviewed progress on the long-term HEP program goals (listed under Contribution to Strategic Goals) in 2006. They found this set of long-term goals to be appropriate, that some of the six goals have already been achieved in part, and that nearly all are likely to be achieved in the 10-year timeframe since they were established in 2004. They further recommended that new goals be established in 2008 when plans and funding profiles for new proposals would be clearer.

In the FY 2003 PART review for the FY 2005 Budget, OMB gave the HEP program a rating of "Moderately Effective". OMB found performance improvements at Fermilab and an ongoing prioritization process. The assessment also found that HEP had developed a limited number of adequate performance measures which are continued for FY 2009. These measures have been incorporated into this budget request, HEP grant solicitations, and the performance plans of senior managers. As appropriate, they will be incorporated into the performance based contracts of M&O contractors. The annual performance targets are tracked through the Department's Joule system and reported in the Department's Annual Performance and Accountability Report.

OMB previously provided HEP with three recommendations to further improve performance:

- Implement the recommendations of past and new external assessment panels, as appropriate.
- Develop a strategy and implementation plan for particle accelerator research and development, including a potential international linear collider.
- Engage the National Academies to help develop a realistic long-term plan for the program that is based on prioritized scientific opportunities and input from across the scientific community.

In response to OMB's recommendations HEP has:

- Established a Committee of Visitors (COV) that provides outside expert validation of the program's merit based review processes for impact on quality, relevance, and performance. The COV reports are available on the web (http://www.science.doe.gov/hep/HEPAPCOVReportfinal.pdf). The HEP action plans are available on the web at (http://www.sc.doe.gov/hep/OfficeofHEPResponsetoCOVreport.shtm).
- HEPAP was charged in 2006 to establish panels to assess progress toward the long-term goals of the HEP program. These goals are spelled out under the "Contribution to Strategic Goals" section above. They found the long-term goals to be appropriate, that some of the six goals have already been achieved in part, and that nearly all are likely to be achieved in the 10-year timeframe since they were established in 2004 (http://www.science.doe.gov/hep/HEPAPlongtermassessmentreport.pdf).
- The National Academies study of elementary particle physics ("EPP2010") transmitted its recommendations on the priorities of scientific opportunities in 2006. In FY 2007, HEPAP was charged to examine the options for addressing these scientific opportunities and mounting a world-class U.S. particle physics program with available resources. The HEPAP study will provide important input for establishing the strategy for HEP accelerator R&D within DOE that incorporates the challenges of a potential international linear collider.

To improve public access to PART assessments and follow up actions, OMB has created the ExpectMore.gov website. Information concerning HEP PART assessments and current follow up actions can be found by searching on "high energy physics" at http://www.ExpectMore.gov.

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) provides advice to the DOE and the NSF regarding the direction and management of the national high energy physics research program. HEPAP (or a subpanel thereof) 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) assesses and prioritizes proposals for mid-sized projects that have been endorsed by laboratory program advisory committees or other advisory committees. HEPAP subpanels are also convened to review progress and/or future plans in particular research areas or elements of the HEP program. A subpanel called the Neutrino Scientific Assessment Group (NuSAG), reporting jointly to HEPAP and the Nuclear Science Advisory Committee (NSAC), is advising DOE and NSF on specific questions concerning the U.S. neutrino program (http://www.science.doe.gov/hep/NUSAGFinalReportJuly13,2007.pdf). A HEPAP subpanel reviewing the DOE advanced accelerator R&D program reported in the summer of 2006 (http://www.science.doe.gov/hep/AARDsubpanelreportfinalamendedAug21.pdf), and one on the university HEP research programs of DOE and NSF reported in summer 2007 (http://www.science.doe.gov/hep/ugpsreportfinalJuly22,2007.pdf). These evaluations and the priorities recommended are important input in the development of the HEP strategic plan. In FY 2007, HEPAP was charged to examine the options for addressing current scientific opportunities and mounting a world-class U.S. particle physics program at various funding levels. The findings and recommendations of this HEPAP report will be submitted in FY 2008 and will be important input for setting the programmatic priorities for the U.S. HEP program that can be implemented with available resources.

The Astronomy and Astrophysics Advisory Committee (AAAC) now reports on a continuing basis to the DOE, as well as to the NSF and 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 may form joint task forces or subpanels as needed to address research issues at the intersection of high energy physics, astrophysics and astronomy, such as dark energy and dark matter. For example, Task Forces on the cosmic microwave background and dark energy reported in spring 2006, and a Scientific Assessment Group for Dark Matter submitted their report in July 2007 (http://www.science.doe.gov/hep/DMSAGReportJuly18,2007.pdf).

The National Academy of Sciences 2006 decadal survey of opportunities in high energy physics and the tools needed to realize them in the next 15 years. The committee's report, *Revealing the Hidden Nature of Space and Time: Charting the Course for Elementary Particle Physics* emphasized the importance of the Large Hadron Collider (LHC) and the International Linear Collider (ILC) in the context of a broad and balanced program that also includes among its elements particle astrophysics and neutrino physics. The report is referred to colloquially as "EPP2010", and is available at http://www7.nationalacademies.org/bpa/EPP2010.html.

In 2006, DOE and NASA charged and jointly funded a National Research Council study by the Beyond Einstein Program Assessment Committee (BEPAC), which was completed in September 2007. This study assisted NASA in determining which of the five proposed NASA Beyond Einstein astrophysics missions should be developed and launched first. The proposed DOE and NASA Joint Dark Energy Mission (JDEM) was recommended to be the first mission, and DOE and NASA now plan to move forward jointly on the mission.

Facility directors seek advice from their Program Advisory Committees (PACs) to determine the scientific justifications and priorities for the allocation of an important scientific resource—available accelerator beam time. Committee members, most of them external to the laboratory, are appointed by the director. PACs review research proposals requesting beam time and technical resources, judging each proposal's scientific merit and technical feasibility, and recommending whether the proposal should be approved, conditionally approved, deferred, or rejected.

The HEP program has also instituted a formal Committee of Visitors 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 Committee of Visitors review took place in summer 2007. The committee report praised the program strongly, but also pointed to several areas that could be improved.

Review and Oversight

The HEP program office reviews and provides oversight for its research portfolio. All university research proposals are subjected to an intensive and multistage review process to ensure high quality research and an appropriate mix of research efforts in the national program. Proposals to DOE for grant support are peer-reviewed by external technical experts. Once a university group is funded, regular site visits and peer reviews are performed to ensure that the quality of the research is maintained. Proposals by university groups to perform an experiment at a laboratory facility are reviewed by the laboratory PAC as described above.

The program also conducts regular in-depth reviews of the high energy physics program at each laboratory, using a panel of external technical experts. These on-site reviews examine the programmatic health of the laboratory, its high energy physics research, and, as appropriate, the state of its user facilities. The results are used in setting priorities both at the laboratory and within the national program. Proposals to initiate significant new research activities at laboratories may also undergo a peer review process, in addition to the laboratory program reviews, to assess in detail the quality and relevance of the specific proposal. In addition, the HEP program office began in FY 2004 to conduct regular, dedicated reviews of operations at its major user facilities in order to maintain high standards of performance and reliability. The HEP program office also participates in the annual SC reviews of each of its laboratories, and conducts *ad hoc* reviews of particular HEP research topics on an as-needed basis.

Review and oversight of construction activities are done by integrated technical, cost, schedule, and management reviews using teams of experts versed in the areas of activity pertinent to the particular project. These reviews are chaired by SC federal employees from outside the HEP program who are expert in project management, and the review results are provided directly to the project's DOE Acquisition Executive.

Significant Program Shifts

After a very successful eight-year run, operation of the SLAC B-factory was completed in FY 2008. Funding is provided in FY 2009 to support analysis of data collected at the B-factory and for safe ramp-down of the facility. The transfer of responsibility for the SLAC linac to Basic Energy Sciences is completed in FY 2009.

Proton Accelerator-Based Physics

Funding Schedule by Activity

(dollars in thousands)

	FY 2007	FY 2008	FY 2009
Proton Accelerator-Based Physics			
Research	110,021	109,238	114,528
Facilities	233,612	259,587	305,049
Total, Proton Accelerator-Based Physics	343,633	368,825	419,577

Description

The mission of the Proton Accelerator-Based Physics subprogram is to foster fundamental research in high energy physics using proton accelerators that will provide new insights into the basic constituents of matter and the forces between them, thereby advancing the DOE's strategic goals for science.

The Proton Accelerator-Based Physics subprogram exploits U.S. leadership at the energy frontier by conducting experimental research at high energy proton collider facilities. This experimental research program will 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.

The Proton Accelerator-Based Physics subprogram also includes precise, controlled measurements of basic neutrino properties performed at accelerator facilities. These measurements, performed with neutrino beams generated from primary proton beams, will provide important clues and constraints to the new world of matter and energy beyond the Standard Model.

The most immediate goal on the particle physics roadmap is to fully understand the unification of the electromagnetic and weak nuclear interactions into a single, "electroweak" force. This is expected to occur at an energy scale of about one trillion electron volts or 1 TeV. The Standard Model has successfully explained almost all particle physics phenomena below 1 TeV in energy, but beyond that energy range a new physical mechanism must be present to prevent Standard Model predictions from becoming unphysical. Originally it was proposed that a single Higgs boson is the solution to this "TeV scale" problem, but newer theories such as supersymmetry, extra hidden dimensions, and technicolor could also solve the TeV scale problem in the Standard Model, either in place of or in combination with, one or more Higgs bosons. No matter which of these theories is shown to be correct, it will provide new insights into the fundamental nature of matter, energy, space, and time. One thing is clear, however: new physics must occur at the Terascale.

Because of the high energy of the collisions at the Tevatron Collider (2 TeV) and the LHC (14 TeV), and the fact that the particles interact differently at different energies, these facilities can be used to study a wide variety of scientific issues. All of the six known types of quarks can be produced in these interactions, but the heaviest, the top and bottom quarks, are of the greatest interest. Most of the force-carrying particles are also produced in these collisions, and if the masses of predicted—but as yet unobserved—particles, such as the Higgs boson or supersymmetric particles are small enough, they will also be discovered. Whether the Tevatron or the LHC is the first accelerator to observe new physics at the TeV scale will depend on the configuration that nature has chosen for these phenomena.

Proton accelerators are capable of producing the highest-energy particle beams made by man, and by colliding proton beams into targets, large samples of other particles like antiprotons, K mesons, muons, and neutrinos can also be produced and formed into beams for experiments. The Proton Accelerator-Based Physics subprogram uses both aspects of proton accelerators.

The major 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/Main Injector Neutrino Oscillation Search (MINOS) facility at Fermilab and at the Soudan Mine site in Minnesota; the research programs of ATLAS and CMS at the Large Hadron Collider (LHC) at CERN program; and the maintenance and operation of these experimental facilities.

Physics at the energy frontier is the primary thrust of the Proton Accelerator-Based Physics subprogram. In FY 2009, the energy frontier moves to the Europe with the start-up of LHC operations. U.S. participation in the LHC program will enable U.S. high energy physicists to remain key players at the new energy frontier. While the LHC experiments will be just beginning to acquire experience with their first data, the well-understood CDF and D-Zero experiments at the Tevatron will continue their searches for the Higgs and precision measurements of known particles—such as the mass of the W boson and the top quark—that will indicate where the Higgs or other new physics is likely to be found. Less than 100 top quarks were accumulated and studied during the previous Tevatron collider run from 1992 to 1996. The new run (started in 2001) has already produced over an order of magnitude more top quarks, and will provide far more precise measurements of its mass, spin, and couplings. Recent measurements of the top mass have reached a precision very near 1% and the W mass a precision near 0.05%, together placing increasingly strong constraints on the mass of a Standard Model Higgs.

Today, neutrino physics presents one of the most promising avenues to probe for extensions of the Standard Model. In the last decade, a number of interesting new results have been reported by several different experiments, including the Super-K and KamLAND experiments in Japan and the Sudbury Neutrino Observatory (SNO) experiment in Canada. These experiments provide compelling evidence that neutrinos do have mass and do change their identities (the different neutrino species "mix") as they travel. These properties of neutrinos are neither required nor predicted by the Standard Model. One of the unique opportunities in the Proton Accelerator-Based Physics subprogram is to explore and make high precision measurements of neutrinos generated at dedicated proton beam facilities in a well-controlled environment (e.g., the NuMI beam at Fermilab). The NuMI/MINOS program is making decisive controlled measurements of fundamental neutrino properties, including neutrino mixing, and will provide important clues and constraints to the theory of matter and energy beyond the Standard Model.

The National Academy of Sciences "EPP2010" report recommended a diverse HEP program using a variety of tools to attack the exciting opportunities in elementary particle physics, including a staged internationally coordinated program in neutrino physics. One of those opportunities, the observation of electron neutrinos from a muon neutrino beam, can be met by the proton accelerator-based research program. A new detector optimized to detect electron neutrinos, NuMI Off-axis Neutrino Appearance (NOνA) Detector will utilize the NuMI beam.

Highlights

Recent accomplishments include:

- Important recent physics results from the CDF and D-Zero detectors at Fermilab include the production of single top quarks, one of the rarest collision processes ever observed at a hadron collider; a new measurement of the top quark mass, which when combined with a new precise measurement of the W mass places increasingly strong bounds on the Standard Model Higgs mass; the first observation of events that simultaneously produce a W boson and a Z boson, an important milestone in the search for the Higgs boson; and the discovery of new particles containing quarks from each of the three different families. The innovative analysis methods employed by CDF and D-Zero scientists, and thorough understanding of detector performance and backgrounds displayed in these results, bode well for future discoveries.

- The MiniBooNE experiment reported its findings and resolved questions about results from the Liquid Scintillator Neutrino Detector (LSND) experiment in the 1990's. All neutrino oscillation results from around the world could be explained by a simple model of three types of neutrinos oscillating among themselves. MiniBooNE researchers showed conclusively that the LSND results could not be due to simple neutrino oscillations, and that a proposed new type of neutrino does not exist.

The major planned efforts in FY 2009 are:

- *The research program using the Tevatron at Fermilab*. This research program is being carried out by a collaboration including 1,400 scientists from Fermilab, Argonne National Laboratory (ANL), Brookhaven National Laboratory (BNL), Lawrence Berkeley National Laboratory (LBNL), 56 U.S. universities, and institutions in over 20 foreign countries. The major effort in FY 2009 will be data taking with the fully upgraded 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 exclusion of a Higgs boson with a mass near 160 GeV/c2 should be within reach soon, while searches for a Higgs boson with lighter mass will require more data. The Tevatron experiments will collect data in FY 2009 that will give the two experiments access to extremely rare subatomic processes, including access to a significant region of the expected Higgs mass range.
- *The research program using the NuMI/MINOS Facilities at Fermilab and the Soudan Mine*. This research program is being carried out by a collaboration including 250 scientists from Fermilab, ANL, BNL, Lawrence Livermore National Laboratory (LLNL), 16 U.S. universities, and institutions in 4 foreign countries. The major effort in FY 2009 will be data taking and analysis, along with optimizing accelerator performance to improve beam intensity for higher statistics. The experiment is planned to run through FY 2010 to achieve its ultimate sensitivity, about a factor of two improvement over its current result. A new experiment, Main Injector Experiment ν-A (MINERνA), which will make precision measurements of neutrino interaction rates in the NuMI beam (an important input to analyze MINOS and NuMI Off-axis Neutrino Appearance [NOνA] data), continues fabrication in FY 2009.
- *A new detector for neutrino physics.* Final engineering design began in FY 2007 for a new Major Item of Equipment, the NOνA Detector which will use the NuMI beam from Fermilab to directly observe and measure the transformation of muon neutrinos into electron neutrinos over distances of hundreds of miles. 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 that MINOS is studying. Funding for NOνA was suspended by Congress in FY 2008. The previously planned funding profile has been shifted by one year, and a revised project plan is under development.

- *The U.S. LHC research program*. In FY 2009, 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 detectors for LHC experiments at CERN will continue.

Detailed Justification

(dollars in thousands)

	FY 2007	FY 2008	FY 2009
Research	**110,021**	**109,238**	**114,528**
▪ **University Research**	**51,593**	**53,749**	**56,623**

The HEP university research program consists of groups at more than 60 universities doing experiments at proton accelerator facilities. These university groups plan, build, execute, analyze, and publish results of experiments; develop the physics opportunities and preliminary designs for future experiments; and train graduate students and postdoctoral researchers. University-based scientists typically constitute about 75% of the personnel needed to create, run, and analyze an experiment, and they usually work in collaboration with other university and laboratory groups. University personnel are fully integrated into the operations of the detector facilities, performing various service functions, and these facilities could not operate without them. University-based research efforts are funded in a manner based on peer review, and funded at levels commensurate with the effort needed to carry out the experiments.

In FY 2009, the overall level of university research support in this subprogram increases significantly to reflect anticipated shifts towards LHC research, as the electron accelerator-based research program begins to wind down with the completion of B-factory operations. This increase in LHC research activity will occur while maintaining strong participation in the Tevatron and neutrino physics programs. Strong participation of university physicists is needed to carry out the collider and neutrino program at the Tevatron during FY 2009. There will be healthy scientific competition between completion of the Run II of the Tevatron Collider program and commencement of the LHC experiments. The detailed funding allocations will take into account the quality of research as well as the involvement of university-based research groups in the targeted physics research activities. These include research efforts related to the Tevatron experiments CDF and D-Zero; the NuMI neutrino experiments MINOS, NOνA, and MINERνA; and U.S. participation in the LHC research program. U.S. university researchers are also contributing to a new accelerator-based neutrino oscillation experiment (T2K) 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, to study neutrino oscillations in a way complementary to NOνA. In FY 2009, $1,000,000 is requested to complete fabrication of the MIE project to build a detector for the T2K beam line (TPC $4,680,000).

▪ **National Laboratory Research**	**57,229**	**54,441**	**56,665**

The national laboratory research program consists of groups at several laboratories participating in experiments at proton accelerator facilities. These groups are involved in all phases of the experiments, with the focus of the physics analysis being similar to that of the university groups

	FY 2007	FY 2008	FY 2009

(dollars in thousands)

described above. They also provide invaluable service to the research program in detector design, construction, and operations. The DOE HEP program office reviews laboratory research groups annually, with input provided by independent peer reviewers. Proton accelerator research activities concentrate on experiments at the Tevatron complex (collider and neutrino physics programs) at Fermilab and the LHC at CERN.

The increase in the support of laboratory research in FY 2009 will enhance participation of laboratory physicists in the A large Toroidal LHC ApparatuS (ATLAS) and Compact Muon Solenoid (CMS) experiments as LHC operations and data analysis begin. Strong involvement of physicists from the national laboratories will also be needed to carry out the research program at the Tevatron during FY 2009, as there will be a competition in resources between the completion of Run II of the Tevatron Collider and commissioning of the LHC experiments. The High Energy Physics program will monitor progress in these areas, and balance resources so as to optimize the national program.

The Fermilab research program includes data taking and analysis of the CDF, D-Zero, and MINOS experiments; the CMS research and computing program; and research related to the new neutrino initiatives, such as the NOνA and MINERνA experiments. This research by physicists at the host laboratory provides the necessary close linkages between the Research and the Facilities activities in the Proton Accelerator-Based Physics subprogram.

Research at LBNL consists of a large and active group in the ATLAS research and computing program. The BNL research group will focus on the ATLAS research and computing program, completing data taking and analysis of the D-Zero experiment, and a small effort on the MINOS experiment and research related to future neutrino initiatives. The research group at ANL will be working on data taking and analysis of the CDF experiment, the ATLAS research and computing program, data taking and analysis of the MINOS detector, and research related to the new neutrino initiatives, such as the NOνA experiment. A research group from SLAC joined the ATLAS experiment in 2006 and will be actively engaged in LHC research and data analysis.

▪ **University Service Accounts**	**1,199**	**1,048**	**1,240**

University Service Accounts facilitate the support of university groups working at accelerator facilities, providing 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 maintain service accounts at Fermilab. Funding for these university service accounts is maintained at about the FY 2007 level, reflecting the anticipated need.

Facilities	**233,612**	**259,587**	**305,049**
▪ **Tevatron Complex Operations**	**119,976**	**144,974**	**157,550**

Operations at Fermilab will include operation of the Tevatron accelerator complex for both collider and neutrino physics programs, including two collider detectors and a neutrino experiment. This will be a major physics run for the D-Zero and CDF detectors with the higher intensity available from the upgraded Main Injector. The Tevatron performance has continued to improve according to plan through FY 2007 and this is to be one of the major data collection periods for the collider experiments pursuing physics topics from the energy frontier facility.

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009

Tevatron operations also include running the Tevatron complex in fixed target mode in parallel with Tevatron collider operations. This running mode will be primarily for the physics data taking of the MINOS experiment using the NuMI beamline.

In FY 2009, the increase in this category is slightly above constant level of effort to ensure the successful completion of Run II. Efforts will be increased in accelerator operations to maintain the Tevatron complex and in detector operations to handle the large datasets expected to be produced in FY 2009. The operations and commissioning activities for the NuMI proton improvement plan to increase the intensity of the proton source from 250 kW to about 400 kW will be completed in FY 2008.

The proposed funding will support operations at the Department's two major high energy physics facilities both at Fermilab: the Tevatron Collider and the NuMI neutrino beamline. The Tevatron Collider provided a total of 4,620 hours of beam time in FY 2007 for a research community of about 700 U.S. scientists in HEP and another 700 researchers from foreign countries, testifying to the fact that this is a unique, world-leading experimental facility. Operation of NuMI began in FY 2006 and served more than 250 researchers, of whom about two-thirds are U.S. researchers. Approximately 500 researchers world-wide participate in Fermilab's other experimental and theoretical research and R&D programs. The FY 2009 request will support facility operations at Fermilab to provide about 5,040 hours of beams for the Tevatron Collider and for NuMI, including an allowance for increased power costs and incremental upgrades.

	FY 2007	FY 2008	FY 2009
Tevatron Complex[a] (including NuMI)			
Optimal hours (estimated)	4,560	5,400	5,400
Planned Operating Hours	4,560	5,040	5,040
Achieved Operating Hours	4,620	N/A	N/A
Unscheduled Downtime	<17%	N/A	N/A
Total Number of Users	2,160	2,160	2,160

▪ **Tevatron Complex Improvements**	**41,515**	**34,070**	**64,300**

The funding in this category includes funds for general plant projects (GPP) and other infrastructure improvements at Fermilab, funding for accelerator improvements, experimental computing expansion and other detector support, and new detector fabrication. Accelerator improvements to increase the luminosity performance of the Tevatron Collider were completed in FY 2006, and the laboratory began to focus on improving the intensity of the NuMI beamline beyond its design power of 250 kW via a phased plan of incremental upgrades. The first phase of these improvements concludes in FY 2008 and will support deployment and commissioning of these improvements to increase the intensity of the proton source to about 400 kW.

[a] Tevatron and NuMI operations run in parallel.

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009

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 than is possible during Run II. 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 NuMI Off-axis Neutrino Appearance (NOνA) Detector, this collection of upgrades and improvements is part of the scope of the NOνA project in order to ensure appropriate project management oversight and integration. Accelerator upgrade activities are mostly contained in the NOνA MIE to allow for optimization of the physics delivered by the project within the overall budget.

The NOνA detector (preliminary TPC $270,000,000) 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 into electron-type neutrinos. It will also make important indirect measurements from which we may be able to determine the mass hierarchy for the three known neutrino types (i.e., whether there are two "light" and one "heavier" type of neutrino or vice versa), which will be a key piece of information in determining the currently unknown masses of neutrinos. The project includes the very large "far" detector (approximately football-field size and five stories high), the far detector enclosure, its associated electronics and data acquisition system, and a small "near" detector on the Fermilab site.

The fabrication of the NOνA MIE (TEC) ramps up significantly in FY 2009 after funding was suspended in FY 2008, just prior to the project being baselined. A revised baseline which takes into account the actual FY 2008 spending and a revised project schedule will be completed early in 2008. Other Project Cost funding for the NOνA project in FY 2009 includes the planned cooperative agreement with the University of Minnesota, to build an enclosure for the detector and participate in the NOνA research program, along with final design of detector elements. This project is planned to be completed and taking data in FY 2013.

NOνA MIE (TEC)	1,000	—	7,000
NOνA (OPC)—R&D and cooperative agreement	6,970	5,970[a]	30,000
Total, NOνA (TPC)	7,970	5,970	37,000

Also included in this category is $4,900,000 in FY 2009 to continue fabrication of the MINERνA MIE (TEC $10,700,000). This is a small experiment in the MINOS near detector hall at Fermilab that will measure the rates of neutrino interactions with ordinary matter. This is

[a] The FY 2008 Energy and Water Development and Related Agencies Appropriation provided no funds for NOνA activities, but at the time the appropriation had been signed $5,970,000 had already been obligated under the Continuing Resolution. Steps were taken to cease spending immediately after passage of the Appropriation. It may be possible to deobligate a portion of the $5,970,000; if so, this amount would be reduced and the funding shifted to another activity.

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009

important data for MINOS and other neutrino experiments including NOνA, and can be measured with much better precision than previous experiments using the powerful NuMI beam. This project is planned to be completed and taking data in FY 2010.

	FY 2007	FY 2008	FY 2009
▪ **Large Hadron Collider Project**	**3,180**	**—**	**—**
• **LHC Detectors**	**3,180**	**—**	**—**
♦ **ATLAS Detector, Operating Expenses**	**1,880**	**—**	**—**
♦ **CMS Detector**	**1,300**	**—**	**—**
Operating Expenses	**50**	**—**	**—**
Capital Equipment	**1,250**	**—**	**—**

Under the agreement with CERN regarding U.S. participation in the LHC program, DOE has provided $450,000,000 to the LHC accelerator and detectors (with an additional contribution of $81,000,000 from the NSF). The DOE total contribution was separated into detectors ($250,000,000) and accelerator ($200,000,000), with the accelerator funding consisting of $88,500,000 for direct purchases by CERN from U.S. vendors, and $111,500,000 for fabrication of components by U.S. laboratories.

A significant problem did occur in 2007 during commissioning with one of the U.S. supplied accelerator components, an inner triplet magnet, built by Fermilab; it failed during a pressure test at CERN. The response of the laboratory and the project management team to the problem was effective and efficient; a remediation was developed and carried out, and all components have now been successfully tested. No delays to the overall LHC schedule were incurred. The first LHC collisions are expected in 2008.

In addition to the $450,000,000 DOE and $81,000,000 NSF contributions to the fabrication of LHC accelerator and detector hardware, U.S. participation in the LHC involves a significant fraction of its physics community in the research program at the LHC. Over 1,000 U.S. scientist members of the U.S.-ATLAS and the U.S.-CMS detector collaborations, or the U.S.-LHC accelerator consortium, will be supported by the DOE and NSF core research programs by FY 2009.

The overall U.S. LHC Project reached a status of 98% complete by the end of FY 2006, in compliance with the “CD-4a” project-completion requirement prescribed by the DOE. Essentially all of the equipment is already at CERN, and the remaining portion of the accelerator project was completed in 2006. The two detector projects, tied to the final stages of the CERN schedule, will be completed before the end of FY 2008. The latter activities are related primarily to the final assembly, testing, and installation of the completed detectors, as well as to the purchase of computing hardware for data acquisition. Under the current schedule, completion of these two detector projects will take place in early calendar year 2008, in full agreement with the U.S. DOE deadline for the completion of the project. The overall result of previous delays in the CERN schedule was a stretch-out by two years in the planned U.S. contributions to the LHC detectors. The final cost of each detector remains unchanged, and the final year of DOE funding for all aspects of the U.S. participation in fabrication of the LHC was FY 2007.

U.S. LHC Accelerator and Detectors Funding Profile

(dollars in thousands)

Fiscal Year	Department of Energy			National Science Foundation (Detectors)
	Accelerator	Detectors	Total	
1996[a]	2,000	4,000	6,000	—
1997[a]	6,670	8,330	15,000	—
1998[a]	14,000	21,000	35,000	—
1999	23,491	41,509	65,000	22,150
2000	33,206	36,794	70,000	15,900
2001	27,243	31,627	58,870	16,370
2002	21,303	27,697	49,000	16,860
2003	21,310	37,900	59,210	9,720
2004	29,330	19,470	48,800	—
2005	21,447	11,053	32,500	—
2006	—	7,440	7,440	—
2007	—	3,180	3,180	—
Total	200,000[b]	250,000	450,000	81,000

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009
▪ **Large Hadron Collider Support**	**56,820**	**63,622**	**72,450**

The U.S. LHC effort is one of the highest priority components of the HEP program, endorsed repeatedly by HEPAP, and by the recent National Academy of Sciences study (EPP2010). With LHC turn-on occurring in 2008, the U.S. LHC program, jointly supported by the DOE and the NSF, will be in a critical phase in FY 2009. An increase of almost 14% in DOE support above FY 2008 is planned. This includes increased costs for Fermilab direct program support. The main use of the resources will be for LHC software and computing, and pre-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 using the LHC, along with R&D for potential future upgrades to both the machine and the detectors. Most of the increase in FY 2009 funding is for accelerator R&D aimed at supporting LHC upgrades. With first data anticipated in 2008, a high priority will be on the ramp-up of operations in FY 2009.

[a] The FY 1996 and FY 1997 LHC funding was for R&D, design, and engineering work in support of the proposed U.S. participation in LHC. Beginning in FY 1998 funding was used for: fabrication of machine and detector hardware, supporting R&D, prototype development, and purchases by CERN from U.S. vendors
[b] Includes $111,500,000 for LHC supporting R&D and accelerator components to be fabricated by U.S. laboratories and $88,500,000 for purchases by CERN from U.S. vendors.

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009
• **LHC Software and Computing**	**21,759**	**26,327**	**26,960**

The LHC software and computing effort will enable U.S. physicists to analyze the vast quantities of LHC data and empower them to play a leading role in exploiting the physics opportunities presented by the LHC. The LHC Software and Computing program will also be in a critical stage in FY 2009, when the combination of software development, facilities hardware and support, and grid computing must come together and operate smoothly. Prior to FY 2008, the U.S. effort focused on data and service challenges, with testing of the hardware and infrastructure needed for full LHC data analysis using professional-quality software on simulated data. These systems have to mature rapidly into fully functional production systems over a period of one to two years. The funding will provide for equipment purchases, computing personnel, and user support at Tier 1 and Tier 2 computing and data handling centers in the U.S. This will allow U.S. physicists, especially at universities, to play a central role. Grid computing solutions will continue to be integrated in the LHC computing model, building on the tools provided by the Scientific Discovery through Advanced Computing (SciDAC) Open Science Grid project, and providing U.S. researchers the access and computing power needed to analyze the large and complex LHC data. In FY 2009, full-scale analysis with physics-quality data will form the final stress test for the completed systems, and will likely indicate areas where the analysis model can be better optimized.

• **LHC Experimental Support**	**24,061**	**25,377**	**27,490**

Funding is provided for operations and maintenance of the U.S.-built LHC detector subsystems as well as increasing support for generic detector R&D with specific focus on detector technologies needed to accommodate a possible LHC upgrade in luminosity. This effort will support the continuing development and deployment of tools for control, calibration, and exploitation of LHC data, including remote detector monitoring and control systems. These tools will facilitate remote participation by U.S. physicists in the operation of the LHC detectors.

Support will also be provided for technical coordination and program management, both at the participating U.S. national laboratories and at CERN.

• **LHC Accelerator Research**	**11,000**	**11,918**	**18,000**

The U.S. LHC Accelerator Research Program (LARP), supported solely by the DOE, will continue to focus R&D on producing full-scale accelerator-quality magnets with the highest possible sustained magnetic fields. This R&D will provide important technical data to CERN for management decisions on possible future LHC accelerator upgrades to increase luminosity. In FY 2009, funding is increased by approximately 50%, to speed fabrication of advanced prototypes of state-of-the-art LHC interaction region magnets made of optimized niobium-tin (Nb_3Sn) superconductor material. Special instrumentation is also being provided for collimation and monitoring of the LHC beams that will play an important role during the accelerator commissioning phase.

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009
▪ **Alternating Gradient Synchrotron (AGS) Support**	**650**	**644**	**650**

Funding continues for long-term decontamination and decommissioning (D&D) of the AGS facility, whose operations as a HEP user facility at BNL were terminated at the end of FY 2002.

▪ **Other Facilities**	**11,471**	**16,277**	**10,099**

Includes funding for private institutions and other government laboratories and institutions that participate in high energy physics research, 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.

In FY 2009, funding in this category includes $1,154,000 for General Purpose Equipment at LBNL for landlord related activities and $2,230,000 for LHCNet, the transatlantic data link between the U.S. and CERN.

Total, Proton Accelerator-Based Physics	**343,633**	**368,825**	**419,577**

Explanation of Funding Changes

	FY 2009 vs. FY 2008 ($000)
Research	
▪ Funding for university-based research in this subprogram increases to support the expanding research program at the LHC. Additional funds are included to support increased university grantee research expenses associated with travel to CERN.	+2,874
▪ Funding for laboratory-based research in this subprogram increases to support the research program that is ramping up in FY 2009 at the LHC. It maintains support for ongoing scientist effort at the Fermilab Tevatron Collider.	+2,224
▪ Increase in university service accounts reflects the anticipated need, based on the most recent actual costs in this category.	+192
Total, Research	+5,290
Facilities	
▪ Tevatron Complex Operations receives increased support to maintain constant level of effort in order to ensure a successful completion of Run II.	+12,576
▪ Tevatron Complex Improvements increase significantly because the NuMI Off-axis Neutrino Appearance experiment (NOvA) MIE is largely contained in this budget category, and fabrication activities for both the far detector and the detector enclosure ramp-up in FY 2009.	+30,230

	FY 2009 vs. FY 2008 ($000)
▪ LHC Support funding increases to provide approximately constant level-of-effort in support of LHC detector operations, planned increases for computing hardware to enable U.S. researchers to keep pace with increasing LHC datasets, and accelerated fabrication of prototype niobium-tin superconducting interaction region magnets to demonstrate the feasibility of LHC luminosity upgrades.	+8,828
▪ Funding for AGS Operations/Support restores the appropriate level for this activity.	+6
▪ Funding for Other Facilities support decreases as GPP funding at LBNL is transferred to the Science Laboratories Infrastructure program ($-4,490,000) along with a decrease in funding held pending completion of peer review and/or programmatic decisions ($-1,688,000).	-6,178
Total, Facilities	**+45,462**
Total Funding Change, Proton Accelerator-Based Physics	**+50,752**

Electron Accelerator-Based Physics

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009
Electron Accelerator-Based Physics			
Research	22,314	22,063	22,952
Facilities	78,970	43,531	25,820
Total, Electron Accelerator-Based Physics	101,284	65,594	48,772

Description

The mission of the Electron Accelerator-Based Physics subprogram is to foster fundamental research in high energy physics using electron accelerators that will provide new insights into the basic constituents of matter and the forces between them, thereby advancing the DOE's strategic goals for science.

The Electron Accelerator-Based Physics subprogram utilizes accelerators with high-energy and ultra-precise beams to create and investigate matter at its most basic level. It was the electron accelerator at SLAC that, in the 1960's, first identified the existence of quarks as the inner constituents of the proton and neutron. During the 1980's, electron accelerators—in tandem with proton machines—were instrumental in establishing the Standard Model as the correct and precise theory of particle interactions.

Over the last few years, the electron B-factory at SLAC has provided precision measurements of how matter and antimatter behave differently in the decay products of B-mesons. This asymmetric behavior is called "CP [charge-parity] violation" and is considered by physicists to be vital to understanding why the universe appears to be predominantly matter, rather than equal quantities of matter and antimatter, one of the greatest puzzles we face in comprehending the universe.

While electron accelerators can be used to study a wide variety of physics topics, the Electron Accelerator subprogram is currently focused on the study of charm and bottom quarks and the tau lepton. These particles are all heavier than the particles of everyday matter and well suited for studying rare processes. The most interesting of these processes is CP violation.

CP violation has been observed in the decays of particles containing strange quarks (K mesons) and most recently in particles containing bottom quarks (B mesons). After the observations of CP violation in B mesons were made early in this decade at the SLAC B-factory and a similar accelerator at the Japanese national laboratory for high energy physics, the High Energy Accelerator Research Organization (KEK) B-factory [KEK-B], it has been possible to do a systematic study of the process and test whether our current theoretical explanation of CP violation, the Standard Model, is correct. This ongoing study requires both new measurements of CP violation in other B meson decays, as well as measurements of other properties of particles containing bottom or charm quarks. The measurements of these other properties have been used as inputs to the theoretical calculations of CP violation, as our current knowledge of those properties limits our understanding of CP violation.

In addition to studies of CP violation, the BaBar experiment at the SLAC B-factory has pursued a broad program of research on particles containing bottom or charm quarks. The Belle experiment at KEK-B has carried out a similar program, with a small number of U.S. university researchers participating. There has been regular cooperation as well as competition between the BaBar and Belle experiments, leading to more precise measurements and a better understanding of the experimental results. The

CLEO-c experiment at the Cornell Electron Storage Ring (CESR) has been concentrating on certain measurements of particles containing charm quarks that are difficult to do at the B-factory. These results test theories used to interpret the CP violation measurements and to provide key inputs to the physics analyses done at the B-factory. The CLEO-c research program will be extended at the recently upgraded Beijing Electron Positron Collider to improve precision measurements of charm quarks and tau leptons.

In FY 2009, the B-factory is in a ramp-down mode, following completion of its scientific program in FY 2008.

Highlights

Recent accomplishments include:

- In FY 2007, the SLAC B-factory delivered 90 fb^{-1} (inverse femtobarns) of which the BaBar detector recorded 86.5 fb^{-1}. The BaBar collaboration analyzed and presented the latest results at the major biennial summer research conference in 2007. The quantum mixing of D-zero particles with their anti-particles was discovered, along with unexpected particle resonances which are challenging the conventional picture of how quarks and gluons form stable bound states.

The major planned efforts in FY 2009 are:

- *The research program at the B-factory/BaBar Facility at SLAC*. This research program is being carried out by a collaboration of approximately 600 physicists including scientists from LBNL, LLNL, SLAC, 40 U.S. universities, and institutions from 7 foreign countries. In FY 2009 this effort will focus on final analysis with the upgraded accelerator and detector. The physics issues to be addressed include expanding our understanding of CP violation in many particle decay modes.
- *The research program at other electron accelerator facilities*. This program complements the B-factory/BaBar efforts and consists of a group of experimental research activities using the CESR and the KEK-B electron accelerator facilities. A total of 4 U.S. university groups work at KEK-B, and 22 U.S. university groups work at CESR. CESR, operated by the NSF, also completes running in FY 2008. In FY 2009, the work will concentrate on the final analysis of data taken at the CESR. A smaller effort will be devoted to operations of the Belle detector at KEK-B in Japan and analysis of the data taken.

Detailed Justification

(dollars in thousands)

	FY 2007	FY 2008	FY 2009
Research	**22,314**	**22,063**	**22,952**
▪ **University Research**	**10,968**	**11,176**	**11,576**

The HEP university research program includes groups at about 40 universities doing experiments at electron accelerator facilities. These university groups analyze and publish results of experiments; develop the physics rationale and preliminary designs for future experiments; and train graduate students and postdoctoral researchers. The BaBar experiment at the SLAC B-factory has been pursuing a broad program of physics studies on particles containing bottom or charm quarks with CP violation measurements and other measurements that support or complement the CP violation program.

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009

U.S. university scientists constitute about 50% of the personnel needed to analyze the BaBar experiment at the B-factory, and they work in collaboration with groups from national laboratories and foreign institutions. They are fully integrated into the operations of the detector facility, and perform many service functions for the detector.

The university program also supports groups that work at CESR at Cornell University; and groups that work at the KEK-B accelerator complex in Japan. The CLEO-c experiment at CESR is concentrating on certain precise measurements of particles containing charmed quarks that are difficult to perform at the B-factory. There is regular cooperation, as well as competition between the SLAC and KEK experiments, which has led to better data analysis and more precise results. University-based research efforts will be selected based on peer review.

In FY 2009, funding for university-based research in this subprogram continues at approximately a constant level-of-effort to complete analysis of physics data from BaBar and CLEO-c. The detailed funding allocations will take into account the involvement of university-based research groups in targeted physics research activities. These include research efforts related to BaBar research.

	FY 2007	FY 2008	FY 2009
▪ **National Laboratory Research**	**11,153**	**10,777**	**11,196**

The national laboratory research program consists of groups at several laboratories participating in experiments at electron accelerator facilities with a physics program similar to the university program described above. The experimental research groups from national laboratories provide invaluable service in the operation of the detector as well as analysis of the data. The DOE HEP program office reviews laboratory research groups annually with input from independent peer reviewers. The experimental research group from SLAC participates in all phases of the experiments. Because they are embedded in the laboratory structure, they provide invaluable service in the operation and maintenance of the detector as well as reconstruction and analysis of the data. The experimental research group at LBNL makes significant contributions to the physics analysis of the data and the computing system needed to reconstruct the data into physics quantities used for analysis. The LLNL research group contributed to the fabrication of the BaBar detector and is now primarily engaged in data analysis.

In FY 2009, laboratory-based research in this subprogram continues at approximately a constant level-of-effort to complete analysis of physics data from BaBar and CLEO-c. Overall SLAC will continue to maintain strong participation in the B-factory research program, which will be entering a two to three year period of intense analysis of the entire B-factory data set, while research groups at LBNL and LLNL have mostly transitioned to other activities. BaBar analysis will be the priority HEP research program at SLAC in FY 2009. A small electron accelerator-based research program at Fermilab is devoted to physics studies of the ILC.

	FY 2007	FY 2008	FY 2009
▪ **University Service Accounts**	**193**	**110**	**180**

University Service Accounts facilitate the support of university groups working at accelerator facilities, providing funding for these groups to purchase needed supplies and services from the laboratories with a minimum of time and cost overhead. Currently 16 university groups maintain service accounts at SLAC.

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009
Facilities	**78,970**	**43,531**	**25,820**
▪ **B-factory Operations**	**60,820**	**31,681**	**22,400**
• **Linac Operations**	**36,400**	**10,717**	**—**
• **Other B-factory Operations**	**24,420**	**20,964**	**22,400**

Funding for operations supports the transition of the B-factory accelerator complex to a safe and stable maintenance mode, and the planning and initiation of decontamination and decommissioning activities. This funding category also supports ongoing BaBar computing operations and data analysis. No funding is requested within this activity for SLAC Linac operations, as support of Linac Coherent Light Source (LCLS) commissioning is entirely underwritten by the Basic Energy Sciences (BES) program (see the Facilities section of the BES Materials Sciences and Engineering subprogram).

B-factory operations ended in FY 2008 with a significantly shortened physics run due to budget constraints in the Energy and Water Development and Related Agencies Appropriations Act. Faced with a very limited final run for the B-factory, BaBar decided to optimize their science output by moving the B-factory energy to a nearby resonance, slightly below the B meson production threshold where they usually operate to study CP violation and B meson decays. This strategy will generate a unique data set that can be used for detailed studies of QCD processes, rather than only marginally adding to the large existing data set.

The B-factory provided a total of about 4,200 hours of beam time in FY 2007 for a research community of about 300 U.S. scientists in HEP and a comparable number of users from foreign countries. SLAC also hosts approximately 500 researchers world-wide who are active in its other experimental and theoretical research and R&D programs. FY 2008 is the last year of HEP facility operations at SLAC for the B-factory, though analysis of the accumulated data will continue for a few more years. The B-factory will run for only 1,300 hours in FY 2008 instead of 5,720 hours planned in the FY 2008 request, due to the FY 2008 HEP appropriation being 12% lower than the request.

B-factory	FY 2007	FY 2008	FY 2009
Optimal hours (estimated)	5,200	5,850	—
Planned Operating hours	4,800	1,300	—
Achieved Operating Hours	4,200	N/A	—
Unscheduled Downtime	<22%	N/A	—
Total Number of Users	1,100	1,000	800

	FY 2007	FY 2008	FY 2009
▪ **B-factory Improvements**	**18,150**	**11,850**	**3,420**
• **Linac Improvements**	**14,900**	**9,100**	**—**
• **Other B-factory Improvements**	**3,250**	**2,750**	**3,420**

Funding is provided for the necessary enhancement of computing capabilities in order to support the timely analysis of the flood of data the B-factory has provided over the past few years. Activities in

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009
this category also include a contribution to site-wide infrastructure, as well as general maintenance activities.			
Total, Electron Accelerator-Based Physics	**101,284**	**65,594**	**48,772**

Explanation of Funding Changes

	FY 2009 vs. FY 2008 ($000)
Research	
▪ Funding for university-based research in this subprogram continues at approximately a constant level-of-effort to complete analysis of physics data from BaBar and CLEO-c.	+400
▪ Funding for laboratory-based research in this subprogram continues at approximately a constant level-of-effort to complete analysis of physics data from BaBar and CLEO-c.	+419
▪ Increases in university service accounts reflect the anticipated need.	+70
Total, Research	**+889**
Facilities	
▪ Funding for B-factory Operations is significantly reduced to reflect the completion of HEP operations at this facility in FY 2008. Activities in FY 2009 will be focused on the ramp-down of facility operations to a "minimum maintenance" configuration, along with detailed planning for safe and efficient dismantling and decommissioning of the B-factory accelerator and detector.	-9,281
▪ Funding for B-factory Improvements is significantly reduced to reflect the completion of HEP operations of this facility in FY 2008. The main activity supported in FY 2009 will be computing support to enable researchers to complete analyses of the large B-factory dataset.	-8,430
Total, Facilities	**-17,711**
Total Funding Change, Electron Accelerator-Based Physics	**-16,822**

Non-Accelerator Physics

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009
Non-Accelerator Physics			
University Research	18,703	18,960	19,749
National Laboratory Research	31,466	33,107	33,883
Projects	8,796	20,837	32,230
Other	1,690	1,295	620
Total, Non-Accelerator Physics	60,655	74,199	86,482

Description

The mission of the Non-Accelerator Physics subprogram is to foster fundamental research in elementary particle physics using naturally occurring particles and phenomena that will provide new insights into the basic constituents of matter and the forces between them, thereby advancing the DOE's strategic goals for science.

The Non-Accelerator Physics subprogram provides U.S. leadership in the study of those topics in particle physics that cannot be investigated completely with accelerators, or are best studied by other means. These activities—including the search for, or measurement of, dark matter and dark energy—have provided experimental data, new ideas, and techniques complementary to those provided by accelerator-based research. These research activities align with the program mission to understand the universe at its most fundamental level. Non-Accelerator Physics is playing an increasingly important role in High Energy Physics, using ever more sophisticated techniques to probe fundamental physics questions using naturally occurring particles and phenomena. University and laboratory scientists in this subprogram investigate topics such as dark matter, dark energy, neutrino properties, proton decay, the highest energy cosmic rays, 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.

Some of the non-accelerator-based particle sources used in this research are neutrinos from the sun, galactic supernovae, terrestrial nuclear reactors, and cosmic rays striking the earth's atmosphere. Other sources are the light (photons) emitted by supernovae, galaxies and other celestial objects. These experiments utilize particle physics techniques and scientific expertise, as well as the infrastructure of our national laboratories; and are often located at remote sites, such as in deep underground laboratories, on mountain tops, across deserts, or in space, either as dedicated satellites or as instruments attached to NASA facilities such as the International Space Station.

Research and Facilities

The Non-Accelerator Physics subprogram supports the university and laboratory scientists performing experimental particle physics, astrophysics, and cosmology research in the U.S. and abroad that does not directly involve the use of high-energy accelerator particle beams. The research groups are based at about 35 universities. This program is carried out in collaboration with physicists from DOE national laboratories and other government agencies and institutes including NSF, NASA, the Naval Research Laboratory (NRL), and the Smithsonian Astrophysical Observatory. Strong interagency coordination and collaboration is one of the hallmarks of the efforts in this subprogram. As in the rest of the HEP portfolio, most projects involve international collaboration in all phases of the experiment.

The Non-Accelerator Physics subprogram includes support for special facilities and research groups to perform experimental measurements. While research activities (including remote site operations of Non-Accelerator Physics experiments) are covered under the Research activities, the Projects activity in the Non-Accelerator Physics subprogram supports the technical R&D, engineering and design, and fabrication of detector apparatus. Remote sites where U.S. groups are participating in research include: the Soudan Mine in Minnesota; the Sudbury Mine in Ontario, Canada; the Kamiokande Mine in Japan; Daya Bay in China; the Whipple Observatory in Arizona; the Pierre Auger Observatory in Argentina; the Cerro-Tololo Inter-American Observatory (CTIO) in Chile; the Apache Point observatory in New Mexico; the Waste Isolation Pilot Project (WIPP) in Carlsbad, New Mexico; the Boulby Mine in the United Kingdom (UK); and the Gran Sasso Underground Laboratory in Italy. Other research supported includes space-based projects such as participation in NASA's Gamma-ray Large Area Space Telescope (GLAST) mission, a DOE and NASA Joint Dark Energy Mission (JDEM) space-based satellite, and the Alpha Magnetic Spectrometer (AMS) led by the Massachusetts Institute of Technology.

Highlights

Recent accomplishments include:

- The Large Area Telescope (LAT), a DOE and NASA partnership and the primary instrument on NASA's GLAST mission, was tested and integrated into its launch vehicle in 2007 and is scheduled for launch from Kennedy Space Center in mid-2008. It will begin full operations late in 2008 and continue taking data for at least five years. SLAC led the DOE participation in the fabrication of the LAT and will run the instrument science operations center during the data-taking phase.
- First light from the Very Energetic Radiation Imaging Telescope Array System (VERITAS) was observed in 2007, with the telescope installed at the Whipple Observatory in Arizona. This facility is now one of the world's leading ground-based gamma-ray observatories.
- The Pierre Auger cosmic ray detector array in Argentina, a collaboration with the NSF and international partners, completed fabrication of its full array in 2007 and is now in full scale operations. The array covers an area of 3,000 square kilometers and is the largest of its kind in the world. Its purpose is to observe and study the very highest energy cosmic rays in the universe. The Auger experiment announced in November 2007 a major step forward in solving the long-standing mystery of the nature and origin of the highest energy cosmic rays: the collaboration traced the sources of the highest energy cosmic rays to the locations of nearby galaxies that have active galactic nuclei in their centers.

The major planned efforts in FY 2009 are:

- *Operation of the Large Area Telescope,* the primary instrument on NASA's GLAST mission. The goals of the LAT are to observe and understand the highest energy gamma rays observed in nature and yield information about extreme particle accelerators in space, including active galactic nuclei and gamma ray bursts, as well as to search for dark matter candidates. It is complementary to the ground-based VERITAS experiment, which samples a higher energy region of the gamma ray spectrum. This research program is being carried out by a collaboration, which includes particle physicists and astrophysicists from SLAC, NASA research centers, the NRL, U.S. universities, and institutions in Italy, France, Japan, and Sweden.
- *Operations of the VERITAS Telescope Array*. VERITAS is a ground-based multi-telescope array that will study astrophysical sources of high energy gamma rays, from about 50 GeV to about 50 TeV. The primary scientific objectives are the detection and study of sources that could produce these

gamma-rays such as black holes, neutron stars, active galactic nuclei, supernova remnants, pulsars, the galactic plane, and gamma-ray bursts. VERITAS will also search for dark matter candidates. The experimental technique was developed by the HEP-supported researchers at the Harvard-Smithsonian Whipple Observatory on Mt. Hopkins in Arizona, and the project is supported by a partnership between DOE, NSF, and the Smithsonian Institution.

- *Fabrication of the Dark Energy Survey (DES) Project.* This Major Item of Equipment will provide the next step in determining the nature of dark energy, which is causing the universe to expand at an accelerating rate, by measuring the distances to approximately 300 million galaxies. DES employs several methods to measure the effects of dark energy on the distribution of these galaxies and other astrophysical objects. The DES scientific collaboration will build three systems which include the dark energy camera, the data management system and upgrades to the telescope facility. The camera is to be installed and operated on the Blanco 4 meter Telescope at the Cerro Tololo Inter-American Observatory (CTIO) in Chile. In FY 2009, $7,500,000 is requested to continue fabrication of the DES MIE. The project is a partnership between DOE and the NSF, which operates the telescope. The scientific collaboration is led by Fermilab and includes participants from laboratories and universities in the U.S., UK, and Spain.
- *Participation in a reactor neutrino experiment*. The FY 2009 request includes $13,000,000 for continued U.S. contributions for the fabrication of a Major Item of Equipment, a Reactor Neutrino Detector located in Daya Bay, China. This project is supported by a partnership between DOE and research institutes in China. This experiment will use anti-neutrinos produced from reactors to precisely measure a crucial parameter needed to pursue new physics opened up by the discovery of neutrino mass and mixing. The value and precision of this parameter will help resolve ambiguities in determinations of other neutrino properties, and will be a key input to determining the directions for further research in the neutrino sector.
- *Fabrication of the CDMS-25 Detector.* The Cryogenic Dark Matter Survey-25kg (CDMS-25) is a next-generation dark matter search experiment expected to increase sensitivity for direct detection of dark matter over current experiments by a factor of 10. It will use ultra-cold, super sensitive superconducting germanium detectors. The detectors will be manufactured at Stanford and tested at various U.S. institutions before being run in a refrigerated cryostat (designed and built by Fermilab) at SNOLab in Canada, one of the deepest underground laboratories in the world. This location will virtually eliminate cosmic ray backgrounds from the experiment and allow it to obtain its detection sensitivity. $500,000 is requested in FY 2009 to initiate fabrication of the CDMS-25 detector for deployment in the SNOLab underground facility, subject to successful peer review. This experiment was recommended by the Dark Matter Scientific Advisory Group and P5, but competes with other experiments of comparable sensitivity (using alternative technologies) for priority and funding.
- *R&D for future dark energy experiments*. In order to fully determine the nature of dark energy, the Dark Energy Task Force (DETF), a subpanel of both HEPAP and the Astronomy and Astrophysics Advisory Committee (AAAC) recommended a mix of experiments with independent and complementary measurements. The DETF report will be used to aid in the development of a coordinated dark energy research program containing specific experiments. The FY 2009 budget supports continued concept studies for JDEM, leading to a mission concept selection in 2009 and a planned FY 2010 fabrication start; and R&D for other near-term and next-generation ground- and space-based dark energy concepts.

Detailed Justification

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009
University Research	**18,703**	**18,960**	**19,749**

The university program consists of groups at more than 35 universities doing experiments at Non-Accelerator Physics facilities, using ever more sophisticated techniques to probe fundamental physics questions using naturally occurring particles and phenomena.

These university groups plan, build, execute, analyze, and publish results of experiments; develop the physics rationale and preliminary designs for future experiments; develop new models and provide interpretations of existing experimental data; and train graduate students and postdoctoral researchers.

University physicists in this research area often work in collaboration with other university and laboratory groups. University-based research efforts will be selected based on peer review.

In FY 2009, the university program in Non-Accelerator Physics will support research on several experiments including VERITAS, Pierre Auger, and GLAST/LAT which have completed their fabrication phase in recent years and are currently active in commissioning, operations, and/or data analysis. The detailed funding allocations will take into account the discovery potential of the proposed research. Other research efforts that will be continuing in this subprogram include: Super-Kamiokande, a proton decay, solar and atmospheric neutrino detector located in the Kamioka Underground Laboratory in Japan; CDMS-II dark matter search in the Soudan Mine in Minnesota; a direct search for axion dark matter particles (ADMX-I) at LLNL; and a 200 kg neutrinoless double beta decay experiment (EXO-200) at WIPP.

Continued R&D and design for a next-generation dark matter search experiment will take place, including extensions of the CDMS solid-state technology to larger detector sizes (greater than 25 kg), and alternative technologies based on noble liquid or gaseous detectors.

University groups are also participating in the design and R&D efforts for experiments in NSF's proposed Deep Underground Science and Engineering Laboratory, the Dark Energy Survey and the Reactor Neutrino Detector, as described above. Finally, R&D for a larger-scale (about 1,000 kg) neutrinoless double beta decay experiment will be supported. This experiment would measure the absolute mass of the neutrino and determine whether the neutrino is its own antiparticle. University groups are leading these efforts.

National Laboratory Research	**31,466**	**33,107**	**33,883**

The national laboratory research program consists of groups at several laboratories participating in Non-Accelerator Physics experiments similar to the university physics program described above. With strong laboratory technical resources, they provide invaluable service to the research program in experiment design, construction, and operations, in addition to scientists involved in the research. The DOE HEP program office reviews laboratory research groups annually with input from independent peer reviewers.

In FY 2009, the laboratory research program in Non-Accelerator Physics will continue to support research activities directed at fabrication of new detectors for dark energy and neutrino physics, including the Dark Energy Survey and the Reactor Neutrino Detector, and ongoing R&D of next-generation experiments, including a large-scale double beta decay experiment. The laboratory experimental physics research groups will be focused mainly on supporting the instrument science operations center and data-taking and research for the GLAST/LAT telescope; operations and data analysis for the Pierre Auger cosmic ray detector array and the CDMS-II dark matter detector; operations of ADMX-I and EXO-200; R&D for ground- and space-based concepts for dark energy experiments; and analysis of data from Sloan Digital Sky Survey (SDSS) and the follow-on SDSS-II, which ends operation in 2008.

	FY 2007	FY 2008	FY 2009
Projects	**8,796**	**20,837**	**32,230**

In FY 2009, this effort will be focused on R&D for the JDEM space-based dark energy mission concept and other potential dark energy experiments; and fabrication of three Major Items of Equipment (MIEs): the Dark Energy Survey (DES), the Reactor Neutrino Detector and CDMS-25 kg. In FY 2008, this budget category includes support for R&D to investigate a variety of methods and technologies for dark energy measurements using ground- and/or space-based facilities, to be selected using competitive peer review.

The FY 2009 JDEM R&D activities ($10,030,000) will focus on the conceptual design needed for a potential future space-based JDEM mission. A National Research Council's panel recommended in late 2007 that JDEM be the first of NASA's five Beyond Einstein program missions to be developed and launched. DOE and NASA are moving forward jointly on JDEM, and the selection of a specific concept for the JDEM mission is planned to take place in 2009. The selected concept would then begin the technical design phase, followed by fabrication and a launch near the middle of the next decade.

In their 2006 "roadmap" for high energy physics, the P5 prioritization subpanel of HEPAP recommended that DOE and NSF jointly pursue the DES project, a small-scale ground-based experiment that can provide significant advances in our knowledge of dark energy in the near term in a cost-effective manner. The FY 2009 request includes $1,200,000 for Other Project Costs, and $7,500,000 to continue fabrication of the DES MIE (preliminary DOE TPC $24,100,000–$26,700,000).

In FY 2009, $13,000,000 is provided to continue fabrication of the Reactor Neutrino Detector MIE (preliminary DOE TPC $32,000,000–$34,000,000[a]). This experiment will measure a crucial unknown neutrino property by precisely measuring the disappearance of electron antineutrinos generated by a nuclear reactor as they travel several hundred meters through the Earth to the underground detectors. In 2006, HEP, in cooperation with Chinese research institutes, decided to pursue this experiment at a site near the nuclear reactor facility in Daya Bay, China. The U.S. collaboration is led by groups from BNL and LBNL.

Funds are also requested to begin fabrication in FY 2009 of the CDMS-25 detector MIE (preliminary TPC $5,000,000–$7,000,000). The detector is planned to operate in the SNOLab underground facility.

[a] The estimated TPC for the Reactor Neutrino Detector has increased since the FY 2008 President's request budget, based on the results of project reviews and stretch out of the funding profile.

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009
Other	**1,690**	**1,295**	**620**

This category includes funding mainly for non-accelerator-based research activities to be determined by peer review, and to respond to new and unexpected physics opportunities. It also includes funding for private institutions and other government laboratories and institutions that participate in Non-Accelerator Physics research, including support of the Smithsonian Institute for operations and research using the VERITAS telescope array.

Total, Non-Accelerator Physics	**60,655**	**74,199**	**86,482**

Explanation of Funding Changes

	FY 2009 vs. FY 2008 ($000)
University Research	
Funding for university-based research in this subprogram continues at approximately a constant level-of-effort to support research on several experiments which are currently active in commissioning, operations, and/or data analysis.	+789
National Laboratory Research	
Funding for laboratory-based research in this subprogram continues at slightly below a constant level-of-effort as some effort is redirected toward the fabrication of new projects.	+776
Projects	
Funding for Non-Accelerator Projects increases to reflect planned funding profiles for the Dark Energy Survey ($+3,200,000) and Reactor Neutrino Detector experiments ($+7,060,000), as these projects ramp-up fabrication efforts, the beginning of fabrication for the new 25-kg Cryogenic Dark Matter Survey MIE ($+500,000), and a ramp-up of JDEM R&D ($+4,773,000) during the final phase of the technology selection for the JDEM mission. These increases are partially offset by decreased R&D for possible other dark energy concepts ($-4,140,000) as the mission concept selection planned for 2009 focuses the near-term effort on JDEM.	+11,393
Other	
Funding for other non-accelerator-based activities is decreased, reflecting a shift of funds held for activities to be determined by peer review, and to respond to new and unexpected physics opportunities, into the general non-accelerator-based university and national laboratory research categories.	-675
Total Funding Change, Non-Accelerator Physics	**+12,283**

Theoretical Physics

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009
Theoretical Physics			
University Research	24,101	24,951	25,824
National Laboratory Research	24,075	24,271	25,724
SciDAC	5,870	5,248	5,600
Other	5,909	5,764	5,888
Total, Theoretical Physics	59,955	60,234	63,036

Description

The mission of the Theoretical Physics subprogram is to foster fundamental research in theoretical high energy physics that will provide new insights into the basic constituents of matter and the forces between them, thereby advancing the DOE's strategic goals for science.

The Theoretical Physics subprogram provides the vision and mathematical framework for interpreting, understanding, and extending the knowledge of particles, forces, space-time, and the universe. It includes activities ranging from detailed calculations of the predictions of the Standard Model of elementary particles to the extrapolation of current knowledge to a new plane of physical phenomena and the identification of the means to experimentally search for them. The Theoretical Physics subprogram also includes a major effort to incorporate Einstein's theory of gravity and space-time geometry into a unified description of all the forces of nature and cosmology, and to illuminate the origin and evolution of the universe.

Though they are typically not directly involved in the planning, fabrication, or operations of experiments, theoretical physicists play key roles in determining what kinds of experiments would likely be the most interesting to perform, and in explaining experimental results in terms of a fundamental underlying theory that describes all of the components and interactions of matter, energy, and space-time. Our understanding of the universe relies on the active, integrated participation of theorists in interpreting the results of particle physics experiments. The research activities supported by the Theoretical Physics subprogram include: calculations in the quantum field theories of elementary particles that constitute the Standard Model and developing other models for elementary particle processes; interpreting results of measurements in the context of these models; identifying where new physical principles are needed and what their other consequences may be; developing and exploiting new mathematical and computational methods for analyzing theoretical models; and constructing and exploiting powerful computational facilities for theoretical calculations of importance for the experimental program. Major themes are symmetry and unification in the description of diverse phenomena.

Research at Universities and National Laboratories

The University and National Laboratory activities of the Theoretical Physics subprogram support scientists performing research in theoretical high energy physics and related areas. The research groups are based at approximately 75 colleges and universities and at 6 DOE laboratories (Fermilab, SLAC, BNL, ANL, LBNL, and Los Alamos National Laboratory [LANL]).

The Theoretical Physics subprogram involves collaborations between scientists based at different universities and laboratories, and also collaborations between scientists supported by this program and others whose research is supported by other Offices of the DOE and by other federal agencies, including NSF and NASA. There are also many international collaborations in theoretical physics research. These collaborations are typically smaller and less formal than the efforts required to mount large experiments.

The Theoretical Physics subprogram also includes support for special facilities for numerical and algebraic computation of developed theories, and for research groups to carry out these activities.

Highlights

Recent accomplishments include:

- 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.
- Recently, powerful new techniques derived from string theory have been developed to calculate high-energy strong interaction processes that will be measured at the LHC. These procedures came from the study of string theory. In traditional perturbative calculations, one calculates only one or two of the largest terms in an infinite series; but with the new approach, one can calculate an infinite set of terms, which will lead to more accurate predictions.
- Another recent development is the discovery of a correspondence between string theory in multi-dimensional space and conventional field theories in four dimensions. This insight enables completion of many previously intractable model calculations, which in turn illuminate physics related to quark-gluon plasmas and high energy scattering processes.

By its nature, progress in theoretical physics cannot be predicted in advance. Nevertheless, there are some current major thrusts in theoretical physics that we expect to continue in FY 2009:

- *LHC Phenomenology.* As the start of LHC operations approaches, a greatly increased effort will be made to identify the most promising and sensitive methods for finding signs of new phenomena in the voluminous data that will be produced. Many attractive ideas have been proposed for the solution of fundamental problems such as the mysteries of the origin of the masses of the elementary particles and the mechanisms through which fundamental symmetries are broken in nature. Identifying which ideas are true will entail the calculation of detailed predictions of many suggested models for extensions of the Standard Model.
- *Lattice QCD*. QCD is a highly successful theory that describes the strong interactions between quarks and gluons. Although the equations that define this theory are in principle exact, none of the analytical methods that are so successful elsewhere in theoretical physics are adequate to analyze it. The reason that QCD is so intractable is that the coupling strength is near zero at very short distances but very strong at large distances (where "large" means the size of an atomic nucleus). The lack of

precision in current QCD calculations is now limiting the understanding of many experimental results. It has long been known that QCD can be analyzed to any desired precision by numerical methods, given enough computational power. Recent advances in numerical algorithms coupled with the ever-increasing performance of computing have now made some QCD calculations feasible with quite high precision (one to two percent). Some of the computational software for this effort are provided through the SciDAC program.

- *New Ideas*. Theoretical physicists are speculating on whether there might be additional space dimensions that are normally hidden from us. These ideas are motivated by the effort to unify Einstein's theory of gravity with quantum mechanics in a mathematically consistent way. It is even possible that some of these dimensions and their consequences are accessible to experiment, perhaps manifesting themselves at the LHC in the production of mini-black holes, or so-called Kaluza-Klein excitations, named after the physicists who first suggested in the 1920's that we actually live in a 5-dimensional universe. Perhaps these ideas can explain the nature of dark matter, or dark energy, or even suggest new cosmologies explaining the history and evolution of the universe.

Detailed Justification

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009
University Research	**24,101**	**24,951**	**25,824**

The university program consists of groups at approximately 75 colleges and universities doing theoretical physics research. As part of their research efforts, the university groups train graduate students and postdoctoral researchers. University physicists in this theoretical research area often work in collaboration with other university and laboratory groups. University-based research efforts will be selected based on peer review.

The theory program addresses problems across the full range of theoretical physics research. There is currently a "window of opportunity" to interpret and understand the exciting new physics results expected from the Fermilab Tevatron, currently searching for new physics at the energy frontier, and from the LHC, which will extend the energy frontier when it begins operations. The detailed funding allocations will take into account the involvement of university-based research groups in these targeted physics research activities.

In FY 2009, the university theory program is maintained at about a constant level-of-effort to support university research personnel participating in analysis of current and previous experiments, and in the design and optimization of new experiments, so that these experiments can fulfill their maximum potential.

National Laboratory Research	**24,075**	**24,271**	**25,724**

The national laboratory research program consists of groups at several laboratories. The scientists in these groups pursue a research agenda quite like that pursued at universities. In addition, the laboratory groups are a general resource for the national research program. Through continuing interaction with experimental scientists, they provide a clear understanding of the significance of measurements from ongoing experiments and help to shape and develop the laboratory's experimental program. The DOE HEP program office reviews laboratory research groups annually with input from independent peer reviewers.

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009

In FY 2009, the laboratory theoretical research groups will address problems across the full range of theoretical physics research, including the analysis and interpretation of the new data expected from the Tevatron Collider detectors, CDF and D-Zero, and preparation for the new higher energy data from the LHC. In FY 2009, actual funding for the laboratory theory program will be maintained at about a constant level-of-effort to support laboratory research personnel participating in analysis of current and previous experiments, and design and optimization of new experiments, so that these experiments can fulfill their potential to make new discoveries about the nature of the universe.

SciDAC	**5,870**	**5,248**	**5,600**

In FY 2009, HEP will continue support for successful proposals selected in the re-competition of the SciDAC program in FY 2006, and the separate accelerator simulation solicitation, awarded in FY 2007. Proposals are selected based on peer review. The SciDAC program is managed and cooperatively funded by the SC program offices, including the Advanced Scientific Computing Research program. The principal HEP-supported SciDAC efforts are in the areas of: 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 Other below), a joint effort with NP; very large scale, fault-tolerant data handling and distributed "grid" computing that can respond to the serious data challenges posed by modern HEP and NP experiments, a joint effort with NP and the 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.

Other	**5,909**	**5,764**	**5,888**

This activity includes funding for the Lattice QCD Computer Program, as well as for education and outreach activities, compilations of HEP data and 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.

A coordinated effort with the NP and Advanced Scientific Computing Research programs is aimed toward the development of a multi-teraflops computer facility for Lattice QCD simulations. During FY 2006, a joint effort with NP to develop and operate a dedicated Lattice QCD facility with about 13 teraflop capacity was started, and in FY 2009 this program will proceed as planned.

In each year of the Lattice QCD investment, procurement of computers employing the most cost-effective option will be undertaken. Given current projections of price performance for this kind of high-performance computing, commodity clusters are the most effective investment. The HEP contribution of $1,200,000 to this effort in FY 2009 will correspond to about 2 teraflops of sustained computing performance, in addition to the computing power acquired in previous years.

This category also includes $750,000 for the QuarkNet education project in FY 2009. This project takes place in QuarkNet "centers" which are set up at universities and laboratories around the country. The purpose of each center is to allow students to understand and analyze real data from an active HEP experiment (such as the Tevatron or LHC experiments). Each center has 2 physicist mentors and, over a 3 year period, goes through several stages to a full operating mode with 12 high school teachers. The

	FY 2007	FY 2008	FY 2009
project began in 1999 with an initial complement of 12 centers starting in the first of three yearly stages of development. The full complement of 52 centers was in place in FY 2004. Several centers have retired and new ones have started in the last few years. In FY 2009, most of the centers will be in stage 3, which is the full operations mode. QuarkNet operations will continue through the life of the LHC program at CERN.			
Total, Theoretical Physics	**59,955**	**60,234**	**63,036**

(dollars in thousands)

Explanation of Funding Changes

	FY 2009 vs. FY 2008 ($000)
University Research	
Funding for university-based research in this subprogram is maintained at approximately a constant level-of-effort.	+873
National Laboratory Research	
Funding for laboratory-based research in this subprogram is maintained at approximately a constant FY2008 level-of-effort.	+1,453
SciDAC	
Funding for the HEP-supported cooperative agreements under the SciDAC program is increased according to the planned funding profiles for those agreements.	+352
Other	
Funding for other theoretical physics research activities is approximately the same as FY 2008. Decreases due to the planned funding profile for the Lattice QCD hardware project ($-800,000), which is in its final year in FY 2009, are offset by an increase in funding held pending completion of peer review and/or programmatic decisions ($+924,000).	+124
Total Funding Change, Theoretical Physics	**+2,802**

Advanced Technology R&D

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009
Advanced Technology R&D			
Accelerator Science	36,619	37,208	47,229
Accelerator Development	98,556	44,859	95,638
Other Technology R&D	31,732	20,759	23,838
SBIR/STTR	—	17,653	20,388
Total, Advanced Technology R&D	166,907	120,479	187,093

Description

The mission of the Advanced Technology R&D subprogram is to foster world-leading research into the science of particle accelerators, as well as particle acceleration and detection techniques and instrumentation. These in turn provide enabling technologies and new research methods to advance scientific knowledge in a broad range of energy-related fields, including high energy physics, thereby advancing the DOE's strategic goals for science.

The Advanced Technology R&D subprogram provides the technologies and tools needed to design and build the accelerator and detector facilities needed to accomplish the programmatic mission. This is accomplished by supporting proposal driven, peer reviewed research in the fundamental sciences underlying the technologies used for experimental HEP research. These efforts focus on developing new technologies to the point where they can be successfully incorporated into construction projects that will significantly extend the program's research capabilities.

The Advanced Technology R&D subprogram includes not only R&D to bring new accelerator and detector concepts to the stage where they can be considered for use in existing or new facilities, but also advancement of the basic sciences underlying the technology. Most of the technology applications developed for high energy physics that prove useful to other science programs and to industry, flow from the work carried out in this subprogram.

High energy physics research relies on the use of high energy particle beams provided by charged particle accelerators, storage rings, and their associated detectors. The instrumentation to carry out a forefront, successful research program requires specialized technology that is state-of-the-art. The R&D programs that support such technology development are typically high-risk and long-term, but they have a high payoff in fundamental scientific breakthroughs.

The DOE HEP program has supported a very successful program of technology R&D that has ensured the availability of the most technically advanced research facilities and a world-class U.S. HEP program. Since in many cases the same technologies find applications to synchrotron light sources, intense neutron sources, very short pulse, high brightness electron beams, and computational software for accelerator and charged particle beam optics design, they are also widely used in nuclear physics, materials science, chemistry, medicine, and industry. Particle accelerators in particular have migrated into general usage for medical therapy and diagnostics, for preparation of radionuclides used in medical treatment facilities, and for the electronics and food industries. They are also now finding defense and homeland security applications.

Accelerator Science

The Accelerator Science activity in this subprogram focuses on the science underlying the technologies used in particle accelerators and storage rings, and the fundamental physics of charged particle beams. There is an emphasis on future-oriented, high-risk R&D, particularly in the development of new accelerating concepts, but essential infrastructure to support the HEP technology R&D programs is also addressed. Examples of the latter include testing of advanced superconducting materials, and user facilities for general support of accelerator research, such as the Accelerator Test Facility (ATF) at BNL.

Accelerator Development

The task of reducing new concepts and technical approaches to the stage of proven engineering feasibility, so that they can be incorporated into existing or new facilities, is done under Accelerator Development. Included in this activity are superconducting 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.

Other Technology R&D

This category includes funding at universities under Advanced Detector Research and at national laboratories under Detector Development. Advanced Detector Research is similar to Accelerator Science in that it addresses the development and application of an underlying science to foster new technologies in particle detection, measurement, and data processing. The Detector Development program provides funding to national laboratories and some universities to bring new detection and data processing concepts to an engineering readiness state so that they can be incorporated into an existing detector or into a new experiment.

Highlights

Recent accomplishments include:

- At LBNL, a laser-driven plasma wakefield experiment has successfully trapped a bunch of electrons in a plasma and accelerated them to energies of 1 GeV in a few millimeters. The process creates an electron bunch in which the distribution of individual electron energies is very narrow, within a few percent of the average energy of the bunch. This is an important step forward from the earlier experiments that produced bunches with 100% energy spread and is an essential step in developing a useful plasma-based accelerator.

The major Advanced Technology R&D efforts in FY 2009 are:

- *Accelerator Science.* A broad range of topics in Accelerator Science will continue to be pursued. At the same time, increased support will be provided for a few of the most promising advanced acceleration concepts in order to capitalize on past investments and develop more compact, less expensive options for future high-energy accelerators beyond the ILC. Such a strategy was suggested by the external HEP Advanced Accelerator R&D Program Review Committee in 2007. In particular, funding is requested to support a new Advanced Accelerator R&D test facility that can provide a testbed for advanced acceleration concepts, such as plasma wakefield acceleration, that will broadly benefit the accelerator science community.

- *Research and Development of Superconducting RF technology.* HEP and a broad spectrum of other SC programs need a rigorous research and development program to produce cost competitive and reliable superconducting RF components for possible future accelerators that serve the overall science mission. This program will require extensive testing capability in our national laboratories to stimulate and evaluate new techniques, to demonstrate the quality of commercial products and to acquire crucial information needed for process improvements and quality control.

- *International Linear Collider R&D.* A TeV scale linear electron-positron collider has been identified by the 2006 National Academies' "EPP2010" study as "the essential component of U.S. leadership in particle physics in the decades ahead." In FY 2009, the R&D and design activities addressing critical performance and cost issues will continue on an international basis. The ILC R&D program in FY 2009 supports an important U.S. role in a comprehensive and coordinated international R&D program, and lays groundwork for U.S. industry to compete successfully for major subsystem contracts, should the ILC be built. The work needed to maintain U.S. leadership in specific technical areas for which the U.S. has unique capabilities will be continued.

  The Department will continue consultations with our international partners, with a goal of establishing a set of international agreements for accelerator R&D, including elements of ILC R&D. The information provided through these international activities would inform future decisions on the construction of and U.S. participation in the proposed ILC. These initial agreements may eventually lead to multilateral agreements for siting and construction of the ILC, similar to the ITER Engineering Design Activities (EDA) agreement (http://www.iter.org/EDA.htm).

Detailed Justification

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009
Accelerator Science	**36,619**	**37,208**	**47,229**
▪ **University Research**	**10,223**	**10,940**	**11,840**

The FY 2009 budget will continue support for a broad university research program in advanced accelerator physics and related technologies. The research program will continue to pursue investigations of novel acceleration concepts, including 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; development of high-field superconducting magnets and materials; studies of accelerating gradient limits in both normal conducting and superconducting RF 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.

University-based research programs are selected based on review by well-qualified peers, and progress is monitored through a system of formal site visits, presentations at appropriate workshops, participation in conferences, and publications.

In FY 2009, funding for the university research program will increase somewhat above the FY 2008 level-of-effort to support additional researchers and infrastructure to make optimal use of the new laboratory-based facility for advanced accelerator R&D (see below).

▪ **National Laboratory Research**	**25,203**	**25,288**	**34,071**

There are areas of Accelerator Science research that require the more extensive or specialized research facilities located at DOE national laboratories. The FY 2009 budget includes MIE funds of $8,000,000 for beginning fabrication of an Advanced Accelerator R&D Test Facility (preliminary TPC $15,000,000—$19,000,000) at a national laboratory to advance one or more of the most promising advanced acceleration schemes to the next level of development.

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009

In addition, there is increased funding in support of general laboratory-based accelerator science research ($+783,000), reflecting an approximately constant level-of-effort with respect to the FY 2008 programmatic effort and costs in this category.

The Accelerator Science program at ANL explores advanced methods to accelerate charged particles with the goal of more efficient, compact, and inexpensive particle accelerators. Effort in FY 2009 will focus on the development of dielectric wake-field accelerating structures via theoretical, computer simulation, and experimental studies. Other activities include the development of materials for high gradient acceleration, photonic band-gap accelerating structures, high-power/high-brightness electron beams, and advanced beam diagnostics.

BNL is the home of the very successful Accelerator Test Facility (ATF), supporting research that HEP funds at universities and in industry including research funded through the Small Business Innovation Research (SBIR) Program. In FY 2009, the ATF will continue a program of testing advanced accelerator concepts, developing new instrumentation, and developing next generation high brightness electron sources based on laser-driven photocathodes.

In FY 2009, LBNL will conduct research in laser-driven plasma acceleration at the L'Oasis laboratory. R&D on muon ionization cooling and theoretical studies of alternative muon acceleration schemes will also be carried out.

At Fermilab, the FY 2009 budget will support experimental studies of electron beam physics in a high-brightness photo-injector, research on muon acceleration, and research by the Accelerator Physics Center in beam theory and accelerator simulation. R&D in support of the international muon cooling collaboration with Rutherford Appleton Laboratory in the UK will continue.

The advanced accelerator R&D program at SLAC in FY 2009 will continue to support R&D into advanced particle acceleration technologies, and work with BES on R&D for new experimental capabilities at SLAC that take advantage of the unique qualities of the Linac beam. R&D into ultra high-frequency microwave systems for accelerating charged particles will be focused on high field breakdown phenomena and new accelerating geometries that support very high gradients. Very advanced electron-positron collider concepts and theoretical studies in advanced beam dynamics methods and new computer computation and simulation codes will continue. Much of the work on advanced accelerator concepts at SLAC is done in collaboration with universities funded by the Accelerator Science activity.

Also supported in FY 2009 are theoretical studies of space-charge dominated beams at PPPL. National laboratory research efforts are selected based on review by appropriate peers, laboratory program advisory committees, and special director-appointed review committees. Measurement of progress includes the annual High Energy Physics program review supported by well-qualified peers, publications in professional journals, and participation in conferences and workshops.

▪ **Other**	**1,193**	**980**	**1,318**

This subactivity includes funding for Accelerator Science at sites other than universities and national laboratories. These include interagency agreements with NRL and the National Institute of Standards and Technology (NIST) and funding of industrial grants. Also included is funding for Accelerator

	FY 2007	FY 2008	FY 2009
	(dollars in thousands)		

Science activities that are awaiting approval pending the completion of peer review and program office detailed planning.

Accelerator Development	**98,556**	**44,859**	**95,638**
▪ **General Accelerator Development**	**32,190**	**24,620**	**35,638**

This research includes R&D to bring new concepts to a stage of engineering readiness where they can be incorporated into existing facilities, used in upgrading existing facilities, or applied to the design of new facilities. The work is mostly done at Fermilab, LBNL, SLAC, and BNL, with supporting activities at Thomas Jefferson National Accelerator Facility, ANL, LLNL, and LANL. 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 R&D program at Fermilab in FY 2009 will address a broad spectrum of technology needs for that facility, including advanced superconducting magnet R&D, R&D for a high-intensity neutrino beam facility, advanced beam instrumentation, and simulation codes to provide improved modeling of all aspects of accelerator operations. Among these topics, emphasis will be placed on developing very high intensity proton sources for neutrino physics research. In particular, funding in this category in FY 2009 increases to further promote this R&D effort.

The LBNL R&D supported in FY 2009 includes work on very high field superconducting magnets using niobium-tin and similar advanced superconductors, on advanced RF systems, laser manipulation and measurement of charged particle beams, and a broad program in instrumentation development, accelerator theory, and computation. The very successful industrially-based program managed by LBNL to develop advanced superconductors, particularly niobium-tin, for the very high field superconducting magnet R&D program will continue to be supported.

The FY 2009 program at SLAC encompasses high-powered RF systems, beam instrumentation, generic electron-positron collider R&D, and advanced beam dynamics and machine simulation code development. Simulation codes for modeling RF system components and high-powered microwave tubes will receive special R&D focus.

The R&D program at BNL includes work on superconducting magnet R&D and associated superconducting magnet materials measurement facility.

▪ **Superconducting RF R&D**	**24,680**	**5,405**	**25,000**

The FY 2008 Energy and Water Development and Related Agencies Appropriations Act resulted in sharply reduced funding for Superconducting RF (SRF). This request resumes support for infrastructure needed for the testing and development of high-gradient superconducting accelerating cavity and cryomodule prototypes. The testing facilities and prototypes will help enable a host of SRF-based next generation scientific and industrial facilities, and in particular will be a critical component for the next generation of accelerators across the Office of Science complex, not just those with HEP applications.

In FY 2009, this effort will provide funds for procurement of components and support equipment necessary to prototype multi-cavity cryomodules. This request also enables continued development of U.S. capability for testing individual bare cavities, dressed cavities with all power components

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009

attached, and cryomodules. Fermilab is the lead U.S. laboratory coordinating the national R&D program in this area.

▪ **International Linear Collider R&D**	**41,686**	**14,834**	**35,000**

The ILC is considered by the world-wide high energy physics community as the successor facility to the LHC, and essential for advancing scientific progress at the Terascale. In FY 2007, the ILC international collaboration under the auspices of the International Linear Collider Steering Group, and the direction of the Global Design Effort (GDE), completed a detailed review of the R&D to be accomplished world wide, with milestones and priorities for that work.

The FY 2008 Energy and Water Development and Related Agencies Appropriations Act resulted in sharply reduced funding for ILC R&D. In response, the FY 2009 budget supports a U.S. ILC R&D program with reduced scope compared to FY 2007, but addressing priority areas identified by the global R&D plan, and focused on topics for which the U.S. has unique expertise. Accelerator efforts will be centered on R&D for systems associated with the generation and maintenance of very bright particle beams such as electron sources, damping rings, beam dynamics, and beam delivery. Support will also be provided for development and prototyping of high level RF equipment and development of components associated with the main linac, including ILC cryomodules.

Where appropriate, directed R&D aimed at cost reduction of present baseline systems and developing alternate low-risk components will be undertaken.

Other Technology R&D	**31,732**	**20,759**	**23,838**
▪ **Advanced Detector Research**	**1,000**	**1,000**	**1,455**

The Advanced Detector Research (ADR) program supports university physicists to develop new detector technologies, or technology advances which would be generally applicable to a wide range of HEP experiments. The chosen technologies are motivated by the needs of conceptually foreseen but not yet developed experimental applications. Approximately six to eight grants a year are awarded through a competitive peer review program. Final funding levels will depend on the number and quality of proposals received. This program complements the detector development programs of the national laboratories.

▪ **Detector Development**	**30,732**	**19,759**	**22,383**

New experiments frequently depend on advancements in technologies. This funding supports detector development work at the national laboratories and about 40 universities to advance these technologies to a point where there is reasonable chance that an experiment can adopt the technology successfully. Current areas of investigation include R&D on detector technologies that could be used to pursue new opportunities in future colliders (such as the ILC), particle astrophysics, and neutrino physics. Funding for this effort reflects current plans for general detector development activities.

The FY 2009 request will maintain R&D efforts directed toward developing new detectors including much needed prototyping and in-beam studies. In particular, funding is increased to enable greater participation of university researchers in these efforts. A diverse program applicable to dark matter and dark energy studies, as well as accelerator-based programs will be continued, including efforts on particle flow calorimeters, very low-mass trackers, liquid noble gas detectors, transducer technology (e.g., advanced charged-coupled devices, silicon photomultipliers), and radiation

	(dollars in thousands)		
	FY 2007	FY 2008	FY 2009

resistant, fast readout electronics. Prototype calorimeter tracking and muon detection systems will be studied in the Fermilab test beam, providing a major test of particle flow algorithms and detector construction techniques.

SBIR/STTR	**—**	**17,653**	**20,388**

The Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) set-asides are mandated by Congress. The HEP program manages topics related to accelerator science and technology and two topics related to detector science and technology in the annual procurement solicitation. The contents of each topic are based on material provided in response to an annual HEP solicitation for suggestions from scientists and engineers in universities and DOE national laboratories working in support of the HEP Advanced Technology R&D programs. There is also coordination with the DOE Nuclear Physics and Fusion Energy Sciences programs concerning areas of mutual interest. The selection of the R&D topics to be included in the annual solicitation is treated as an important and integral component of the advanced accelerator R&D program, and selections of grants are made based on a combination of the recommendations of the peer reviewers and the importance to the HEP programs in Accelerator Science and Accelerator Development. In FY 2007, $17,279,000 was transferred to the SBIR program and $2,073,000 was transferred to the STTR program. The FY 2008 and FY 2009 amounts shown are estimated requirements for the continuation of the SBIR and STTR program.

Total, Advanced Technology R&D	**166,907**	**120,479**	**187,093**

Explanation of Funding Changes

	FY 2009 vs. FY 2008 ($000)
Accelerator Science	
▪ Funding for university-based research increases somewhat above the FY 2008 level-of-effort to support additional researchers and infrastructure to make optimal use of the new laboratory-based facility for advanced accelerator R&D.	+900
▪ Funding for laboratory-based research in this subprogram increases ($+8,000,000) to support a new Advanced Accelerator R&D test facility that can provide a testbed for advanced acceleration concepts such as plasma wakefield acceleration, that will broadly benefit the accelerator science community. In addition, there is increased funding in support of general laboratory-based accelerator science research ($+783,000), reflecting an approximately constant level-of-effort with respect to the FY 2008 programmatic effort and costs in this category.	+8,783
▪ Funding for other accelerator science research activities reflects a slight increase in funding held pending completion of peer review and/or programmatic decisions.	+338
Total, Accelerator Science	**+10,021**

	FY 2009 vs. FY 2008 ($000)
Accelerator Development	
▪ Funding for general accelerator development activities increases to further promote development of very high intensity proton sources for potential application in neutrino physics research.	+11,018
▪ Funding for superconducting RF development increases to support continued development of U.S. infrastructure and test capability for RF cavities and cryomodules. This capability is essential for continued progress on, and for a full range of future applications, and in particular will be a critical component for the next generation of HEP accelerators.	+19,595
▪ Funding for International Linear Collider R&D increases to support an ILC R&D program focused on a limited number of machine issues, high level RF development, and cryomodule prototyping. The U.S. ILC collaboration will focus its R&D efforts on accelerator issues for which the U.S. has unique expertise and on development of components associated with the main linac.	+20,166
Total, Accelerator Development	**+50,779**
Other Technology R&D	
▪ Funding for Advanced Detector R&D reflects the planned funding level for this competitive solicitation.	+455
▪ Funding for Detector Development is increased to enable greater participation of university researchers in these efforts.	+2,624
Total, Other Technology R&D	**+3,079**
SBIR/STTR	
▪ Funding for SBIR/STTR increases according to the prescribed percentage.	+2,735
Total Funding Change, Advanced Technology R&D	**+66,614**

Capital Operating Expenses and Construction Summary

Capital Operating Expenses

(dollars in thousands)

	FY 2007	FY 2008	FY 2009
General Plant Projects	8,850	11,390	6,600
Accelerator Improvement Projects	9,300	4,300	3,000
Capital Equipment	42,619	43,300	68,220
Total, Capital Operating Expenses	60,769	58,990	77,820

Major Items of Equipment *(TEC $2 million or greater)*

(dollars in thousands)

	Total Project Cost (TPC)	Other Project Cost (OPC)	Total Estimated Cost (TEC)	Prior Year Appro-priations	FY 2007	FY 2008	FY 2009	Completion Date
Large Hadron Collider–CMS Detector, CERN	147,050[a]	75,261	71,789	70,539	1,250	—	—	FY 2007
Reactor Neutrino Detector, Daya Bay, China	32,000-34,000[b]	TBD	TBD	—	500	3,960	13,000	FY 2012
NuMI Off-axis Neutrino Appearance (NOνA) Detector, Fermilab	270,000[c]	TBD	TBD	—	1,000	—	7,000	FY 2014
Dark Energy Survey, Cerro-Tololo Inter-American Observatory, Chile	24,100-26,700[d]	TBD	TBD	—	—	3,610	7,500	FY 2011
Main Injector Experiment ν–A (MINERνA), Fermilab	16,800	6,100	10,700	—	—	5,000	4,900	FY 2010
Tokai-to-Kamioka (T2K) Near Detector, Tokai, Japan	4,680	1,700	2,980	—	—	1,980	1,000	FY 2009

[a] The total U.S. contribution (TPC) for this project is $167,250,000, including $20,200,000 from NSF.
[b] The estimated TPC for the Reactor Neutrino Detector has increased since the FY 2008 President's budget request, based on the results of project reviews and stretch out of the funding profile. CD-1 was approved in September 2007 with a preliminary TPC range of $32,000,000–$34,000,000. The TPC/TEC/OPC will be baselined at CD-2, planned for early 2008.
[c] TPC shown is an estimate. CD-1 was approved in May 2007 with a preliminary TPC range of $244,000,000–$293,000,000. CD-2 was planned for January 2008, but funding for FY 2008 was suspended by Congress and CD-2 will be rescheduled for early 2008 while this change is accommodated in the planning.
[d] The estimated TPC for the Dark Energy Survey has increased since the FY 2008 President's budget request which was based on CD-0, approved in November 2005 with a TPC range of $16,000,000–$20,000,000. CD-1 approval was granted in October 2007 with a preliminary TPC range of $24,100,000–$26,700,000 reflecting successful review of the Conceptual Design Report in May 2007.

(dollars in thousands)

	Total Project Cost (TPC)	Other Project Cost (OPC)	Total Estimated Cost (TEC)	Prior Year Appro-priations	FY 2007	FY 2008	FY 2009	Completion Date
CDMS-25 kg Detector, SNOLab, Canada	5,000-7,000[a]	TBD	TBD	—	—	—	500	FY 2012
Advanced Accelerator R&D test facility, TBD	15,000-19,000[b]	TBD	TBD	—	—	—	8,000	FY 2013
Total, Major Items of Equipment					2,750	14,550	41,900	

[a] The TPC is preliminary and CD-0 was approved in November 2007.
[b] The TPC is preliminary and CD-0 is planned for early 2008.