High Energy Physics

Funding Profile by Subprogram

(dollars in thousands)

	FY 2005 Current Appropriation	FY 2006 Original Appropriation	FY 2006 Adjustments	FY 2006 Current Appropriation	FY 2007 Request
High Energy Physics					
Proton Accelerator-Based Physics	391,360	392,093	-16,994[ab]	375,099	376,536
Electron Accelerator-Based Physics	135,001	132,822	-15,789[ab]	117,033	117,460
Non-Accelerator Physics	55,590	38,589	+9,427[ab]	48,016	59,271
Theoretical Physics	50,065	49,103	-913[ab]	48,190	52,056
Advanced Technology R&D	90,145	111,326	+17,030[ab]	128,356	159,476
Subtotal, High Energy Physics	722,161	723,933	-7,239	716,694	764,799
Construction	745	—	—	—	10,300
Total, High Energy Physics	722,906[c]	723,933	-7,239	716,694	775,099

Public Law Authorizations:
Public Law 95-91, "Department of Energy Organization Act"
Public Law 103-62, "Government Performance and Results Act of 1993"
Public Law 109-58, "Energy Policy Act of 2005"

Mission

The mission of the HEP program is to understand how our universe works. We do this by discovering the most elementary constituents of matter and energy, exploring the basic nature of space and time itself, and probing the interactions between them. These fundamental ideas are at the heart of physics and hence all of the physical sciences. HEP underpins and advances the DOE missions and objectives through the development of key technologies and trained manpower needed to work at the cutting edge of science.

[a] Reflects a rescission in accordance with P.L. 109-148, the Emergency Supplemental Appropriations Act to Address Hurricanes in the Gulf of Mexico and Pandemic Influenza, 2006, as follows: Proton Accelerator-Based Physics ($-3,921,000); Electron Accelerator-Based Physics ($-1,328,000); Non-Accelerator Physics ($-386,000); Theoretical Physics ($-491,000); and Advanced Technology R&D ($-1,113,000).
[b] Reflects a reallocation of funding in accordance with H.Rpt. 109-275, the conference report for the Energy and Water Development Appropriations Act, 2006, as follows: Proton Accelerator-Based Physics ($-13,073,000); Electron Accelerator-Based Physics ($-14,461,000); Non-Accelerator Physics ($+9,813,000); Theoretical Physics ($-422,000); and Advanced Technology R&D ($+18,143,000).
[c] Total is increased by $4,500,000 for a reprogramming from Science Laboratories Infrastructure and is decreased by $5,936,000 for a rescission in accordance with P.L. 108-447, the Consolidated Appropriations Act, 2005; $16,105,000, which was transferred to the SBIR program; and $1,933,000, which was transferred to the STTR program.

Benefits

HEP supports DOE's mission of world-class scientific research capacity by providing facilities and advancing our knowledge of high energy physics and related fields, including particle astrophysics and cosmology. Research advances in any one of these fields often have a strong impact on research directions in another. These fields also have a substantial overlap in technological infrastructure, including particle accelerators and detectors, data acquisition and computing. Technology that was developed in response to the demands of high energy physics research has also become indispensable to other fields of science and has found wide applications in industry and medicine, often in ways that could not have been predicted when the technology was first developed. Examples include: medical imaging, radiation therapy for cancer using particle beams, ion implantation of layers in semiconductors, materials research with electron microscopy, and the World Wide Web. The accelerator technologies of high-power x-ray light sources, from synchrotron radiation facilities to the new coherent light sources, are derived from high energy physics accelerator technology.

Strategic and Program Goals

The Department's Strategic Plan identifies four strategic goals (one each for defense, energy, science, and environmental aspects of its mission) plus seven general goals that tie to the strategic goals. The HEP program supports the following goal:

Science Strategic Goal
General Goal 5, World-Class Scientific Research Capacity: Provide world-class scientific research capacity needed to: ensure the success of Department missions in national and energy security; advance the frontiers of knowledge in physical sciences and areas of biological, medical, environmental, and computational sciences; or provide world-class research facilities for the Nation's science enterprise.

The HEP program has one program goal which contributes to General Goal 5 in the "goal cascade":
Program Goal 05.19.00.00: 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 Program Goal 05.19.00.00 (Explore the Fundamental Interactions of Energy, Matter, Time and Space)

The High Energy Physics (HEP) program contributes to this goal by advancing our understanding of the basic constituents of matter, deeper symmetries in the physical laws of particles at high energies, dark energy and dark matter, and the possible existence of other dimensions of space. HEP uses particle accelerators and very sensitive detectors to study fundamental interactions at the highest possible energies. Because particle physics is fundamentally involved in 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 mountain tops, 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. At the same time, the HEP program can shed new light on other mysteries of the cosmos, uncovering the mysterious dark matter that holds galaxies together and the even more mysterious dark energy that is stretching space apart; explaining why there is any matter in the universe at all; and showing how the tiniest constituents of the universe play a leading role in shaping its birth, growth, and ultimate fate. Our goals in FY 2007 address all of these challenges. The FY 2007 budget request also contributes to this program goal by placing high priority on operations, upgrades, and infrastructure for the three major HEP user facilities: the Tevatron Collider and Neutrinos at the Main Injector (NuMI) at the Fermi National Accelerator Laboratory (Fermilab), and the B-factory at the Stanford Linear Accelerator Center (SLAC), to produce maximum scientific data to address these fundamental questions. HEP and Basic Energy Sciences (BES) will jointly support accelerator operations at SLAC through the construction of the Linac Coherent Light Source (LCLS) and the transition of that facility to BES.

The following indicators establish 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."

These indicators spell out some of the important scientific goals of the HEP program for the next decade and can only be evaluated over a period of several years. However, each of these long-term goals is supported by one or more of the annual performance targets in Facilities Operations or Construction/Major Items of Equipment listed in the following table. Achieving success in these annual targets will be an important component of making progress towards the long-term goals.

Funding by General and Program Goal

	(dollars in thousands)		
	FY 2005	FY 2006	FY 2007
General Goal 5, World-Class Scientific Research Capacity			
Program Goal 5.19.00.00, Explore the Fundamental Interactions of Energy, Matter, Time and Space (High Energy Physics)	722,906	716,694	775,099

Annual Performance Results and Targets

FY 2002 Results	FY 2003 Results	FY 2004 Results	FY 2005 Results	FY 2006 Targets	FY 2007 Targets
Program Goal 05.19.00.00 (Explore the Fundamental Interactions of Energy, Matter, Time and Space)					
All HEP Facilities					
Maintain and operate HEP facilities such that unscheduled downtime is on average less than 20% of the total scheduled operating time. [Met Goal]	Maintain and operate HEP facilities such that unscheduled downtime is on average less than 20% of the total scheduled operating time. [Met Goal]	Maintain and operate HEP facilities such that unscheduled downtime is on average less than 20% of the total scheduled operating time. [Met Goal]	Maintain and operate HEP facilities such that unscheduled downtime is on average less than 20% of the total scheduled operating time. *[Goal Not Met]*	Maintain and operate HEP facilities such that unscheduled downtime is on average less than 20% of the total scheduled operating time.	Maintain and operate HEP facilities such that unscheduled downtime is on average less than 20% of the total scheduled operating time.
Proton Accelerator-Based Physics/Facilities					
Deliver data as planned (80 pb-1) to CDF and D-Zero detectors at the Tevatron. *[Met Goal]*	Deliver data as planned (225 pb-1) to CDF and D-Zero detectors at the Tevatron. *[Met Goal]*	Deliver data as planned within 20% of the baseline estimate (240 pb-1) to CDF and D-Zero detectors at the Tevatron. *[Met Goal]*	Deliver data as planned within 20% of the baseline estimate (390 pb-1) to CDF and D-Zero detectors at the Tevatron. *[Met Goal]*	Deliver data as planned within 20% of the baseline estimate (675 pb-1) to CDF and D-Zero detectors at the Tevatron.	Deliver data as planned within 20% of the baseline estimate (800 pb-1) to CDF and D-Zero detectors at the Tevatron.
				Deliver data as planned within 20% of the baseline estimate ($1x10^{20}$ protons on target) for the MINOS experiment using the NuMI facility.[a]	Deliver data as planned within 20% of the baseline estimate ($1.5x10^{20}$ protons on target) for the MINOS experiment using the NuMI facility.[a]
Electron Accelerator-Based Physics/Facilities					
Increase the total data delivered to BaBar at the SLAC B-factory by delivering 35 fb-1 of total luminosity. *[Met Goal]*	Increase the total data delivered to BaBar at the SLAC B-factory by delivering 45 fb-1 of total luminosity. *[Goal Not Met]*	Deliver data as planned within 20% of baseline estimate (45 fb-1) to the BaBar detector at the SLAC B-factory. *[Met Goal]*	Deliver data as planned within 20% of baseline estimate (50 fb-1) to the BaBar detector at the SLAC B-factory. *[Met Goal]*	Deliver data as planned within 20% of the baseline estimate (100 fb-1) to the BaBar detector at the SLAC B-factory.	Deliver data as planned within 20% of the baseline estimate (150 fb-1) to the BaBar detector at the SLAC B-factory.
Construction/Major Items of Equipment					
Maintain cost and schedule milestones for upgrades and new major construction projects within 10% of baseline estimates. *[Met Goal]*	Maintain cost and schedule milestones for upgrades and new major construction projects within 10% of baseline estimates. *[Met Goal]*	Maintain cost and schedule milestones for upgrades and new major construction projects within 10% of baseline estimates. *[Met Goal]*	Maintain cost and schedule milestones for upgrades and new major construction projects within 10% of baseline estimates. *[Met Goal]*	Maintain cost and schedule milestones for major items of equipment and new construction projects within 10% of baseline estimates.	Maintain cost and schedule milestones for major items of equipment and new construction projects within 10% of baseline estimates.

[a] These annual targets are tracked and reported by the internal DOE performance management system, but are not currently tracked as PART measures.

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, 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 set down 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. All 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 (e.g., 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 implemented a tool to evaluate selected programs. PART was developed by 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 2005 and FY 2006 Budget Requests and has taken the necessary steps to continue to improve performance.

In the FY 2005 PART review, OMB gave the HEP program a relatively high score of 84% overall which corresponds to a rating of "Moderately Effective." OMB found performance improvements at Fermilab and an ongoing prioritization process. The assessment found that HEP has developed a limited number of adequate performance measures which are continued for FY 2007. 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. To better explain these complex scientific measures, the Office of Science has developed a website (http://www.sc.doe.gov/measures/) that answers questions such as "What does this measure mean?" and "Why is it important?" Roadmaps, developed in consultation with the High Energy Physics Advisory Panel (HEPAP—see Advisory and Consultative Activities below) and also available on the website, will guide reviews, every three years by HEPAP, of progress toward achieving the long-term performance measures. The annual performance targets are tracked through the Department's Joule system and reported in the Department's Annual Performance Report. In response to PART findings, HEP 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 report is available on the web (http://www.science.doe.gov/hep/HEPAPCOVReportfinal.pdf). Within 30 days of receiving the report, HEP developed an action plan to respond to its findings and recommendations. This action plan is also available on the web at (http://www.sc.doe.gov/hep/OfficeofHEPResponsetoCOVreport.shtm). The Particle Physics Project Prioritization Panel (P5—see Advisory and Consultative Activities) also submitted its first report in September 2003, and a revised update in August 2004. These reports are available on the web (http://www.science.doe.gov/hep/hepap_reports.shtm). HEP plans for future facilities, based upon that input, are reflected in this Budget Request.

For the FY 2007 Budget, OMB has developed PARTWeb—a new interface for PART that facilitates collaboration between agencies and OMB. PARTWeb will link to the website http://ExpectMore.gov and will improve public access to PART assessments and follow up actions. For 2006 there are three actions for High Energy Physics.

- Implementing the recommendations of past and new external assessment panels, as appropriate.
- Developing a strategy and implementation plan for particle accelerator research and development, including a potential international linear collider.
- Engaging 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.

HEP values input from outside the High Energy Physics community and is working with the National Academies to develop a prioritized long term plan. HEP also takes seriously its role in supporting accelerator R&D for the Department, and will initiate a planning process, with community input, to develop a strategy for accelerator R&D within DOE that incorporates the challenges of a potential international linear collider. HEP is actively working to implement recommendations from expert panels as appropriate.

Improvements are posted at http://www.sc.doe.gov/measures/FY06.html.

Overview

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.

But 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 deeper theory that can explain these new phenomena. A revolution in particle physics, and in our understanding of the universe in which we live, is coming.

Questions

A worldwide program of particle physics research is underway to explore the new scientific landscape. A recent HEPAP subpanel report, *Quantum Universe*, summarized the key questions:

- Are there undiscovered principles of nature: new symmetries, new physical laws?

  The quantum ideas that so successfully describe familiar matter fail when applied to cosmic physics. The problem might be solved by the appearance of new forces and new particles signaling the discovery of new symmetries—undiscovered principles of nature's behavior.

- 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. Dark energy might be similar to the Higgs field, a quantum field representing "vacuum energy" that exists throughout space.

- Are there extra dimensions of space?

  Current theories that attempt to reconcile quantum ideas with gravity predict the real existence of undiscovered dimensions of space that might explain much of the observed complexity of particle physics. The discovery of extra dimensions would be an epochal event in human history. It would change our understanding of the birth and evolution of the universe. If some of these extra dimensions are as large as some theories predict, the force of gravity could increase at short distances. This increase could be seen at the Large Hadron Collider (LHC) by production of "mini-black-holes" and a whole new spectrum of particle states.

- Do all the forces become one?

  At the most fundamental level all forces and particles in the universe are thought to be related, with all the forces thought to be manifestations of a single unified force. Such a unified theory of all forces was Einstein's great dream. Recent theoretical efforts have made progress toward this goal.

- Why are there so many kinds of particles?

  Why do three families of particles exist, and why do their masses differ so dramatically? Patterns and variations in the families of elementary particles suggest undiscovered principles that tie together the quarks and leptons of the Standard Model.

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

  Most of the matter in the universe is unknown dark matter; probably particles produced in the Big Bang that interact very rarely with normal matter. These particles may have a small enough mass to be produced and studied at accelerators, or detected "au naturel" in cosmic rays, using ultra-sensitive detectors.

- What are neutrinos telling us?

  Of all the known particles, neutrinos are the most mysterious. They played an essential role in the evolution of the universe, and their tiny but nonzero masses may imply new physics and unification at very high energies.

- How did the universe come to be?

  According to current cosmological ideas, our universe may have begun with a disturbance of space-time, followed by a burst of inflationary expansion of space itself. This model of the cosmos is called the "Big Bang." Following inflation, the universe cooled, allowing the formation of stars, galaxies, and ultimately life. A fuller understanding of the evolution of the universe requires breakthrough in our understanding of quantum physics and quantum gravity.

- What happened to the antimatter?

  The universe now is made almost entirely of matter, with very little antimatter, although it is thought the Big Bang must have produced the same amounts of matter and antimatter, because we find this to be the case in high energy collisions in the laboratory. How then did the asymmetry arise?

All these questions are addressed at some level by the existing and planned HEP program described in the rest of this budget request. Theoretical research, technology development, 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.

How We Work

The HEP program coordinates and funds high energy physics research. In FY 2005, the DOE HEP program provided about 90% of the federal support for high energy physics research in the nation; the NSF provides most of the remaining support. The program is responsible for: planning and prioritizing all aspects of supported research; conducting ongoing assessments to ensure a comprehensive and balanced portfolio, regularly seeking advice from stakeholders; supporting core university and national laboratory programs; and maintaining a strong infrastructure to support high energy physics research.

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 on a continuing basis regarding the direction and management of the national high energy physics research program. HEPAP regularly meets to advise the agencies on their research programs, assess their scientific productivity, and evaluate the scientific case for new facilities. HEPAP (or a subpanel thereof) also 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. Priorities recommended by P5 and other subpanels will have an important influence on long-range planning (see Planning and Priority Setting*,* below). A subpanel called the Neutrino Scientific Assessment Group (NuSAG), reporting jointly to HEPAP and the Nuclear Science Advisory Committee (NSAC), will advise DOE and NSF on specific questions concerning the U.S. neutrino program. 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.

The National Academy of Sciences was chartered by Congress to advise the federal government on scientific and technical matters. It fulfills this function principally through the National Research Council (NRC), which conducts decadal surveys of research directions in all fields of physics and astronomy, as commissioned by its Board on Physics and Astronomy. It conducted a "science assessment and strategy for…research at the intersection of astronomy and physics," which was published in 2003 as *Connecting Quarks with the Cosmos.* A new study is being carried out for the DOE and the NSF by the NRC in 2005-2006, which will assess and prioritize opportunities in high energy physics and the tools needed to realize them in the next 15 years.

DOE was part of the National Science and Technology Council's (NSTC) Interagency Working Group on the Physics of the Universe. In 2004, the Working Group released a strategic plan for how the agencies will address the recommendations from the *Connecting Quarks with the Cosmos* report. Included in this plan are specific recommendations for the DOE to work together with the NSF and NASA to develop investments in emerging areas including dark energy, dark matter, and neutrino physics.

Laboratory 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.

Review and Oversight

The HEP program provides review and 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 experiments 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 annual 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 annual laboratory reviews, to assess in detail the quality and relevance of the specific proposal. In addition, the HEP program 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 also participates in the annual SC reviews of each of its laboratories.

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.

As noted above in the PART section, the HEP program has also instituted a formal "committee of visitors" that will provide 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 first such review took place in the second quarter of 2004. The committee report praised the program strongly, but also pointed to several areas that could be improved.

Planning and Priority Setting

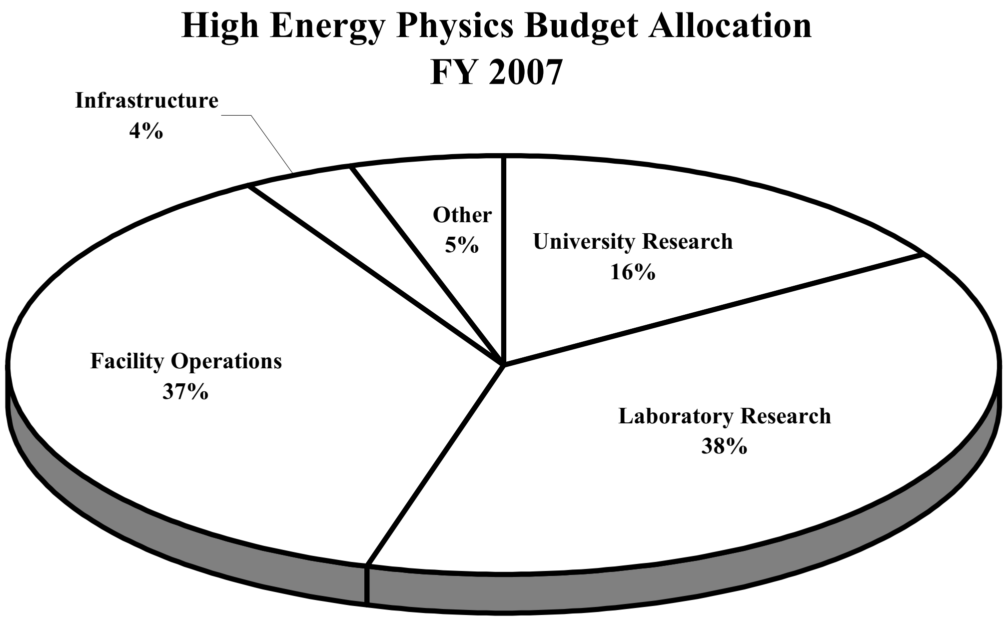
One of the most important functions of HEPAP is the development of long-range plans that express community-wide priorities for future research. The most recent such plan was submitted in January 2002 and presented a "roadmap" for the field, laying out the physics opportunities envisioned for the next 20 years. As part of this roadmap, the panel recommended that the highest priority of the U.S. program be a high energy, high-luminosity electron-positron linear collider to be built as a fully international effort. HEPAP further recommended that a vigorous long-term R&D program aimed toward future high energy research facilities be carried out with high priority within the HEP program.

HEPAP also played an important role in advising the Director of the Office of Science on future facilities needed to address the most important HEP research questions for the next decade. Their recommendations on the scientific importance and technical readiness of several possible facilities were key elements in developing the Office of Science *Facilities Outlook,* published in 2003.

HEPAP also recommended a mechanism to update the roadmap and set priorities across the program. This recommendation has been implemented in the form of the P5 subpanel that is charged with advising the funding agencies on priorities for new facilities. P5 will play an important role in determining which new facilities appear on the HEP roadmap in future years. Several scientific review panels (including P5) are currently meeting to evaluate specific proposed future HEP facilities and recommend a detailed programmatic roadmap.

How We Spend Our Budget

The HEP budget has three major program elements: research, facility operations, and laboratory infrastructure support. About 37% of the FY 2007 budget request is primarily provided to the three major HEP facilities for facility operations (Tevatron Collider and NuMI at Fermilab and B-factory at SLAC); a total of 38% is provided to laboratories, including multipurpose laboratories, in support of their HEP research and advanced technology R&D activities; 16% is provided for university-based physics research and advanced technology R&D; 4% for infrastructure improvements (general plant projects [GPP] and general purpose equipment [GPE]) and construction funds; and 5% for other activities (including Small Business Innovative Research [SBIR] and Small Business Technology Transfer [STTR]). It is notable that DOE provides about 70% of the Federal core support for university-based research groups working in high energy physics, including most of the support for students and postdoctoral researchers. The FY 2007 budget request is focused on facility operations at Fermilab to advance research with the CDF and D-Zero detectors at the Tevatron, and the Main Injector Neutrino Oscillation Search (MINOS) detector using the NuMI beam; and facility operations at SLAC to advance research with the BaBar detector at the B-factory. Priority is also given to the ramp-up of the LHC research program in support of commissioning, operations and maintenance activities in anticipation of the start of the LHC physics program in 2007; and to a significant increase in R&D efforts focused in development of an International Linear Collider.



Research

The DOE HEP program supports approximately 2,400 researchers and students at more than 100 U.S. universities located in 36 states, Washington, D.C., and Puerto Rico, and 10 laboratories located in 6 states. In addition, the HEP research program includes significant participation from university scientists supported by the NSF, a substantial number of scientists from foreign institutions, and astrophysicists supported by NASA. These physicists conceive and carry out the high energy physics research program. Typically, they work together in large international collaborations, involving hundreds of scientists from many institutions, to carry out a program that may take a decade or more to complete. A long time scale is one of the signature features of high energy physics research. Funding for most university and laboratory research is maintained at approximately the FY 2006 level-of-effort, with the main emphasis on supporting analysis of the large datasets now being generated by our user facilities, and enhancing long-range accelerator science research. This is below the FY 2005 level-of-effort in most areas, so research managers will continue to exploit efficiencies and cost savings wherever possible. Research scientists at national laboratories and universities work together in the experimental collaborations to collect and analyze data as well as support and maintain the detectors. The laboratories also maintain state-of-the-art resources needed for future upgrades and new facilities, and together with the university-based research program, perform R&D for future detectors and accelerator facilities.

- **University Research:** University researchers play a critical role in the national high energy physics research effort and in the training of graduate students and postdoctoral researchers, only about half of whom remain in the field, the rest going into industry and commerce where they are well-received. This highly trained human resource is part of the nation's economic and strategic strength. During FY 2005, the DOE High Energy Physics program supported approximately two-thirds of the nation's university researchers engaged in fundamental high energy physics research, and approximately 90% of the graduate students engaged in accelerator R&D. Typically, about 120 Ph.D. degrees are granted annually to students for research supported by the high energy physics program and 10 per year in the accelerator physics program.

  The university grants program is proposal driven, and funds the best and brightest of those ideas submitted in response to grant solicitation notices. Proposals are reviewed by external scientific peers and grants are competitively awarded according to the guidelines published in Office of Science Regulation 10 CFR 605. Thereafter, the research is monitored to ensure that a high quality of research is maintained (see Review and Oversight, above).

- **National Laboratory Research**: The HEP program supports research groups at the Fermi National Accelerator Laboratory; at Lawrence Berkeley, Lawrence Livermore, Argonne, Brookhaven, Oak Ridge, and Los Alamos National Laboratories; and at the Princeton Plasma Physics Laboratory, SLAC and the Thomas Jefferson National Accelerator Facility. The directions of laboratory research programs are driven by the needs of the Department and are tailored to the major scientific facilities at the laboratories. Laboratory researchers collaborate with academic users of the facilities and play a key role in developing and maintaining the accelerators, large experimental detectors, and computing facilities for data analysis. Laboratory researchers play a critical role in the national high energy physics research effort and in the training of postdoctoral researchers, engineers and technical personnel, many of whom spend much of their later careers in industry.

  The HEP program funds selected field work proposals from the national laboratories. Performance of the laboratory groups is reviewed annually by program staff assisted by an external panel of technical experts (see Review and Oversight, above) to examine the quality and balance of their research and identify needed changes, corrective actions, or redirection of effort. Individual laboratory groups have special capabilities or access to laboratory resources that can be profitably utilized in the development of the scientific program.

Significant Program Shifts

The U.S. HEP program in FY 2007 will continue to lead the world with forefront user facilities at Fermilab and SLAC that help answer the key scientific questions outlined above, but these facilities are scheduled to complete their scientific missions by the end of the decade. Thus the longer-term HEP program supported by this request begins to develop new cutting-edge facilities in targeted areas (for example, neutrino physics) that will establish a U.S. leadership role in these areas in the next decade, when the centerpiece of the world HEP program will be the LHC at the European Organization for Nuclear Research (CERN). Further, we have prioritized our current R&D efforts to select those which will provide the most compelling science opportunities in the coming decade within the available resources. For these reasons, our highest priority R&D effort is the development of the proposed International Linear Collider (ILC), and this request significantly advances the ILC R&D program. In making these decisions we have carefully considered the recommendations of HEPAP and planning studies produced by the U.S. HEP community. This prioritization process will continue as the R&D programs evolve.

- The planned operational improvements, equipment, upgrades and infrastructure enhancements for the Tevatron program at Fermi National Accelerator Laboratory will be completed by FY 2007. The luminosity improvements have been successfully carried out while still running the Tevatron collider at high efficiency. They were planned in detail using modern project management techniques and regularly reviewed by experts solicited by the Office of High Energy Physics. Much of the accelerator development effort will move to the neutrino program, which began in 2005 with the commissioning of the NuMI neutrino beam. The NuMI beam uses the proton source section of the Tevatron complex and will put much higher demands on that set of accelerators. A new program of enhanced maintenance, operational improvements, and equipment upgrades is being developed to meet these higher demands, while continuing to run the accelerator. The plan will be managed and monitored in the same manner as the Run II luminosity improvements.

- In order to exploit the unique opportunity to expand the boundaries of our understanding of the origin of mass in the universe, a high priority is given to continued operations and infrastructure support for the B-factory at SLAC. Upgrades to the accelerator and detector are currently scheduled for completion in 2006, and B-factory operations will conclude no later than FY 2008. As part of its ongoing development of a U.S. HEP program "roadmap" for the upcoming decade, the HEP prioritization subpanel (P5) will consider the scientific importance of the final year (2008) of B-factory running in Spring 2006.
- As the LHC accelerator nears its turn-on date in 2007, U.S. activities related to fabrication of detector components will be completed and new activities related to commissioning and pre-operations of these detectors, along with software and computing activities needed to analyze the data, will ramp-up significantly. Support of an effective role for U.S. research groups in the LHC physics program will continue to be a high priority of the HEP program.
- R&D in support of the ILC is doubled relative to FY 2006 to support a U.S. leadership role in a comprehensive, coordinated international R&D program, and to provide a basis for U.S. industry to compete successfully for major subsystem contracts should the ILC be built. The long-term goal of this effort is to provide a go/no go decision on a construction start for an international electron-positron linear collider near the end of the decade. In FY 2005 an international collaboration called the Global Design Effort (GDE) was organized to coordinate the R&D and design of a linear collider based on the superconducting radiofrequency technology.
- To provide a nearer-term future HEP program, and to preserve future research options, R&D for accelerator and detector technologies, particularly in the emerging area of neutrino physics, will continue at an increased level relative to FY 2006. Engineering design will begin on a new detector optimized to detect electron neutrinos, the Electron Neutrino Appearance (EνA) Detector, which will utilize the existing NuMI beam. Participation will begin in a reactor-based neutrino experiment and R&D for a high-intensity neutrino super beam facility and a double beta decay experiment will continue. These efforts are part of a coordinated neutrino program developed from an American Physical Society study and a joint HEPAP/NSAC subpanel review.
- In order to explore the nature of dark energy, support for R&D for the SNAP mission concept will be increased in FY 2007. SNAP will be a mission concept proposed for a potential interagency-sponsored experiment with NASA, the Joint Dark Energy Mission (JDEM). This experiment will provide important new information about the nature of dark energy that will in turn lead to a better understanding of the birth, evolution, and ultimate fate of the universe.
- In addition, to fully determine the nature of dark energy, independent and complementary measurements are scientifically advisable. In FY 2007, R&D will be done for ground facilities (in cooperation with NSF) and/or a variety of space-based facilities which could provide these measurements. Advice from the scientific community will be solicited to aid in selecting the particular concepts to be developed.

Scientific Discovery through Advanced Computing

The Scientific Discovery through Advanced Computing (SciDAC) program is a set of coordinated investments across all SC mission areas with the goal of achieving scientific breakthroughs via advanced computer science and simulations that were unattainable using theoretical or laboratory studies alone. The power of computers and networks is increasing exponentially. Advances in high-end computing technology, together with innovative algorithms and software, are being exploited as intrinsic tools for scientific discovery. SciDAC has also pioneered an effective new model of multidisciplinary collaboration among discipline-specific scientists, computer scientists, computational scientists, and mathematicians. The product of this collaborative approach is a new generation of scientific simulation codes that can productively exploit terascale computing and networking resources. The program is bringing computation and simulation into parity with experiment and theory in the scientific research enterprise as demonstrated by major advances in climate modeling and prediction, plasma physics, particle physics, accelerator design, astrophysics, chemically reacting flows, and computational nanoscience.

More details on the specific scientific impact of HEP contributions to SciDAC programs on lattice gauge Quantum Chromo Dynamics (QCD) calculations, astrophysical simulations, accelerator simulation and modeling, and grid technology and deployment, as well as the FY 2007 work plan can be found below in the description of the Theoretical Physics subprogram.

Scientific Facilities Utilization

The High Energy Physics request supports the Department's scientific user facilities. This investment will provide significant research time for several thousand scientists based at universities and other Federal laboratories. It will also leverage both federally and privately sponsored research, consistent with the Administration's strategy for enhancing the U.S. national science investment.

The proposed funding will support operations at the Department's three major high energy physics facilities: the Tevatron Collider at Fermilab, NuMI beam line at Fermilab, and the B-factory at SLAC. The Tevatron Collider provided a total of 5,040 hours of beam time in FY 2005 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. The construction of NuMI has been completed and operation of the facility has begun, serving more than 250 researchers, of whom about two-thirds are U.S. researchers. The FY 2007 request will support facility operations at Fermilab that will provide ~4,560 hours of beams for the Tevatron Collider and for NuMI, including an allowance for increased power costs and fully funded upgrades. The B-factory provided a total of ~3,380 hours of beam time in FY 2005 for a research community of about 300 U.S. scientists in HEP and a comparable number of users from foreign countries. The FY 2007 request will support facility operations at SLAC that provide ~5,200 hours of beams for the B-factory, including an allowance for increased power costs.

High Energy Physics will maintain and operate its major scientific user facilities so that the unscheduled operational downtime will be kept below 20%, on average, of total scheduled operating time.

	FY 2005	FY 2006	FY 2007
Tevatron Complex at Fermilab			
Optimal hours	5,040	4,320	4,560
Beam Hours - Tevatron	5,040	4,320	4,560
Unscheduled Downtime - Tevatron	<20%	<20%	<20%
Scheduled Hours - NuMI	N/A	4,320	4,560
Unscheduled Downtime - NuMI	N/A	<20%	<20%
Total Number of Users	2,160	2,125	2,160
B-factory at SLAC			
Optimal hours	4,550	5,200	5,200
Beam hours	3,380	5,200	5,200
Unscheduled Downtime	<20%	<20%	<20%
Total Number of Users	1,100	1,100	1,100

Construction and Infrastructure

Preliminary engineering design for a potential new construction project, the Electron Neutrino Appearance (EvA) Detector, begins in FY 2007. Overall funding for capital equipment is down slightly compared to FY 2006 as some resources shift to Construction, but one new Major Item of Equipment, the Reactor Neutrino Detector, begins fabrication. Capital equipment expenditures at Fermilab required to improve sections of the accelerator complex for the ongoing neutrino program continue. No AIP projects are currently planned. Funding for GPP is increased to improve site-wide infrastructure at Fermilab, SLAC, and Lawrence Berkeley National Laboratory (LBNL).

Workforce Development

The HEP program supports development of the R&D workforce through support of graduate students working toward a doctoral degree and post-doctoral associates developing their research and management skills. The R&D workforce developed under this program not only provides new scientific talent in areas of fundamental research, but also provides talent for a wide variety of technical, medical, and industrial areas that require the incisive thinking and problem solving abilities and computing and technical skills that are developed through education and experience in a fundamental research field. Scientists trained as high energy physicists can be found working in such diverse areas as hospitals (radiation therapy, medical imaging, and medical physics), national security, space exploration, software and computing, telecommunications, finance, and many other fields.

About 1,200 postdoctoral associates and graduate students supported by the HEP program in FY 2005 were involved in a large variety of theoretical and experimental research, including advanced technology R&D. About one-fifth are active in theoretical research. Of those involved in experimental research about 85% utilize a number of scientific accelerator facilities supported by the DOE, NSF, and foreign countries; and about 15% participate in non-accelerator research.

Details of the High Energy Physics program workforce are given below. These numbers include people employed by universities and laboratories. The university grants include both Physics Research and Accelerator Technology grants. In FY 2005, there were ~150 university grants with average funding of $750,000 per year. Most of these are multi-task grants with an average of three tasks. The duration of the grants is three years. The number of laboratory groups is an estimate of the number of distinct HEP research groups (experiment, theory, accelerator R&D) at the laboratories, which is a collection of single- and multi-task efforts.

	FY 2005	FY 2006 estimate	FY 2007 estimate
# University Grants	150	135	140
# Laboratory Groups	50	47	47
# Permanent Ph.D.'s (FTEs)	1,230	1,210	1,250
# Postdoctoral Associates (FTEs)	540	540	595
# Graduate Students (FTEs)	635	585	620
# Ph.D.'s awarded	120	115	110

In addition, there is a joint DOE/HEP and NSF research-based physics education program ("QuarkNet") aimed at professional development for high school teachers. In this program, active researchers in high energy physics serve as mentors for high school teachers to provide long term professional development based on participation in frontier high energy physics research. Through these activities, the teachers enhance their knowledge and understanding of science and technology research. They transfer this experience to their classrooms, engaging their students in both the substance and processes of contemporary research as appropriate for the high school classroom. For more details see the Detailed Justification section that follows.

Facilities Summary

Fermilab

In FY 2007, Fermilab plans 4,560 hours of running for both the Tevatron Collider program and the Tevatron neutrino physics program. The annual goal for the Tevatron Collider program is to achieve a performance goal of 800 inverse picobarns (pb^{-1}) of data delivered to the major Tevatron Collider experiments. Approximately 900 people are involved in day-to-day Tevatron Collider operations that include operation of the Tevatron accelerator complex and the CDF and D-Zero detectors for the collider program. This is one of the major data collection periods for the Collider experiments studying fundamental properties of matter and their interactions and also searching for supersymmetry, extra dimensions, and possible observation of the long-awaited Higgs boson at the world's energy frontier facility.

Tevatron operations also include running the Tevatron complex in fixed target mode in parallel with Tevatron Collider operation. This mode is used for physics data taking by the MINOS experiment and for test beam runs (both using 120 GeV protons extracted from the Main Injector). During FY 2007, the MINOS experiment will be operating its beam line and detectors to collect data. Test beam runs will be scheduled as needed. These functions do not interfere with the high-priority Tevatron Collider operations.

Fully achieving the physics goals of the Tevatron program over the next few years has required a series of significant performance improvements to the accelerator complex. These efforts are proceeding in parallel with current Tevatron operations and research program. The technical scope, cost and schedule of work for the accelerator upgrades is periodically reviewed by the SC Office of Project Assessment and the reports from their reviews are available on the HEP website http://www.science.doe.gov/hep/TevatronReports.shtm. The most recent review of the Tevatron operations was conducted in March 2005.

SLAC

In FY 2007, SLAC plans 5,200 hours of running to achieve a performance goal of 150 inverse femtobarns (fb^{-1}) of data delivered to the BaBar experiment. Approximately 450 people are involved in day-to-day B-factory and BaBar operations. This will be the priority research program at SLAC in FY 2007. The collected data will provide a significant enhancement to the BaBar dataset for precision studies of Charge-Parity (CP) violation in the B-meson system, a phenomenon thought to be responsible for the excess of matter over antimatter in the universe. The opportunity to expand the boundaries of our understanding of the origin of mass in the universe through the research conducted at this facility will continue to pay dividends in outstanding accelerator and detector performance and research quality and productivity. These efforts are more fully described in the Detailed Justification sections that follow.

HEP facilities operations funding is summarized in the table below for the Tevatron, NuMI and B-factory:

	(dollars in thousands)		
	FY 2005	FY 2006	FY 2007
Tevatron Complex Operations	190,305	191,500	191,500
Tevatron Complex Improvements	47,050	24,255	24,255
Total, Tevatron Complex	237,355	215,755	215,755
B-factory Operations	94,617	77,024	82,892
B-factory Improvements	14,060	16,500	10,000
Total, B-factory	108,677	93,524	92,892

External Independent Reviews

Beginning in FY 2005, the costs of conducting External Independent Reviews (EIRs) for Capital Asset Projects greater than $5,000,000 within SC have been funded by SC. Examples of EIRs include conducting Performance Baseline EIRs prior to Critical Decision-2 (CD-2) to verify the accuracy of cost and schedule baseline estimates and conducting Construction/Execution Readiness EIRs, which are done for all Major System projects prior to CD-3. These funds, which are managed by the Office of Engineering and Construction Management, are exclusively used for EIRs directly related to these projects funded within SC. Beginning in FY 2007, the EIR business line will be financed via the Working Capital Fund to achieve parity on how EIRs are funded and to standardize the administration of these critical activities.

Proton Accelerator-Based Physics

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2005	FY 2006	FY 2007
Proton Accelerator-Based Physics			
Research	78,261	76,384	79,738
Facilities	313,099	298,715	296,798
Total, Proton Accelerator-Based Physics	391,360	375,099	376,536

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.

Benefits

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 evidence of new physics beyond the Standard Model.

The Proton Accelerator-Based Physics subprogram also includes precise, controlled measurements of basic neutrino properties, including neutrino oscillations, at accelerator-based neutrino facilities. These measurements will provide important clues and constraints to the theory of matter and energy beyond the Standard Model. This subprogram addresses five of the six long-term indicators that contribute to the Program Goal as well as the majority of the key questions for HEP outlined in the Overview section above.

Supporting Information

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 most particle physics phenomena below 1 TeV in energy, but beyond that energy range a new physical mechanism is needed to prevent Standard Model predictions from becoming inconsistent. Up until recently, it has been assumed that the Higgs boson is the solution to this "TeV scale" problem. Theories such as supersymmetry, extra hidden dimensions, and technicolor could solve the TeV scale problem in the Standard Model either in place of or in combination with, a Higgs boson. No matter which of these theories is shown to be correct, it will provide a deeper understanding of the fundamental nature of matter, energy, space and time. A single, "standard" Higgs boson would explain the origin of mass. Supersymmetry—which has multiple Higgs bosons—not only explains the origin of mass, but could also lead to the next step in unification: combining the electroweak interaction with the strong nuclear interaction. Discovery of hidden dimensions could point the way to a unification of gravity with the other forces of nature.

The major activities under the Proton Accelerator-Based Physics subprogram are broad research programs using the CDF and D-Zero detectors at the Tevatron at Fermilab; the neutrino research program using the NuMI/MINOS facility at Fermilab and at the Soudan Mine site in Minnesota; the LHC program; and maintenance and operation of these facilities. The Tevatron collider programs will address many key questions about the Standard Model and the physics of the "TeV scale" as described above. The NuMI/MINOS program will perform decisive controlled measurements of fundamental neutrino properties, including neutrino oscillations that will provide important clues and constraints to the theory of matter and energy beyond the Standard Model. The LHC program will substantially increase the power of the U.S. high energy physics research program to explore physics beyond the Standard Model and will enable it to be a key player at the next energy frontier. There are also much smaller specialized efforts at other accelerators worldwide.

Physics at the energy frontier is the primary thrust of the Proton Accelerator-Based Physics subprogram. In FY 2007, the energy frontier remains at the Fermilab Tevatron. The CDF and D-Zero experiments will make precision measurements of known particles, like the mass of the W boson and the top quark – by far the most massive fundamental particle known. The number of top quarks accumulated and studied during the previous Tevatron collider run was less than 100. The new run will produce an order of magnitude more top quarks and allow a serious study of its mass, spin, and couplings. These precision measurements give indirect but important information about the major theories on electroweak unification and that information can guide and constrain the direct searches. They will also pursue the questions of electroweak unification with direct searches for the Higgs boson, supersymmetry, and hidden dimensions. When the LHC at CERN is operational, the energy frontier will move there and the Compact Muon Solenoid (CMS) and A Toroidal LHC Apparatus (ATLAS) experiments will take over the program begun at the Tevatron.

The Tevatron at Fermilab is the highest-energy particle accelerator in the world. It produces collisions of 1 TeV protons with 1 TeV antiprotons. Because of the high energy of the collisions and the fact that the particles interact in several different ways, the collisions can be used to study a wide variety of physics topics. All of the six different types of quarks are produced in these interactions, and the heaviest, the top and bottom quarks, are of the greatest interest. Most of the force-carrying particles are also directly produced and if the masses of predicted – but as yet unobserved – particles, such as the Higgs boson or supersymmetric particles are low enough, they will also be produced at the Tevatron. Its two large general-purpose detectors, CDF and D-Zero, mine this rich lode of physics. Precise measurements of the mass of the W boson and detailed studies of the charm quarks will also be carried out.

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 be produced and formed into beams for experiments. The Proton Accelerator-Based Physics subprogram uses both of these aspects of proton accelerators.

Today, neutrino physics presents one of the most promising avenues to probe for extensions of the Standard Model. There is no fundamental reason why neutrinos should not have mass or why there should be no mixing between different neutrino species. In the last decade, a number of interesting new results have been reported by several different experiments, including the Liquid Scintillation Neutrino Detector (LSND) experiment at Los Alamos, 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 that they do change their identities (the different neutrino species "mix") as they travel. Unfortunately, the neutrinos used by these experiments have a wide range of energies and are produced in insufficient numbers to precisely measure their mixing parameters. One of the unique opportunities in the Proton Accelerator-Based Physics subprogram is to explore and make precision measurements of neutrinos generated at dedicated proton beam facilities in a well-controlled environment (e.g., the Neutrinos at the Main Injector beam at Fermilab).

The American Physical Society's report, *The Neutrino Matrix*, described a broad program using a variety of tools to attack the exciting opportunities 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, Electron Neutrino Appearance (EνA) Detector, will begin engineering design in FY 2007 and is planned to utilize the NuMI beam.

Research and Facilities

The Research category in the Proton Accelerator-Based Physics subprogram supports the university and laboratory based scientists performing experimental research at proton accelerator facilities in the U.S. and abroad. Experimental research activities are collaborative efforts by research groups from Argonne National Laboratory (ANL), Brookhaven National Laboratory (BNL), Fermilab, LBNL, and about 60 colleges and universities and include: planning, design, fabrication and installation of experiments and associated computing infrastructure; preparation for experimental operations and conduct of experiments; analysis and interpretation of data; and publication of results. These research programs are carried out at various facilities where the accelerators and detectors are located, and at the universities where many of the scientists are located. The university program also provides a small amount of funds at national laboratories (so-called "university service accounts") to allow university groups to travel and perform specific tasks connected with the experimental research program, such as purchasing needed supplies from laboratory stores.

The Facilities category in the Proton Accelerator-Based Physics subprogram supports maintenance, operation, and technical improvements for proton accelerator facilities in the U.S. In addition, this category supports the U.S. share of detector maintenance and operations, software and computing infrastructure, and directed technical R&D for international proton accelerator facilities such as the LHC at CERN. Facilities activities include: installation, commissioning, maintenance and operations of accelerators and experiments; provision of computing hardware and software infrastructure to support the experiments and the accelerators, and provision of platforms for data analysis; and directed R&D for accelerator and detector enhancements and performance improvements. Since physicists are often involved in these activities as well as research activities, some are partially supported by both categories of funding where appropriate.

The proton accelerator facilities support personnel are based primarily at ANL, BNL, Fermilab, and LBNL, working together with experimental groups from various universities and foreign institutions.

Highlights

Recent accomplishments include:

- The CDF and D-Zero detectors at Fermilab have collected over 8 times more data in Run II of the Tevatron collider than in all of Run I (1992-1996). The collaborations published their first papers from Run II in 2004 and have presented a large number of new results at conferences. The number of publications based on Run II data has tripled in 2005 and will continue to increase. These detectors have much greater sensitivity than before and will make numerous high-precision measurements, including the masses of the top quark and the W boson. The most recent measurements of top and W masses from CDF and D-Zero imply that the Higgs boson is most likely to have a mass around 115-120 GeV, just beyond the limits of past direct searches at CERN.

- An accelerator-based neutrino program in the U.S. was launched in 2002 when the MiniBooNE detector at Fermilab began taking data using a low-energy proton beam to confirm or refute hints of neutrino oscillations discovered at Los Alamos in the LSND experiment. The data taking will be completed and results are expected by fall of 2006.
- The NuMI beamline and the associated MINOS detectors have been completed and have begun operations. They are making precision measurements of muon neutrino properties.

The major planned efforts in FY 2007 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, ANL, BNL, LBNL, 56 U.S. universities, and institutions in over 20 foreign countries. The major effort in FY 2007 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.
- *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 2007 will be data taking and analysis, along with optimizing accelerator performance to improve beam intensity for higher statistics.
- *A new detector for neutrino physics.* Engineering design begins in FY 2007 for a new experiment, the Electron Neutrino Appearance (EνA) Detector. A multi-division study from the American Physical Society has identified a series of opportunities in neutrino physics. The EνA Detector is one component of a program developed from that study. It plans to utilize 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 occurrence of these particular neutrino "flavor" changes is expected to be much rarer than the phenomenon that MINOS is studying.
- *Planning and preparation for the U.S. portion of the research program of the LHC*. A major effort in FY 2007 will continue to be the implementation of the U.S. data handling and computing capabilities needed for full participation in the LHC research program. Commissioning and maintenance of U.S.-supplied detectors for LHC experiments will continue at CERN.

Detailed Justification

	(dollars in thousands)		
	FY 2005	FY 2006	FY 2007
Research...	**78,261**	**76,384**	**79,738**
▪ **University Research**......................................	**45,619**	**45,526**	**47,694**

The university 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 rationale and preliminary designs for future experiments; and train graduate students and post-docs. University 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

	FY 2005	FY 2006	FY 2007

(dollars in thousands)

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 at an overall level commensurate with the effort needed to carry out the experiments. Proton accelerator activities concentrate mainly on experiments at the Tevatron Collider at Fermilab; development of the physics program for the LHC, under fabrication at CERN; and the MINOS and MiniBooNE neutrino experiments at Fermilab and the Soudan Mine.

In FY 2007, the overall level of support is increased above the FY 2006 level-of-effort to maintain strong participation in both the Tevatron and LHC physics programs. Within the total, there will be some redirection of effort to LHC activities in FY 2007. Full participation of university physicists is needed to exploit the physics potential of the very active program at the Tevatron during FY 2007, and there will be healthy scientific competition between the completion of the Run II of Tevatron Collider program and commissioning of the LHC experiments. To the extent possible, 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 high-priority experiments such as CDF, D-Zero, and MINOS and U.S. participation in the LHC research program.

▪ **National Laboratory Research**	**31,159**	**29,696**	**30,548**

The national laboratory research program consists of groups at several laboratories participating in experiments at proton accelerator facilities. These groups participate in all phases of the experiments, with the focus of the physics program being similar to that of the university groups described above. Although they lack the specific educational mission of their colleagues at universities, they are imbedded in the laboratory structure and therefore 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 from independent peer reviewers. Proton accelerator activities concentrate on experiments at the Tevatron complex (collider and neutrino physics programs) at Fermilab and the LHC at CERN.

In FY 2007, the national laboratory research program is maintained at approximately the FY 2006 level of effort to maintain strong participation in both the Tevatron and LHC physics programs. Full participation of national laboratory physicists is needed to exploit the physics potential of the very active program at the Tevatron during FY 2007, and there will be healthy scientific competition between the completion of the Run II of Tevatron Collider program and commissioning of the LHC experiments. The laboratory experimental physics research groups will be focused mainly on data taking with the CDF, D-Zero, and MINOS experiments, and analysis of data taken during previous years; support for commissioning of the ATLAS and CMS detectors for the LHC; and for physicists working on preparation for U.S. participation in the LHC Research Program. HEP will monitor progress in these areas, and balance resources as needed to achieve the optimal 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, analysis of the MiniBooNE experiment, and research activities related to the neutrino initiatives, such as the EvA

	(dollars in thousands)		
	FY 2005	FY 2006	FY 2007

experiment. These activities by physicists at the host laboratory provide the necessary close linkages between the Research and the Facilities categories in the Proton Accelerator-Based Physics subprogram.

Research activities at LBNL will be dominated by the ATLAS research and computing program, along with analyzing data from the CDF experiment.

Activities by the BNL research group will cover data taking and analysis of the D-Zero experiment, the ATLAS research and computing program, and a small effort on the MINOS experiment and research activities related to the 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 activities related to the future neutrino initiatives.

	FY 2005	FY 2006	FY 2007
▪ **University Service Accounts**	**1,483**	**1,162**	**1,496**

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 U.S. proton accelerator facilities. Funding for these university service accounts is increased in FY 2007, reflecting the overall size of the University Research program, and work at the new LHC Physics Center at Fermilab.

	FY 2005	FY 2006	FY 2007
Facilities	**313,099**	**298,715**	**296,798**
▪ **Tevatron Complex Operations**	**190,305**	**191,500**	**191,500**

Operations at Fermilab will include operation of the Tevatron accelerator complex for both collider and neutrino physics programs, including operations of two collider detectors and a neutrino experiment. In FY 2007, increased power costs for Accelerator Operations are offset as implementation of Run II accelerator upgrades is completed. For Detector Operations, improved operational efficiencies in FY 2007 offset increased costs due to infrastructure (i.e. increased power costs) and enhanced operational requirements as fully upgraded detectors come on-line.

This will be a major physics run for the D-Zero and CDF detectors with the higher intensity available from the Main Injector. The Tevatron performance has continued to improve according to plan through FY 2005 and this is to be one of the major data collection periods for the collider experiments pursuing physics topics from the energy frontier facility.

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

	FY 2005	FY 2006	FY 2007
Tevatron Complex Operations in hours	5,040	4,320	4,560

	(dollars in thousands)		
	FY 2005	FY 2006	FY 2007
▪ **Tevatron Complex Improvements**	**47,050**	**24,255**	**24,255**

The funding in this category includes GPP funds at Fermilab, funding for accelerator improvements, experimental computing expansion, and new detector fabrication. Accelerator improvements to increase the luminosity performance of the Tevatron Collider will be completed in FY 2006. In FY 2007, funding will support those improvements needed to increase the intensity and reliability of the proton source in order to enhance the neutrino physics program. In addition, the project engineering and design of the Electron Neutrino Appearance (EνA) Detector begins in FY 2007. Funding for this project is described in the Construction section of this request.

Pre-conceptual R&D is supported for a potential new small experiment in the MINOS near detector hall at Fermilab that will measure the rates of neutrino interactions with ordinary matter. This is very useful input data for MINOS and other neutrino experiments and can be done with much better precision than previous experiments with the powerful NuMI beam.

▪ **Large Hadron Collider Project**	**32,500**	**7,440**	**3,180**

The LHC has immense potential for resolving fundamental questions about the basic forces and symmetries that determine the properties of the universe. The origin of mass and the mechanism for breaking of symmetries in nature, the existence of totally new types of matter, e.g., the supersymmetric (SUSY) particles and the possibility of space having extra dimensions are but a few of the fascinating ideas that will be investigated with data from the LHC.

The goals of the physics program at the LHC include a search for the "Higgs" particle, which is thought to be responsible for the origin of mass, the exploration of the detailed properties of the top quark to determine whether this most massive fundamental object can offer insight into the nature of symmetry breaking, and the search for anticipated but not fully delineated new phenomena.

As part of the U.S. participation in the LHC program, DOE and NSF have entered into a joint agreement with CERN specifying U.S. contributions to the LHC accelerator and detectors. This agreement, approved by CERN, the DOE and the NSF in December of 1997, assures access for U.S. scientists to the premier high energy physics facility of the next decade. In addition to specifying the U.S. contributions to the LHC, as detailed below, the agreement and its incorporated protocols specify that U.S. scientific institutions have the right to fully participate in the ATLAS and CMS experiments, and that CERN will provide standard services and facilities "free of charge," including particle beams and beam time, for the duration of the experiments.

The members of the U.S. LHC Project assumed full responsibility for the design and fabrication of specific subsystems of the accelerator complex and the two large detectors. Much of the funding for the project was therefore channeled directly to participating U.S. laboratories and university groups, and their U.S. contractors for the fabrication of subsystems and components that are to become part of the LHC accelerator or the two major detectors. Some of the project funds have also been allocated directly to CERN to pay U.S. vendors for purchases of material and components needed in the fabrication of the accelerator.

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

The total cost of the LHC on a basis comparable to that used for U.S. projects is estimated as about $6,000,000,000. (This estimate, prepared by CERN, does not include the costs of the permanent laboratory staff nor other standard laboratory resources made available for the design and fabrication of the LHC machine.) The total DOE contribution of $450,000,000 and the estimated cost of $6,000,000,000 for fabrication of the LHC accelerator do not include support of the European and U.S. research physicists participating in the program.

The agreement negotiated with CERN provides for U.S. involvement in the management of the project through participation on key international oversight committees (CERN Council, CERN Committee of Council, LHC Board, etc.). This offers an effective base from which to monitor the progress of the project, and helps ensure that U.S. physicists have full access to the opportunities available in the scientific program of the LHC. The Office of Science has examined the cost and schedule of the entire LHC project and has held regular reviews of the specific U.S. funded components of the LHC. The reviews have concluded that, in general, the costs were estimated properly and that the schedules were reasonable and on track, and continue to be so.

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. This involvement, supported by the core research funds of the DOE and the NSF has grown quite dramatically, with over 800 U.S. scientists now members of the U.S.-ATLAS detector collaboration, the U.S.-CMS detector collaboration or the U.S.-LHC accelerator consortium. Most of the effort in FY 2007 will be devoted to the U.S. LHC Research Program that will deploy the infrastructure needed for exploiting the physics opportunities presented by the new energy frontier to be opened in the first collisions at the LHC in 2007.

Previous fabrication and technical difficulties in the CERN-funded and CERN-managed portion of the LHC accelerator led to delays in the entire project. The problems now appear to be resolved, with the latest CERN schedule indicating first collisions in 2007. While the U.S. has no direct control over the LHC schedule, we maintain close contact with CERN management and the U.S. LHC project managers to ensure that schedules for U.S. deliverables conform to those of CERN. Changes in the funding profile of the three U.S. LHC projects, now matched to the updated LHC fabrication schedule developed by CERN, will enable the U.S. LHC Project to comply with the latest CERN schedule, without affecting the expected completion date or the total U.S. cost.

The detailed plans of the three U.S. LHC projects continue to be reviewed and updated in the context of any revisions by CERN. The overall U.S. LHC Project reached a status of 97% complete by the end of FY 2005, in compliance with the “CD-4a” project-completion requirement prescribed by the DOE. Most of the equipment is already at CERN, and the remaining portion of the accelerator project is to be completed by March 30, 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 complete detectors, as well as to the purchase of computing hardware for data acquisition. Under the current schedule, this will take place in 2006 and 2007, in full agreement with the U.S. DOE deadline for the completion of the project. The increased costs arising from the delays in the initial schedule are modest and will be contained within the projects' contingency allowances. The overall result of these changes in the CERN schedule has been a stretch-out by two years in the planned U.S. contributions to the LHC detectors. The FY 2007 funding for the detectors reflects the current plans. The final cost of each detector remains unchanged.

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[b]	—	7,440	7,440	—
2007	—	3,180	3,180	—
Total	200,000[c]	250,000	450,000	81,000

[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] At the end of FY 2005 approximately 95% of the U.S. CMS and U.S. ATLAS detector projects was completed on schedule. The remaining 5% of the project scope is integrally connected to the CERN portion of the project. As such, the recent slip in the CERN project schedule will significantly impact our ability to complete the remaining 5% of this project on the present schedule. The 95% portion of this project that will be complete at the end of FY 2005 will be closed out at that time. The remaining 5% of the project will continue, consistent with DOE project management policies and practices. Based on CERN's current schedule, it is anticipated that the remaining work will be completed by the end of FY 2008, with no change in the total estimated cost of the project.

[c] 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.

LHC Accelerator and Detectors Funding Summary

	(dollars in thousands)		
	FY 2005	FY 2006	FY 2007
LHC			
Accelerator Systems			
Operating Expenses	283	—	—
Capital Equipment	4,137	—	—
Total, Accelerator Systems	4,420	—	—
Procurement from Industry	17,027	—	—
ATLAS Detector			
Operating Expenses	1,626	1,642	1,034
Capital Equipment	3,863	1,598	846
Total, ATLAS Detector	5,489	3,240	1,880
CMS Detector			
Operating Expenses	2,054	1,300	50
Capital Equipment	3,510	2,900	1,250
Total, CMS Detector	5,564	4,200	1,300
Total, LHC	32,500	7,440	3,180

Changes, based on actual expenditures and progress made during FY 2005, and updated planning based on the experience during FY 2005, have been made by each of the three U.S. projects, and approved by DOE.

In FY 2006 and FY 2007, funding will be used for completing the fabrication of detector subsystems such as tracking chambers and data acquisition electronics.

All these LHC deliverables were manufactured at many different locations, including 4 DOE laboratories and 60 U.S. universities. Most are now being installed and commissioned at CERN.

	(dollars in thousands)		
	FY 2005	FY 2006	FY 2007
• **Accelerator Systems**	**4,420**	—	—

All fabrication activities including production of quadrupole magnets, cryogenic/electrical power feed boxes, and beam absorbers for the LHC beam interaction regions were 98% complete at the end of FY 2005, per current LHC project execution plan. Testing of superconducting wire and cable for the LHC main magnets was completed in FY 2005, as planned. No project funds are needed for the accelerator after FY 2005.

• **Procurement from Industry**	**17,027**	—	—

Final funding will be provided in FY 2005 to support reimbursement to CERN of purchases from U.S. industry that included superconducting materials, superconducting wire, superconducting cable, cable insulation, and other technical items.

	(dollars in thousands)		
	FY 2005	FY 2006	FY 2007
• **ATLAS Detector**	**5,489**	**3,240**	**1,880**

In FY 2007, funding will primarily support completion of the installation and pre-commissioning of the remaining U.S.-supplied equipment at CERN, namely the transition-radiation tracker (barrel), the tile calorimeter, the silicon inner tracker, and the muon drift-tube chambers. In addition, with the imminent turn-on of the accelerator, completion of elements of the trigger and data acquisition system, and the purchase of components of associated computing hardware will be a major goal.

• **CMS Detector**	**5,564**	**4,200**	**1,300**

In FY 2007, funding will primarily support completion of the installation and pre-commissioning of the remaining U.S.-supplied equipment at CERN, namely the hadron calorimeter endcap muon chambers, electronics for the electromagnetic calorimeter, and the silicon detectors, including the pixel layers. In addition, with the imminent turn-on of the accelerator, completion of elements of the trigger and data acquisition system, and the purchase of components of associated computing hardware will be a major goal.

▪ **Large Hadron Collider Support**	**29,401**	**52,641**	**56,820**

With final preparations for LHC turn-on in mid 2007, the U.S. LHC Research Program, also negotiated by the DOE and NSF in the agreement with CERN, will enter a critical phase in FY 2007. Increases of 8% above FY 2006 in this area are planned. 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. LHC effort is one of the high priority components of the HEP program, and endorsed repeatedly by HEPAP. With quality data expected before the end of FY 2008, it is imperative to focus attention on the needs anticipated during the start-up of operations in FY 2007.

Funding for pre-operations of the LHC detector subsystems built by U.S. physicists will increase somewhat in FY 2007. This effort will support the 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 pre-startup activities at the LHC, ensuring proper commissioning and operation of U.S.-supplied components. U.S. CMS collaborators will perform integration tests of the major detector subsystems using final data-acquisition systems. U.S. ATLAS collaborators will commission all their detector subsystems. The effort on detector R&D, with specific focus on a possible LHC upgrade in luminosity will start to increase. Support will also be provided for technical coordination and program management and for analysis, both at the participating U.S. national laboratories and at CERN. The U.S. LHC Accelerator Research Program (LARP), supported only by the DOE, will focus R&D on producing full-scale accelerator-quality magnets with the highest possible sustained magnetic fields. This R&D also provides important technical data to CERN for management decisions on possible future LHC accelerator upgrades to improve luminosity. This effort ramped-up significantly in FY 2006. It continues at that same level, as fabrication begins on advanced prototypes of state-of-the-art LHC interaction region magnets made of optimized niobium-tin (Nb_3Sn) superconductor material.

The LHC software and computing effort will enable U.S. physicists to analyze the vast quantities of LHC data in a transparent manner, and empower them to play a leading role in exploiting the physics

	(dollars in thousands)		
	FY 2005	FY 2006	FY 2007

opportunities presented by the LHC. The LHC Software and Computing program will also enter a critical year in FY 2007, when the combination of software development, facilities hardware and support, and grid computing must come together. Prior to FY 2007 the U.S. effort will be focused on serious 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 grow rapidly from prototypes to fully functional systems in 2006. The planned funding ramp-up in FY 2006 will provide 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 maintain the central role during data analysis that they played during fabrication of detectors. During this period, grid computing solutions will be integrated in the LHC computing model, providing U.S. researchers the access and computing power needed to analyze the large and complex LHC data. FY 2007 will form the final testing ground for the completed systems.

	FY 2005	FY 2006	FY 2007
▪ **Alternating Gradient Synchrotron (AGS) Support**	**650**	**650**	**650**

Operations at BNL for HEP experiments using the AGS facility were terminated at the end of FY 2002. Funding continues for close-out costs and long-term decontamination and decommissioning (D&D).

	FY 2005	FY 2006	FY 2007
▪ **Other Facilities**	**13,193**	**22,229**	**20,393**

Includes funding for private institutions and other government laboratories and institutions that participate in high energy physics research. This category also includes funding to respond to new opportunities and unexpected changes in facilities operations and support.

Includes $1,624,000 for General Purpose Equipment and $4,065,000 for General Plant Projects at LBNL for landlord related activities.

	FY 2005	FY 2006	FY 2007
Total, Proton Accelerator-Based Physics	**391,360**	**375,099**	**376,536**

Explanation of Funding Changes

	FY 2007 vs. FY 2006 ($000)
Research	
▪ University Research is increased to maintain strong participation in both the Tevatron and LHC physics programs. Full participation of HEP researchers is needed to exploit the physics potential of the very active program at the Tevatron during FY 2007, in parallel with final commissioning of the LHC experiments	+2,168
▪ National Laboratory Research is increased to maintain strong participation in both the Tevatron and LHC physics programs, as above	+852

	FY 2007 vs. FY 2006 ($000)
▪ In University Service Accounts, the increase is consistent with the increased need for LHC-related work (e.g., remote commissioning activities) at Fermilab.	+334
Total, Research	**+3,354**
Facilities	
▪ In LHC Project, the decrease reflects the revised funding profile consistent with the changes to the CERN LHC completion date and its impact on the U.S. portions of the LHC detector sub-projects. The total project cost is unchanged	-4,260
▪ In LHC Support, the increase is provided in the computing systems and networks to form the final testing ground for the completed systems. The support for the detector pre-operations is also increased, as fabrication begins on initial prototypes for upgraded LHC quadrupole magnets.	+4,179
▪ In Other Facilities, resources held pending completion of peer and/or programmatic review decrease as new R&D initiatives commence.	-1,836
Total, Facilities	**-1,917**
Total Funding Change, Proton Accelerator-Based Physics	**+1,437**

Electron Accelerator-Based Physics

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2005	FY 2006	FY 2007
Electron Accelerator-Based Physics			
Research	26,324	23,509	24,568
Facilities	108,677	93,524	92,892
Total, Electron Accelerator-Based Physics	135,001	117,033	117,460

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.

Benefits

The Electron Accelerator-Based Physics subprogram utilizes accelerators with high-energy and ultra-accurate 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 precise theory of electromagnetic and weak 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. The measurement of "CP violation" is considered by physicists to be vital to understand why the universe appears to be predominantly matter, rather than an equal quantity of matter and antimatter, one of the greatest puzzles we face in comprehending the universe. This subprogram addresses two of the six long-term indicators that contribute to the Program Goal and several of the key HEP questions identified in the Overview section above.

Supporting Information

While electron accelerators can be used to study a wide variety of physics topics, and historically have been so used, the current electron accelerator subprogram is 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 needed to explain the fact that our universe is mostly made of matter and not antimatter.

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 at the KEK B-factory, a similar accelerator in Japan at their national laboratory for high energy physics (KEK), 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 systematic study required both new measurements of CP violation in other B meson decays, and 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, and our limited current knowledge of those properties also limits our understanding of CP violation.

Since 1999, the BaBar experiment at the SLAC B-factory has pursued a broad program of physics studies on particles containing bottom or charm quarks as well as other measurements that support or complement the CP violation program. The Belle experiment at the KEK B-factory has carried out a very similar program. A small number of U.S. university researchers participate in the Belle experiment. There has been regular cooperation as well as competition between the BaBar and Belle experiments that has led to a better understanding of results that are more precise. The CLEO-C experiment at the Cornell Electron Storage Ring (CESR) has been concentrating on certain precision measurements of particles containing charm quarks that are difficult to do at the B-factory. These are used both for testing the theories used to interpret the CP violation measurements and as input to the physics analyses done at the B-factory.

Research and Facilities

The Research category in the Electron Accelerator-Based Physics subprogram supports the university and laboratory based scientists performing experimental research at electron accelerator facilities in the U.S. and abroad. Experimental research activities are collaborative efforts by research groups from LBNL, LLNL, SLAC, and about 40 colleges and universities, along with a large number of foreign research institutions, and include analysis and interpretation of data and publication of results. The university program also includes a small amount of funds at national laboratories (so-called "university service accounts") to allow university groups to perform specific tasks connected with the experimental research program.

The Facilities category in the Electron Accelerator-Based Physics subprogram supports the maintenance and operations of, and technical improvements to, electron accelerator facilities in the U.S., including: installation, commissioning, maintenance and operations of accelerators and experiments; providing computing hardware and software infrastructure to support the experiments and the accelerators, and provide platforms for data analysis; and directed R&D for accelerator and detector enhancements and performance improvements. Since physicists are often involved in these activities as well as research activities, some are partially supported by both categories of funding where appropriate.

The electron accelerator facilities support personnel are based primarily at LBNL, LLNL, and SLAC, working together with the experimental groups from various universities and foreign institutions.

Highlights

Recent accomplishments include:

- In FY 2005, the SLAC B-factory delivered 53.5 fb^{-1} (inverse femtobarns) of which the BaBar detector recorded 51.1 fb^{-1}. BaBar promptly analyzed and presented the latest results with over 170 submitted publications since 1999, of those 51 appeared during FY 2005. At a major summer conference, Lepton-Photon 2005, BaBar contributed 75 abstracts on the full spectrum of new results.
- BaBar made substantial progress in a comprehensive set of measurements for CP-violating asymmetries, a systematic exploration of rare decay processes, and detailed studies to elucidate the dynamics of processes involving heavy quarks. Data collected to date are consistent with the current Standard Model description of CP violation, although there are possible indications of new physics in the data, as discussed below.

- Combined data from BaBar and Belle continue to show hints of possible new physics beyond the Standard Model in a class of B meson decays to particles (such as K mesons) which contain the strange quark. Current statistics are not sufficient to make a definitive measurement in any single decay mode and several related decays must be averaged to observe the effect. If the effect is real, it should be convincingly demonstrated (or ruled out) with approximately a factor of 2 increase in the total dataset for each experiment, which is expected to be accumulated by 2007.

The major planned efforts in FY 2007 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 2007 this effort will focus on data taking with the upgraded accelerator and detector. The physics issues to be addressed include expanding our understanding of the matter-antimatter asymmetry in many particle decay modes and the origin of mass in the universe.
- *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.

Detailed Justification

	(dollars in thousands)		
	FY 2005	FY 2006	FY 2007
Research..	**26,324**	**23,509**	**24,568**
▪ **University Research**	**14,865**	**15,000**	**15,539**

The university program consists of 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 post-docs. The current Electron Accelerator-Based Physics subprogram is focused on the study of charm and bottom quarks and the tau leptons that 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 that is needed to explain the fact that our universe is mostly made of matter and not antimatter. 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.

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 will also support five groups that work at the CESR at Cornell University; and four groups that work at the KEK-B accelerator complex in Japan. The CLEO-C experiment at the CESR is concentrating on certain precision measurements of particles containing charmed quarks that are difficult to do at the B-factory. There is regular cooperation as well as competition between the SLAC and KEK experiments that has led to a better understanding of how to do the data analysis

	FY 2005	FY 2006	FY 2007

(dollars in thousands)

leading to physics results that are more precise than they would be otherwise. University-based research efforts will be selected based on peer review.

In FY 2007, the university program is maintained at approximately the FY 2006 level-of-effort in order to support analysis of the unprecedented amount of physics data generated by the B-factory and other electron accelerators. To the extent possible, the detailed funding allocations will take into account the involvement of university based research groups in the targeted physics research activities. These include research efforts related to the high priority experiments such as BaBar.

▪ **National Laboratory Research**	**11,197**	**8,275**	**8,698**

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. In addition, 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 imbedded in the laboratory structure, they provide invaluable service in the upgrade, calibration and operation 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 software 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 2007, the national laboratory research program is increased to maintain strong participation in both the B-factory research program, and to efficiently maintain B-factory operations.

▪ **University Service Accounts**..........................	**262**	**234**	**331**

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 U.S. electron accelerator facilities.

Facilities..	**108,677**	**93,524**	**92,892**
▪ **B-factory Operations**	**94,617**	**77,024**	**82,892**

Funding for operations supports continued running of the accelerator and the operation of the BaBar detector for data collection for 5,200 hours. An additional $40,000,000 is provided for SLAC linac operations in support of the Linac Coherent Light Source (LCLS) project by the Basic Energy Sciences (BES) program (see the *Facilities* section of the BES Materials Science and Engineering subprogram). Including the operations support from BES, the increase in total operations funding over FY 2006 is needed to pay for longer running time along with increased power costs.

BaBar will be the priority HEP research program at SLAC in FY 2007. It is anticipated that the collected data will be twice the total collected in FY 2006 and ensure a U.S. leadership role in the program to study the excess of matter over antimatter in the universe and allow researchers to continue to extract all the physics: resolving whether current intriguing discrepancies in physics

	(dollars in thousands)		
	FY 2005	FY 2006	FY 2007

results between the SLAC B-factory and the Japanese B-factory are signs of new physics; searching for other discoveries that may be revealed with a factor of two increase in data; and maintaining a world leadership role in the field of B-physics.

	FY 2005	FY 2006	FY 2007
B-factory Operations in hours	3,380	5,200	5,200

▪ **B-factory Improvements**	**14,060**	**16,500**	**10,000**

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 provided over the past few years. Overall funding is reduced as incremental upgrades to the accelerator and detector are completed in FY 2006. Activities in this category also include support for GPP funding to renew site-wide infrastructure.

Total, Electron Accelerator-Based Physics	**135,001**	**117,033**	**117,460**

Explanation of Funding Changes

	FY 2007 vs. FY 2006 ($000)
Research	
▪ In University Research, an increase is provided to maintain approximately the FY 2006 level-of-effort in order to carry out the BaBar research program with sufficient research personnel to analyze data and operate the BaBar detector.	+539
▪ In National Laboratory Research, an increase is provided to efficiently maintain B-factory operations and to maintain strong participation in the BaBar research program.	+423
▪ In University Service Accounts, the increase supports ongoing research of university groups working at the B-factory.	+97
Total, Research	**+1,059**
Facilities	
▪ In B-factory Operations, the increase is provided to support full operations of the B-factory in FY 2007, including increased power costs, along with higher data rates resulting from detector and accelerator upgrades completed in FY 2006.	+5,868

	FY 2007 vs. FY 2006 ($000)
▪ In B-factory Improvements, the decrease is due to the planned ramp down of accelerator and detector improvement activities	-6,500
Total, Facilities	**-632**
Total Funding Change, Electron Accelerator-Based Physics	**+427**

Non-Accelerator Physics

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2005	FY 2006	FY 2007
Non-Accelerator Physics			
University Research	15,716	16,350	17,271
National Laboratory Research	23,103	21,854	25,957
Projects	16,421	9,049	15,554
Other	350	763	489
Total, Non-Accelerator Physics	55,590	48,016	59,271

Description

The mission of the Non-Accelerator Physics subprogram is to foster fundamental research in high energy 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.

Benefits

The Non-Accelerator Physics subprogram provides U.S. leadership in the study of those aspects of the fundamental nature of particles, forces and the universe that cannot be determined solely through the use of accelerators. These activities—including the search for or measurement of dark matter and dark energy—have the capability of probing the basic structure and composition of the universe not easily or directly accessible through accelerator-based experiments and provide complementary experimental data, new ideas and techniques. The research activities explore and discover the laws of nature as they apply to the basic constituents of matter and therefore align with the program mission on investigations of elementary particles and their interactions. This subprogram addresses two of the six long-term indicators that contribute to the Program Goal and several of the key HEP questions identified in the Overview section above.

Supporting Information

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 pursue searches for surprising discoveries, such as dark matter, dark energy, Majorana neutrinos, proton decay, the highest energy cosmic rays, or primordial antimatter. They also study the properties of neutrinos from the sun, galactic supernovae, terrestrial nuclear reactors and cosmic rays in the earth's atmosphere. In addition, high energy gamma ray observations yield information about active galactic nuclei, gamma ray bursters, massive black holes, and particle acceleration mechanisms beyond the capabilities of accelerators on earth. These areas of research probe well beyond the Standard Model of particle physics and offer possibilities for discovery of significant new physics. These experiments utilize particle physics techniques, scientific expertise, and 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 NASA, NSF, Naval Research Laboratory (NRL), and the Smithsonian Astrophysical Observatory. Strong interagency coordination and collaboration is one of the hallmarks of the projects in this subprogram. As with 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 these experimental measurements. While research activities (including remote site operations of Non-Accelerator Physics experiments) are covered under the Research categories, the Projects category 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; the Whipple Observatory and Kitt Peak National Observatory in Arizona; the Pierre Auger Observatory in Argentina; the Stanford Underground Facility at Stanford University; 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 activities supported in this category include R&D and operations related to the Gamma-ray Large Area Space Telescope (GLAST), the Large Area Telescope (LAT) by SLAC, and the Alpha Magnetic Spectrometer (AMS) led by Massachusetts Institute of Technology (MIT).

Highlights

Recent accomplishments include:

- The Sloan Digital Sky Survey (SDSS), using data from its galaxy survey, the largest ever collected, measured the imprint on nearby galaxies of matter oscillations in the very early universe. These data help to explain the role of gravity in understanding how a smooth and homogenous early universe became the clumpy array of galaxies that we see today. The data collection and processing of SDSS is managed by Fermilab and is partially supported by DOE. In 2005, additional operations were approved and called SDSS-II. This data collection will continue through 2008 and will allow the study of the structure and origins of the Milky Way galaxy and the nature of dark energy.
- The Cryogenic Dark Matter Search (CDMS II) experiment completed its full complement of 5 towers of silicon and germanium detectors in the Soudan Mine in Minnesota beginning in mid-2005. Preliminary results were reported in 2005 from data-taking with two towers, setting new world-record limits on the existence of massive dark matter particles in our galaxy, entering the realm of supersymmetric masses and interaction cross sections. The full experiment will take data through 2007, setting limits about 10 times more sensitive than its existing ones for discovery of dark matter particles, well into the realm where new particles are predicted by supersymmetry.

The major planned efforts in FY 2007 are:

- *Operation of the VERITAS Telescope Array*. VERITAS is a new 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 DOE/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.

- *Operation of the Pierre Auger Observatory*. The Pierre Auger Observatory is the world's largest area cosmic ray detector, covering about 3,000 square kilometers in Argentina, the goal of which is to observe, understand and characterize the very highest energy cosmic rays. The full array is scheduled to begin operations in 2007, and operations have already begun with the partially completed array. This research program is being carried out by an international collaboration including scientists from U.S. universities, Fermilab, and institutions from 19 foreign countries. The U.S. part of the project has been funded jointly with the NSF and a significant contribution from the University of Chicago. Fermilab provides the project management team.
- *Operation of the Axion Dark Matter experiment (Stage I)* – The ADMX Stage I, performed at LLNL, searches for "axions," particles predicted to exist from a hypothesis explaining the smallness of CP violation (matter-antimatter asymmetry) in strong interactions, which could also account for the "dark matter" in the universe. The previous experiment set the world's best limits in the search for these particles, and work on an upgrade to the experiment was completed at the end of FY 2005. The upgraded experiment has more than twice the sensitivity of the previous version because of advanced signal amplifier electronics and larger sensitive volume. Data-taking will continue into FY 2007.
- *Operation of the Enriched Xenon Observatory 200 kilogram experiment (EXO*-200). This experiment is an outgrowth of a directed R&D program, conducted by scientists at SLAC, Stanford University, and several other U.S. universities and foreign institutes. It will be operated underground at WIPP, and will search for a process known as neutrinoless double beta decay in an active detector composed of isotopically enriched liquid xenon. This decay occurs only if neutrinos have the property that they are identical to their own anti-particles (so-called "Majorana" neutrinos). This experiment will begin operations in 2007 and is expected to set the best world limits on the existence and effective mass of Majorana neutrinos when it reports results. The EXO-200 experiment also serves as a prototype for a possible, much larger scale (~1000 kg) double beta decay experiment which could measure the neutrino mass. R&D on technical options for a large-scale experiment will be pursued.
- *Preparations for launch of the Large Area Telescope (LAT).* The LAT telescope fabrication was completed at the end of 2005 and integration on the spacecraft has commenced. The LAT is the primary instrument to be flown on NASA's GLAST mission, scheduled for launch in 2007. Its goals 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 Bursters as well as search for dark matter candidates. It is complementary to the ground-based VERITAS experiment, sampling a lower energy, but somewhat overlapping, 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, NRL, U.S. universities, and institutions from Italy, France, Japan, and Sweden.
- *Participation in a Reactor Neutrino experiment*. The FY 2007 request assumes U.S. research groups will play an important role in design and fabrication of a new Major Item of Equipment, a Reactor Neutrino Detector. A multi-division study from the American Physical Society has identified

opportunities in neutrino physics, and recommended such a reactor-based experiment as part of an overall neutrino research program. This experiment will use neutrinos produced from reactors to precisely measure a crucial parameter needed to pursue the new physics opened up by the discovery of neutrino mass and mixing. The value of this parameter will help resolve ambiguities in determinations of other neutrino properties, and will help determine directions for further research in the neutrino sector.

- *R&D for future Dark Energy experiment(s)*. In order to fully determine the nature of dark energy, independent and complementary measurements are scientifically advisable. In recent years, a number of methods have been developed with different levels of theoretical and observational understanding. In FY 2007, R&D and/or conceptual design will be performed for experiments that can increase our knowledge of dark energy using ground- or space-based facilities. These facilities could include new detectors on existing ground telescopes; new ground telescope facilities (coordinated with the NSF); or space-based experiments, such as the SuperNova Acceleration Probe (SNAP) Experiment, a mission concept to be proposed for a space-based DOE/NASA Joint Dark Energy Mission (JDEM). In any case, proposals will be selected based on open competition and peer review. A Dark Energy Task Force has reported to both HEPAP and the Astronomy and Astrophysics Advisory Committee (AAAC) on their development of a scientific roadmap for the study of dark energy, and specific proposals will be assessed by a follow-on panel. These reports will aid in the development of a coordinated dark energy research program.

Detailed Justification

	(dollars in thousands)		
	FY 2005	FY 2006	FY 2007
University Research...	**15,716**	**16,350**	**17,271**

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.

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

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 2007, the university program in Non-Accelerator Physics will increase to support significant new research opportunities. Several new experiments (e.g., VERITAS, Pierre Auger, AMS, and GLAST/LAT) will have completed their fabrication phase and are moving into deployment, commissioning, operations and data analysis. To the extent possible, 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: KamLAND, an underground neutrino oscillation detector which detects reactor-produced neutrinos in Japan; Super-Kamiokande, a proton decay, solar and atmospheric neutrino detector located in the Kamioka Underground Laboratory in Japan; CDMS-II in the Soudan Mine in Minnesota; ADMX-I at LLNL, EXO-200 at WIPP, and R&D for ground- and space-based concepts for dark energy experiments. Pre-conceptual R&D will continue

	(dollars in thousands)		
	FY 2005	FY 2006	FY 2007

on a next-generation dark matter search experiment. University groups will also participate in the design, R&D and fabrication efforts for the Reactor Neutrino Detector, as described above.

R&D for a 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	**23,103**	**21,854**	**25,957**

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 detector 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 2007, the laboratory research program in Non-Accelerator Physics will increase in order to support the operations of newly completed experiments (mainly GLAST/LAT). R&D activities directed at new initiatives in dark energy and neutrino physics, and ongoing R&D of next-generation detectors to directly detect dark matter will also be supported. The laboratory experimental physics research groups will be focused mainly on supporting the spacecraft integration for the GLAST/LAT telescope and analysis of previous experimental data; operations of ADMX-I; R&D for ground- and space-based concepts for dark energy experiments; analysis of data from SDSS; and, continued operation of SDSS-II. Laboratory groups will also participate in the design of the Reactor Neutrino Detector and the R&D for the double beta decay experiment as described above.

Projects	**16,421**	**9,049**	**15,554**

In FY 2007, this effort will be focused on R&D and conceptual design for the SNAP dark energy mission concept and other potential dark energy experiments; and a new Major Item of Equipment (MIE) for a Reactor Neutrino Detector. This category also includes funding for VERITAS.

Fabrication of the VERITAS telescope is scheduled to be completed at the end of FY 2006, with operations beginning at the start of FY 2007. However, in 2005, the work on VERITAS at Kitt Peak was stopped so that the National Environmental Policy Act (NEPA) process could be redone. Since the National Science Foundation holds the lease for the Kitt Peak National Observatory, they are leading the NEPA process with DOE as a cooperating agency. Due to delays incurred in this process, it is likely that the fabrication will not be completed on schedule.

The new MIE is the start of U.S. participation in fabrication of a Reactor Neutrino Detector ($3,000,000). DOE Mission Need has been approved for this experiment. This experiment would measure a crucial unknown neutrino property by precisely measuring the disappearance of electron antineutrinos generated by the reactor as they travel several hundred meters through the earth to the underground detector. The MIE project includes the DOE contribution to the fabrication of the experiment. The technical options to deploy such an experiment are being further studied by a HEPAP Subpanel, and decisions on which option(s) to pursue will be made in 2006.

This request also supports R&D ($12,554,000) for investigating a variety of methods and technologies for dark energy measurements using ground- and/or space-based facilities. The application of this R&D funding will be determined incorporating advice from subpanels of the relevant Federal scientific

	FY 2005	FY 2006	FY 2007

(dollars in thousands)

advisory panels (described above) as well as assessment of specific proposals. As part of this effort, the FY 2007 SNAP R&D activities will focus on the conceptual design needed for a potential future space-based mission. DOE is actively engaged with NASA on planning for JDEM.

Other	**350**	**763**	**489**

This category includes funding mainly for research activities that have not yet completed 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.

Total, Non-Accelerator Physics	**55,590**	**48,016**	**59,271**

Explanation of Funding Changes

	FY 2007 vs. FY 2006 ($000)
University Research	
In University Research, the increase is provided to support significant new research opportunities with newly-operating experiments and facilities.	+921
National Laboratory Research	
In National Laboratory Research, the increase is provided to support initial operations of the GLAST/LAT telescope.	+4,103
Projects	
An increase of $3,000,000 to begin U.S. participation in fabrication of a Reactor Neutrino Detector, and an increase of $4,654,000 in the SNAP R&D effort to develop a conceptual design is offset by a decrease of $1,149,000 for the VERITAS fabrication according to the planned profile.	+6,505
Other	
The decrease reflects a slight reduction in funds held pending completion of peer and/or programmatic review.	-274
Total Funding Change, Non-Accelerator Physics	**+11,255**

Theoretical Physics

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2005	FY 2006	FY 2007
Theoretical Physics			
University Research	22,975	22,500	24,043
National Laboratory Research	16,105	15,996	17,242
SciDAC	5,000	5,000	5,000
Other	5,985	4,694	5,771
Total, Theoretical Physics	50,065	48,190	52,056

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.

Benefits

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, to illuminate the origin and evolution of the universe. Because theoretical interpretation and analysis underpins almost all progress in HEP, this subprogram addresses all of the six long-term indicators that contribute to the Program Goal and all of the key HEP questions identified in the Overview section above.

Supporting Information

Though they are typically not directly involved in the planning, design, 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. The research activities supported by the Theoretical Physics subprogram include: calculations in the quantum field theories of the 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 categories of the Theoretical Physics subprogram support scientists performing research in theoretical high energy physics and related areas of theoretical physics. The research groups are based at approximately 75 colleges and universities and at 6 DOE laboratories (Fermilab, SLAC, BNL, ANL, LBNL, and 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 NASA and NSF. 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.

Scientific Discovery through Advanced Computing

In FY 2005, the HEP program completed the original SciDAC programs in the areas of accelerator modeling and design (Advanced Computing for 21st Century Accelerator Science and Technology), theoretical physics (National Computational Infrastructure for Lattice Gauge Theory), astrophysics (SciDAC Center for Supernova Research and Shedding New Light on Exploding Stars: TeraScale Simulations of Neutrino-Driven Supernovae and their Nucleosynthesis), and applying grid technology (Particle Physics Data Grid Collaborative Pilot). Each of these projects has made significant strides in forging new and diverse collaborations (both among different disciplines of physics and between physicists and computational scientists) that have enabled the development and use of new and improved software for large-scale simulations. Examples include the development of algorithms to solve the underlying algebraic equations for multidimensional radiation transport (for supernova simulations); the first complete three-dimensional calculation of the complete evolution of a core collapse supernova; the first parallel beam-beam simulation code that includes, in a single application, weak-strong and strong-strong models, finite crossing angle, longitudinal effects, and long-range collisions via a new shifted Green function algorithm; development of a full Applications Programming Interface (API) for running lattice gauge calculations on a variety of hardware platforms; and improvement and use of grid technology in running experiments.

To build on these successes, the HEP program will re-compete its SciDAC portfolio in FY 2006 to obtain significant new insights through computational science into challenging problems that have the greatest impact in HEP mission areas.

Highlights

Recent accomplishments include:

- Observations of distant supernovae have indicated that the rate at which the Universe is expanding is actually accelerating, in contradiction to all expectations based on the attractive nature of the gravitational force. This discovery, which has been dubbed “dark energy,” has opened two new lines of theoretical work. One is the attempt to characterize the new phenomenon in such a way that future observations can most meaningfully confirm or deny its reality. The second is the attempt to find what new kinds of fundamental forces, or changes to the Einsteinian model of gravity, could give rise to this new aspect of Nature.

- High precision numerical simulations of the simplest strong interaction decay constants and mass differences, including the important but difficult "virtual quark" effects were recently carried out. The agreement between the calculated and experimental values was about one percent. This is an improvement by nearly an order of magnitude over previous calculations and was accomplished by the application of new highly efficient algorithms combined with the use of today's supercomputers. A major step completed during FY 2005 was the completion of a large scale prototype of a new generation of computers to enable simulations of more important processes. These simulations will require both the use of the completed prototype computer and the new computers being planned for fabrication in FY 2006 and beyond.
- Recently, powerful new techniques to calculate high energy strong interaction processes that will be measured at the LHC have been developed. These relevant analytic procedures came out of working the most esoteric branch of theoretical high energy physics, known as "string theory." In addition, sophisticated mathematical techniques are being employed to relate the spectra of new particles hopefully observed at the LHC to patterns of supersymmetry or possible extra dimensions.

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 2007:

- *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 as the origin of the masses of the elementary particles and the mechanism 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*. Quantum Chromo Dynamics (QCD) is a very 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 it is a strongly coupled gauge field theory. 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 precision). Some of the computational tools for this effort are provided through the SciDAC program. Progress during FY 2007 will come from the continuation of the major IT investment to fabricate the necessary computer hardware in partnership with the Nuclear Physics (NP) program.
- *Neutrino Phenomenology*. The accumulating evidence that neutrinos have mass raises a host of fundamental and timely questions: whether neutrinos might be their own anti-particles; whether there might be CP violation, or even CPT violation (the combination of CP-and Time-invariance violation), in the neutrino sector; the role of neutrinos in supernova explosions; and whether neutrinos might be the origin of the matter-antimatter asymmetry in the universe. In turn these questions have strong connections to astrophysics, cosmology, and other sectors of particle physics, so that new developments have wide-ranging impacts. New theories of neutrinos are being developed, and the active worldwide program of neutrino experiments can be expected to clarify this interesting domain of elementary particles.

- *New Ideas*. Theoretical physicists are speculating on whether there might be additional space dimensions that are normally hidden from us. It is even possible that some of these dimensions and their consequences are accessible to experiment, perhaps manifesting themselves in the production of mini-black holes at the LHC. Perhaps they 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 2005	FY 2006	FY 2007
University Research	**22,975**	**22,500**	**24,043**

The university program consists of groups at approximately 75 colleges and universities doing theoretical physics research. These university groups develop new theoretical models and provide interpretations of existing experimental data; they identify where new physical principles may be required and determine how to confirm their presence, thereby providing guidance for new experiments; they develop new mathematical and computational methods for analyzing theoretical models; and they are deeply involved in the SciDAC activities described below. The university groups train graduate students and post-docs. 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 in FY 2007. To the extent possible, the detailed funding allocations will take into account the involvement of university-based research groups in these targeted physics research activities.

In FY 2007, the university theory program is increased above the FY 2006 level-of-effort to support university 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.

National Laboratory Research	**16,105**	**15,996**	**17,242**

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, those at the laboratories are a general resource for the national research program. Through continuing interaction with a diverse set of experimental scientists, they provide a clear understanding of the significance of measurements from ongoing experiments. It is also through such discussions that they 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.

In FY 2007, 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 both the Tevatron Collider detectors, CDF and D-Zero, and preparation for the new higher energy data from the LHC. In FY 2007, the funding for the laboratory theory program will be increased above the FY 2006 level-of-effort to support laboratory research personnel participating in analysis of current and

	(dollars in thousands)		
	FY 2005	FY 2006	FY 2007

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	**5,000**	**5,000**	**5,000**

In FY 2007, the HEP program will continue support for successful new proposals selected in the re-competition of the SciDAC program in FY 2006. Proposals will be selected based on peer review. In FY 2005 there were four principal continuing HEP-supported SciDAC efforts in the areas of: advanced accelerator beam simulations; supernova simulations; platform-independent software to facilitate large-scale QCD calculations (see "Other" below); and very large scale, fault-tolerant data handling and "grid" computing that can respond to the serious data challenges posed by modern HEP experiments.

Other	**5,985**	**4,694**	**5,771**

This category 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 research activities that have not yet completed peer review, and responding to new and unexpected physics opportunities.

A coordinated effort with the NP and ASCR programs is aimed toward the development of a multi-teraflops computer facility for Lattice QCD simulations. During FY 2005, a ~5 teraflops prototype computer was built using custom chip technology. The machine is called QCDOC, named for QCD On-a-Chip (QCDOC). This platform enabled U.S. researchers to stay competitive with other worldwide efforts in computational QCD research while developing a larger-scale hardware platform. During FY 2006, a joint effort with NP to develop a facility with about 13 additional teraflops capacity was started, and in FY 2007 this program will proceed as planned.

In each year of the Lattice QCD IT investment, fabrication of computers employing the most cost-effective option will be undertaken. Given current projections of price performance for this kind of high-performance computing, the HEP contribution to this effort in FY 2007 of $2,000,000 will correspond to an additional ~3 teraflops of sustained computing performance deployed, in addition to the 5 teraflops already available from the QCDOC prototype and ~3 teraflops commodity cluster that will have been fabricated by that time.

Several key R&D activities carried out from FY 2003 through FY 2006 have enabled this program. One is the successful completion and implementation of the uniform software environment on 2 types of parallel computer platforms developed for this program under SciDAC. Another is the completion and commissioning of the 5 teraflops prototype QCDOC computer at BNL in FY 2005. A third is the program of design and optimization of commercial cluster computers carried out jointly with the NP program at Fermilab and the Thomas Jefferson National Accelerator Facility (TJNAF).

In FY 2007, a program of the most important and accessible research computations on the QCDOC computer at BNL and the cluster computers at Fermilab and TJNAF will continue. This research is expected to yield high precision calculations of parameters that are needed to interpret current experiments, particularly results from the SLAC B-factory. These calculations are expected to reduce the theoretical uncertainty in interpreting experimentally measured quantities by up to a factor of 2.

	(dollars in thousands)		
	FY 2005	FY 2006	FY 2007

This category also includes support for the QuarkNet education project ($750,000). This project takes place in QuarkNet "centers" which are set up at universities and laboratories around the country. The eventual goal 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 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, with 625 teachers, was in place in FY 2004. In FY 2007, all of these 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	**50,065**	**48,190**	**52,056**

Explanation of Funding Changes

	FY 2007 vs. FY 2006 ($000)
University Research	
University Research is increased above the FY 2006 level-of-effort to support university researchers participating in analysis of current and previous experiments, and design and optimization of new experiments.	+1,543
National Laboratory Research	
National Laboratory Research is increased above the FY 2006 level-of-effort to support laboratory researchers participating in analysis of current and previous experiments, and design and optimization of new experiments	+1,246
Other	
Reflects an increase for the Particle Data Group ($+307,000), as well as funds held for activities under this general category pending completion of peer and/or programmatic review ($+770,000).	+1,077
Total Funding Change, Theoretical Physics	**+3,866**

Advanced Technology R&D

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2005	FY 2006	FY 2007
Advanced Technology R&D			
Accelerator Science	27,623	27,923	33,016
Accelerator Development	47,963	58,030	88,030
Other Technology R&D	14,559	23,929	18,568
SBIR/STTR	—	18,474	19,862
Total, Advanced Technology R&D	90,145	128,356	159,476

Description

The mission of the Advanced Technology R&D subprogram is to foster fundamental research into 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.

Benefits

The Advanced Technology R&D subprogram provides the technologies needed to design and build the accelerator, colliding beam, and detector facilities used to carry out the experimental program essential to accomplishing the programmatic mission in high energy physics. This is accomplished by supporting proposal driven, peer reviewed research in the fundamental sciences underlying the technologies used for HEP research facilities with a particular focus on new concepts and inventions and in the reductions of these new concepts and inventions to practice; that is, developing the new technologies to the point where they can be successfully incorporated into construction projects whose performance will significantly extend the research capabilities beyond those that currently exist. Because accelerator and detector R&D underpins almost all progress in HEP research capability, this subprogram addresses all of the six long-term indicators that contribute to the Program Goal and all of the key HEP questions identified in the Overview section.

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 are useful to other science programs and to industry, flow from the work carried out in this subprogram.

Supporting Information

High Energy particle physics research remains now, and for the foreseeable future, strongly dependent on the use of high energy particle beams provided by charged particle accelerators, storage rings, and their associated detectors. Operating in the extreme domains essential for successful particle physics research demands very specialized technology that takes substantial time and expense to invent, design, build, maintain and upgrade. The R&D programs that support such technology development are unavoidably costly and long term.

Since few of the core technologies used in high energy physics research are directly marketable, industry has no motivation to develop the necessary expertise or to do the essential R&D. Consequently, 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 these 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, the applications are widely used in nuclear physics, materials science, chemistry, medicine, and industry.

In 2003, SC prepared a list of major science facilities that could be built over the next 20 years to maintain a leading U.S. scientific program of research. The list divides the needs into near term, midterm and long term. The International Linear Collider (ILC) was identified as the highest priority item for SC for a future major science facility in the midterm.

Active world-wide, inter-regional cooperation on linear collider accelerator systems, physics studies, and detector development has been underway for the past decade. In 2003, the International Linear Collider Steering Committee (ILCSC) was formed to coordinate scientific, technical, and governmental aspects of the activities leading to an international proposal to construct a linear collider. Since its inception, the ILCSC has been coordinating the activities of regional groups in the Americas, Asia, and Europe in the process of establishing a standard set of linear collider operating parameters, selection of the preferred technology to deliver the specified performance, and organizing an international collaboration. The superconducting radio frequency accelerating technology was chosen for the accelerator in September 2004. In 2005 two important steps were taken: the international organization to coordinate and provide leadership in the international R&D effort, the Global Design Effort (GDE), was established; and the GDE delivered a baseline configuration document for the ILC and established a controlled configuration change process. The baseline configuration is the basis for a reference design to be prepared by the end of 2006 and is the focus for continued progress in the internationally-coordinated R&D program.

The ILC reference design process will include a preliminary cost estimate, first steps to industrialization of the components, development of sample sites in the U.S. and elsewhere, and physics detector concepts. In parallel with the steps taken toward reaching a design for the ILC, an ad hoc group of senior science program managers from a dozen developed nations has been formed to provide support for the GDE and begin discussions on organizing a future ILC project.

Accelerator Science

The Accelerator Science category in this subprogram focuses on the science underlying the technologies used in accelerators and storage rings. 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 standards for testing of advanced superconducting materials, instrumentation standards, the physics of charged particle beams and optics, and user facilities for general support of accelerator research, such as the Accelerator Test Facility (ATF) at BNL.

Accelerator Development

The larger 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 category is work on developing very high field superconducting magnet technology, studies of very high intensity proton sources for application in neutrino physics research, and muon accelerator proof-of-principle research. When concepts develop enough to be viewed as part of a larger system or as leading to a planned or possible future proposal for a construction project, they are given special attention. The ILC is the current R&D activity in this special category.

Other Technology R&D

This category includes funding at universities under Advanced Detector Research and at universities and national laboratories under Detector Development. Advanced Detector Research is similar to Accelerator Science in that it addresses the development and application of the underlying science to new particle detection, measurement, and data processing technologies. 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:

- A new type of accelerator structure called the photonic band gap accelerator has been successfully tested in 2005 at an accelerating gradient of 30 MeV per meter in a university research program at MIT. The structure prototype has the unique property of being transparent to all radiofrequencies except the accelerating frequency. The photonic band gap principle was first discovered in the propagation of waves in crystals, and is now used to control the propagation of light in fiber optics for high speed communications. The gradient of 30 MeV/meter is 50% higher than the current operating gradient of 20 MeV/meter of the SLAC 50 GeV linac.
- Progress has been made on alternate methods of charged particle acceleration. In particular, current experiments at SLAC address the potential feasibility of a plasma wakefield "afterburner" that could potentially double the energy of a linear collider in only a few meters of plasma. An accelerating gradient of greater than 40 GeV per meter has been measured in a 30 centimeter long plasma channel for a net energy gain in excess of 10 GeV. The acceleration of positrons (anti-electrons) by particle driven plasma wake fields has also been demonstrated, an essential step if the plasma accelerators are to ever be applied to electron-positron colliders.
- At LBNL, a laser driven plasma wakefield experiment has successfully trapped a bunch of electrons in a plasma and accelerated them to energies of several hundred MeV 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 accelerator.

The major Advanced Technology R&D efforts in FY 2007 are:

- *Support for International Linear Collider R&D.* A TeV scale linear electron-positron collider has been identified by the international high energy particle physics community, including international advisory committees and HEPAP, as an essential international facility to extend particle physics research beyond what is feasible at the LHC. In FY 2007 pre-conceptual design will be completed and an R&D plan describing the industrialization plan, procurement plan, cost estimate, and schedule will be submitted to all participating governments. The R&D activities addressing critical performance and cost issues will be expanded and internationalized. The support for ILC R&D is expanded in FY 2007 to support a U.S. leadership role in a comprehensive, coordinated international

R&D program, and to provide the basis for U.S. industry to compete successfully for major subsystem contracts, should it be built.

- *Accelerator Science.* The pursuit of new acceleration concepts at universities and laboratories will be intensified to develop more options for future high-energy accelerators beyond the ILC. New concepts will be explored through simulations, and promising candidates will be tested with experiments at universities and at laboratory-based user facilities. The test capabilities of user facilities will be enhanced and operation will be expanded to meet user demand.
- *Neutrino Physics R&D.* In FY 2007 we are continuing a focused effort to develop the new accelerator and detector technologies that will be needed to address research opportunities in neutrino physics that have recently become accessible, and redirecting the funding to the proton accelerator and non accelerator subprograms. Neutrinos played an essential role in the evolution of the universe, and their recently-discovered tiny, non-zero masses imply new physics and unification at very high energies and have energized this area of research – discoveries await. But the very weak interactions with ordinary matter that make neutrinos such useful probes also make them very hard to detect, so new detector technologies and higher intensity accelerators are needed.

Detailed Justification

	(dollars in thousands)		
	FY 2005	FY 2006	FY 2007
Accelerator Science	**27,623**	**27,923**	**33,016**
▪ **University Research**	**10,015**	**9,930**	**13,037**

The increase in funding in FY 2007 will support a renewed university research program in advanced accelerator physics and related technologies. The research program will continue to pursue development of niobium-tin and similar superconductors and their application, as well as R&D in the application of high temperature superconductors; investigations of the use of plasmas and lasers to accelerate charged particles, which will focus on the use of laser driven plasma wakefields; development of novel high power radiofrequency (RF) sources for driving accelerators and for conducting high gradient research including studies of vacuum breakdown phenomena and material properties; and R&D into the issues of much higher accelerating gradient in RF superconductors. Development of advanced particle beam instrumentation; theoretical studies in advanced beam dynamics, including the study of non-linear optics; space-charge dominated beams and plasmas; and development of new computational and simulation methods and programs will also be continued. Accelerator R&D into the fundamental issues associated with the ionization cooling of muon beams is included in this effort and will be continued.

The FY 2007 budget will enable the restoration of the university program to a level that can provide support needed for long-term R&D, in parallel with overall program increases aimed at nearer-term R&D for future facilities. Modest new initiatives, including an expanded program in the physics of very high accelerating gradients, will be supported. Funds will also be directed at bringing the research infrastructure at some of the university-based laboratories up-to-date.

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.

	(dollars in thousands)		
	FY 2005	FY 2006	FY 2007
▪ **National Laboratory Research**....................	**16,178**	**16,563**	**18,323**

There are areas of Accelerator Science research that require the more extensive or specialized research facilities located at DOE national laboratories. 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 HEP program review supported by well-qualified peers, publications in professional journals, and participation in conferences and workshops.

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 2007, 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. R&D on the muon production target experiment at CERN will also be funded.

The Center for Beam Physics at LBNL is supported in FY 2007 for research in laser-driven plasma acceleration, advanced RF systems, laser manipulation and measurement of charged particle beams, and a broad program in instrumentation development, accelerator theory, and computation. R&D on muon ionization cooling and theoretical studies of alternative muon acceleration schemes will also be carried out.

The advanced accelerator R&D program at SLAC in FY 2007 will not include support for particle-driven plasma acceleration experiments, due to the loss of access to the necessary 30 GeV beam at the end of FY 2006, as construction of the Linac Coherent Light Source begins. However, HEP 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 category.

Other activities supported in FY 2007 include theoretical studies of space-charge dominated beams at PPPL and research on new means of generating high-brightness electron beams, and the use of charged particle wakefields to generate microwaves for particle acceleration at ANL.

Funding in this category in FY 2007 is increased to enhance support for simulations and testing of new accelerator concepts, including increased operation of user facilities to meet demand.

▪ **Other**..	**1,430**	**1,430**	**1,656**

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

	(dollars in thousands)		
	FY 2005	FY 2006	FY 2007
Accelerator Development	**47,963**	**58,030**	**88,030**
▪ **General Accelerator Development**	**24,216**	**28,030**	**28,030**

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 almost entirely done at BNL, Fermilab, LBNL and SLAC. The major areas of R&D are superconducting magnet and related materials technology; high-powered RF acceleration systems; instrumentation; stochastic and electron cooling technologies; beam dynamics, both linear and nonlinear; and development of large simulation programs.

The R&D program at Fermilab in FY 2007 will address a broad spectrum of technology needs for that facility, including development of the high-intensity neutrino super beam facility, implementation of a generic superconducting RF cavity test facility, advanced superconducting magnet R&D, advanced beam instrumentation, and simulation codes to provide improved modeling of all aspects of Tevatron operations. R&D in support of the international muon cooling collaboration with Rutherford Appleton Laboratory in the UK will continue. The LBNL R&D supported in FY 2007 includes work on very high field superconducting magnets using niobium-tin and similar superconductors, on new beam instrumentation for use at Fermilab and SLAC, and on extensive beam dynamics and simulation studies with particular emphasis on the electron cloud instability and related efforts in proton and electron colliders. The very successful industrially-based program to develop advanced superconductors, particularly niobium-tin, for the very high field superconducting magnet R&D program will continue to be supported. The FY 2007 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.

▪ **International Linear Collider R&D**	**23,747**	**30,000**	**60,000**

The International Linear Collider (ILC) as currently conceived will collide beams of electrons and positrons head-on at very high energies (500 GeV–1 TeV). This will permit precise and clean measurements of currently undiscovered particles and forces. Particle physicists worldwide have strongly advised that the ILC is the tool that is needed to make the next scientific steps forward after the Large Hadron Collider (LHC) starts operations in Europe in 2007. There are strong reasons to believe that the LHC will open the door to a new domain of particles and forces. Building a coherent theory describing these particles and forces will require the precise and clean measurements that the ILC can provide. In particular: Is one of these new particles stable, with properties consistent with the cosmic dark matter that makes up a quarter of the universe? Is whatever is found at the LHC really the Higgs boson? Does it give mass to the other particles? Are the particles found at the LHC related to those we already know through a new symmetry of nature?

In FY 2006 and FY 2007, the ILC international collaboration under the direction of the Global Design Effort will be completing a detailed review of the R&D accomplished world wide, pre-conceptual design work, and technical issues, and preparing to publish a consolidated pre-conceptual "reference" design in FY 2007. The pre-conceptual design will be used to develop the detailed R&D

	(dollars in thousands)		
	FY 2005	FY 2006	FY 2007

plan, industrialization plan, procurement plan, cost estimate, and schedule. All of these will be submitted to the sponsoring governments for review. A detailed set of site requirements will also be developed and published. Starting in FY 2007, all ILC funding is consolidated in this budget category including both accelerator and detector R&D efforts, as well as support of GDE management activities (see Detector Development below).

In FY 2007, the U.S. collaboration will continue to focus its R&D efforts on developing the high-gradient accelerating components and the steps needed to reduce their costs through industrial engagement; and designing and testing systems needed to create the high brightness beams, and the critical elements needed to bring the beams into collisions. Work will continue on improving systems reliability and large-scale simulations of the full machine. R&D on critical concepts for the experimental detectors will be conducted to position U.S. scientists for leadership in the ILC scientific program. Prototype calorimeter and tracking systems will be studied in the Fermilab test beam, providing a major test of particle flow algorithms and detector construction techniques. To prepare for a potential U.S. bid to host the ILC, should it be built, detailed conventional construction studies related to potential U.S. sites will be performed.

Other Technology R&D	**14,559**	**23,929**	**18,568**
▪ **Advanced Detector Research**	**996**	**750**	**1,421**

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. This program complements the detector development programs of the national laboratories.

The additional funding with respect to FY 2006 reflects the increased interest of the HEP community in early-stage detector development aimed at the detection challenges of new experimental initiatives. The challenges posed by new accelerator and non-accelerator based experiments drive the need for: tolerance to high radiation environments, high resolution detectors with very fast readouts, lower-cost implementations of existing technologies, and novel detection techniques.

▪ **Detector Development**	**13,563**	**19,355**	**13,628**

New experiments frequently depend on advancements in technologies. This funding supports detector development work at the national laboratories and ~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 particle astrophysics and neutrino physics. In FY 2006 these efforts included funds for detector R&D related to the International Linear Collider program as well. The reduction from FY 2006 reflects the consolidation of funding for International Linear Collider detector R&D into the overall ILC program, see above.

The FY 2007 request will maintain R&D efforts directed toward developing new detectors including much needed prototyping and in-beam studies. A diverse program applicable to dark matter and dark energy studies, as well as accelerator-based programs will be continued, including efforts on liquid

	FY 2005	FY 2006	FY 2007

noble gas detectors, transducer technology (e.g., advanced charged-coupled devices, silicon photomultipliers), simulation development, and fast readout electronics.

	FY 2005	FY 2006	FY 2007
▪ **Other**...	**—**	**3,824**	**3,519**

This category includes funding for research activities that have not yet completed peer review, and to respond to new and unexpected physics opportunities. In FY 2006, these efforts are funded to develop new accelerator and detector concepts related to neutrino physics. A joint report of the HEP/NP neutrino physics community outlining the most promising future research directions in neutrino physics was released in Fall 2004; and a joint HEPAP/NSAC neutrino subpanel will report its recommendations early in 2006 that will help inform the decision on which research directions to pursue. These include but are not limited to: R&D for development of scintillation detectors for reactor and accelerator-based experiments; large-scale active liquid argon detectors for accelerator-based experiments; and specialized experiments to measure neutrino interaction cross-sections. In FY 2007, these activities continue, though the overall level is reduced as new experiments begin fabrication, funded in the non-accelerator subprogram (the Reactor Neutrino Detector) and under Construction (the Electron Neutrino Appearance Detector).

	FY 2005	FY 2006	FY 2007
SBIR/STTR...	**—**	**18,474**	**19,862**

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 organization of the topics and the annual solicitations for suggestions for R&D to be included in the annual solicitation are 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 2005, $16,105,000 was transferred to the SBIR program and $1,933,000 was transferred to the STTR program.

	FY 2005	FY 2006	FY 2007
Total, Advanced Technology R&D	**90,145**	**128,356**	**159,476**

Explanation of Funding Changes

	FY 2007 vs. FY 2006 ($000)
Accelerator Science	
▪ University Research is increased to enable the restoration of the university program to the level needed to support long-term R&D.	+3,107

	FY 2007 vs. FY 2006 ($000)
▪ National Laboratory Research is increased to enhance support for simulations and testing of new accelerator concepts, including increased operations of user facilities to meet demand.	+1,760
▪ Other Research is increased to support additional proposals pending completion of peer and/or programmatic review.	+226
Total, Accelerator Science	**+5,093**
Accelerator Development	
The increase for International Linear Collider is provided to support a U.S. leadership role in the international R&D program, and to provide the basis for U.S. industry to compete successfully for major subsystem contracts. Includes funding for ILC detector R&D and support of Global Design Effort management activities.	+30,000
Other Technology R&D	
▪ In Advanced Detector R&D, an increase is provided to support further development aimed at detectors for new experimental initiatives.	+671
▪ In Detector Development, a decrease of $4,800,000 reflects a move of ILC-related detector R&D to the ILC funding category (see above) and a redirection of $927,000 to partially support directed R&D activities	-5,727
▪ The decrease in Other reflects an overall decline in R&D for new neutrino detector initiatives as some of these efforts move into fabrication.	-305
Total, Other Technology R&D	**-5,361**
SBIR/STTR	
The increase reflects the mandated funding for the SBIR and STTR programs	+1,388
Total Funding Change, Advanced Technology R&D	**+31,120**

Construction

Funding Schedule by Activity

	(dollars in thousands)		
	FY 2005	FY 2006	FY 2007
Construction			
07-SC-07, Electron Neutrino Appearance (EvA) Detector, PED	—	—	10,300
98-G-304, Neutrinos at the Main Injector Accelerator	745	—	—
Total, Construction	745	—	10,300

Description

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

Detailed Justification

	(dollars in thousands)		
	FY 2005	FY 2006	FY 2007
07-SC-07, Electron Neutrino Appearance (EvA), PED	**—**	**—**	**10,300**

The Electron Neutrino Appearance (EvA) Detector is a very large detector (approximately football-field size and five stories high), to be fabricated by Fermilab and collaborating universities, that would be sited in northern Minnesota. This detector is optimized to identify electron-type neutrinos, and using the NuMI beam from Fermilab it will observe for the first time the transformation of muon-type neutrinos in an accelerator beam into electron-type neutrinos. It will also make important indirect measurements of the mass ordering 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 large "far" detector itself, the far detector enclosure, its associated electronics and data acquisition system, and a small "near" detector on the Fermilab site.

The request provides for preliminary engineering and design for both the near and far detectors, that will use the NuMI neutrino beam from Fermilab to observe for the first time the transformation of muon-type neutrinos in an accelerator beam into electron-type neutrinos.

	FY 2005	FY 2006	FY 2007
98-G-304, Neutrinos at the Main Injector	**745**	**—**	**—**

This project, completed in the second quarter of FY 2005, provided for the construction of new facilities at Fermilab that are specially designed for the study of the properties of the neutrino and in particular to search for neutrino oscillations.

	FY 2005	FY 2006	FY 2007
Total, Construction	**745**	**—**	**10,300**

Explanation of Funding Changes

	FY 2007 vs. FY 2006 ($000)
07-SC-07, Electron Neutrino Appearance Detector, PED	
The request supports initiation of preliminary engineering and design for a new project to observe the expected but as yet unmeasured transformation of muon neutrinos into electron neutrinos. The project will utilize the NuMI beamline recently commissioned at Fermilab and consist of two detectors, a very large one located in Minnesota and a small one on the Fermilab site.	+10,300
Total Funding Change, Construction	**+10,300**

Capital Operating Expenses and Construction Summary

Capital Operating Expenses

	(dollars in thousands)		
	FY 2005	FY 2006	FY 2007
General Plant Projects	15,257	11,835	15,495
Accelerator Improvements Projects	5,270	4,500	—
Capital Equipment	66,851	42,165	39,927
Total, Capital Operating Expenses	87,378	58,500	55,422

Construction Projects

	(dollars in thousands)					
	Total Estimated Cost (TEC)	Prior Year Appro-priations	FY 2005	FY 2006	FY 2007	Unappro-priated Balance
07-SC-07, Electron Neutrino Appearance (EvA) Detector, PED	10,300	—	—	—	10,300	—
98-G-304, Neutrinos at the Main Injector	109,162	108,417	745	—	—	—
Total, Construction			745	—	10,300	

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

(dollars in thousands)

	Total Project Cost (TPC)	Total Estimated Cost (TEC)	Prior Year Appro-priations	FY 2005	FY 2006	FY 2007	Completion Date
Large Hadron Collider — Machine	111,500	91,969	87,832	4,137	—	—	FY 2006
Large Hadron Collider — ATLAS Detector	102,950[a]	55,549	49,242	3,863	1,598	846	FY 2007
Large Hadron Collider — CMS Detector	147,050[b]	71,789	64,129	3,510	2,900	1,250	FY 2007
GLAST/LAT	45,000[c]	45,000[c]	33,579	11,421	—	—	FY 2005
Run IIb D-Zero Detector	10,719[d]	10,719	8,794	1,925	—	—	FY 2006
VERITAS	7,399[e]	4,799	1,600	2,050	1,149	—	FY 2006
BaBar Instrumented Flux Return (IFR) Upgrade	4,900	4,900	3,000	1,200	700	—	FY 2006
Reactor Neutrino Detector	TBD[f]	TBD[f]	—	—	—	3,000	FY 2010
Total, Major Items of Equipment				28,106	6,347	5,096	

[a] The total U.S. contribution (TPC) for this project is $163,750,000, including $60,800,000 from NSF.
[b] The total U.S. contribution (TPC) for this project is $167,250,000, including $20,200,000 from NSF.
[c] The TEC/TPC includes DOE scope only and reflects a rebaselining approved March 2005.
[d] The total TPC for this project is $18,143,000, including $3,068,000 from NSF and $4,356,000 from foreign partners.
[e] The total TPC for this project is $17,534,000 including $7,333,000 from NSF, $2,000,000 from the Smithsonian Institution, and $802,000 from foreign partners.
[f] The total TPC for this project is to be determined after partnerships are identified and the project is baselined. No funding will be used for fabrication until approval and validation of the Performance Baseline and Approval of Start of Construction.