High Energy Physics

Funding Profile by Subprogram

(dollars in thousands)

	FY 2004 Comparable Appropriation	FY 2005 Original Appropriation	FY 2005 Adjustments	FY 2005 Comparable Appropriation	FY 2006 Request
High Energy Physics					
Proton Accelerator-Based Physics	382,634	417,092	-15,972[ab]	401,120	387,093
Electron Accelerator-Based Physics	144,965	150,890	-6,961[ab]	143,929	132,822
Non-Accelerator Physics	47,385	42,936	+3,998[ab]	46,934	38,589
Theoretical Physics	49,433	49,630	-635[ab]	48,995	49,103
Advanced Technology R&D	79,327	81,081	+13,640[ab]	94,721	106,326
Subtotal, High Energy Physics	703,744	741,629	-5,930	735,699	713,933
Construction	12,426	751	-6[a]	745	0
Total, High Energy Physics	716,170[c]	742,380	-5,936	736,444	713,933

Public Law Authorizations:

Public Law 95-91, "Department of Energy Organization Act"

Public Law 103-62, "Government Performance and Results Act of 1993"

Mission

The mission of the High Energy Physics (HEP) program is to explore and to discover the laws of nature as they apply to the basic constituents of matter and the forces between them. The core of the mission centers on investigations of elementary particles, their nature and their mutual interactions, thereby underpinning and advancing the Department of Energy (DOE) missions and objectives through the development of key cutting-edge technologies and trained manpower that provide unique support to these missions.

Benefits

HEP supports DOE's mission of world-class scientific research capacity by providing world-class, peer-reviewed scientific results in high energy physics and related fields, including particle astrophysics and

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[a] Reflects a rescission in accordance with P.L. 108-447, the Consolidated Appropriations Act, 2005, as follows: Proton Accelerator-Based Physics ($-3,270,000); Electron Accelerator-Based Physics ($-1,253,000); Non-Accelerator Physics ($-321,000); Theoretical Physics ($-394,000); Advanced Technology R&D ($-692,000); and Construction ($-6,000).

[b] Includes a reallocation of funding in accordance with H. Rpt. 108-792, accompanying P.L. 108-447, as follows: Proton Accelerator-Based Physics ($-12,702,000); Electron Accelerator-Based Physics ($-5,708,000); Non-Accelerator Physics ($+4,319,000); Theoretical Physics ($-241,000); and Advanced Technology R&D ($+14,332,000). The reduction in Proton Accelerator-Based Physics subprogram is predominantly the result of the recategorization of costs associated with Non-Accelerator Research, Linear Collider R&D and Detector Development into other subprograms since the time the FY 2005 Congressional Budget was prepared. The current allocation in the Electron Accelerator-Based Physics subprogram reflects the current suspension of operations at the B-factory, with some of these funds redirected into compelling R&D for the future of HEP, particularly in the Non-Accelerator Physics and Advanced Technology R&D subprograms.

[c] Includes reductions of $4,347,000 rescinded in accordance with P.L. 108-137, the Consolidated Appropriations Act, 2004, $15,590,000, which was transferred to the SBIR program, and $1,871,000, which was transferred to the STTR program.

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.

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 physical laws of particles at high energies, dark energy and dark matter, and the possible existence of other dimensions. HEP uses particle accelerators and highly sensitive detectors to study fundamental interactions at the highest possible energies. Because particle physics relates to the origin and evolution of the universe itself, the HEP program also supports studies of cosmic particles and phenomena that do not involve accelerators, including experiments 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 may have a leading role in shaping its birth, growth, and ultimate fate. Our goals in FY 2006 address all of these challenges. The FY 2006 budget request also contributes to this program goal by placing high priority on the operations, upgrades and infrastructure for the two major HEP user facilities (Tevatron and Neutrinos at the Main Injector [NuMI]) at the Fermi National Accelerator Laboratory (Fermilab), and the major HEP user facility (the B-Factory) at the Stanford Linear Accelerator Center (SLAC), to produce maximum scientific data to address these fundamental questions.

The following indicators establish specific long-term (10 year) goals in scientific advancement that the HEP program is committed to. 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.

Annual Performance Results and Targets

FY 2001 Results	FY 2002 Results	FY 2003 Results	FY 2004 Results	FY 2005 Targets	FY 2006 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.*	*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					
Complete first phase of upgrades to enable the Tevatron to run at much higher luminosity. Begin commissioning of phase-one accelerator upgrades. *[Met Goal]*	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.	Deliver data as planned within 20% of the baseline estimate (450 pb-1) to CDF and D-Zero detectors at the Tevatron.
					Deliver $1x10^{20}$ protons on target for the MINOS experiment at NuMI facility.
Electron Accelerator-Based Physics/Facilities					
Double the total data delivered to BaBar at the SLAC B-factory by delivering 25 fb-1 of total luminosity. *[Met Goal]*	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. *[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.	Deliver data as planned within 20% of the baseline estimate (100 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.	Maintain cost and schedule milestones for major items of equipment and new construction projects within 10% of baseline estimates.

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 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 that cannot be mitigated in a timely manner; and (5) strategic and programmatic decisions made by other (non-DOE) 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 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 verify and validate 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 2006. 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) to provide 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.

Funding by General and Program Goal

	(dollars in thousands)		
	FY 2004	FY 2005	FY 2006
General Goal 5, World-Class Scientific Research Capacity			
Program Goal 5.19.00.00, Explore the Fundamental Interactions of Energy, Matter, Time and Space			
Proton Accelerator-Based Physics	382,634	401,120	387,093
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Total, General Goal 5, World-Class Scientific Research Capacity	716,170	736,444	713,933

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 about the nature of our world throughout human history. Today, these questions are addressed scientifically though research in **high energy physics**, also known as **particle physics**. The DOE High Energy Physics program and its predecessors have supported research into these fundamental questions for more than five decades.

In the last 30 years, this research has lead to a profound and far-reaching understanding of the fundamental particles and the physical laws that govern matter, energy, space and time. This understanding is encapsulated in a “Standard Model” that physicists use to predict the behavior of particles and forces. It has been subjected to countless experimental tests; and, again and again, its predictions have held true. The series of research breakthroughs that combined to produce the Standard

Model has been recognized with over a dozen Nobel Prizes and is celebrated as one of the great scientific triumphs of the 20^{th} century.

But now, startling new data have revealed that only 5% of the universe is made of 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 the new phenomena. A revolution in particle physics is coming.

Questions

A worldwide program of particle physics research is underway to explore the new scientific landscape. The possible pathways ahead have been defined in many complementary ways; here we choose the questions as defined in a recent HEPAP subpanel report, "The Quantum Universe":

- **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 and opened up a whole new way of seeing the universe. 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 possible real existence of undiscovered dimensions of space that might explain much of the apparent 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 and could affect the force of gravity at short distances.

- **Do all the forces become one?**

  At the most fundamental level all forces and particles in the universe are thought to be related, and all the forces are thought to be manifestations of a single unified force, 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 underlying 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 natural" with 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 apparent tiny nonzero masses may imply new physics and unification at very high energies.

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

  According to current cosmological ideas, the universe may have begun with a disturbance of space-time, followed by a burst of inflationary expansion of space itself. It is called the "Big Bang". Understanding the evolution of the universe requires breakthroughs in our understanding of quantum physics and quantum gravity. Following inflation, the universe cooled, passing through a series of phase transitions and allowing the formation of stars, galaxies, and ultimately life.

- **What happened to the antimatter?**

  The universe now is made almost entirely of matter, with very little extant antimatter, although the Big Bang, it is thought, must have produced the same amounts of matter and antimatter. How 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. 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 2004, 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 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. Non-accelerator-based research proposals to DOE and NSF are reviewed by a HEPAP subpanel called the *Scientific Assessment Group for Experiments in Non-Accelerator Physics (SAGENAP)*. 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 such as SAGENAP. Priorities recommended by P5 and SAGENAP will have an important influence on long-range planning (see *Planning and Priority Setting*, below). The *Astronomy and Astrophysics Advisory Committee (AAAC)* now reports to the DOE, as well as the NSF and NASA, on a continuing basis 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. Most recently, it conducted a "science assessment and strategy for…research at the intersection of astronomy and physics," published in 2003 as *Connecting Quarks with the Cosmos*. A new study is being carried out for DOE and 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 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 *Program Advisory Committees (PACs)* to determine the scientific justifications and priorities and 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 by the university groups to perform an experiment at a laboratory facility are reviewed by the laboratory PAC as described above. Its proposal to DOE for support is peer-reviewed by a group of 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.

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 dedicated activities at laboratories may also undergo peer review process in addition to the laboratory annual 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 Institutional Reviews for 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 they envision 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.

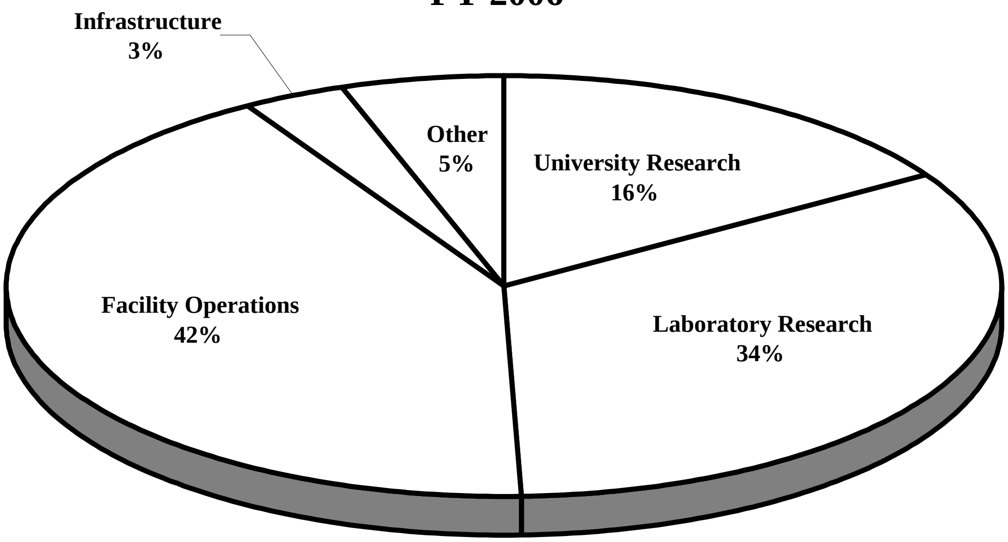
HEPAP also played an important role in advising the Director of the Office of Science on the future facilities needed to address all the centrally important HEP research questions for the next decade. Their recommendations on the scientific importance and technical readiness of several possible facilities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

HEPAP also recommended a new mechanism to update the roadmap and set priorities across the program. This recommendation has been implemented in the form of the P5 that is charged with advising the funding agencies on priorities for new facilities with estimated costs in the range of $50-600 million. The first meeting of P5 was held in early 2003 and its first report on selected projects was delivered in late summer 2003. In 2004, P5 was charged to revisit some of its initial recommendations in the light of new data on project schedules. P5 will play an important role in determining which new facilities appear on the HEP roadmap in future years.

How We Spend Our Budget

The HEP budget has three major program elements: research, facility operations, and laboratory infrastructure support. About 42% of the FY 2006 budget request is provided to the two major HEP laboratories (Fermilab and SLAC) for facility operations; a total of 34% 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; 3% for infrastructure improvements (general plant projects [GPP] and general purpose equipment [GPE]); and 5% for other activities (including Small Business Innovative Research [SBIR] and Small Business Technology Transfer [STTR]). The FY 2006 budget request is focused on facility operations and upgrades at Fermilab and SLAC to advance research with the CDF and D-Zero detectors at the Tevatron, the Main Injector Neutrinos Oscillation Search (MINOS) detector using the NuMI beam and the BaBar detector at the B-factory. Also, a priority is given to the ramp-up of the Large Hadron Collider (LHC) research program in support of commissioning, operations and maintenance activities in anticipation of the start of the LHC physics program in 2007.

High Energy Physics Budget Allocation
FY 2006



Research

The DOE HEP program supports approximately 2,450 researchers and students at over 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. Funding for accelerator-based university and laboratory research is down slightly compared to FY 2005 with a main emphasis on supporting research efforts focused on the large datasets now being generated by our user facilities. National laboratory research scientists work together with the experimental collaborations to collect and analyze data as well as support and maintain the detectors. The laboratories provide state-of-the-art resources for detector and accelerator R&D needed for future upgrades and new facilities.

- ***University Research:*** University researchers play a critical role in the nation's research effort and in the training of graduate students and postdoctoral researchers. During FY 2004, the DOE High Energy Physics program supported approximately two-thirds of the nation's university researchers and graduate students engaged in fundamental high energy physics research. Typically, about 120 Ph.D. degrees are granted annually to students for research supported by the 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, Lawrence Berkeley, Lawrence Livermore, Argonne, Brookhaven, Oak Ridge, and Los Alamos National Laboratories, 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 are important for developing and maintaining the accelerators, large experimental detectors and computing facilities for data analysis.

The HEP program funds 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 2006 will continue to lead the world with forefront user facilities producing data that help answer the key scientific questions outlined above, but these facilities will complete their scientific missions by the end of the decade. Thus we have structured the FY 2006 HEP program not only to maximize the scientific returns on our investment in these facilities, but also to invest in R&D now for the most promising new facilities that will come online in the next decade. This has required a prioritization of our current R&D efforts to select those which will provide the most compelling science within the available resources. In making these decisions we have seriously 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.

- Because of its broad relevance in addressing many of the long-term goals of the HEP program, and its unique potential for new discoveries, the highest priority is given to the planned operations, upgrades and infrastructure for the Tevatron program at Fermi National Accelerator Laboratory. This includes the completion of the upgrade to the Tevatron accelerator complex in 2007 to provide increased luminosity and additional computational resources to support analysis of the anticipated larger volume of data. Over the last few years, the laboratory has developed and implemented a detailed, resource-loaded plan for Tevatron operations and improvements, which has resulted in more reliable luminosity projections. The Office of Science has reviewed the plan and is actively engaged in tracking its progress.
- In order to fully exploit the unique opportunity to expand our understanding of the asymmetry of matter and antimatter in the universe, a high priority is given to the operations, upgrades and infrastructure for the B-factory at SLAC. Support for B-factory will include an allowance for increased power costs and fully funded upgrades for the accelerator and detector which are currently scheduled for completion in 2006. This includes: the completion of the upgrade to the accelerator complex and BaBar detector to provide more data; additional computational resources to support analysis of the larger volume of data; and, increased infrastructure spending to improve reliability. Funding for SLAC operations includes support from the Basic Energy Sciences (BES) program for the Linac Coherent Light Source (LCLS) project, marking the beginning of the transition of Linac operations from HEP to BES as B-factory operations are terminated by FY 2008 at the latest.
- As the LHC accelerator nears its turn-on date of 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 a leadership role for U.S. research groups in the LHC physics program will continue to be a high priority for the HEP program.

- In order to explore the nature of dark energy, pre-conceptual R&D for potential interagency-sponsored experiments with NASA will continue in FY 2006. These experiments will provide important new information about the nature of dark energy and dark matter that will in turn lead to a better understanding of the birth, evolution and ultimate fate of the universe. At this time, no funding for a space-based DOE/NASA Joint Dark Energy Mission past the pre-conceptual stage has been identified.
- The engineering design of the BTeV ("B Physics at the Tevatron") experiment, which was scheduled to begin in FY 2005 as a new Major Item of Equipment, will be terminated by the end of FY 2005. This is also consistent with the guidance of HEPAP, which rated BTeV as of lesser scientific potential than other projects, although still important scientifically; and P5, which supported BTeV but only if it could be completed by 2010, which is not feasible given schedule and funding constraints.
- In FY 2009, at the end of Tevatron Run II, Fermilab will still be operating NuMI/MINOS for at least another year, and will participate in LHC and various particle astrophysics programs. The future of Fermilab past the end of the decade will be the subject of a continuing dialogue between the Administration, Congress, the laboratory, and the broader U.S. and international particle physics communities.
- In order to address the opportunity for significant new future research options, R&D in support of an international electron-positron linear collider is increased relative to FY 2005 to support the continued international participation and leadership in linear collider R&D and planning by U.S. scientists. The long-term goal of this effort is a construction start on an international Linear Collider in the next decade. To provide a nearer-term future program, and to preserve future research options, R&D for other new accelerator and detector technologies, particularly in the emerging area of neutrino physics, will also increase. The Linear Collider has been judged of the highest scientific importance by HEPAP as well as by advisory bodies of the Asian and European HEP communities.

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 computer simulation 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 ChromoDynamics (QCD) calculations, supernova simulations, accelerator simulation and modeling, and grid technology and deployment, as well as the FY 2006 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 and NuMI at Fermilab, and the B-factory at SLAC. The Tevatron provided a total of 3,960 hours of beam time in FY 2004 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. In FY 2005, construction of NuMI will be completed and operation of the facility will begin, serving over 300 researchers, of whom about two-thirds are U.S. researchers. The B-factory provided a total of 4,810 hours of beam time in FY 2004 for a research community of about 300 U.S. scientists in HEP and a comparable number of users from foreign countries. The FY 2006 Request will support facility operations that will provide ~4,560 hours of beams for each of the Tevatron and NuMI at Fermilab and ~5,200 hours of beams for B-factory at SLAC, including an allowance for increased power costs and fully funded upgrades.

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 2004	FY 2005	FY 2006
Tevatron Complex at Fermilab			
Optimal hours	4,320	4,320	4,800
Beam Hours - Tevatron	3,960	4,320	4,560
Unscheduled Downtime - Tevatron	<20%	<20%	<20%
Scheduled Hours - NuMI	N/A	N/A	4,560
Unscheduled Downtime - NuMI	N/A	N/A	<20%
Total Number of Users	2,160	2,160	2,125
B-factory at SLAC			
Optimal hours[a]	5,070	4,550	5,200
Beam hours[a]	4,810	3,380	5,200
Unscheduled Downtime	<20%	<20%	<20%
Total Number of Users	1,100	1,100	1,100

Construction and Infrastructure

Funding for construction and capital equipment is down significantly compared to FY 2005 as several projects are completed or ramping down. In addition, equipment funding at SLAC and Fermilab required to improve accelerator and detector complex reliability and performance is either completed or significantly ramping down. Funding for GPP is increased to renew site-wide infrastructure and to address deferred maintenance issues at Fermilab, SLAC, and Lawrence Berkeley National Laboratory (LBNL). Funding for Accelerator Improvement Projects (AIP) is down at Fermilab and SLAC relative

[a] B-factory operations have been suspended in FY 2005 pending the acceptance of a safety remediation plan. Optimal hours and beam hours shown are subject to change.

to FY 2005, as accelerator upgrade activities, designed to increase the rate of physics data delivered to experiments, begin to ramp down.

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 developed through an 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 2004 were involved in a large variety of theoretical and experimental research, including advanced technology R&D. About one-fifth are involved in theoretical research. About 90% of those involved in experimental research utilize a number of scientific accelerator facilities supported by the DOE, NSF, and foreign countries; and about 10% participate in non-accelerator research.

Details of the High Energy Physics manpower are given below. These numbers include people employed by universities and laboratories. The university grants include Physics Research and Accelerator Technology grants. In FY 2004, there were 140 university grants with average funding of $850,000 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 2004	FY 2005 est.	FY 2006 est.
# University Grants	140	140	135
# Laboratory Groups	50	50	47
# Permanent Ph.D.'s (FTEs)	1,255	1,255	1,230
# Postdoctoral Associates (FTEs)	565	565	540
# Graduate Students (FTEs)	610	610	585
# Ph.D.'s awarded	120	120	115

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 2006, Fermilab plans 4,560 hours of running to achieve a performance goal of 450 inverse picobarns $(pb)^{-1}$ of data delivered to the major Tevatron experiments[a]. Approximately 900 people are involved in day-to-day Tevatron operations that include operation of the Tevatron accelerator complex and the CDF and D-Zero detectors. This is one of the major data collection periods for the 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 as described in more detail above.

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. These efforts are proceeding in parallel with current Tevatron operations and research and are more fully described in the Detailed Justification sections that follow. The following table shows the funding profile to support the Tevatron Run II accelerator upgrades. The technical scope, cost and schedule of work for the Run II accelerator upgrades is periodically reviewed by the SC Construction Management Support Division 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 Run II accelerator upgrade plan was conducted in September 2004, and the next review is scheduled for the second quarter of 2005.

Tevatron Run II Accelerator Luminosity Upgrades

(dollars in thousands)

FY 2004	FY 2005	FY 2006
33,140	18,440	8,800

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 Main Injector). During FY 2006, 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.

SLAC

In FY 2006, SLAC plans 5,200 hours of running to achieve a performance goal of 100 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 2006. 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

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[a] This unit measures the amount of accumulated data, expressed in particle interactions per unit cross-section. Cross-section is a measure of the probability of an interaction, and the unit of cross-section used in particle interactions is the barn, b, equal to 10^{-28} m^2. In interactions between high energy particles, smaller units such as the picobarn ($pb = 10^{-12}$ b) or even femtobarn ($fb = 10^{-15}$ b) are often used.

understanding of the origin of matter 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 section in the Electron Accelerator-Based Physics subprogram.

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

	(dollars in thousands)		
	FY 2004	FY 2005	FY 2006
Tevatron Complex Operations[a]	190,286	190,400	196,570
Tevatron Complex Improvements[b]	42,357	56,019	34,530
Total, Tevatron Complex	232,643	246,419	231,100
B-factory Operations	95,996	96,637	93,457
B-factory Improvements[c]	21,939	21,835	14,500
Total, B-factory	117,935	118,472	107,957

[a] Includes operations of Tevatron complex, NuMI beam line, and CDF, D-Zero, and MINOS detectors.

[b] Includes Run IIb CDF and D-Zero detectors and Tevatron Accelerator, R&D on possible future accelerator improvements, the MINOS detector, BTeV (in FY 2004 and FY 2005) and general improvements to the laboratory infrastructure. For details see the Detailed Justification section in the Proton Accelerator-Based Physics subprogram.

[c] Includes upgrades to the BaBar detector and B-factory accelerator, and general improvements to the laboratory infrastructure. For details see the Detailed Justification section in the Electron Accelerator-Based Physics subprogram.

Proton Accelerator-Based Physics

Funding Schedule by Activity

	(dollars in thousands)				
	FY 2004	FY 2005	FY 2006	$ Change	% Change
Proton Accelerator-Based Physics					
Research	76,359	75,656	75,424	-232	-0.3%
Facilities	306,275	325,464	311,669	-13,795	-4.2%
Total, Proton Accelerator-Based Physics	382,634	401,120	387,093	-14,027	-3.5%

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 accurate, 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 2006, 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 the European Organization for Nuclear Research (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. *A priori*, 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 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).

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. The university program also provides 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, such as purchasing needed equipment 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

Most recent research highlights reflect milestones in completion, operations, or preparation for operations of new experiments and facilities. This subprogram is in transition to focus on operations and data analysis for maximum science in future years. Recent accomplishments include:

- The CDF and D-Zero detectors at Fermilab have collected over three 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. 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.
- A new 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 initial phase of data taking will be completed and results are expected by summer of 2005.

- The MINOS far detector in the Soudan mine has been completed ahead of schedule and has operated with cosmic rays since the summer of 2003. The near detector at Fermilab has been installed and is being commissioned. The NuMI beamline begins commissioning in early 2005.
- The LHC Software and Computing program will continue in order to develop, design and implement a computing system to process, store and support the analysis of the huge amount of data anticipated after the LHC begins commissioning in FY 2007. A parallel effort began in 2002 to test, commission, and eventually operate the U.S.-supplied systems that are part of the LHC detectors. A significant ramp-up of these activities will continue in FY 2006 in anticipation of the LHC accelerator turn on in 2007.

The major planned efforts in FY 2006 are:

- *The research program using the Tevatron at Fermilab*. This research program is being carried out by a collaboration including 1400 scientists from Fermilab, ANL, BNL, LBNL, 56 U.S. universities, and institutions in over 20 foreign countries. The major effort in FY 2006 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 2006 will be data taking and analysis, along with optimizing accelerator performance to improve beam intensity for higher statistics.
- *Planning and preparation for the U.S. portion of the research program of the LHC.* A major effort in FY 2006 will continue to be the design and implementation of the U.S. data handling and computing capabilities needed for full participation in the LHC research program. Pre-operations of U.S.-supplied detectors for LHC experiments will continue at CERN.

Detailed Justification

	(dollars in thousands)		
	FY 2004	FY 2005	FY 2006
Research..	**76,359**	**75,656**	**75,424**
▪ **University Research**......................................	**46,453**	**44,470**	**44,470**

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 physicists 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-based research efforts will be selected based on peer review. Proton accelerator activities concentrate on experiments at the Tevatron complex at Fermilab; development of the physics program for the Large Hadron Collider, under construction at CERN; and the MINOS and MiniBooNE neutrino experiments at Fermilab and the Soudan Mine.

	(dollars in thousands)		
	FY 2004	FY 2005	FY 2006

In FY 2006, the overall level of support is unchanged. Full participation of university physicists is needed to exploit the physics potential of the very active program at the Tevatron and the increase in installation and commissioning activities on the LHC experiments, CMS and ATLAS, during FY 2006. 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 CDF and D-Zero, work to support the fabrication of the LHC detector components, and work on the preparation for U.S. participation in the LHC research program.

	FY 2004	FY 2005	FY 2006
▪ **National Laboratory Research**	**28,659**	**29,885**	**29,554**

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 at Fermilab and the Large Hadron Collider, under construction at CERN.

In FY 2006, the national laboratory research program is slightly reduced because of the need to support facility operations. Full participation of national laboratory physicists is needed to exploit the physics potential of the very active program at the Tevatron during FY 2006. The laboratory experimental physics research groups will be focused mainly on data taking with the CDF and D-Zero collider detector facilities, and analysis of data taken during previous years; operations of the MINOS detector using the neutrino beam from NuMI; support for the MiniBooNE experiment; support for pre-operations of the ATLAS and CMS detectors for the LHC; and for physicists working on preparation for U.S. participation in the LHC Research Program.

The Fermilab research program ($12,983,000) includes data taking and analysis of the CDF, D-Zero, and MiniBooNE experiments, the CMS research and computing program, and data taking and analysis of the MINOS detector. 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 ($5,165,000) will be dominated by the ATLAS research and computing program, along with analyzing data from the CDF and D-Zero experiments.

Activities by the BNL research group ($7,356,000) will cover data taking and analysis of the D-Zero experiment, the ATLAS research and computing program, preparation for future NSF-funded experiments, and a small effort on the MINOS experiment.

The research group at ANL ($4,050,000) 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.

	(dollars in thousands)		
	FY 2004	FY 2005	FY 2006
▪ **University Service Accounts**	**1,247**	**1,301**	**1,400**

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.

Facilities	**306,275**	**325,464**	**311,669**

	FY 2004	FY 2005	FY 2006
Facilities			
Tevatron Complex Operations	190,286	190,400	196,570
Tevatron Complex Improvements	42,357	56,019	34,530
Large Hadron Collider Project	48,800	32,500	7,440
Large Hadron Collider Support	15,600	29,400	52,640
AGS Operations/Support	650	650	637
Other Facilities.	8,582	16,495	19,852
Total, Facilities	306,275	325,464	311,669

▪ **Tevatron Complex Operations**	**190,286**	**190,400**	**196,570**

Operations at Fermilab will include operation of the Tevatron accelerator complex in collider mode and operations of two collider detectors for about 4,560 hours. This will be a major physics run for the D-Zero and CDF detectors with the higher intensity available from the Main Injector.

This is to be one of the major data collection periods for the experiments pursuing physics topics from the energy frontier facility as described in more detail above.

The Tevatron has shown significant performance improvement through FY 2003 and FY 2004. The Run II improvement plan has been reviewed three times in FY 2003 and 2004 with improving evaluations at each review. The FY 2006 budget for Tevatron Complex Operations draws from the plans submitted to these reviews. Funding for associated luminosity improvements is discussed below under Tevatron Complex Improvements.

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 MINOS experiment using the NuMI beamline.

	FY 2004	FY 2005	FY 2006
Tevatron Complex Operations in hours	3,960	4,320	4,560

	(dollars in thousands)		
	FY 2004	FY 2005	FY 2006
▪ **Tevatron Complex Improvements**	**42,357**	**56,019**	**34,530**

This funding includes specific improvements to the Tevatron collider complex to substantially increase the rate of data delivery support for improvement to the associated detectors to enable them to handle the higher data rates, and significant increases to accelerator maintenance and operational support to improve Tevatron reliability.

Funding in the amount of $7,800,000 is included in this budget category for the program to increase the Tevatron luminosity, and provide the computing capability needed to analyze the data collected. Plans for luminosity upgrades involve several steps toward increasing the number of antiprotons in the Tevatron, since that is the main factor that enables higher luminosity. In FY 2006, this effort will be concentrating on improvements to the Tevatron ring itself, so that the largest number of antiprotons generated by the FY 2005 improvements can be successfully stored in the Tevatron. Funding for Tevatron upgrades follows the planned profile of the luminosity upgrade. Since the detector upgrades have been completed and the accelerator upgrades are near completion, funding for this activity decreases by $16,080,000 from FY 2005.

Funding in the amount of $26,730,000 is included for Other Tevatron Improvement activities (other than those specified above). Funding for this category decreases in FY 2006 by $5,409,000 due to the cancellation of the engineering design for the BTeV project ($-10,250,000; noted above in Significant Program Shifts) and the completion of the MINOS project in FY 2005 ($-550,000), offset by increases to accelerator R&D and support activities related to increasing the proton flux on target for the NuMI beam ($+3,935,000), and support for the critical laboratory infrastructure, particularly the high voltage power system needed to run the accelerator ($+1,456,000).

▪ **Large Hadron Collider Project**.....................	**48,800**	**32,500**	**7,440**

Changes were made in 2003 to better match the funding profile to the funding needs of: (1) the three U.S. LHC fabrication projects based on their current fabrication plans and schedules; and (2) the updated LHC construction schedule as determined by CERN. This funding profile will allow the project to continue on the revised approved CERN schedule and will not affect the planned completion date or the total cost of the U.S. projects and the LHC itself.

Construction and technical difficulties in the CERN funded portion of the LHC project on the CERN site in Geneva, Switzerland have led to delays in the project. The problems are being overcome and the latest CERN schedule has first collisions in 2007. While the U.S. does not control the LHC schedule, we maintain active contact with CERN management and the U.S. LHC project managers to ensure that schedules for U.S. deliverables conform to the latest official LHC schedules issued by CERN.

The detailed schedules of the three U.S. LHC projects have been reviewed in the context of this schedule revision by CERN. The U.S. LHC Accelerator Components Project is expected to be completed in FY 2005. The U.S. detector projects (ATLAS and CMS) will complete ~95% of their planned work by the previously scheduled end-date (fourth quarter FY 2005), but for each, a small amount of work is intimately tied to the late stages of the CERN schedule. This is primarily work directly related to the final assembly, testing, and installation of the full detectors, as well as purchase of computing hardware for data acquisition. Under the current schedule, this work will

	(dollars in thousands)		
	FY 2004	FY 2005	FY 2006

occur in 2006 and 2007, changing the final project completion date. The increased costs arising from the delay are modest and will be contained within the projects' contingency allowances. The result of these changes is a stretch out of the planned U.S. contributions to the LHC detectors by two years. The FY 2006 funding for the detectors reflects the stretch out plans. The final cost of each detector is unchanged.

Participation by the U.S. in the LHC program is extremely important to U.S. High Energy Physics program goals. The LHC will become the foremost high energy physics research facility in the world when it begins commissioning in 2007. The LHC will have a center-of-mass energy seven times that of the Tevatron at Fermilab, thus opening up substantial new frontiers for scientific discovery.

With the LHC at the next energy frontier, American scientific research at that frontier depends on participation in LHC. The HEPAP Subpanel on Vision for the Future of High Energy Physics strongly endorsed participation in the LHC, and this endorsement has been restated by HEPAP on several occasions.

The physics goals of the LHC include a search for the origin of mass as represented by the "Higgs" particle, exploration in detail of the structure and interactions of the top quark, and the search for totally unanticipated new phenomena. LHC has strong potential for answering the question of the origin of mass. The LHC energies are sufficient to test theoretical arguments for a totally new type of matter. In addition, history shows that major increases in the particle energy nearly always yield unexpected discoveries.

DOE and NSF have entered into a joint agreement with CERN about contributions to the LHC accelerator and detectors as part of the U.S. participation in the LHC program. This agreement, approved by CERN, the DOE and the NSF, in December of 1997, will ensure access for U.S. scientists to the next decade's premier high energy physics facility.

Participation in the LHC project (accelerator and detectors) at CERN primarily takes the form of the U.S. accepting responsibility for designing and fabricating particular subsystems of the accelerator and of the two large detectors. Thus, much of the funding goes to U.S. laboratories, university groups, and industry for fabrication of subsystems and components that will become part of the LHC accelerator or detectors. A portion of the funds is being used to pay for purchases by CERN of material needed for construction of the accelerator from U.S. vendors.

The agreement provides for a U.S. DOE contribution of $450,000,000 to the LHC accelerator and detectors (with an additional $81,000,000 being provided by the NSF). The DOE contribution is broken down as follows: detectors $250,000,000 and accelerator $200,000,000 (including $90,000,000 for direct purchases by CERN from U.S. vendors and $110,000,000 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 at about $6,000,000,000. (The LHC cost estimates prepared by CERN, in general, do not include the cost of permanent laboratory staff and other laboratory resources used to construct the project.)

Neither the proposed U.S. DOE $450,000,000 contribution nor the estimated total cost of $6,000,000,000 include support for the European and U.S. research physicists working on the LHC program.

The agreement negotiated with CERN provides for U.S. involvement in the management of the project through participation in key management committees (CERN Council, CERN Committee of Council, LHC Board, etc.). This provides an effective base from which to monitor the progress of the project, and will help ensure that U.S. scientists have full access to the physics opportunities available at the LHC. SC has conducted a cost and schedule review of the entire LHC project and similar reviews of the several proposed U.S. funded components of the LHC. All of these reviews concluded the costs are properly estimated and that the schedule is on track.

In addition to the proposed U.S. DOE $450,000,000 contribution and $81,000,000 NSF contribution to the LHC accelerator and detector hardware fabrication, U.S. participation in the LHC will involve a significant portion of the U.S. High Energy Physics community in the research program at the LHC. This physicist involvement has grown dramatically with over 700 U.S. scientists joining 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 2006 will be devoted to the Research Program, which will deploy the infrastructure necessary for U.S. scientists to exploit the physics potential presented by the new energy frontier during first collisions in 2007.

U.S. LHC Accelerator and Detector Funding Profile

(dollars in thousands)

Fiscal Year	Department of Energy			National Science Foundation[a] (Detector)
	Accelerator	Detector	Total	
1996[b]	2,000	4,000	6,000	0
1997[b]	6,670	8,330	15,000	0
1998[b]	14,000	21,000	35,000	0
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	0
2005	21,447	11,053	32,500	0
2006[c]	0	7,440	7,440	0
2007	0	3,180	3,180	0
Total	200,000[d]	250,000	450,000	81,000

[a] The NSF funding was approved by the National Science Board.
[b] 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.
[c] At the end of FY 2005 approximately 95% of the U.S. CMS and U.S. ATLAS projects will be 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.
[d] Includes $110,000,000 for LHC supporting R&D and accelerator components to be fabricated by U.S. laboratories and $90,000,000 for purchases by CERN from U.S. vendors.

LHC Accelerator and Detector Funding Summary

	(dollars in thousands)		
	FY 2004	FY 2005	FY 2006
LHC			
Accelerator Systems			
Operating Expenses	1,000	500	0
Capital Equipment	5,130	2,420	0
Total, Accelerator Systems	6,130	2,920	0
Procurement from Industry	23,200	18,527	0
ATLAS Detector			
Operating Expenses	4,280	3,076	1,642
Capital Equipment	4,710	2,413	1,598
Total, ATLAS Detector	8,990	5,489	3,240
CMS Detector			
Operating Expenses	4,450	2,054	1,300
Capital Equipment	6,030	3,510	2,900
Total, CMS Detector	10,480	5,564	4,200
Total, LHC	48,800	32,500	7,440

Changes have been made by each of the three U.S. projects, and approved by DOE project management, based on actual expenditures and progress during FY 2004, and updated planning based on the FY 2004 experience.

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

The LHC work is being performed at various locations including 4 DOE laboratories and 60 U.S. universities.

	(dollars in thousands)		
	FY 2004	FY 2005	FY 2006
• **Accelerator Systems**	**6,130**	**2,920**	**0**

All construction work including production of quadrupole magnets, cryogenic/electrical power feed boxes, and beam absorbers for the LHC beam interaction regions are scheduled to be completed in FY 2005 per the LHC project execution plan. Production testing of superconducting wire and cable for the LHC main magnets is also scheduled to be completed in FY 2005 per the plan. Funding is reduced to zero for FY 2006.

	(dollars in thousands)		
	FY 2004	FY 2005	FY 2006
• **Procurement from Industry**	**23,200**	**18,527**	**0**

Final funding will be provided in FY 2005 to support reimbursement to CERN for purchases from U.S. industry that included superconducting raw materials, superconducting wire, superconducting cable, cable insulation materials, and other technical components. Funding is reduced to zero for FY 2006.

• **ATLAS Detector**	**8,990**	**5,489**	**3,240**

In FY 2006, funding will primarily support the installation of U.S.-supplied equipment at CERN, namely the transition radiation tracker barrel, the tile calorimeter, the silicon inner tracker, and the muon drift test chambers. In addition, fabrication of the detector trigger and data acquisition system will continue. Funding is decreased by $2,249,000 to follow the ramp-down of detector fabrication.

• **CMS Detector**	**10,480**	**5,564**	**4,200**

In FY 2006, funding will primarily support the assembly and installation of U.S.-supplied equipment at CERN. Assembly of the hadron calorimeter and installation of electronics and readout boxes will continue at CERN. Endcap muon chambers will also be installed at CERN, and production of electronics for the electromagnetic calorimeter and the mechanics for the inner tracker will continue. Production assembly of the silicon detector layers will continue. Funding is decreased by $1,364,000 to follow the ramp-down of detector fabrication.

▪ **Large Hadron Collider Support**	**15,600**	**29,400**	**52,640**

The U.S. LHC Research program enters a critical phase in FY 2006 with final preparations for LHC turn-on in 2007. Significant increases in this area are planned for FY 2006 to meet the growing need for LHC support activities. The main use of the resources will be for LHC software and computing, and pre-operations for 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 has been repeatedly endorsed by HEPAP.

Funding for pre-operations of the LHC detector subsystems built by U.S. physicists will increase significantly to $21,270,000 in FY 2006. The ramp-up in funding ($+9,368,000) will support the development and deployment of tools for control, calibration, and exploitation of detector data, including databases and 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 startup of U.S.-supplied components. U.S. CMS collaborators will be performing vertical integration tests of the major detector subsystems and using functional prototypes of the final data acquisition system in advance of their final installation in the underground cavern. U.S. ATLAS collaborators will be performing testing and commissioning of most detector subsystems. A small effort focused on R&D for specific possible LHC detector upgrades will continue.

Increased support will also be provided for technical coordination and program management during those crucial years, both at the participating U.S. national laboratories and at CERN. The U.S. LHC Accelerator Research Program will be conducting R&D towards possible future LHC accelerator

	(dollars in thousands)		
	FY 2004	FY 2005	FY 2006

upgrades ($10,999,000). This effort ramps-up significantly in FY 2006 ($+7,749,000) as fabrication begins on initial prototypes for upgraded LHC quadrupole magnets.

The LHC software and computing effort will enable U.S. physicists to analyze the vast quantity of LHC data in a transparent manner, and empower them to take a leading role in exploiting the physics opportunities presented by the LHC. The LHC Software and Computing program ($20,371,000) will enter a critical year in FY 2006, when the combination of software development, facilities hardware and support, and grid computing must come together to allow U.S. scientists to participate fully in the data challenges and analyses that will be conducted in preparation for the 2007 turn-on. In FY 2006, the U.S. effort will be focused on data challenges, where a significant fraction of the hardware needed for full LHC data analysis will be tested with professional-quality software on simulated data. These systems need to grow rapidly from prototypes to fully functional systems in 2006. The planned funding ramp-up in FY 2006 ($+6,123,000) will provide for equipment purchases, computing personnel, and user support at Tier 1 and Tier 2 computing and data handling centers in the U.S. This will allow U.S. physicists, especially at universities, to maintain the central role during data analysis that they played during detector fabrication. During this period, grid computing solutions will be integrated in the LHC computing model, allowing U.S. researchers full access to data and CPU needed to analyze the large and complex LHC dataset.

	FY 2004	FY 2005	FY 2006
▪ **AGS Operations/Support**	**650**	**650**	**637**

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 2004	FY 2005	FY 2006
▪ **Other Facilities**	**8,582**	**16,495**	**19,852**

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

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

This category also includes funding to respond to new opportunities and unexpected changes in facilities operations and support.

	FY 2004	FY 2005	FY 2006
Total, Proton Accelerator-Based Physics	**382,634**	**401,120**	**387,093**

Explanation of Funding Changes

	FY 2006 vs. FY 2005 ($000)
Research	
▪ In National Laboratory Research, a small decrease is reallocated to partially support high-priority facilities operations	-331

	FY 2006 vs. FY 2005 ($000)
▪ In University Service Accounts, a small increase supports university groups working at the Tevatron	+99
Total, Research	**-232**
Facilities	
▪ In Tevatron Complex Operations, the increase supports operations of the Tevatron complex, as effort shifts from Tevatron Complex Improvements (see below). This includes continued implementation of the Run II luminosity upgrades in Tevatron running according to the planned profile, as well as the first year of full operations for the NuMI/MINOS program using the Main Injector in fixed-target mode.	+6,170
▪ In Tevatron Complex Improvements, the decrease reflects reductions for Tevatron complex support and Technology R&D supporting projects. This includes a decrease of $10,250,000 as the effort on BTeV is terminated; this is offset by an increase of $3,935,000 in AIP, operations and R&D support as the effort to improve proton flux for the NuMI beam begins, and an increase of $1,456,000 in GPP to enhance site-wide infrastructure. A decrease of $550,000 is taken for the MINOS project as reflected in the approved profile; and a decrease of $16,080,000 in the Run II upgrades of the Tevatron complex, also follows the planned funding profile.	-21,489
▪ In the Large Hadron Collider 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. The U.S. LHC accelerator funding ramps down as that project completes	-25,060
▪ In Large Hadron Collider Support, the increase is provided in part for significantly increased effort in providing the computing systems and networks needed to effectively handle and process the large volume of LHC data. The support for the detector pre-operations is also significantly increased, as detector testing and commissioning activities are ramping up quickly in 2006. A small accelerator R&D effort focused on LHC machine improvements also increases.	+23,240
▪ In AGS Operations/Support the small decrease reflects the cost of continued decommissioning of AGS experimental areas.	-13
▪ In Other Facilities, the increase is held pending completion of peer review and/or programmatic review. The extent of the increase is somewhat overstated because the FY 2005 funding level has already been reduced by programmatic decisions that have resulted in a reallocation of some of the FY 2005 funding from this activity.	+3,357
Total, Facilities	**-13,795**
Total Funding Change, Proton Accelerator-Based Physics	**-14,027**

Electron Accelerator-Based Physics

Funding Schedule by Activity

	(dollars in thousands)				
	FY 2004	FY 2005	FY 2006	$ Change	% Change
Electron Accelerator-Based Physics					
Research	27,030	25,457	24,865	-592	-2.3%
Facilities	117,935	118,472	107,957	-10,515	-8.9%
Total, Electron Accelerator-Based Physics	144,965	143,929	132,822	-11,107	-7.7%

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 anti-matter, 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 the KEK-B accelerator in Japan, 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 accelerator in Japan 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 charmed 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 subprogram supports the maintenance operation and technical improvements for electron accelerator facilities in the U.S. 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 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 2004, the BaBar collaboration announced the first conclusive evidence of “direct CP violation” in B meson decays. This phenomenon is observed as a difference in the decay rates of B mesons (versus anti-B mesons) into the same final state, as opposed to the “indirect,” time-dependent difference first seen in 1999. This effect is much larger than in the K meson system where CP violation was originally observed.
- 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 2006.

- In 2004, the B-factory continued its impressive performance: PEP-II delivered over 100 fb^{-1}. Data collection continues at a high rate to improve the precision of the results, look for evidence in new modes, and resolve any discrepancies. 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 above.

The major planned efforts in FY 2006 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 2006, 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. This research program will conclude by FY 2008 at the latest.
- *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 2004	FY 2005	FY 2006
Research..	**27,030**	**25,457**	**24,865**
▪ **University Research**	**16,157**	**15,500**	**15,500**

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 physicists 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.

The university program also supports nine groups that work at the CESR at Cornell University; and four groups that work at the KEK-B accelerator complex at KEK 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

	(dollars in thousands)		
	FY 2004	FY 2005	FY 2006

analysis 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 2006, the university program is unchanged in order to continue support of operation of the detector and 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.

	FY 2004	FY 2005	FY 2006
▪ **National Laboratory Research**	**10,614**	**9,697**	**9,055**

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 FY 2006, the laboratory experimental physics research groups will be focused mainly on supporting operations of the detector as well as analysis of the unprecedented amount of physics data generated by the B-factory and other electron accelerators. This effort decreases somewhat in FY 2006 as some laboratory groups move to other research areas.

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 efforts from LLNL are much smaller, limited to only a handful of scientists working on the BaBar experiment.

	FY 2004	FY 2005	FY 2006
▪ **University Service Accounts**...........................	**259**	**260**	**310**

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 16 university groups maintain service accounts at U.S. electron accelerator facilities.

	FY 2004	FY 2005	FY 2006
Facilities...	**117,935**	**118,472**	**107,957**
▪ **B-factory Operations**	**95,996**	**96,637**	**93,457**

Funding for operations, along with the additional $30,000,000 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) supports continued running of the accelerator and the operation of the BaBar detector for data collection for 5,200 hours. Including the operations support from BES, the increase in total operations funding over FY 2005 is needed to pay for longer running time along with significantly increased power costs. This marks the beginning of the transition of the SLAC linac to LCLS.

	(dollars in thousands)		
	FY 2004	FY 2005	FY 2006

The B-factory will be the priority HEP research program at SLAC in FY 2006. It is anticipated that the collected data will be about twice the amount collected in FY 2005 and will ensure a continuing U.S. leadership role in the program to study the excess of matter over antimatter in the universe. The funding includes full support for increases in power costs as well as computing support to analyze the collected data.

	FY 2004	FY 2005	FY 2006
B-factory Operations in hours	4,810	3,380	5,200

▪ **B-factory Improvements**	**21,939**	**21,835**	**14,500**

Funding is provided for accelerator and detector maintenance activities, repair and replacement of failing or obsolescent components, and minor improvements and upgrades ($3,075,000) to existing systems. In addition, an upgrade of the associated computing system ($2,500,000) is provided to handle the unprecedented data volumes being generated by the expected luminosity improvement of the B-factory. Also included is funding for the completion of the Major Item of Equipment, BaBar Instrumented Flux Return (IFR) Upgrade in FY 2006 according to the planned profile ($700,000; TEC and TPC of $4,900,000), and increased support for general site-wide infrastructure to ensure reliable and efficient operations by providing assistance with ES&H, infrastructure and maintenance needs ($8,225,000). The decrease in funding in FY 2006 reflects the completion of accelerator and detector upgrades ($-9,378,000) offset by an increase in GPP funding for infrastructure ($+2,043,000).

Total, Electron Accelerator-Based Physics	**144,965**	**143,929**	**132,822**

Explanation of Funding Changes

	FY 2006 vs. FY 2005 ($000)
Research	
▪ In National Laboratory Research, the decrease reflects the move of some Electron Accelerator-Based Physics research groups to other research areas	-642
▪ In University Service Accounts, the increase supports university groups working at the B-factory	+50
Total, Research	**-592**

	FY 2006 vs. FY 2005 ($000)
Facilities	
▪ In B-factory Operations, the decrease reflects support for SLAC operations that is now provided by the Basic Energy Sciences program. Including the support from BES, total SLAC operations funding is increased ($+26,820,000) to pay for full B-factory operations while beginning the transition of the SLAC linac to LCLS	-3,180
▪ In B-factory Improvements, the decrease reflects the planned ramp down of the B-factory upgrades ($-7,790,000) and support ($-1,588,000); partially offset by the increased GPP funding ($+2,043,000) to assist with ES&H and infrastructure needs.	-7,335
Total, Facilities	**-10,515**
Total Funding Change, Electron Accelerator-Based Physics	**-11,107**

Non-Accelerator Physics

Funding Schedule by Activity

	(dollars in thousands)				
	FY 2004	FY 2005	FY 2006	$ Change	% Change
Non-Accelerator Physics					
University Research	13,565	12,750	12,750	0	0.0%
National Laboratory Research	18,820	17,120	17,120	0	0.0%
Projects	14,000	13,721	4,049	-9,672	-70.5%
Other	1,000	3,343	4,670	+1,327	+39.7%
Total, Non-Accelerator Physics	47,385	46,934	38,589	-8,345	-17.8%

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 rare and exotic particles or processes, 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, 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 colleges and universities. This program is carried out in collaboration with physicists from five DOE national laboratories (Fermilab, SLAC, LBNL, LLNL, and LANL) and other government agencies 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 groups are covered under the Research categories, the Projects category in the Non-Accelerator Physics subprogram supports the technical R&D, engineering and design, detector apparatus, and remote site operations of Non-Accelerator Physics experiments. Remote sites include the Soudan Mine in Minnesota, the Kamiokande Mine in Japan, the Whipple Observatory in Arizona, the Pierre Auger Observatory in Argentina, the Stanford Underground Facility at Stanford University, Kitt Peak in Arizona and the Gran Sasso Laboratory in Italy. Other activities include the fabrication and operation of the GLAST/LAT at SLAC and the AMS led by Massachusetts Institute of Technology (MIT).

Highlights

Recent accomplishments include:

- Findings from the Sloan Digital Sky Survey (SDSS), along with NASA's Wilkinson Microwave Anisotropy Probe (WMAP) were named *Science* Magazine's "Discovery of the Year" in 2003 for their results on the properties of dark energy. Analysis and processing of SDSS data is supported by DOE and managed by Fermilab. WMAP, SDSS, and a new set of supernova observations released in FY 2004 are beginning to give scientists a handle on the way dark energy reacts to expansion or contraction of the universe.
- The Cryogenic Dark Matter Search (CDMS II) experiment completed and installed its full complement of towers of silicon and germanium detectors in the Soudan Mine in Minnesota in 2004 and the full experiment will take data until the end of 2005. Analysis of three months of data with one tower already provides the best results in the world to date on detection of dark matter particles.

The major planned efforts in FY 2006 are:

- *Fabrication of the VERITAS Telescope Array*. VERITAS is a planned new ground-based multi-telescope array that will study astronomical sources of high energy gamma rays, from about 100 GeV to about 50 TeV. This facility will complement the GLAST/LAT telescope which does the same physics up to about 100 GeV. Scientists are particularly interested in gamma rays from poorly-understood astronomical sources such as Active Galactic Nuclei and Gamma Ray Bursters, and searches for signatures of supersymmetric dark matter. The experimental technique was developed by the DOE/HEP-supported researchers at the Harvard-Smithsonian Whipple

Observatory on Mt. Hopkins in Arizona, and the new project is supported by a partnership between DOE, NSF and the Smithsonian Institution. Fabrication began in FY 2004 on Kitt Peak in Arizona and will be completed at the end of FY 2006.

- *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 southern array will complete fabrication in 2005, and operations have already begun with the partially completed array. Full operations begin in 2006. 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 is funded jointly with 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)* – This experiment, performed at LLNL, searches for "axions," particles that could explain the smallness of CP violation (matter-antimatter asymmetry) in strong interactions and at the same time account for the so-called "dark matter" in the universe. The previous experiment (AXION-I) set the world's best limits in the search for these hypothetical particles, and work on an upgrade to the experiment started in FY 2004. Data-taking will continue for three or four years. The upgraded experiment has greater sensitivity than AXION-I because of advanced signal amplifier electronics.
- *Preparations for launch of the LAT.* The LAT telescope fabrication will be completed at the end of FY 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. This research program is being carried out by a collaboration, which includes particle physicists and astrophysicists from SLAC, NASA, NRL, U.S. universities, and institutions from Italy, France, Japan, and Sweden.
- *Preparations for launch of the AMS*. AMS is an international consortium experiment, led by MIT, to be placed on the International Space Station in 2008. Fabrication will be completed in 2005. It will measure cosmic rays in search of anti-matter in the universe, and will search for evidence of supersymmetric dark matter.
- *Research, development, and design for the SuperNova Acceleration Probe (SNAP) Experiment, a concept for the DOE/NASA Joint Dark Energy Mission (JDEM).* LBNL is leading an effort to develop this space-based dark energy experiment, designed to discover and precisely measure thousands of type Ia supernovae. The resulting data precisely probe the nature of dark energy, responsible for the accelerating expansion of the universe, as well as determining the history of accelerations and decelerations of the universe from the present back to approximately 10 billion years ago. The project and collaboration is led by LBNL and includes scientists from DOE laboratories, NASA centers, U.S. universities and foreign institutions.

Detailed Justification

	(dollars in thousands)		
	FY 2004	FY 2005	FY 2006
University Research..	**13,565**	**12,750**	**12,750**

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 2006, the university program in Non-Accelerator Physics will provide support for those universities involved in projects at the same level as FY 2005. Several new experiments (e.g., Pierre Auger, AMS, and GLAST/LAT) will have completed their fabrication phase and are moving in to 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. One notable example is the AMS experiment, the goal of which is to detect sources of extra-galactic antimatter, using an instrument attached to the International Space Station. In FY 2006, the AMS collaboration will continue preparations for the planned 2008 launch. This project is led by scientists at MIT and consists of a collaboration among NASA, multiple U.S. universities, and numerous international institutions.

In FY 2006, the LAT telescope will be integrated into its spacecraft before its launch on the GLAST mission in 2007. This project is led by SLAC and consists of a collaboration among NASA institutions, U.S. universities and four international partners.

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; VERITAS in Arizona; and R&D for the SNAP mission concept for a future DOE/NASA JDEM.

National Laboratory Research.........................	**18,820**	**17,120**	**17,120**

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 2006, the laboratory experimental physics research groups (including groups at LBNL, Fermilab and SLAC) will be focused mainly on supporting the spacecraft integration for the GLAST/LAT telescope and analysis of previous experimental data; research and development for the SNAP mission concept; and continued analysis of data from SDSS.

	FY 2004	FY 2005	FY 2006
	(dollars in thousands)		
Projects	**14,000**	**13,721**	**4,049**

In FY 2006, this effort will be focused mainly on R&D for the SNAP mission concept, and fabrication of VERITAS; with the completion of the DOE contribution to GLAST/LAT fabrication in FY 2005, the overall effort in this category is significantly reduced.

The FY 2006 program for VERITAS ($1,149,000; TEC of $4,799,000; TPC of $7,399,000) will continue the fabrication phase for the full telescope array and complete this project.

The DOE contribution to GLAST/LAT fabrication (current TEC and TPC of $42,000,000) is completed in FY 2005; all pre-operations are covered under the Research categories above.

The FY 2006 SNAP program ($2,900,000) will focus on finalizing the research and development for technology needed to provide a mission concept for the future JDEM mission. Funding for JDEM fabrication has not been identified by DOE or NASA. Funding is sufficient to continue the detailed SNAP design and prototyping phase. DOE is actively engaged with NASA on JDEM. The recent National Science and Technology Council's Interagency Working Group on the Physics of the Universe report recommended that DOE and NASA develop JDEM.

	FY 2004	FY 2005	FY 2006
Other	**1,000**	**3,343**	**4,670**

Includes funding for private institutions and other government laboratories and institutions that participate in Non-Accelerator Physics research. This category also includes funding for research activities that have not yet completed peer review, and to respond to new and unexpected physics opportunities.

	FY 2004	FY 2005	FY 2006
Total, Non-Accelerator Physics	**47,385**	**46,934**	**38,589**

Explanation of Funding Changes

	FY 2006 vs. FY 2005 ($000)
Projects	
The decrease reflects a ramp down of $8,421,000 for GLAST/LAT fabrication and $901,000 for the VERITAS fabrication, both according to their planned profiles, and decreases of $300,000 in AMS pre-operations testing activities and $50,000 in SNAP R&D.	-9,672
Other	
The increase reflects funds held pending completion of peer review and/or programmatic review. The extent of the increase is somewhat overstated because the FY 2005 funding level has already been reduced by programmatic decisions that have resulted in a reallocation of some of the FY 2005 funding from this activity.	+1,327
Total Funding Change, Non-Accelerator Physics	**-8,345**

Theoretical Physics

Funding Schedule by Activity

	(dollars in thousands)				
	FY 2004	FY 2005	FY 2006	$ Change	% Change
Theoretical Physics					
University Research	23,478	22,550	22,550	0	0.0%
National Laboratory Research	15,343	16,161	16,135	-26	-0.2%
SciDAC	5,000	5,000	5,000	0	0.0%
Other	5,612	5,284	5,418	+134	+2.5%
Total, Theoretical Physics	49,433	48,995	49,103	+108	+0.2%

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 High Energy Physics and multi-program 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

The HEP program funds 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.

Highlights

Recent accomplishments include:

- The 2004 Nobel Prize in Physics was awarded to three physicists for discovery of “asymptotic freedom” in the theory of strong interactions, Quantum ChromoDynamics (QCD). The research of two of them has been supported by the High Energy Physics program for many years.
- 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 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 could give rise to this new aspect of Nature.
- During the past year, the first high precision numerical simulation of the simplest strong interaction decay constants and mass differences, including the important but difficult “virtual quark” effects

was 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. Extending these simulations to more important quantities will require the new computers being planned for fabrication in FY 2005 and beyond. See first bullet below.

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 2006:

- *Lattice QCD*. Quantum ChromoDynamics (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 2006 will come from the major effort to fabricate the necessary computer hardware in partnership with the Nuclear Physics (NP) program and the Advanced Scientific Computing Research (ASCR) 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 2004	FY 2005	FY 2006
University Research...	**23,478**	**22,550**	**22,550**

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

	(dollars in thousands)		
	FY 2004	FY 2005	FY 2006

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.

In FY 2006, the university theory program will address 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 searching for new physics at the energy frontier, as described in previous sections. 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.

National Laboratory Research	**15,343**	**16,161**	**16,135**

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 2006, 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 the B-factory's detector, BaBar.

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

In FY 2006 there will be three principal continuing HEP SciDAC efforts: in the areas of advanced accelerator beam simulations, which support the accelerator development efforts for the Linear Collider, as well as optimizing performance for the Tevatron; platform-independent software to facilitate large-scale QCD calculations (see also 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. We also expect a new solicitation for SciDAC proposals in FY 2006 to build on or enhance these pioneering software efforts.

Other	**5,612**	**5,284**	**5,418**

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 joint effort with the Nuclear Physics (NP) and Advanced Scientific Computing Research (ASCR) programs is aimed toward the development of a ~5 Teraflops prototype computer by the end of FY 2005, using the custom QCD On-a-Chip (QCDOC) technology. This platform will enable U.S.

	(dollars in thousands)		
	FY 2004	FY 2005	FY 2006

researchers to stay competitive with other worldwide efforts in computational QCD research while developing a larger-scale hardware platform. Continuing the joint effort with NP, development of large-scale facilities (~20 Teraflops) will begin in FY 2006 for providing computing capabilities based on the most promising technology. This effort will be captured in a single Major IT investment.

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 2006 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 by that time.

Several key R&D activities carried out from FY 2003 through FY 2005 have enabled this program. One is the successful completion and implementation of the uniform software environment on two 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 Nuclear Physics program at Fermilab and the Thomas Jefferson National Accelerator Facility (TJNAF).

In FY 2006, a program of the most important and accessible research computations on the QCDOC computer at BNL will continue and is expected to yield high precision calculations of parameters that are needed to interpret current experiments at 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.

This category also includes support for the QuarkNet education project ($775,000). This project takes place in QuarkNet "centers" which are set up at universities and laboratories around the country. Each center has 2 physicist mentors and, over 3 years, 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 60 centers, with 720 teachers, will be in place in FY 2004. In FY 2005, 10 of these centers will still be at stage 2, with the rest in full operations mode. The project plans to ramp-up to its planned steady-state level of 60 fully operating centers in FY 2006. The operations will continue through the life of the LHC program at CERN.

Total, Theoretical Physics	**49,433**	**48,995**	**49,103**

Explanation of Funding Changes

	FY 2006 vs. FY 2005 ($000)
National Laboratory Research	
The small decrease is reallocated to partially support increased costs in facilities operations..	-26

	FY 2006 vs. FY 2005 ($000)
Other	
The increase is primarily for the Quarknet education project	+134
Total Funding Change, Theoretical Physics	**+108**

Advanced Technology R&D

Funding Schedule by Activity

	(dollars in thousands)				
	FY 2004	FY 2005	FY 2006	$ Change	% Change
Advanced Technology R&D					
Accelerator Science	23,316	27,335	27,165	-170	-0.6%
Accelerator Development	39,660	35,825	42,125	+6,300	+17.6%
Other Technology R&D	16,351	13,698	18,852	+5,154	+37.6%
SBIR/STTR	0	17,863	18,184	+321	+1.8%
Total, Advanced Technology R&D	79,327	94,721	106,326	+11,605	+12.3%

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, 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

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 used in nuclear physics, materials science, chemistry, medicine, and industry.

The High Energy Physics Advisory Panel (HEPAP), consisting of leading members of the high energy physics community, 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. Their 2002 long range planning report identified an accelerator that collides electrons and positrons at a center-of-mass energy of 500 GeV or higher (a "Linear Collider") as the highest priority next research facility for high energy physics. A similar endorsement has come from the European Committee on Future Accelerators and from the Asian Committee on Future Accelerators.

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 Linear Collider is identified as the highest priority item for SC 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 or more. Central to this cooperation is the International Committee on Future Accelerators (ICFA). ICFA was created in 1976 by the International Union of Pure and Applied Physics for the purpose of facilitating International collaboration in the construction and use of accelerators for high energy physics research. In 2003, ICFA formed the International Linear Collider Steering Committee (ILCSC) to coordinate scientific, technical, and governmental aspects of the activities leading to an international proposal to construct a linear collider. Also in 2003, three groups were created to interface national R&D programs with the ILCSC. They are the U.S. Linear Collider Steering Group (USLCSG), created by HEPAP, the European Committee on Future Accelerators (ECFA), and a similar group in Asia created by the Asian Committee for Future Accelerators (ACFA). Since its formation, the ILCSC has been coordinating the activities of the three regional groups in the process of establishing a standard set of linear collider operating parameters, establishing a technology recommendation process, and exploring the organization of an international design team.

In August 2004, after 8 months of careful deliberation, the International Technology Recommendation Panel (ITRP) convened by the ILCSC, selected the superconducting radiofrequency (cold) technology as the preferred technology for building an international linear collider. ICFA unanimously endorsed the recommendation.

The Advanced Technology R&D (ATRD) subprogram includes both R&D to bring new accelerator concepts to the stage where they can be considered for use in existing or new facilities (General Accelerator R&D), and advancement of the basic sciences underlying the technology (Accelerator Science). The third activity, Other Technology R&D, includes Advanced Detector Research and Detector Development. 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 the Advanced Technology R&D subprogram.

Accelerator Science

The Accelerator Science category in the ATRD 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. When concepts develop enough to be viewed as part of a larger system or as leading to a possible future proposal for a construction project, they are given special attention. The Linear Collider is the current R&D activity in this special category. Also 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, muon accelerator proof-of-principle research, and R&D in support of possible future upgrades at the LHC.

Other Technology R&D

This category includes funding at universities under Advanced Detector Research and primarily at 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:

- Researchers continue to make evolutionary progress in high field magnets for the next generation of both electron and hadron colliders. An industry-based R&D program funded by ATRD has provided production quantities of niobium-tin (Nb_3Sn) superconducting material in 2003 with a world record current density of over 3,000 amps per square millimeter at 12 Tesla. In addition to enabling R&D on very high field magnets for accelerators and storage rings, this material opens the way for the industrial development of very high-resolution magnetic resonance imaging (MRI) devices operating at 1gigahertz.
- Work at the national laboratories and at universities has shown interesting approaches in the fabrication of very high field accelerator magnets that address the engineering challenges of working with superconducting materials like niobium-tin and the high temperature superconductors. One of these has used the new niobium-tin material to demonstrate a dipole magnet with a central field of 16 Tesla, a new world record, and opening a path to the eventual doubling of the LHC's beam energy from 7 TeV to 14 TeV.
- Progress has been made on alternate methods of charged particle acceleration. In particular, current experiments at SLAC address the potential feasibility of a plasma-based “afterburner” that could potentially double the energy of a linear collider in only a few meters of plasma. Accelerating gradients of greater than 4 GeV per meter have been measured, and the acceleration of positrons (anti-electrons) by particle driven plasma wakefields has also been demonstrated, an essential step if the plasma accelerators are to ever be applied to electron-positron colliders.

The major Advanced Technology R&D efforts in FY 2006 are:

- *The Accelerator Science Research Program*. This program supports studies in scientific topics such as laser and radiofrequency (RF) driven acceleration, plasma-based accelerators, alternative radiofrequency accelerating structures, ionization cooling of muon beams, superconducting material development and applications, and nonlinear dynamics and chaos. This research is performed at about 27 universities and 6 DOE national laboratories (ANL, BNL, LANL, LBNL, Princeton Plasma Physics Laboratory [PPPL], and SLAC), and 2 Federal laboratories (NRL and National Institute of Standards and Technology [NIST]). The programs of research at the universities and national laboratories are complementary, and collaboration between the laboratories and the university research groups is strongly encouraged.
- *The Research and Development Program in General Technology R&D.* A component of the technology R&D at BNL, Fermilab, LBNL, and SLAC is focused on "reduction to practice" of new ideas and in general areas of technology important to the future research programs at that laboratory but not directly relevant to an operating facility or a new facility under construction. The principal activities funded are R&D on advanced superconducting magnets with a particular emphasis on reaching dipole fields above 18 Tesla and quadrupole fields approaching 300 Tesla per meter, development of an ultra high-intensity neutrino beam facility, RF acceleration systems for gradients above 75 megavolts per meter, new beam instrumentation, particle beam "cooling" techniques (particularly muon cooling), high intensity muon production targets, and advanced computation and computer modeling techniques.
- *Support for Linear Collider R&D.* A TeV scale linear electron-positron collider has been identified by the international high energy particle physics community, including various national laboratories, international advisory committees, and HEPAP, as an essential international facility to extend particle physics research beyond what is feasible at the LHC. In the U.S., the national collaboration will be reoriented and expanded to support R&D and design activities on a machine using the cold radio frequency accelerating structure recommended by the ITRP. In FY 2006 the R&D industrialization and related activities will be considerably expanded and internationalized. The support for a linear collider is, consequently, significantly expanded in FY 2006 to support the larger international R&D program.
- *Neutrino Physics R&D.* In FY 2006 we are initiating a broad-based effort to develop new accelerator and detector technologies that will be needed to address research opportunities in neutrino physics that have recently become accessible. The fundamental properties of neutrinos may shed light on how all the forces of nature unify into one, or why there is an abundance of matter over anti-matter in the universe. 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 will be needed.

Detailed Justification

	(dollars in thousands)		
	FY 2004	FY 2005	FY 2006
Accelerator Science	**23,316**	**27,335**	**27,165**
▪ **University Research**	**9,547**	**10,350**	**10,350**

In FY 2006, funding will provide for a program of accelerator physics and related technologies at about 27 universities at the same level as FY 2005. The research program includes development of new applications of niobium-tin and similar superconductors as well as high temperature superconductors; investigations of the use of plasmas and lasers to accelerate charged particles; development of novel high power RF sources for driving accelerators; 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. Accelerator R&D into the fundamental issues associated with the ionization cooling of muon beams is included in this effort. 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.

▪ **National Laboratory Research**	**12,339**	**15,328**	**15,219**

There are areas of Accelerator Science research that require the more extensive or specialized research facilities located at DOE national laboratories. Funding for this work is provided to six national laboratories, ANL, BNL, LANL, LBNL, PPPL, and SLAC. 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. Part of the funding included in this area supports R&D into high-power target studies required for possible future neutrino facilities, including for example, possible upgrades to the NuMI beam, and into support of muon ionization cooling studies, and in particular the international Muon Ionization Cooling Experiment (MICE) at Rutherford Laboratory in the UK.

BNL ($3,360,000) is the home of the very successful Accelerator Test Facility (ATF), supporting research that HEP funds at universities and in industry (particularly through the SBIR Program). In FY 2006, 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 muon ionization cooling will also be carried out.

The Center for Beam Physics at LBNL ($4,443,000) is supported in FY 2006 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.

	(dollars in thousands)		
	FY 2004	FY 2005	FY 2006

An advanced accelerator R&D program is supported at SLAC ($4,000,000) in FY 2006 to explore particle-driven plasma accelerators, direct laser acceleration of electrons in vacuum, ultra high-frequency microwave systems for accelerating charged particles, very advanced electron-positron collider concepts, and theoretical studies in advanced beam dynamics methods and new computer computation and simulation codes. Much of the work on advanced accelerator concepts at SLAC is done in collaboration with universities funded by the ATRD subprogram.

Other activities ($3,416,000) supported in FY 2006 include: theoretical studies of space-charge dominated beams at PPPL; 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; and development and maintenance of accelerator beam simulation codes at LANL.

▪ **Other**	**1,430**	**1,657**	**1,596**

This category includes funding for Accelerator Science at sites other than universities and national laboratories. These include interagency agreements with NRL and 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.

Accelerator Development.................................	**39,660**	**35,825**	**42,125**
▪ **General Accelerator Development**.............	**15,600**	**13,225**	**17,125**

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. Funding in this category increases in FY 2006 to support R&D directed towards developing a next-generation accelerator neutrino facility for the next decade that can significantly expand on the physics program begun with NuMI/MINOS.

Work at BNL in FY 2006 will focus on superconducting magnet R&D and related advanced materials development. R&D in support of high intensity muon production targets is also included in the BNL program. The R&D program at Fermilab in FY 2006 will address a broad spectrum of technology needs for that facility, including development of an ultra high-intensity neutrino facility, development of a superconducting RF module test facility, advanced superconducting magnet R&D, electron cooling, advanced beam instrumentation, and simulation codes to provide improved modeling of all aspects of Tevatron operations. Pre-conceptual R&D in support of an international muon ionization cooling experiment, a collaboration with Rutherford Appleton Laboratory in the UK, is also included. The LBNL R&D supported in FY 2006 includes work on very high field superconducting magnets using niobium-tin and possibly niobium-aluminum, on development of superconducting wire and cable in collaboration with U.S. industry for the national program in magnet R&D, on new beam instrumentation for use at Fermilab and SLAC, and on extensive beam dynamics and simulation studies with particular emphasis on electron cloud and related efforts in proton and electron colliders. The FY 2006 program at SLAC encompasses high-powered RF

	(dollars in thousands)		
	FY 2004	FY 2005	FY 2006

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.

	FY 2004	FY 2005	FY 2006
▪ **Linear Collider**	**19,600**	**22,600**	**25,000**

The need for an electron-positron linear collider as a complement to and precision augmentation of the research program that will be carried out at the LHC now under construction at CERN was reviewed in 2001 by the International Committee of Future Accelerators (ICFA), the European Committee on Future Accelerators (ECFA), and the Asian Committee on Future Accelerators (ACFA) and HEPAP. These bodies have all identified a TeV-scale linear collider as the highest priority facility following the LHC to address the broad range of crucial, unresolved physics questions central to high energy physics.

The accomplishment of the international R&D program was to demonstrate that there are two principal, viable technical approaches to constructing a high energy linear collider. One of these approaches, developed by an international collaboration led by the German high energy physics laboratory, Deutsches Elektronen-Synchrotron (DESY), is based on the use of a superconducting RF acceleration system cooled to approximately 456 degrees Fahrenheit below 0. As noted previously, the ITRP has recommended this technology as the most suitable technology to provide the performance needs for the linear collider.

In FY 2005, a new international group is being put in place to coordinate and direct the international R&D program. The organization of this group and its management relationships to the three regional groups, in Asia, Europe and the U.S., will be based on the recommendations made by a task force set up by the ILCSC. The responsibilities of the international management team include a detailed review of the R&D, pre-conceptual design work, technical reviews for the chosen technology, and preparation of a consolidated design and design report. The pre-conceptual design which is not site-specific at this time will be used to develop a detailed R&D plan, industrialization plan, procurement plan, cost estimate, and schedule that is resource loaded and based on what is known about the scheduling of completion of pieces of the linear collider during construction. A detailed set of site requirements will also be developed and published.

In the U.S., a research collaboration will participate in preparing the consolidated design and the detailed R&D and industrialization activity planning. The U.S. collaboration will also layout and present a plan to the DOE and NSF on the R&D work that the U.S. will carryout as part of the international R&D team. It is anticipated that the U.S. linear collider activity will be jointly managed by the DOE and the NSF.

In FY 2006, all of the activities begun in FY 2005 to support development of a "cold" technology international design for the linear collider facility will be in force. The increase in U.S. linear collider funding from $22,600,000 in FY 2005 to $25,000,000 in FY 2006 will be essential for completing the reorganization of the U.S. linear collider collaboration to support the cold technology design and increased participation in the international collaborative activities.

	(dollars in thousands)		
	FY 2004	FY 2005	FY 2006
▪ **Muon Accelerators**	**4,460**	**0**	**0**

In FY 2003, this R&D effort was reviewed as part of a HEP long range planning exercise. As a result of this study, and recent future facilities planning undertaken by HEPAP, it was recognized that the work should be restructured to reflect the longer range nature of this R&D and the need to demonstrate the necessary technologies before committing to the more extensive work that would form the basis for proposing any new facility. Thus, this effort was redirected in FY 2005 into the Accelerator Science category while the necessary R&D is done to show that technical obstacles to producing and controlling high-intensity muon beams can be overcome.

Other Technology R&D	**16,351**	**13,698**	**18,852**
▪ **Advanced Detector Research**	**930**	**1,000**	**1,594**

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 foreseen but not yet approved experiments. 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.

▪ **Detector Development**	**15,421**	**12,698**	**13,356**

New experiments frequently depend on advancements in technologies. This funding supports detector development work at the national laboratories and universities to advance these technologies to a point where there is reasonable chance that an experiment can adopt the technology successfully; one current area of investigation is R&D on detector technologies that could be used at a future Linear Collider. In FY 2006, this research area is slightly increased to augment development of new detectors and technologies that will be required to pursue new opportunities in particle astrophysics or at future accelerators (see also “Other” below).

▪ **Other**	**0**	**0**	**3,902**

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 will help inform the decision on which research directions to pursue.

SBIR/STTR	**0**	**17,863**	**18,184**

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.

	FY 2004	FY 2005	FY 2006

(dollars in thousands)

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 2004, $15,590,000 was transferred to the SBIR program and $1,871,000 was transferred to the STTR program.

	FY 2004	FY 2005	FY 2006
Total, Advanced Technology R&D	**79,327**	**94,721**	**106,326**

Explanation of Funding Changes

	FY 2006 vs. FY 2005 ($000)
Accelerator Science	
The small decrease is redirected to partially support increases in General Accelerator Development	-170
Accelerator Development	
▪ The increase is provided to advance R&D directed towards developing a next-generation accelerator neutrino facility	+3,900
▪ The increase is provided to accelerate the pace of Linear Collider R&D and provide leadership to the international R&D effort	+2,400
Total, Accelerator Development	**+6,300**
Other Technology R&D	
▪ **Advanced Detector R&D**	
The increase is provided for increased university involvement to bring to the prototype stage new detector technologies so that they can be investigated in the detector development programs	+594
▪ **Detector Development**	
The increase provides for additional support of R&D for new detectors needed for future accelerators	+658
▪ **Other**	
The increase is provided to develop new accelerator and detector concepts related to neutrino physics	+3,902
Total, Other Technology R&D	**+5,154**

	FY 2006 vs. FY 2005 ($000)
SBIR/STTR	
The increase reflects the mandated funding for the SBIR and STTR programs	+321
Total Funding Change, Advanced Technology R&D	**+11,605**

Construction

Funding Schedule by Activity

	(dollars in thousands)				
	FY 2004	FY 2005	FY 2006	$ Change	% Change
Construction					
Neutrinos at the Main Injector (NuMI)	12,426	745	0	-745	-100.0%

Description

This provides for the construction of major new facilities needed to meet the overall objectives of the High Energy Physics program.

Benefits

The construction of the Neutrino at the Main Injector (NuMI) as a new facility at the Fermi National Accelerator Laboratory will enable decisive and controlled measurements of basic neutrino properties, including neutrino oscillations with a high flux beam of neutrinos in the energy range of 1 to 40 GeV. The study of the basic neutrino properties will provide important clues and constraints to the theory of matter and energy beyond the Standard Model.

Detailed Justification

	(dollars in thousands)		
	FY 2004	FY 2005	FY 2006
Neutrinos at the Main Injector (NuMI)	**12,426**	**745**	**0**

This project provides 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. Completion of this project is scheduled for FY 2005.

Explanation of Funding Changes

	FY 2006 vs. FY 2005 ($000)
Neutrinos at the Main Injector (NuMI)	
Decrease reflects project completion in FY 2005.	-745

Capital Operating Expenses and Construction Summary

Capital Operating Expenses

(dollars in thousands)

	FY 2004	FY 2005	FY 2006	$ Change	% Change
General Plant Projects	13,726	18,791	22,290	+3,499	+18.6%
Accelerator Improvements Projects	9,401	7,085	2,375	-4,710	-66.5%
Capital Equipment	69,450	72,047	39,837	-32,210	-44.7%
Total, Capital Operating Expenses	92,577	97,923	64,502	-33,421	-34.1%

Construction Projects

(dollars in thousands)

	Total Estimated Cost (TEC)	Prior Year Appro-priations	FY 2004	FY 2005	FY 2006	Unappro-priated Balance
98-G-304 Neutrinos at the Main Injector	109,162	95,991	12,426	745	0	0

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 2004	FY 2005	FY 2006	Acceptance Date
Large Hadron Collider — Machine	110,000	90,252	82,702	5,130	2,420	0	FY 2005
Large Hadron Collider — ATLAS Detector	102,950[a]	54,099	44,532	4,710	2,413	1,598	FY 2008
Large Hadron Collider — CMS Detector	147,050[b]	71,789	58,099	6,030	3,510	2,900	FY 2008
MINOS	60,272	44,510	41,960	2,000	550	0	FY 2005
GLAST/LAT	42,000[cd]	42,000[d]	25,679	7,900	8,421	0	FY 2006
Cryogenic Dark Matter Search (CDMS)	9,090[e]	4,908	4,358	550	0	0	FY 2004
Auger	4,730[f]	3,230	2,230	1,000	0	0	FY 2004
Run IIb D-Zero Detector	12,502[g]	12,502	6,252	2,542	3,708	0	FY 2007
Run IIb CDF Detector	10,374[h]	10,374	6,969	1,673	1,732	0	FY 2007
VERITAS	7,399[i]	4,799	0	1,600	2,050	1,149	FY 2006
BaBar Instrumented Flux Return (IFR) Upgrade	4,900	4,900	0	3,000	1,200	700	FY 2006
BTeV	6,750	6,750[j]	0	0	6,750	0	N/A
Total, Major Items of Equipment				36,135	32,754	6,347	

[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 total TPC for this project is $136,600,000, including $93,400,000 from NASA and $1,200,000 from Japan.
[d] We expect a rebaselining of the GLAST/LAT project to be completed during the second quarter of FY 2005, possibly resulting in a new TEC and TPC for the DOE contribution of no more than $45,000,000. This change will not affect the scheduled FY 2005 completion date for DOE's portion of the GLAST project.
[e] The total TPC for this project is $18,390,000 including $9,300,000 from NSF.
[f] The total U.S. contribution (TPC) for this project is $8,680,000 including $3,950,000 from NSF.
[g] The total TPC for this project is $19,926,000, including $3,068,000 from NSF and $4,356,000 from foreign partners.
[h] The total TPC for this project is $13,545,000 including $3,171,000 from foreign partners.
[i] 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.
[j] The TEC for this project has been decreased to $6,750,000 from the range of estimate $187,000,000 to $221,000,000 reflecting the termination of the project after the engineering design phase in FY 2005.