High Energy Physics

Funding Profile by Subprogram

(dollars in thousands)

	FY 2003 Comparable Appropriation	FY 2004 Original Appropriation	FY 2004 Adjustments	FY 2004 Comparable Appropriation	FY 2005 Request
High Energy Physics					
Proton Accelerator-Based Physics	383,787	399,494	-8,934[ab]	390,560	412,092
Electron Accelerator-Based Physics	137,933	159,486	-13,774[b]	145,712	150,890
Non-Accelerator Physics	44,309	43,000	+6,401[ab]	49,401	42,936
Theoretical Physics	44,792	42,256	+5,367[b]	47,623	49,630
Advanced Technology R&D	71,375	81,242	+6,667[b]	87,909	81,081
Subtotal, High Energy Physics	682,196	725,478	-4,273[a]	721,205	736,629
Construction	19,842	12,500	-74[a]	12,426	751
Subtotal, High Energy Physics	702,038	737,978	-4,347[a]	733,631	737,380
Use of Prior Year Balances	0	-1,205	0	-1,205	0
Total, High Energy Physics	702,038[cd]	736,773	-4,347[a]	732,426	737,380

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 and their interactions, thereby underpinning and advancing DOE missions and objectives through the development of key cutting-edge technologies and trained manpower that provide unique support to these missions.

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[a] Excludes a rescission of $4,346,960 in accordance with the Consolidated Appropriations Act, 2004, as reported in conference report H. Rpt. 108-401, dated November 25, 2003, as follows: Proton Accelerator-Based Physics ($2,648,210); Non-Accelerator Physics ($1,625,000); and Construction ($73,750).

[b] Reflects reallocation of funding within High Energy Physics in accordance with H. Rpt. 108-212, accompanying the FY 2004 Energy and Water Development Appropriations Act, HR 2754, as follows: Proton Accelerator-Based Physics ($-6,286,000); Electron Accelerator-Based Physics ($-13,774,000); Non-Accelerator Physics ($+8,026,000); Theoretical Physics ($+5,367,000); and Advanced Technology R&D ($+6,667,000).

[c] Excludes $14,984,000 which was transferred to the SBIR program and $899,000 which was transferred to the STTR program.

[d] Excludes $4,697,019 rescinded in accordance with the Consolidated Appropriations Resolution, FY 2003.

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 cosmology. Research advances in any one of these fields often have a strong impact on research directions in another. These fields also share a common technological infrastructure, ranging from particle accelerators and detectors to data acquisition and computing. Technology that was developed in response to the demands of high energy physics 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.

Strategic and Program Goals

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

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, to advance the frontiers of knowledge in physical sciences and areas of biological, medical, environmental, and computational sciences, and to 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 understanding of dark energy and dark matter, the lack of symmetry in the universe, the basic constituents of matter, and the possible existence of other dimensions, collectively revealing key secrets of the universe. HEP expands the energy frontier with particle accelerators to study fundamental interactions at the highest possible energies, which may reveal new particles, new forces or undiscovered dimensions of space and time; explains how everything came to have mass; and illuminates the pathway to the underlying simplicity of the universe. At the same time, the HEP program sheds new light on other mysteries of the cosmos, uncovering what holds galaxies together and what is pushing the universe apart; understanding why there is any matter in the universe at all; and exposing how the tiniest constituents of the universe may have the largest role in shaping its birth, growth, and ultimate fate. Our goals in FY 2005 address all of these challenges. The FY 2005 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 at the Fermi National Accelerator Laboratory (Fermilab) and the Stanford Linear Accelerator Center (SLAC), to produce maximum scientific data to address these fundamental questions. In FY 2005 we also expect to begin engineering design of a new Major Item of Equipment, the BTeV ("B Physics at the TeVatron") experiment at Fermilab that will extend current investigations aimed at an explanation of the absence of antimatter in the universe.

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 very roughly to current research priorities, but 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 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 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 2000 Results	FY 2001 Results	FY 2002 Results	FY 2003 Results	FY 2004 Targets	FY 2005 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.	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.	Deliver data as planned within 20% of the baseline estimate (390 pb-1) to CDF and D-Zero detectors at the Tevatron.
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.	Deliver data as planned within 20% of baseline estimate (50 fb-1) to the BaBar detector at the SLAC B-factory.
Construction					
		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 upgrades and new major 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., National Science Foundation (NSF), 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 High Energy Physics (HEP) program has incorporated feedback from OMB into the FY 2005 Budget Request and has taken, or will take, the necessary steps to continue to improve performance.

In the PART review, OMB gave the High Energy Physics (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. HEP will work to develop a resource-loaded project plan for Fermilab’s Run II effort and will submit that plan to OMB by June 2004. The Particle Physics Project Prioritization Panel (P5) will continue its work and submit a final report in FY 2004. Although HEP is establishing 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, this committee has not yet met. Once the COV issues a report, HEP will develop an action plan to respond to the findings and recommendations within 30 days. The assessment found that HEP has developed a limited number of adequate performance measures. However, OMB noted concerns regarding the collection and reporting of performance data. To address these concerns, HEP will work with its Advisory Committee to develop research milestones for the long-term performance goals, will include the long term research goals in grant solicitations, will work to improve performance reporting by grantees and contractors, and will work with the CFO to improve HEP sections of the Department's performance documents. HEP's role in providing scientific research facilities is strongly supported by the Administration. Funding is provided in FY 2005 to operate the program's two large facilities at 93 percent of maximum capacity.

Reviews of the program are conducted by HEPAP. Also, the Office of High Energy Physics conducts annual reviews, using independent consultants, of the HEP programs at five major laboratories. However, it was called out that the program does not currently have regular reviews of its research portfolio and processes by ad hoc panels of outside technical experts.

As a result of the above findings, the High Energy Physics program has taken the following actions. The program has worked further to reform its performance measures and goals while being sensitive to the problems that basic research programs face in attempting to predict future scientific progress. Also, the FY 2004 budget focused resources on addressing construction and upgrade activities at Fermilab while simultaneously operating the laboratory at 82 percent of maximum capacity (compared to 87 percent in FY 2003 and 78 percent in FY 2002). The program has formed a committee, called the Particle Physics Project Prioritization Panel (P5), to prioritize its medium and large ($50-600M TEC) construction projects and MIEs within the program that have not yet reached the full construction phase. The committee was charged in January 2003 to study and prioritize three proposed projects; and a response was received from the committee in September 2003. In addition, the program has instituted a process for reviewing its research portfolio by a formal committee of visitors every three years. The first review is tentatively scheduled for the 2nd quarter in 2004.

Funding by General and Program Goal

	(dollars in thousands)				
	FY 2003	FY 2004	FY 2005	$ Change	% Change
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	383,787	390,560	412,092	+21,532	+5.5%
Electron Accelerator-Based Physics	137,933	145,712	150,890	+5,178	+3.6%
Non-Accelerator Physics	44,309	49,401	42,936	-6,465	-13.1%
Theoretical Physics	44,792	47,623	49,630	+2,007	+4.2%
Advanced Technology R&D	71,375	87,909	81,081	-6,828	-7.8%
Construction	19,842	12,426	751	-11,675	-94.0%
Total, Program Goal 5.19.00.00, Explore the Fundamental Interactions of Energy, Matter, Time and Space	702,038	733,631	737,380	+3,749	+0.5%
Use of Prior Year Balances	0	-1,205	0	+1,205	+100.0%
Total, High Energy Physics	702,038	732,426	737,380	+4,954	+0.7%

Overview

The study of high energy physics, also known as particle physics, grew out of nuclear and cosmic ray physics in the 1950's that measured the properties and interactions of fundamental particles at the highest energies (millions of electron-volts or "MeV") then available with a relatively new technology: particle accelerators. Today that technology has advanced so that forefront particle accelerators produce exquisitely controlled beams with energies of trillions of electron-volts ("TeV") and intense enough to melt metal. The science has advanced with the technology to study ever-higher energies and very rare phenomena that probe the smallest dimensions we can see and tells us about the very early history of our universe. While the science has revolutionized our understanding of how the universe works, elements of the technology have helped transform other fields of science, medicine, and even everyday life. The science and its impacts will be remembered as one of the highlights of the history of the late 20th century.

But science can not be content to rest on its achievements, and high energy physics is poised to make new discoveries that may well remake our world and our understanding of it in the 21st century. The challenge of the HEP program is to exploit those scientific opportunities that appear most promising while maintaining diverse efforts that allow for the unexpected discoveries that are a hallmark of scientific inquiry. The High Energy Physics Advisory Panel (HEPAP), consisting of leading members of the high energy physics community, provides advice to the Department of Energy and the National Science Foundation on a continuing basis regarding the direction and management of the national high energy physics research program. Their 2002 Long Range Planning report conveys the excitement of the questions being addressed by the field today:

Particle physics stands at the threshold of a new era of discovery….experiments in progress and under development offer the potential to… reshape our view of matter and energy, space and time.

The goals outlined in the HEPAP long-range plan are bold and long-term:

During the next twenty years, we will try to understand how the disparate forces and particles of our universe merge together into a single coherent picture….. We will seek new dimensions of space-time, …. And we will seek the mysterious particles and forces that have created indelible imprints on our universe.

The long-range plan outlines the steps to be taken to reach these goals as a "roadmap" for particle physics over the next twenty years. The program described below takes the first steps on that journey.

Major Advances

Since the Department of Energy and its predecessors began supporting research in this field around 1950, our understanding of the fundamental nature of matter has deepened profoundly, generating a stream of Nobel Prizes that are a source of national pride, prestige, and scientific leadership. The most recent example is the 2002 Nobel Prize in Physics, shared by Raymond Davis, Jr., of Brookhaven National Laboratory (BNL) for his groundbreaking experiment that demonstrated the existence of neutrinos coming from the sun and conclusively proved that the sun shines via thermonuclear reactions.

Many of the Nobel Prizes awarded for research in high energy physics have been tied to the development of the "Standard Model," a comprehensive theoretical description of all the fundamental particles and their interactions (except gravity). The success of the Standard Model in predicting and explaining a wide variety of experimental data with impressive precision and economy has made it the theoretical gold standard over the last half-century. A major role in establishing the Standard Model is one of the proudest accomplishments of the HEP program supported by the DOE and its predecessor agencies.

Major Questions

Though the Standard Model has been subjected to an array of rigorous tests for many years -- and has survived all of them at the particle energies we have been able to explore -- important questions remain. It is known that the Standard Model is incomplete at TeV energies. At energies above 1 TeV, the electromagnetic and weak interactions are unified into a single electroweak force, and the W and Z bosons that carry the weak interaction have zero mass (like the photon, which carries the electromagnetic interaction). This situation is dramatically changed as the energy falls through 1 TeV, with the W and Z acquiring large masses (nearly a hundred times the mass of a proton). The Standard Model accommodates this effect via a hypothetical (not yet observed) field called the Higgs, but does not explain *why* the symmetry is broken. Furthermore, estimates of the Higgs boson mass are unnaturally sensitive to quantum mechanical corrections that must be finely tuned to avoid driving the calculated mass far above the TeV scale. New physics is needed to stabilize the calculation and provide sensible results.

A theory called supersymmetry is one possible example of such new physics. It predicts one new particle for each particle that is known today, and their contributions to quantum corrections of the Higgs boson mass cancel others, stabilizing the mass. Moreover, supersymmetry may help us to understand how the separate forces we see today in the universe “unify” into a coherent whole. The investigation of unification phenomena is one of the central thrusts of the HEP research program.

Another powerful insight, emphasized by both the HEPAP long-range plan and the recent National Research Council study entitled “Connecting Quarks with the Cosmos,” is that cosmological questions are intimately connected with fundamental particles and forces. The study of elementary particles is necessary to answer questions about the origin, evolution, and fate of the universe, and precise observations of the universe can yield clues to the nature of the particles and forces. The study of these “cosmic connections” between the very large and the very small forms another major research thrust of the HEP program.

The key scientific questions that are now being asked about the universe at its two extremes – the very large and the very small – are inextricably intertwined. These questions define the major scientific goals of the program:

- Can we realize Einstein’s dream of a unified description of fundamental particles and forces in the universe?
- Where is the fundamental particle that endows all other particles with their masses?
- Are there additional or “hidden” dimensions of space-time?
- What are the masses of the neutrinos, and what is their role in the universe?
- Why is there more matter than anti-matter in the universe?
- What are dark matter and the dark energy, which together make up more than 95% of the universe?

Major Experimental Tools

Obtaining definitive answers to these questions require – as with all scientific research – conduct of controlled experiments to test hypotheses. The HEP program has developed, in collaboration with the NSF, NASA, and other U.S. funding agencies, as well as international research partners, a coordinated experimental program that seeks to address these questions:

- Einstein's dream of unification will be pursued experimentally by the CDF and D-Zero experiments at the Fermilab Tevatron that will investigate particles and forces at the current energy frontier. With these experiments, we will also be directly searching for evidence of supersymmetry, extra space-time or quantum dimensions, particle candidates for dark matter, and for other new phenomena beyond the Standard Model.
- Extending the energy frontier, the Large Hadron Collider (LHC) at the European Organization for Nuclear Research (CERN) and its associated experiments, A Toroidal LHC Apparatus (ATLAS) and Compact Muon Solenoid (CMS), will begin operations later this decade. This higher energy scale will lead us to a deeper understanding of the unification of forces and should provide the crucial evidence for the mechanism causing all particles to have masses.
- Evidence for additional space-time dimensions as well as supersymmetry and the source of mass will be sought at the Tevatron and the LHC. These investigations would be further enhanced by a high-energy electron linear collider that can map the nature, shapes and sizes of these other dimensions and precisely measure the properties of new particles. A hadron collider, with its rich abundance of particles, is a discovery machine for new physics, while an electron collider can focus sharply on a precise energy and make very clean measurements of the properties of new particles. Working in tandem, the two instruments provide an extremely powerful tool to explore the TeV energy scale which is sure to be a fertile ground for new physics. This is the main reason for our continued support of a vigorous program of accelerator R&D leading towards higher energy accelerators.
- That neutrinos have mass and transform themselves among their different types was recently discovered and confirmed. In order to investigate these elusive particles in detail experimentally, a powerful neutrino source is needed. The world's highest intensity neutrino beam, Neutrinos at the Main Injector (NuMI), has been constructed at Fermilab and will begin operations in 2005.
- The question of why the universe is predominantly made of matter rather than a balance of matter and antimatter is inextricably tied to the phenomenon of "CP violation." This small imbalance observed in particle interactions is being investigated for b-quarks with electron collisions at the SLAC B-factory, while planning is underway for the next-generation of B-particle experiments at Fermilab, called BTeV. The possibility of investigation of this phenomenon in neutrinos is also being explored.
- Confirming earlier spectacular discoveries, many independent measurements, including the Sloan Digital Sky Survey, now show that the expansion of the universe is accelerating due to "Dark Energy," which apparently comprises 70 percent of the energy density of the universe. The proposed SuperNova Acceleration Probe (SNAP) is one option for a space-based Joint Dark Energy Mission (JDEM) with NASA, designed to measure the expansion history of the universe and uncover the nature of dark energy. The overwhelming evidence for the mysterious Dark Energy was chosen the 2003 "Breakthrough of the Year" by the editors of *Science.*

- “Dark Matter,” that was recently determined to comprise about 25 percent of the energy density of the universe, is another great mystery. Searches for the particles that make up dark matter are underway or planned not only at the Tevatron and LHC, but also in experiments that do not use accelerators.

The U.S. HEP program takes advantage of the unique tools that have been developed both here and abroad to answer these fundamental questions, using both man-made and cosmic accelerators, and a wide variety of particle detection technologies. Cross-cutting the entire program are activities in theoretical physics and advanced technology development, which help define the right questions to be asked and provide new tools for answering them.

Theoretical Research

Theoretical research in high energy physics seeks to comprehend elementary particles and forces in a mathematical framework that enables calculation of particle properties and interactions. The theory may also predict new phenomena. One recent exciting development in theoretical research is the prospect that neutrinos may be involved in the explanation of the matter-antimatter asymmetry in the universe.

A promising, if challenging, theoretical approach is string theory that represents elementary particles as “musical notes” of tiny loops of string. There are several string theory models, and all require extra dimensions of space-time. These could have such small extent that we don’t perceive them, but might explain why gravity is so much weaker than the other basic forces: perhaps its effect is spread among more than three dimensions. These tiny, rolled-up spatial dimensions may not only exist but also may be observable at the Tevatron and the LHC.

String theories also offer the possibility of combining the forces that govern the behavior of particles with the force of gravity. Gravity has been best explained by the general theory of relativity that defines it as a curvature of space-time. As a fundamental force of nature, it stands alone, but with string theory, it may someday be unified with other forces, fulfilling Einstein’s dream. This would extend the current Standard Model of particles and interactions in a very important way. At the same time, recently available precision results in particle astrophysics and cosmology are leading to the development of a “Standard Model” for cosmology.

Some theoretical problems also require massive computing resources. For example, the theory of strong interactions (called “Quantum Chromodynamics” or QCD) can only be calculated to high precision by using advanced, high-performance computers. These high-precision calculations are needed to allow improvement in the measurements of a number of phenomena, e.g., CP-violation measurements at B-factories. Development of suitable computing resources for experiment and theory is supported by the program and additional resources are provided through the *Scientific Discovery through Advanced Computing* (SciDAC) program (see below).

Advanced Technology R&D

High energy physics experiments involve precise measurements of phenomena buried in a background of noise or conventional physics processes. A typical experiment will record multiple interactions of many (10-100) extremely high-energy particles occurring in a very short period of time (10-100 nanoseconds). Such research demands particle beams of great intensities and high energies; and robust detectors with high sensitivity and careful selectivity. The HEP program supports advanced technology research and development aimed at developing higher energy and more intense particle accelerators and more sophisticated, high-performance detectors.

Operating in these extreme domains requires substantial time and expense to design, build, maintain, operate, and upgrade the complex and technically advanced research apparatus. A new accelerator or colliding beam device now requires 10 to 20 years of intensive research and development work to bring it to the point of cost effective construction, and a similar effort is required for detectors and computing systems. The R&D programs to sustain a forefront science program are unavoidably costly and long-term. Since few of the core technologies for these devices are marketable, industry has little motivation to research, develop, or manufacture the key technical items, except as (usually expensive) special procurements. Consequently, in order to advance the science, it is essential for the universities and national laboratories engaged in high energy physics to develop the cutting edge technologies that are needed for their research. Fortuitously, it is from this technology R&D that many of the spin-offs to other sciences and the marketplace originate. See *Benefits to Other Sciences and Citizens* below for examples.

Current research in these areas includes studies in nonlinear dynamics of particle beam optics, applications of chaos theory to the behavior of particle beams, new computational techniques, and computer modeling of accelerator and detector systems. An essential part of the research is looking for new accelerator and detector concepts and methods. Excellent progress has been made in the use of lasers and plasmas for the acceleration of electrons and positrons, the exploration of alternate radio frequency acceleration techniques the industrial availability of very high current superconductors, the operation of record magnetic fields in experimental superconducting magnets, and the development of new types of semiconductor-based particle detectors.

Benefits to Other Sciences and to Citizens

High energy physics is profoundly connected to nuclear physics and to astrophysics and cosmology. Research advances in any one of these fields often have a strong impact on research directions in another: a good example is the recent discovery of “Dark Energy” by teams of high energy physicists and astronomers that overturned the conventional picture of cosmology and led to the SNAP research proposal. These fields also share a common technological infrastructure, ranging from particle accelerators and detectors to data acquisition and computing.

Technology that was developed in response to the demands of high energy physics 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:

- Synchrotron light sources, an outgrowth of electron accelerators and storage rings, have become invaluable tools for materials science, structural biology, chemistry, environmental science, and medical science. All of the current “light sources” in the Basic Energy Sciences program are based on this enabling technology. Synchrotron radiation is also used in the semiconductor industry to study structures on silicon surfaces at the nanometer level, and in studies of molecular structures that promise to provide new tools for drug design and disease prevention.

- Accelerators are used for radiation therapy and to produce isotopes for medical imaging. Moreover, many medical imaging technologies rely on detectors and techniques developed for research in high energy and nuclear physics, including computerized axial tomography (CAT scans), single photon emission computerized tomography (SPECT) and positron emission tomography (PET scans). In U.S. hospitals, one patient in three benefits from a diagnostic or therapeutic nuclear medicine procedure.

- The amount of superconducting wire and cable required to build the Fermilab Tevatron in the 1970's was far beyond the capacity of what industrial vendors had ever been asked to supply. By placing an order that required tons of material rather than pounds and working closely with industry, Fermilab helped to create the large-scale manufacturing techniques needed, and thereby created an industry with the capability to supply a commercial market. By the 1980's the market existed, through demand for a powerful new medical diagnostic tool: Magnetic Resonance Imaging or MRI. Today this is a billion-dollar worldwide market. In the words of one industry veteran: "Every program in superconductivity that there is today owes itself in some measure to the fact that Fermilab built the Tevatron and it worked."

- The World Wide Web was invented by high energy physicists to transport large bodies of data among international collaborators and has brought about a worldwide revolution in communications and commerce. The next phase in this development is the "Data Grid," a worldwide network of connected computing resources that can be seamlessly accessed and optimally used by individual physicists, just as the electrical grid powers our everyday life. HEP experimenters and computer scientists are developing and using prototype "grids" today to analyze data from current experiments (e.g., BaBar and D-Zero), and preparing larger and more robust versions to cope with the flood of data expected from the LHC at the end of this decade. Many players in the computing industry are watching these developments closely.

While it is not possible to predict which technologies developed in support of HEP research today will impact the broader scientific community and society at large over the next 20 years, it can be expected that the technologies we are investing in will, as they have in the past, make notable contributions. One area is continued development of advanced superconducting wire and cable for use in high-field superconducting magnets, necessary for upgrades to the LHC or construction of any future proton accelerator. The development of niobium-tin and niobium-aluminum, as well as the application of the newer high temperature superconductors, is done in collaboration with U.S. industry through direct grants and the Small Business Innovation Research (SBIR) program. Another significant effort is development of compact microwave and radiofrequency (RF) power sources and accelerating structures that are needed for technically feasible and cost-effective linear collider designs. Many years of R&D into high-resolution, radiation-hard silicon pixel detectors have paid off in the first working detectors for HEP applications, and will be installed in the LHC.

Finally, an important product of the HEP program is the corps of graduate students trained at universities in the large variety of scientific and engineering skills required to support this discipline. This is a group of highly talented people, well versed in scientific methods and state-of-the-art technologies, and skilled at working in large teams. More than half of them ultimately go into careers in high-tech industries, contributing to our country's economic strength in a multitude of ways.

How We Work

The High Energy Physics program coordinates and funds high energy physics research. In FY 2003, the DOE HEP program provided about 90% of the federal support for high energy physics research in the nation. The National Science Foundation (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, the Department of Energy 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 Department of Energy and the National Science Foundation 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 also undertakes special studies and planning exercises in response to specific charges from the funding agencies.

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), that 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 as *Connecting Quarks with the Cosmos*.

As noted above, the central scientific questions identified in both the recent HEPAP Long Range Plan and the NRC "Quarks to Cosmos" report form the major goals of the HEP research program.

Laboratory directors seek advice from ***Program Advisory Committees (PACs)*** to determine the allocation of a scarce scientific resource—available beam time. Committee members, mostly external to the laboratory, are appointed by the director. PACs review research proposals requesting time at the facilities and technical resources; judging each proposal's scientific merit, technical feasibility, and manpower requirements and recommending whether the proposal should be approved, conditionally approved, deferred, or rejected.

Non-accelerator-based research proposals to DOE and NSF often do not receive review by laboratory PACs; instead, they are reviewed by a special advisory committee called the ***Scientific Assessment Group for Experiments in Non-Accelerator Physics (SAGENAP),*** which assesses the scientific merit of such proposals.

Review and Oversight

The High Energy Physics 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. A university proposal to perform an experiment at a laboratory facility is 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 institutional health of the laboratory, its high energy physics research program, 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. In addition, the HEP program will begin in FY 2004 to conduct regular, dedicated reviews of operations and infrastructure at its major user facilities in order to maintain high standards of performance and reliability. HEPAP generally meets once a year at one of the major high energy physics laboratories and devotes one-third of its time to a review of that laboratory's program. Findings and recommendations are transmitted to DOE. In addition, the HEP program participates in the annual SC Institutional Reviews for each of its laboratories and semi-annual reviews of each of its ongoing construction projects conducted by the Construction Management Support Division in SC.

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 review. 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 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 is tentatively scheduled for the 2nd quarter in 2004.

Planning and Priority Setting

One of the most important functions of HEPAP is 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 as possibilities for the next twenty 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 recommended a new mechanism to update the roadmap and set priorities across the program. This recommendation has been implemented in the form of the Particle Physics Project Prioritization Panel ("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. The recommendations of this report have been implemented in this budget submission 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 High Energy Physics budget has five major components by function. About 51% of the FY 2005 budget request is provided to the two major HEP laboratories (Fermilab and SLAC) for facility operations; a total of 25% is provided to laboratories, including multipurpose laboratories, in support of their HEP research activities; 15% is provided for university-based research; 3% for infrastructure improvements (construction plus GPP and GPE); and 6% for other activities (including Small Business Innovative Research [SBIR] and Small Business Technology Transfer [STTR]). The FY 2005 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 and the BaBar detector at the B-factory.

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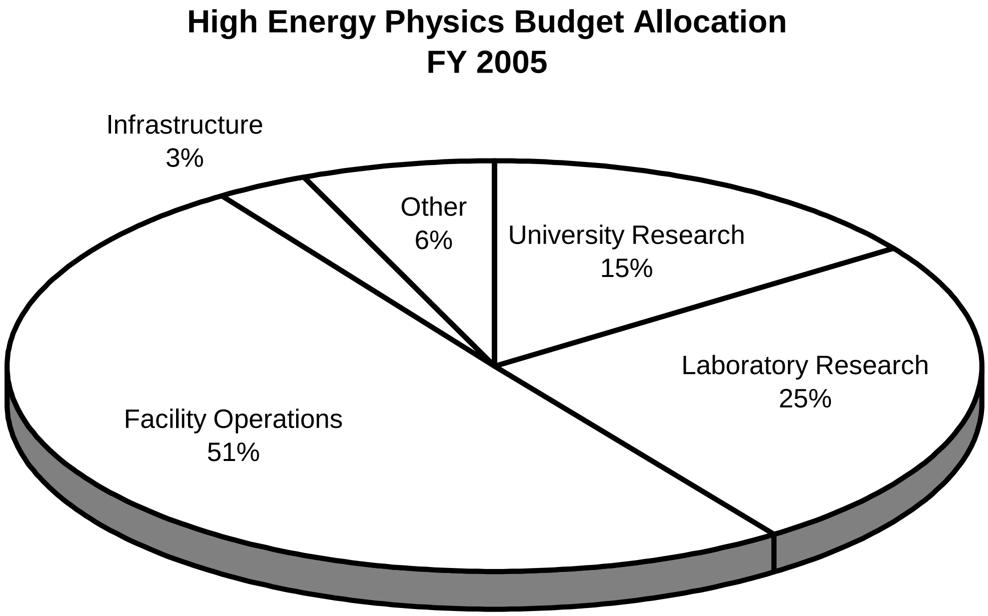
[*] A U.S. Linear Collider Steering Group has been formed, comprised of eminent scientists in the field, to coordinate U.S. efforts toward a linear collider. This group is working closely with the recently formed International Linear Collider Steering Committee to develop an international strategy and formally organize an international R&D collaboration (See detailed justification for Advanced Technology R&D below).



Research

The DOE High Energy Physics 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 9 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 particle 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 up slightly compared to FY 2004 in order to support 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 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 2003, 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 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 High Energy Physics program supports research groups at the Fermi, Lawrence Berkeley, Lawrence Livermore, Argonne, Brookhaven, Oak Ridge, and Los Alamos National Laboratories, Princeton Plasma Physics Laboratory, and the Stanford Linear

Accelerator Center. 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 large experimental detectors and computing facilities for data analysis.

The High Energy Physics 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 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

- To fully exploit their unique discovery potential, the highest priority is given to the operations, upgrades and infrastructure for the Tevatron and B-factory. These include upgrades to the two accelerators to provide increased luminosity, detector component replacements to accommodate the higher intensities, and additional computational resources to support analysis of the anticipated larger volume of data. Planned accelerator and detector upgrades are scheduled for completion in 2006. Infrastructure spending is increased to improve Tevatron reliability and B-factory performance by installing new and upgraded diagnostic and feedback systems and by replacing outdated technology components.
- The Tevatron has recovered from its poor start after the commissioning of the Main Injector ("Run II"). While luminosities have nearly reached the level planned for in the initial Main Injector construction project, Fermilab continues to face technical and management challenges in meeting more aggressive luminosity goals developed in the last few years. The laboratory has developed a detailed, resource-loaded plan for accelerator operations and improvements that should result in more reliable luminosity projections; SC has reviewed that plan, and is actively engaged in tracking its progress.
- The D-Zero and CDF Detector Upgrade projects have been descoped, canceling the silicon tracker replacements. The original detector upgrade plans proposed in the FY 2002 budget called for replacement of both silicon tracker subsystems in two large Tevatron collider experiments, CDF and D-Zero. At the time, the Tevatron luminosity upgrade plan was much more aggressive, projecting much larger integrated luminosities by the end of Run II than the current plan. Such large integrated luminosities would have delivered an unacceptably large radiation load, or dose, to the inner silicon tracking systems of the two detectors, leading to their failure before the end of data-taking. With the revised luminosity projections, replacement of the silicon tracker systems is not required, and is in fact detrimental to the overall Run II physics goals, because of the long shutdown required to extract the existing detectors and replace them.
- The U.S. LHC projects will be about 97% complete in FY 2005. To insure the greatest benefit from the investment made, strong support of the U.S. LHC research program will be provided in the areas of pre-operations of U.S.-built systems, development of software and computing for physics analysis, and accelerator R&D related to the LHC machine.
- An exciting and expanding partnership with NASA continues in the area of Particle Astrophysics and Cosmology. Fabrication of the Large Area Telescope (LAT) for the NASA Gamma-ray Large Area Space Telescope (GLAST) mission will be complete in 2005, while the Alpha Magnetic Spectrometer (AMS) will be in pre-operations testing. There will be a significant increase in the U.S.

scope of the GLAST/LAT effort in FY 2005 because of the default of one of the international partners in the experiment. DOE and NASA are sharing the cost of this scope increase to maintain the scientific reach of the LAT. GLAST is scheduled for launch in 2006 and AMS in 2007.

- There is also an exciting new potential for an interagency experiment to explore the nature of the recently-discovered "Dark Energy" that is causing an accelerating expansion of the universe. NASA has a Dark Energy probe in its research program starting in FY 2004 and is developing mission concepts. R&D for the SuperNova Acceleration Probe (SNAP) will be continued as a possible option for an interagency experiment on the Joint Dark Energy Mission (JDEM). These experiments, and others that may be proposed, will provide important new information about the birth, evolution and ultimate fate of the universe that will in turn lead to a better understanding of dark matter, dark energy, and the original Big Bang.
- In FY 2005 we will begin engineering design of a new Major Item of Equipment, the BTeV ("B Physics at the TeVatron") experiment at Fermilab, subject to successful independent cost and technical reviews of the project to take place in 2004. This is a dedicated experiment that will run at the Tevatron after the conclusion of Collider Run II at the end of this decade. This experiment will study CP violation and search for new phenomena in the B meson system with much higher statistics than is possible at the B-factories, including studies of B meson species that are inaccessible to the B-factories. The importance of the physics addressed by BTeV has been endorsed by HEPAP and recognized in the Office of Science's Report, "*Facilities for the Future: A Twenty Year Outlook*."
- The construction of the Neutrinos at the Main Injector (NuMI) project is proceeding well, and completion is expected within the projected cost and schedule in FY 2005, followed by the operations of these facilities to provide neutrino beams for the next generation of neutrino experiments.

Scientific Discovery through Advanced Computing

The Scientific Discovery through Advanced Computing (SciDAC) program is a set of coordinated investments across all Office of Science mission areas with the goal of achieving breakthrough scientific advances via computer simulation that were impossible 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 to 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 HEP contributions to SciDAC and the FY 2005 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 two major high energy physics facilities: the Tevatron at Fermilab, and the B-factory at the SLAC. These facilities provided a total of 9,250 hours of beam time in FY 2003 for a research community of about 2,200 U.S. scientists in HEP and related fields. A comparable number of users come from foreign countries, testifying to the fact that these are unique, world-leading experimental facilities. The FY 2005 Congressional Budget Request will support facility operations that will provide ~8,740 hours of beams for research. This plan will increase above the FY 2004 level at Fermilab and a decrease at SLAC associated with required shutdown for facility modification and upgrades and expected increases in power costs.

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

	FY 2003	FY 2004	FY 2005 Request
Tevatron Collider at Fermilab			
Maximum hours = 5,400			
Scheduled Hours	4,440	3,960	4,320
Unscheduled Downtime	15%	<20%	<20%
Number of Users = 2,160			
B-factory at SLAC			
Maximum hours = 5,850			
Scheduled hours	4,810	4,810	4,420
Unscheduled Downtime	10%	<20%	<20%
Number of Users = 1,100			

In FY 2003, the operation of fixed target experiments using the SLAC linac at End Station A concluded its program of High Energy Physics research.

High Energy Physics will meet the cost and schedule milestones for construction of facilities and Major Items of Equipment (MIE) within their contingencies allocated in the baseline estimates.

	FY 2001	FY 2002	FY 2003	FY 2004	FY 2005 Request
Major milestones completed or committed to	Completed D-Zero Run II upgrade at Fermilab				
	Completed U.S. Compact Muon Solenoid (CMS) hadron calorimeter absorber and delivered to CERN	Completed construction of U.S. A Toroidal LHC Apparatus (ATLAS) tile calorimeter sub-modules	Completed first inner triplet quadrupole magnet for LHC accelerator	Complete U.S. ATLAS Transition radiation tracker module production Complete U.S. CMS Hadron calorimeter readout test	Complete U.S. contribution to LHC machine Complete Phase I of US ATLAS and U.S. CMS fabrication
		Completed fabrication of first half of Main Injector Neutrino Oscillation (MINOS) experiment	Completed Neutrinos at the Main Injector (NuMI) excavation	Complete NuMI civil construction	Complete NuMI/MINOS construction
			Completed fabrication of MINOS far detector.		
				Complete CDMS II project fabrication Complete Pierre Auger project fabrication	
					Complete LAT fabrication Complete Run IIb detector upgrades of CDF and D-Zero.

Construction and Infrastructure

Funding for construction is down significantly compared to FY 2004 as several projects are completed or ramping down. Funding for capital equipment increases as engineering design begins for the new BTeV experiment at Fermilab; and other capital equipment funding at SLAC and Fermilab to address accelerator and detector complex reliability and performance issues is significantly increased. Similarly, funding for general plant projects (GPP) is significantly 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 slightly at SLAC and Fermilab relative to FY 2004, as accelerator upgrade projects designed to increase the rate of physics data delivered at both laboratories begin to ramp down.

Workforce Development

The High Energy Physics 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 finely honed 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 in such diverse areas as hospitals (radiation therapy, medical imaging, and medical physics), national security, space exploration, software and computing, telecommunications, finance, and many more fields.

About 1,200 post-doctoral associates and graduate students supported by the High Energy Physics program in FY 2003 were involved in a large variety of theoretical and experimental research, including advanced technology R&D. About one-fifth are involved in theoretical research. Those involved in experimental research utilize a number of scientific accelerator facilities (~90%) supported by the DOE, NSF, and foreign countries as well as participating in non-accelerator research (~10%).

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 2003, there were 140 University grants with an 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.

Human Resources (Full-Time Equivalent) in High Energy Physics at Laboratories and Universities, DOE Supported

	FY 2002	FY 2003	FY 2004 est.	FY 2005 est.
University Grants	140	140	140	140
Lab Groups	51	50	50	50
Ph.D.'s with permanent positions	1,255	1,255	1,255	1,255
Postdoctoral Associates	565	565	565	565
Graduate Students	605	610	610	610
# Ph.D.'s awarded	120	120	120	120

In addition, there is a joint DOE/HEP and NSF research-based physics education project ("QuarkNet") aimed at professional development for high school teachers. In this project, active researchers in high energy physics serve as mentors for the 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 to follow.

Facilities Summary

Fermilab

In FY 2005, Fermilab plans 4,320 hours of running to achieve a performance goal of 390 inverse picobarns $(pb)^{-1}$ of data delivered to the major Tevatron experiments (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). 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 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 four years requires a series of performance enhancements to the accelerator and the CDF and D-Zero detectors. These efforts are proceeding in parallel with current Tevatron operations and research and are more fully described in the Detailed Justification sections that follow.

Tevatron operations also include the running of the Tevatron complex in fixed target mode in parallel with Tevatron collider operation. This will be for the physics data taking of the MiniBooNE experiment (8 GeV protons extracted from Booster ring) and MINOS experiment (120 GeV protons extracted from

Main Injector to NuMI beamline) and for test beam runs (120 GeV protons extracted from Main Injector). During FY 2005, the MiniBooNE experiment will be operating its beam line and detector to collect data until NuMI begins operations. Test beam runs will be scheduled as needed. These functions are non-interfering with the high-priority Tevatron collider operations.

SLAC

In FY 2005, SLAC plans 4,420 hours of running to achieve a performance goal of 50 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 2005. The collected data will provide a significant enhancement to the BaBar dataset for precision studies of CP violation in the B-meson system, as described above.

Fully achieving the physics goals of the B-factory program has required a series of performance enhancements to the accelerator and the BaBar detectors. Plans to improve the collision luminosity to an ultimate value of $3x10^{34}cm^{-2}s^{-1}$, an order of magnitude greater than the design value have been carried out since FY 2002 and are expected to be completed in FY 2005. These efforts are proceeding in parallel with current B-factory operations and research and are more fully described in the Detailed Justification sections that follow.

Operations of the fixed target experimental program using the SLAC linac and End Station A were terminated in FY 2003.

HEP facilities operations funding and running weeks are summarized in the table below for the Tevatron and B-factory:

	(dollars in thousands)		
	FY 2003	FY 2004	FY 2005
Tevatron Operations	184,933	196,926	193,665
Tevatron Improvements[a]	44,583	42,185	69,826
Total, Tevatron	229,516	239,111	263,491
Running Hours	4,440	3,960	4,320
B-factory Operations	95,095	96,913	100,290
B-factory Improvements[b]	15,709	20,665	21,770
Total, B-factory.	110,804	117,578	122,060
Running Hours	4,810	4,810	4,420

[a] Includes Run IIb CDF and D-Zero detectors and Tevatron Accelerator, R&D on possible future accelerator improvements, the MINOS detector and general improvements to the laboratory infrastructure. For details see the Detailed Justification to follow.

[b] Includes upgrades to the BaBar detector and B-factory accelerator, and general improvements to the laboratory infrastructure. For details see the Detailed Justification to follow.

Proton Accelerator-Based Physics

Funding Schedule by Activity

	(dollars in thousands)				
	FY 2003	FY 2004	FY 2005	$ Change	% Change
Proton Accelerator-Based Physics					
Research	76,016	73,295	74,048	+753	+1.0%
Facilities	307,771	317,265	338,044	+20,779	+6.5%
Total, Proton Accelerator-Based Physics	383,787	390,560	412,092	+21,532	+5.5%

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 Department of Energy'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 the high energy proton collider facilities. This experimental research will determine whether the Standard Model correctly predicts the mechanism that generates mass for all fundamental particles and search for the first evidence of new physics beyond the Standard Model.

The Proton Accelerator subprogram also consists of accurate, controlled measurements of basic neutron properties, including neutrino oscillations at the accelerator-based neutrino facilities. These measurements will provide important clues and constraints to the theory of matter and energy beyond the Standard Model. These research thrusts are aligned with the key unification and cosmology questions identified under Program Mission.

Supporting Information

The most immediate concern of the unification goal on the particle physics roadmap is fully understanding 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 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 should 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 interactions.

The energy frontier is the primary thrust of the Proton Accelerator subprogram. In FY 2005 the energy frontier remains at the Tevatron at Fermilab. The CDF and D-Zero experiments will pursue these questions of electroweak unification with direct searches for the Higgs Boson, supersymmetry, and hidden dimensions. There will also be precision measurements of known particles, like the mass of W boson and the top quark – 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 that will allow a serious study of its mass, spin, and couplings. These types of precision measurements give indirect but useful information about the major theories on electroweak unification, and that information can guide and constrain the direct searches. When the LHC at CERN is operational, the energy frontier will move there and the CMS and ATLAS experiments will take over the program begun at the Tevatron.

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 subprogram uses both of these aspects of proton accelerators.

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 with the heaviest, the top and bottom quarks, being of the most interest. Most of the force carrying particles are also directly produced, and if the masses of predicted – but as yet unobserved – particles, like the Higgs boson or supersymmetric particles are low enough, they will also be produced at the Tevatron. Two large general-purpose detectors, CDF and D-Zero, have been built to mine this rich lode of physics.

A variety of B meson studies will be done, including independent confirmation of CP violation, that has been observed at the B-factories at SLAC and in Japan. Other processes, inaccessible to the B-factories, can also be measured. Recently, a proposal for a dedicated collider experiment at the Tevatron that can significantly advance this research has been reviewed and endorsed by the community. These measurements provide vital pieces of the theoretical framework used to explain CP violation, and an explanation of CP violation is necessary to understand why matter (and not antimatter) is what makes up the universe we live in. A precision measurement of mass of the W boson and detailed studies of the charm quarks will also be carried out.

Neutrino physics presents today one of the most promising avenues to probe for extensions of the Standard Model. *A priori*, no fundamental reason exists why neutrinos should have zero mass or why there should be no mixing between different neutrino species. In the past few years, 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 oscillation parameters. One of the unique opportunities in the Proton Accelerator subprogram is exploring and making precision measurements of the neutrinos that will be generated by using dedicated proton beam facilities in a well-controlled environment (e.g., the Neutrinos at the Main Injector or NuMI project at Fermilab).

The major activities under the Proton Accelerator subprogram are the broad research programs using the CDF and D-Zero detectors at the Tevatron at Fermilab; the neutrino research program using the NuMI/MINOS and MiniBooNE facilities at Fermilab and at the Soudan Mine site in Minnesota; the LHC program; engineering design for the proposed "BTeV" experiment at Fermilab; 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 and MiniBooNE programs 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 insure that the U.S. high energy physics research program will be one of the key players at the next energy frontier. The proposed BTeV experiment will extend the measurements of the current B-factories to explain the absence of antimatter in the universe. There are much smaller specialized efforts involving the HERA accelerator machine at DESY in Germany, and the KEK proton accelerator in Japan.

Research and Facilities

The Research category in the Proton Accelerator 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), 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 subprogram supports the maintenance and operations of, and technical improvements to, 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; providing computing hardware and software infrastructure to support the experiments and the accelerators, and provide platforms for data analysis; and directed R&D for accelerator and detector enhancements and performance improvements. Since physicists are often involved in these activities as well as research activities, some are partially supported by both categories of funding where appropriate.

The 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, initial operations of, or preparation for, 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 more data in Run II of the Tevatron collider than all of Run I (1992-1996). The collaborations published their first papers and have presented a larger number new of results at conferences. These detectors have much greater sensitivity than before and will make numerous 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. Data taking is continuing and results are expected in 2005.
- The MINOS far detector in the Soudan mine has been completed ahead of schedule. Commissioning with cosmic rays is progressing.
- A formal program has been initiated 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 to test, commission, and eventually operate the U.S.-supplied systems that are part of the LHC detectors has also been initiated, and significant pre-operations activities will begin in FY 2004.

The major planned research efforts in FY 2005 are:

- *The research program using the Tevatron/CDF Facility at Fermilab*. This research program is being carried out by a collaboration including 750 scientists from Fermilab, ANL, LBNL, 25 U.S. universities, and institutions in 10 foreign countries. The physics issues to be addressed include searches for the Higgs boson, supersymmetry or other new phenomena; B meson studies including CP violation; and precision measurements of the top quark and the W boson properties.

- *The research program using the Tevatron/D-Zero Facility at Fermilab*. This research program is being carried out by a collaboration including 650 scientists from Fermilab, BNL, LBNL, 33 U.S. universities and institutions in 16 foreign countries. The physics issues to be addressed include searches for the Higgs boson, supersymmetry or other new phenomena; B meson studies including CP violation; and precision measurements of the top quark and the W boson properties.

- *The research program using the MiniBooNE and NuMI/MINOS Facilities at Fermilab and the Soudan Mine*. These research programs are being carried out by a collaboration including 250 scientists from Fermilab, ANL, BNL, LANL, LLNL, 26 U.S. universities, and institutions in 5 foreign countries. This research is also supported in part through the DOE Nuclear Physics program. The major efforts in FY 2005 will be data taking and analysis (MiniBooNE) and detector commissioning, developing computing tools, and cosmic ray data analysis (MINOS).

- *Planning and preparation for the U.S. portion of the research program of the LHC*. A major effort in FY 2005 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 begin at CERN.

The major planned facilities efforts in FY 2005 are:

- *Operations of the Tevatron at Fermilab*. Fermilab plans 4,320 hours of running to achieve a performance goal of 390 pb^{-1} of data delivered to the major Tevatron experiments. 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.
- *Preparation for Tevatron/CDF/D-Zero performance enhancements*. The Run II Tevatron program utilizes a series of performance enhancements to the accelerator and the CDF and D-Zero detectors that will be completed in FY 2006. This effort begins to roll off in FY 2005, which as discussed above, proceeds in parallel with current Tevatron operations and research.
- *Operation of the MiniBooNE and MINOS facilities at Fermilab and the Soudan Mine*. The MiniBooNE experiment will be operating its beam line and detector to collect data. The MINOS far-detector at Soudan Mine will make the first measurements that can separate atmospheric neutrinos from atmospheric antineutrinos, while construction of the NuMI beamline is completed.
- *Fabrication and support for the U.S. portion of the LHC project*. The fabrication of the U.S. portion of the ATLAS and CMS detector components will continue along with the support for these detector activities. The production of the U.S. portion of the LHC accelerator components will be completed in FY 2005.
- *Engineering design for the BTeV experiment at Fermilab*. BTeV is a dedicated experiment that will run at the Fermilab Tevatron after the conclusion of Collider Run II. This experiment will study matter-antimatter asymmetries and search for new phenomena in the B meson system with much higher statistics than is possible at the B-factories, including studies of B meson species that are inaccessible to the B-factories. Assuming successful completion of independent cost and technical reviews in 2004, detailed engineering design would begin in FY 2005.

Detailed Justification

	(dollars in thousands)		
	FY 2003	FY 2004	FY 2005
Research..	**76,016**	**73,295**	**74,048**
▪ **University Research**...	**46,069**	**46,000**	**46,625**

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; the MINOS and MiniBooNE experiments at Fermilab and the Soudan Mine; and the HERA accelerator complex at DESY in Germany.

In FY 2005, the overall level of support is basically 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 activities on the LHC experiments, CMS and ATLAS, during FY 2005. 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 2003	FY 2004	FY 2005
▪ **National Laboratory Research**	**28,507**	**26,208**	**26,023**

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 they 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; the Large Hadron Collider, under construction at CERN; and to a much smaller degree at the HERA accelerator complex at DESY in Germany.

In FY 2005, the national laboratory research program is basically unchanged. Full participation of national laboratory physicists is needed to exploit the physics potential of the very active program at the Tevatron during FY 2005. 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 in the FY 2002-4 collider run; pre-operations of the MINOS detector and preparation for neutrino beam from NuMI; data taking with the MiniBooNE detector; support for the fabrication 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 ($8,283,000) includes data taking and analysis of the CDF, D-Zero, and MiniBooNE experiments, the CMS research and computing program, and commissioning of the MINOS detector. Being imbedded at the host laboratory, these activities provide the close linkages between the Research and the Facilities categories in the Proton Accelerator subprogram.

Research activities at LBNL ($5,350,000) will include data taking and analysis of the CDF and D-Zero experiments, and the ATLAS research and computing program.

Activities by the BNL research group ($7,840,000) will cover data taking and analysis of the D-Zero experiment, the ATLAS research and computing program, analysis of BNL Alternating Gradient Synchrotron (AGS) experiments from the last data-taking run and preparation for future NSF-funded experiments, and a small effort on the MINOS experiment.

	(dollars in thousands)		
	FY 2003	FY 2004	FY 2005

The research group at ANL ($4,550,000) will be working on data taking and analysis of the CDF experiment, the ATLAS research and computing program, commissioning of the MINOS detector, and data taking and analysis of the ZEUS experiment at HERA.

▪ **University Service Accounts**	**1,440**	**1,087**	**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	**307,771**	**317,265**	**338,044**

Facilities			
Tevatron Operations	184,933	196,926	193,665
Tevatron Improvements	44,583	42,185	69,826
Large Hadron Collider Project	59,210	48,800	32,500
Large Hadron Collider Support	7,300	15,400	29,400
AGS Operations/Support	625	0	0
Other Facilities	11,120	13,954	12,653
Total, Facilities	307,771	317,265	338,044

▪ **Tevatron Operations**	**184,933**	**196,926**	**193,665**

Operations at Fermilab will include operation of the Tevatron accelerator complex in collider mode and operations of two collider detectors for about 4,320 hours. This will be a major physics run with the higher intensity available from the Main Injector and with the D-Zero and CDF detectors. 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 recovered from its poor start after the commissioning of the Main Injector (“Run II”). While luminosities have nearly reached the level planned for in the initial Main Injector construction project, Fermilab continues to face technical and management challenges in meeting more aggressive luminosity goals developed in the last few years. The laboratory has developed a detailed, resource-loaded plan for accelerator operations and improvements that will result in more reliable luminosity projections; SC has reviewed that plan and is actively engaged in tracking its progress, with a follow-up review scheduled for early 2004. The FY 2005 budget for Tevatron Operations is consistent with that plan. Funding for associated luminosity improvements are discussed below under Tevatron Improvements.

	(dollars in thousands)		
	FY 2003	FY 2004	FY 2005

The extra resources needed to meet Tevatron Run II luminosity goals are mostly the efforts of accelerator and experimental staff at Fermilab. SLAC, LBNL and BNL accelerator physicists with specialized expertise relevant to Run II problems have been recruited to help as well. Enhancements to Tevatron reliability are discussed under Tevatron Improvements below.

Tevatron operations also include the running of the Tevatron complex in fixed target mode in parallel with Tevatron collider operation. This running mode will be primarily for the physics data taking of the MiniBooNE experiment (8 GeV proton extracted from Booster ring). Final installation and commissioning of the NuMI beam line will also take place in 2005 in preparation for the beginning of NuMI/MINOS operations.

Tevatron Operations

	(in hours)		
	FY 2003	FY 2004	FY 2005
Tevatron Operations..	4,440	3,960	4,320

▪ **Tevatron Improvements**	**44,583**	**42,185**	**69,826**

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. The funding will also provide the cost for the various utility improvement projects to operate the entire Fermilab site with higher reliability and efficiency. The category also includes funding for R&D and engineering design for a proposed new experiment, “B Physics at the TeVatron” (BTeV).

Plans for luminosity upgrades involve several steps toward increasing the number of antiprotons in the Tevatron, since that is the factor that limits luminosity. In FY 2005, this effort will be concentrating on the commissioning of the new Recycler ring that will allow for much larger (~twice as big) “bunches” of antiprotons to be injected into the Tevatron. With a larger rate of antiprotons, the rate of collisions between protons and antiprotons, and thus physics productivity, will increase by a similar rate. Funding for this particular effort is comparable to FY 2004, following the planned profile of the luminosity upgrade plan.

Detector upgrades are also needed to cope with the larger data rates that will be provided by the Tevatron. Funding for these upgrades will be completed in FY 2005 and the detector systems will be fully installed by 2006. The scope of the upgrades includes data acquisition, trigger, and computing systems for the collider experiments that will allow a greater amount of data to be recorded and analyzed.

The detector upgrade plan had been significantly descoped as noted above (under “*Significant Program Shifts*”). The revised plan for the detector upgrades includes phase out the silicon replacement activities, including measurement and documentation of the characteristics of the silicon prototypes, and bringing to publication the research results which have advanced state-of-the-art silicon detector technology. The revised funding profile includes these closeout costs for the silicon replacements, and has been reviewed and approved via standard procedures. Cost savings realized from the descoping of these projects has been applied to Run II luminosity upgrades and operations.

Funding in the amount of $21,745,000 is included for the program to increase the Tevatron luminosity, fabricate Run IIb CDF and D-Zero detector improvements and provide the computing capability needed to analyze the data collected. This is a decrease of $5,870,000 from FY 2004. This includes capital equipment for continuation of the two projects including closeout silicon tracker replacement for both the CDF Detector ($1,732,000; TEC of $10,374,000) and the D-Zero Detector ($3,708,000; TEC of $12,502,000). The TEC of the two Run IIb detector upgrade projects has been reduced and is now final as an outcome of the baseline review in fall 2003. The scope and funding profile for the Run IIb accelerator upgrades was reviewed in July 2003, and it is anticipated that the accelerator upgrades will have a baseline established prior to the next planned DOE/HEP review in February 2004.

Funding in the amount of $37,281,000 is included for Other Tevatron Improvement activities (other than those specified above). This is a significant increase of $24,711,000 from FY 2004. Activities in this category include: specific accelerator improvement projects (AIP) aimed at improving Tevatron reliability (+$6,800,000); support for ongoing Tevatron accelerator (+$9,403,000) and detector (+$2,359,000) operations, not directly related to identified upgrades, including: accelerator and detector maintenance activities, repair and replacement of failing or obsolescent components, and minor improvements and upgrades to existing systems. Increased support for these critical infrastructure areas was identified by independent reviews in 2003 as being crucial to the success of the luminosity upgrade plan. Also included in this funding category is R&D for approved accelerator upgrades (+$3,890,000), including projects to improve the throughput of antiprotons in the Tevatron complex and to mitigate the long-range interactions between the proton and antiproton beams that tend to disrupt them before they reach collision; and general complex operations support (+$345,000). GPP funding is also significantly increased to $8,544,000 (+$1,914,000) to assist with urgent ES&H and infrastructure needs.

The detector upgrades, general laboratory needs and AIP funding reflect the high priority given to highly effective operation of the Tevatron for the physics goals and are aimed at improving the luminosity and efficiency of the operation of the Tevatron.

MINOS is the detector part of the NuMI project that will provide a major new capability for neutrino research. Capital equipment for the MINOS Detector is included at $550,000 (TEC $44,510,000). This is reduced from FY 2004 by $1,450,000 following the planned profile.

In FY 2005 we will begin engineering design of a Major Item of Equipment, the BTeV experiment at Fermilab, subject to successful independent cost and technical reviews of the project to take place in 2004. This is a dedicated experiment that is proposed to run at the Fermilab Tevatron after the conclusion of Collider Run II at the end of this decade. This experiment will study CP violation and search for new phenomena in the B meson system with much higher statistics than is possible at the B-factories, including studies of B meson species which are inaccessible to the B-factories.

The importance of the physics addressed by BTeV has been endorsed by HEPAP and recognized in the Office of Science's Report, "*Facilities for the Future: A Twenty Year Outlook*." BTeV is one of the high-priority new projects described in the Outlook which could begin fabrication in the next few years. In addition, the Particle Physics Project Prioritization Panel (P5), a subpanel of the HEPAP, reviewed BTeV along with other projects at Fermilab. HEPAP endorsed the P5 report that supported the fabrication of BTeV as the highest priority new project at Fermilab after completion of the Run II upgrades, subject to constraints within the HEP budget.

The BTeV experiment will have scientific competition from a dedicated B-physics experiment at the CERN LHC, so timely completion of BTeV is important. Thus we are pursuing an aggressive schedule of R&D ($3,500,000) and engineering design ($6,750,000) in FY 2005 to be ready to begin fabrication in FY 2006. Resources for this effort will come from re-direction of other elements of the Fermilab program but will not impact the highest-priority efforts on Tevatron Run II. The Total Estimated Cost range of estimate is $190,000,000 to $230,000,000 and will be refined upon completion of detailed engineering design in FY 2005.

Funding for pre-conceptual R&D leading up to the BTeV proposal was previously funded under the Detector Development category (in the *Advanced Technology R&D* subprogram) so that category shows a corresponding decrease in FY 2005, as the R&D effort is now captured here.

	FY 2003	FY 2004	FY 2005
▪ **Large Hadron Collider Project**	**59,210**	**48,800**	**32,500**

The funding requested follows the profile approved in FY 2003, that is a revision from the original profile. Changes have been made 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 April 2007.

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 will go forward without modification and will be 100% complete in FY 2005. The U.S. detector projects (ATLAS and CMS) will complete ~95% of their planned work by the previously scheduled end-date (4^{th} 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 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 2005 funding for the detectors is reduced and the funds rescheduled in FY 2006 and FY 2007 accordingly. The final cost of each detector is unchanged.

CERN initiated the LHC project in FY 1996. This will consist of a 7 on 7 TeV proton-proton colliding beams facility to be constructed in the existing Large Electron-Positron Collider (LEP) machine tunnel (LEP will be removed). The LHC will have an energy 7 times that of the Tevatron at Fermilab, thus opening up substantial new frontiers for scientific discovery.

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. With the LHC at the next energy frontier, American scientific research at that frontier depends on participation in LHC. The High Energy Physics Advisory Panel (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 to provide access for U.S. scientists to the next decade’s premier high energy physics facility. The resulting agreements were approved by CERN, the DOE and the NSF and were signed in December of 1997.

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; 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.)

	(dollars in thousands)	
FY 2003	FY 2004	FY 2005

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 will provide 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. The Office of Science 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 already begun. Over 600 U.S. scientists have joined the U.S.-ATLAS detector collaboration, the U.S.-CMS detector collaboration, or the U.S.-LHC accelerator consortium, and are hard at work helping to design the initial physics research program to be carried out at the LHC, helping to specify the planned physics capabilities of the LHC accelerator and detectors, and helping to design and fabricate accelerator and detector components and subsystems.

U.S. LHC Accelerator and Detector Funding Profile

(dollars in thousands)

Fiscal Year	Department of Energy			National Science Foundation[a]
	Accelerator	Detector	Total	(Detector)
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 2003	FY 2004	FY 2005
LHC			
Accelerator Systems			
Operating Expenses	800	1,000	100
Capital Equipment	7,900	5,130	2,820
Total, Accelerator Systems	8,700	6,130	2,920
Procurement from Industry	12,610	23,200	18,527
ATLAS Detector			
Operating Expenses	7,282	4,280	3,076
Capital Equipment	10,134	4,710	2,413
Total, ATLAS Detector	17,416	8,990	5,489
CMS Detector			
Operating Expenses	10,290	4,450	2,054
Capital Equipment	10,194	6,030	3,510
Total, CMS Detector	20,484	10,480	5,564
Total, LHC	59,210	48,800	32,500

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 2003, and updated planning based on the FY 2003 experience.

In FY 2005, funding will be used for completion of the fabrication of accelerator magnets and equipment; and 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 2003	FY 2004	FY 2005
• **Accelerator Systems**	**8,700**	**6,130**	**2,920**

In FY 2005, funding will support completion of production of quadrupole magnets, cryogenic/ electrical power feedboxes, and beam absorbers for the LHC beam interaction regions. Production testing of superconducting wire and cable for the LHC main magnets will be completed. Funding is reduced by $3,210,000 as production activities conclude.

• **Procurement from Industry**	**12,610**	**23,200**	**18,527**

In FY 2005, final funding will be provided to support reimbursement to CERN for purchases from U.S. industry including superconducting wire, cable, cable insulation materials, and other technical components. This figure reflects the latest information on the planned expenditure profile. Funding is decreased by $4,673,000 to complete the currently estimated schedule of actual CERN payments to U.S. industrial suppliers.

• **ATLAS Detector**	**17,416**	**8,990**	**5,489**

In FY 2005, funding will support continued production of detector hardware and electronics and the installation of U.S.-supplied equipment at CERN. Installation of the transition radiation tracker barrel, the silicon inner tracker and the muon drift test chambers, and fabrication of the detector trigger and data acquisition system will continue. Funding is decreased by $3,501,000 to follow the ramp-down of detector fabrication.

• **CMS Detector**	**20,484**	**10,480**	**5,564**

In FY 2005, funding will support continued production of detector hardware and electronics and 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 in the U.S. Funding is decreased by $4,916,000 to follow the ramp-down of detector fabrication.

▪ **Large Hadron Collider Support**	**7,300**	**15,400**	**29,400**

In FY 2005, LHC Support work will concentrate on the preparation for U.S. participation in the LHC research program. 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. Significant increases in this area are planned for FY 2005 to meet the urgent and growing need for LHC support activities in advance of LHC turn-on in 2007.

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. In FY 2005, the U.S. software efforts will be focused on “data challenges” where a significant fraction (~10%) of the hardware needed for full LHC data

	(dollars in thousands)		
	FY 2003	FY 2004	FY 2005

analysis will be tested with professional-quality software on simulated data. These systems need to grow rapidly from prototypes, capable of handling a few percent of the eventual data in 2002, to fully-functional 10%-scale systems in 2005.

Funding for pre-operations and operations of the LHC detector subsystems built by U.S. physicists will also ramp-up significantly in FY 2005 as LHC turn-on approaches. U.S. CMS collaborators will be performing vertical integration tests of the major detector subsystems that they built, 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. U.S. LHC Accelerator Research Program will be conducting R&D towards possible future LHC accelerator upgrades. A small effort focused on R&D for specific possible LHC detector upgrades will continue.

LHC computer and networking increments will support U.S. leadership in the physics analysis phase by developing a distributed computing environment (the Grid) that will allow researchers remote from CERN full access to data and CPU needed to analyze the large and complex LHC dataset.

	FY 2003	FY 2004	FY 2005
▪ **AGS Operations/Support**	**625**	**0**	**0**

Operations at BNL for HEP experiments using the AGS facility were terminated at the end of FY 2002 with some close out costs remaining in FY 2003.

	FY 2003	FY 2004	FY 2005
▪ **Other Facilities**	**11,120**	**13,954**	**12,653**

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 2003	FY 2004	FY 2005
Total, Proton Accelerator-Based Physics	**383,787**	**390,560**	**412,092**

Explanation of Funding Changes

	FY 2005 vs. FY 2004 ($000)
Research	
▪ In University Research, an increase of $625,000 provides additional support for university groups participating in Tevatron Run II operations and data analysis	+625
▪ In National Laboratory Research, a decrease of $185,000 is taken in partial support of high-priority facilities operations	-185

	FY 2005 vs. FY 2004 ($000)
▪ In University Service Accounts, an increase of $313,000 provides additional equipment and services for university groups.	+313
Total, Research	+753
Facilities	
▪ In Tevatron Operations, a reduction of $3,261,000 is taken in funding for operations of the Tevatron complex, as effort shifts to Tevatron Improvements (see below). This includes continued implementation of the Run II luminosity upgrades in Tevatron running according to the planned profile, as well as installation and commissioning for the NuMI/MINOS program using the Main Injector in fixed-target mode.	-3,261
▪ In Tevatron Improvements, an additional $27,641,000 is provided for Tevatron complex support and Technology R&D support projects. This includes $10,250,000 to complete conceptual R&D and initiate detailed engineering design for the BTeV experiment (previously funded under Detector Development, Advanced Technology R&D subprogram); and $24,711,000 for AIP, GPP, operations and R&D support to continue a major effort to improve operational reliability across the complex. This is offset by a decrease of $1,450,000 in capital equipment for the MINOS project as reflected in the approved profile and a decrease of $5,870,000 in the Run II upgrades of the Tevatron complex, following the planned funding profile.	+27,641
▪ In the Large Hadron Collider project, a decrease of $16,300,000 follows the revised funding profile that reflects 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...	-16,300
▪ In Large Hadron Collider Support, an increase of $14,000,000 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 2005. A small accelerator R&D effort focused on LHC machine improvements also increases.	+14,000
▪ In Other Facilities, a decrease of $1,866,000 in funds held pending completion of peer review and/or programmatic review is offset by an increase of $565,000 in GPP at LBNL to address urgent infrastructure needs	-1,301
Total, Facilities	+20,779
Total Funding Change, Proton Accelerator-Based Physics	**+21,532**

Electron Accelerator-Based Physics

Funding Schedule by Activity

(dollars in thousands)

	FY 2003	FY 2004	FY 2005	$ Change	% Change
Electron Accelerator-Based Physics					
Research	27,129	28,134	28,830	+696	+2.5%
Facilities	110,804	117,578	122,060	+4,482	+3.8%
Total, Electron Accelerator-Based Physics	137,933	145,712	150,890	+5,178	+3.6%

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 Department of Energy'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 constituent 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.

Currently, SLAC's electron B-factory established and is precisely measuring 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.

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). This most recent observation has been made at the SLAC B-factory and the KEK-B accelerator in Japan. Now that observations of CP violation in B mesons have been made, it is 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 will require 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 are 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.

The BaBar experiment at the SLAC B-factory will pursue a broad program of physics studies on particles containing bottom or charm quarks with CP violation measurements being its highest priority, but other measurements that support or complement the CP violation program will also be pursued. The Belle experiment at the KEK-B accelerator in Japan has a very similar program planned. A small number of U.S. university researchers participate in the Belle experiment. There is regular cooperation as well as competition between the BaBar and Belle experiments that has led to a better understanding of how to run the accelerators and detectors and do the data analysis leading to results that are more precise. The CLEO-C experiment at the Cornell Electron Storage Ring (CESR) is 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 as input to the physics analyses done at the B-factory.

Research and Facilities

The Research category in the Electron Accelerator 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 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 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, such as purchasing needed equipment from laboratory stores.

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

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

Highlights

Recent accomplishments include:

- In 2003, physicists using the BaBar detector at the SLAC B-factory obtained new, improved measurements of CP violation in the B-meson system. American physicists also participated in the BELLE experiment at the Japanese KEK laboratory that reported similar measurements. The two sets of results are largely consistent with each other, and with their earlier results announced in 2002, though interesting (and possibly significant) discrepancies remain to be resolved. The BaBar experiment also reported evidence for a new subatomic particle that appears to be an unexpected configuration of a charm quark and a strange anti-quark; the CLEO experiment at CESR subsequently confirmed this result and found a related particle, and BELLE has recently confirmed these results. Data collected to date are mostly consistent with the current Standard Model description of CP violation. Data collection continues at a high rate to improve the precision of the results, look for evidence in new modes, and resolve any discrepancies.

The major planned research efforts in FY 2005 are:

- *The research program at the B-factory/BaBar Facility at SLAC*. This research program is being carried out by a collaboration of approximately 550 physicists including scientists from LBNL, LLNL, Oak Ridge National Laboratory (ORNL), SLAC, 35 U.S. universities, and institutions from 7 foreign countries.
- *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.

The major planned facilities efforts in FY 2005 are:

- *Operations of the B-factory at SLAC*. SLAC plans 4,420 hours of running to achieve a performance goal of 50 fb^{-1} of data delivered to the BaBar experiment. Approximately 450 people are involved in day-to-day B-factory operations.
- *Planning and preparation for B-factory/BaBar performance enhancements*. Fully achieving the physics goals of the B-factory program over the next few years requires a series of performance enhancements to the accelerator and the BaBar detectors. These efforts are proceeding in parallel with current B-factory operations and research.

Detailed Justification

	(dollars in thousands)		
	FY 2003	FY 2004	FY 2005
Research...	**27,129**	**28,134**	**28,830**
▪ **University Research**.......................................	**16,871**	**16,800**	**16,965**

The university program consists of groups at about 40 universities doing experiments at electron 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. The current Electron Accelerator subprogram is focused on the study of charm and bottom quarks and the tau lepton 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 will pursue a broad program of physics studies on particles containing bottom or charm quarks with CP violation measurements being its highest priority, but other measurements that support or complement the CP violation program will also be pursued.

U.S. university physicists constitute about 50% of the personnel needed to create, run, and analyze the BaBar experiment at the B-factory, and they work in collaboration with groups from national laboratories and foreign institutions.

	(dollars in thousands)		
	FY 2003	FY 2004	FY 2005

The university program also supports nine groups that work at the Cornell Electron Storage Ring at Cornell University; and four groups that work at the KEK-B accelerator complex at KEK in Japan. The CLEO-C experiment at the Cornell Electron Storage ring 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 run the accelerators and detectors and do the data 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 2005, the university program is slightly increased for those universities that support analysis of the unprecedented amount of physics data generated by the B-factory and other electron accelerators. To the extent possible, the detailed funding allocations will take into account the involvement of university based research groups in the targeted physics research activities. These include research efforts related to the high priority experiments such as BaBar.

	FY 2003	FY 2004	FY 2005
▪ **National Laboratory Research**	**10,045**	**11,075**	**11,555**

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 2005, the laboratory experimental physics research groups will be focused mainly on data-taking with the BaBar detector, analysis of data taken in earlier runs, and planning for detector enhancements needed for future runs. The laboratory research program is increased slightly for those groups that support analysis of the unprecedented amount of physics data generated by the B-factory and other electron accelerators.

The DOE HEP program office reviews laboratory research groups annually with input from independent peer reviewers.

The experimental research group from SLAC ($8,210,000) participates in all phases of the experiments. Because they are imbedded in the laboratory structure, they provide invaluable service in the design, construction, and calibration, and operations of the detector, as well as the reconstruction and analysis of the data.

The experimental research group at LBNL ($3,040,000) has broad responsibilities on the BaBar experiment. They were responsible for constructing and commissioning significant portions of the charged particle tracking detectors and their electronics. Now they contribute to operating, maintaining and calibrating the detector. They also make significant contributions to the computing system used to control the detector and acquire the data, and the computing system used to reconstruct the data into physics quantities used for analysis.

The efforts from LLNL ($305,000) are much smaller, limited to only a handful of scientists working on the BaBar experiment.

	(dollars in thousands)		
	FY 2003	FY 2004	FY 2005
▪ **University Service Accounts**	**213**	**259**	**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.

Facilities	**110,804**	**117,578**	**122,060**
▪ **B-factory Operations**	**95,095**	**96,913**	**100,290**

Funding for operations supports running the accelerator for 4,420 hours, the operation of the BaBar detector for data collection, and computing support to analyze the collected data. This will be the priority research program at SLAC in FY 2005. It is anticipated that the collected data will be slightly more than the total collected in FY 2004, despite fewer hours of operations. With a modest funding increase, the total scheduled running hours decreases due to the expected increases in power costs. The expected increase in cost per kilowatt-hour arises because SLAC's current contract for electrical power expires in FY 2004.

The fixed target research program in End Station A was terminated in FY 2003, due to overall budget constraints and the high priority assigned to B-factory operations.

SLAC Operation

	(in hours)		
	FY 2003	FY 2004	FY 2005
Fixed Target[a]	(1,040)	(0)	(0)
B-factory Operation	4,810	4,810	4,420
Total, SLAC Operation	4,810	4,810	4,420

▪ **B-factory Improvements**	**15,709**	**20,665**	**21,770**

An important component of the FY 2005 SLAC program will be continuation of the accelerator R&D aimed at improving the luminosity and operational efficiency of the B-factory complex. Particular attention will be paid to finding ways to continue to improve the collision luminosity to an ultimate value of $3 \times 10^{34} cm^{-2}s^{-1}$, an order of magnitude greater than the design value. The planned improvements include additional RF acceleration systems, improvements to the vacuum pumping system, and improvements to the beam control systems.

Funding in the amount of $10,085,000 is included for the projects to upgrade the B-factory, the BaBar detector, and the SLAC computing facilities needed to process the BaBar data. This is a decrease of $3,015,000 relative to FY 2004. The projects include: upgrades to B-factory vacuum and

[a] Fixed Target operation in parallel with B-factory operation.

	FY 2003	FY 2004	FY 2005

(dollars in thousands)

acceleration systems, replacement of failing elements of the BaBar muon detector system; upgrade of Instrumented Flux Return (IFR Upgrade) by installing additional brass absorber to enhance the performance of the muon detector system ($1,200,000; TEC of $4,900,000), and continuous enhancement of computing capabilities to keep pace with the flood of data the B-factory provides.

Activities in this category also include support for ongoing B-factory accelerator and detector operations, not related to identified upgrades (+$4,120,000), including: accelerator and detector maintenance activities, repair and replacement of failing or obsolescent components, and minor improvements and upgrades to existing systems. Most of the increase relative to FY 2004 is directed at GPP funding (+$1,982,000) to assist with urgent ES&H and infrastructure needs.

	FY 2003	FY 2004	FY 2005
Total, Electron Accelerator-Based Physics	**137,933**	**145,712**	**150,890**

Explanation of Funding Changes

	FY 2005 vs. FY 2004 ($000)
Research	
▪ In University Research, an additional $165,000 is provided for maintaining effort on the BaBar research program.	+165
▪ In National Laboratory Research, an additional $480,000 is provided for maintaining effort on the BaBar research program.	+480
▪ In University Service Accounts, an increase of $51,000 provides additional equipment and services to university groups.	+51
Total, Research	+696
Facilities	
▪ In B-factory Operations, an additional $3,377,000 is provided for operation of the B-factory complex to help address projected increases in power costs and meet performance targets.	+3,377
▪ In B-factory Improvements, an increase of $2,877,000 is provided in part for increased effort on the computing upgrade and for GPP funding to assist with urgent ES&H and infrastructure needs. This is offset by a decrease of $1,772,000 as the B-factory accelerator and detector upgrades begin to roll-off, following their planned funding profile.	+1,105
Total, Facilities	+4,482
Total Funding Change, Electron Accelerator-Based Physics	**+5,178**

Non-Accelerator Physics

Funding Schedule by Activity

(dollars in thousands)

	FY 2003	FY 2004	FY 2005	$ Change	% Change
Non-Accelerator Physics					
University Research	11,564	11,500	11,565	+65	+0.6%
National Laboratory Research	16,020	14,363	10,420	-3,943	-27.5%
Projects	15,925	20,636	18,051	-2,585	-12.5%
Other	800	2,902	2,900	-2	-0.1%
Total, Non-Accelerator Physics	44,309	49,401	42,936	-6,465	-13.1%

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 Department of Energy'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 idea 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.

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 and the Gamma-ray Large Area Space Telescope (GLAST) Mission.

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, 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, and the Gran Sasso Laboratory in Italy. Other operations include the ground-based facilities laboratories for fabrication and operation of the Gamma-ray Large Area Space Telescope (GLAST) Large Area Telescope (LAT) at SLAC and for the Alpha Magnetic Spectrometer (AMS) at Massachusetts Institute of Technology (MIT).

Highlights

Recent accomplishments include:

- The Pierre Auger Project in Argentina to observe ultra-high energy cosmic rays completed an engineering array in FY 2002 consisting of 40 air-shower detectors and 2 resonance fluorescence detectors. The full array of 1600 air-shower detectors and 4 fluorescence detectors will be completed in 2005 by an international collaboration, but physics measurements commenced in 2002 with the engineering array, and will continue with increasing fractions of the full array as they are completed.
- The Cryogenic Dark Matter Search (CDMS II) experiment completed and installed its first two towers of silicon and germanium detectors in the Soudan Mine in Minnesota. Data taking began in June 2003. The second tower will be installed in December 2003. The final three towers will be installed in 2004, and the full experiment will run until the end of 2005. The prototype experiment (CDMS-I) in a shallow site (10.6 meters below the Stanford University campus) at the Stanford Underground Facility has completed its measurements, already setting the best limits in the world to date on detection of dark matter particles.
- In December 2002, after six months of running, KamLAND's first results were announced, showing a deficit in the expected flux of anti-neutrinos coming from a number of reactors to a detector located in the Kamiokande mine in Japan. Further corroborating results were released in June 2003. This result indicates that neutrinos have mass and are not stable in time, apparently oscillating into other types of neutrinos. The KamLAND results make the case for oscillations and mass of solar neutrinos seemingly inescapable, and are in accord with other results from experiments on neutrinos coming from the sun.

The major planned efforts in FY 2005 are:

- *Fabrication of the GLAST/LAT Telescope*. DOE and NASA are partners on the LAT, which uses particle physics detector technology and is the primary instrument to be flown on the NASA space-based GLAST Mission, scheduled to complete fabrication in late 2005 and to be launched in late 2006. 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.
- *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. There is particular interest 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 will begin in FY 2004 on Kitt Peak in Arizona and will be completed in three years.
- *Operation of the Pierre Auger Observatory*. The Pierre Auger Observatory is a very large area cosmic ray detector, covering about 3,000 square kilometers in Argentina, whose goal is to observe, understand and characterize the very highest energy cosmic rays. The southern array is under construction on the pampas of Mendosa, Argentina, but physics analysis has already begun based on results from the partially completed array. This research program is being carried out by an international collaboration including scientists from U.S. universities, Fermilab, and institutions from 19 foreign countries. The U.S. part of the project is funded jointly with NSF and a significant contribution from the University of Chicago. Fermilab provides the project management team.
- *Operation of the Cryogenic Dark Matter Search (CDMS).* CDMS-II is the most sensitive direct search for super-symmetric dark matter undertaken to date. It consists of specially developed cryogenic silicon and germanium detectors with dual ionization and phonon signal capabilities. These detectors must operate at very low temperature (25 milliKelvin) in a cryostat located deep underground at the Soudan Mine Laboratory in Northern Minnesota. This research program is being carried out by a collaboration including scientists from U.S. universities and Fermilab. The project is funded jointly with NSF and Fermilab provides the project management team.
- *Prepare to launch the Alpha Magnetic Spectrometer (AMS).* AMS is an international consortium experiment, led by Massachusetts Institute of Technology (MIT), to be placed on the International Space Station in 2007. 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 proposed Supernova Acceleration Probe (SNAP) Experiment 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 2003	FY 2004	FY 2005
University Research..	**11,564**	**11,500**	**11,565**

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 2005, the university program in Non-Accelerator Physics will provide support for those universities involved in projects that may yield exciting new physics at about the level of FY 2004, as several new experiments (e.g., CDMS II, AMS) have completed their fabrication phase and moving into detector operations and datataking. 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, whose goal is to detect sources of extra-galactic antimatter, using an instrument attached to the International Space Station. In FY 2005, the AMS collaboration will enter preparations for the planned 2007 launch. This project is led by scientists at MIT and consists of a collaboration of NASA, multiple U.S. universities, and numerous international institutions.

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; Pierre Auger Project in Argentina; VERITAS in Arizona; and AMS, GLAST/LAT and SNAP in space.

National Laboratory Research.........................	**16,020**	**14,363**	**10,420**

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.

	FY 2003	FY 2004	FY 2005
	(dollars in thousands)		

In FY 2005, the laboratory experimental physics research groups (including groups at LBNL, LLNL, Fermilab and SLAC) will be focused mainly on supporting the fabrication of the GLAST/LAT telescope and analysis of previous experimental data (SLAC); analysis of data from the Auger engineering array, the CDMS-II detector and the Sloan Digital Sky Survey (Fermilab); and research and development for the proposed SNAP experiment proposal and continued analysis of data from KamLAND (LBNL). The apparent reduction in this category FY 2005 is mainly due to redirection of effort at SLAC to enhance support of GLAST/LAT fabrication, and is captured in the Projects category below.

	FY 2003	FY 2004	FY 2005
Projects	**15,925**	**20,636**	**18,051**

In FY 2005, this effort will be focused mainly on completing fabrication of the GLAST/LAT telescope, continuing deployment of the full Auger array, installation of the Phase-I CDMS detector, R&D for the proposed SNAP experiment, and initial fabrication of VERITAS.

The FY 2005 GLAST/LAT program ($8,421,000; TEC of $42,000,000) will focus on completing the fabrication of the LAT instrument in preparation for integration and launch on the GLAST mission in late in 2006, and development of the data processing and analysis capability at SLAC. The project was rebaselined in FY 2003, and as a result, the DOE TEC has been increased by $5,000,000.

The FY 2005 program for VERITAS ($2,050,000; TEC of $4,799,000) will continue the fabrication phase for the full telescope array.

The FY 2005 SNAP program ($7,580,000) will focus on finalizing the research and development for technology needed for the JDEM mission. Funding is maintained at about the same level to provide the significant resources needed to continue the detailed design and prototyping phase. This effort is consistent with the 2002 HEPAP Long Range Planning Subpanel and 2003 HEPAP New Facilities panel recommendation that the physics of SNAP (the "dark energy" phenomenon) is exciting and of central importance to HEP, and that the R&D effort should be supported. It is also consistent with the recent National Research Council report ("Connecting Quarks with the Cosmos") which identified this interdisciplinary research area as a high priority for an interagency initiative. DOE is actively engaged with NASA on JDEM. DOE funding for SNAP takes into account expected contributions from NASA towards JDEM.

	FY 2003	FY 2004	FY 2005
Other	**800**	**2,902**	**2,900**

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 2003	FY 2004	FY 2005
Total, Non-Accelerator Physics	**44,309**	**49,401**	**42,936**

Explanation of Funding Changes

	FY 2005 vs. FY 2004 ($000)
University Research	
An increase of $65,000 for universities active in Non-Accelerator research projects...........	+65
National Laboratory Research	
A decrease of $3,943,000 is taken in this activity. This includes a decrease of $3,843,000 in this category as effort is redirected to completion of the GLAST/LAT project (see below); and a decrease of $100,000 in funds held pending completion of peer review and/or programmatic review.	-3,943
Projects	
A decrease of $2,585,000 is taken to the Projects activity. This includes a decrease of $676,000 for the SNAP R&D program during transition to the Joint Dark Energy Mission collaboration with NASA; a decrease to equipment funding reflecting the completion of the Auger (-$1,000,000) and CDMS-II (-$550,000) projects in FY 2004; and a decrease of $1,330,000 in funds held pending completion of peer review and/or programmatic review.	
These are offset by: an increase of $450,000 to continue fabrication of VERITAS according to the planned profile; and an increase of $521,000 for the GLAST/LAT project in FY 2005, consistent with the profile in the approved Baseline Change Proposal..	-2,585
Other	
A minor decrease in Other	-2
Total Funding Change, Non-Accelerator Physics..	**-6,465**

Theoretical Physics

Funding Schedule by Activity

	(dollars in thousands)				
	FY 2003	FY 2004	FY 2005	$ Change	% Change
Theoretical Research					
University Research	23,336	23,300	23,694	+394	+1.7%
National Laboratory Research........	15,018	14,998	15,062	+64	+0.4%
SciDAC……………………	4,785	4,600	6,600	+2,000	+43.5%
Other...	1,653	4,725	4,274	-451	-9.5%
Total, Theoretical Physics.................	44,792	47,623	49,630	+2,007	+4.2%

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 Department of Energy'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 to a new plane of physical phenomena and how 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, in order to illuminate the origin and evolution of the universe.

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 especial 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 multiprogram 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 more informal than the efforts required mounting 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 High Energy Physics Office 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). After 18 months, 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:

- Recent 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.

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 2005:

- *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 a wide variety of QCD calculations feasible with relatively high precision (errors of a few percent). Some of the computational tools for this effort are provided through the SciDAC program, and there will be a major effort to fabricate the necessary computer hardware.
- *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 world-wide 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 2003	FY 2004	FY 2005
University Research..	**23,336**	**23,300**	**23,694**

The university program consists of groups at approximately 75 colleges and universities doing theoretical physics research. These university groups develop new theoretical models and provide interpretations of existing experimental data; they identify where new physical principles may be required and determine how to confirm their presence, thereby providing guidance for new experiments; they develop new mathematical and computational methods for analyzing theoretical models; and they are deeply involved in the SciDAC activities described below. The university groups train graduate students and post-docs. University physicists in this theoretical research area often work in collaboration with other university and laboratory groups. University-based research efforts will be selected based on peer review.

In FY 2005, 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

	(dollars in thousands)		
	FY 2003	FY 2004	FY 2005

frontier, and the SLAC B-factory experiments studying CP violation and the matter - antimatter asymmetry, 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	**15,018**	**14,998**	**15,062**

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 2005, 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	**4,785**	**4,600**	**6,600**

Following upon the successful completion and installation of the uniform software environment on two types of parallel computer platforms being developed for this program, in FY 2005 there will be two principal SciDAC efforts. A program of the most important and accessible research computations begun on the prototype QCDOC ("QCD On a Chip") computer at BNL will continue and, assuming technical milestones are met, R&D for more powerful computers of this kind will proceed. The FY 2005 increment of $2,000,000 is provided to begin fabrication of a ~3 teraflop prototype hardware platform. In addition, further R&D will be undertaken on the optimization of commercial cluster computers for Fermilab. The goal of this R&D effort is to provide an efficient design for a large QCD computing cluster based on commercial components to address the hardware challenges of lattice QCD computing, as noted above. Both the customized and the commercial component approaches are viewed as important and useful in addressing the magnitude of the QCD computational problem; however, if both R&D efforts are successful, only the most cost-effective option will be pursued.

Other	**1,653**	**4,725**	**4,274**

This category includes funding for education and outreach activities, conferences, studies, and workshops, funding for research activities that have not yet completed peer review, and to respond to new and unexpected physics opportunities.

This category also includes support for the QuarkNet education project. This project takes place in QuarkNet "centers" which are set up at universities and laboratories around the country. Each center has two physicist mentors and, over three years, goes through several stages to a full operating mode with twelve high school teachers. The project began in 1999 with an initial complement of 12 centers starting

	(dollars in thousands)		
	FY 2003	FY 2004	FY 2005

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.

	FY 2003	FY 2004	FY 2005
Total, Theoretical Physics	**44,792**	**47,623**	**49,630**

Explanation of Funding Changes

	FY 2005 vs. FY 2004 ($000)
University Research	
An increase of $394,000 is provided to maintain support for university researchers...........	+394
National Laboratory Research	
An increase of $64,000 is provided to maintain support for laboratory researchers	+64
SciDAC	
An increase of $2,000,000 is provided for the SciDAC program for the QCDOC initial prototype hardware complement of a multi-teraflop computer.	+2,000
Other	
A decrease of $451,000 is taken reflecting a reduction in funds held pending completion of peer review and/or programmatic review.	-451
Total Funding Change, Theoretical Physics..	**+2,007**

Advanced Technology R&D

Funding Schedule by Activity

	(dollars in thousands)				
	FY 2003	FY 2004	FY 2005	$ Change	% Change
Advanced Technology R&D					
Accelerator Science	22,170	22,423	26,250	+3,827	+17.1%
Accelerator Development............	37,245	38,384	32,936	-5,448	-14.2%
Other Technology R&D................	11,960	9,713	4,412	-5,301	-54.6%
SBIR/STTR..................................	0	17,389	17,483	+94	+0.5%
Total, Advanced Technology R&D ..	71,375	87,909	81,081	-6,828	-7.8%

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 Department of Energy's strategic goals for science.

Benefits

The 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 existing.

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 and storage rings. 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 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 Department of Energy and the National Science Foundation 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, the Office of Science prepared a list of essential science facilities required 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 the Office of Science in the midterm.

The emphasis on exploiting current unique opportunities through full operations of HEP facilities in the U.S. for physics research has required a reduction of funding in important areas of accelerator and detector R&D in 2005 particularly at Fermilab. These are reflected in the reductions shown for general accelerator R&D and Other R&D (Detector R&D is contained in this category). Details are provided in the following sections.

The Advanced Technology (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 topic, Other Technology R&D, describes 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 and the proposed ORION facility at SLAC.

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 largest 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, over twice the field strength of comparable SSC magnets. 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.
- 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 250 MeV 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 2005 are:

- *The Accelerator Science Research Program*. This program supports studies in scientific topics such as laser and radiofrequency driven acceleration, plasma-based accelerators, alternative radiofrequency (RF) accelerating structures, ionization cooling of muon beams, superconducting material development and applications, and nonlinear dynamics and chaos. This research is performed at some 25 universities and 6 DOE national laboratories (ANL, BNL, LANL, LBNL, Princeton Plasma Physics Laboratory (PPPL), and SLAC). The programs of research at the universities and national laboratories are complementary and collaboration between the national 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 16 Tesla and quadrupole fields approaching 300 Tesla per meter, RF acceleration systems for gradients above 75 megavolts per meter, new beam instrumentation, 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 the U.S. High Energy Physics Advisory Panel (HEPAP), as an essential international facility to extend particle physics research beyond what is feasible at the LHC. A U.S. National Collaboration, including SLAC, Fermilab, LBNL, LLNL, and BNL, is funded to develop new technologies that enable a higher performance, lower cost machine, focusing on systems engineering, value engineering and risk analysis studies of applicable technologies.

Detailed Justification

	(dollars in thousands)		
	FY 2003	FY 2004	FY 2005
Accelerator Science	**22,170**	**22,423**	**26,250**
▪ **University Research**	**9,103**	**9,060**	**9,665**

In FY 2005, funding will provide for a program of accelerator physics and related technologies at some 25 universities at about the same level of effort as FY 2004. 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 will be 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**	**11,714**	**11,843**	**14,843**

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 is by these means, the annual HEP Program review supported by well-qualified peers, and publications in professional journals and participation in conferences and workshops. Part of the funding previously allocated to the Muon Accelerator R&D effort ($2,400,000) is redirected to this area to support R&D into high-

	(dollars in thousands)		
	FY 2003	FY 2004	FY 2005

power target studies required for possible future neutrino facilities, including e.g., possible upgrades to the NuMI beam and into support of muon ionization cooling and alternate accelerating methods for muons.

BNL ($3,360,000) is the home of a very successful user facility, the Accelerator Test Facility (ATF), supporting research that HEP funds at universities and in industry (particularly through the SBIR Program). In FY 2005, 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 ($3,943,000) is supported in FY 2005 for research in laser-driven plasma acceleration, advanced radiofrequency 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.

An advanced accelerator R&D program is supported at SLAC ($4,000,000) in FY 2005 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 colliders 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 supported in FY 2005 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 maintenance and development of standard accelerator, storage ring, and beam optics computer codes at the Accelerator Code Group at LANL, which also maintains an online encyclopedia of accelerator-related computer codes developed throughout the U.S.

▪ **Other**	**1,353**	**1,520**	**1,742**

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................................	**37,245**	**38,384**	**32,936**
▪ **General Accelerator Development**	**14,032**	**15,550**	**13,736**

This research includes R&D to bring new concepts to a stage of engineering readiness wherein 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 radiofrequency acceleration systems; instrumentation; stochastic and electron cooling technologies; beam dynamics, both linear and nonlinear; and development of large simulation programs. In FY 2005 this general research area continues to be funded at a reduced level in order to support the high priority operations for high physics productivity. Part of the funding previously allocated to the

	(dollars in thousands)		
	FY 2003	FY 2004	FY 2005

Muon Accelerator R&D effort ($1,200,000) is redirected to this area to support R&D into high-power target studies required for possible future neutrino facilities, including e.g., possible upgrades to the NuMI beam, and demonstration experiments to validate muon ionization cooling.

Work at BNL in FY 2005 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 2005 will address a broad spectrum of technology needs for that facility, including 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 2005 includes work on very high field superconducting magnets using niobium-tin and possibly niobium-aluminum, on development of superconducting wire and cable for their magnet R&D, on new beam instrumentation for use at Fermilab and SLAC, and on an extensive beam dynamics and simulation studies program with particular emphasis on electron cloud and related efforts in proton and electron colliders. The FY 2005 program at SLAC encompasses high-powered RF systems, beam instrumentation, generic electron-positron collider R&D, and advanced beam dynamics and machine simulation code development. Simulation codes for modeling radiofrequency system components and high-powered microwave tubes will receive special R&D focus.

▪ **Linear Collider**	**19,600**	**19,200**	**19,200**

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 physics questions central to high-energy physics.

The result of the international R&D Program is that there are now two principal, viable technical approaches to constructing a high energy linear collider. One of these approaches, developed by a collaboration led by the German high energy physics laboratory, Deutsches Elektronen-Synchrotron (DESY), is based on the use of a superconducting radiofrequency acceleration system cooled to approximately 452 degrees Fahrenheit below zero. The other approach, developed by a U.S. - Japan collaboration, led in the U.S. by SLAC and including BNL, Fermilab, LBNL and LLNL and in Japan by the high energy physics laboratory, KEK, is based on a room temperature RF accelerating system similar in principle to the one used successfully in the original (100 GeV) SLAC Linear Collider in the early 1990’s.

In FY 2005, the U.S. linear collider collaboration will continue the systems engineering, value engineering, risk analysis, and cost studies that have been used to guide the R&D. A particular focus in FY 2005 will be on completing an operational run for at least 2,000 hours of a prototype accelerator section, including RF power source, pulse compressor, and eight accelerating structures. In addition work will continue with KEK on the injection damping ring technology using the

	FY 2003	FY 2004	FY 2005
	(dollars in thousands)		

prototype ring built at KEK and on design of the electron and positron sources and final focus beam optics systems.

In 2003, a Linear Collider Steering Group was formed by the U.S. HEP community as the U.S. component of a proposed future international collaboration. Similar regional groups were formed in Europe and Asia. About the same time the International Committee on Future Accelerators, ICFA, a long-standing group whose membership is made up of the Directors of all of the world's leading high energy physics laboratories, sponsored the formation of an International Linear Collider Steering Committee (ILCSC) whose membership is drawn from the three regional groups. The ILCSC has set up several groups to address issues relative to the possible construction of an international linear collider. The International Technology Recommendation Panel (ITRP) is charged with deciding whether a cold or warm accelerator technology can better meet the needs of the experimental physics program. Another committee is reviewing the issues involved in setting up a central, international team to coordinate and manage the first phase of a truly international R&D effort directed at the design of an international facility based on the technology recommended by the ITRP. These two committees are to provide their recommendations to ICFA by the fall of 2004.

	FY 2003	FY 2004	FY 2005
▪ **Muon Accelerators**......................................	**3,613**	**3,634**	**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.

The requirements for muon accelerators rely on new technologies that do not yet exist. The two principal technology areas are ultra-high-intensity beam targets that are applicable to any future neutrino research program, and transverse and longitudinal phase-space cooling to reduce beam size. Consequently, the R&D program has been split into the Accelerator Science ($2,400,000) and the General Accelerator Development ($1,200,000) categories. System studies will be continued as part of both activities as necessary to guide the research. The specific activities assigned to each are included in the descriptions of the FY 2005 R&D provided above.

	FY 2003	FY 2004	FY 2005
Other Technology R&D....................................	**11,960**	**9,713**	**4,412**
▪ **Advanced Detector Research**.....................	**743**	**990**	**500**

The Advanced Detector Research (ADR) program supports university physicists to develop new detector technologies. 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.

	FY 2003	FY 2004	FY 2005
▪ **Detector Development**	**11,217**	**8,530**	**3,043**

New experiments frequently depend on advancements in technologies. This funding supports detector development work at the national laboratories to advance these technologies to a point where there is reasonable chance that an experiment can adopt the technology successfully. Technology choices are based on the needs of foreseen experiments. In FY 2005, this research area

	(dollars in thousands)		
	FY 2003	FY 2004	FY 2005

is further reduced in order to meet high-priority needs for facility operations. In addition, funding for pre-conceptual R&D leading up to the BTeV proposal was previously provided under this category (and is now reported under *Tevatron Improvements*).

	FY 2003	FY 2004	FY 2005
▪ **Other**	**0**	**193**	**869**

This category includes funding for research activities that have not yet completed peer review, and to respond to new and unexpected physics opportunities.

	FY 2003	FY 2004	FY 2005
SBIR/STTR	**0**	**17,389**	**17,483**

The two activities funded are the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) set asides mandated by Congress. The High Energy Physics Program manages four technical 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 programs concerning areas of mutual interest. The organization of the topics and the annual solicitations for suggestions for R&D to be included in the annual solicitation are treated as an important and integral component of the advance accelerator R&D program and selections of grants are made 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 2003, $14,984,000 was transferred to the SBIR program and $899,000 was transferred to the STTR program.

	FY 2003	FY 2004	FY 2005
Total, Advanced Technology R&D	**71,375**	**87,909**	**81,081**

Explanation of Funding Changes

	FY 2005 vs. FY 2004 ($000)
Accelerator Science	
An increase of $3,827,000 provides increased support for long-term R&D efforts at universities and small laboratories focused on developing new particle acceleration techniques, including a redirection of $2,400,000 from the Muon Accelerator R&D category, to focus on ionization cooling R&D	+3,827
Accelerator Development	
▪ A decrease is taken in General Accelerator Development R&D of $3,014,000 to support high-priority facility operations at Fermilab and SLAC, partially offset by $1,200,000 transferred from the Muon Accelerator R&D to focus on high-power target development for future neutrino sources.	-1,814

	FY 2005 vs. FY 2004 ($000)
▪ The Muon Accelerator R&D effort is redirected as described above…………………..	-3,634
Total, Accelerator Development	-5,448

Other Technology R&D

A decrease of $5,301,000 is taken primarily in Detector Development, reflecting a transfer of BTeV R&D effort ($4,000,000) to Tevatron Improvements; and also reduced R&D efforts on future experiments ($1,977,000), to maintain support for high-priority facility operations and is partially offset by an increase of $676,000 in the funds held pending completion of peer review and/or program considerations......................................	-5,301

SBIR/STTR

An increase of $94,000 for the SBIR and STTR programs.	+94
Total Funding Change, Advanced Technology R&D..	**-6,828**

Construction

Funding Schedule by Activity

(dollars in thousands)

	FY 2003	FY 2004	FY 2005	$ Change	% Change
Neutrinos at the Main Injector............	19,842	12,426	751	-11,675	-94.0%

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 2003	FY 2004	FY 2005
Neutrinos at the Main Injector (NuMI)	**19,842**	**12,426**	**751**
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.			
Total, Construction	**19,842**	**12,426**	**751**

Explanation of Funding Changes

	FY 2005 vs. FY 2004 ($000)
Neutrinos at the Main Injector (NuMI)	
▪ Funding needs decrease as project completes in FY 2005..	-11,675
Total Funding Change, Construction	**-11,675**

Capital Operating Expenses & Construction Summary

Capital Operating Expenses

(dollars in thousands)

	FY 2003	FY 2004	FY 2005	$ Change	% Change
General Plant Projects	9,453	14,330	18,791	+4,461	+31.1%
Accelerator Improvements Projects	5,263	24,700	21,665	-3,035	-12.3%
Capital Equipment	81,285	61,114	71,790	+10,676	+17.5%
Total, Capital Operating Expenses	96,001	100,144	112,246	+12,102	+12.1%

Construction Projects

(dollars in thousands)

	Total Estimated Cost (TEC)	Prior Year Approp-riations	FY 2003	FY 2004	FY 2005	Unapprop-riated Balance
98-G-304 Neutrinos at the Main Injector	109,168	76,149	19,842	12,426	751	0

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

(dollars in thousands)

	Total Estimated Cost (TEC)	Prior Year Approp-riations	FY 2003	FY 2004	FY 2005	Accept-ance Date
Large Hadron Collider — Machine[a]	90,652	74,802	7,900	5,130	2,820	FY 2005
Large Hadron Collider — ATLAS Detector[b]	54,099	34,398	10,134	4,710	2,413	FY 2008
Large Hadron Collider — CMS Detector[b, c]	71,789	47,905	10,194	6,030	3,510	FY 2008
MINOS	44,510	36,520	5,440	2,000	550	FY 2005
GLAST/LAT[d]	42,000	16,769	8,910	7,900	8,421	FY 2006
Cryogenic Dark Matter Search (CDMS)	4,908	3,568	790	550	0	FY 2004
Auger	3,230	1,000	1,230	1,000	0	FY 2004
Alpha Magnetic Spectrometer (AMS) Upgrade	5,506	4,006	1,500	0	0	FY 2004
Run IIb D-Zero Detector[e]	12,502	3,460	2,792	2,542	3,708	FY 2007
Run IIb CDF Detector[f]	10,374	3,460	3,509	1,673	1,732	FY 2007

[a] The TEC has increased by $4,980,000 to reflect the need to increase funding for certain high risk, state-of-of-art pieces of hardware, such as the IR quads, which are part of the LHC accelerator MIE project. The total amount of funding for the LHC program does not change, rather there is a shift between the operating and capital equipment distribution.

[b] At the end of FY 2005 approximately 95% of the U.S. ATLAS and U.S. CMS 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 will continue, consistent with all 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 costs of the project.

[c] The TEC has increased by $4,738,000 to reflect the need to cover additional needs associated with the detector installation, currently underway at CERN. Based on the favorable experience on operating costs compared to original conservative estimates, FY 2004 operating funds were converted to equipment funds. The total amount of funding for the U.S. CMS program does not change, rather there is a shift between the operating and capital equipment distribution.

[d] The TEC for this project has increased by $5,000,000 to cover the scope of one international partner's default. The Total Project Cost of $133.4M is being funded jointly by DOE ($42M), NASA ($90M) and Japan ($1.4M).

[e] The TEC for this project has been decreased by $8,119,000 from the baseline established in 2002. This is based on the decision made in the September 2003 to reduce the scope of the project in recognition of the lower integrated luminosity projection in outyears.

[f] The TEC for this project has been decreased by $14,613,000 from the baseline established in 2002. This is based on the decision made in the September 2003 to reduce the scope of the project in recognition of the lower integrated luminosity projection in outyears.

(dollars in thousands)

	Total Estimated Cost (TEC)	Prior Year Approp-riations	FY 2003	FY 2004	FY 2005	Accept-ance Date
VERITAS………………………	4,799	0	0	1,600	2,050	FY 2006
BaBar Instrumented Flux Return (IFR) Upgrade[a]............	4,900	0	0	3,000	1,200	FY 2006
BTeV[b]......................................	TBD	0	0	0	6,750	FY 2010
Total, Major Items of Equipment................................		225,888	52,399	36,135	33,154	

[a] New MIE to replace and upgrade failing elements of the BaBar detector. Congressional approval will be requested to initiate fabrication in FY 2004.

[b] TEC range of estimate is $190,000,000 to $230,000,000. Estimate will be refined upon completion of detailed engineering design in FY 2005.

98-G-304, Neutrinos at the Main Injector (NuMI), Fermi National Accelerator Laboratory, Batavia, Illinois

(Changes from FY 2004 Congressional Budget Request are denoted with a vertical line [|] in the left margin.)

Significant Changes

The cost estimate for the building increases due to the amount of a competitively bid, fixed-price subcontract for construction of service buildings and outfitting of the tunnels and halls.

1. Construction Schedule History

	Fiscal Quarter				Total Estimated Cost ($000)	Total Project Cost ($000)
	A-E Work Initiated	A-E Work Completed	Physical Construction Start	Physical Construction Complete		
FY 1998 Budget Request *(A-E and technical design only)*	1Q 1998	4Q 1998	N/A	N/A	5,500	6,300
FY 1999 Budget Request (Preliminary Estimate)	--	3Q 1999	1Q 1999	4Q 2002	75,800	135,300
FY 2000 Budget Request	3Q 1998	2Q 2000	3Q 1999	2Q 2003	76,200	136,100
FY 2001 Budget Request	3Q 1998	2Q 2000	3Q 1999	2Q 2004	76,200	138,600
FY 2001 Budget Request (Amended)	3Q 1998	2Q 2000	3Q 1999	4Q 2003	76,200	138,400
FY 2002 Budget Request	3Q 1998	4Q 2000	3Q 1999	4Q 2003	76,149	139,390
FY 2003 Budget Request	3Q 1998	4Q 2000	3Q 1999	4Q 2005	109,242	171,442
FY 2004 Budget Request	3Q 1998	4Q 2000	3Q 1999	4Q 2005	109,242	171,442
FY 2005 Budget Request	3Q 1998	4Q 2000	3Q 1999	4Q 2005	109,168[a]	171,368[a]

[a] TEC and TPC were decreased by $73,750 based on the Consolidated Appropriations Act, 2004, as reported in conference report H. Rpt. 108-401, dated November 25, 2003.

2. Financial Schedule

(dollars in thousands)

Fiscal Year	Appropriations	Obligations	Costs
Design & Construction			
1998	5,500	5,500	1,140
1999	14,300	14,300	5,846
2000	22,000	22,000	15,089
2001	22,949	22,949	19,752
2002	11,400	11,400	21,489
2003	19,842[a]	19,842	24,000
2004	12,426[b]	12,426	13,926
2005	751	751	7,926

3. Project Description, Justification and Scope

The project provides for the design, engineering and construction of new experimental facilities at Fermi National Accelerator Laboratory in Batavia, Illinois and at the Soudan Underground Laboratory at Soudan, Minnesota. The project is called NuMI which stands for Neutrinos at the Main Injector. The purpose of the project is to provide facilities that will be used by particle physicists to study the properties of neutrinos, which are fundamental elementary particles. In the Standard Model of elementary particle physics there are three types of neutrinos that are postulated to be massless and to date, no direct experimental observation of neutrino mass has been made. However, there are compelling hints from experiments that study neutrinos produced in the sun and in the earth's atmosphere that indicate that if neutrinos were capable of changing their type it could provide a credible explanation for observed neutrino deficits in these experiments.

The primary element of the project is a high flux beam of neutrinos in the energy range of 1 to 40 GeV. The technical components required to produce such a beam will be located on the southwest side of the Fermilab site, tangent to the Main Injector accelerator at the MI-60 extraction region. The beam components will be installed in a new tunnel of approximately 1.5 km in length and 6.5 m diameter. The beam is aimed at two detectors (MINOS), which will be assembled in two new experimental halls located along the trajectory of the neutrino beam. One such detector will be located on the Fermilab site, while a second will be located in the Soudan Underground Laboratory. Two similar detectors in the same neutrino beam and separated by a large distance are an essential feature of the experimental plan. The FY 2005 funding is to complete the installation and commissioning of the neutrino beam line and the detector in the underground facility at Fermilab.

[a] The FY 2003 original appropriation amount was $20,093,000. The revised appropriation excludes $121,000 for the share of the Science general reduction and $129,819 rescinded in accordance with the Consolidated Appropriations Resolution, FY 2003.

[b] The FY 2004 original appropriation amount was $12,500,000. The revised appropriation excludes $73,750 for a rescission in accordance with the Consolidated Appropriations Act, 2004, as reported in conference report H.Rpt. 108-401, dated November 25, 2003.

The experiments that are being designed to use these facilities will be able to search for neutrino oscillations occurring in an accelerator produced neutrino beam and hence determine if neutrinos do have mass. Fermilab is the only operational high energy physics facility in the U.S. with sufficiently high energy to produce neutrinos which have enough energy to produce tau leptons. This gives Fermilab the unique opportunity to search for neutrino oscillations occurring between the muon and the tau neutrino. Additionally, the NuMI facility is designed to accommodate future enhancements to the physics program that could push the search for neutrino mass well beyond the initial goals established for this project.

4. Details of Cost Estimate[a]

	(dollars in thousands)	
	Current Estimate	Previous Estimate
Design Phase		
Preliminary and Final Design costs	7,150	7,150
Design Management costs (0.0% of TEC)	10	10
Project Management costs (0.0% of TEC)	20	20
Total, Engineering design inspection and administration of construction costs (6.6% of TEC)	7,180	7,180
Construction Phase		
Buildings	15,965	12,265
Special Equipment	20,923	20,902
Other Structures	40,184	40,184
Construction Management (8.6% of TEC)	9,379	9,379
Project Management (4.1% of TEC)	4,430	4,430
Total, Construction Costs	90,881	87,160
Contingencies		
Construction Phase (10.2% of TEC)	11,107	14,902
Total, Contingencies (10.2% of TEC)	11,107	14,902
Total, Line Item Cost (TEC)	109,168	109,242

5. Method of Performance

Design of the facilities will be by the operating contractor and subcontractor as appropriate. To the extent feasible, construction and procurement will be accomplished by fixed-price contracts awarded on the basis of competitive bids.

[a] The annual escalation rates assumed for FY 1999 through FY 2005 are 2.4, 2.8, 2.7, 3.0, 3.1, 3.4, and 3.3 percent respectively.

6. Schedule of Project Funding

(dollars in thousands)

	Prior Years	FY 2003	FY 2004	FY 2005	Total
Project Cost					
Facility Cost					
Design	7,180	0	0	0	7,180
Construction	56,136	24,000	13,926	7,926	101,988
Total, Line item TEC	63,316	24,000	13,926	7,926	109,168
Other Project Costs					
Capital equipment [a]	31,414	9,443	2,000	1,653	44,510
R&D necessary to complete construction [b]	1,768	0	0	0	1,768
Conceptual design cost [c]	1,928	0	0	0	1,928
Other project-related costs [d]	11,828	983	800	383	13,994
Total, Other Project Costs	46,938	10,426	2,800	2,036	62,200
Total Project Cost (TPC)	110,254	34,426	16,726	9,962	171,368

[a] Costs to fabricate the near detector at Fermilab and the far detector at Soudan. Include systems and structures for both near detector and far detector, active detector elements, electronics data acquisition, and passive detector material.

[b] This provides for project conceptual design activities, for design and development of new components, and for the fabrication and testing of prototypes. R&D on all elements of the project to optimize performance and minimize costs will continue through early stages of the project. Specifically included are development of active detectors and engineering design of the passive detector material. Both small and large scale prototypes will be fabricated and tested using R&D operating funds. Prior year total has been adjusted to more accurately account for actual R&D costs.

[c] Includes operating costs for development of conceptual design and scope definition for the NuMI facility. Also includes costs for NEPA documentation, to develop an Environmental Assessment, including field tests and measurements at the proposed construction location. Prior year total has been adjusted to more accurately account for actual conceptual design costs.

[d] Includes funding required to complete the construction and outfitting of the Soudan Laboratory for the new far detector. In particular, includes $9,301,000 in prior years (including $1,468,000 in FY 2002) for capital costs of cavern construction; remainder is operating expenses related to the construction of the cavern and the MINOS detector. Prior year total has been adjusted to more accurately account for actual other project-related costs.

7. Related Annual Funding Requirements

(FY 2003 dollars in thousands)

	Current Estimate	Previous Estimate
Annual facility operating costs [a]	500	500
Utility costs (estimate based on FY 1997 rate structure) [b]	500	500
Total related annual funding	1,000	1,000
Total operating costs *(operating from FY 2005 through FY 2010)*	5,000	5,000

[a] Including personnel and M&S costs (exclusive of utility costs), for operation, maintenance, and repair of the NuMI facility.

[b] Including incremental power costs for delivering 120 GeV protons to the NuMI facility during Tevatron collider operations, and utility costs for operation of the NuMI facilities, which will begin beyond FY 2004.