# High Energy Physics

## Program Mission

The mission of the High Energy Physics (HEP) program is to understand the universe at a fundamental level by investigating the elementary particles that are the basic constituents of matter and the forces between them, 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. This program will provide world-class, peer-reviewed research results in HEP and related fields, including particle astrophysics and cosmology, executing a long-range strategy for high energy physics research and technology.

## Strategic Objectives

**SC1:** Answer two key questions about the fundamental nature of matter and energy. Determine whether the Standard Model accurately predicts the mechanism that breaks the symmetry between natural forces and generates mass for all fundamental particles by 2010 or whether an alternate theory is required, and on the same timescale determine whether the absence of antimatter in the universe can be explained by known physics phenomena.

**SC7**: Provide major advanced scientific user facilities where scientific excellence is validated by external review; average operational downtime does not exceed 10% of schedule; construction and upgrades are within 10% of schedule and budget; and facility technology research and development programs meet their goals.

Progress toward accomplishing these Strategic Objectives will be measured by Program Strategic Performance Goals, Indicators and Annual Targets, as follows:

## Program Strategic Performance Goals

**SC1-1:** Exploit U.S. leadership at the energy frontier by conducting an experimental research program that will establish the foundations for a new understanding of the physical universe. (Research and Technology subprogram and HEP Facilities subprogram).

### Performance Indicator

Amount of data delivered and analyzed; Number of significant scientific discoveries.

### Performance Standards

As discussed in Corporate Context/Executive Summary.

## Annual Performance Results and Targets

| FY 2001 Results | FY 2002 Targets | FY 2003 Targets |
|---|---|---|
| Completed first phase of upgrades to enable the Tevatron at Fermilab to run with much higher luminosity. Began commissioning of phase-one accelerator upgrades. [Met Goal] | Deliver integrated luminosity as planned (80 pb-1) to CDF and D-Zero at the Tevatron. Begin implementation of second phase of accelerator upgrades: install four performance improvements to existing systems and begin design and construction of two new systems. (SC1-1) | Deliver integrated luminosity as planned (250 pb-1) to CDF and D-Zero at the Tevatron. Complete and install two new accelerator systems. Design new device to improve yield in antiproton target. (SC1-1) |
| Completed and commissioned upgrades of the CDF and D-Zero detectors at the Tevatron facility at Fermilab. [Met Goal] | Collect data and begin analysis. (SC1-1) | Take data with high efficiency; record over 60% of available data and continue analysis. (SC1-1) |

**SC1-2:** Explain the observed absence of antimatter in the universe through understanding of the phenomenon of Charge Parity (CP) Violation (Research and Technology subprogram and HEP Facilities subprogram).

### Performance Indicator

Amount of data delivered; Precision of final results; Number of significant scientific discoveries.

### Performance Standards

As discussed in Corporate Context/Executive Summary.

## Annual Performance Results and Targets

| FY 2001 Results | FY 2002 Targets | FY 2003 Targets |
|---|---|---|
| Delivered sufficient luminosity (25 fb-1) to double total BaBar data set. Added one new RF station. [Met Goal] | Increase the total data recorded by BaBar at the SLAC B-factory by delivering 35 fb-1 of total luminosity. (SC1-2) | Increase the total data delivered to BaBar at the SLAC B-factory by delivering 50 fb-1 of total luminosity. (SC1-2) |
| | Add one new RF station. (SC1-2) | Add one new RF station. Begin interaction region upgrade. (SC1-2) |
| BaBar collaboration published first unambiguous observation of CP violation in B meson decays. Errors on the measurement are +/- 0.15. [Met Goal] | Measure CP violation in B mesons with an uncertainty of +/- 0.12. (SC1-2) | Measure CP violation in B mesons with an uncertainty of +/- 0.10. (SC1-2) |

**SC7-1A:** Manage HEP facility operations to the highest standards of performance, using merit evaluation with independent peer review. Meet U.S. commitments to the accelerator and detector components of the Large Hadron Collider (LHC) facility now under construction (HEP Facilities subprogram)

### Performance Indicator

Percent on time/on budget, Percent unscheduled downtime.

### Performance Standards

As discussed in Corporate Context/Executive Summary.

## Annual Performance Results and Targets

| FY 2001 Results | FY 2002 Targets | FY 2003 Targets |
|---|---|---|
| The completion figures for the U.S. portion of the LHC project were:<br>CMS 61%<br>ATLAS 61%<br>Accelerator 68% | The completion targets for the U.S. portion of the LHC project are:<br>CMS 77%<br>ATLAS 72%<br>Accelerator 85%<br>(SC7-1A) | The completion targets for the U.S. portion of the LHC project are:<br>CMS 85%<br>ATLAS 82%<br>Accelerator 92%<br>(SC7-1A) |
| HEP scientific facilities were scheduled and operated such that unscheduled downtime on average is about 20% of scheduled operating time. | Maintain and operate HEP forefront scientific facilities such that unscheduled downtime is less than 20% of the total scheduled operating time. (SC7-1A) | Maintain and operate HEP forefront scientific facilities such that unscheduled downtime is less than 20% of the total scheduled operating time. (SC7-1A) |

**SC7-1B:** Perform the research and development needed to support the operation and upgrade of existing HEP facilities and to provide the tools and technology to develop new forefront facilities. (Research and Technology subprogram).

### Performance Indicator

Demonstration of R&D milestones and prototype components.

### Performance Standards

As discussed in Corporate Context/Executive Summary.

## Annual Performance Results and Targets

| FY 2001 Results | FY 2002 Targets | FY 2003 Targets |
|---|---|---|
| Demonstrated that 50 MV/m accelerating gradients in 11.4 GHz Next Linear Collider (NLC) accelerating structures are sustainable without significant structure damage. | Demonstrate operation of 11.4 GHz accelerating structure for an NLC at 75 MV/m without significant structural damage. (SC7-1B) | Demonstrate operation of advanced design accelerating structure for the NLC at 70 MV/m. (SC7-1B) |
| Successfully completed, at BNL, initial tests of carbon and mercury jet targets for the next generation of proton-driven accelerators. | Complete construction of Linac Test Area at BNL for detailed targeting & capture studies. (SC7-1B) | |

### Unique Opportunities for World Leadership

In FY 2003, the U.S. High Energy Physics program is focused on unique opportunities for great discoveries in physics. The Large Electron-Positron Collider (LEP) at CERN left a tantalizing hint of a *Higgs boson* when it ceased operations in late 2000. The data suggest a Higgs mass of about 115 GeV, well within reach of the Tevatron. The Higgs boson is associated with a field that is believed to give mass to the quarks and leptons, which are the fundamental constituents of matter. Its discovery would be a major advance in physics. The Large Hadron Collider (LHC) now being constructed in the LEP tunnel at CERN has been designed to find the Higgs, but cannot begin its physics program before 2006. Thus the Tevatron at Fermilab, with substantial upgrades completed and further improvements in progress, will have a chance to discover the Higgs before the LHC can get fully underway. With protons and antiprotons colliding head-on at an energy of nearly one trillion electron volts (1 TeV), the Tevatron is now at the world's energy frontier and will hold the lead until 2006. In order to find the Higgs by then, the Tevatron will need to run extensively, increase its luminosity (data rate) substantially, and replace some of its particle detectors components. A program of luminosity and detector improvements is now underway, interleaved with intensive data runs. If it is successful, the data in hand by the time LHC produces its first results should be enough to find the Higgs if its mass is less than 165 GeV. Tevatron data will also give more information about the surprisingly heavy *top quark* discovered there in 1995, and could reveal an entire new class of particles (*supersymmetric* particles) that have been predicted by new theories that seek to complete the unification of fundamental interactions.

At Stanford Linear Accelerator Center (SLAC), the highly successful B-factory and its BaBar detector will have the opportunity to shed light on the mysterious preponderance of matter over antimatter in the universe. Electrons colliding at several billion electron volts (GeV) will allow the study of a phenomenon known as *Charge-Parity (CP) violation* in B-mesons. B mesons contain a heavy b-quark or its anti-particle, and have roughly five times the proton mass. CP violation was originally discovered in 1964 in an experiment at Brookhaven National Laboratory involving the much lighter K mesons, and its accommodation within the current theory has only recently been established through extremely difficult and exquisitely precise measurements at Fermilab and CERN. The big question for SLAC is whether CP violation in the B-mesons will follow theoretical predictions or will instead indicate some additional, hitherto unknown source of the phenomenon. Such a discovery would have profound implications for our understanding of the matter-dominated universe in which we live. The B-factory will need a progressive series of upgrades in order to be competitive with a similar facility now operating in Japan

that has three times more design luminosity. To fully exploit the discovery potential of the Tevatron at Fermilab and the B-factory at the SLAC along with their corresponding detectors as discussed above, these facilities must be strongly utilized and significantly upgraded. Therefore, the FY 2002 budget focused on the utilization and upgrades of these facilities together with support for the research groups (primarily university based) performing the research. Thus, the focus is on maximizing the discovery potential with lower priority being given to other parts of the program. The distribution of resources as specified in this budget continues this focused program.

Although the emphasis will be on the discovery potential at Fermilab and SLAC, there are other unique opportunities in the program.

The first results were announced in early 2001 from a precise measurement of the anomalous magnetic moment of the *muon*, one of the twelve fundamental constituents of matter. The measurement, from a dedicated experiment (called *g-2*) at Brookhaven's Alternating Gradient Synchrotron (AGS) accelerator, differs significantly from theoretical predictions. If this early result holds up after further analysis, it will be a signal of new physics beyond current theories. For example, it could mean that the supersymmetric particles mentioned above will indeed be discovered at the Tevatron. Final results are expected by 2003 after data analysis is completed. A long baseline neutrino detection experiment called MINOS (the Main Injector Neutrino Oscillation Search) is currently being fabricated at Fermilab, and the NuMI (Neutrinos at the Main Injector) beamline construction project will provide a dedicated beam of neutrinos for MINOS. Fermilab is also in the final stages of preparation for a smaller neutrino oscillation experiment, MiniBoone, which will take its first data in 2002. With NuMI/MINOS and MiniBoone, Fermilab will have the opportunity to confirm or refute early indications of neutrino mass and to make precise mass measurements. Positive results would require that the current theory of elementary particles and interactions be modified and that a non-zero neutrino mass be incorporated into a larger, more encompassing theory.

## Major Advances

The DOE HEP program has been extremely successful. Since the DOE and its predecessors began supporting more than 90% of the research in this field around 1950, our understanding of the fundamental nature of matter has deepened profoundly, generating a stream of Nobel Prizes. Cutting edge experimental research at DOE accelerator laboratories in the 1960s and 1970s revealed a deeper level in the structure of matter, and theoretical physicists developed a new theory to explain it. Neutrons and protons, the building blocks of atomic nuclei, were shown to be tightly bound systems of more basic constituents called *quarks*. The last one, and the heaviest, was the top quark, found at Fermilab in 1995. DOE-supported university groups played major roles in all of these discoveries.

The strong force that binds quarks into nucleons is carried by particles called *gluons*, discovered at the DESY laboratory in Germany in 1978. The carriers of a second nuclear force, the weak interaction responsible for radioactivity, are called *W* and *Z bosons*, and they were discovered at the CERN Laboratory in Switzerland in 1983. The *photon*, which carries the electromagnetic force so familiar in our everyday lives, has been known since the turn of the twentieth century.

The discoveries of quarks and gluons revealed a deeper level of the structure of matter, a scientific advance that may be compared to the discovery of the atomic nucleus in the early twentieth century. This new knowledge is part of a theory known as the Standard Model, which identifies the basic constituents of matter and the fundamental forces that affect them. The theory also provides a mathematical structure to calculate properties of the particles and the ways they interact. The Standard

Model lists twelve fundamental constituents of matter (*fermions*): six quarks and six leptons. They occur in three families, each containing two quarks and two leptons. All three families are organized in the same patterns, but the members have different masses. There is strong evidence that no more families of quarks and leptons exist.

The theory includes three of the four known basic forces: the *strong, electromagnetic,* and *weak* forces, and twelve force carriers (called *bosons)*: eight gluons, two W's, the Z, and the photon. The fourth basic force, gravity, is not included. The quarks are subject to all four basic forces. The leptons (familiar examples are the electron and the neutrino) are subject to all of the basic forces except the strong force. Only two of the quarks—called *up* and *down*—are needed to make protons and neutrons. Thus these two quarks and just one of the leptons—the familiar electron—are sufficient to form all the stable matter that we observe on Earth. The Higgs field mentioned above is also an essential component of the Standard Model. 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

The Standard Model has been subjected to an array of rigorous tests for many years, and has survived all of them. It explains an amazing array of experimental data. Yet many important questions remain, many of which can be directly addressed through experiments:

What gives elementary particles their great variety of masses; is it the Higgs boson predicted by the Standard Model? Why are there exactly three families of quarks and leptons? Are these fermions truly the fundamental constituents of matter, or are they made of still smaller particles? Do the leptons called *neutrinos* really have no mass at all? Can gravity be incorporated into the Standard Model to make a complete theory of all particles and forces? Are there hidden, extra dimensions of space beyond the three we know? For every type of fermion, we have also created examples of its antiparticle (a kind of mirror image) but little of this *antimatter* is observed in the universe—why not? What is the *dark matter* that provides most of the mass in the universe, but emits no electromagnetic radiation? And what is the source of the recently observed acceleration in the expansion of the universe? Is there an undiscovered force or energy—the so-called *dark energy*?

## Methods and Resources

Theoretical research in high energy physics develops theories of elementary particles and forces. A theory expresses what is known in mathematical form and provides a way to calculate particle properties and predict processes. Thus it predicts new phenomena that can be tested experimentally. Experimental work explores for new phenomena not predicted by theory, and tests specific theoretical predictions. It relies principally on particle accelerators and particle storage rings, where beams of particles collide with targets or with other beams. Accelerator experiments typically require large and complex apparatus (*detectors*) built and used by large collaborations of physicists and engineers from universities and laboratories. The scientists who design and oversee these large detectors are primarily faculty and staff at many of the nation's best universities (DOE-HEP supports research groups at over 100 U.S. universities). In addition, there are university scientists supported by the NSF, participating scientists at DOE labs (principally Fermilab, SLAC, Brookhaven National Laboratory (BNL), Lawrence Berkeley National Laboratory (LBNL), and Argonne National Laboratory (ANL)), and a substantial number of scientists from foreign institutions. Typically, these scientists work together in large international collaborations, involving hundreds of scientists from many institutions, to carry out a scientific program of experimentation that may take a decade or more to complete.

The main accelerator facilities in the United States are at two DOE laboratories: the Tevatron proton-antiproton collider at Fermilab in Illinois and the B-factory electron-positron collider at SLAC in California. Prior to its termination in FY 2003, HEP research was also conducted at the Alternating Gradient Synchroton at BNL. DOE scientists also use the Cornell Electron Storage Ring (CESR) electron-positron collider at Cornell (operated by NSF), and facilities in other countries. American scientists have long used facilities at the European Organization for Nuclear Research (CERN), near Geneva, Switzerland, and those facilities will be even more important to the DOE program in the future. CERN has just shut down its LEP electron-positron collider and is building the LHC, which will begin operations in 2006. Under an international agreement established in 1997, DOE in collaboration with the National Science Foundation (NSF), is providing substantial resources to help CERN build the collider itself and two major detectors (ATLAS and CMS). American scientists will participate strongly in research at the LHC.

### Non-accelerator Experiments

It is important to note that while accelerators and accelerator- based experiments play a predominant role in the fields of high energy and nuclear physics, there are significant experiments that do not require the use of accelerators. Some of the non-accelerator experiments locate experimental apparatus on the earth's surface, others deep underground, and others in space. Non-accelerator experimentation is a growing part of the field of high energy physics and offers many exciting opportunities for the future.

Examples include the study of neutrinos coming from the sun, the search for dark matter, and the search for extremely rare processes such as proton decay or neutrino-less double beta decay, all of which require specialized detectors deep underground. Other non-accelerator experiments are located at ground level, such as the Pierre Auger project, in which a system of detectors will cover thousands of square kilometers and study the highest energy cosmic rays; and the Supernova Cosmology Project, which discovered the accelerating universe, suggesting the existence of dark energy.

Still others take place in space. For example, the Alpha Magnetic Spectrometer (AMS) detector will be located on the International Space Station to search for anti-matter in space, and the Gamma Large Area Space Telescope (GLAST) will be placed in earth orbit to study high energy gamma rays from "gamma ray bursters" and other astrophysical sources. This class of astrophysical phenomena is particularly interesting because it indicates that out in space there are concentrations of matter and acceleration mechanisms, and hence forces, far greater than any encountered here on earth.

### Technical Requirements

High energy physics works with particle energies higher than exist anywhere but in certain stellar or cosmological environments and studies distance scales that are extraordinarily small. It often must make precision measurements of phenomena buried in a background of noise or search for very rare processes that may signal new physics. Such research demands particle beams of great intensities and detectors with both the sensitivity to see the rare events and the selectivity to pull these out of a cacophony of background noise. It requires accelerators and storage rings that operate at trillions of electron volts of energy and particle currents that can routinely burn holes in steel, and demands particle detectors that can identify one particle out of several thousand and catch particles that live less that a trillionth of a second. It is essential to accumulate, store, process, and transmit to hundreds of researchers worldwide the increasingly large data sets produced by modern experiments. As international collaborations in

high energy physics grow from roughly 500 physicists presently working at each CERN, Fermilab, and SLAC detector to approximately 1800 in each of the collaborations preparing detectors for the LHC, the need for sophisticated data handling at widely separated data centers becomes even more crucial.

Operating in these extreme domains requires substantial time and expense to design, build, maintain, operate, and upgrade the impressively 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 a new technology 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 big, costly, and long-term. Since few of the core technologies for these devices are marketable, industry has no 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.

## Benefits to Other Sciences and to Citizens

High energy physics is profoundly connected to nuclear physics and to astrophysics and cosmology. Advances in any one of these fields often have a strong impact on one another. A principal objective of nuclear physics research now is to incorporate the quark discovered by high energy physics into the understanding of nuclear structure. High energy physics, nuclear physics, and astrophysics detectors use many of the same techniques.

Technology that was developed in response to the demands of high energy physics has become exceedingly useful to other fields of science, and thus has helped science to advance on a broad front. 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. Accelerators are used for radiation therapy and to produce isotopes for medical imaging. In U.S. hospitals, one patient in three benefits from a diagnostic or therapeutic nuclear medicine procedure, techniques derived from research in high energy and nuclear physics. 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. International research collaborations in high energy physics have set an example for other endeavors that require cooperative efforts by thousands of workers who must share facilities, data, and results, communicating among continents and managing the activities of diverse groups.

An important product of the HEP program is the corps of graduates trained in this discipline. This is a group of very talented people, well versed in scientific methods and state-of-the-art technologies, and skilled at working in teams. Many of them go into careers in high-tech industries, contributing to our country's economic strength.

## Accelerator Research and Development

The Department is continuing research and development directed toward accelerator facilities that will be needed for the future. Several approaches are being investigated. One is a linear electron-positron collider, often called the Next Linear Collider (NLC), following the successful example of the SLAC Linear Collider. Work is directed toward achieving a center-of-mass energy in the TeV range (500 to 1000 GeV, expandable to 1.5 TeV. A GeV is one billion electron volts of energy.). The current NLC R&D program, led by SLAC and Fermilab, seeks to develop new technologies that would provide high

performance while limiting cost. The R&D develops new technologies, applies available technologies, and uses industrial firms to expand its R&D reach on certain technologies and to engage in necessary technology transfer. A facility like the NLC may well be international, and research and development on linear colliders is also underway in other countries, primarily Germany and Japan.

Research is also underway on a storage ring for muons rather than electrons. Radiation losses of energy from the beam would be less than for electrons and thus a circular machine could be used. The challenge for any accelerator based on muons is their short lifetime (two millionths of a second), which demands very rapid production and acceleration of the beams. Fortunately, relativistic time dilation means a muon lives longer the faster it is moving through the laboratory. The decays of muons in a storage ring could also provide an intense source of neutrinos, and this idea (known as the "neutrino factory") is being actively investigated. Physicists also are investigating the more technically challenging possibility of a storage ring that could serve as a muon collider.

In spite of the more complicated interactions of its "bags of quarks," for energies well beyond the LHC, the best discovery machine may still be a high energy hadron collider, with its broad range of physics interactions. Work is underway at several laboratories and universities toward designing magnets that could make possible an affordable very high energy hadron collider. Such a facility could have collision energy of greater than 100 TeV, much higher than that of the LHC.

## Significant Accomplishments and Program Shifts

Research and Technology

SCIENCE ACCOMPLISHMENTS

DOE's High Energy Physics Program has a long and rich history of producing world-class research, much of which has been recognized by Nobel Prizes in Physics. Theoretical research supported by the program was responsible for the initial formulation of the Standard Model, and DOE-supported researchers at universities and laboratories provided much of its experimental basis including discovery of all of the quarks and most of the leptons. Specifically, DOE-supported research produced the following major accomplishments.

- 1950's: Theoretical prediction of Columbia University physicists that parity is not conserved in weak interactions (1957 Nobel Prize)
- 1950's: Discovery of the electron neutrino by Los Alamos National Laboratory scientists using the Savannah River Plant (1995 Nobel Prize)
- 1963: Discovery of the muon neutrino at Brookhaven National Laboratory (1988 Nobel Prize)
- 1964: Quark model of elementary particle physics proposed by a CalTech physicist (1969 Nobel Prize)
- 1964: Discovery of the omega-minus particle at Brookhaven National Laboratory, demonstrating the existence of the strange quark and supporting the quark model
- 1964: Discovery of charge-parity (CP) violation in K mesons at Brookhaven National Laboratory (1980 Nobel Prize)
- 1968: Experimental basis for up and down quarks at the Stanford Linear Accelerator Center (1990 Nobel Prize)
- 1974: Discovery of the charm quark at the Stanford Linear Accelerator Center and Brookhaven National Laboratory (1976 Nobel Prize)
- 1975: Discovery of the tau lepton at the Stanford Linear Accelerator Center (1995 Nobel Prize)

- 1977: Discovery of the bottom quark at Fermi National Accelerator Laboratory
- 1995: Discovery of the top quark at Fermi National Accelerator Laboratory
- 2000: Discovery of the tau neutrino at Fermi National Accelerator Laboratory
- 2001: Discovery of CP violation in B mesons at the Stanford Linear Accelerator Center

FY 2001 accomplishments are summarized below:

- The tau neutrino was discovered by the DONUT collaboration, a team of university and laboratory scientists working at Fermilab. This completed the last generation of leptons, and capped a major American achievement: the discovery of 11 of the 12 basic constituents of matter, the quarks and leptons of the Standard Model of elementary particles. (The first of the 12, the electron, had been discovered in England in 1897.) The discovery of the tau neutrino was considered by the American Institute of Physics to be one of the top three physics news stories of the year 2000, and has been published in peer reviewed scientific journals.
- University groups from the United States working on experiments at the LEP electron-positron collider at CERN completed their final data collection during FY 2000. Early analysis gave tantalizing indications that the Higgs boson may have been produced at LEP. Although not a definitive discovery, this finding was considered one of the top three physics news stories of the year 2000. The data analysis should be completed in 2002. Discovery and study of the Higgs boson, believed to be the source of mass for all elementary particles, is a major objective of the LHC, and will be vigorously pursued before the LHC by the Tevatron Collider at Fermilab.
- In 2001, physicists using the new BaBar detector at the new SLAC B-factory announced a definitive measurement of CP violation in the B-meson system. American physicists also participated in the BELLE experiment at the Japanese KEK laboratory, which reported similar measurements. The two results are consistent with each other, and with an earlier, less precise measurement from CDF at the Fermilab Tevatron. They are also consistent with the current Standard Model description of CP violation. Data collection continues with high priority to improve the precision of the result.
- The g-2 experiment at BNL, designed to study magnetic properties of the muon, has obtained the most precise measurement of the muon anomalous magnetic moment. Preliminary results announced in 2001 do not quite agree with the Standard Model, suggesting a first glimpse of new physics. The measurement precision should improve by a factor of two as analysis proceeds and more data are collected. If this result is confirmed, it would be the first clear indication of new physics beyond the Standard Model.
- Theoretical studies have led to a prediction that the "missing dimensions" in string theories may, under certain circumstances, be experimentally detectable, thus suggesting a way to test the validity of this class of theories.
- A SLAC 30 GeV electron beam was directed through a 1.5-meter segment of lithium plasma, creating a plasma wave that exhibited an accelerating gradient of greater than 0.5 GeV per meter. This is a record in a program that may have a potential of eventually approaching accelerating gradients of 10's of GeV per meter.
- Further evidence was obtained by studying very distant Supernovae of Type Ia that the universe is accelerating outward under the influence of an unknown force (dubbed "dark energy") that may comprise 70% of the critical density of the Universe. This result was obtained utilizing techniques adapted from HEP, and agrees with earlier results obtained by DOE researchers using completely different methods. The original discovery of the accelerating universe was Science magazine's Top Science Story of 1998.

High Energy Physics Facilities

FACILITY ACCOMPLISHMENTS

- The Tevatron completed commissioning with the new Main Injector, and the two upgraded detectors (CDF and D-Zero) were brought into operation in FY 2001. FY 2003 will be the second full year of operation to exploit these new capabilities.
- The B-factory at SLAC was brought into full operation during the early part of FY 2000 and has achieved and surpassed design luminosity. During FY 2003, the B-factory will be operated for maximum data collection on the key scientific question of understanding matter-antimatter asymmetry in the universe.
- The new BaBar detector at the B-factory at SLAC became fully operational in FY 2000 and performed very well in FY 2002, collecting and analyzing data at a high rate.
- 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 when the LHC begins physics operation in FY 2006.

PROGRAM SHIFTS

- Research with the CDF and D-Zero detectors at the Tevatron and the BaBar detector at the B-factory will continue to receive priority emphasis to take advantage of the major science opportunities described above.
- For the same reason, a number of planned upgrades to both facilities intended to increase the luminosity and improve the machine and detectors are being given high priority. 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. Lower priority parts of the program will be reduced.
- A long range planning study of the High Energy Physics program, entitled "Planning for the Future of U.S. High Energy Physics," was prepared in 1998 by a Subpanel of the High Energy Physics Advisory Panel (HEPAP). The Subpanel's recommendations were considered carefully in preparing this budget.
- An update of this report, entitled "HEPAP White Paper on Planning for U.S. High Energy Physics," has recently been prepared by HEPAP and was also used in planning this budget.
- A new HEPAP Subpanel has been assembled and charged to prepare an updated long range planning report. This report is expected early in 2002.
- DOE is establishing an exciting and expanding partnership with NASA in the area of Particle Astrophysics. The Alpha Magnetic Spectrometer (AMS) and Gamma Large Area Space Telescope (GLAST) experiments have been underway for some time. Preliminary consideration is being given to the interagency SuperNova Acceleration Probe (SNAP) experiment. These experiments, and others that may be proposed, will provide important new information about cosmic rays and the rate of expansion of the universe which will in turn lead to a better understanding of dark matter, dark energy, and the original big bang. The AMS and GLAST experiments, which are joint DOE-NASA projects, have received NASA mission approval.
- The Neutrinos at the Main Injector project has encountered serious problems in several areas. These include the construction of the beam tunnel at Fermilab and design changes in the beam line components and shielding needed to accommodate the high radiation levels resulting from the very

high intensity of the proton beam used to produce the neutrinos. The MINOS detector for NuMI, is proceeding well, and completion is expected within the projected cost and schedule. Because of these developments, the project costs have risen. The TPC is increased to $171,442,000 from the previously approved $139,390,000, and the TEC is increased to $109,242,000 from the previously approved $76,149,000. The completion is delayed by about two years to the end of FY 2005.

## Scientific Facilities Utilization

The High Energy Physics request includes $480,453,000 to maintain support of 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 Stanford Linear Accelerator Center (SLAC). In FY 2003, the Alternating Gradient Synchrotron at Brookhaven National Laboratory is terminated for High Energy Physics research.

## Workforce Development

The High Energy Physics program supports development of the R&D workforce through support of undergraduate researchers, graduate students working toward a doctoral degree, and postdoctoral 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), space exploration, and the stock market.

About 1,000 post-doctoral associates and graduate students supported by the High Energy Physics program in FY 2001 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 facilities supported by the DOE, NSF, and foreign countries. The majority of the experimental postdoctoral associates and graduate students have worked at one of the three High Energy Physics User Facilities: Fermi National Accelerator Laboratory, Stanford Linear Accelerator Center, and Brookhaven National Laboratory.

## Funding Profile

(dollars in thousands)

| | FY 2001 Comparable Appropriation | FY 2002 Original Appropriation | FY 2002 Adjustments | FY 2002 Comparable Current Appropriation | FY 2003 Request |
|---|---|---|---|---|---|
| High Energy Physics | | | | | |
| Research and Technology..... | 240,653 | 247,870 | -3,645 [a] | 244,225 | 258,545 |
| High Energy Physics Facilities ... | 422,945 | 456,830 | +715 [a] | 457,545 | 446,352 |
| Subtotal, High Energy Physics..... | 663,598 | 704,700 | -2,930 | 701,770 | 704,897 |
| Construction ..... | 32,329 | 11,400 | 0 | 11,400 | 20,093 |
| Subtotal, High Energy Physics..... | 695,927 | 716,100 | -2,930 | 713,170 | 724,990 |
| General Reduction..... | 0 | -2,930 | +2,930 | 0 | 0 |
| Total, High Energy Physics ..... | 695,927 [b] [c] | 713,170 | 0 | 713,170 | 724,990 |

**Public Law Authorization:**

Public Law 95-91, “Department of Energy Organization Act”

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

[a] Funding in the amount of $2,455,000 transferred from Research and Technology to High Energy Physics Facilities to more appropriately account for LHC program support.

[b] Excludes $14,409,000 which has been transferred to the SBIR program and $865,000 which has been transferred to the STTR program.

[c] Excludes $800,000 which was transferred to the Science Safeguards and Security program in an FY 2001 reprogramming.

## Funding by Site

(dollars in thousands)

| | FY 2001 | FY 2002 | FY 2003 | $ Change | % Change |
|---|---|---|---|---|---|
| Albuquerque Operations Office | | | | | |
| Los Alamos National Laboratory | 1,075 | 869 | 825 | -44 | -5.1% |
| Sandia National Laboratory | 4 | 0 | 0 | 0 | -- |
| Total, Albuquerque Operations Office | 1,079 | 869 | 825 | -44 | -5.1% |
| Chicago Operations Office | | | | | |
| Argonne National Laboratory | 9,887 | 8,762 | 10,293 | +1,531 | +17.5% |
| Brookhaven National Laboratory | 38,437 | 30,432 | 23,319 | -7,113 | -23.4% |
| Fermi National Accelerator Laboratory | 306,567 | 304,791 | 313,340 | +8,549 | +2.8% |
| Princeton Plasma Physics Laboratory | 394 | 310 | 364 | +54 | +17.4% |
| Chicago Operations Office | 88,336 | 80,590 | 74,527 | -6,063 | -7.5% |
| Total, Chicago Operations Office | 443,621 | 424,885 | 421,843 | -3,042 | -0.7% |
| Nevada Operations Office | 30 | 0 | 0 | 0 | -- |
| Oakland Operations Office | | | | | |
| Lawrence Berkeley National Laboratory | 40,694 | 37,817 | 32,530 | -5,287 | -14.0% |
| Lawrence Livermore National Laboratory | 1,556 | 441 | 429 | -12 | -2.7% |
| Stanford Linear Accelerator Center | 159,503 | 164,545 | 163,887 | -658 | -0.4% |
| Oakland Operations Office | 39,020 | 37,245 | 44,000 | +6,755 | +18.1% |
| Total, Oakland Operations Office | 240,773 | 240,048 | 240,846 | +798 | +0.3% |
| Oak Ridge Operations Office | | | | | |
| Oak Ridge Inst. for Science & Education | 330 | 5 | 130 | +125 | +2,500.0% |
| Oak Ridge National Laboratory | 790 | 663 | 660 | -3 | -0.5% |
| Thomas Jefferson National Accelerator Facility | 5 | 0 | 0 | 0 | -- |
| Oak Ridge Operations Office | 15 | 0 | 0 | 0 | -- |
| Total, Oak Ridge Operations Office | 1,140 | 668 | 790 | +122 | +18.3% |
| Washington Headquarters | 9,284 | 46,700 | 60,686 | +13,986 | +29.9% |
| Total, High Energy Physics | 695,927 [a] [b] | 713,170 | 724,990 | +11,820 | +1.7% |

[a] Excludes $14,409,000 which has been transferred to the SBIR program and $865,000 which has been transferred to the STTR program.

[b] Excludes $800,000 which has been transferred to the Science Safeguards and Security program in an FY 2001 reprogramming.

# Site Description

## Argonne National Laboratory

Argonne National Laboratory (ANL) in Argonne, Illinois, is a multiprogram laboratory located on a 1,700-acre site in suburban Chicago. ANL has a satellite site located in Idaho Falls, Idaho. High Energy Physics supports a program of physics research and technology R&D at ANL, using unique capabilities of the laboratory in the areas of advanced accelerator and computing techniques.

## Brookhaven National Laboratory

Brookhaven National Laboratory (BNL) is a multiprogram laboratory located on a 5,200-acre site in Upton, New York. High Energy Physics supports a program of physics research and technology R&D at BNL, using unique capabilities of the laboratory, including the Accelerator Test Facility and its capability for precise experimental measurement. High Energy Physics has also made limited use of the Alternating Gradient Synchrotron (AGS), a 28 GeV proton accelerator, which is principally supported by the Nuclear Physics program. Use of the AGS for HEP experiments will be terminated at the end of FY 2002.

## Fermi National Accelerator Laboratory

Fermi National Accelerator Laboratory (Fermilab) is a program-dedicated laboratory (High Energy Physics) located on a 6,800-acre site in Batavia, Illinois. Fermilab operates the Tevatron accelerator and colliding beam facility, which consists of a four-mile ring of superconducting magnets and is capable of accelerating protons and antiprotons to an energy of one trillion electron volts (1 TeV). The Tevatron is the highest energy proton accelerator in the world, and will remain so until the LHC begins physics operation in 2006. With the recent shutdown of the LEP machine at CERN in Switzerland, the Tevatron became the only operating particle accelerator at the energy frontier. Fermilab also includes the Main Injector, a pre-accelerator to the Tevatron. The Main Injector is also used to produce antiprotons for the Tevatron and will be used independently of the Tevatron for a 120 GeV fixed target program. Fermilab and SLAC are the principal experimental facilities of the DOE High Energy Physics program.

## Lawrence Berkeley National Laboratory

Lawrence Berkeley National Laboratory (LBNL) is a multiprogram laboratory located in Berkeley, California. The laboratory is on a 200-acre site adjacent to the Berkeley campus of the University of California. High Energy Physics supports a program of physics research and technology R&D at LBNL, using unique capabilities of the laboratory primarily in the areas expertise in superconducting magnet R&D, world-forefront expertise in laser driven particle acceleration, expertise in design of forefront electronic devices, and design of modern, complex software codes for acquisition and analysis of data from HEP experiments.

### Lawrence Livermore National Laboratory

Lawrence Livermore National Laboratory (LLNL) is a multiprogram laboratory located on an 821 acre site in Livermore, California. High Energy Physics supports a program of physics research and technology R&D at LLNL, using unique capabilities of the laboratory primarily in the area of advanced accelerator R&D.

### Los Alamos National Laboratory

Los Alamos National Laboratory (LANL) is a multiprogram laboratory located on a 27,000-acre site in Los Alamos, New Mexico. High Energy Physics supports a program of physics research and technology R&D at LANL, using unique capabilities of the laboratory primarily in the area of theoretical studies, and development of computational techniques for accelerator design.

### Oak Ridge Institute for Science and Education

Oak Ridge Institute for Science and Education (ORISE) is located on a 150-acre site in Oak Ridge, Tennessee. The High Energy Physics program supports a small effort at ORISE in the area of program planning and review.

### Oak Ridge National Laboratory

Oak Ridge National Laboratory (ORNL) is a multiprogram laboratory located on a 24,000-acre site in Oak Ridge, Tennessee. The High Energy Physics program supports a small research effort using unique capabilities of ORNL primarily in the area of particle beam shielding calculations. Through the Scientific Discovery through Advanced Computing (SciDAC) program, HEP will support an effort to model the physics processes that drive supernova explosions.

### Princeton Plasma Physics Laboratory

Princeton Plasma Physics Laboratory (PPPL) is a program-dedicated laboratory (Fusion Energy Sciences) located on 72 acres in Princeton, New Jersey. The High Energy Physics program supports a small theoretical research effort using unique capabilities of PPPL staff in the area of advanced accelerator R&D.

### Sandia National Laboratory

Sandia National Laboratory (SNL) is a multiprogram laboratory located on a 3,700-acre site in Albuquerque, New Mexico, with other sites in Livermore, California and Tonopah, Nevada. The High Energy Physics program supports a small effort at SNL in the area of logic modeling.

## Stanford Linear Accelerator Center

Stanford Linear Accelerator Center (SLAC) is a program-dedicated laboratory (High Energy Physics) located on 426 acres in Menlo Park, California. SLAC operates for High Energy Physics the recently completed B-factory and its detector, BaBar, and a program of fixed target experiments. The B-factory, a high energy electron-positron collider, was constructed to support a high quality search for and study of CP symmetry violation in the B meson system. All of these facilities make use of the two-mile long linear accelerator, or linac. SLAC and Fermilab are the principal experimental facilities of the DOE High Energy Physics program.

## Thomas Jefferson National Accelerator Facility

Thomas Jefferson National Accelerator Facility is a program-dedicated laboratory (Nuclear Physics) located on 273 acres in Newport, News, Virginia dedicated to the exploration of nuclear and nucleon structure. Through the SciDAC program, the High Energy Physics program supports an R&D effort aimed at computer modeling of the fundamental interactions between quarks and gluons, and a collaborative effort to develop software tools for data-intensive computing.

## All Other Sites

The High Energy Physics program supports about 260 research groups at more than 100 colleges and universities located in 37 states, Washington, D.C., and Puerto Rico. The strength and effectiveness of the university-based program is critically important to the success of the program as a whole. This university-based component of the HEP program provides access to some of the best scientific talent in the nation, and train the next generation of scientists.

The High Energy Physics program also directly funds research at a small number of non-DOE laboratories and non-government laboratories and institutes (e.g., National Institute for Standards and Technology, Naval Research Laboratory, the Smithsonian Institute), and a few small companies. Through its participation in the SBIR and STTR programs, the DOE HEP program also supports advanced technology R&D at some 60 small businesses located throughout the U.S.

# Research and Technology

## Mission Supporting Goals and Objectives

During the next five years, the DOE High Energy Physics program (HEP) will maintain its position as a world leader in experimental and theoretical research toward the fundamental understanding of matter, space, and time. It will provide the world's highest energy collisions at Fermilab's Tevatron, offering the best opportunity to explain how elementary particles get their mass. The B-factory will operate as one of the world's two electron-positron colliders that could explain the lack of antimatter in the universe.

The United States will execute its long-range strategy for high energy physics research and technology, with important input and consensus from the 20-year "roadmap" submitted by the High Energy Physics Advisory Panel (HEPAP) to DOE in 2002.

- HEP will perform the research and development needed to support and improve the operation of existing facilities—both accelerators and detectors—and to support the design and construction of new facilities needed to maintain our leading role in high energy physics research.
- The HEP program, which is the U.S. leader in sponsoring accelerator technology R&D with long-term applications spanning both the physical and the life sciences, will also search for completely new principles that could substantially increase the efficiency and performance of future accelerators.
- Resources provided for the Scientific Discovery through Advanced Computing (SciDAC) initiative will be used to support work on lattice Quantum Chromodynamics (QCD) computation of fundamental particle physics parameters, work on simulations of complex accelerators, and work on the design and utilization of distributed computer systems.
- The Research and Technology subprogram provides support for the university and laboratory based research groups carrying out the planned physics research and technology development programs for FY 2003 described below and planning the programs to be carried out in future years.

### Physics Research

The Physics Research category in the Research and Technology subprogram supports the university and laboratory based scientists performing experimental and theoretical HEP research.

Experimental research activities include: planning, design, fabrication and installation of experiments; conduct of experiments; analysis and interpretation of data; and publication of results. Theoretical physics research provides the framework for interpreting and understanding observed phenomena and, through predictions and extrapolations based on current understanding, identifies key questions for future experimental investigation. The research groups are based at ANL, BNL, Fermilab, LANL, LBNL, LLNL, ORNL, and SLAC, and about 100 colleges and universities.

The major planned Physics Research efforts in FY 2003 are:

- THE RESEARCH PROGRAM AT THE B-FACTORY/BABAR FACILITY AT SLAC. This research program is being carried out by a collaboration including scientists from SLAC, LBNL, LLNL, ORNL, 31 U.S. universities, and institutions from 6 foreign countries.
- THE RESEARCH PROGRAM USING THE TEVATRON/CDF FACILITY AT FERMILAB. This research program is being carried out by a collaboration including scientists from Fermilab, ANL, LBNL, 25 U.S. universities, and institutions in 10 foreign countries.
- THE RESEARCH PROGRAM USING THE TEVATRON/D-ZERO FACILITY AT FERMILAB. This research program is being carried out by a collaboration including scientists from Fermilab, BNL, LBNL, 33 U.S. universities and institutions in 16 foreign countries.
- A program of theoretical research at both universities and laboratories to identify questions for future research, and to further the understanding of new experimental results.
- A group of experimental research activities using the Cornell Electron Storage Ring and various international accelerator facilities with special capabilities, and other experimental activities, which do not require an accelerator beam.
- A small program of generic detector R&D.

**High Energy Physics Technology**

The High Energy Physics Technology category in the Research and Technology subprogram provides support for the specialized advanced technology R&D required to sustain and upgrade the presently operating facilities, to support accelerator and detector facilities presently under construction, and to extend the technology base so as to make possible new accelerator and detector technologies which will be needed to continue advancing the frontiers of the field.

The major planned High Energy Physics Technology efforts in FY 2003 are:

- SUPPORT FOR R&D RELATED TO EXISTING FACILITIES AND FACILITIES UNDER CONSTRUCTION. This R&D ensures the cost-effective performance of the facility, the ready adaptation for new research requirements, and the machine and detector performance improvements needed to address new research frontiers. This R&D is carried out at Fermilab, and SLAC.
- SUPPORT FOR GENERAL TECHNOLOGY R&D. A component of the R&D at each of the HEP laboratories is focused on improvements in the general areas of technology important at that laboratory but not directly connected to the operating machine or a facility under construction. The principal activities are R&D on high field superconducting accelerator magnets, improved radiofrequency acceleration, new beam instrumentation, and new detection technologies.
- SUPPORT FOR R&D RELATED TO A POSSIBLE FUTURE MUON STORAGE RING (NEUTRINO SOURCE). The muon is over 200 times heavier than an electron, but otherwise very similar in properties. The mass of the muon effectively eliminates the radiation losses, which severely limit circular electron machines. Thus a muon colliding beam machine, if it can be made to work, is an attractive alternate approach to research needing high energy colliding beams of leptons. Moreover, the decay of the circulating muons can result in a well-collimated, very intense beam of

neutrinos, with additional interesting physics possibilities, such as searching for evidence of neutrino mass.

The technical requirements for this new kind of accelerator present major challenges to the development of extremely high power beam targets, high power radio frequency systems, and intense beam transport systems. This R&D program involves a collaboration of national laboratories and universities.

- SUPPORT FOR LINEAR COLLIDER R&D. It has been long recognized that lepton and proton colliders provide very complementary capabilities and there is general agreement in the research community that it is essential for the HEP program to pursue both techniques to the highest possible energies, for which a lepton-collider complement to the LHC is needed.

  This approach to LHC scale energies was first demonstrated with the operation of the Stanford Linear Collider (SLC) at SLAC. Following on the success of the SLC, an international R&D collaboration (with SLAC as a major participant) has identified and attacked the technical barriers to the construction of a TeV scale linear collider. The SLAC version of this concept is called the Next Linear Collider (NLC). The R&D program focused on solution of the technical challenges related to building TeV scale linear electron-positron colliders is being carried out on an international basis. The international collaboration includes the Japanese high energy physics center, KEK, through a SLAC-KEK inter-laboratory memorandum of understanding, and by less formal arrangements, with R&D groups at the German DESY Laboratory, CERN, and the Budker Institute in Russia. The U.S. is a world leader in this R&D program. The NLC program is being carried out by a national collaboration that includes SLAC as the principal laboratory, Fermilab as the major collaborator, and with significant contributions from Lawrence Berkeley National Laboratory and Lawrence Livermore National Laboratory.

  The specific goals of the present NLC R&D program include developing new technologies that enable a higher performance, lower cost machine; carrying out systems engineering, value engineering, and risk analysis studies to identify additional R&D issues that could effect cost and performance and to select from available technologies; and using industrial firms to carry out R&D on selected technologies, thus exploiting the special "design-for-manufacture" expertise available in industry and effecting technical transfer from the NLC R&D program to industry. In addition, cost analysis and scheduling tools are being developed that can be used to guide the R&D program by identifying cost driving technologies. In FY 2003, the R&D program led by Fermilab and SLAC will focus on reliably achieving accelerating gradients in radio frequency structures in the required range of 75 to 100 MeV/meter.

- SUPPORT FOR FUTURE ORIENTED R&D. Advances in HEP are strongly dependent upon the development of new, higher-performance research instruments. The principal technologies that have been used to produce high particle energies are radio frequency acceleration and high field magnets. Today, the needs of high energy physics are pushing these technologies to limits unimagined twenty years ago. To respond, HEP funds an Advanced Accelerator R&D program looking for new approaches to these underlying technical needs. A further goal is to support a program for graduate training in the science and technologies underlying charge particle beam sources – the accelerators and storage ring systems essential to forefront research in high energy particle physics. To this end, the DOE/HEP Advanced Accelerator R&D program supports an extensive university-based and laboratory based accelerator physics program. The range of topics explored in the Advanced Accelerator R&D activity is very broad, but the principal goals are improved accelerating systems,

stronger and more precise beam focusing systems, and improved mathematical understanding and computer modeling of accelerators.

Conventional radio frequency accelerating systems probably cannot operate above gradients of 100 to 200 million volts per meter, so the use of lasers and plasmas as advanced accelerating devices is being studied. Today's magnetic fields (e.g., LHC magnets) routinely reach up to about 10 Tesla. This Advanced Accelerator R&D program has as a goal, magnets that can operate at 16 to 18 Tesla and are cost effective to build. This goal requires improved industrially available superconductors and new magnet geometries and structures and all of these are being explored. A major part of the research program is devoted to developing new theoretical, mathematical and computational approaches. These efforts focus heavily on the areas of classical non-linear dynamics, space charge dominated charged particle beams, and physical phenomenon associated with plasma waves moving close to the speed of light.

This Advanced Accelerator R&D research is carried out at ANL, BNL, LBNL, LANL, two non-DOE laboratories (Naval Research Laboratory and National Institute for Science and Technology), and thirty-four universities, the largest programs being at the University of Maryland and University of California, Los Angeles.

**SciDAC**

- The SciDAC program is aimed at improving the availability of and effective utilization of large scale computing. A major activity in the Technology category is developing tools to allow research scientists to more easily utilize currently available large scale computing resources.

  SciDAC funding is included in both the Physics Research category and the HEP Technology category (and a small amount is in the High Energy Physics Facilities subprogram). The total funding in FY 2003 in all categories is $4,410,000. The funding is distributed to a set of multiyear programs selected by peer review during FY 2001. These projects include work on tracking accelerator beams during the acceleration process, computing precise solutions to some of the fundamental equations of particle physics, development of systems to manage and analyze the very large quantities of data which are the routine output from the current generation of colliding beams detectors.

## Funding Schedule

(dollars in thousands)

| | FY 2001 | FY 2002 | FY 2003 | $ Change | % Change |
|---|---|---|---|---|---|
| Physics Research ..... | 163,778 | 159,307 | 166,110 | +6,803 | +4.3% |
| High Energy Physics Technology..... | 76,875 | 82,540 | 83,603 | +1,063 | +1.3% |
| SBIR/STTR ..... | 0 | 2,378 | 8,832 | +6,454 | +271.4% |
| Total, Research and Technology..... | 240,653 | 244,225 | 258,545 | +14,320 | +5.9% |

# Detailed Program Justification

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2001 | FY 2002 | FY 2003 |
| **Physics Research** | **163,778** | **159,307** | **166,110** |

| | | | |
|---|---|---|---|
| Physics Research | | | |
| Universities | 104,284 | 104,443 | 106,927 |
| Fermilab | 10,828 | 8,363 | 9,880 |
| SLAC | 12,755 | 12,930 | 13,082 |
| BNL | 10,989 | 10,316 | 10,391 |
| LBNL | 15,393 | 13,673 | 14,093 |
| ANL | 6,296 | 6,016 | 6,148 |
| Other Physics Research | 3,233 | 3,566 | 5,589 |
| Total, Physics Research | 163,778 | 159,307 | 166,110 |

- **Universities** ..... **104,284** **104,443** **106,927**

The university program consists of research groups at more than 100 universities doing experiments and theory. These university groups plan, build, execute, analyze and publish results of experiments; train graduate students and post-docs; and provide theoretical concepts, simulations and calculations of physical processes involved in high energy physics. The university groups usually work in collaboration with other university and laboratory groups. University based research efforts are selected based on peer review. The previous HEPAP Subpanel (1998), recommended that the level of funding for the university-based portion of the program be substantially increased over inflation over a two-year period. Due to budget constraints and other priorities, this has not been accomplished.

The university program is increased to provide support for those universities involved in the initiative to exploit the "window of opportunity" for exciting new physics results described in the introductory sections. 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, D-Zero, and BaBar, work on the design and fabrication of the LHC detector components, and research in support of U.S. participation in the LHC project.

These university based research activities are described in more detail below. The funding levels presented are estimates based on FY 2001 experience.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2001 | FY 2002 | FY 2003 |
| ► **University Based Research at Fermilab** ..... | **29,655** | **29,700** | **30,410** |

Some 55 DOE-funded universities participate in large international collaborations doing experiments at Fermilab. These experiments include the CDF and D-Zero collider detectors, and the KTeV, MINOS, and Mini Boone experiments using external beams of kaons and neutrinos. Other experiments are performed in the antiproton accumulator. The experiments study the production and interaction of quarks and gluons as a probe for new particles such as the Higgs; search for evidence for the possible mass of the neutrino and for the transition of neutrinos among the various types; search for possible sources for the asymmetry of matter over antimatter in the universe, and a number of other topics. These universities help to fabricate the detectors, plan and execute the experiments, analyze data and publish the results. The emphasis of groups working at Fermilab is shifting as activity related to 800 GeV fixed target experiments is finished and activities related to Tevatron, MINOS, and other new experiments increase.

| | | | |
|---|---|---|---|
| ► **University Based Research at SLAC** ..... | **12,340** | **12,360** | **12,650** |

Some 22 DOE-funded universities participate in large international collaborations doing experiments at SLAC. The experiments involve the BaBar detector and other smaller detectors for fixed target experiments. In particular, the BaBar detector is being used to study the nature of CP violation in the B meson system. These universities help to build the detectors, plan and carry out experiments, analyze the data and publish the results.

| | | | |
|---|---|---|---|
| ► **University Based Research at BNL**..... | **1,885** | **1,890** | **1,935** |

Some seven DOE-funded universities have participated in collaborative experiments at BNL. These experiments involved fixed targets and kaon or pion beams, colliding beams of protons (RHIC-SPIN) or nuclei (PHOBOS) at RHIC, and an external storage ring measuring the muon anomalous magnetic moment to high precision.

| | | | |
|---|---|---|---|
| ► **University Based Research at Cornell**..... | **4,300** | **4,310** | **4,410** |

Some nine university High Energy Physics groups with DOE funding participate in the electron-positron colliding beam experiments at the Cornell Electron Storage Ring (CESR) facility utilizing the collaboratively built CLEO detector studying various aspects of B meson interactions and decay.

| | | | |
|---|---|---|---|
| ► **University Based Non Accelerator Research** ..... | **10,400** | **10,415** | **10,665** |

Some 34 DOE-funded universities are involved in supporting the High Energy Physics experiments not utilizing accelerators. The principal experiments being supported in FY 2003 are:

- The Cryogenic Dark Matter Search (CDMS) and Pierre Auger projects are currently being fabricated. A description of CDMS is under the Fermilab section and Auger is described under the Other Physics Research section, and the project funding is included there. The physicists working on these projects are included here in university based non-accelerator research.

(dollars in thousands)

| FY 2001 | FY 2002 | FY 2003 |
|---|---|---|

- The first phase of the Alpha Magnetic Spectrometer (AMS) experiment is complete and the data has been analyzed to obtain key information on the presence of antimatter in the cosmic radiation. The Detector is being upgraded for a second shuttle flight. The planned FY 2003 funding for this Major Item of Equipment (MIE) is $750,000 and the TEC for the DOE portion of the AMS upgrade is $4,756,000.
- The Very Energetic Radiation Imaging Telescope Array System (VERITAS) is a ground based high energy cosmic gamma ray detector designed to search for and study astrophysical gamma ray sources. As such, it will complement GLAST. It will be built at a site in Arizona with fabrication of the detector initiated in FY 2003. The VERITAS collaboration includes both U.S. and foreign university groups, and the funding is being provided approximately equally by NSF, the Smithsonian, and the DOE. The total planned expenditures for the DOE portion of VERITAS is estimated at about $6,000,000; the planned FY 2003 DOE funding is estimated at about $1,500,000.
- Other active experiments, which are primarily in the areas of high energy astrophysics and cosmology, include Super-Kamiokande (Japan), KamLAND (Japan), SNO (Canada), GRANITE (Mt. Hopkins, Arizona), and AXION (LLNL).

| | | | |
|---|---|---|---|
| ▸ **University Based Research at Foreign Labs** ..... | **17,915** | **17,940** | **18,370** |

Universities funded by the DOE are doing experiments with international collaborations using facilities at foreign accelerator labs. Some 45 universities are conducting experiments at CERN (Switzerland), 11 at DESY (Germany), 10 at KEK (Japan), 1 at IHEP (Russia), 1 at BINP (Russia), and 2 at Beijing (China). This research addresses a wide range of fundamental questions such as the search for the Higgs boson, which may be a key to understanding the source of mass. The emphasis of university groups is shifting to the LHC research program at CERN/LHC and away from activities at DESY and the older programs at CERN.

| | | | |
|---|---|---|---|
| ▸ **University Research in Theory**..... | **23,905** | **23,940** | **24,510** |

Some 75 universities with DOE funding participate in research in theoretical high energy physics. Theoretical ideas, concepts, calculations and simulations of physical processes in high energy physics are a key to progress in that they provide guidance for the design of experiments and the basis for program priorities.

| | | | |
|---|---|---|---|
| ▸ **Other University Funding** ..... | **3,884** | **3,888** | **3,977** |

Primarily includes funding held pending completion of peer review of proposals that have been received, and funds to respond to new and unexpected physics opportunities. The Outstanding Junior Investigator program, that is intended to identify and provide support for highly promising investigators at an early stage in their careers, will continue at a level of about $400,000.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2001 | FY 2002 | FY 2003 |
| ▪ **Fermilab** | **10,828** | **8,363** | **9,880** |

In FY 2003, the experimental physics research groups at Fermilab will be focused mainly on data-taking with the upgraded CDF and D-Zero collider detector facilities, analysis of data taken in the FY 2002 collider run and the concluded 800 GeV fixed-target program, installation and commissioning of the MINOS detector, and fabrication of the CMS detector for the LHC. Also includes funding for work in theory and astrophysics.

The request includes funds to continue the Cryogenic Dark Matter Search (CDMS). The CDMS detector will use cryogenic techniques to search for weakly interacting massive particles (WIMPS). WIMPS are proposed as a possible explanation for the "missing" mass in the universe. CDMS is being done by a collaboration of universities and laboratories. The detector will be installed in the Soudan II underground laboratory in northern Minnesota. The planned FY 2003 funding for this Major Item of Equipment is $1,050,000 and the TEC for CDMS is $8,600,000.

The theoretical physics group will continue to emphasize topics related to the experimental physics programs as well as string theory and extra dimensions, lattice gauge theory, and Supersymmetry.

Funding is increased to provide additional support for the initiative to exploit the "window of opportunity" for exciting new physics results described in the introductory sections.

| | | | |
|---|---|---|---|
| ▪ **SLAC** | **12,755** | **12,930** | **13,082** |

The experimental physics research groups at SLAC will concentrate their efforts in FY 2003 on data taking and analysis of data from the BaBar detector operating with the B-factory accelerator facility. These data will be used to study CP violation in B meson decays, which may help explain the preponderance of matter over antimatter in the universe. The large BaBar dataset will provide many other forefront research results related to B meson decays. Fabrication of the Gamma Large Area Space Telescope (GLAST) will be a significant effort in FY 2003 in preparation for the launch projected to be in FY 2006. GLAST will study the very high energy cosmic rays reaching the earth before they have interacted in the atmosphere. Some physics research will also be done by fixed target experiments. The theoretical physics group will continue to emphasize topics related to BaBar and the other SLAC experimental physics programs as well as tests of the Standard Model, Quantum Chromodynamics (QCD) and Supersymmetry. **Performance will be measured** by progress toward the goal of describing and understanding CP Symmetry violation in the B meson system.

Funding is increased to provide additional support for the initiative to exploit the "window of opportunity" for exciting new physics results described in the introductory sections.

(dollars in thousands)

| | FY 2001 | FY 2002 | FY 2003 |
|---|---|---|---|
| ▪ **BNL** | **10,989** | **10,316** | **10,391** |

In FY 2003, the BNL experimental physics research groups will be primarily working on the D-Zero experiment, that will be taking data at Fermilab, and overseeing the fabrication of the U.S. portion of the ATLAS detector for the LHC. Data analysis for the precision measurement of the anomalous magnetic moment of the muon will be completed. The theoretical physics group will continue to emphasize topics related to the national experimental HEP program, including precision tests of the Standard Model, QCD and lattice gauge theories.

Funding is increased to provide additional support for the initiative to exploit the "window of opportunity" for exciting new physics results described in the introductory sections.

| | | | |
|---|---|---|---|
| ▪ **LBNL** | **15,393** | **13,673** | **14,093** |

In FY 2003, LBNL researchers will be focused on a number of research activities, including: data-taking with the CDF collider detector at Fermilab; data-taking with the BaBar detector at the B-factory storage ring at SLAC; data-analysis on the HYPER-CP experiment at Fermilab will be completed; and fabrication of the ATLAS detector, primarily the silicon tracking system, for the LHC, as well as development of the core software infrastructure for ATLAS. The researchers will also be working on supernova measurements to establish values of cosmological parameters. LBNL is involved in the SuperNova Acceleration Probe (SNAP) project to put in orbit a large infrared/optical telescope designed and instrumented to perform a precision measurement of the motion of Type Ia supernovae. The ultimate objective would be to determine whether the universe is accelerating outward in response to a fundamental new force, "dark energy." Funding ($400,000) is provided to support an R&D program to clarify the design, feasibility, and scientific capability of the proposed instrument. Additional funding ($980,000) is held as contingency pending further review of the progress of the challenging R&D presently underway. Funding is included for the Particle Data Group at LBNL, that continues as an international clearinghouse for particle physics information. The theoretical physics group will continue their research, that is strongly coupled to the LBNL experimental HEP program, including BaBar and ATLAS.

Funding is increased to provide additional support for the initiative to exploit the "window of opportunity" for exciting new physics results described in the introductory sections.

| | | | |
|---|---|---|---|
| ▪ **ANL** | **6,296** | **6,016** | **6,148** |

The experimental high energy physics group will continue collaborating in research on the CDF at Fermilab, and ZEUS at the DESY/HERA facility in Hamburg, Germany. They also will be working on the fabrication and installation of two major new detector facilities: the ATLAS detector for the LHC facility, and the MINOS detector at the Soudan site in Minnesota. The MINOS detector is part of the NuMI project and will use a neutrino beam from Fermilab. The theoretical physics group will continue their research in formal theory, collider phenomenology, and lattice gauge calculations.

Funding is increased to provide additional support for the initiative to exploit the "window of opportunity" for exciting new physics results described in the introductory sections.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2001 | FY 2002 | FY 2003 |
| ▪ **Other Physics Research** | **3,233** | **3,566** | **5,589** |

This activity includes funds to continue the Pierre Auger project. The Pierre Auger Project (Auger) is intended to detect and study very high energy cosmic rays using a very large array of surface detectors spread over 30,000 square kilometers. Auger is being done by a large international collaboration. The presently approved part of the project includes an array at a site in Argentina. The U.S. will provide only a small portion of the cost of the Argentine array. The total planned FY 2003 funding for this Major Item of Equipment is $1,140,000, of which $565,000 has been allocated to Fermilab. The TEC for the U.S. portion of this phase of the Auger project is $3,000,000.

The SuperNova Acceleration Probe (SNAP) project is intended to put in orbit a large infrared/optical telescope designed and instrumented to perform a precision measurement of the motion of Type Ia supernovae. The ultimate objective would be to determine whether the universe is accelerating outward in response to a fundamental new force, "dark energy." FY 2003 funding ($400,000) has been allocated to LBNL to support an R&D program to clarify the design, feasibility, and scientific capability of the proposed instrument. Additional FY 2003 funding ($980,000) is held as contingency pending further review of the progress of the challenging R&D presently underway.

This category also includes FY 2003 funding for smaller labs and other non-university performers ($2,306,000), conferences and workshops, studies, and research activities that have not yet completed peer review and programmatic decisions ($1,728,000).

| | | | |
|---|---|---|---|
| **High Energy Physics Technology** | **76,875** | **82,540** | **83,603** |

| High Energy Physics Technology | | | |
|---|---|---|---|
| Fermilab | 20,183 | 24,458 | 23,818 |
| SLAC | 22,333 | 24,280 | 24,810 |
| BNL | 6,479 | 4,735 | 5,145 |
| LBNL | 12,183 | 10,100 | 10,155 |
| ANL | 2,479 | 2,005 | 2,005 |
| Universities | 9,638 | 9,736 | 9,980 |
| Other Technology R&D | 3,580 | 7,226 | 7,690 |
| Total, High Energy Physics Technology | 76,875 | 82,540 | 83,603 |

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2001 | FY 2002 | FY 2003 |
| ▪ **Fermilab** | **20,183** | **24,458** | **23,818** |
| ▸ **Accelerator R&D** | **15,021** | **15,773** | **15,168** |

The major focus of the Accelerator R&D program in FY 2003 will be the continuation of the effort to design and install modifications aimed at improving the luminosity (intensity) and operational efficiency of the Tevatron complex to aid in the search for the Higgs, etc. The planned improvements include improved beam focusing magnets, improvements to the RF beam acceleration and control systems, and improvements to the beam position monitors. Funding in the amount of $4,000,000 is included for support of this urgent R&D effort.

Other activities in FY 2003 include design of an electron cooling system to improve the quality of an antiproton beam processed through the recycler ring; R&D on superconducting RF cavities for a separated kaon beam; R&D on quadrupole magnets for the LHC interaction regions; and R&D to lay the technology foundations, long term, for possible future accelerators and experiments.

R&D on the NLC began formally at Fermilab in the first quarter of FY 2000 under a memorandum of understanding with SLAC. Funding will be at the same level as FY 2002 ($3,000,000). Fermilab has assumed the principal R&D responsibility for the two main linac beam lines, including accelerating structures, supports, and instrumentation and control. A major SLAC and Fermilab collaborative R&D activity is application of the Fermilab developed permanent magnet technology throughout the entire NLC beam optics chain. Fermilab is also responsible for applying their expertise in conventional civil construction to issues that could significantly reduce the NLC construction cost. There will also be an accelerator physics effort, in collaboration with SLAC, to more fully understand all aspects of the beam optics and beam transport for the NLC from the electron and positron sources to the electron-positron collision point.

Longer range R&D addresses the feasibility and design issues for muon storage rings/neutrino sources. Fermilab is lead laboratory for the muon cooling experiment, and LBNL is a major collaborator. This is a critical test issue for demonstrating the feasibility of ionization cooling in the muon storage ring context. Muon storage ring R&D is funded at about $890,000. Fermilab is also engaged in an advanced superconducting magnet and materials program (principally niobium tin) to develop magnetic optical elements for use in a muon storage ring/neutrino source and, in the very far term, a possible 100 TeV proton collider.

Funding is reduced slightly for Accelerator R&D. An increase was considered to be of less importance than continued support for the initiative to exploit the “window of opportunity” for exciting new physics results described in the introductory sections.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2001 | FY 2002 | FY 2003 |
| ▸ **Experimental Facilities R&D** | **5,162** | **8,685** | **8,650** |

R&D will continue on pixel silicon detectors, on a possible dedicated collider detector for studying B meson interactions (B-TeV); on photon veto systems for an experiment searching for rare decays of kaons; and on computing techniques and on specialized electronics to better process the high event rates seen and anticipated in the large detectors.

Funding is reduced slightly. An increase was considered to be of less importance than continued support for the initiative to exploit the "window of opportunity" for exciting new physics results described in the introductory sections.

| | | | |
|---|---|---|---|
| ▪ **SLAC** | **22,333** | **24,280** | **24,810** |
| ▸ **Accelerator R&D** | **21,390** | **23,215** | **23,790** |

An important component of the FY 2003 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 $3x10^{34}cm^{-2}s^{-1}$, 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.

Activities in FY 2003 will include R&D on issues central to the design of the Next Linear Collider (NLC), an electron-positron colliding beam facility to operate in the 500 GeV to 1 TeV center-of-mass energy regime and upgradeable to 1.5 TeV. The R&D activity at SLAC will focus on understanding and overcoming limitations to achievable accelerating gradients, design and supporting engineering R&D on the electron and positron sources, damping rings, and connecting beam transport systems. Much of this work is done in collaboration with the Japanese laboratory for HEP, KEK. Technology development for the 11.4 GHz high-powered microwave sources that generate the power to accelerate electrons and positrons will continue with the goal of proving new, more cost effective technical approaches. Systems engineering, value engineering and risk analysis studies will be carried out to identify R&D opportunities to lower cost, exploit new technologies, and improve performance. The NLC R&D program at SLAC will be funded at $16,200,000 in FY 2003, the same as in FY 2002.

A program of general R&D into very advanced collider concepts will continue at a low level. This activity at SLAC will be closely coordinated with other participants in the high risk R&D program in advanced accelerator physics that is exploring the potential of lasers, plasmas, and ultra high frequency microwave systems to accelerate charged particles at ultra high gradients that is described in the introduction.

Funding is increased slightly for Accelerator R&D to allow continued support for the initiative to exploit the "window of opportunity" for exciting new physics results described in the introductory sections.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2001 | FY 2002 | FY 2003 |
| ▸ **Experimental Facilities R&D** | **943** | **1,065** | **1,020** |

In FY 2003, the emphasis will be on work to support and improve performance of BaBar, the newly operating B-factory detector, and a modest program of R&D, on developing preliminary designs for a detector to operate with a possible new electron-positron linear collider operating at the TeV center of mass energy scale. Funding in the amount of $250,000 is included for R&D related to the upgrade of the BaBar detector.

Funding is reduced slightly. An increase was considered to be of less importance than continued support for the initiative to exploit the "window of opportunity" for exciting new physics results described in the introductory sections. With no increase, the level of research activity will decrease due to the impact of inflation.

| | | | |
|---|---|---|---|
| ▪ **BNL** | **6,479** | **4,735** | **5,145** |
| ▸ **Accelerator R&D** | **5,466** | **3,795** | **4,205** |

Activities in FY 2003 will include, R&D on new methods of particle acceleration such as laser acceleration and inverse free electron laser (IFEL) accelerators, primarily using the excellent capabilities of the BNL Accelerator Test Facility.

BNL also has a major involvement in muon storage ring R&D, primarily in the area of the muon production target and collection systems. This target/capture R&D is critical for demonstrating the feasibility of a muon storage ring. This funding is increased by $39,000 to $1,064,000.

The BNL superconductor test facility will be used to study the characterization of new high critical temperature superconductors as well as the special requirements for high field magnet fabrication. The program for testing of superconducting cable for LHC magnets will continue.

Funding is increased by $371,000 to partially offset the impact of inflation.

| | | | |
|---|---|---|---|
| ▸ **Experimental Facilities R&D** | **1,013** | **940** | **940** |

In FY 2003, semiconductor drift photo diodes for detection of photons of energies as low as 50 eV will be designed and produced. Development of radiation hardened monolithic electronics for a number of experiments will continue. Development of lead-tungstate crystals with improved light output will continue. Testing of the modules that constitute the ATLAS barrel calorimeters will continue.

Funding for this activity is held flat in order to exploit the "window of opportunity" for exciting new physics results described in the introductory sections. With no increase, the level of research activity will decrease due to the impact of inflation.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2001 | FY 2002 | FY 2003 |
| ▪ **LBNL** | **12,183** | **10,100** | **10,155** |
| ► **Accelerator R&D** | **10,065** | **8,130** | **8,185** |

The high-gradient, all-optical, laser-plasma wakefield accelerator at LBNL will begin accelerating electron bunches in preparation for a series of experiments in novel acceleration techniques and their application to high-intensity positron sources.

LBNL is a major contributor to accelerator and superconducting magnet R&D for advanced accelerator concepts, including the muon storage ring and the next linear collider. Development of these concepts is needed to advance the energy and luminosity frontiers to better understand the structure of matter. In FY 2003, preparations for muon cooling experiments to be performed at Fermilab, needed to confirm the practicality of a muon storage ring, will continue, using components fabricated at LBNL. Funding for this activity is increased by $5,000 relative to FY 2002 to $280,000 in FY 2003.

| | | | |
|---|---|---|---|
| ► **Experimental Facilities R&D** | **2,118** | **1,970** | **1,970** |

LBNL has an industry forefront capability for designing and producing custom state-of-the-art electronics, such as silicon vertex detectors, integrated circuit (IC) systems, and other components for high energy particle detectors such as BaBar at the B-factory and the upgrades to CDF and D–Zero for the next, higher luminosity, runs at Fermilab. LBNL is also involved in developing computer programs for experimental data taking and analysis. In FY 2003, work will continue on large area charge-coupled devices and high-resolution imaging systems, plus the production and testing of IC systems.

Funding for this activity is held flat in order to exploit the "window of opportunity" for exciting new physics results described in the introductory sections. With no increase, the level of research activity will decrease due to the impact of inflation.

| | | | |
|---|---|---|---|
| ▪ **ANL** | **2,479** | **2,005** | **2,005** |
| ► **Accelerator R&D** | **1,575** | **1,160** | **1,160** |

R&D will continue on the acceleration of electrons using structures with plasmas or structures made of dielectric materials called wakefield accelerators. Researchers have achieved predicted accelerating gradients at encouraging levels using this new technique. Results are expected in obtaining high accelerating gradients with greatly enhanced beam stability using dielectric structures, and planning is underway for an upgraded experimental capability to generate much higher accelerator gradients using plasmas in structures driven by intense bunches of electrons. Related theoretical work will also continue.

Funding for this activity is held flat in order to exploit the "window of opportunity" for exciting new physics results described in the introductory sections. With no increase, the level of research activity will decrease due to the impact of inflation.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2001 | FY 2002 | FY 2003 |
| ▸ **Experimental Facilities R&D** | **904** | **845** | **845** |

In FY 2003 work will be underway on the MINOS detector, the ATLAS detector for the LHC, and an upgrade of the ZEUS detector at DESY.

Funding for this activity is held flat in order to exploit the "window of opportunity" for exciting new physics results described in the introductory sections. With no increase, the level of research activity will decrease due to the impact of inflation.

| | | | |
|---|---|---|---|
| ▪ **Universities** | **9,638** | **9,736** | **9,980** |

The funding will provide for a program of high priority technology R&D at about 20 universities relevant to the development of particle accelerators. The R&D is aimed at breakthrough technologies; superconductors for high-field magnets; laser and collective-effect accelerator techniques; novel, high-power radio frequency generators; muon storage rings; theoretical studies in particle beam physics, including the non-linear dynamics of particle beams; and at lowering the cost and improving the performance of future experiments and facilities. University based research efforts will be selected based on review by appropriate peers.

Funding is increased slightly to continue support for the initiative to exploit the "window of opportunity" for exciting new physics results described in the introductory sections.

| | | | |
|---|---|---|---|
| ▪ **Other Technology R&D** | **3,580** | **7,226** | **7,690** |

This category includes funding ($1,987,000) for R&D at a number of smaller DOE labs and other non-university sites on several of the topics described. This funding is increased slightly ($+71,000). This R&D effort is primarily a part of the high risk R&D described in the Mission Supporting Goals and Objectives – Technology R&D discussion. The R&D is aimed at breakthrough technologies; superconductors for high-field magnets; laser and collective-effect accelerator techniques; novel, high-power radio frequency generators; theoretical studies in particle beam physics, including the non-linear dynamics of particle beams; and at lowering the cost and improving the performance of future experiments and facilities.

This category also includes $1,264,000 held as contingency for muon storage ring/neutrino source challenging R&D. Most of the muon storage ring/neutrino source funding has been allocated to the participating laboratories. The total funding for Muon Storage Ring in FY 2003 is $3,563,000 which is decreased by $2,226,000 from FY 2002.

Funding for Other Technology R&D activities that have not been allocated pending completion of peer review or program office detailed planning is included at $4,439,000 an increase of $1,873,000.

| | | | |
|---|---|---|---|
| **SBIR/STTR** | **0** | **2,378** | **8,832** |

Includes $1,512,000 for the SBIR program and $866,000 for the STTR program in FY 2002 and $7,947,000 for the SBIR program and $885,000 for the STTR program in FY 2003. This is partially offset by a decrease for the SBIR program in the High Energy Physics Facilities subprogram.

| | | | |
|---|---|---|---|
| **Total, Research and Technology** | **240,653** | **244,225** | **258,545** |

## Explanation of Funding Changes from FY 2002 to FY 2003

| | FY 2003 vs. FY 2002 ($000) |
|---|---|
| ▪ **Physics Research** | |
| ► In University Physics Research, an increase of $2,484,000 to assist participation in the high priority experiments at Fermilab and SLAC | +2,484 |
| ► In Physics Research at Fermilab, an increase of $1,517,000 to assist with physics studies and data analysis from the high priority Higgs search | +1,517 |
| ► In Physics Research at SLAC, an increase of $152,000 to partially offset the impact of inflation. | +152 |
| ► In Physics Research at BNL, an increase of $75,000 to assist participation in the high priority experiments at Fermilab. | +75 |
| ► In Physics Research at LBNL, an increase of $420,000 to assist participation in the high priority experiments at Fermilab and SLAC. | +420 |
| ► In Physics Research at ANL, an increase of $132,000 to assist participation in the high priority experiments at Fermilab. | +132 |
| ► In Other Physics Research, an increase of $135,000 in funding for small labs and other non-university participants; a decrease of $565,000 in funds held as contingency for the Auger project ($565,000 has been allocated to Fermilab); a decrease of $189,000 in funds held as contingency for the SciDAC program; and an increase of $2,642,000 in the funds held pending completion of peer review and programmatic consideration. | +2,023 |
| Total, Physics Research | +6,803 |
| ▪ **High Energy Physics Technology** | |
| ► Technology R&D activities at Fermilab decrease $640,000 reflecting decreases of $790,000 in muon collider R&D and of $35,000 in Experimental Facilities R&D offset by an increase of $185,000 in funding for general accelerator R&D. | -640 |
| ► Technology R&D activities at SLAC increase $530,000 to partially offset the impact of inflation. | +530 |
| ► Technology R&D activities at BNL increase $410,000 to offset the impact of inflation and assist with operation of the Accelerator Test Facility. | +410 |
| ► Technology R&D activities at LBNL increase $55,000 to partially offset the impact of inflation.. | +55 |
| ► In Technology R&D at Universities, an increase of $244,000 to partially offset the impact of inflation. | +244 |

| | FY 2003 vs. FY 2002 ($000) |
|---|---|
| ▸ In Other Technology R&D, an increase of $71,000 for funding at small labs and other non-university sites and an increase of $1,873,000 in funding held as contingency pending the completion of peer review and program office considerations and a reduction to muon collider R&D for higher priority activities of $1,480,000. | +464 |
| Total, High Energy Physics Technology | +1,063 |

- **SBIR/STTR**

| | |
|---|---|
| ▸ An increase of $6,454,000 in the SBIR/STTR allocations. This is partially offset by a decrease in High Energy Physics Facilities of $5,596,000 for SBIR. | +6,454 |
| Total Funding Change, Research and Technology | +14,320 |

The following table displays funding in High Energy Physics for R&D on possible future HEP facility concepts:

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2001 | FY 2002 | FY 2003 |
| Next Linear Collider | 19,157 | 19,200 | 19,200 |
| Muon Storage Ring/Neutrino Source | 5,445 | 5,789 | 3,563 |

# High Energy Physics Facilities

## Mission Supporting Goals and Objectives

The program will operate and improve its existing research facilities to ensure efficiency, effectiveness, and safety. The Tevatron data rate will increase by a factor of 2-5 by FY 2005. The B-factory will continue to accumulate substantial data on a range of heavy quark physics topics, with special emphasis on the asymmetry between matter and antimatter in the universe.

The United States will execute its long-range strategy for high energy physics facilities, with important input and consensus from the 20-year "roadmap" submitted by the High Energy Physics Advisory Panel (HEPAP) to DOE and NSF in 2002.

During the next five years, the program will meet its commitments to the accelerator and detector components of the Large Hadron Collider (LHC) facility now under construction. It will participate fully in the research program when the LHC begins operations at CERN, planned for 2006.

During the next five years, NuMI/MINOS will be completed and begin accumulating data, which will be analyzed to answer fundamental questions about the neutrino—whether it has mass and transforms ("oscillates") from one type to another.

Resources provided by the Scientific Discovery through Advanced Computing (SciDAC) initiative will be used to support access to and manipulation of the massive data flows from high energy physics research facilities.

The High Energy Physics Facilities subprogram includes the provision and operation of the large accelerator and detector facilities, the essential tools that enable scientists in university and laboratory based research groups to perform experimental research in high energy physics.

The FY 2003 program described earlier contains the following facility operation elements.

- Full operation of the Tevatron at Fermilab and the B-factory at SLAC for the research program planned at those facilities. This includes operation of the accelerators and storage rings, and operation of the ancillary and support facilities including in particular the computing facilities. The Alternating Gradient Synchrotron is terminated for High Energy Physics research in FY 2003.
- Continuation of the planned program of upgrades for the Tevatron and the B-factory. The physics goals of the HEP program described earlier (detection of Higgs; study of CP Violation, etc.) require a substantial amount of data collection. Facility upgrades that increase the beam intensity and detector efficiency are extremely important since they increase the data collection rate just as effectively as does additional operation. The data collection goals needed to achieve the physics objectives require both extended running and an ongoing program of facility and detector upgrades.
- Continued work on the agreed to components and subsystems for the LHC accelerator and detectors.
- Site infrastructure maintenance and improvement. The High Energy Physics Facilities subprogram includes general plant projects (GPP) funding (at Fermilab, SLAC and LBNL) and general purpose equipment (GPE) funding (at LBNL).

The principal objective of the High Energy Physics Facilities subprogram is to maximize the quantity and quality of data collected for approved experiments being conducted at the High Energy Physics facilities. The ultimate measure for success in the High Energy Physics Facilities subprogram is whether the research scientists have data of sufficient quantity and quality to do their planned measurements. The quality of the data is dependent on the accelerator and detector capabilities, and on the degree to which those capabilities are achieved during a particular operating period. The quantity of the data relates primarily to the beam intensity, the length of the operating periods, and the operational availability of the accelerator and detector facilities.

| | (in weeks) | | |
|---|---|---|---|
| | FY 2001 | FY 2002 | FY 2003 |
| Fermilab | 22 | 39 | 39 |
| SLAC[a] | 34 | 35 | 39 |
| BNL | 19 | 16 | 0 |

## Funding Schedule

(dollars in thousands)

| | FY 2001 | FY 2002 | FY 2003 | $ Change | % Change |
|---|---|---|---|---|---|
| Fermi National Accelerator Lab | 219,388 | 244,535 | 239,042 | -5,493 | -2.2% |
| Stanford Linear Accelerator Center | 119,226 | 127,335 | 125,995 | -1,340 | -1.1% |
| Brookhaven National Laboratory | 6,014 | 5,725 | 0 | -5,725 | -- |
| Other Support | 19,447 | 18,032 | 14,518 | -3,514 | -19.5% |
| Large Hadron Collider | 58,870 | 49,000 | 60,000 | +11,000 | +22.4% |
| SBIR/STTR | 0 | 12,918 | 6,797 | -6,121 | -47.4% |
| Total, High Energy Physics Facilities | 422,945 | 457,545 | 446,352 | -11,193 | -2.4% |

[a] The number of weeks is projected on the basis of the continuing availability of electrical power at affordable prices, an assumption that may be questionable in California.

## Detailed Program Justification

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2001 | FY 2002 | FY 2003 |
| **Fermilab** | **219,388** | **244,535** | **239,042** |

Provides support for operation, maintenance, improvement, and enhancement of the Tevatron accelerator and detector complex and for maintenance of the laboratory physical plant. This complex includes the Tevatron, that can operate in a collider mode with protons and antiprotons, or in a fixed target mode with protons only; the Main Injector that was completed and commissioned in FY 1999 and is fully operational; the Booster; the Linac; and the Antiproton Source and Accumulator. The Tevatron collider and the 800 GeV fixed target modes are mutually exclusive, and no 800 GeV fixed-target running is planned in the foreseeable future; however, a fixed target program at 120 GeV using the new Main Injector is possible in parallel with Tevatron collider operation.

Tevatron operation in FY 2003 will be focused on an extended run to collect the maximum amount of data for the physics goals (Higgs, etc.) described earlier. This will include full operation of the two large detectors, CDF and D-Zero, and the supporting computing facilities. The Tevatron will operate for about 39 weeks in FY 2003. **Performance will be measured by** adherence to planned running schedules and by progress on maintaining and enhancing luminosity and operational efficiency for the Tevatron at Fermilab in its new mode of operation with the new Main Injector.

- **Operations** ..... **188,809** **198,230** **194,757**

  Operations at Fermilab will include operation of the Tevatron in collider mode for about 39 weeks. This will be a major physics run with the higher intensity available from the new Main Injector and with the newly upgraded D-Zero and CDF detectors. This is to be a major data collection period for the experiments searching for the Higgs and related phenomena as described in more detail earlier.

  The funding provided will support the planned Tevatron operation and will assist with installation and commissioning of planned luminosity upgrades.

**Tevatron Operation**

| | (in weeks) | | |
|---|---|---|---|
| | FY 2001 | FY 2002 | FY 2003 |
| Tevatron Operation | 22 | 39 | 39 |

- **Support and Infrastructure** ..... **30,579** **46,305** **44,285**

  Funding in the amount of $25,500,000 (Capital Equipment - $19,000,000; AIP - $6,500,000) is included for the program to increase the Tevatron luminosity, upgrade the CDF and D-Zero detectors, and provide the computing capability needed to analyze the data collected. This is all aimed at exploiting the "window of opportunity" described above. This is an increase of $11,580,000 (Capital Equipment +$12,080,000; AIP -$500,000) over FY 2002 and includes continuation of the two Major Items of Equipment projects involving the replacement of the Silicon Tracker Subsystems with new state-of-the-art radiation-hard silicon for both the CDF Detector ($7,500,000; TEC of $15,000,000) and D-Zero Detector ($7,500,000; TEC of $15,000,000). Also included is $4,000,000 for smaller projects needed for the upgrades. The increased funding for the

machine and detector upgrades reflects the high priority given to the highly effective operation of the Tevatron for the physics goals and are aimed at improving the luminosity and efficiency of operation of the Tevatron. The Silicon Tracker Subsystem replacements will be necessary since in the normal course of operation the silicon in the detectors gets damaged by radiation and needs to be replaced. The technology involving radiation-hard silicon has improved significantly since the design for the last upgrades to the detectors was completed five years ago. This will allow these detector subsystems to better withstand the higher intensities needed in the search for the Higgs.

Capital Equipment for the MINOS Detector, a Major Item of Equipment, is included at $5,490,000. This is reduced from FY 2002 by $9,785,000 following the revised funding profile and is consistent with the NuMI project completion date. MINOS is the detector part of the NuMI project that will provide a major new capability for neutrino research. Capital Equipment for other laboratory needs is reduced (-$3,155,000) to $6,495,000. AIP for other laboratory needs is reduced from FY 2002 (-$660,000) to $2,000,000.

GPP funding is unchanged at $4,800,000 to address urgent ES&H and infrastructure needs at the lab.

| | | | |
|---|---|---|---|
| **SLAC** ..... | **119,226** | **127,335** | **125,995** |

Provides for the operation, maintenance, improvement and enhancement of the accelerator and detector complex on the SLAC site. The accelerator facilities include the electron linac, the B-factory, completed in FY 1999, and the NLC Test Accelerator. The B-factory is fully operational and is performing well. The detector facilities include BaBar, the detector for the B-factory, the End Station A experimental set-ups, and the Final Focus Test Beam. This will be a major data collection period for the experiment studying the B meson system and the phenomenon of CP Violation as described earlier.

B-factory operation in FY 2003 will be focused on an extended run to collect the maximum amount of data for the physics goals described earlier. This will include full operation of the large detectors – BaBar – and the supporting computing facilities. The B-factory will operate for about 39 weeks in FY 2003. **Performance will be measured by** adherence to planned running schedules and progress on achieving and increasing luminosity and operational efficiency for the B-factory at SLAC as measured by comparison with stated project goals.

Also provides for the fabrication of the GLAST detector, which is to be a satellite-based study of high energy gamma rays in the cosmic radiation.

Also provides for maintenance of the laboratory physical plant.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2001 | FY 2002 | FY 2003 |
| ▪ **Operations** | **94,971** | **100,890** | **97,275** |

The funding will provide operations at SLAC in FY 2003 for about 39 weeks of strong utilization of the asymmetric B-factory colliding beam storage rings to maximize the data collected by the BaBar detector facility, and for corresponding support of detector operations and computing operations. This will be the priority research program at SLAC in FY 2003. This will be supplemented by a modest (8 weeks) fixed target research program in End Station A that will be run in parallel with B-factory operation. The linac will serve as the injector of positrons and electrons to the B-factory storage rings during this time.

**SLAC Operation**

| | (in weeks) | | |
|---|---|---|---|
| | FY 2001 | FY 2002 | FY 2003 |
| Fixed Target[a] | 8 | 8 | 8 |
| B-factory Operation | 34 | 35 | 39 |
| Total, SLAC Operation | 34 | 35 | 39 |

| | | | |
|---|---|---|---|
| ▪ **Support and Infrastructure** | **24,255** | **26,445** | **28,720** |

Funding for the projects to upgrade the B-factory, the BaBar detector, and the SLAC computing facilities needed to process the BaBar data is included at $11,800,000 (Capital Equipment $4,200,000; AIP $7,600,000). Capital equipment funding for the GLAST Major Item of Equipment, the large gamma ray detector designed to study cosmic gamma rays from a satellite, is increased by $830,000 to $8,910,000. GLAST is a joint DOE-NASA project aimed at studying gamma rays in the cosmic radiation using a satellite-based instrument; the TEC is $35,000,000. Funding for other Capital Equipment needs is included at $1,120,000. Funding for other AIP is included at $2,690,000 (up from $800,000 in FY 2002) to assist in maintaining the operational efficiency of the B-factory and its injection system. Funding for GPP is held constant at $4,200,000 to address urgent ES&H and infrastructure needs.

| | | | |
|---|---|---|---|
| **BNL** | **6,014** | **5,725** | **0** |

Provides support for the HEP related operation, maintenance, improvement, and enhancement of the AGS complex at BNL and its complement of experimental set ups. The AGS is operated by the Nuclear Physics program as part of the RHIC facility and operation of the AGS for the HEP program has been on an incremental cost basis. The AGS will not be operated for the HEP physics experiments in FY 2003.

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

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2001 | FY 2002 | FY 2003 |
| ▪ **Operations** | **5,634** | **5,630** | **0** |

Funding provided for the incremental cost of running the AGS complex for HEP in FY 2001 and FY 2002. There will be no operation of the AGS for High Energy Physics experiments in FY 2003.

**AGS Operation**

| | (in weeks) | | |
|---|---|---|---|
| | FY 2001 | FY 2002 | FY 2003 |
| AGS Operation for HEP | 19 | 16 | 0 |

| | | | |
|---|---|---|---|
| ▪ **Support and Infrastructure** | **380** | **95** | **0** |

Includes capital equipment funding for HEP use of the AGS in FY 2001 and FY 2002. There will be no operation of the AGS for High Energy Physics experiments in FY 2003.

| | | | |
|---|---|---|---|
| **Other Support** | **19,447** | **18,032** | **14,518** |

Full and effective participation by U.S. scientists in the LHC research program (the LHC is scheduled to begin operation in 2006) requires an effective system to make the data recorded by the detectors at CERN available for analysis by participating scientists at U.S. universities and laboratories. This problem is compounded by the enormous magnitude of the amount of data that will be recorded. This category includes funding for continuing the design, implementation, and operation of the computing facilities and network links needed to process, store, and analyze this large body of data. The total funding for LHC computing support is $5,730,000 which is increased by $2,040,000 from FY 2002.

Full and effective participation by U.S. scientists in the LHC research program also requires support for the preparation for operation of the two large detectors in which U.S. scientists are major collaborators. The nature and magnitude of these costs is under active discussion with CERN and the international collaborations that have overall responsibility for the detectors. Preliminary estimates are $300,000 in FY 2002 and $1,000,000 in FY 2003.

This category also includes $135,000 for the SciDAC program. Total funding in the HEP program for this activity is $4,410,000 which is decreased by $510,000 from FY 2002.

This category also includes $1,950,000 (-$147,000) for General Purpose Equipment and $3,500,000 (+$458,000) for General Plant Projects at LBNL. The combined funding at LBNL increases by $311,000.

This category also includes funding ($2,203,000) for a number of small activities including computer networking and funds held in reserve pending completion of peer review and programmatic consideration. These funds are decreased substantially (-$6,700,000) to support higher priority activities.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2001 | FY 2002 | FY 2003 |
| **Large Hadron Collider** ..... | **58,870** | **49,000** | **60,000** |

The funding requested follows the currently approved profile which is revised from the original profile. Changes have been made to better match the funding profile to the funding needs of (1) the three U.S. projects based on their current fabrication plans and schedules, (2) the updated LHC construction schedule as determined by CERN, and (3) to reflect CERN's updated billing profile for payments under the "Procurements from U.S. Industry" program. This funding 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 on the CERN site have led to delays in the project. These problems are being overcome and the latest official CERN schedule shows approximately a nine-month slippage with first collisions in April 2006. This schedule slippage is being accommodated in the planning for the U.S. LHC projects with minimal impact on schedule and no increase in total cost to the U.S.

The CERN managed LHC project overall has undergone a cost growth on the order of twenty percent. CERN management is moving aggressively to reduce costs and to establish a solid plan for completing the LHC. This plan is being developed, and is expected to be completed and approved by June 2002. The U.S. position is that the DOE and NSF contributions will <u>not</u> be increased in response to the CERN cost growth problem.

The European Center for Nuclear Research (CERN) in Geneva, Switzerland initiated the Large Hadron Collider (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 the LHC will open up substantial new frontiers for scientific discovery. Completion of the LHC is projected for 2006.

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 operations in 2006. 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 (Drell) 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. Although LHC will have a lower energy than the Superconducting Super Collider (canceled in 1993), it 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.

(dollars in thousands)

| FY 2001 | FY 2002 | FY 2003 |
|---|---|---|

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 over the period FY 1996 through FY 2005 (with approximately $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. Thus the U.S. contribution represents less than 10 percent of the total. (The LHC cost estimates prepared by CERN, in general, do not include the cost of permanent laboratory staff and other laboratory resources used to construct the project.) Neither the proposed U.S. DOE $450,000,000 contribution nor the estimated total cost of $6,000,000,000 include support for the European and U.S. research physicists working on the LHC program.

The agreement negotiated with CERN provides for U.S. involvement in the management of the project through participation in key management committees (CERN Council, CERN Committee of Council, LHC Board, etc.). This 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 feasible.

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 500 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 | |
| 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 | 22,100 | 37,900 | 60,000 | 9,720 |
| 2004 | 29,330 | 30,670 | 60,000 | 0 |
| 2005 | 20,657 | 10,473 | 31,130 | 0 |
| Total | 200,000[c] | 250,000 | 450,000 | 81,000 |

[a] The NSF funding has been 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] 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 2001 | FY 2002 | FY 2003 |
| High Energy Physics Facilities | | | |
| LHC | | | |
| Accelerator Systems | | | |
| Operating Expenses | 1,098 | 1,900 | 1,850 |
| Capital Equipment | 18,068 | 8,196 | 6,850 |
| Total, Accelerator Systems | 19,166 | 10,096 | 8,700 |
| Procurement from Industry | 8,077 | 11,207 | 13,400 |
| ATLAS Detector | | | |
| Operating Expenses | 8,919 | 3,594 | 7,282 |
| Capital Equipment | 5,556 | 6,913 | 10,134 |
| Total, ATLAS Detector | 14,475 | 10,507 | 17,416 |
| CMS Detector | | | |
| Operating Expenses | 10,785 | 11,190 | 12,482 |
| Capital Equipment | 6,367 | 6,000 | 8,002 |
| Total, CMS Detector | 17,152 | 17,190 | 20,484 |
| Total, LHC | 58,870 | 49,000 | 60,000 |

In FY 2003, funding will be used for the fabrication of accelerator magnets and equipment and the R&D, prototype development, and fabrication of detector subsystems such as tracking chambers, calorimeters, 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 2001 | FY 2002 | FY 2003 |
| ▪ **Accelerator Systems** | **19,166** | **10,096** | **8,700** |

In FY 2003, funding will support continued production of quadrupole magnets, cryogenic/electrical power feedboxes, and beam absorbers for the LHC beam interaction regions. Production of dipole magnets for the interaction and radio-frequency regions will be completed. Production testing of superconducting wire and cable for the LHC main magnets will continue at peak rates. Accelerator physics calculations will continue. Funding is reduced by $1,396,000 as production activities begin to ramp down.

| | | | |
|---|---|---|---|
| ▪ **Procurement from Industry** | **8,077** | **11,207** | **13,400** |

In FY 2003, funding will continue 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 increased by $2,193,000 to support the current estimate of actual invoices from U.S. industrial suppliers which are expected to peak in 2004.

| | | | |
|---|---|---|---|
| ▪ **ATLAS Detector** | **14,475** | **10,507** | **17,416** |

In FY 2003, funding will support continued production of detector hardware and electronics and the installation of U.S.-supplied equipment at CERN. Production of the transition radiation tracker mechanics will be completed and the production of the inner tracker will continue. The delivery to CERN of monitored drift tubes chambers and various components of the liquid argon calorimeter will continue. The last tile calorimeter components will be shipped to CERN. Fabrication of the detector trigger and data acquisition system will begin. Funding is increased by $6,909,000 to support peak production rates for detector components. Funding will ramp down in subsequent years.

| | | | |
|---|---|---|---|
| ▪ **CMS Detector** | **17,152** | **17,190** | **20,484** |

In FY 2003, 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 will continue at CERN in parallel with the production of final electronics and readout boxes. Endcap muon chambers will be delivered to CERN, production of electronics for the electromagnetic calorimeter and the mechanics for the inner tracker will continue. Final tests of prototype hardware for the trigger will be completed. Funding is increased by $3,294,000 to support peak production rates for detector components. Funding will ramp down in subsequent years.

| | | | |
|---|---|---|---|
| **SBIR/STTR** | **0** | **12,918** | **6,797** |

In FY 2001, $14,409,000 was transferred to the SBIR program and $865,000 was transferred to the STTR program. This section includes $12,918,000 in FY 2002 and $6,797,000 in FY 2003 for the SBIR program. The balance of the SBIR and the STTR allocations are included in the Research and Technology subprogram.

| | | | |
|---|---|---|---|
| **Total, High Energy Physics Facilities** | **422,945** | **457,545** | **446,352** |

## Explanation of Funding Changes from FY 2002 to FY 2003

| | FY 2003 vs. FY 2002 ($000) |
|---|---|
| ▪ **Fermilab** | |
| ▸ A decrease of $3,473,000 in Operations results primarily from completion of site preparation for MINOS at the Soudan site | -3,473 |
| ▸ Increases in Capital Equipment totaling $8,080,000 for the two detector upgrade projects, and an increase of $4,000,000 for additional computer hardware needed to take advantage of major scientific opportunities | +12,080 |
| ▸ A decrease of $9,785,000 for MINOS consistent with revised project profile and the NuMI construction schedule, and a decrease of $3,155,000 in other laboratory equipment. This decrease is partially offset by an increase of $8,693,000 for NuMI construction shown in the Construction section. | -12,940 |
| ▸ Accelerator Improvement Project (AIP) funding is reduced by $500,000 related to the planned upgrade. AIP funding for other projects is reduced by $660,000 | -1,160 |
| Total, Fermilab | -5,493 |
| ▪ **Stanford Linear Accelerator Center** | |
| ▸ A decrease of $3,615,000 in Operations. This primarily reflects funds shifted to AIP in order to obtain of a better balance between operation of the B-factory and support for the high priority program of upgrading the machine and detector. | -3,615 |
| ▸ An increase of $2,275,000 consisting almost entirely of an increase in AIP funding related to planned luminosity increases | +2,275 |
| Total, Stanford Linear Accelerator Center | -1,340 |
| ▪ **Brookhaven National Laboratory** | |
| ▸ At BNL, a decrease of $5,725,000 reflecting termination of the AGS for HEP research. | -5,725 |
| Total, Brookhaven National Laboratory | -5,725 |

| | FY 2003 vs. FY 2002 ($000) |
|---|---|
| ▪ **Other Support** | |
| ▸ The landlord funding at LBNL (GPP and GPE) is increased by $311,000. Funding held in reserve for the SciDAC program is increased by $135,000. The funding to establish a data handling system for the LHC data is increased by $2,040,000. Funding for pre-operations of the LHC detectors is increased by $700,000. Other funding, including funds held in reserve pending completion of peer review and program office considerations, is decreased by $6,700,000. | -3,514 |
| ▪ **Large Hadron Collider** | |
| ▸ A increase of $11,000,000 reflecting the revised approved expenditure profile | +11,000 |
| ▪ **SBIR/STTR** | |
| ▸ A decrease of $6,121,000 in funding for SBIR. This reflects a shift in funding to Research and Technology for the SBIR program. | -6,121 |
| Total Funding Change, High Energy Physics Facilities | -11,193 |

The following table shows the details of the funding for the GLAST and MINOS projects.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2001 | FY 2002 | FY 2003 |
| GLAST (SLAC Capital Equipment) | 5,192 | 8,080 | 8,910 |
| GLAST (University Capital Equipment) | 497 | 0 | 0 |
| Total | 5,689 | 8,080 | 8,910 |
| MINOS | | | |
| Operating | 3,000 | 3,725 | 224 |
| Capital Equipment | 11,974 | 15,275 | 5,490 |
| Total | 14,974 | 19,000 | 5,714 |

# Construction

## Mission Supporting Goals and Objectives

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

## Funding Schedule

(dollars in thousands)

| | FY 2001 | FY 2002 | FY 2003 | $ Change | % Change |
|---|---|---|---|---|---|
| Neutrinos at the Main Injector | 22,949 | 11,400 | 20,093 | +8,693 | +76.3% |
| Wilson Hall Safety Improvement Project | 4,191 | 0 | 0 | 0 | -- |
| SLAC Research Office Building | 5,189 | 0 | 0 | 0 | -- |
| Total, Construction | 32,329 | 11,400 | 20,093 | +8,693 | +76.3% |

## Detailed Program Justification

(dollars in thousands)

| | FY 2001 | FY 2002 | FY 2003 |
|---|---|---|---|
| ▪ **Neutrinos at the Main Injector (NuMI)** | **22,949** | **11,400** | **20,093** |

This project provides for the construction of new facilities at Fermilab and at the Soudan Underground Laboratory in Soudan, Minnesota that are specially designed for the study of the properties of the neutrino and in particular to search for neutrino oscillations. The FY 2003 funding is for construction and installation of the neutrino beam line in the underground tunnel, and for construction of the surface buildings at Fermilab.

The project has encountered serious problems in several areas resulting in an increase of $33,093,000 in the project TEC and a schedule slip of two years. Due to a tight market for civil construction, the cost for excavating tunnels and halls at the Fermi National Accelerator Laboratory (Fermilab) is considerably higher than the initial estimate. Rebidding this subcontract to reduce its cost entailed a significant delay, as has the subsequent performance of the work. The contractor boring the tunnel for the neutrino production beam has encountered problems with the startup of the tunnel boring machine. This has led to a significant delay. Treatment and disposal of the ground water flowing into the tunnel is requiring significant effort. The experiment requires an extremely high intensity proton beam to produce an adequate number of neutrinos. The shielding required to suppress the secondary radioactivity has turned out to be significantly more extensive than originally planned, and the radiation levels near the target station will require a significant remote handling capability for routine operation and maintenance.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2001 | FY 2002 | FY 2003 |

The MINOS detector for NuMI, funded as part of the Other Project Costs, is proceeding well, and completion is expected within the revised projected cost and schedule.

Because of these developments, the project costs have risen. The TPC is increased to $171,442,000 from the previously approved $139,390,000, and the TEC is increased to $109,242,000 from the previously approved $76,149,000. The completion is delayed by about two years to the end of FY 2005. **Performance will be measured** by accomplishment of scheduled milestones as detailed in the revised benchmark plan.

| | | | |
|---|---|---|---|
| ▪ **Wilson Hall Safety Improvement Project (Fermilab)**..... | **4,191** | **0** | **0** |

This project provides for urgently needed rehabilitation of the main structural elements of Wilson Hall, and for urgently needed rehabilitation of windows, plumbing, the roof and the exterior of the building. Funding was completed in FY 2001 and the project is on schedule for completion in FY 2002. **Performance will be measured** by the total cost at completion and by the completion date.

| | | | |
|---|---|---|---|
| ▪ **SLAC Research Office Building** ..... | **5,189** | **0** | **0** |

This project provides urgently needed office space for the substantial expansion of visiting scientists, or "users," resulting from the B-factory becoming operational. The visiting user population is projected to increase from 200 visitors per year to 1,100 visitors per year. The new building will provide about 30,000 square feet and is on schedule for completion at the end of FY 2001. **Performance will be measured** by the total cost at completion and by the completion date.

| | | | |
|---|---|---|---|
| **Total, Construction**..... | **32,329** | **11,400** | **20,093** |

## Explanation of Funding Changes from FY 2002 to FY 2003

| | FY 2003 vs. FY 2002 ($000) |
|---|---|
| ▪ **Neutrinos at the Main Injector (NuMI)** | |
| ▸ Provides for completion of the Fermilab NuMI project on the revised profile. Reflects the increased project TEC described above. ..... | +8,693 |
| Total Funding Change, Construction ..... | +8,693 |

# Capital Operating Expenses & Construction Summary

## Capital Operating Expenses

(dollars in thousands)

| | FY 2001 | FY 2002 | FY 2003 | $ Change | % Change |
|---|---|---|---|---|---|
| General Plant Projects | 10,292 | 12,042 | 12,500 | +458 | +3.8% |
| Accelerator Improvements Projects | 11,069 | 17,660 | 18,790 | +1,130 | +6.4% |
| Capital Equipment | 83,383 | 84,476 | 83,831 | -645 | -0.8% |
| Total, Capital Operating Expenses | 104,744 | 114,178 | 115,121 | +943 | +0.8% |

## Construction Projects

(dollars in thousands)

| | Total Estimated Cost (TEC) | Prior Year Approp-riations | FY 2001 | FY 2002 | FY 2003 | Unapprop-riated Balance |
|---|---|---|---|---|---|---|
| 98-G-304 Neutrinos at the Main Injector | 109,242 | 41,800 | 22,949 | 11,400 | 20,093 | 13,000 |
| 99-G-306 Wilson Hall Safety Improvements | 15,591 | 11,400 | 4,191 | 0 | 0 | 0 |
| 00-G-307 SLAC Research Office Building | 7,189 | 2,000 | 5,189 | 0 | 0 | 0 |
| Total, Construction | | 55,200 | 32,329 | 11,400 | 20,093 | 13,000 |

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

(dollars in thousands)

| | Total Estimated Cost (TEC) | Prior Year Approp-riations | FY 2001 | FY 2002 | FY 2003 Request | Accept-ance Date |
|---|---|---|---|---|---|---|
| D-Zero Upgrade | 61,208 | 56,912 | 4,296 | 0 | 0 | FY 2001 |
| Large Hadron Collider — Machine | 85,972 | 46,438 | 18,068 | 8,196 | 6,850 | FY 2005 |
| Large Hadron Collider — ATLAS Detector | 56,113 | 21,200 | 5,556 | 6,913 | 10,134 | FY 2005 |
| Large Hadron Collider — CMS Detector | 65,057 | 35,538 | 6,367 | 6,000 | 8,002 | FY 2005 |
| MINOS[a] | 44,510 | 9,271 | 11,974 | 15,275 | 5,490 | FY 2005 |
| GLAST [b] | 35,000 | 3,000 | 5,689 | 8,080 | 8,910 | FY 2005 |
| Cryogenic Dark Matter Search (CDMS) | 8,600 | 800 | 1,798 | 1,050 | 1,050 | FY 2007 |
| Auger | 3,000 | 0 | 0 | 1,140 | 1,140 | FY 2004 |
| Alpha Magnetic Spectrometer (AMS) Upgrade [c] | 4,756 | 1,000 | 1,228 | 1,778 | 750 | FY 2003 |
| D-Zero Silicon Tracker Replacement[d] | 15,000 | 0 | 0 | 3,460 | 7,500 | FY 2005 |
| CDF Silicon Tracker Replacement[d] | 15,000 | 0 | 0 | 3,460 | 7,500 | FY 2005 |
| Total, Major Items of Equipment | | 174,159 | 54,976 | 55,352 | 57,326 | |

[a] Reflects recently approved baseline revision.

[b] Total estimated cost is subject to further negotiations with NASA and potential foreign collaborators.

[c] A change in the assignment of responsibilities within the international AMS collaboration has been agreed to by DOE. This results in an expanded scope for the U.S. portion of AMS and an increase of $1,728,000 in the TEC of the DOE portion of the project.

[d] These upgrade projects are only in an advanced planning stage. Thus changes to the TEC and the profile may be needed.