# 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. The mission has been consistently affirmed by the science community in long range planning efforts sponsored by the High Energy Physics Advisory Panel (HEPAP). The program supports one of the four business lines of the Department of Energy Strategic Plan: *Science*, and two goals of the Office of Science Strategic Plan: *Explore Matter and Energy* and *Provide Extraordinary Tools for Extraordinary Science*.

### Unique Opportunities for World Leadership

Within the framework of a constant budget request for FY 2002, the U.S. High Energy Physics program is being realigned to take advantage of unique opportunities for history-making discoveries that have developed in the past year. The Large Electron-Positron Collider (LEP) experimental program at CERN was terminated in November 2000, leaving behind a tantalizing hint of a *Higgs boson* with a mass of about 115 GeV, well within reach of the Tevatron. The field transmitted by the Higgs boson is believed to be the source of all mass, and its discovery would be a major advance in physics. The Large Hadron Collider (LHC) now being constructed in the LEP tunnel at CERN will be a strong contender to find the Higgs, but cannot begin its active physics program before the spring of 2006. Thus the Tevatron at Fermilab, just upgraded with its new Main Injector, 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 will be at the world's energy frontier during this period. In order to find the Higgs in a few years, the Tevatron will need to run extensively and to increase its luminosity (and thus its data rate) as much as possible. To do this will require progressive fine-tuning of collider operations as well as further equipment upgrades to increase luminosity by a factor of ten. It will require a program of improvements to be carried out from 2002 to 2004, interleaved with intensive data runs. The data taken in 2005-2007 would then 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 (170 times the mass of the proton) *top quark* discovered there in 1995, and could reveal other important new particles that have been predicted by current theories (for example, *supersymmetric* particles).

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 an asymmetry known as *Charge-Parity (CP) violation* in B-mesons, which 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 in FY 2002 and beyond. Therefore, the FY 2002 budget focuses on the utilization and upgrades of these facilities to maximize the discovery potential with lower priority being given to other parts of the program. The distribution of resources as specified in this budget reflects 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 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. Because of the potential importance of the g-2 experiment, its running time will be extended in 2002.

A long baseline neutrino detection experiment called MINOS (the Main Injector Neutrino Oscillation Search) is currently being fabricated at Fermilab, and the NuMI project (Neutrinos at the Main Injector) will provide a dedicated beam of neutrinos for MINOS. With NuMI/MINOS, Fermilab will have the opportunity to confirm 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 about 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*, all of which were discovered at DOE HEP laboratories. 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*, and they were 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.

These discoveries give us a new vision of the basic structure of matter that may be compared to the discovery of the atomic nucleus in the early twentieth century. It is encompassed within 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 combine and interact with each other. 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.

A major role in establishing the Standard Model is one of the proudest accomplishments of the DOE and its predecessor agencies. An American theoretical physicist supported by DOE took the lead in proposing that protons and neutrons must be made of smaller constituents, which he called quarks. American physicists, many of them working at DOE accelerator facilities, discovered all of the quarks and all but one of the leptons (the electron, known since 1897).

**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.

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? 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 processes. It also predicts new phenomena in ways that can be tested experimentally. Experimental work explores for new phenomena in promising areas 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 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. DOE scientists also use the Alternating Gradient Synchrotron (AGS) proton synchrotron at BNL (operated for the DOE Nuclear Physics program), the 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 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 has long supported an extensive program in technology research. This activity is a large annual investment, and it is fair to ask why is such a continuing investment necessary and given such high priority?

High-energy physics works with particle energies higher than exist anywhere but in certain stellar or cosmological environments and studies phenomenon on distance scales that are incomprehensibly small, much smaller than is required of any other science, except possibly nuclear physics. To make precision measurements of phenomenon buried in a background of noise and to search for very rare processes that may signal new physics, demands particle beams of greater 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. Thus the science demands 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. An unavoidable consequence is the essential need to accumulate, store, process, and transmit the increasingly large data sets produced by modern experiments. As international collaborations in high energy physics grow from the roughly 500 physicists presently working at each CERN, Fermilab, and SLAC detector to the approximately 1800 in each of the collaborations preparing detectors for the LHC, the need for data handling at widely separated data centers will become even more crucial.

The unavoidable consequence of operating in these extreme domains is the technological complexity, sophistication and size of the equipment used and the time and expense to design, build, maintain, operate, and upgrade the research apparatus. The R&D to conceive of a new accelerator or colliding beam device now requires 10 to 20 years of intensive work to bring the technology to the point of confidently proposing a new and cost effective construction, and the detectors and related computing needs have similar R&D needs. The R&D programs to sustain a forefront science program are unavoidably big, costly, and long term. Since almost none of the core technologies for these devices are marketable, particularly as systems, industry has no motivation to research, develop, or manufacture the key technical items, except as (usually expensive) special procurements. Consequently, in order to survive and to advance the science, it is essential for the universities and national laboratories engaged in high energy physics to themselves explore the scientific frontiers and cutting edge technologies that can generate the high energies, resolve the very small, make the measurements and analyze the results. Cutting edge science requires cutting technologies, and these require time and expense to produce and to make work effectively.

### 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 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, and environmental 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. The World Wide Web was invented by high-energy physicists to transport large bodies of data among international collaborators and is now bringing 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 set of talented people, trained in scientific methods and in state-of-the-art technologies. 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 may be needed in 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 that would collide 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 a muon collider is the short lifetime of the muon (two microseconds), which demands very rapid production, acceleration, and colliding 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 is being investigated. Physicists are investigating the possibility of a storage ring that could serve as a muon collider and/or a neutrino factory.

In spite of the more complicated interactions of its “bags of quarks,” at 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 hadron collider. Such a facility would have collision energy of perhaps 100 TeV, much higher than that of the LHC.

## Program Goals

- Take advantage of unique opportunities for history-making discoveries.
- Advance our understanding of matter and energy at the most fundamental level, identifying the basic constituents of matter and characterizing their interactions.
- Advance our understanding of the origin and fate of the universe, from the Big Bang to the present time and beyond.
- Base programmatic decisions on the excellence of the science, the relevance to our national needs, and our ability to be among the leaders in international research in high-energy physics.

Regular peer review is used to evaluate research grants (primarily at universities). Program advisory committees advise DOE laboratories on the general direction of their accelerator research programs and review specific proposals for experiments. Overall **performance of the HEP program is measured by** the quality of scientific results as recognized by the scientific community and the productivity and utilization of research facilities.

## Program Objectives

### General Objectives

*Theoretical research* – Subject new experimental findings to thorough analysis and interpretation. Synthesize new and existing results into an overall coherent view of nature, developing new analytical structures as necessary. Identify key questions to be resolved by experiment.

*Experimental research* – Put our theoretical understanding of elementary particles and forces to rigorous experimental tests. Search for any new particles or interactions that may exist. Investigate astrophysical phenomena, using the knowledge and techniques of high-energy physics.

*Accelerator facilities* – Build new facilities in the United States as required to advance physics or take a substantial role in building facilities if the scope demands an international effort.

*Preparation for future research* – Progress in high-energy physics requires an ever-increasing experimental capability. Accelerator beams must increase in energy, intensity, and quality; detectors must improve in scope, resolution, and data recording rates, and in the ability to selectively identify events of interest. These preparations include modifications to existing accelerators and detectors, R&D aimed at possible new technologies, and the application of existing technologies to improve beams and detectors. Improvements are needed in the ability to store, transfer, and analyze increasing amounts of data. International collaborations must share access to these huge data sets.

### Objectives for FY 2002

The main activities of the research component of the FY 2002 HEP Program are summarized below:

- Research using the Collider Detector Facility (CDF) and D-Zero at the Tevatron at Fermilab. A major upgrade of the CDF and D-Zero detectors was completed and brought into operation in FY 2001, providing significantly improved performance with the higher particle production rates available from the improved Tevatron, and improved precision in particle detection. The Tevatron is expected to operate for about 39 weeks in FY 2002, the first full year of operation after the upgrade.

  Search for the Higgs boson. The Higgs plays a key role in explaining the origin of mass.

  Study of the details of Quantum Chromodynamics (QCD), that is one basis of the Standard Model.

  A study of B-meson decays providing information complementary to that being obtained at the B-factory. The B-meson is one of only two particles, which exhibit CP violation.

  Precise measurements of masses and interactions of the W and Z bosons, that will set tighter bounds on the mass of the Standard Model Higgs boson.

- Research using the BaBar detector at the B-factory at SLAC. The B-factory is expected to operate for about 35 weeks in FY 2002.

  Study of the details of CP violation in B-meson decays. The B-meson is one of only two particles that exhibit CP violation. The B-factory was designed as the copious source of B-mesons needed for this research and has performed beyond expectations.

  Study of hadrons made only of combinations of the bottom quark and its antiquark (bottomonium spectroscopy).

Study of B-meson decays with a focus on very rare decay modes.

- Research using the AGS at BNL. The AGS is expected to operate for about 16 weeks for HEP research in FY 2002.

  Search for a very rare decay of the K meson. This experiment uses the K meson system to look for indications of physics beyond the Standard Model.

  Additional data taking for a precise measurement of the anomalous magnetic moment of the muon using the g-2 storage ring to pursue its early indications of physics beyond the Standard Model. In FY 2001, this experiment produced possible evidence for a significant deviation from the predictions of the Standard Model.

  A program of theoretical research at many of the universities and all of the major HEP laboratories.

- Other Research.

  Research at Super Kamiokande, in Japan, to study neutrino oscillations.

  Preliminary operation of the Cold Dark Matter Search (CDMS) an experiment designed to search for the dark matter, that apparently pervades the universe. CDMS is being constructed underground at a site in Minnesota.

  Operation of Phase I of the Pierre Auger experiment to study cosmic radiation at the highest energies. The Auger detector array is being constructed by an international collaboration at a site in Argentina.

  Experiments using the Cornell Electron Storage Ring, various international facilities with special capabilities, and a number of experiments, that do not use accelerators.

The main activities of the preparation-for-future-research component of the FY 2002 HEP program are summarized below:

- Continuation of the NuMI construction project at Fermilab that will provide a world-class facility to study neutrino properties and to make crucial measurements of neutrino mass.
- Continuation of U.S. participation in the LHC project at CERN. The HEP program is fabricating specific portions of the accelerator and of the two large detectors, ATLAS and CMS. It is also working to develop the computing and data management infrastructure in the United States that is the key to participation by U.S. scientists in obtaining physics results from the LHC experimental program. When the physics program begins in 2006, the LHC will be the world's energy frontier accelerator, and U.S. participation in its research program will become an integral part of the U.S. high-energy physics program.
- Technology R&D on new and improved magnets and accelerating devices, on needed improvements and enhancements of existing facilities, on possible future machine concepts, and on innovative, high risk possible new technologies. As always, the emphasis is on improved performance and reduced cost. R&D leading to improved performance of the facilities at Fermilab and SLAC is particularly important for the extraction of world-class physics results in a timely manner. While Technology R&D is sometimes focused on a particular possible future facility or facility upgrade, the results usually have wider application.
- Continued support for the fabrication of the CDMS, AMS and GLAST experiments, and R&D leading toward the SNAP project.

### Funding Priorities

This program described above results in the following funding priorities which are designed to take advantage of the opportunity to discover the Higgs, search for physics beyond the Standard Model, and confirm and characterize neutrino oscillations and neutrino mass:

- Strong support for the operation and upgrades of the facilities at Fermilab – CDF, D-Zero and the Tevatron, as well as the supporting computing facilities.
- Strong support for the operation and upgrades of the BaBar detector, the linac, and B-factory at SLAC, as well as the supporting computing facilities.
- Support for accelerator R&D.
- Support for university and laboratory based physics research activities (both theory and experiment). The several experimental programs discussed above all are being performed by large collaborations of university (primarily) and laboratory based scientists. These scientists provide the effort needed to operate and maintain the detectors and to analyze the resulting data.
- Support for the continuation of the LHC fabrication activities as planned, and planning and preparation for the U.S. participation in the LHC research program.
- Continuation of the NuMI/MINOS construction project at Fermilab.
- Support for the operation of the AGS at BNL to conduct HEP experiments.

### Evaluation of Objectives

The overall quality of the research in the High Energy Physics (HEP) Program will be judged excellent and relevant by external evaluation by peers, and through various forms of external recognition.

Leadership in key HEP disciplines that are critical to DOE's mission and the Nation will be measured through external review and other mechanisms.

At least 80% of all new research projects supported by HEP will be peer reviewed and competitively selected, and will undergo regular peer review merit evaluation.

Upgrades and construction of HEP scientific facilities will be managed to keep within 10 percent on average of schedule and cost milestones, including the U.S./DOE commitments to the international Large Hadron Collider project as reflected in the latest international agreement and corresponding plan.

HEP will ensure that operational downtime of the facilities it manages will be, on average, less than 10 percent of total scheduled operating days, barring unforeseen circumstances.

HEP will ensure the safety and health of the workforce and members of the public and the protection of the environment in all its program activities.

## Significant Accomplishments and Program Shifts

Research and Technology

SCIENCE ACCOMPLISHMENTS

The following were accomplished in FY 2000:

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.

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. In FY 2002, the data analysis should be well advanced. Discovery and study of the Higgs boson, believed to be the source of mass for all elementary particles (and hence, of all matter) is a major objective of the LHC.

At a 2000 conference in Osaka, Japan, physicists using the new BaBar detector at the new SLAC B-factory announced their first 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 measurement from CDF at the Fermilab Tevatron. They are also consistent with the current Standard Model description of CP violation. More data are needed to make an incisive measurement that will confirm or refute the Standard Model. BaBar has collected much more data since the summer of 2000 and has recently announced new results which are very interesting but not conclusive. Data collection continues with high priority.

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 agree with the standard model, suggesting new physics beyond the standard model. The measurement precision should improve by perhaps a factor of 2 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.

Teams of university and laboratory scientists using the CDF and D-Zero detectors at the Fermilab Tevatron measured the mass and production properties of the top quark. This is the last and by far the heaviest of the quarks (fundamental building blocks of matter) predicted by the Standard Model. The mass of the top quark is now measured more accurately than that of any other quark. Further refinements of this result are continuing and will improve even more with data from the upcoming run of the Tevatron with the newly upgraded Main Injector.

Two physicists shared the Nobel Prize for Physics for 1999, for theoretical work that helped establish the Standard Model. One of the two was long supported by DOE as a physics professor at the University of Michigan.

A team of university and laboratory scientists working at the Fermilab Tevatron made the world's most precise measurement of the mass of the W boson, which transmits the weak interaction, one of the basic forces. This result is now considerably more precise than the best measurement from the

LEP facility at CERN. It will improve even more with data from the upcoming run of the Tevatron with the newly upgraded Main Injector.

The world's highest precision single measurement of the weak mixing angle, a fundamental parameter of the Standard Model, was made by a group of university and laboratory scientists working at the SLAC Linear Collider (SLC) with the Stanford Large Detector (SLD). The ability to longitudinally polarize the electron beams (align their spins along their flight paths) in a linear collider was the key to achieving high precision. The final result from the final data run has now been obtained.

The B meson containing a charmed quark was observed and its properties measured by the international CDF collaboration working at Fermilab. This discovery completes the observations of the predicted family of B mesons, lending support to the Standard Model.

The first convincing observation of direct CP violation in the fundamental Standard Model interaction was found in decays of K mesons by a team of university and laboratory scientists working on the KTeV experiment at the Fermilab Tevatron. Additional data is being analyzed to refine this key result and to compare it with a new measurement at CERN.

The observation of the predicted CP-violating decay of the kaon into a pair of pions and an electron-positron pair was made for the first time ever by the KTeV collaboration at Fermilab. This decay could be an indication of another fundamental asymmetry, violation of time reversal invariance. Further refinement of this result was achieved.

U.S. university groups involved in the new HERA-B experiment at the DESY machine in Germany began their first data collection run with the newly upgraded detector in FY 2000.

Observations of the gamma ray flare from Hercules X-1 as recorded at the Whipple Observatory on Mt. Hopkins in Arizona has provided data which puts a new upper limit on quantum gravity effects.

A major advance in theoretical physics was achieved when it was shown and verified that all of the known "string" theories are equivalent. This greatly reduces the number of possible theories that could describe all of the known forces including gravity (which is not described by the Standard Model). Further work toward delineating the underlying theory from which all string theories originate is continuing at a fast pace.

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 highly speculative program that may have a potential of eventually approaching accelerating gradients of 10's of GeV per meter.

Evidence of neutrino mass and quantum mixing of neutrino types was obtained in a U.S.-Japanese experiment with the Super-Kamiokande experiment in Japan. Further data and refinement of these results was achieved. Long-baseline neutrino beam experiments in Japan and at Fermilab are underway to verify the results.

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.

Facility Operations

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 2002 will be a 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 design luminosity. During FY 2002, 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 is performing very well in FY 2001, collecting data at a high rate.

The Alternating Gradient Synchrotron at BNL is operated by the Nuclear Physics program as part of the Relativistic Heavy Ion Collider (RHIC) facility but is available for use by the High Energy Physics program on an incremental cost and programmatic non-interference basis. The high precision muon magnetic moment experiment (the "g-2" experiment) at the AGS reported its first results in FY 2001, obtaining a record level of precision and indicating the possibility of new physics phenomena. In FY 2002, the AGS will be operated for the g-2 experiment and for a high priority rare kaon decay experiment.

The newly upgraded CLEO-III detector at the upgraded CESR facility at Cornell began operation in FY 2000 and is performing very well in FY 2001. DOE supports more than half the university groups using this new facility.

PROGRAM SHIFTS

Research with the CDF and D-Zero detectors at the Tevatron and the BaBar detector at the B-factory will receive greater 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. 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 by the end of 2001.

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.

## Scientific Facilities Utilization

The High Energy Physics request includes $495,506,000 to maintain support of the Department's scientific user facilities. This investment will provide significant research time for several thousand scientists in 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). The Alternating Gradient Synchrotron (AGS) at the Brookhaven National Laboratory (BNL), is now part of the Nuclear Physics (NP) funded Relativistic Heavy Ion Collider (RHIC) complex and is being operated for HEP purposes on a limited basis.

## 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 1250 post-doctoral associates and graduate students supported by the High Energy Physics program in FY 2001 were involved in a large variety of experimental and theoretical research. 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 2000 Comparable Appropriation | FY 2001 Original Appropriation | FY 2001 Adjustments | FY 2001 Comparable Current Appropriation | FY 2002 Request |
|---|---|---|---|---|---|
| High Energy Physics | | | | | |
| Research and Technology | 236,028 | 234,720 | +8,116 [a] | 242,836 | 247,870 |
| High Energy Physics Facilities | 418,322 | 459,010 | -22,174 [a] | 436,836 | 456,830 |
| Subtotal, High Energy Physics | 654,350 | 693,730 | -14,058 | 679,672 | 704,700 |
| Construction | 28,700 | 32,400 | -71 | 32,329 | 11,400 |
| Subtotal, High Energy Physics | 683,050 [b] | 726,130 | -14,129 | 712,001 | 716,100 |
| General Reduction | 0 | -7,101 | 7,101 | 0 | 0 |
| General Reduction for Safeguards and Security | 0 | -5,458 | 5,458 | 0 | 0 |
| Omnibus Rescission | 0 | -1,570 | 1,570 | 0 | 0 |
| Subtotal, High Energy Physics | 683,050 [c] [d] | 712,001 | 0 | 712,001 | 716,100 |
| Pending Budget Amendment | 0 | 0 | 0 | 0 | 5,000 [e] |
| Total, High Energy Physics | 683,050 | 712,001 | 0 | 712,001 | 721,100 |

**Public Law Authorization:**

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

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

[a] Includes $12,969,000 transferred from High Energy Physics Facilities to Research and Technology in FY 2002 to realign capital equipment funding.

[b] Excludes $13,797,000 which has been transferred to the SBIR program and $828,000 which has been transferred to the STTR program.

[c] Includes $5,180,000 for Waste Management activities at Lawrence Berkeley National Laboratory that were transferred from the Office of Environmental Management in FY 2001.

[d] Excludes $5,248,000 for Safeguard and Security activities transferred to consolidated Safeguards and Security program in FY 2001.

[e] A Budget Amendment transferring $5,000,000 from this program will be submitted shortly. The narrative description for this program has already been adjusted to reflect the revised levels.

## Funding by Site

| (dollars in thousands) | FY 2000 | FY 2001 | FY 2002 | $ Change | % Change |
|---|---|---|---|---|---|
| Albuquerque Operations Office | | | | | |
| Los Alamos National Laboratory .......... | 1,375 | 711 | 661 | -50 | -7.0% |
| Sandia National Laboratory ................. | 0 | 4 | 0 | -4 | -100.0% |
| Albuquerque Operations Office........... | 13 | 0 | 0 | 0 | 0.0% |
| Total, Albuquerque Operations Office ......... | 1,388 | 715 | 661 | -54 | -7.6% |
| Chicago Operations Office | | | | | |
| Argonne National Laboratory ............... | 10,828 | 8,858 | 9,990 | +1,132 | +12.8% |
| Brookhaven National Laboratory.......... | 38,778 | 26,507 | 32,595 | +6,088 | +23.0% |
| Fermi National Accelerator Laboratory . | 294,627 | 289,507 | 314,878 | +25,371 | +8.8% |
| Princeton Plasma Physics Laboratory .. | 157 | 394 | 364 | -30 | -7.6% |
| Chicago Operations Office.................. | 89,067 | 85,107 | 72,566 | -12,541 | -14.7% |
| Total, Chicago Operations Office................ | 433,457 | 410,373 | 430,393 | +20,020 | +4.9% |
| Oakland Operations Office | | | | | |
| Lawrence Berkeley National Laboratory | 45,376 | 37,782 | 35,170 | -2,612 | -6.9% |
| Lawrence Livermore National Laboratory | 1,185 | 1,425 | 1,357 | -68 | -4.8% |
| Stanford Linear Accelerator Center ...... | 152,858 | 158,681 | 164,343 | +5,662 | +3.6% |
| Oakland Operations Office .................. | 38,713 | 37,788 | 34,804 | -2,984 | -7.9% |
| Total, Oakland Operations Office ............... | 238,132 | 235,676 | 235,674 | -2 | 0.0% |
| Oak Ridge Operations Office | | | | | |
| Oak Ridge Inst. for Science & Education | 186 | 130 | 130 | 0 | 0.0% |
| Oak Ridge National Laboratory ........... | 536 | 327 | 307 | -20 | -6.1% |
| Thomas Jefferson National Accelerator Facility............................. | 90 | 5 | 5 | 0 | 0.0% |
| Oak Ridge Operations Office ............... | 27 | 15 | 0 | -15 | -100.0% |
| Total, Oak Ridge Operations Office ............ | 839 | 477 | 442 | -35 | -7.3% |
| Washington Headquarters ......................... | 9,234 | 64,760 | 48,930 | -15,830 | -24.4% |
| Subtotal, High Energy Physics.................. | 683,050[abc] | 712,001 | 716,100 | +4,099 | +0.6% |
| Pending Budget Amendment ..................... | 0 | 0 | 5,000 [d] | +5,000 | -- |
| Total, High Energy Physics........................ | 683,050 | 712,001 | 721,100 | +9,099 | +1.3% |

[a] Excludes $13,797,000 that has been transferred to the SBIR program and $828,000 that has been transferred to the STTR program.

[b] Includes $5,180,000 for Waste Management activities at Lawrence Berkeley National Laboratory that were transferred from the Office of Environmental Management in FY 2001.

[c] Excludes $5,248,000 for Safeguards and Security activities transferred to the consolidated Safeguards and Security program in FY 2001.

[d] A Budget Amendment transferring $5,000,000 from this program will be submitted shortly. The narrative description for this program has already been adjusted to reflect the revised levels.

# 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 accelerator R&D techniques and participation in the CDF and MINOS detector collaborations.

## 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 also makes limited use of the Alternating Gradient Synchrotron (AGS), a 28 GeV proton accelerator, which is principally supported by the Nuclear Physics program. The AGS is used for high-energy physics experiments that need its unique high quality and high intensity beams of secondary particles such as pions, kaons, and muons.

## 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). Thus 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. Thus Fermilab has an excellent window of opportunity for making important new scientific discoveries. 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 of participation in the BaBar collaboration, expertise in superconducting magnet R&D, world-forefront expertise in laser driven particle acceleration, and expertise in design of forefront electronic devices.

## 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 and participation in the B-factory effort.

## 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 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.

## 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 research effort using unique capabilities of PPPL 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. The High Energy Physics program supports an R&D effort aimed at computer modeling of accelerator behavior.

## 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. These university based components 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 funds research at a small number of non-DOE laboratories and non-government laboratories and institutes (National Institute for Standards and Technology, Naval Research Laboratory).

# Research and Technology

## Mission Supporting Goals and Objectives

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 2002 described below and planning the programs to be carried out in future years. **Performance will be measured by** the results of reviews of ongoing activities, by sustained achievement in advancing knowledge, as measured by the quality of the research based on results published in refereed scientific journals, and by the degree of invited participation at national and international conferences and workshops.

**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, ORNL, LANL, LBNL, LLNL, and SLAC, and about 100 colleges and universities.

The major planned Physics Research efforts in FY 2002 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.
- Planning and preparation for the U.S. portion of the research program of the LHC when it becomes operational in 2006. A major effort in FY 2002 will be the design and initial implementation of the U.S. data handling and computing capabilities needed for full participation in the LHC research program.
- The research program using the AGS at BNL. This research program is being carried out by a collaboration including scientists from BNL, Fermilab, one U.S. university and institutions in three foreign countries.
- A program of theoretical research at both universities and laboratories to identify questions for future research, and further the understanding of new experimental results.

- A group of experimental research activities using the Cornell Electron Storage Ring and various international facilities with special capabilities, and experimental activities, which do not require an accelerator beam.

**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 new accelerator and detector facilities presently under construction, and to extend the technology base so as to make possible and cost effective use of the new future facilities which will be needed to continue progress in the field.

The major planned High Energy Physics Technology efforts in FY 2002 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, SLAC and BNL for the AGS.

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 activity is R&D on high field superconducting accelerator magnets and new detection technologies.

Support for R&D related to a possible future muon collider or 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 (to large linear colliders) approach to research needing high-energy colliding beams of leptons. Moreover, the decay of the circulating muons can result in a well-collimated, intense beam of neutrinos, with additional interesting physics possibilities, such as searching for evidence of neutrino mass.

The fundamental problem with muon storage rings is that the muon has a finite lifetime measured in millionths of a second. Thus the production, capture, acceleration, storage, and collision of the muons must be done very rapidly. A key feasibility issue is the need to show experimentally that this production, capture, acceleration and storage can be done with sufficient speed and efficiency so as to provide usable beam intensity. The other key feasibility issue is that after the muons are stored in the ring, the beam must be focused and the beam size reduced so as to provide a useful muon-muon collision rate (this is known as “cooling”). R&D, and planning for appropriate experimental verification is underway aimed at both issues. The requirements 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. Fermilab is the lead laboratory for work related to the “cooling” issue, and BNL is the lead laboratory for work related to the “production” issue.

Support for Linear Collider R&D. Electrons (and muons) are simple point particles; protons (and antiprotons) are composite particles made up of three different quarks. In electron-positron collisions, the initial state is quite simple, and the collision receives all the available energy. In proton-antiproton collisions the initial state is more complex consisting of two sets of three quarks. Only one pair of quarks actually collide, and the energy transferred to the collision is only that portion of the total available which is carried by the two colliding quarks. (This fraction of the total energy varies from collision to collision significantly, complicating the experimental analyses.) In short, electron 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 energies, and that an electron complement to the LHC is needed.

The apparent research advantage for electron colliders is significantly offset by the difficulty in providing very high-energy electron collisions. In the 1 TeV energy regime, circular electron accelerators are impossible due to the enormous radiation losses from the stored beams. (The higher masses of protons or even muons completely avoid this limitation). The alternative is a linear arrangement in which beams from two linear accelerators are aimed at each other and produce electron-positron collisions. This approach was demonstrated to work 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) and the focus of the R&D effort has shifted toward cost reduction strategies.

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 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 2002, the R&D program led by Fermilab and SLAC will focus on reliably achieving accelerating gradients in radio frequency structures in the range of 75 to 100 MeV/meter. There will also be significant studies of design alternatives for electron-positron sources with a goal of higher performance (higher brightness) and much lower cost, and studies of designing for ease of manufacturability (i.e. lower cost) of subsystems and major components.

Support for future oriented, high risk R&D. Advances in HEP are strongly dependent upon the development of new, higher-performance research instruments. Probing ever more deeply into the structure of matter and energy requires particle accelerators, and detectors operating at higher and higher energies and intensities. 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 research looking for new approaches to these underlying technical needs. A further goal is to develop 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.

The range of topics explored in the HEP Technology 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 routinely reach up to about 10 Tesla. This 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.

The HEP Technology research is carried out at BNL, ANL, 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.

**Performance will be measured by** reporting accomplishments on the common performance measures on leadership, excellence and relevance; quality; and safety and health.

## Funding Schedule

(dollars in thousands)

| | FY 2000 | FY 2001 | FY 2002 | $ Change | % Change |
|---|---|---|---|---|---|
| Physics Research......................... | 161,706 | 156,386 | 155,140 | -1,246 | -0.8% |
| High Energy Physics Technology ... | 74,322 | 84,971 | 84,779 | -192 | -0.2% |
| SBIR/STTR ................................. | 0 | 1,479 | 7,951 | +6,472 | +437.6% |
| Total, Research and Technology .... | 236,028 | 242,836 | 247,870 | +5,034 | +2.1% |

## Detailed Program Justification

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2000 | FY 2001 | FY 2002 |
| **Physics Research** | **161,706** | **156,386** | **155,140** |

| | | | |
|---|---|---|---|
| Physics Research | | | |
| Universities | 105,266 | 101,307 | 96,637 |
| Fermilab | 8,756 | 8,980 | 10,747 |
| SLAC | 12,812 | 12,187 | 13,795 |
| BNL | 11,212 | 10,834 | 10,242 |
| LBNL | 14,178 | 14,556 | 13,743 |
| ANL | 6,652 | 6,483 | 6,125 |
| Other Physics Research | 2,830 | 2,039 | 3,851 |
| Total, Physics Research | 161,706 | 156,386 | 155,140 |

| | | | |
|---|---|---|---|
| **Universities** | **105,266** | **101,307** | **96,637** |

The University Program consists of 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 will be selected based on review by appropriate peers. The last 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.

The university program is reduced by about 4.6%. The funds are shifted to support the strong initiative to exploit the "window of opportunity" for exciting new physics results described in the introductory sections. To the extent possible, the reductions 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 at CDF, D-Zero, BaBar, etc., work on the design and fabrication of the LHC detector components, and work on the preparation for U.S. participation in the LHC research program.

These university based research activities are described in more detail below. The funding levels presented are estimates based on FY 2000 experience.

| | | | |
|---|---|---|---|
| **University Based Research at Fermilab** | **30,375** | **29,160** | **27,885** |

Some 55 DOE-funded universities participate in large international collaborations doing experiments at Fermilab. These experiments involve 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;

| | (dollars in thousands) | |
|---|---|---|
| FY 2000 | FY 2001 | FY 2002 |

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 diminishes and activities related to Tevatron, MINOS, and other new experiments increase.

| | FY 2000 | FY 2001 | FY 2002 |
|---|---|---|---|
| **University Based Research at SLAC** | **12,205** | **11,755** | **11,205** |

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. These experiments are investigating fundamental constituents of matter such as the b quark. 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.

| | FY 2000 | FY 2001 | FY 2002 |
|---|---|---|---|
| **University Based Research at BNL** | **2,685** | **2,585** | **2,465** |

Some 8 DOE-funded universities participate in collaborative experiments at BNL. These experiments involve 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.

| | FY 2000 | FY 2001 | FY 2002 |
|---|---|---|---|
| **University Based Research at Cornell** | **5,195** | **5,005** | **4,765** |

Some 11 university High Energy Physics groups with DOE funding participate in the electron-positron colliding beam experiments at Cornell's CESR facility utilizing the collaboratively built CLEO detector studying various aspects of b meson interactions and decay.

| | FY 2000 | FY 2001 | FY 2002 |
|---|---|---|---|
| **University Based Non Accelerator Research** | **10,960** | **10,555** | **10,060** |

Some 34 DOE-funded universities are involved in supporting the High Energy Physics experiments not utilizing accelerators. The principal experiments being supported in FY 2002 are:

- The Cryogenic Dark Matter Search (CDMS) and Pierre Auger projects that are currently being fabricated. A description of CDMS is under the Fermilab section and Auger is described under the Other Physics Research section.
- The first phase of the Alpha Magnetic Spectrometer (AMS) experiment is complete and the data are being 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 2002 funding is $1,000,000 and the TEC for the DOE portion of the AMS upgrade is $3,028,000.
- Other active experiments, which are primarily in the areas of high-energy astrophysics and cosmology, include MACRO (Italy), Super-Kamiokande (Japan), KamLAND (Japan), SNO (Canada), CHOOZ (France), SOUDAN (Minnesota), GRANITE (Mt. Hopkins, Arizona), Palo Verde (Arizona), GLAST and SNAP (satellite).

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2000 | FY 2001 | FY 2002 |
| **University Based Research at Foreign Labs** ................ | **20,405** | **19,660** | **18,735** |

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** ..................................... | **21,810** | **21,015** | **20,025** |

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** ............................................ | **1,631** | **1,572** | **1,497** |

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.

| | | | |
|---|---|---|---|
| **Fermilab**..................................................................... | **8,756** | **8,980** | **10,747** |

In FY 2002, 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 800 GeV fixed-target program and the FY 2001 collider run, fabrication 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 2002 funding is $1,060,000 and the TEC for CDMS is $8,600,000. Funding is increased substantially reflecting the importance of collecting and analyzing data from the Run II Campaign. **Performance will be measured by** capitalizing on the opportunities to discover the Higgs Boson, to search for physics not adequately described by the standard model, and to confirm and characterize neutrino oscillations and neutrino mass.

| | | | |
|---|---|---|---|
| **SLAC**......................................................................... | **12,812** | **12,187** | **13,795** |

The experimental physics research groups at SLAC will concentrate their efforts in FY 2002 on data taking and analysis of data from the BaBar detector operating with the PEP-II accelerator facility. This data will be used to study CP violation in B meson decays and to help explain the preponderance of matter over antimatter in the universe. They will also work on completing the analysis of the data from the operation of the SLD detector. Fabrication of the Gamma Large Area

| | (dollars in thousands) | |
|---|---|---|
| FY 2000 | FY 2001 | FY 2002 |

Space Telescope (GLAST) will be a significant effort in FY 2002 in preparation for the launch projected to be in FY 2005. 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. Funding is increased substantially to reflect the importance of having the scientific data collected and analyzed by the scientists.

| | FY 2000 | FY 2001 | FY 2002 |
|---|---|---|---|
| **BNL** ........................................................................................ | **11,212** | **10,834** | **10,242** |

In FY 2002, the BNL experimental physics research groups will be primarily working on the D-Zero experiment, which will be taking data at Fermilab, and overseeing the fabrication of the U.S. portion of the ATLAS detector for the LHC. Data collection for the precision measurement of the anomalous magnetic moment of the muon will be completed. An upgraded rare kaon decay experiment at the AGS facility will begin operation. Also includes funding for theoretical research.

Funding is decreased to support the strong initiative to exploit the "window of opportunity" for exciting new physics results described in the introductory sections. This will significantly impact the viability and productivity of the BNL physics research groups.

| | FY 2000 | FY 2001 | FY 2002 |
|---|---|---|---|
| **LBNL** ...................................................................................... | **14,178** | **14,556** | **13,743** |

In FY 2002, 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 PEP-II storage ring at SLAC; data-analysis on the HYPER-CP experiment at Fermilab will be underway; and fabrication of the ATLAS detector, primarily the silicon tracking system, for the LHC. The researchers will also be working on supernova measurements to establish values of cosmological parameters. Funding is included for the Particle Data Group at LBNL, which continues as an international clearinghouse for particle physics information.

Funding is decreased to support the strong initiative to exploit the "window of opportunity" for exciting new physics results described in the introductory sections. This will significantly impact the viability and productivity of the LBNL physics research groups.

| | FY 2000 | FY 2001 | FY 2002 |
|---|---|---|---|
| **ANL** ........................................................................................ | **6,652** | **6,483** | **6,125** |

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 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 decreased to support the strong initiative to exploit the "window of opportunity" for exciting new physics results described in the introductory sections. This will significantly impact the viability and productivity of the ANL physics research groups.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2000 | FY 2001 | FY 2002 |
| **Other Physics Research**........................................................ | **2,830** | **2,039** | **3,851** |

Includes $1,000,000 in FY 2002 for the Scientific Discovery through Advance Computing (SDAC) program. (Additional SDAC funding in the amount of $3,960,000 is included in the High Energy Physics Facilities Subprogram. In FY 2001, these funds were all in the High Energy Physics Facilities Subprogram). The principal objective of this program is to provide software tools which will reduce the effort needed to utilize very large scale computing resources in the solution of key scientific questions. The program includes the development of these software tools, and the application of these tools to high priority scientific questions. The funds will be allocated on the basis of a proposal and peer review process. Possible areas of application include precision, multiple turn orbit calculations for particle accelerators; numerical calculations on the details of particle substructure; development of systems for collecting, processing, storing and distribution for analysis of the very large data sets resulting from operation of the current generation of HEP and NP detectors; and astrophysical calculations.

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 planned FY 2002 funding is $1,150,000 and the TEC for the U.S. portion of this phase of Auger is $3,000,000.

Full and effective participation by U.S. scientists in the LHC research program (the LHC will begin operation in 2006) requires an effective way for the data recorded by the detectors at CERN to be available for analysis by 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 increased (+$980,000) funding for planning and R&D activities to continue implementing the U.S. based computing system to process, store and support the analysis of the large body of data anticipated when the LHC begins operation for physics in FY 2006. Additional funding is included in the High Energy Physics Technology activity (+$240,000). The total funding for LHC related computing in FY 2002 will be $2,720,000.

This category also includes funding for smaller labs, conferences, studies, and workshops, and funding for research activities that have not yet completed their peer review, which is reduced by $168,000.

| | FY 2000 | FY 2001 | FY 2002 |
|---|---|---|---|
| | (dollars in thousands) | | |
| **High Energy Physics Technology** | **74,322** | **84,971** | **84,779** |

| | FY 2000 | FY 2001 | FY 2002 |
|---|---|---|---|
| High Energy Physics Technology | | | |
| Fermilab | 16,084 | 24,421 | 24,300 |
| SLAC | 23,620 | 22,159 | 22,770 |
| BNL | 7,400 | 5,574 | 5,265 |
| LBNL | 11,737 | 11,343 | 10,595 |
| ANL | 2,389 | 2,203 | 2,075 |
| Universities | 10,028 | 9,568 | 8,680 |
| Other Technology R&D | 3,064 | 9,703 | 11,094 |
| Total, High Energy Physics Technology | 74,322 | 84,971 | 84,779 |

| | FY 2000 | FY 2001 | FY 2002 |
|---|---|---|---|
| **Fermilab** | **16,084** | **24,421** | **24,300** |
| **Accelerator R&D** | **9,618** | **19,259** | **18,100** |

The major focus of the Accelerator R&D program in FY 2002 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.

Other activities in FY 2002 include design of an electron cooling system to improve the quality of an antiproton beam processed through the recycler ring; R&D in support of the NuMI project; R&D on superconducting RF cavities for a separated kaon beam; R&D and engineering on and fabrication of 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 by a memorandum of understanding with SLAC. Funding will be at about the same level as FY 2001 ($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.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2000 | FY 2001 | FY 2002 |

Longer range R&D addresses the feasibility and design issues for muon colliders/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 collider context. Muon collider R&D is funded at about $900,000.

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 collider/neutrino source and, in the very far term, a possible 100 TeV proton collider.

The decrease of $1,159,000 reflects the anticipated completion of R&D in support of the initiation of the Tevatron operation with two new detectors in FY 2001 offset, in part, by increased efforts related to planned luminosity improvements.

| | | | |
|---|---|---|---|
| **Experimental Facilities R&D**....................................... | **6,466** | **5,162** | **6,200** |

Activities in FY 2002 will focus on R&D (increased about $1,000,000) needed for upgrades to the two large detectors so as to accommodate the increased luminosity from the planned upgrades of the Tevatron. R&D will continue at a lower level 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.

| | | | |
|---|---|---|---|
| **SLAC**.......................................................................... | **23,620** | **22,159** | **22,770** |
| **Accelerator R&D** .......................................................... | **19,975** | **21,216** | **21,680** |

An important component of the FY 2002 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 improve the collision luminosity from the design value of $3x10^{33}cm^{-2}s^{-1}$ to greater than $10^{34}cm^{-2}s^{-1}$. The planned improvements include additional RF acceleration systems, improvements to the vacuum pumping system, and improvements to the beam control systems.

Activities in FY 2002 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 upgradable to 1.5 TeV. The R&D activity at SLAC will focus on 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 $14,810,000 in FY 2002, about the same as in FY 2001.

| | FY 2000 | FY 2001 | FY 2002 |
|---|---|---|---|

(dollars in thousands)

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.

| | FY 2000 | FY 2001 | FY 2002 |
|---|---|---|---|
| **Experimental Facilities R&D**...................................... | **3,645** | **943** | **1,090** |

In FY 2002, 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.

| | FY 2000 | FY 2001 | FY 2002 |
|---|---|---|---|
| **BNL**........................................................................... | **7,400** | **5,574** | **5,265** |
| **Accelerator R&D** .......................................................... | **6,360** | **4,561** | **4,315** |

Activities in FY 2002 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 collider 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 collider.

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.

Funding for the above activities is decreased to support the strong initiative to exploit the "window of opportunity" for exciting new physics results described in the HEP program mission section above. This will significantly impact the viability and productivity of the BNL technology groups.

| | FY 2000 | FY 2001 | FY 2002 |
|---|---|---|---|
| **Experimental Facilities R&D**........................................ | **1,040** | **1,013** | **950** |

In FY 2002, 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 begin.

Funding is decreased to support the strong initiative to exploit the "window of opportunity" for exciting new physics results described in the HEP program mission statement above. This will significantly impact the viability and productivity of the BNL technology groups.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2000 | FY 2001 | FY 2002 |
| **LBNL** | **11,737** | **11,343** | **10,595** |
| **Accelerator R&D** | **9,624** | **9,225** | **8,605** |

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.

LBNL is a major contributor to accelerator and superconducting magnet R&D for advanced accelerator concepts, including the muon collider 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 2002, preparations for muon cooling experiments to be performed at Fermilab, needed to confirm the practicality of a muon collider, will continue, using components fabricated at LBNL.

Funding for some of the above activities is decreased to support the strong initiative to exploit the "window of opportunity" for exciting new physics results described in the introductory sections. This will significantly impact the viability and productivity of the LBNL technology groups.

LBNL is also involved in the NLC R&D program in FY 2001. Continuation of this effort in FY 2002 will be at about the same level of funding ($650,000).

| | | | |
|---|---|---|---|
| **Experimental Facilities R&D** | **2,113** | **2,118** | **1,990** |

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 2002, work will continue on large area charge-coupled devices and high-resolution imaging systems, plus the production and testing of IC systems.

Funding is decreased to support the strong initiative to exploit the "window of opportunity" for exciting new physics results described in the introductory sections. This will significantly impact the viability and productivity of the LBNL technology groups.

| | | | |
|---|---|---|---|
| **ANL** | **2,389** | **2,203** | **2,075** |
| **Accelerator R&D** | **1,481** | **1,299** | **1,220** |

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.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2000 | FY 2001 | FY 2002 |

Funding is decreased to support the strong initiative to exploit the "window of opportunity" for exciting new physics results described in the introductory sections. This will significantly impact the viability and productivity of the ANL technology groups.

| | | | |
|---|---|---|---|
| **Experimental Facilities R&D**....................................... | **908** | **904** | **855** |

In FY 2002 work will be underway on the MINOS detector, the ATLAS detector for the LHC, and a possible upgrade of the ZEUS detector at DESY.

Funding is decreased to support the strong initiative to exploit the "window of opportunity" for exciting new physics results described in the introductory sections. This will significantly impact the viability and productivity of the ANL technology groups.

| | | | |
|---|---|---|---|
| **Universities**........................................................................... | **10,028** | **9,568** | **8,680** |

The funding will provide for a program of high priority technology R&D at about 20 universities relevant to the development of particle accelerators. 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; muon colliders; 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 decreased to support the strong initiative to exploit the "window of opportunity" for exciting new physics results described in the introductory sections. This will significantly impact the viability and productivity of these technology groups.

| | | | |
|---|---|---|---|
| **Other Technology R&D**...................................................... | **3,064** | **9,703** | **11,094** |

The funding will provide for a program of high priority technology R&D at a number of other federal laboratories and industrial sites relevant to the development of particle accelerators. 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.

The increase of $1,391,000 is primarily for Other Technology R&D activities that has not been allocated pending completion of peer review or program office detailed planning.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2000 | FY 2001 | FY 2002 |
| **SBIR/STTR** | **0** | **1,479** | **7,951** |

In FY 2000, $1,100,000 was transferred to the SBIR program. This includes $615,000 for the SBIR program and $864,000 for the STTR program in FY 2001 and $7,090,000 for the SBIR program and $861,000 for the STTR program in FY 2002. Additional funding for the SBIR program is contained in the High Energy Physics Facilities subprogram.

| | | | |
|---|---|---|---|
| **Total, Research and Technology** | **236,028** | **242,836** | **247,870** |

## Explanation of Funding Changes from FY 2001 to FY 2002

| | FY 2002 vs. FY 2001 ($000) |
|---|---|
| **Physics Research** | |
| At Fermilab, an increase in the Physics Research category to provide increased support for Fermilab scientists to exploit the window of opportunity to search for the source of mass | +1,767 |
| At SLAC, an increase in the Physics Research category to provide increased support for SLAC scientists collecting and analyzing data from the BaBar detector to exploit the window of opportunity to study CP violation in B meson decays and help explain the preponderance of matter over antimatter in the universe | +1,608 |
| Funding for research at a number of sites has been decreased to make funds available for the operation and upgrade of the high priority "window of opportunity" efforts at Fermilab and SLAC as discussed in the introductory sections. | |
| In University Physics Research, a decrease of $4,670,000 | -4,670 |
| At BNL, a decrease of $592,000. | -592 |
| At LBNL, a decrease of $813,000. | -813 |
| At ANL, a decrease of $358,000 | -358 |
| In Other Physics Research, an increase of $1,000,000 reflecting the transfer of a portion of the funding for the large scale computer modeling and simulation initiative from the High Energy Physics Facilities Subprogram. This is based on further analysis of the objectives of the program. An additional $3,960,000 for computer modeling and simulation remains in the High Energy Physics Facilities Subprogram. The total for this activity is increased slightly relative from FY 2001. | |

| | FY 2002 vs. FY 2001 ($000) |
|---|---|
| In Other Physics Research an increase of $980,000 in funding for preparation for handling the data from LHC. | |
| In Other Physics Research, other adjustments totaling a decrease of $168,000. | +1,812 |
| Total, Physics Research | -1,246 |
| **High Energy Physics Technology** | |
| At Fermilab, a decrease of about $121,000 reflecting the anticipated completion of the final commissioning and shakedown operation of the Tevatron with the new Main Injector which occurred during FY 2001, offset by an increased emphasis on R&D needed for the planned luminosity upgrades of the Tevatron. The cooperative (with SLAC) R&D program on the Next Linear Collider and the program of R&D on muon colliders are held at about a constant level. | -121 |
| At SLAC, an increase to support the R&D needed to further increase the luminosity of the B-factory and to make the BaBar detector fully effective at these higher intensities. | +611 |
| Funding for technology at a number of sites has been decreased to make funds available for the operation and upgrade of the high priority "window of opportunity" programs at Fermilab and SLAC as discussed in the introductory sections. | |
| In the University program, a decrease of $888,000 | -888 |
| At BNL, a decrease of $309,000 | -309 |
| At LBNL, a decrease of $748,000 | -748 |
| At ANL, a decrease of $128,000 | -128 |
| In Other Technology R&D, an increase of $240,000 in funding for activities related to meeting the anticipated computing needs of the LHC research program, and an increase of $1,151,000 primarily in the funding held in reserve pending the completion of peer review and program office considerations. | +1,391 |
| Total, High Energy Physics Technology | -192 |
| **SBIR/STTR** | |
| An increase of $6,472,000 in the SBIR allocation | +6,472 |
| Total Funding Change, Research and Technology | +5,034 |

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

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2000 | FY 2001 | FY 2002 |
| Next Linear Collider | 17,400 | 19,157 | 19,200 |
| Muon-Muon Collider | 9,675 | 5,269 | 4,993 |

# High Energy Physics Facilities

## Mission Supporting Goals and Objectives

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 2002 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.
- Continuation of the planned program of upgrades for these two facilities. 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 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 requires both extended running and an ongoing program of facility upgrades.
- Strong operation of the AGS at BNL for the research program planned at the AGS as described earlier.
- 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 or to discover new phenomena. 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. **Performance will be measured by** reporting accomplishments on the common performance measures on leadership, excellence and relevance; quality; and safety and health.

| | (in weeks) | | |
|---|---|---|---|
| | FY 2000 | FY 2001 | FY 2002 |
| Fermilab | 29 | 22 | 39 |
| SLAC[a] | 44 | 34 | 35 |
| BNL | 15 | 16 | 16 |

## Funding Schedule

| | (dollars in thousands) | | | | |
|---|---|---|---|---|---|
| | FY 2000 | FY 2001 | FY 2002 | $ Change | % Change |
| Fermi National Accelerator Lab | 212,590 | 211,406 | 244,739 | +33,333 | +15.8% |
| Stanford Linear Accelerator Center | 111,787 | 116,449 | 125,078 | +8,629 | +7.4% |
| Brookhaven National Laboratory | 3,471 | 5,729 | 5,690 | -39 | -0.7% |
| Other Facility Support | 10,384 | 20,204 | 14,655 | -5,549 | -27.5% |
| Large Hadron Collider | 70,000 | 58,870 | 49,000 | -9,870 | -16.8% |
| Waste Management | 10,090 | 10,391 | 10,410 | +19 | +0.2% |
| SBIR/STTR | 0 | 13,787 | 7,258 | -6,529 | -47.4% |
| Total, High Energy Physics Facilities | 418,322 | 436,836 | 456,830 | +19,994 | +4.6% |

## Detailed Program Justification

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2000 | FY 2001 | FY 2002 |
| **Fermilab** | **212,590** | **211,406** | **244,739** |

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 new 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; 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 2002 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 2002. **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.

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

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2000 | FY 2001 | FY 2002 |
| **Operations** | **182,455** | **177,993** | **194,409** |

Operation 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 increased funding ($16,416,000) will support the additional Tevatron operation, will provide for increased operations staffing to enhance the reliability and efficiency of the planned operations, and will assist with installation and commissioning of planned luminosity upgrades.

**Tevatron Operation**

| | (in weeks) | | |
|---|---|---|---|
| | FY 2000 | FY 2001 | FY 2002 |
| Fixed Target | 6 | 0 | 0 |
| Collider | 15 | 22 | 39 |
| Commissioning | 8 | 0 | 0 |
| Total, Tevatron Operation | 29 | 22 | 39 |

| | | | |
|---|---|---|---|
| **Support and Infrastructure** | **30,135** | **33,413** | **50,330** |

Capital Equipment funding is increased from $24,789,000 to $39,280,000. These funds provide for initiation of two new Major Items of Equipment involving the replacement of the Silicon Tracker Subsystems with new state-of-the-art radiation-hard silicon for both the CDF Detector (TEC of $15,000,000) and D-Zero Detector (TEC of $15,000,000), the MINOS Detector (TEC of $47,118,000), and general laboratory needs. Increases of $7,000,000 for the two new detector MIE's, $3,976,000 for MINOS and $7,811,000 for general laboratory needs are partially offset by the completion of the D-Zero Upgrade project in FY 2001. AIP is increased by $2,415,000 to $6,250,000. The detector upgrades, general laboratory needs and AIP funding reflect the high priority given to highly effective operation of the Tevatron for the physics goals and are aimed at improving the luminosity and efficiency of 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 them to better withstand the higher intensities needed in the search for the Higgs. MINOS is the detector part of the NuMI project that will provide a major new capability for neutrino research. GPP funding increased slightly ($11,000) to $4,800,000 to assist with urgent ES&H and infrastructure needs.

| | | | |
|---|---|---|---|
| **SLAC** | **111,787** | **116,449** | **125,078** |

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

| | (dollars in thousands) | |
|---|---|---|
| FY 2000 | FY 2001 | FY 2002 |

studying the B meson system and looking for information about CP Violation as described earlier.

B-factory operation in FY 2002 will be focused on an extended run to collect the maximum amount of data for the physics goals (CP Violation, etc.) described earlier. This will include full operation of the large detectors – BaBar – and the supporting computing facilities. The B-factory will operate for about 35 weeks in FY 2002. **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.

- **Operations** ........................................................................ **88,945** **94,298** **99,705**

  The increased funding will provide operations at SLAC in FY 2002 for about 35 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 2002. This will be supplemented by a modest (8 weeks) fixed target research program in End Station A which 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.

  The increased funding ($5,407,000) will provide for increased operation (1 week), increased operations staffing to enhance the reliability and effectiveness of the planned operations, and assist with installation and commissioning of luminosity upgrades.

**SLAC Operation** [a]

| | (in weeks) | | |
|---|---|---|---|
| | FY 2000 | FY 2001 | FY 2002 |
| Fixed Target [b] | 15 | 8 | 8 |
| B-factory Operation | 44 | 34 | 35 |
| Total, SLAC Operation | 44 | 34 | 35 |

**Support and Infrastructure** ............................................. **22,842** **22,151** **25,373**

Funding for capital equipment for general laboratory purposes is decreased by $2,140,000 to $5,140,000. Funding for AIP is increased by $2,872,000 to $8,360,000. These funds are primarily related to urgent upgrades needed to improve the luminosity and operational efficiency of the B-factory. Capital equipment funding for GLAST, a large gamma ray detector designed to study cosmic gamma rays from a satellite, is increased by $2,481,000 to $7,673,000. GLAST is a joint

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

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

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2000 | FY 2001 | FY 2002 |
| DOE-NASA project aimed at studying gamma rays in the cosmic radiation using a satellite-based instrument. Additional funding of $497,000 is provided under Other Facilities Support for GLAST. The total funding (including the $497,000 in Other Facilities Support) requested for GLAST in FY 2002 is $8,170,000 and the TEC is $35,000,000. Funding for GPP is increased slightly (+$9,000) to $4,200,000 to assist with urgent ES&H and infrastructure needs. | | | |
| **BNL** | **3,471** | **5,729** | **5,690** |

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 is on an incremental cost basis.

The AGS will be operated for the HEP program for about 16 weeks in FY 2002 in support of further operation of the experiment studying the magnetic properties of the muon and the new experiment searching for a very rare decay mode of the K meson. **Performance will be measured by** adherence to planned running schedules.

| | | | |
|---|---|---|---|
| **Operations** | **3,377** | **5,634** | **5,595** |

Funding will provide for the incremental cost of running the AGS complex for HEP. Operation for High Energy Physics in FY 2002 will be for about 16 weeks for a major data-taking run for muon experiment and for the initiation of the upgraded rare kaon decay experiment.

**AGS Operation**

| | (in weeks) | | |
|---|---|---|---|
| | FY 2000 | FY 2001 | FY 2002 |
| AGS Operation for HEP | 15 | 16 | 16 |

| | | | |
|---|---|---|---|
| **Support and Infrastructure** | **94** | **95** | **95** |

Includes capital equipment funding for HEP use of the AGS.

| | | | |
|---|---|---|---|
| **Other Facility Support** | **10,384** | **20,204** | **14,655** |

Includes $3,960,000 (-$959,000) for the Scientific Discovery through Advance Computing program. Additional funding in the amount of $1,000,000 is included in the Research and Technology subprogram and is more fully described there.

| | (dollars in thousands) | |
|---|---|---|
| FY 2000 | FY 2001 | FY 2002 |

Includes $1,050,000 (-$397,000) for General Purpose Equipment and $1,900,000 (-$1,592,000) for General Plant Projects at LBNL for landlord related activities.

In FY 2001, included $3,000,000 of MINOS Other Project Costs expended through the University of Minnesota for excavation at the Soudan Laboratory. This phase of the activity is complete and no funding is planned in FY 2002 (-$3,000,000).

In FY 2001, LBNL was provided $499,000 for modifications to the Oakland Scientific Facility and $253,000 for work related to the BaBar computing facilities at SLAC. Both activities are complete and no funding is planned in FY 2002 (-$752,000).

Includes funding for a number of small activities including computer networking and funding held in reserve pending the completion of peer review and programmatic considerations.

| | FY 2000 | FY 2001 | FY 2002 |
|---|---|---|---|
| **Large Hadron Collider**........................................................... | **70,000** | **58,870** | **49,000** |

The reduction in funding in FY 2002 ($11,000,000 below the previously planned profile) reflects a further analysis of the detailed expenditure plans for the project. This funding will allow the project to continue on the approved schedule and will not affect the planned completion date and the total cost of the U.S. projects and the LHC itself. CERN has indicated agreement with this change.

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 around the middle of the next decade. 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.

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 are being used to pay for purchases by CERN of material needed for construction of the accelerator. As a result of the negotiations, CERN has agreed to make these purchases 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.

Fabrication of LHC subsystems and components by U.S. participants began in FY 1998. Funding was provided in FY 1996 ($6,000,000) and FY 1997 ($15,000,000) for preliminary R&D, design and engineering work on the subsystems and components being proposed for inclusion in the agreement with CERN. This funding was essential in order to provide the cost and technical bases for the proposed U.S. responsibilities in LHC, and to be ready for rapid start to satisfy the anticipated timetable for the project.

## 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 2000 | FY 2001 | FY 2002 |
| High Energy Physics Facilities | | | |
| LHC | | | |
| Accelerator Systems | | | |
| Operating Expenses | 4,160 | 5,371 | 1,800 |
| Capital Equipment | 20,758 | 3,991 | 12,400 |
| Total, Accelerator Systems | 24,918 | 9,362 | 14,200 |
| Procurement from Industry | 8,288 | 17,881 | 7,103 |
| ATLAS Detector | | | |
| Operating Expenses | 5,135 | 7,285 | 3,647 |
| Capital Equipment | 11,359 | 7,190 | 6,860 |
| Total, ATLAS Detector | 16,494 | 14,475 | 10,507 |
| CMS Detector | | | |
| Operating Expenses | 9,100 | 11,465 | 8,480 |
| Capital Equipment | 11,200 | 5,687 | 8,710 |
| Total, CMS Detector | 20,300 | 17,152 | 17,190 |
| Total, LHC | 70,000 | 58,870 | 49,000 |

In FY 2002, funding will be used for: R&D and measurement/testing on superconducting materials, cable, and wire; calculations and R&D on accelerator physics issues regarding the design, instrumentation, and prototypes of the magnets for the colliding beam intersection regions and RF accelerating regions. Activities on the detectors will include R&D and prototype development of subsystems such as tracking chambers, calorimeters, and data acquisition electronics.

The LHC work is being performed at various locations including 4 major DOE labs and more than 55 U.S. universities.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2000 | FY 2001 | FY 2002 |
| **Accelerator Systems** | **24,918** | **9,362** | **14,200** |

In FY 2002, funding will support continued production of interaction region quadrupole magnets, dipole magnets, feedboxes, and absorbers; production of radio-frequency region dipole magnets; and completion of fabrication of the superconducting cable for these magnets. Production testing of wire and cable for the LHC main magnets and accelerator physics calculations will continue.

| | | | |
|---|---|---|---|
| **Procurement from Industry** | **8,288** | **17,881** | **7,103** |

In FY 2002, 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. The reduction reflects the latest information on the planned expenditure profile.

| | | | |
|---|---|---|---|
| **ATLAS Detector** | **16,494** | **14,475** | **10,507** |

In FY 2002, funding will support production of detector hardware and electronics. The barrel cryostat procurement for the liquid argon calorimeter will be completed and procurement and testing will continue for the silicon strip electronics, and the transition radiation tracker electronics. Fabrication efforts will continue for the silicon strip modules, the forward calorimeter, the extended barrel tile calorimeter modules and submodules, the endcap monitored drift tubes, and the cathode strip chambers. Fabrication will be completed for the liquid argon calorimeter feed-throughs and motherboards and installation will begin. The reduction reflects the latest information on the planned expenditure profile.

| | | | |
|---|---|---|---|
| **CMS Detector** | **20,300** | **17,152** | **17,190** |

In FY 2002, funding will support full rate production and testing of endcap muon system chambers and the procurement of the electronics and cables for the muon system. The hadron calorimeter barrel will be completed and delivered to CERN and the scintillator and brass absorber assembly will continue along with the testing of the associated electronics. The trigger designs will be completed and testing of the electronics will continue. The data acquisition system will complete prototyping efforts and continue test beam studies. The forward pixel system will complete advanced testing and prepare for production of readout chips and sensors.

| | | | |
|---|---|---|---|
| **Waste Management** | **10,090** | **10,391** | **10,410** |

Provides funding for packaging, shipment and disposition of hazardous, radioactive or mixed waste generated in the course of normal operations at Fermilab, SLAC, and LBNL. The laboratories continue to explore opportunities to reduce the volume of newly generated waste and its associated management and disposal costs.

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2000 | FY 2001 | FY 2002 |
| **SBIR/STTR** | **0** | **13,787** | **7,258** |

In FY 2000, $12,697,000 was transferred to the SBIR program and $828,000 was transferred to the STTR program. Includes $13,787,000 in FY 2001 and $7,258,000 in FY 2002 for the SBIR program. The balance of the SBIR and STTR allocations are included in the Research and Technology Subprogram.

| | | | |
|---|---|---|---|
| **Total, High Energy Physics Facilities** | **418,322** | **436,836** | **456,830** |

## Explanation of Funding Changes from FY 2001 to FY 2002

| | FY 2002 vs. FY 2001 ($000) |
|---|---|
| **Fermilab** | |
| At Fermilab, an increase of $16,416,000 in Operations to support 39 weeks of operation of the Tevatron with the Main Injector and the newly upgraded CDF and D-Zero detectors | +16,416 |
| At Fermilab, increases of $7,000,000 for two new detector MIE's, $3,976,000 for MINOS and $7,811,000 for general laboratory needs are partially offset by a decrease of $4,296,000 resulting from the completion of the D-Zero Upgrade project for capital equipment. AIP funding is increased by $2,415,000. Also, GPP funding is increased by $11,000 to assist with urgent ES&H and infrastructure needs. | +16,917 |
| Total, Fermilab | +33,333 |
| **Stanford Linear Accelerator Center** | |
| At SLAC, an increase of $5,407,000 in Operations to support 35 weeks of operation of the B-factory for data collection on the key question of understanding the ratio of matter to antimatter in the universe. | +5,407 |
| At SLAC, a decrease of $2,140,000 in capital equipment and an increase of $2,872,000 in AIP is provided to support planned upgrades of the B-factory needed to achieve the planned luminosity increases. There is also an increase of $2,481,000 in the GLAST project, and an increase of $9,000 in GPP to assist with urgent ES&H and infrastructure needs. | +3,222 |
| Total, Stanford Linear Accelerator Center | +8,629 |

| | FY 2002 vs. FY 2001 ($000) |
|---|---|
| **Brookhaven National Laboratory** | |
| At BNL, a decrease of $39,000. | -39 |
| **Other Facility Support** | |
| A decrease of $959,000 reflects the transfer of a portion of the funding for the large scale computer modeling and simulation initiative to the Research and Technology subprogram. Decreases of $397,000 in GPE funding and $1,592,000 in GPP funding at LBNL. A decrease at LBNL in operating funding for modifications to the Oakland Scientific Facility (-$499,000) and a project related to computing needs for the BaBar detector (-$253,000) is reflected. Both projects are complete and no FY 2002 funding is planned. A decrease of $3,000,000 in the funding provided to the University of Minnesota for excavations for the Soudan Laboratory which will house the MINOS detector since the project is complete and no FY 2002 funding is planned. An increase of $1,151,000 mainly in funding held pending completion of peer review and program office consideration is proposed. | -5,549 |
| **Large Hadron Collider** | |
| A decrease of $9,870,000 reflecting the revised expenditure profile | -9,870 |
| **Waste Management** | |
| An increase of $19,000. | +19 |
| **SBIR/STTR** | |
| A decrease of $6,529,000 in funding for SBIR | -6,529 |
| Total Funding Change, High Energy Physics Facilities | +19,994 |

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

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2000 | FY 2001 | FY 2002 |
| GLAST (SLAC Capital Equipment) | 2,719 | 5,192 | 7,673 |
| GLAST (Other Facility Support Capital Equipment) | 281 | 497 | 497 |
| Total | 3,000 | 5,689 | 8,170 |
| | | | |
| MINOS | | | |
| Operating | 4,632 | 3,000 | 2,050 |
| Capital Equipment | 6,671 | 11,974 | 15,950 |
| Total | 11,303 | 14,974 | 18,000 |

# 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 2000 | FY 2001 | FY 2002 | $ Change | % Change |
| Neutrinos at the Main Injector | 22,000 | 22,949 | 11,400 | -11,549 | -50.3% |
| Wilson Hall Safety Improvement Project | 4,700 | 4,191 | 0 | -4,191 | -100.0% |
| SLAC Research Office Building | 2,000 | 5,189 | 0 | -5,189 | -100.0% |
| Total, Construction | 28,700 | 32,329 | 11,400 | -20,929 | -64.7% |

## Detailed Program Justification

| | (dollars in thousands) | | |
|---|---|---|---|
| | FY 2000 | FY 2001 | FY 2002 |
| **Neutrinos at the Main Injector (NuMI)** | **22,000** | **22,949** | **11,400** |

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 2002 funding is primarily for the underground beam tunnel. Work on the neutrino production target, neutrino focusing horns, underground detector and detector halls, and surface buildings at Fermilab will continue. **Performance will be measured by** accomplishment of scheduled milestones as detailed in the benchmark plan.

| | | | |
|---|---|---|---|
| **Wilson Hall Safety Improvement Project (Fermilab)** | **4,700** | **4,191** | **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** | **2,000** | **5,189** | **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 | **28,700** | **32,329** | **11,400** |

## Explanation of Funding Changes from FY 2001 to FY 2002

| | FY 2002 vs. FY 2001 ($000) |
|---|---|
| Provides for completion of the Fermilab NuMI project on the planned profile. | -11,549 |
| The Wilson Hall Safety Improvement Project at Fermilab will be completed as planned in FY 2002. | -4,191 |
| The Research Office Building at SLAC will be completed as planned in FY 2001. | -5,189 |
| Total Funding Change, Construction | -20,929 |

# Capital Operating Expenses & Construction Summary

## Capital Operating Expenses

(dollars in thousands)

| | FY 2000 | FY 2001 | FY 2002 | $ Change | % Change |
|---|---|---|---|---|---|
| General Plant Projects | 10,645 | 12,472 | 10,900 | -1,572 | -12.6% |
| Accelerator Improvements Projects | 10,233 | 9,323 | 14,610 | +5,287 | +56.7% |
| Capital Equipment | 89,828 | 69,300 | 94,878 | +25,578 | +36.9% |
| Total, Capital Operating Expense | 110,706 | 91,095 | 120,388 | +29,293 | +32.2% |

## Construction Projects

(dollars in thousands)

| | Total Estimated Cost (TEC) | Prior Year Approp-riations | FY 2000 | FY 2001 | FY 2002 | Unapprop-riated Balance |
|---|---|---|---|---|---|---|
| 98-G-304 Neutrinos at the Main Injector [a] | 76,149 | 19,800 | 22,000 | 22,949 | 11,400 | 0 |
| 99-G-306 Wilson Hall Safety Improvements | 15,591 | 6,700 | 4,700 | 4,191 | 0 | 0 |
| 00-G-307 SLAC Research Office Building | 7,189 | 0 | 2,000 | 5,189 | 0 | 0 |
| Total, Construction | | 26,500 | 28,700 | 32,329 | 11,400 | 0 |

[a] A Cost, Scope, and Schedule Review of the NuMI project is planned for this spring. The results of this review may change the funding profile, TEC, and TPC.

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

(dollars in thousands)

| | Total Estimated Cost (TEC) | Prior Year Approp-riations | FY 2000 | FY 2001 | FY 2002 | Accept-ance Date |
|---|---|---|---|---|---|---|
| D-Zero Upgrade | 61,208 | 52,547 | 4,365 | 4,296 | 0 | FY 2001 |
| CDF Upgrade | 56,646 | 51,037 | 5,609 | 0 | 0 | FY 2001 |
| Large Hadron Collider — Machine | 88,769 | 25,680 | 20,758 | 3,991 | 12,400 | FY 2005 |
| Large Hadron Collider — ATLAS Detector | 57,119 | 9,841 | 11,359 | 7,190 | 6,860 | FY 2005 |
| Large Hadron Collider — CMS Detector | 64,390 | 24,338 | 11,200 | 5,687 | 8,710 | FY 2005 |
| MINOS | 47,118 | 2,600 | 6,671 | 11,974 | 15,950 | FY 2003 |
| GLAST [a] | 35,000 | 0 | 3,000 | 5,689 | 8,170 | FY 2005 |
| Cryogenic Dark Matter Search (CDMS) | 8,600 | 0 | 800 | 1,798 | 1,060 | FY 2007 |
| Auger | 3,000 | 0 | 0 | 100 | 1,150 | FY 2003 |
| Alpha Magnetic Spectrometer (AMS) Upgrade [b] | 3,028 | 0 | 1,000 | 1,028 | 1,000 | FY 2003 |
| D-Zero Silicon Tracker Replacement | 15,000 | 0 | 0 | 0 | 3,500 | FY 2004 |
| CDF Silicon Tracker Replacement | 15,000 | 0 | 0 | 0 | 3,500 | FY 2004 |
| Total, Major Items of Equipment | | 166,043 | 64,762 | 41,753 | 62,300 | |

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

[b] A change in the assignment of responsibilities within the international AMS collaboration is being discussed which would result in an increase of $1,700,000 in the TEC of the DOE portion of the project. A decision with regard to changing the DOE TEC and funding profile will be made when an appropriate proposal has been received and reviewed.

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

(Changes from FY 2001 Congressional Budget Request are denoted with a vertical line [ | ] in the left margin.)

## Significant Changes

Total Project Cost and the Completion Date have been adjusted due to changes in the MINOS detector profile.

## 1. Construction Schedule History

| | Fiscal Quarter | | | | Total Estimated Cost ($000) | Total Project Cost ($000) |
|---|---|---|---|---|---|---|
| | A-E Work Initiated | A-E Work Completed | Physical Construction Start | Physical Construction Complete | | |
| FY 1998 Budget Request *(A-E and technical design only)*........................ | 1Q '98 | 4Q '98 | NA | NA | 5,500 | 6,300 |
| FY 1999 Budget Request (Preliminary Estimate)......................................... | -- | 3Q '99 | 1Q '99 | 4Q '02 | 75,800 | 135,300 |
| FY 2000 Budget Request .................. | 3Q '98 | 2Q '00 | 3Q '99 | 2Q '03 | 76,200 | 136,100 |
| FY 2001 Budget Request .................. | 3Q '98 | 2Q '00 | 3Q '99 | 2Q '04 | 76,200 | 138,600 |
| FY 2001 Budget Request (Amended)... | 3Q '98 | 2Q '00 | 3Q '99 | 4Q '03 | 76,200 | 138,400 |
| FY 2002 Budget Request ................. | 3Q '98 | 4Q '00 | 3Q '99 | 4Q '03 | 76,149 | 139,390 |

## 2. Financial Schedule*

(dollars in thousands)

| Fiscal Year | Appropriations | Obligations | Costs |
|---|---|---|---|
| Design & Construction | | | |
| 1998 | 5,500 | 5,500 | 1,140 |
| 1999 | 14,300 | 14,300 | 5,846 |
| 2000 | 22,000 | 22,000 | 15,089 |
| 2001 | 22,949 | 22,949 | 26,949 |
| 2002 | 11,400 | 11,400 | 14,900 |
| 2003 | 0 | 0 | 12,225 |

*A Cost, Scope and Schedule Review of the NuMI Project is planned for this spring. The results of this Review may change the funding profile, TEC and TPC.

## 3. Project Description, Justification and Scope

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

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

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

## 4. Details of Cost Estimate [a]

| | (dollars in thousands) | |
|---|---|---|
| | Current Estimate | Previous Estimate |
| Design Phase | | |
| Preliminary and Final Design costs | 7,150 | 7,150 |
| Design Management costs (0.0% of TEC) | 10 | 10 |
| Project Management costs (0.0% of TEC) | 20 | 20 |
| Total, Engineering design inspection and administration of construction costs (9.4% of TEC) | 7,180 | 7,180 |
| Construction Phase | | |
| Buildings | 8,320 | 8,320 |
| Special Equipment | 10,120 | 10,120 |
| Other Structures | 30,960 | 30,960 |
| Construction Management (6.0% of TEC) | 4,590 | 4,590 |
| Project Management (2.8% of TEC) | 2,170 | 2,170 |
| Total, Construction Costs | 56,160 | 56,160 |
| Contingencies | | |
| Design Phase (2.8% of TEC) | 2,172 | 2,172 |
| Construction Phase (14.0% of TEC) | 10,637 | 10,688 |
| Total, Contingencies (16.8% of TEC) | 12,809 | 12,860 |
| Total, Line Item Cost (TEC) | 76,149 | 76,200 |

## 5. Method of Performance

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

[a] The annual escalation rates assumed for FY 1996 through FY 2002 are 2.5, 2.8, 3.0, 3.1, 3.3, 3.4, and 3.4 percent respectively.

## 6. Schedule of Project Funding*

(dollars in thousands)

| | Prior Years | FY 2000 | FY 2001 | FY 2002 | Outyears | Total |
|---|---|---|---|---|---|---|
| Project Cost | | | | | | |
| Facility Cost | | | | | | |
| Total, Line item TEC............................ | 6,986 | 15,089 | 26,949 | 14,900 | 12,225 | 76,149 |
| Other Project Costs | | | | | | |
| Capital equipment [a]............................ | 2,560 | 5,067 | 11,974 | 15,950 | 11,567 | 47,118 |
| R&D necessary to complete construction [b] | 1,300 | 0 | 0 | 0 | 0 | 1,300 |
| Conceptual design cost [c]...................... | 830 | 0 | 0 | 0 | 0 | 830 |
| Other project-related costs [d].................. | 3,480 | 5,062 | 3,000 | 2,050 | 401 | 13,993 |
| Total, Other Project Costs........................... | 8,170 | 10,129 | 14,974 | 18,000 | 11,968 | 63,241 |
| Total Project Cost (TPC)............................. | 15,156 | 25,218 | 41,923 | 32,900 | 24,193 | 139,390 |

* A Cost, Scope and Schedule Review of the NuMI Project is planned for this spring. The results of this Review may result in a need to change the funding profile, TEC and TPC.

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

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

[c] Includes operating costs for development of conceptual design and scope definition for the NuMI facility. Also includes costs for NEPA documentation, to develop an Environmental Assessment, including field tests and measurements at the proposed construction location.

[d] Include funding required to complete the construction and outfitting of the Soudan Laboratory for the new far detector by the University of Minnesota.

## 7. Related Annual Funding Requirements

| | (FY 2003 dollars in thousands) | |
|---|---|---|
| | Current Estimate | Previous Estimate |
| Annual facility operating costs [a] | 500 | 500 |
| Utility costs (estimate based on FY 1997 rate structure) [b] | 500 | 500 |
| Total related annual funding | 1,000 | 1,000 |
| Total operating costs *(operating from FY 2003 through FY 2007)* | 5,000 | 5,000 |

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

[b] Including incremental power costs for delivering 120 GeV protons to the NuMI facility during Tevatron collider operations, and utility costs for operation of the NuMI facilities, which will begin beyond FY 2002.