High Energy Physics

Program Mission

The mission of the High Energy Physics (HEP) program is to understand the universe at a fundamental level by investigating the elementary particles that are the basic constituents of matter and the forces between them, thereby underpinning and advancing DOE missions and objectives through the development of key cutting-edge technologies and trained manpower that provide unique support to these missions. This program will provide world-class, peer-reviewed research results in HEP and related fields, including particle astrophysics and cosmology, executing a long-range strategy for high energy physics research and technology.

Strategic Objectives

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

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

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

Program Strategic Performance Goals

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

Performance Indicator

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

Performance Standards

As discussed in Corporate Context/Executive Summary.

Annual Performance Results and Targets

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

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

Performance Indicator

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

Performance Standards

As discussed in Corporate Context/Executive Summary.

Annual Performance Results and Targets

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

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

Performance Indicator

Percent on time/on budget, Percent unscheduled downtime.

Performance Standards

As discussed in Corporate Context/Executive Summary.

Annual Performance Results and Targets

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

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

Performance Indicator

Demonstration of R&D milestones and prototype components.

Performance Standards

As discussed in Corporate Context/Executive Summary.

Annual Performance Results and Targets

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

Unique Opportunities for World Leadership

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

At Stanford Linear Accelerator Center (SLAC), the highly successful B-factory and its BaBar detector will have the opportunity to shed light on the mysterious preponderance of matter over antimatter in the universe. Electrons colliding at several billion electron volts (GeV) will allow the study of a phenomenon known as *Charge-Parity (CP) violation* in B-mesons. B mesons contain a heavy b-quark or its anti-particle, and have roughly five times the proton mass. CP violation was originally discovered in 1964 in an experiment at Brookhaven National Laboratory involving the much lighter K mesons, and its accommodation within the current theory has only recently been established through extremely difficult and exquisitely precise measurements at Fermilab and CERN. The big question for SLAC is whether CP violation in the B-mesons will follow theoretical predictions or will instead indicate some additional, hitherto unknown source of the phenomenon. Such a discovery would have profound implications for our understanding of the matter-dominated universe in which we live. The B-factory will need a progressive series of upgrades in order to be competitive with a similar facility now operating in Japan that has three times more design luminosity. To fully exploit the discovery potential of the Tevatron at Fermilab and the B-factory at the SLAC along with their corresponding detectors as discussed above, these facilities must be strongly utilized and significantly upgraded. Therefore, the FY 2002 budget focused on the utilization and upgrades of these facilities together with support for the research groups (primarily university based) performing the research. Thus, the focus is on maximizing the discovery potential with lower priority being given to other parts of the program. The distribution of resources as specified in this budget continues this focused program.

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

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

Major Advances

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

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

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

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

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

Major Questions

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

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

Methods and Resources

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

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

Non-accelerator Experiments

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

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

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

Technical Requirements

High energy physics works with particle energies higher than exist anywhere but in certain stellar or cosmological environments and studies distance scales that are extraordinarily small. It often must make precision measurements of phenomena buried in a background of noise or search for very rare processes that may signal new physics. Such research demands particle beams of great intensities and detectors with both the sensitivity to see the rare events and the selectivity to pull these out of a cacophony of background noise. It requires accelerators and storage rings that operate at trillions of electron volts of energy and particle currents that can routinely burn holes in steel, and demands particle detectors that can identify one particle out of several thousand and catch particles that live less that a trillionth of a second. It is essential to accumulate, store, process, and transmit to hundreds of researchers worldwide the increasingly large data sets produced by modern experiments. As international collaborations in high energy physics grow from roughly 500 physicists presently working at each CERN, Fermilab, and SLAC detector to approximately 1800 in each of the collaborations preparing detectors for the LHC, the need for sophisticated data handling at widely separated data centers becomes even more crucial.

Operating in these extreme domains requires substantial time and expense to design, build, maintain, operate, and upgrade the impressively complex and technically advanced research apparatus. A new accelerator or colliding beam device now requires 10 to 20 years of intensive research and development work to bring a new technology to the point of cost effective construction, and a similar effort is required for detectors and computing systems. The R&D programs to sustain a forefront science program are unavoidably big, costly, and long-term. Since few of the core technologies for these devices are marketable, industry has no motivation to research, develop, or manufacture the key technical items, except as (usually expensive) special procurements. Consequently, in order to advance the science, it is essential for the universities and national laboratories engaged in high energy physics to develop the cutting edge technologies that are needed.

Benefits to Other Sciences and to Citizens

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

Technology that was developed in response to the demands of high energy physics has become exceedingly useful to other fields of science, and thus has helped science to advance on a broad front. Synchrotron light sources, an outgrowth of electron accelerators and storage rings, have become invaluable tools for materials science, structural biology, chemistry, environmental science and medical science. Accelerators are used for radiation therapy and to produce isotopes for medical imaging. In U.S. hospitals, one patient in three benefits from a diagnostic or therapeutic nuclear medicine procedure, techniques derived from research in high energy and nuclear physics. The World Wide Web was invented by high energy physicists to transport large bodies of data among international collaborators and has brought about a worldwide revolution in communications and commerce. International research collaborations in high energy physics have set an example for other endeavors that require cooperative efforts by thousands of workers who must share facilities, data, and results, communicating among continents and managing the activities of diverse groups.

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

Accelerator Research and Development

The Department is continuing research and development directed toward accelerator facilities that will be needed for the future. Several approaches are being investigated. One is a linear electron-positron collider, often called the Next Linear Collider (NLC), following the successful example of the SLAC Linear Collider. Work is directed toward achieving a center-of-mass energy in the TeV range (500 to 1000 GeV, expandable to 1.5 TeV. A GeV is one billion electron volts of energy.). The current NLC R&D program, led by SLAC and Fermilab, seeks to develop new technologies that would provide high performance while limiting cost. The R&D develops new technologies, applies available technologies, and uses industrial firms to expand its R&D reach on certain technologies and to engage in necessary technology transfer. A facility like the NLC may well be international, and research and development on linear colliders is also underway in other countries, primarily Germany and Japan.

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

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

Significant Accomplishments and Program Shifts

Research and Technology

SCIENCE ACCOMPLISHMENTS

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

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

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

FY 2001 accomplishments are summarized below:

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

High Energy Physics Facilities

FACILITY ACCOMPLISHMENTS

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

PROGRAM SHIFTS

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

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

Scientific Facilities Utilization

The High Energy Physics request includes $480,453,000 to maintain support of the Department's scientific user facilities. This investment will provide significant research time for several thousand scientists based at universities and other Federal laboratories. It will also leverage both Federally and privately sponsored research, consistent with the Administration's strategy for enhancing the U.S. National science investment. The proposed funding will support operations at the Department's two major high energy physics facilities: the Tevatron at Fermilab, and the B-factory at the Stanford Linear Accelerator Center (SLAC). In FY 2003, the Alternating Gradient Synchrotron at Brookhaven National Laboratory is terminated for High Energy Physics research.

Workforce Development

The High Energy Physics program supports development of the R&D workforce through support of undergraduate researchers, graduate students working toward a doctoral degree, and postdoctoral associates developing their research and management skills. The R&D workforce developed under this program not only provides new scientific talent in areas of fundamental research, but also provides talent for a wide variety of technical, medical, and industrial areas that require the finely honed thinking and problem solving abilities and computing and technical skills developed through an education and experience in a fundamental research field. Scientists trained as High Energy Physicists can be found in such diverse areas as hospitals (radiation therapy, medical imaging, and medical physics), space exploration, and the stock market.

About 1,000 post-doctoral associates and graduate students supported by the High Energy Physics program in FY 2001 were involved in a large variety of theoretical and experimental research, including advanced technology R&D. About one-fifth are involved in theoretical research. Those involved in experimental research utilize a number of scientific facilities supported by the DOE, NSF, and foreign countries. The majority of the experimental postdoctoral associates and graduate students have worked at one of the three High Energy Physics User Facilities: Fermi National Accelerator Laboratory, Stanford Linear Accelerator Center, and Brookhaven National Laboratory.

Funding Profile

(dollars in thousands)

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

Public Law Authorization:

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

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

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

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

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

Funding by Site

(dollars in thousands)

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

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

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

Site Description

Argonne National Laboratory

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

Brookhaven National Laboratory

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

Fermi National Accelerator Laboratory

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

Lawrence Berkeley National Laboratory

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

Lawrence Livermore National Laboratory

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

Los Alamos National Laboratory

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

Oak Ridge Institute for Science and Education

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

Oak Ridge National Laboratory

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

Princeton Plasma Physics Laboratory

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

Sandia National Laboratory

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

Stanford Linear Accelerator Center

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

Thomas Jefferson National Accelerator Facility

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

All Other Sites

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

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

Research and Technology

Mission Supporting Goals and Objectives

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

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

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

Physics Research

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

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

The major planned Physics Research efforts in FY 2003 are:

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

High Energy Physics Technology

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

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

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

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

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

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

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

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

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

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

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

SciDAC

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

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

Funding Schedule

(dollars in thousands)

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

Detailed Program Justification

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

	FY 2001	FY 2002	FY 2003
Physics Research			
Universities	104,284	104,443	106,927
Fermilab	10,828	8,363	9,880
SLAC	12,755	12,930	13,082
BNL	10,989	10,316	10,391
LBNL	15,393	13,673	14,093
ANL	6,296	6,016	6,148
Other Physics Research	3,233	3,566	5,589
Total, Physics Research	163,778	159,307	166,110

	FY 2001	FY 2002	FY 2003
▪ **Universities**	**104,284**	**104,443**	**106,927**

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

The university program is increased to provide support for those universities involved in the initiative to exploit the "window of opportunity" for exciting new physics results described in the introductory sections. To the extent possible, the detailed funding allocations will take into account the involvement of university based research groups in the targeted physics research activities. These include research efforts related to the high priority experiments such as CDF, D-Zero, and BaBar, work on the design and fabrication of the LHC detector components, and research in support of U.S. participation in the LHC project.

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

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

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

▸ **University Based Research at SLAC**	**12,340**	**12,360**	**12,650**

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

▸ **University Based Research at BNL**..............................	**1,885**	**1,890**	**1,935**

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

▸ **University Based Research at Cornell**..........................	**4,300**	**4,310**	**4,410**

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

▸ **University Based Non Accelerator Research**	**10,400**	**10,415**	**10,665**

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

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

	(dollars in thousands)		
	FY 2001	FY 2002	FY 2003

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

► **University Based Research at Foreign Labs**	**17,915**	**17,940**	**18,370**

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

► **University Research in Theory**......................................	**23,905**	**23,940**	**24,510**

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

► **Other University Funding**	**3,884**	**3,888**	**3,977**

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

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

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

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

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

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

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

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

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

	(dollars in thousands)		
	FY 2001	FY 2002	FY 2003
▪ **BNL**	**10,989**	**10,316**	**10,391**

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

	FY 2001	FY 2002	FY 2003
▪ **SLAC**	**22,333**	**24,280**	**24,810**
▸ **Accelerator R&D**	**21,390**	**23,215**	**23,790**

An important component of the FY 2003 SLAC program will be continuation of the accelerator R&D aimed at improving the luminosity and operational efficiency of the B-factory complex. Particular attention will be paid to finding ways to continue to improve the collision luminosity to an ultimate value of $3x10^{34}cm^{-2}s^{-1}$, an order of magnitude greater than the design value. The planned improvements include additional RF acceleration systems, improvements to the vacuum pumping system, and improvements to the beam control systems.

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

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

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

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

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

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

	FY 2001	FY 2002	FY 2003
▪ **BNL**	**6,479**	**4,735**	**5,145**
▸ **Accelerator R&D**	**5,466**	**3,795**	**4,205**

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

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

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

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

	FY 2001	FY 2002	FY 2003
▸ **Experimental Facilities R&D**	**1,013**	**940**	**940**

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

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

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

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

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

▸ **Experimental Facilities R&D**	**2,118**	**1,970**	**1,970**

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

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

▪ **ANL**	**2,479**	**2,005**	**2,005**
▸ **Accelerator R&D**	**1,575**	**1,160**	**1,160**

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Explanation of Funding Changes from FY 2002 to FY 2003

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

	FY 2003 vs. FY 2002 ($000)
▸ In Other Technology R&D, an increase of $71,000 for funding at small labs and other non-university sites and an increase of $1,873,000 in funding held as contingency pending the completion of peer review and program office considerations and a reduction to muon collider R&D for higher priority activities of $1,480,000.	+464
Total, High Energy Physics Technology	+1,063
▪ **SBIR/STTR**	
▸ An increase of $6,454,000 in the SBIR/STTR allocations. This is partially offset by a decrease in High Energy Physics Facilities of $5,596,000 for SBIR.	+6,454
Total Funding Change, Research and Technology	+14,320

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

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

High Energy Physics Facilities

Mission Supporting Goals and Objectives

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

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

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

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

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

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

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

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

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

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

Funding Schedule

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

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

Detailed Program Justification

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

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

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

	FY 2001	FY 2002	FY 2003
▪ **Operations**	**188,809**	**198,230**	**194,757**

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

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

Tevatron Operation

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

	FY 2001	FY 2002	FY 2003
▪ **Support and Infrastructure**	**30,579**	**46,305**	**44,285**

Funding in the amount of $25,500,000 (Capital Equipment - $19,000,000; AIP - $6,500,000) is included for the program to increase the Tevatron luminosity, upgrade the CDF and D-Zero detectors, and provide the computing capability needed to analyze the data collected. This is all aimed at exploiting the “window of opportunity” described above. This is an increase of $11,580,000 (Capital Equipment +$12,080,000; AIP -$500,000) over FY 2002 and includes continuation of the two Major Items of Equipment projects involving the replacement of the Silicon Tracker Subsystems with new state-of-the-art radiation-hard silicon for both the CDF Detector ($7,500,000; TEC of $15,000,000) and D-Zero Detector ($7,500,000; TEC of $15,000,000). Also included is $4,000,000 for smaller projects needed for the upgrades. The increased funding for the machine and detector upgrades reflects the high priority given to the highly effective operation of the Tevatron for the physics goals and are aimed at improving the luminosity and efficiency of operation of the Tevatron. The Silicon Tracker Subsystem replacements will be necessary since in the normal course of operation the silicon in the detectors gets damaged by radiation and needs to be replaced. The technology involving radiation-hard silicon has improved significantly since the design for the last upgrades to the detectors was completed five years ago. This will allow these detector subsystems to better withstand the higher intensities needed in the search for the Higgs.

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

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

	FY 2001	FY 2002	FY 2003
SLAC	**119,226**	**127,335**	**125,995**

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

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

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

Also provides for maintenance of the laboratory physical plant.

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

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

SLAC Operation

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

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

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

BNL..	**6,014**	**5,725**	**0**

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

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

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

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

AGS Operation

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

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

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

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

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

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

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

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

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

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

The funding requested follows the currently approved profile which is revised from the original profile. Changes have been made to better match the funding profile to the funding needs of (1) the three U.S. projects based on their current fabrication plans and schedules, (2) the updated LHC construction schedule as determined by CERN, and (3) to reflect CERN's updated billing profile for payments under the "Procurements from U.S. Industry" program. This funding will allow the project to continue on the revised approved CERN schedule and will not affect the planned completion date or the total cost of the U.S. projects and the LHC itself.

Construction and technical difficulties on the CERN site have led to delays in the project. These problems are being overcome and the latest official CERN schedule shows approximately a nine-month slippage with first collisions in April 2006. This schedule slippage is being accommodated in the planning for the U.S. LHC projects with minimal impact on schedule and no increase in total cost to the U.S.

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

The European Center for Nuclear Research (CERN) in Geneva, Switzerland initiated the Large Hadron Collider (LHC) project in FY 1996. This will consist of a 7 on 7 TeV proton-proton colliding beams facility to be constructed in the existing Large Electron-Positron Collider (LEP) machine tunnel (LEP will be removed). The LHC will have an energy 7 times that of the Tevatron at Fermilab. Thus the LHC will open up substantial new frontiers for scientific discovery. Completion of the LHC is projected for 2006.

Participation by the U.S. in the LHC program is extremely important to U.S. High Energy Physics program goals. The LHC will become the foremost high energy physics research facility in the world when it begins operations in 2006. With the LHC at the next energy frontier, American scientific research at that frontier depends on participation in LHC. The High Energy Physics Advisory Panel (HEPAP) Subpanel on Vision for the Future of High Energy Physics (Drell) strongly endorsed participation in the LHC, and this endorsement has been restated by HEPAP on several occasions.

The physics goals of the LHC include a search for the origin of mass as represented by the "Higgs" particle, exploration in detail of the structure and interactions of the top quark, and the search for totally unanticipated new phenomena. Although LHC will have a lower energy than the Superconducting Super Collider (canceled in 1993), it has strong potential for answering the question of the origin of mass. The LHC energies are sufficient to test theoretical arguments for a totally new type of matter. In addition, history shows that major increases in the particle energy nearly always yield unexpected discoveries.

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

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

The agreement provides for a U.S. DOE contribution of $450,000,000 to the LHC accelerator and detectors over the period FY 1996 through FY 2005 (with approximately $81,000,000 being provided by the NSF). The DOE contribution is broken down as follows: detectors $250,000,000; accelerator $200,000,000 (including $90,000,000 for direct purchases by CERN from U.S. vendors and $110,000,000 for fabrication of components by U.S. laboratories).

The total cost of the LHC on a basis comparable to that used for U.S. projects is estimated at about $6,000,000,000. Thus the U.S. contribution represents less than 10 percent of the total. (The LHC cost estimates prepared by CERN, in general, do not include the cost of permanent laboratory staff and other laboratory resources used to construct the project.) Neither the proposed U.S. DOE $450,000,000 contribution nor the estimated total cost of $6,000,000,000 include support for the European and U.S. research physicists working on the LHC program.

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

In addition to the proposed U.S. DOE $450,000,000 contribution and $81,000,000 NSF contribution to the LHC accelerator and detector hardware fabrication, U.S. participation in the LHC will involve a significant portion of the U.S. High Energy Physics community in the research program at the LHC. This physicist involvement has already begun. Over 500 U.S. scientists have joined the U.S.-ATLAS detector collaboration, the U.S.-CMS detector collaboration, or the U.S.-LHC accelerator consortium, and are hard at work helping to design the initial physics research program to be carried out at the LHC, helping to specify the planned physics capabilities of the LHC accelerator and detectors, and helping to design and fabricate accelerator and detector components and subsystems.

U.S. LHC Accelerator and Detector Funding Profile

(dollars in thousands)

Fiscal Year	Department of Energy			National Science Foundation[a]
	Accelerator	Detector	Total	
1996[b]	2,000	4,000	6,000	0
1997[b]	6,670	8,330	15,000	0
1998[b]	14,000	21,000	35,000	0
1999	23,491	41,509	65,000	22,150
2000	33,206	36,794	70,000	15,900
2001	27,243	31,627	58,870	16,370
2002	21,303	27,697	49,000	16,860
2003	22,100	37,900	60,000	9,720
2004	29,330	30,670	60,000	0
2005	20,657	10,473	31,130	0
Total	200,000[c]	250,000	450,000	81,000

[a] The NSF funding has been approved by the National Science Board.

[b] The FY 1996 and FY 1997 LHC funding was for R&D, design and engineering work in support of the proposed U.S. participation in LHC. Beginning in FY 1998 funding was used for: fabrication of machine and detector hardware, supporting R&D, prototype development, and purchases by CERN from U.S. vendors.

[c] Includes $110,000,000 for LHC supporting R&D and accelerator components to be fabricated by U.S. laboratories and $90,000,000 for purchases by CERN from U.S. vendors.

LHC Accelerator and Detector Funding Summary

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

In FY 2003, funding will be used for the fabrication of accelerator magnets and equipment and the R&D, prototype development, and fabrication of detector subsystems such as tracking chambers, calorimeters, and data acquisition electronics.

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

	(dollars in thousands)		
	FY 2001	FY 2002	FY 2003
▪ **Accelerator Systems**	**19,166**	**10,096**	**8,700**

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

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

In FY 2003, funding will continue to support reimbursement to CERN for purchases from U.S. industry including superconducting wire, cable, cable insulation materials, and other technical components. This figure reflects the latest information on the planned expenditure profile. Funding is increased by $2,193,000 to support the current estimate of actual invoices from U.S. industrial suppliers which are expected to peak in 2004.

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

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

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

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

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

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

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

Explanation of Funding Changes from FY 2002 to FY 2003

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

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

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

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

Construction

Mission Supporting Goals and Objectives

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

Funding Schedule

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

Detailed Program Justification

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

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

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

	FY 2001	FY 2002	FY 2003
	(dollars in thousands)		

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

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

	FY 2001	FY 2002	FY 2003
▪ **Wilson Hall Safety Improvement Project (Fermilab)**.....	**4,191**	**0**	**0**

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

	FY 2001	FY 2002	FY 2003
▪ **SLAC Research Office Building**	**5,189**	**0**	**0**

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

	FY 2001	FY 2002	FY 2003
Total, Construction..	**32,329**	**11,400**	**20,093**

Explanation of Funding Changes from FY 2002 to FY 2003

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

Capital Operating Expenses & Construction Summary

Capital Operating Expenses

(dollars in thousands)

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

Construction Projects

(dollars in thousands)

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

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

(dollars in thousands)

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

[a] Reflects recently approved baseline revision.

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

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

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

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

(Changes from FY 2002 Congressional Budget Request are denoted with a vertical line [|] in the left margin.)

Significant Changes

The Total Project Cost (TPC) has been adjusted due to an increase in the Total Estimated Cost (TEC). This adjustment was made as a result of the recent Cost, Scope and Schedule Rebaselining review that took place in September 2001, as well as a staff review of the results of the Rebaselining review. The increase in the TEC/TPC has been approved by the Department of Energy.

There are several causes for the TEC change. Due to a tight market for civil construction, the cost for excavating tunnels and halls at the Fermi National Accelerator Laboratory (Fermilab) is considerably higher than the initial estimate. Rebidding this subcontract to reduce its cost entailed a significant delay, as has the subsequent performance of the work. Treatment and disposal of tunnel discharge water has also increased the cost. Experience has demonstrated that inadequate engineering resources were initially applied to the project. Thus, the cost of beam-line components was underestimated. The difficulty of constructing an underground facility to safely accommodate the extremely high intensity proton beam needed to produce an adequate number of neutrinos was also underestimated. The shielding required to suppress the secondary radioactivity has turned out to be significantly more extensive than originally planned, and the radiation levels near the target station will require a significant remote handling capability for routine operation and maintenance. The beam-line technical components costs now reflect results of a prototyping program along with more refined engineering estimates; labor is a substantial part of the increase. Also, the overall contingency on the TEC has been adjusted to reflect these changes. Both the Department of Energy and Fermilab have strengthened their management to execute the project within the new baseline.

The MINOS detector for NuMI, funded as part of the Other Project Costs, is proceeding well, and the contingency and the projected total cost for the detector have been reduced accordingly. Completion is expected within the revised project cost and schedule.

The funding schedule for the project now extends through FY 2005, with operation of the NuMI facility starting in FY 2005.

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
FY 2003 Budget Request	3Q '98	4Q '00	3Q '99	4Q '05	109,242	171,442

2. Financial Schedule

(dollars in thousands)

Fiscal Year	Appropriations	Obligations	Costs
Design & Construction			
1998	5,500	5,500	1,140
1999	14,300	14,300	5,846
2000	22,000	22,000	15,089
2001	22,949	22,949	19,752
2002	11,400	11,400	30,000
2003	20,093	20,093	20,000
2004	12,500	12,500	14,000
2005	500	500	3,415

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 (6.6% of TEC)	7,180	7,180
Construction Phase		
Buildings	12,228	8,320
Special Equipment	20,902	10,120
Other Structures	41,265	30,960
Construction Management (6.3% of TEC)	6,846	4,590
Project Management (4.4% of TEC)	4,788	2,170
Total, Construction Costs	86,029	56,160
Contingencies		
Design Phase (0.0% of TEC)	0	2,172
Construction Phase (14.7% of TEC)	16,033	10,637
Total, Contingencies (14.7% of TEC)	16,033	12,809
Total, Line Item Cost (TEC)	109,242	76,149

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

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.

6. Schedule of Project Funding

(dollars in thousands)

	Prior Years	FY 2001	FY 2002	FY 2003	Outyears	Total
Project Cost						
Facility Cost						
Total, Line item TEC................................	22,075	19,752	30,000	20,000	17,415	109,242
Other Project Costs						
Capital equipment [a]................................	7,627	9,571	14,681	9,928	2,703	44,510
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]	8,542	3,069	3,725	224	0	15,560
Total, Other Project Costs.............................	18,299	12,640	18,406	10,152	2,703	62,200
Total Project Cost (TPC)................................	40,374	32,392	48,406	30,152	20,118	171,442

[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] Includes 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.

Nuclear Physics

Program Mission

The mission of the Nuclear Physics (NP) program is to foster fundamental research in nuclear physics that will provide new insights and advance our knowledge on the nature of matter and energy and develop the scientific knowledge, technologies and trained manpower that are needed to underpin the DOE's missions for nuclear-related national security, energy, and environmental quality. The Program provides world-class, peer-reviewed research results and operates user accelerator facilities in the scientific disciplines encompassed by the NP mission areas under the mandate provided in Public Law 95-91 that established the Department.

Strategic Objectives

SC2: By 2015, describe the properties of the nucleon and light nuclei in terms of the properties and interactions of the underlying quarks and gluons; by 2010, establish whether a quark-gluon plasma can be created in the laboratory and, if so, characterize its properties; by 2020, characterize the structure and reactions of nuclei at the limits of stability and develop the theoretical models to describe their properties, and characterize using experiments in the laboratory the nuclear processes within stars and supernovae that are needed to provide an understanding of nucleosynthesis.

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

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

Program Strategic Performance Goals

SC2-1: Determine the structure of nucleons in terms of bound states of quarks and gluons. Measure the effects of this structure on the properties of atomic nuclei. (Medium Energy Nuclear Physics and Nuclear Theory subprograms)

Performance Indicators

Results of external and internal reviews of quality, relevance and leadership of research activities and facility operations; number of significant scientific discoveries.

Performance Standards

As discussed in Corporate Context/Executive Summary.

Annual Performance Results and Targets

FY 2001 Results	FY 2002 Targets	FY 2003 Targets
As elements of the electron beam program, (a) completed fabrication of the BLAST detector at MIT/Bates in accordance with project milestones and (b) conducted precise studies of nucleon structure, including studies of the proton's internal charge distribution and role of QCD in nuclear structure by delivering high intensity (140 microamps), highly polarized (75%) electron beams with CEBAF at TJNAF. (SC4-1) [Met goal]	As elements of the electron beam program, (a) complete commissioning of the BLAST detector at MIT/Bates and initiate first measurements and (b) complete fabrication, installation and commissioning of the G0 detector, a joint NSF-DOE project, at TJNAF. (SC2-1)	As elements of the electron beam program, (a) complete first experiments with the BLAST detector at MIT/Bates, studying the structure of nucleons and few body nuclei and (b) map out the strange quark contribution to nucleon structure using the G0 detector, utilizing the high intensity polarized electron beam developed at TJNAF. (SC2-1)
	Commission polarized protons at RHIC. (SC2-1)	Collect first data with polarized protons with the RHIC STAR, PHENIX and pp2pp detectors. (SC2-1)

SC2-2: Determine the behavior and properties of hot, dense nuclear matter as a function of temperature and density. Discover and characterize the quark-gluon plasma. (Heavy Ion Nuclear Physics and Nuclear Theory subprograms)

Performance Indicators

Results of external and internal reviews of quality, relevance and leadership of research activities and facility operations; number of significant scientific discoveries.

Performance Standards

As discussed in Corporate Context/Executive Summary.

Annual Performance Results and Targets

FY 2001 Results	FY 2002 Targets	FY 2003 Targets
Produced first heavy-ion collisions at the Relativistic Heavy Ion Collider (RHIC - construction completed FY1999) at 10% of its design luminosity, as planned, with four experimental detectors. Published first results of heavy-ion collisions. [Met Goal]	Complete first round of experiments at RHIC at full energy; achieve the full design luminosity (collision rate) of 2 x 10^{26} cm^{-2} s^{-1} for heavy ions. (SC2-2)	Initiate first round of experiments with collisions with other ions to compare to results of gold-gold collisions. (SC2-2)
Continued major accelerator improvement projects at RHIC in order to improve machine reliability and efficiency. [Met Goal]	Complete Helium Storage addition and liquid nitrogen standby cooling system at RHIC leading to better cost effectiveness ($0.5M savings) and operational efficiency (10% increase). (S2-2/SC7-2)	Upgrade the RHIC cryogenics system by replacing turbine oil skids and removing seal gas compressor, eliminating a single point failure. (S2-2/SC7-2)

SC2-3: Determine the low energy properties of nuclei, particularly at their limits of stability. Use these properties to understand energy generation and the origin of the elements in stars, and the fundamental symmetries of the "Standard Model" of elementary particle physics. (Low Energy Nuclear Physics and Nuclear Theory subprograms)

Performance Indicators

Results of external and internal reviews of quality, relevance and leadership of research activities and facility operations; number of significant scientific discoveries.

Performance Standards

As discussed in Corporate Context/Executive Summary.

Annual Performance Results and Targets

FY 2001 Results	FY 2002 Targets	FY 2003 Targets
Produced first results on the solar neutrino flux with the Sudbury Neutrino Observatory (SNO). SNO measures properties of solar neutrinos. [Met Goal]	Collect the first data from neutral current interactions from SNO. (SC2-3)	Collect the first data from KamLAND, a joint U.S.-Japan experiment measuring neutrinos produced in nuclear reactors. (SC2-3)
Tested low-energy prototype of RIA fast catcher and tested low-beta accelerator cavities. [Met Goal]	Construct a prototype high energy, high power gas catcher for RIA. (SC2-3)	Complete testing the prototype high energy, high power gas catcher, and prototype targets for RIA. Complete prototype ECR ion source and work on the development of the high-beta superconducting RF cavities for RIA. (SC2-3)

SC7-2: Manage all NP facility operations and construction to the highest standards of overall performance, using merit evaluation with independent peer review. (Medium Energy Nuclear Physics, Heavy Ion Nuclear Physics, and Low Energy Nuclear Physics subprograms)

Performance Indicators

Percent on time/on budget; percent unscheduled downtime.

Performance Standards

As discussed in Corporate Context/Executive Summary.

Annual Performance Results and Targets

FY 2001 Results	FY 2002 Targets	FY 2003 Targets
Maintained and operated NP scientific user facilities so that the unscheduled operational downtime was 15%, on average, of total scheduled operating time. [Met Goal]	Maintain and operate NP scientific user facilities so that the unscheduled operational downtime will be kept to less than 20%, on average, of total scheduled operating time. (SC7-2)	Maintain and operate NP scientific user facilities so that the unscheduled operational downtime will be kept to less than 20%, on average, of total scheduled operating time. (SC7-2)
Met the cost and schedule milestones for construction of facilities and Major Items of Equipment within 10% of baseline estimates. Completed on schedule the Analysis System for RHIC Detectors and RHIC Silicon Vertex Detector. [Met Goal]	Meet the cost and schedule milestones for construction of facilities and Major Items of Equipment within 10% of baseline estimates. Complete the PHENIX Muon Arm Instrumentation. (SC7-2)	Meet the cost and schedule milestones for construction of facilities and Major Items of Equipment within 10% of baseline estimates. Complete the RHIC STAR EMCAL. (SC7-2)

Significant Accomplishments and Program Shifts

In FY 2001, the DOE Nuclear Physics (NP) program was the major sponsor of fundamental nuclear physics research in the nation, providing about 90% of the federal support, with the National Science Foundation (NSF) providing most of the remaining support.

Over one-third of the program's funding was provided to scientists at universities and laboratories to conceive and carry out the research. The DOE NP program involves over 1900 researchers and students at over 100 U.S. academic, federal and private sector institutions. The program funds research activities at over 85 academic institutions located in 35 states and at 7 DOE Laboratories in 6 states. University researchers play a critical role in the nation's research effort and in the training of graduate students. About two-thirds of the nation's university researchers and graduate students doing fundamental nuclear physics research in FY 2001 were supported by the DOE Nuclear Physics program. Typically about 90 Ph.D. degrees are granted annually to students for research supported by the program. State-of-the-art facilities to address forefront physics are essential for the U.S. to maintain its world leadership role in nuclear physics research. They are necessary not only to make progress in our understanding of fundamental nuclear physics, but also to provide scientific opportunities for discovery that generate the interest and excitement to attract the brightest, most talented students.

The DOE Nuclear Physics program has made important discoveries in the past decade of great relevance to the field and DOE science missions. The assembly of a large set of precision nucleon-nucleon scattering data has provided critical input for theoretical models that now produce a significantly more quantitative description of nuclei, now making possible the development of a "Standard Model for Nuclei". The past decade has seen a growing interest by the field to understand nucleons in terms of the quarks and gluons of QCD. This interest has been spurred by advances in both theory and experiment. The discoveries in the late eighties that the quarks carried only 1/3 of the nucleon spin instead of all of it and that the velocity distributions of quarks in iron nuclei were different from those in deuterium raised interest in studying the roles of gluons and the nuclear medium in nucleon structure. This was the first clear evidence of nuclear medium effects at the quark level. The start of the Continuous Electron Beam Accelerator Facility (CEBAF) in 1995 at the Thomas Jefferson National Accelerator Facility, using a new superconducting radio-frequency (SRF) technology, provided a unique high-energy, high-intensity polarized electron beam, the "world's finest electron microscope," to perform detailed measurements of the structure of the nucleon and of light nuclei. This has led to the use of SRF for powerful new light and particle sources, worldwide, such as the Spallation Neutron Source. Recent results from CEBAF are revealing evidence of the transition from hadronic to quark degrees of freedom.

In the Heavy Ion program, after decades of search and study, the elusive transition of nuclear matter from a liquid to a gaseous phase was observed in the late 1990's. At much higher energies, the study of hot and extremely dense hadronic matter became possible with the advent of gold beams at the Alternating Gradient Synchrotron in 1992 and lead beams at the CERN SPS in 1994, where the U.S. played a substantial role in major experiments. The "fireball" systems formed in these collisions equilibrated rapidly and at a high temperature and density, producing conditions that indicated that the new phase of nuclear matter, the predicted quark-gluon plasma, would likely be formed at the even higher energies that would be available with the Relativistic Heavy Ion Collider at Brookhaven National Laboratory. First gold-gold collisions were observed at RHIC in 2000. With this new facility, the U.S. is leading the world effort in creating and characterizing the quark-gluon plasma, a new form of matter that is thought to have existed shortly after the "Big Bang."

The Low Energy subprogram embraces studies of nuclear structure and nuclear astrophysics, as well as related work in fundamental interactions and neutrino physics. The 1990's began with an effervescent research effort at the 88" Cyclotron, ATLAS, and other facilities to identify and characterize rapidly rotating superdeformed nuclei that have elongated football shapes. These spectroscopic studies have led to a deeper understanding of nuclear structure at high spin and large deformation. In 1997, the HRIBF facility became operational and is now producing over 100 proton-rich and neutron-rich radioactive beams. Research at these three facilities has explored nuclei at the extremes of nuclear spin, deformation, stability, and excitation energy. Stable beams and the first radioactive beams in the mid-1990's enabled nuclear structure and cross-section experiments to determine the nuclear reaction paths and some rates for the breakout from the stellar carbon-nitrogen-oxygen (CNO) cycle that leads to production of heavier elements. In neutrino physics following the pioneering work in solar neutrinos with radiochemical experiments, the SNO experiment was conceived in the late 1980's to search for neutrino flavor oscillations due to their having mass, and designed and built it in the 1990's. In 2001, SNO reported its first physics results, which, together with other experimental results, make a persuasive case for neutrino oscillations and that neutrinos have mass.

It has been known for a long time that nuclear structure cannot be explained fully using only two-body (nucleon-nucleon) interactions. The first fully converged calculations of the properties of the tri-nucleon (^{3}H and ^{3}He) ground states were completed in 1991. The description of the three-body system is one of the most fundamental problems of nuclear physics and had been studied for decades before this result. Recently, the origin of many collective modes of motion in even-even nuclei was explained by the interacting boson model, which makes use of the symmetry properties of valence neutron-proton pairs. In a series of papers published between 1989 and 1995, a new method for understanding the quark structure of matter via QCD was developed by focusing on systems in which one of the quarks is very heavy. This technique has led to a significant advance for using QCD to describe hadron structure. In the past five years, the availability of enormous computing power has allowed theorists to make spectacular progress on problems that were previously thought intractable. It is now possible to simulate complex nuclear physics processes at extreme length scales ranging from astrophysical objects, nuclei, to the quark structure of matter. The development of the Green's Function Monte Carlo Technique, as a solution to the nuclear many-body system, and the Monte Carlo Shell Model of nuclei are state-of-the-art computational methods that could provide a framework for a "Standard Nuclear Model" in the near future. In the last few years, large-scale parallel processor machines have been exploited to simulate QCD problems on a space-time lattice.

Recent accomplishments are detailed below.

SCIENCE ACCOMPLISHMENTS

Medium Energy Nuclear Physics

- *Role of the Strange Quark in the Structure of the Proton:* The SAMPLE experiment at Bates and the HAPPEX experiment in Hall A at TJNAF have provided information on the contribution of strange quarks to the electromagnetic form factors of the proton. The SAMPLE experiment was completed in FY 2001 and provided the first direct information on how different quark flavors in the quark "sea" contribute to the proton's magnetic moment. The HAPPEX experiment measured these form factors in a different kinematic regime than the SAMPLE experiment. Both found, quite unexpectedly, that the strange quarks play a small role in contributing to the electromagnetic form factors.
- *New Measurements of the Deuteron Provide Information on the Role of QCD in Nuclear Structure:* The deuteron is the simplest nucleus that can be formed, a bound proton and neutron. New measurements of deuteron structure functions at TJNAF allow scientists to study how well conventional nuclear models compare with calculations done by the full theory of Quantum Chromodynamics (QCD). Such measurements provide scientists with guidance on how to mathematically "connect" high-energy QCD calculations to low energy systems in which QCD cannot be calculated exactly.
- *New Precision Measurement of G_E^p / G_M^p Yields Surprising Results:* A recent experiment which measures the ratio of the proton's internal charge distribution to its magnetic (or current) distribution indicates that this ratio significantly decreases from unity as one probes as a function of increasing spatial resolution. This was unexpected since the charge distribution and current distributions are related and the ratio was expected to remain near unity. This experiment used a new technique that capitalizes on the high intensity polarized beam that is unique to TJNAF. The measurement is very important for understanding the internal quark structure of the proton and will constrain quark models of the proton that try to predict this effect. New measurements are planned which will go to even higher resolution to determine if the trend continues or reverses.
- *Recent Results on Flavor Asymmetry in the Nucleon's Quark "Sea:"* Recent publications of work done at Fermilab and the HERMES experiment at DESY in Germany clearly show a strong asymmetry in the number of "down" antiquarks compared to "up" antiquarks in the nucleon's "sea" of virtual quarks. The asymmetry varies significantly with the degree of momentum transferred to the struck quark in the "sea". This "sea" of virtual quarks and gluons is believed to play a significant role in the properties of the nucleon. Many theoretical models have been proposed to explain this asymmetry. Most of these models indicate that the asymmetry can be explained by the existence of virtual mesons in the nucleon. These results have distinct implications for the spin and flavor structure of hadrons that can be tested in future experiments.
- *Precision Measurements of an Excited State of the Nucleon Yield Information on its Dynamic Structure:* Recently published data from Hall B at TJNAF report on a resonance, an excited state of the nucleon, that has unusual properties which makes it possible that it is not a standard three-quark excited state of the nucleon. These new data will provide strong constraints on theoretical models that attempt to explain the resonance's properties.
- *First Determination of the Shrinkage of a Nucleus Due to the Presence of Strange Quarks:* Recent measurements by the HyperBall detector using the Alternating Gradient Synchrotron at Brookhaven National Laboratory have measured a 20% shrinkage in the nuclear radius of ^{7}Li when a neutron is changed into a Lamda (Λ) particle by exchanging a "down" quark with a "strange" quark, which is much heavier. While the shrinkage was expected, the magnitude of the effect was surprising. The precision of the measurement makes it possible to study the effect of this heavier quark in the

nuclear environment, giving us information on both the strange quark and the binding forces inside the nucleus.

- *Development of a New Isotope-Counting Technique with Potential for Important Applications:* A new precision technique for Atom Trap Trace Analysis (ATTA) to identify and count extremely rare isotopes has been developed at Argonne National Laboratory. The technique allows one to make precision measurements of the charge radius of several helium isotopes for fundamental tests of nuclear models and to measure the solar neutrino flux integrated over several million years as a test of the solar model prediction for neutrino production in the sun. The latter is an important test for understanding the low solar neutrino flux problem. This technique also potentially has broad new practical applications, such as dating ground water and polar ice for environmental and geologic studies, dating bones for archeological purposes, and, in medicine, monitoring bone loss in humans.

Heavy Ion Nuclear Physics

- *First Relativistic Heavy Ion Collider Results:* First RHIC measurements indicate that the energy density – a measure of the energy deposited in the collision region by the colliding nuclei – is the highest ever achieved in a laboratory, at least 70% higher than in similar experiments at CERN, and sufficient to create the long sought quark-gluon plasma (QGP), believed to be the state of matter of the universe shortly after the "Big Bang." Several papers reporting results have already been published and many others are expected to follow shortly. Discussion of these results dominated the premier international conference of this field - Quark Matter 2001.

- *3D Imaging:* Collisions between heavy ions create a brief microcosm of strongly interacting subatomic particles termed a "fireball". Using a correlation technique called HBT (Hanbury Brown Twiss) first applied to determine stellar sizes, physicists have measured the volume of the fireball created in the collisions at RHIC to be about as large as that of a gold nucleus. Two-particle correlations can be used to map out the time profile of hadron emission from the hot, dense matter.

- *Expansion of the Fireball:* In the most violent collisions at RHIC, over 5000 subatomic particles emanate from the fireball. By measuring their energies, scientists have determined that the fireball expands rapidly with a velocity approaching 2/3 the speed of light. This is evidence of the extremely rapid thermalization of the incident energy and its conversion into heating up the fireball.

- *Elliptic Flow:* The fireball emits particles asymmetrically in space. This information suggests the fireball geometry has an 'almond' shape – a result that has intrigued the scientific community. One theoretical model suggests this shape occurs as a consequence of pressure generated by an early fluid-like expansion of the quark-gluon plasma – a plasma of nearly massless quarks and gluons.

- *Abundance of Anti-matter:* Scientists have analyzed the constituents of the fireball and have found the ratio of baryonic matter and anti-matter to be nearly 0.8 (i.e., almost equal amounts of each). An equal mixture of matter and anti-matter is thought to have existed in the primitive universe. The RHIC observation is a preliminary indication that favorable conditions exist for QGP formation.

- *Jet Quenching:* A very energetic quark and anti-quark pair may decay into many subatomic particles focused in a narrow cone called a jet. First results suggest these 'hard scattered' pairs are created in a fireball with a high energy density. Jets lose energy as they travel through a QGP and, in turn, fewer subatomic particles are found with high energies. The preliminary RHIC data provide tantalizing hints of a suppression of high momentum subatomic particles. This quenching effect is not observed in lower energy collisions.

Low Energy Nuclear Physics

- *First Solar Neutrino Physics Results from SNO:* The first phase of data taking with the SNO solar neutrino experiment has been completed and the first published results report that neutrino oscillations, not lower than expected neutrino production by the sun, are the reason for deficits in solar neutrinos detected on earth. The SNO experiment is unique among solar neutrino experiments in that in its second experimental phase now underway it can also measure the appearance of non-electron neutrino flavors into which the solar electron neutrinos oscillate. If neutrinos oscillate, as first SNO results indicate, they must have a non-zero mass. These results will have profound implications for the present understanding of the Standard Model of fundamental particles and interactions.
- *Measurement of the $^{44}Ti(\alpha,p)$ Reaction Cross Section:* At ATLAS (ANL) the cross section for the ^{44}Ti (α,p) reaction has been measured experimentally for the first time using a beam of radioactive ^{44}Ti; this cross section has been determined to be significantly larger than previously estimated. ^{44}Ti can be used to identify and study supernovae remnants in the nearby cosmos because it has a half-life of 60 years and emits high-energy gamma rays. The use of the measured cross section for the ^{44}Ti (α,p) reaction in supernova explosion calculations results in lower residual ^{44}Ti in a supernova remnant, since this reaction process is a principal cause of ^{44}Ti destruction in these explosions. As the residual ^{44}Ti is less than previously assumed, this means that supernovae remnants studied by orbiting gamma-ray spectrometers are closer that previously believed.
- *First Identification Of The Di-Proton Decay Mode:* Decay of a nucleus by simultaneous emission of two protons has been identified for the first time by researchers at the ORNL HRIBF. The decaying nucleus, ^{18}Ne, was produced using a radioactive ^{17}F beam reacting with a hydrogen target. Future measurements will be undertaken to determine if the two protons are correlated (i.e., briefly interacting as a pair of protons) or uncorrelated (i.e., moving independently in the nucleus before decay). These data will provide information on the structure of nuclei near the proton dripline.
- *Characterization of the Superdeformed Band in ^{36}Ar:* The lifetimes of superdeformed states in the light Z = N nucleus ^{36}Ar have been measured with Gammasphere using beams provided by the ANL ATLAS facility. This information can be used to understand the microscopic origin of collective nuclear rotations. Superdeformed states occur in rapidly rotating nuclei that are oblong shaped with axes having ratios of about 2:1. Most of these are heavy nuclei where protons and neutrons are treated collectively by theoretical models. Since ^{36}Ar has comparatively few protons and neutrons, it may be possible to calculate the detailed properties of these states with the nuclear shell model that describes nuclei in terms of individual protons and neutrons.
- *First Evidence of Freeze-Out Effects in the S-Process:* At ORNL the resonance analysis of ^{192,194,195,196}Pt(n,γ) data from the Oak Ridge Electron Linac Accelerator (ORELA), and the study of the slow neutron capture process (s-process) branching at ^{192}Ir, have resulted in first evidence of long-sought freeze-out effects during s-process nucleosynthesis in a certain class of stars. These freeze-out effects involve the time dependence of the mean neutron density and temperature in the star as the capture process proceeds, thus providing details on stellar dynamics.
- *Observation and Characterization of Chiral Symmetry in Nuclei*: Scientists at several universities, including Yale University and the University of Tennessee, have identified twin bands of nuclear levels interpreted as resulting from chiral (mirror) symmetry. Although this symmetry in nuclei has been predicted theoretically it had never been experimentally observed. The existence of chiral symmetry requires specific conditions, including a deformed nucleus with an odd neutron and an odd proton. The spin vectors of the nuclear core, the odd neutron and the odd proton point in three

mutually perpendicular directions, forming either a right-handed or left-handed coordinate system and giving rise to the twin band structure.

Nuclear Theory

- *Advances in Neutron Star Science:* A number of theoretical nuclear astrophysicists have focused their recent efforts on understanding the characteristics of neutron stars. Increasingly realistic calculations are testing assertions that there may be condensation of kaons in these giant 'nuclei' and that there may be quasi-crystalline structure within them. Input to these studies includes both the fundamental understanding of particle interactions folded into massive numerical simulations, and experimental observations. The mass accretion properties of these stars have been deduced through study of 'X-ray bursters' that has shed light on both their equation of state and their rotational properties. The sudden spin-up behavior of pulsars known as 'glitches' has also been analyzed to yield an important new constraint on the mass-radius relationship for neutron stars that does not depend on their equation of state.
- *Quark Structure of the Deuteron:* New calculations have successfully explained the breakup of the deuteron into a proton and neutron by photons at high energies in terms of a single quark-level process. This is an important step toward understanding the quark and gluon degrees of freedom in nuclei, since deuterium is the simplest stable nucleus with more than a single nucleon. Previous theoretical attempts had successfully described the angular distributions of the emitted protons and neutrons fairly well, but predicted the basic probability of the breakup to occur to be 100 times too small. The new theory describes the data on average with better than 20% accuracy using only a single process; several further improvements are possible.
- *Thermalization in Ultra Relativistic Heavy Ion Collisions:* Recent work in perturbative QCD, the high-energy theory of the strong interaction, has determined that thermalization is guaranteed to occur for sufficiently high energies and sufficiently heavy nuclei in ultra relativistic heavy ion collisions. The system formed in the collision achieves thermal equilibrium surprisingly rapidly compared to the time required for it to fly apart, and the mechanism for achieving the equilibrium is an unexpected one. The thermal equilibrium condition, when achieved, greatly simplifies the interpretation of the particle spectrum ejected from the collision and permits much simpler calculations to describe the reaction.
- *New Theoretical Tool Ties Together Many Different Phenomena:* Generalized Parton Distributions (GPD's) were invented in recent years to describe certain exclusive high-energy electromagnetic reactions on the proton and neutron. GPD's have now been broadly linked to a much larger variety of electromagnetic observables or processes such as elastic form factors, high-energy meson production, inclusive deep-inelastic-scattering measurements, and virtual Compton scattering. The impact of this is that these distributions, when measured, will be able to be cross-correlated among these several very different types of reactions, testing the correctness of this theory and providing a compact description of a wide range of disparate phenomena.
- *Advances in Few-Body Reactions:* Low-energy properties of three-body systems such as ^{3}He have long been successfully described by a complicated method called Faddeev calculations. This method, while exact in principle, could not be extended to higher energies: the procedure fails to be practical because the number of angular momentum states becomes very large. A technical breakthrough in computational methods now permits a full three-dimensional solution of the Faddeev equations without using angular momentum decomposition; this will permit the method to be extended to higher energies. The first test of the new calculations against the older method has shown excellent agreement, verifying the new approach to very high accuracy.

- *Indicators of Quark-Gluon Plasma Formation:* While a number of indicators for the quark-gluon plasma have been proposed by theorists in the field, a particularly interesting method developed recently is that of event-by-event fluctuations in the ratio of particle types. A quark-gluon plasma is hoped to be formed in ultra-relativistic heavy-ion collisions such as those studied at RHIC. Fluctuations in the ratio of positively charged particles to negatively charged particles give a direct measure of the charge fluctuations per unit entropy. Since quarks in the quark-gluon plasma have only fractional charges (1/3 or 2/3 the charge of composite particles), the fluctuations are expected to be much smaller for the quark-gluon plasma compared to that in normal nuclear matter. This simple-sounding prediction has continued to hold up under detailed scrutiny by numerous researchers.

FACILITY AND TECHNICAL ACCOMPLISHMENTS

Medium Energy Nuclear Physics

- In FY 2001, the *Continuous Electron Beam Accelerator Facility at the Thomas Jefferson National Accelerator Facility Provided 140 Microamperes of Nearly 80% Polarized Beam at 5.7 GeV* (42% greater than the design energy of 4 GeV). These high intensity, highly polarized beam capabilities are unique in the world for electron accelerators. A newly developed diode laser with a Ti:Sapphire optical amplifier will make it possible to increase the intensity of this polarized beam by a factor of more than 500. In the past three years of full operations, 32 experiments have been completed and another 50 are partially completed, resulting in about 100 published papers and 60 Ph.D. theses.
- *CEBAF Represents the World's Most Powerful Superconducting Radio Frequency (SRF) Accelerator.* The SRF cavities have exceeded their design specifications by 50%, making it possible for CEBAF to accelerate 6 GeV beams. It is expected that further advances in SRF technology and the production of a new compact cryomodule could lead to a relatively simple and inexpensive upgrade of CEBAF's top energy to 12 GeV. R&D funding is provided in FY 2003 for this upgrade that is identified in the most recent NSAC long range planning exercise as a high priority opportunity that should be pursued.
- *RHIC Accelerates the Highest Energy Polarized Protons to Date.* The RHIC Spin program at Brookhaven National Laboratory successfully accelerated polarized protons in the RHIC rings to an energy of approximately 32 GeV with 20% polarization during its commissioning run in FY 2001 and reached an energy of 100 GeV in early FY 2002. This demonstrated that polarized protons can be successfully accelerated in the rings and set a record for the highest energy polarized proton beam ever achieved. This is not an easy accomplishment because the polarized protons are subject to depolarizing resonances as their energy is increased. Special approaches had to be developed to maintain the polarization during acceleration.
- The *BLAST Detector* at the MIT/Bates facility is nearing completion, and in FY 2002 a unique research program will be initiated to study the structure of the nucleon and few-body nuclei. The successful storage of 200 milliamperes of polarized beams in the South Hall Ring in FY 2001 demonstrated that the needed beam capabilities have been developed to carry out the BLAST research program in FY 2002-2004.
- *Fabrication of the G0 Detector* at the Thomas Jefferson National Accelerator Facility (TJNAF) is on cost and schedule to be completed in FY 2002 and initiate commissioning. It utilizes the very high intensity polarized electron beam developed at TJNAF in mapping out the strange quark contribution to nucleon structure over a wide range of momentum transfer.

- *Scintimammography and Molecular Imaging Developed at TJNAF:* In the past few years, the detector group at TJNAF has developed high resolution gamma imagers for biomedical applications. This is a device that "senses" gamma rays emitted by a tumor after absorption of a biological tracer and then builds an image of the tumor, thus improving breast cancer detection. In combining scintimammography and digital x-ray techniques, the group has designed a mini gamma camera for use in conjunction with a commercially available x-ray guidance system for stereotactically guided core needle breast biopsies.
- *Hyperpolarized Gas Provides Enhanced MRI Imaging:* A new technique has been developed by university researchers that enhances MRI imaging of lungs through the use of "hyperpolarized gas." The technique, initially developed to provide polarized targets for nuclear physics experiments, uses lasers to polarize large volumes of noble gases that can then be inhaled. The MRI equipment detects the resonance of the polarized gas to provide an image of the air volume of the lungs. The process is presently undergoing clinical trials.

Heavy Ion Nuclear Physics

- *Construction of the Relativistic Heavy Ion Collider (RHIC)* at Brookhaven National Laboratory was completed in FY 1999 on cost and schedule (TPC of $616,530,000). Commissioning started in FY 1999 and data taking started in FY 2000, as scheduled. During the FY 2000 run RHIC reached about 10% of its design luminosity (collision rate), as planned. RHIC reached operation at full luminosity for gold-gold collisions early in FY 2002.
- *Real Time Pattern Recognition and Tracking:* The STAR Time Projection Chamber is one of the most advanced instruments used to study heavy ion collisions, providing digital information from over 100,000 sensors. Scientists have developed software algorithms and built a farm of high-speed computers that sift through the sensor data to carry out pattern recognition. Images of thousands of tracks that are emitted in each head-on gold-gold collision are reconstructed in a fraction of a second in real time. The stunning STAR-burst pictures were published by news media throughout the world.
- *RHIC Detector Enhancements Remain on Cost and Schedule:* Fabrication of the STAR Silicon Vertex Detector (SVT), a high-resolution, high-granularity, charged-particle tracking system very close to the collision region, was successfully completed in FY 2000 and installed in FY 2001. The RHIC Data Analysis System was completed in FY 2000 and successfully recorded and stored the acquired experimental data that has been analyzed and published in several papers. One PHENIX Muon Arm will be completed and commissioned in FY 2001; the second Arm (funded substantially by Japanese collaborators) will be completed in FY 2002. The Electro-Magnetic Calorimeter (EMCal) for STAR began production fabrication of modules in FY 2000, will commission existing modules in FY 2001, and is on schedule for completion of the planned system in FY 2003. An enhancement of the EMCAL, providing additional modules for full coverage of the barrel and optimizing the performance for the RHIC Spin Program, will commence in FY 2003.

Low Energy Nuclear Physics

- *Production of Accelerated Radioactive Ion Beams:* In FY 2001 over 100 neutron-rich radioactive beams were produced and accelerated at the HRIBF at ORNL, the only facility in the world where these high-quality, high-energy beams are available for research. These accelerated neutron-rich radioactive beams are suitable for a variety of nuclear spectroscopy studies. The first spectroscopy experiments with these low-intensity beams utilized a combination of gamma-ray, charged-particle, and recoil-particle spectrometers, and included Coulomb excitation experiments and fusion and incomplete-fusion reactions.

- *Development of Crucial Technologies for the Rare Isotope Accelerator (RIA):* A prototype of the fast ion gas catcher, a technology that greatly extends the exotic beam production capability of RIA, was designed, built and successfully tested at ANL. A test of a full-scale version of the gas catcher will be mounted in the near future. The Versatile Electron Cyclotron Resonance (ECR) for Nuclear Science (VENUS) ion source, under construction at LBNL, is a test bed for technologies that will provide the high intensity ion source for the RIA driver linac and can be used to produce higher intensity beams at the other operating facilities such as ATLAS. Prototypes of several of the superconducting radiofrequency accelerator cavities have been built at ANL, including an intermediate energy cavity not previously designed.
- *First Nuclear Physics Experiments at the High Intensity Gamma-ray Source (HIγS):* The first nuclear physics experiments have begun at HIγS at TUNL for gamma-ray energies below 12 MeV. HIγS uses a special optical cavity at the Duke University Free Electron Laser to generate a narrow beam of mono-energetic high-energy gamma rays. An upgrade begun in FY 2001 will make this facility unique in the world in terms of the gamma-ray flux, energy range and attainable energy resolution it will provide for nuclear physics measurements.
- *The KamLAND Neutrino Detector*: The detector for the KamLAND experiment in Japan is nearing completion. This experiment will search for oscillation of neutrinos produced in distant nuclear reactors to test one of the possible solutions that are compatible with current atmospheric neutrino oscillation results. Scientists from the U.S., jointly supported by the Nuclear and High-Energy Physics programs, are collaborating with Japanese scientists in the construction and operation of KamLAND.
- *High Precision Mass Measurements:* In FY 2001 the first high-precision mass measurements of unstable nuclei have been accomplished with the Canadian Penning Trap at ATLAS (ANL). One of the technique's early uses will be the measurement of the mass of certain Z=N nuclei to completely characterize the Gamow-Teller beta decay of these nuclei, and place constraints on the Standard Model of weak interactions.
- *Development of Segmented Germanium Detectors:* Measurements using a 36-fold segmented germanium crystal at LBNL yield a three-dimensional position resolution of less that 1 mm for the determination of the position of a gamma-ray interaction in the crystal. When all of the interaction positions of a scattered gamma ray are known, the full energy and origin direction of the gamma ray can be reconstructed. This is a critical step in the development of a state-of-the-art tracking detector array that will be 1000 times more sensitive than Gammasphere, presently the most powerful gamma-ray detector in the world.
- *Development of a New Source for Ultra-Cold Neutrons:* Development of a source of ultra-cold neutrons is underway at LANL, and will be completed in FY 2003. Using a prototype source, scientists at LANL have exceeded by a factor of three the world's previous record for number of ultracold neutrons trapped. Further gains are expected with the full-scale source. This ultra-cold neutron source will allow the measurement of the details of neutron decay, and test aspects of the Standard Model.

PROGRAM SHIFTS

In the FY 2003 budget request the scientific scope of the nation's nuclear physics program is maintained. The FY 2003 budget request is focused on optimizing the utilization of its major user facilities. Facility operations are provided a 10% increase in funding in FY 2003 that will result in a 21% increase in beam hours for research compared to FY 2002. The research programs at these major user facilities are integrated partnerships between DOE scientific laboratories and the university community, and the planned experimental research activities are considered essential for effective utilization of the facilities. Funding for university and national laboratory research is increased about 4% compared to FY 2002, maintaining approximate constant level of effort. Funding for capital equipment is held essentially flat compared to FY 2002 and a 25% increase in R&D activities directed at RIA.

The Scientific Discovery through Advanced Computing (*SciDAC)* program is an Office of Science initiative to address major scientific challenges that require advances in scientific computing using terascale resources. An effort managed by the Office of High Energy and Nuclear Physics (HENP) identified the most compelling opportunities for advancements and for coordinated efforts in these two scientific fields by the application of terascale computing resources. This effort resulted in the identification of two such challenge areas within the domain of theoretical nuclear physics, and in FY2001 several major multi-institutional grants in high-priority topical areas were awarded through this program for the first time. One topical area is *Lattice QCD*. The collaboration involved represents essentially the entire U.S. community in this area with efforts from both nuclear and high-energy physics communities and strong involvement of both of the Nuclear Physics program's major accelerator facilities, TJNAF and RHIC. The scientific goal is to solve Quantum Chromodynamics (QCD), the fundamental theory of the strong interaction, on a 'lattice' of space-time points using advanced numerical methods. This is an extremely active area of inquiry world-wide, with major ongoing efforts in Europe and Japan. Of particular relevance to nuclear physics are the activities focused on solving QCD in two domains: the structure of the proton and neutron and their excited states, and the quark-gluon plasma that is anticipated to be produced at RHIC. A second topical area is *Theoretical Nuclear Astrophysics*, particularly focusing on supernova phenomena. Two types of supernova explosions are being modeled: Type Ia explodes because of nuclear reaction processes; types II, Ib, and Ic, are thought to explode through core collapse, fueled by neutrino energy transport. These problems are intrinsically multidisciplinary, involving nuclear physics, general relativity, neutrino science, hydrodynamics and transport theory, and advanced computing techniques. This is an ideal challenge to push the frontiers of advanced computing.

Scientific Facilities Utilization

The Nuclear Physics request includes $260,140,000 to maintain support of the Department's scientific user facilities. This investment will provide 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 six National User Facilities supported by the Nuclear Physics program: the Relativistic Heavy Ion Collider (RHIC) complex at Brookhaven National Laboratory (BNL), the Continuous Electron Beam Accelerator Facility (CEBAF) at Thomas Jefferson National Accelerator Facility (TJNAF), the Bates Linear Accelerator Center at Massachusetts Institute of Technology (MIT), and the three low energy facilities: the Holifield Radioactive Ion Beam Facility (HRIBF) at Oak Ridge National Laboratory (ORNL), the Argonne Tandem Linac Accelerator System (ATLAS) facility at Argonne National Laboratory (ANL), and the 88-Inch Cyclotron at Lawrence

Berkeley National Laboratory (LBNL). Further information on these facilities can be found in the Site Description and Detailed Justifications under the subprogram in which they are funded.

These facilities provided about 20,000 hours of beams in FY 2001 for a research community of about 2,500 scientists. The FY 2003 President's Budget Request will support facility operations that will provide ~20,700 hours of beams for research, an increase of ~21% over the anticipated beam hours in FY 2002.

Workforce Development

The Nuclear 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 provides new scientific talent in areas of fundamental research. It also provides talent for a wide variety of technical, medical, and industrial areas that require the finely-honed thinking and problem solving abilities, and the computing and technical skills, developed through an education and experience in a fundamental research field. Scientists trained as Nuclear Physicists can be found in such diverse areas as nuclear medicine, medical physics, space exploration, national security and the stock market.

About 800 postdoctoral research associates and graduate students supported by the Nuclear Physics program in FY 2001 were involved in a large variety of experimental and theoretical research projects. Nearly one quarter of these researchers 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 (~80%) conducted their research at the Nuclear Physics User Facilities. In FY 2003, emphasis is placed on operations and research efforts at the national user facilities. The funding level will result in approximately the same number of postdoctoral research associates and graduate students that can be supported compared to FY 2002.

Funding Profile

(dollars in thousands)

	FY 2001 Comparable Appropriation	FY 2002 Original Appropriation	FY 2002 Adjustments	FY 2002 Comparable Current Appropriation	FY 2003 Request
Nuclear Physics					
Medium Energy Nuclear Physics ..	113,410	117,953	-443	117,510	123,590
Heavy Ion Nuclear Physics	152,112	156,292	-674	155,618	167,977
Low Energy Nuclear Physics.........	62,650	62,685	-263	62,422	66,158
Nuclear Theory	23,622	23,580	-95	23,485	24,645
Subtotal, Nuclear Physics	351,794	360,510	-1,475	359,035	382,370
General Reduction.........................	0	-1,475	1,475	0	0
Total, Nuclear Physics........................	351,794 [a] [b]	359,035	0	359,035	382,370

Public Law Authorization:

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

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

[a] Excludes $7,760,000 that has been transferred to the SBIR program and $466,000 which has been transferred to the STTR program.

[b] Excludes $488,000 transferred to Science Safeguards and Security program in an FY 2001 reprogramming.

Funding by Site

	(dollars in thousands)				
	FY 2001	FY 2002	FY 2003	$ Change	% Change
Albuquerque Operations Office					
Los Alamos National Laboratory	10,378	9,643	9,123	-520	-5.4%
Sandia National Laboratory	4	0	0	0	--
Total, Albuquerque Operations Office	10,382	9,643	9,123	-520	-5.4%
Chicago Operations Office					
Argonne National Laboratory	17,912	16,532	17,548	+1,016	+6.1%
Brookhaven National Laboratory	140,791	138,671	149,004	+10,333	+7.5%
Fermi National Accelerator Laboratory	50	0	0	0	--
Chicago Operations Office	54,513	50,840	52,111	+1,271	+2.5%
Total, Chicago Operations Office	213,266	206,043	218,663	+12,620	+6.1%
Oakland Operations Office					
Lawrence Berkeley National Laboratory	18,703	17,689	18,615	+926	+5.2%
Lawrence Livermore National Laboratory	755	614	507	-107	-17.4%
Oakland Operations Office	17,368	15,971	16,278	+307	+1.9%
Total, Oakland Operations Office	36,826	34,274	35,400	+1,126	+3.3%
Oak Ridge Operations Office					
Oak Ridge Institute for Science & Education	690	570	189	-381	-66.8%
Oak Ridge National Laboratory	15,879	15,307	16,870	+1,563	+10.2%
Thomas Jefferson National Accelerator Facility	74,135	73,830	79,138	+5,308	+7.2%
Total, Oak Ridge Operations Office	90,704	89,707	96,197	+6,490	+7.2%
Washington Headquarters	616	19,368	22,987	+3,619	+18.7%
Total, Nuclear Physics	351,794 [a] [b]	359,035	382,370	+23,335	+6.5%

[a] Excludes $7,760,000 that has been transferred to the SBIR program and $466,000 which has been transferred to the STTR program.

[b] Excludes $488,000 which was transferred to Science Safeguards and Security program in an FY 2001 reprogramming.

Site Description

Argonne National Laboratory

Argonne National Laboratory (ANL) in Argonne, Illinois, is a Multiprogram Laboratory located on a 1,700 acre site in suburban Chicago. ANL has a satellite site located in Idaho Falls, Idaho. The major Nuclear Physics program activity at ANL supported by the Low Energy subprogram is the operation and research program at the ATLAS national user facility. Other activities include: (1) a Medium Energy group which carries out a program of research at TJNAF, Fermilab, RHIC and DESY in Germany; (2) R&D directed towards the proposed Rare Isotope Accelerator (RIA) facility; (3) a Nuclear Theory group, which carries out theoretical calculations and investigations in subjects supporting the experimental research programs in Medium Energy and Low Energy physics; and (4) data compilation and evaluation activities as part of the National Data Program.

The **Argonne Tandem Linac Accelerator System (ATLAS)** facility provides variable energy, precision beams of stable ions from protons through uranium, at energies near the Coulomb barrier (up to 10 MeV per nucleon) using a superconducting linear accelerator. Most work is performed with stable heavy-ion beams, however, about 6% of the beams are exotic (radioactive) beams. The ATLAS facility features a wide array of experimental instrumentation, including a world-leading atom trap apparatus. The Gammasphere detector, which ATLAS shares on a rotating basis with the LBNL 88-Inch Cyclotron, coupled with the Fragment Mass Analyzer is a unique world facility for measurement of nuclei at the limits of angular momentum (high-spin states). ATLAS is a world leader in superconducting linear accelerator technology, with particular application to the proposed Rare Isotope Accelerator (RIA) facility. The combination of versatile beams and powerful instruments enables the ~125 users annually at ATLAS to conduct research in a broad program in nuclear structure and dynamics, nuclear astrophysics, and fundamental interaction studies.

Brookhaven National Laboratory (BNL)

Brookhaven National Laboratory is a Multiprogram Laboratory located on a 5,200 acre site in Upton, New York. The major Nuclear Physics program effort at BNL, supported by the Heavy Ion subprogram, is the operation and research program of the new Relativistic Heavy Ion Collider (RHIC). Other activities include (1) a Medium Energy group that will use polarized protons in RHIC to understand the internal “spin” structure of the protons, (2) the Laser Electron Gamma Source (LEGS) group, supported by the Medium Energy subprogram, that uses a unique polarized photon beam to carry out a program of photonuclear spin physics at the National Synchrotron Light Source (NSLS), (3) a Nuclear Theory group that does research primarily in the area of relativistic heavy ion physics, (4) a Low Energy group that plays an important role in the research program at the Sudbury Neutrino Observatory (SNO) that is measuring the solar neutrino flux, and (5) the DOE managed National Nuclear Data Center (NNDC) that is the central U.S. site for national and international nuclear data and compilation efforts.

The Relativistic Heavy Ion Collider (RHIC) Facility, completed in 1999, is a major new and unique international facility used by about 1,100 scientists from 19 countries. RHIC uses the Tandem, Booster, and Alternating Gradient Synchrotron (AGS) accelerators in combination to inject beams into two rings of superconducting magnets of almost 4 km circumference with 6 intersection regions where the beams collide. It can accelerate and collide a variety of heavy ions, including gold beams, up to an energy of 100 GeV per nucleon. RHIC will search for the predicted “quark-gluon plasma,” a form of nuclear matter thought to have existed microseconds after the “Big Bang.” Operations began in FY 2000 and first results have already been published. RHIC can also accelerate and collide polarized protons at energies up to 250 GeV for a research program directed at understanding the quark structure of the proton. Four detectors have been fabricated to provide complementary measurements, but with some overlap in order to cross-calibrate the measurements: (1) The core of the Solenoidal Tracker At RHIC (STAR) detector, built at a cost of ~$80,000,000, is a large Time Projection Chamber (TPC) located inside a solenoidal magnet that tracks thousands of charged particles emanating from a single head-on gold-gold collision. There are also end-cap TPC's. A large modular barrel Electro-Magnetic Calorimeter (EMCal), being fabricated with completion in FY 2003, measures deposited energy for high-energy charged and neutral particles and contains particle-photon discrimination capability. An enhancement to this calorimeter is being developed for the RHIC Spin program. An end-cap Calorimeter, also for the RHIC Spin program, is being funded by the NSF (TEC~$6,910,000; completion in FY 2004). A Silicon Vertex Tracker has very high tracking resolution for charged particles close to the collision vertex that greatly increases the tracking capabilities for the very short-lived multi-strange particles. (2) The Pioneering High-Energy Nuclear Interacting eXperiment (PHENIX) detector, built at a cost of ~$87,000,000, has a particular focus on the measurement of rarer probes at high event detection rate. It consists of two transverse smaller acceptance arms that can track charged particles within a magnetic field especially to higher momentum; it provides excellent discrimination among photons, electrons, and hadrons. There is also a Silicon Vertex Detector that can measure the total number of charged particles produced in a collision, but without particle identification. There are also two large muon tracking and identification systems in the forward and backward directions. (3) The PHOBOS detector, built at a cost of ~$7,600,000, is a very compact detector that uses mostly silicon pad sensors for charged particle detection and tracking, with a focus on measurements to very low momentum. It consists of two small-acceptance tracking arms located within a magnetic field and a very large coverage multiplicity detector that measures the total event charged-particle multiplicity and distribution. (4) The Broad Range Hadron Magnetic Spectrometer (BRAHMS) built at a cost of ~$6,200,000, has two very small acceptance magnetic spectrometer arms that be can rotated to scan the broadest range of angles. It is especially designed to study the charged particle distributions in the forward and backward directions.

The **Alternating Gradient Synchrotron (AGS)** provides high intensity pulsed proton beams up to 33 GeV on fixed targets and secondary beams of kaons, muons, pions, and anti-protons. Experiments explore the quark constituents of light nuclei, and test the theories of quantum chromo-dynamics and electro-weak forces. The AGS is the injector of (polarized) proton and heavy-ion beams into RHIC, and its operations are supported by the Heavy Ion subprogram as part of the RHIC facility. Operation of the AGS for fixed targets and secondary beams is terminated in FY 2003.

The **National Nuclear Data Center (NNDC)** is the central U.S. site for national and international nuclear data and compilation efforts. The U.S. Nuclear Data program is the United States repository for information generated in low- and intermediate-energy nuclear physics research worldwide. This information consists of both bibliographic and numeric data. The NNDC is a resource that maintains the U.S. expertise in low- and intermediate-energy nuclear physics by providing evaluated nuclear data for the user community. The NNDC is assisted in carrying out this responsibility by other Nuclear Data program funded scientists at U.S. National Laboratories and universities.

Lawrence Berkeley National Laboratory (LBNL)

Lawrence Berkeley National Laboratory 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. A major Nuclear Physics effort at LBNL, supported by the Low Energy subprogram, is the operations and the research program of the 88-Inch Cyclotron, a national user facility. Other activities include (1) a Relativistic Nuclear Collisions group, with activities primarily at RHIC, where the group has been a major player in the development of the STAR detector; (2) a Low Energy group which has a major role in the implementation and operation of the Sudbury Neutrino Observatory (SNO) detector in Canada, and provides the project management of the U.S. collaboration in the KamLAND detector in Japan which is looking for evidence of neutrino mass; (3) a Nuclear Theory group that carries out a program with emphasis on the theory of relativistic heavy ion physics; (4) a Nuclear Data group whose activities support the National Nuclear Data Center at BNL; and (5) a technical effort involved in RIA R&D.

The **88-Inch Cyclotron** facility provides high intensity stable beams from protons to bismuth at energies above the Coulomb barrier (up to 15 MeV per nucleon). The electron-cyclotron resonance (ECR) ion sources at the facility are state-of-the-art and copied around the world. The Gammasphere array, widely regarded as the world's most powerful gamma-ray detector, is used to study nuclei at the extremes of angular momentum and excitation energy. The Berkeley Gas-filled Separator, a world-class instrument, is used for discovery experiments in superheavy elements. The 88-Inch Cyclotron is used annually by a community of about 230 scientists.

Lawrence Livermore National Laboratory (LLNL)

Lawrence Livermore National Laboratory is a Multiprogram Laboratory located on an 821 acre site in Livermore, California. Nuclear Physics supports research in nuclear structure studies carried out with the GENIE detector that was installed and is maintained by the LLNL group at the LANSCE facility at Los Alamos National Laboratory, in relativistic heavy ions as part of the PHENIX collaboration, for nuclear data and compilation activities, and for a technical effort involved in RIA R&D.

Los Alamos National Laboratory (LANL)

Los Alamos National Laboratory is a Multiprogram Laboratory located on a 27,000 acre site in Los Alamos, New Mexico. Nuclear Physics supports a broad program of research including: (1) a program of neutron beam research that utilizes beams from the LANSCE facility; (2) a relativistic heavy ion effort using the PHENIX detector at the new Relativistic Heavy Ion Collider (RHIC); (3) research directed at the study of the quark substructure of the nucleon in experiments at Fermilab, and at the "spin" structure of nucleons at RHIC using polarized proton beams; (4) the development of the Sudbury Neutrino Observatory (SNO) detector as well as involvement in the SNO and MiniBoone research programs; (5) a broad program of theoretical research into a number of topics in nuclear physics; (6) nuclear data and compilation activities as part of the national nuclear data program; and (7) a technical effort involved in RIA R&D.

Oak Ridge Institute for Science and Education (ORISE)

Oak Ridge Institute for Science and Education is located on a 150 acre site in Oak Ridge, Tennessee. Nuclear Physics support is provided through ORISE for activities in support of the Holifield Radioactive Ion Beam Facility (HRIBF) and its research program.

Oak Ridge National Laboratory (ORNL)

Oak Ridge National Laboratory is a Multiprogram Laboratory located on a 24,000 acre site in Oak Ridge, Tennessee. The major effort at ORNL is the Low Energy program support for research and operations of the Holifield Radioactive Ion Beam Facility (HRIBF) that is operated as a national user facility. Also supported is (1) a relativistic heavy ion group that is involved in a research program using the PHENIX detector at RHIC; (2) a theoretical nuclear physics effort at ORNL that emphasizes investigations of nuclear structure and astrophysics; (3) nuclear data and compilation activities that support the national nuclear data effort; and (4) a technical effort involved in RIA R&D.

The **Holifield Radioactive Ion Beam Facility (HRIBF)** is the only radioactive nuclear beam facility in the U.S. to use the isotope separator on-line (ISOL) method and is used annually by about 100 scientists. It provides a wide range of both proton-rich and neutron-rich nuclei to a suite of instruments designed for studies in nuclear structure, dynamics and astrophysics using radioactive beams. The HRIBF accelerates secondary radioactive beams to higher energies (up to 10 MeV per nucleon) than any other facility in the world with such a broad selection of ions. The HRIBF conducts R&D on ion sources and low energy ion transport for radioactive beams.

Thomas Jefferson National Accelerator Facility (TJNAF)

Thomas Jefferson National Accelerator Facility (TJNAF) is a laboratory operated by the Nuclear Physics program located on 273 acres in Newport News, Virginia. Constructed over the period FY 1987-1995 for a cost of $513,000,000 (Total Project Cost), TJNAF began operations in FY 1995. Support for the research and operations of TJNAF are provided by the Medium Energy subprogram. The center piece of TJNAF is the **Continuous Electron Beam Accelerator Facility (CEBAF)**, a unique international electron-beam user facility for the investigation of nuclear and nucleon structure based on the underlying quark substructure that is used annually by 690 U.S. and foreign researchers. CEBAF consists of two multi-pass, superconducting linear accelerators connected by recirculating magnetic arcs. Polarized and unpolarized electron beams up to 5.7 GeV can be provided by CEBAF simultaneously to 3 different experimental halls, Halls A, B, and C. Hall A is designed for spectroscopy and few-body measurements. There are two high-resolution spectrometers, one for detection of the scattered electron from the beam and another for detection of the scattered particle. Hall B has a large acceptance detector, CLAS, for detecting multiple charged particles coming from a scattering reaction. Hall C is designed for flexibility to incorporate a wide variety of different experiments. Its core equipment consists of two medium resolution spectrometers for detecting high momentum or unstable particles. A large variety of major instruments are available for studying the scattering of and particle production from the electrons with fixed gas and solid targets. Fabrication of the G0 detector, a joint NSF-DOE project in Hall C that will allow a detailed mapping out of the strange quark contribution to nucleon structure, will be completed during FY 2002. As of FY 2002, Hall A will have completed 20 experiments and Hall C will have completed 18. The complex large-acceptance spectrometer in Hall B will have completed 65% of the data taking for 41 experiments. Support is also provided by the nuclear theory subprogram for a group whose program of investigations supports the experimental program of the laboratory. An accelerator R&D group is supported for projects important to the Nuclear Physics program (e.g., the proposed 12 GeV upgrade of CEBAF, and R&D for RIA).

All Other Sites

The Nuclear Physics program funds 180 research grants at 85 colleges/universities located in 35 states. Among these is a grant with the Massachusetts Institute of Technology (MIT) for the operation of the ***Bates Linear Accelerator Center*** as a national user facility used by about 110 scientists. The Bates facility, with electron beams up to 1 GeV, conducts experiments to study the properties and constituents of protons and light nuclei at energies below those of CEBAF. The research program probes the properties of the proton such as its shape and polarizability, and the charge distribution and magnetism of the deuteron. A major instrument for making these measurements will be the Bates Large Acceptance Spectrometer Toroid (BLAST) detector, whose fabrication will be completed in FY 2002. BLAST will observe collisions of polarized electrons in thin polarized gas targets located in the South Hall Pulse Stretcher Ring. Additional unique experiments are performed with the Out-Of Plane Spectrometer (OOPS). The Bates experimental program is scheduled to be concluded in 2004 and phased out in FY 2005-2006.

Grants for the operation of accelerator facilities at four university laboratories are supported by the Low Energy subprogram for research in selected and specialized areas conducted primarily by the in-house faculty members and students. The ***Triangle Universities Nuclear Laboratory (TUNL)*** utilizes a tandem Van de Graaff and polarized beams and targets to test and refine the theory of the nuclear force and its currents. A suite of instrumentation has been built up to take advantage of this unique combination of capabilities and to study fundamental symmetries and reactions important to nuclear astrophysics. ***The Texas A&M Cyclotron Institute (TAMU)*** operates a modern superconducting cyclotron to deliver a wide range of stable and selected radioactive beams for medium energy heavy-ion reaction studies, tests of fundamental constants of the standard model, and nuclear astrophysics. Modern instrumentation takes advantage of the heavy-ion beams, and a number of foreign collaborators use the facility. ***The Yale Tandem Van de Graaff*** provides a variety of stable beams for an extensive suite of instruments that, along with the opportunity for extended running times, provides the capability for detailed experiments on symmetry, collective structures, and evolution of properties in nuclei and nuclear astrophysics. The ***University of Washington Tandem Van de Graaff*** provides precisely characterized proton beams for extended running periods for research in fundamental nuclear interactions and nuclear astrophysics. These four accelerator facilities offer niche capabilities and opportunities not available at the national user facilities, or many foreign low-energy laboratories, such as specialized sources and targets, opportunities for extended experiments, and specialized instrumentation. These facilities operate in a university environment and thus provide a unique setting for the training and education of graduate students in the U.S., where they have the opportunity to be involved in all aspects of low energy nuclear research. These centers of excellence have in the past and continue today to produce the next generation of national leaders in nuclear science research.

The ***Institute for Nuclear Theory (INT)*** at the University of Washington is a premier international center for new initiatives and collaborations in nuclear theory research. Established in 1990, the INT conducts three programs each year on topics identified by an international advisory committee. U.S. and foreign researchers spend varying lengths of time at the Institute during the 2-3 month period of each program to establish collaborations and carry out projects. The institute also supports several workshops per year, some of which are hosted on-site. Currently, approximately 350 physicists visit the Institute per year, with an average stay of 3.5 weeks. Of these, approximately 20% are experimentalists, indicating the broad influence of the INT on nuclear physics research. About one-third of the attendees come from abroad, demonstrating the international stature of the Institute and its world leadership.

There are several major impacts of the INT operations. The first is that it fosters collaboration among researchers. These collaborative efforts, often multidisciplinary in nature, would not arise without the opportunity to spend an extended time focusing on specialty topics in an intellectually stimulating environment. A second major impact is the training of young people. Of the postdoctoral researchers who have been associated with the Institute over the last seven years, seven are now in academic positions and three more have staff positions at national laboratories. There are additional faculty, postdocs, and students in the local University of Washington nuclear theory group who synergistically interact with the INT activities, providing additional student and postdoctoral training. The third major impact is the work of the research group associated with the INT. The senior members of this group have a significant international stature and play a scientific leadership role both in their research work and in activities serving the scientific community.

For 2001, the three programs planned or underway are: "Correlations in Nucleons and Nuclei"; "Neutron Stars"; and "Lattice QCD and Hadron Phenomenology". In addition, there are three workshops: "RHIC-INT Workshop 2001"; "Theories of Nuclear Forces and Few-Nucleon Systems"; and "Computing $\sigma(DD \rightarrow \alpha\pi^{o})$ and Charge Symmetry Breaking." These topics are at the core of modern nuclear physics, and the list displays an impressive breadth of scientific purview.

Medium Energy Nuclear Physics

Mission Supporting Goals and Objectives

The Nuclear Physics program supports the basic research necessary to identify and understand the fundamental features of atomic nuclei and their interactions. The Medium Energy Nuclear Physics subprogram supports fundamental research that is ultimately aimed at achieving a quantitative understanding of the structure of the atomic nucleus in terms of the quarks and gluons, the objects that are believed to be the building blocks of the sub-atomic particles. Equally important is the achievement of an understanding of the "strong force," one of the four fundamental forces in nature, and the force that holds the nucleus of the atom together. Presently, the program supports different experimental approaches to gaining this knowledge: (1) determining the internal quark structure by electron scattering, (2) determining dynamic degrees of freedom by measuring the excited states of hadrons, (3) measuring the effects of the quark and gluon polarizations within the nucleon, and (4) determining the role of the "sea" of virtual quarks and gluons which also contributes to the properties of protons and neutrons. Measurements are normally carried out with beams of electrons or protons whose intrinsic spins have all been lined up in the same direction (polarized beams) to determine what role the intrinsic spins of the quarks and gluons play in the structure of the nucleon. In addition, the program supports research in understanding the structure of light nuclei and studies directed at testing fundamental symmetries. Most of this work is done at the primary research facility, Thomas Jefferson National Accelerator Facility (TJNAF), but the program also supports research at the Bates Linear Accelerator Center, the Relativistic Heavy Ion Collider at Brookhaven, the Stanford Linear Accelerator Center, Fermilab, and at several facilities in Europe. These facilities produce beams of sufficient energy (small enough wavelength) that they can probe at a scale within the size of a proton or neutron.

The two national user facilities, TJNAF and MIT/Bates, supported in Medium Energy Nuclear Physics, serve a nationwide community of about 300 Department of Energy and about 300 National Science Foundation supported scientists and students from over 140 American institutions, of which over 80% are colleges and universities. Both facilities provide major contributions to education at all levels. At both TJNAF and Bates, the National Science Foundation (NSF) has made a major contribution to new experimental apparatus in support of the large number of NSF users. A significant number of foreign scientists collaborate in the research programs of both facilities. The research program at the TJNAF, for example, involves about 300 scientists per year from 19 foreign countries; many of these scientists are from Conseil Europeen pour la Recherche Nucleaire (CERN) member states. At TJNAF, foreign collaborators have also made major investments in experimental equipment.

Funding Schedule

	(dollars in thousands)				
	FY 2001	FY 2002	FY 2003	$ Change	% Change
Research					
University Research	16,506	15,300	15,575	+275	+1.8%
National Laboratory Research	15,357	15,980	16,815	+835	+5.2%
Other Research	457	5,415	5,405	-10	-0.2%
Subtotal, Research	32,320	36,695	37,795	+1,100	+3.0%
Operations					
TJNAF Operations	66,666	67,515	72,513	+4,998	+7.4%
Bates Operations	12,973	12,425	13,282	+857	+6.9%
Other Operations	1,451	875	0	-875	--
Subtotal, Operations	81,090	80,815	85,795	+4,980	+6.2%
Total, Medium Energy Nuclear Physics	113,410	117,510	123,590	+6,080	+5.2%

Detailed Program Justification

	(dollars in thousands)		
	FY 2001	FY 2002	FY 2003
Research	**32,320**	**36,695**	**37,795**
▪ **University Research**	**16,506**	**15,300**	**15,575**

These activities comprise a broad program of research, and include 43 grants at 35 universities in 17 states and the District of Columbia in support of about 165 scientists and 110 graduate students. These research efforts utilize not only each of the accelerator facilities supported under the Medium Energy program, but also use other U.S. and foreign accelerator laboratories. Included in University Research is Bates Research, the effort performed at the MIT/Bates Linear Accelerator Center by MIT scientists. Other University Research includes all other university-based efforts using many research facilities, including activities by MIT scientists that are not carried out at Bates.

▸ **Bates Research**	**3,985**	**2,520**	**2,835**

MIT scientists along with other university researchers have completed “mirror-symmetry violation” studies on the proton and deuteron in the North Experimental Hall. The experiment (SAMPLE) provides important information on the quark flavor contribution to the proton's spin magnetism.

Preparations are being made for a new program of research to study the structure of the nucleon and the nature of the nucleon-nucleon force, utilizing the new Bates Large Acceptance Spectrometer Toroid (BLAST) detector. Funding in FY 2003 is increased to effectively carry out the Bates research program. **Performance will be measured by** the initiation of measurements with BLAST on schedule in FY 2002 using thin gas targets and the high current circulating electron beam in the South Hall Pulse Stretcher Ring.

	(dollars in thousands)		
	FY 2001	FY 2002	FY 2003
▸ **Other University Research**	**12,521**	**12,780**	**12,740**

In FY 2003 university research funds are about constant compared to FY 2002. The highest priority university research supports the activities associated with our main facilities at TJNAF, RHIC, and Bates. At the FY 2003 funding level, a shift in support from lower priority activities will be necessary to properly support these high priority activities. University scientists are collaborating on important ongoing and future experiments at TJNAF. These experiments are largely focused on the study of nucleon structure and its internal dynamics. Planned measurements in Hall A include the electric form factor of the proton and new parity-violation measurements to look for the "strange quark" content of the proton. New, higher-resolution measurements of the ratio of the electric to magnetic form factors of the proton are scheduled. Plans are also underway to carry out a new program of hypernuclear spectroscopy in Hall A in cooperation with researchers from Japan who will provide a new high-resolution spectrometer. A series of studies of the excited states of the proton will continue in Hall B. In Hall C, the newly constructed "G0" experiment will be commissioned in FY 2002 and begin experimental runs in FY 2003. "G0" will allow a "complete mapping" of the strange quark content of the nucleon using parity-violation techniques.

A number of university groups are collaborating in experiments using the new BLAST detector and the South Hall Ring at the MIT/Bates Linear Accelerator Center. BLAST will be used to perform precision polarization measurements of the proton and nuclear structure measurements on light nuclei. It will also be used to measure critical cross sections to improve our understanding of the oxygen-carbon cycle in stellar burning.

University scientists and National Laboratory collaborators will continue to develop the RHIC Spin program at Brookhaven National Laboratory. This program is expected to provide critical information on the contribution of gluons to the nucleon's intrinsic spin. Complementary research presently carried out by the HERMES (HERa MEasurements with Spin) experiment at the DESY laboratory in Hamburg, Germany will be reduced as the RHIC-spin physics program grows.

Supported also are university researchers involved in polarization experiments conducted at the SLAC (Stanford Linear Accelerator Center) facility, aimed at making a precise determination of the weak mixing angle, an important fundamental parameter of the Standard Model of Particle Physics, and fundamental measurements at the Paul Scherrer Institute in Switzerland to measure the proton charge radius using muons captured in atomic orbits.

▪ **National Laboratory Research**..	**15,357**	**15,980**	**16,815**

Included is: (1) the research supported at the Thomas Jefferson National Accelerator Facility (TJNAF), that houses the nation's, and the world's, unique high intensity continuous wave electron accelerator and (2) research efforts at Argonne, Brookhaven, and Los Alamos National Laboratories. The National Laboratory groups carry out research at various world facilities as well as at their home institutions.

	(dollars in thousands)		
	FY 2001	FY 2002	FY 2003
▸ **TJNAF Research**	**5,746**	**5,770**	**5,945**

Scientists at TJNAF, with support of the user community, assembled the large and complex new experimental apparatus for Halls A, B, and C. TJNAF scientists provide experimental support and operate the apparatus for safe and effective utilization by the user community. TJNAF scientists participate in the laboratory's research program, and collaborate in research at other facilities.

As of FY 2002, Hall A will have completed 20 experiments and Hall C will have completed 18. The complex large-acceptance spectrometer in Hall B will have completed 65% of the data taking for 41 experiments. TJNAF researchers participate in all of these experiments.

TJNAF scientists are participating in the assembly of a new detector for the G0 experiment, in cooperation with the National Science Foundation (NSF contribution of $3,605,000) for combined TEC of $7,570,000. The G0 detector will map out the contribution of the strange quark to the nucleon; it will be commissioned in FY 2002.

▸ **Other National Laboratory Research**.........................	**9,611**	**10,210**	**10,870**

Support for researchers at National Laboratories is increased by 6.5% relative to FY 2002 levels to address forefront science at accelerator and non-accelerator facilities. These activities include:

Argonne National Laboratory scientists are pursuing research programs at TJNAF, at the DESY Laboratory in Germany, and have proposed measurements of the quark structure of the nucleon at the new Main Injector at Fermilab. The theme running through this entire effort is the search for a detailed understanding of the internal quark-gluon structure of the nucleon. They have also made important advances in the technique of Atom Trap Trace Analysis to be used in measurements of rare isotopes for precision studies of nuclear structure and a measurement of the integrated solar neutrino flux over a long time scale (approximately one million years).

At Brookhaven National Laboratory, the Medium Energy Research group, which in previous years has concentrated on hadron beam experiments at the AGS, has changed its major emphasis to "RHIC Spin". This is the set of experiments planned for RHIC that will use colliding polarized proton beams to investigate the spin content of the nucleon and, in particular, what role gluons play. In FY 2002-2003, additional funding is being provided to this group to assure that appropriate scientific effort has been assembled in support of the RHIC Spin effort.

Also at Brookhaven, Laser Electron Gamma Source (LEGS) scientists will be utilizing a new spectrometer and a recently-developed polarized "ice" target for a program of spin physics at low energies. This unique facility produces its polarized "gammas" by back scattering laser light from the circulating electron beam at the National Synchrotron Light Source (NSLS). In FY 2003, the research program utilizing the new equipment will commence.

	(dollars in thousands)		
	FY 2001	FY 2002	FY 2003

At Los Alamos National Laboratory, scientists and collaborators have developed a next-generation neutrino oscillation experiment that builds on the experience of the Liquid Scintillator Neutrino Detector (LSND) experiment at Los Alamos, which detected a signal consistent with the existence of neutrino oscillations. This experiment, the Booster Neutrino Experiment (BooNE), uses neutrinos generated from the Fermi National Accelerator Laboratory Booster proton beam; data collection is planned to commence in FY 2002.

Los Alamos scientists also are involved in experiments at Fermilab and at RHIC (RHIC Spin) that will probe the structure of the virtual quark "sea" of the nucleon and the gluonic contribution to its spin, respectively. The Los Alamos group has also been instrumental in providing major components of the PHENIX detector at RHIC that are crucial in carrying out the RHIC Spin program of research.

	FY 2001	FY 2002	FY 2003
▪ **Other Research**	**457**	**5,415**	**5,405**

In FY 2001 $4,273,000 was transferred to the SBIR program and $466,000 was transferred to the STTR program. This section includes $4,403,000 for SBIR and $479,000 for STTR in FY 2002 and $4,346,000 for SBIR and $510,000 for STTR in FY 2003 and other established obligations that the Medium Energy Nuclear Physics subprogram must meet.

	FY 2001	FY 2002	FY 2003
Operations	**81,090**	**80,815**	**85,795**
▪ **TJNAF Operations**	**66,666**	**67,515**	**72,513**

Included is the funding that supports: (1) operation of the Continuous Electron Beam Accelerator Facility (CEBAF) at the Thomas Jefferson National Accelerator Facility (TJNAF), and (2) major manpower, equipment, and staging support for the assembly and dismantling of complex experiments.

	FY 2001	FY 2002	FY 2003
▸ **TJNAF Accelerator Operations**	**42,790**	**42,910**	**46,413**

Funding for accelerator operations in FY 2003 supports a 4,200 hour (28-week) running schedule. In FY 2001, the accelerator routinely delivered beams of differing energies and currents simultaneously to the three experimental halls. A maximum beam energy of 5.7 GeV has been delivered to experiments. High current, high polarization beam capability is now also available and is being used for experiments.

	(hours of beam for research)		
	FY 2001	FY 2002	FY 2003
TJNAF	4180	3900	4200

Funding of $500,000 is provided for R&D for the proposed upgrade of CEBAF to 12 GeV. AIP funding includes polarized injector and beam handling components as well as other additions and modifications to the accelerator facilities. GPP funding is provided for minor new construction and utility systems.

	(dollars in thousands)		
	FY 2001	FY 2002	FY 2003
▸ **TJNAF Experimental Support**....................................	**23,876**	**24,605**	**26,100**

Operating and equipment funding is provided for the experimental support needed to effectively carry out the TJNAF experimental program.

Support is increased by $1,495,000 (6.0%) for the scientific and technical manpower, materials, and services needed to support three hall operations and to integrate rapid assembly, modification, and disassembly of large and complex experiments for optimization of schedules. This includes the delivery or dismantling of cryogenic systems, electricity, water for cooling, radiation shielding, and special equipment for specific experiments.

The G0 detector, a major item of equipment with a Total Estimated Cost of $7,570,000 has been assembled. DOE's contribution was $3,965,000 and the National Science Foundation contributed $3,605,000 to this detector. With G0 fabrication completed in FY 2002, TJNAF is shifting their base capital equipment towards assembly and installation of ancillary equipment items such as polarized targets for experimental Halls A, B, C, spectrometer systems, the completion of a major upgrade of the data reduction system to handle massive amounts of raw data, and the continuation of the fabrication of second generation experiments. **Performance will be measured by** the completion of fabrication, commissioning and initiation of measurements with the G0 detector in FY 2002.

▪ **Bates Operations**	**12,973**	**12,425**	**13,282**

Funding is provided to support accelerator operations at the MIT/Bates Linear Accelerator Center.

Bates Operations in FY 2003 will be focused on the initiation of the research program of the BLAST detector completed in FY 2002. The new BLAST detector will observe collisions in thin gas targets located on the South Hall Pulse Stretcher Ring. **Performance will be measured by** the commissioning of the BLAST detector and the initiation of its research program in FY 2003. When the scientific program of BLAST commences, the Bates research effort will concentrate on this new experimental facility. Upon completion of the BLAST research program in FY 2004, it is now planned that the Bates facility will begin a two-year phaseout. Starting in FY 2005, Decontaminating and Decommissioning (D&D) activities will be initiated. The D&D cost and schedule will be determined at that time.

	(hours of beam for research)		
	FY 2001	FY 2002	FY 2003
Bates..	1800	2100	2700

Accelerator operations in FY 2003 are funded at a level to provide the needed beams to carry out the research program in the South Hall Ring using the BLAST detector. Capital Equipment and AIP funding is maintained at the FY 2002 level to support maintenance of the accelerator and experimental facilities.

	(dollars in thousands) FY 2001	FY 2002	FY 2003
▪ **Other Operations**	**1,451**	**875**	**0**

Operation of the Alternating Gradient Synchrotron (AGS) at Brookhaven National Laboratory for a limited target program is terminated.

	FY 2001	FY 2002	FY 2003
Total, Medium Energy Nuclear Physics	**113,410**	**117,510**	**123,590**

Explanation of Funding Changes from FY 2002 to FY 2003

	FY 2003 vs. FY 2002 ($000)
Research	
▪ **University Research**	
▸ The MIT/Bates research support (+12.5% over FY 2002) is provided to effectively carry out the Bates research program whose focus is the new BLAST detector.	+315
▸ Research support at Other Universities is slightly decreased (0.3%). Lower priority activities will be phased out in order to maintain manpower and focus efforts on the high priority activities at TJNAF, RHIC-Spin, and Bates.	-40
Total, University Research	+275
▪ **National Laboratory Research**	
▸ Funding for TJNAF and other National Laboratory groups is increased by about 4%. Resources will be directed to maintaining manpower and focus on the high-priority activities at TJNAF and RHIC-Spin.	+835
▪ **Other Research**	
▸ Estimated SBIR/STTR and other obligations decrease	-10
Total Research	+1,100
Operations	
▪ **TJNAF Operations**	
▸ **TJNAF Accelerator Operations:** Funding for accelerator operations is increased by about $3,413,000 (+8.3%) relative to FY 2002 in order to provide a 4200 hour (28 week) running schedule. A decrease of $500,000 for AIP is offset by an increase of $500,000 for R&D for the proposed 12 GeV upgrade of CEBAF. GPP is increased by $90,000 (to $440,000).	+3,503

	FY 2003 vs. FY 2002 ($000)
▸ **TJNAF Experimental Support:** Experimental Support is increased by $1,495,000 in order to provide increased manpower and equipment needed for carrying out the experimental program. Overall Capital Equipment funding ($6,100,000) remains the same as FY 2002.	+1,495
Total, TJNAF Operations	+4,998
■ **Bates Operations**	
▸ The increased funding for Bates operations increases the running schedule over FY 2002 to carry out research with the new BLAST detector. Bates will provide 2700 beam hours that will be focused on the commissioning of the BLAST detector and the initiation of its research program.	+857
■ **Other Operations**	
▸ Funding of the operation of the AGS at BNL for producing secondary meson beams for fixed-target experiments is terminated.	-875
Total Operations	+4,980
Total Funding Change, Medium Energy Nuclear Physics	+6,080

Heavy Ion Nuclear Physics

Mission Supporting Goals and Objectives

The Heavy Ion Nuclear Physics subprogram supports research directed at understanding the properties of nuclear matter over the wide range of conditions created in nucleus-nucleus collisions, particularly the predicted phase changes from the liquid to gas state and from normal to quark matter. Using beams of accelerated heavy ions at intermediate bombarding energies, research is focused on the study of the fragmentation of nuclei in highly violent collisions and the flow of nuclear matter in less violent collisions. From such studies of the flow of nuclear matter, one can obtain information regarding the equation of state of nuclear matter; such information is important in understanding the dynamics of supernova explosions. At much higher relativistic bombarding energies, collisions producing hot**,** dense nuclear matter are studied with the goal of observing the deconfinement of normal matter into the quark-gluon plasma. This form of matter is predicted to have been the early phase of the universe, a millionth of a second after the Big Bang. Scientists and students at universities and national laboratories are funded to carry out this research at the DOE supported Relativistic Heavy Ion Collider (RHIC) facility, as well as at the National Science Foundation (NSF) and foreign supported accelerator facilities.

The Heavy Ion Nuclear Physics subprogram supports operation of RHIC at Brookhaven National Laboratory (BNL). This is a unique world-class facility that addresses fundamental questions about the nature of nuclear matter. With it one can study collisions of heavy nuclei at energies over 10 times of that previously available at any other facility in the world, namely at CERN. The RHIC is also the only accelerator facility in the world that provides collisions of polarized protons with polarized protons. From these collisions, important and unique information can be obtained regarding the composition of the gluons that provide the binding of the quarks to make the nucleons, the protons and neutrons that make up the nucleus. The construction of RHIC was completed in August 1999, and first collisions were observed in June 2000. The RHIC facility is utilized by over 1,100 DOE, NSF, and foreign supported researchers. The RHIC experimental program is determined with the guidance of a Program Advisory Committee, consisting of distinguished scientists, that reviews and evaluates proposed experiments and advises the BNL Associate Director for Nuclear and High Energy Physics regarding their merit and scientific priority. Capital Equipment and Accelerator Improvement Project (AIP) funds are provided for additions, modifications, and improvements to the research accelerators and ancillary experimental facilities to maintain and improve the reliability and efficiency of operations, and to provide new experimental capabilities. An annual peer review of the effectiveness of RHIC operations and its research program is conducted by the program.

The Heavy Ion Nuclear Physics subprogram also provides General Purpose Equipment (GPE), General Plant Project (GPP), and other funding as part of Nuclear Physics' stewardship responsibilities for this laboratory. These funds are for general purpose equipment, minor new capital construction, alterations and additions, improvements to land, buildings, and utility systems, and other normal operations.

Funding Schedule

	(dollars in thousands)				
	FY 2001	FY 2002	FY 2003	$ Change	% Change
Research					
University Research	11,776	11,390	11,635	+245	+2.2%
National Laboratory Research	20,760	20,324	21,194	+870	+4.3%
Other Research	0	2,903	3,291	+388	+13.4%
Subtotal, Research	32,536	34,617	36,120	+1,503	+4.3%
Operations					
RHIC Operations	103,991	103,505	117,497	+13,992	+13.5%
Other Operations	15,585	17,496	14,360	-3,136	-17.9%
Subtotal, Operations	119,576	121,001	131,857	+10,856	+9.0%
Total, Heavy Ion Nuclear Physics	152,112	155,618	167,977	+12,359	+7.9%

Detailed Program Justification

	(dollars in thousands)		
	FY 2001	FY 2002	FY 2003
Research	**32,536**	**34,617**	**36,120**
▪ **University Research**	**11,776**	**11,390**	**11,635**

Support is provided for the research of about 130 scientists and 75 graduate students at 26 universities in 18 states.

- Researchers using primarily the NSF supported National Superconducting Cyclotron Laboratory at Michigan State University, at Texas A&M University, and at foreign facilities in France, Germany, and Italy, investigate nuclear reactions at intermediate energies, with the aim of studying the fragmentation of nuclei and the flow of nuclear matter in violent collisions.
- Research using relativistic heavy ion beams is focused on the study of the production and properties of hot, dense nuclear matter at experiments at RHIC, where an entirely new regime of nuclear matter now becomes available to study for the first time. The university groups provide core manpower for the operation of and data analysis for the RHIC detectors. There is a $245,000 increase compared to FY 2002 that provides a 2.2% increase in grant funding.

	FY 2001	FY 2002	FY 2003
▪ **National Laboratory Research**	**20,760**	**20,324**	**21,194**

Support is provided for the research programs of scientists at five National Laboratories (BNL, LBNL, LANL, LLNL and ORNL). These scientists provide essential manpower for the operations of the RHIC detectors. Also, BNL, LBNL, and LLNL provide substantial computing infrastructure for terabyte-scale data analysis and state-of-the-art facilities for detector and instrument development. The 4.2% increase provides an approximate constant level of effort.

	(dollars in thousands)		
	FY 2001	FY 2002	FY 2003
▸ **BNL RHIC Research**..	**10,990**	**10,065**	**9,153**

BNL scientists play a major role in planning and carrying out research with the four detectors (STAR, PHENIX, BRAHMS and PHOBOS) at RHIC and have major responsibilities for maintaining, improving and developing this instrumentation for use by the user community. In FY 2003 with RHIC operating at its design luminosity (collision rate). All four detectors will be capable of discovering signatures of any new forms of nuclear matter in the heavy ion collisions. In FY 2003 funding for capital equipment decreases by $1,012,000 with the completion of projects. The PHENIX muon instrumentation will be fully ready for commissioning. Funding begins for production of modules for the Electromagnetic Calorimeter Enhancement for the STAR RHIC-spin program. Although it is anticipated that this survey work with gold ions will be substantially complete by the end of the FY 2002 run, comparison running with light-ion beams, particularly the deuteron – nucleus collision operation, will not commence before FY 2003.

- The muon instrumentation for PHENIX allows measurement of the yields of muons ("heavy electrons") that probe the early stages of quark-gluon plasma formation will be completed in FY 2002. The Japanese and French are contributing substantial support for the PHENIX muon arms; they are also critical components of the detection systems for measurements in the PHENIX RHIC Spin program.
- The Electromagnetic Calorimeter for STAR provides capability to distinguish electrons from photons, and extends the measurement of particle energy to high energies. The detector system is also a critical component for the RHIC Spin program for STAR. Production of calorimeter modules began in FY 2000 and will be completed in FY 2003. An enhancement to the Electromagnetic Calorimeter, providing additional modules for full coverage of the barrel as well as improved electron/photon discrimination required for the RHIC Spin program, will be initiated in FY 2003.

▸ **Other National Laboratory Research**.............................	**9,770**	**10,259**	**12,041**

Researchers at LANL, LBNL, LLNL, and ORNL provide leadership in the commissioning of the PHENIX muon arm and the STAR electromagnetic calorimeter, as well as play leadership roles in carrying out the research utilizing these detectors. At LBNL an analysis system for RHIC data, in alliance with the National Energy Research Scientific Computing Center (NERSC), is a major resource for data analysis by the STAR collaboration and at LLNL substantial computing resources are made available for PHENIX data analysis. A 7.0% increase of $638,000 for research groups compared to FY 2002 is provided to help restore approximately constant level of effort for the National Laboratory research effort that has been reduced by steady attrition in recent years. An increase of $1,144,000 for capital equipment is provided for computing and other projects important for the RHIC program.

	(dollars in thousands)		
	FY 2001	FY 2002	FY 2003
▪ **Other Research**	**0**	**2,903**	**3,291**

In FY 2001 $2,848,000 was transferred to the SBIR program. This section includes $2,903,00 for SBIR in FY 2002 and $3,291,000 for SBIR in FY 2003.

Operations	**119,576**	**121,001**	**131,857**
▪ **RHIC Operations**	**103,991**	**103,505**	**117,497**

The Relativistic Heavy Ion Collider (RHIC) is anticipated to reach nearly full data production capabilities by the end of the planned running period in FY 2002. RHIC is a unique facility whose colliding relativistic heavy ion beams will permit exploration of hot, dense nuclear matter and recreate the transition from quarks to nucleons that characterized the early evolution of the universe. Studies with colliding heavy ion beams provide researchers with an opportunity to explore a new regime of nuclear matter and nuclear interactions that up to now has only been characterized theoretically. Already during the initial brief run in FY 2000, new features were observed in the data, indicating that conditions are favorable for quark-gluon formation and hints of some characteristic signatures of its existence. The flurry of scientific papers that have been published from these initial results has generated much attention in the press. During the FY 2001-FY 2002 running periods, preparations of RHIC for its spin-physics program will continue, with the anticipation that this experimental program will begin in FY 2003.

▸ **RHIC Accelerator Operations**	**75,275**	**76,345**	**86,950**

Support is provided for the operation, maintenance, improvement and enhancement of the RHIC accelerator complex. This includes the Tandem, Booster and AGS accelerators that together serve as the injector for RHIC. RHIC produced its first collisions in June 2000. Beam time for research increased significantly in FY 2001 with a 13-week operating schedule (1880 hours). FY 2002 funding provides 1,650 hours of beam for research and beam studies and for commissioning operations with polarized protons. FY 2003 funding will support a 22-week schedule (3300 hours) for research. **Performance will be measured by** initiating the first round of experiments with collisions with other ions to compare to results of gold-gold collisions. Capital equipment funding is provided for normal maintenance projects and AIP funding is provided for needed improvement projects. An increase of $400,000 is provided for AIP in order to upgrade the RHIC crygenics system, by replacing turbine oil skids and removing the seal gas compressor, eliminating a single-point failure.

RHIC Operations

	(hours of beam for research)		
	FY 2001	FY 2002	FY 2003
RHIC	1880	1650	3300

	FY 2001	FY 2002	FY 2003
▸ **RHIC Experimental Support**	**28,716**	**27,160**	**30,547**

Support is provided for the operation, maintenance, improvement and enhancement of the RHIC experimental complex, including detectors, experimental halls, computing center and support for users. The RHIC detectors (STAR, PHENIX, BRAHMS and PHOBOS) will reach their initial planned potential by FY 2002. About 1,100 scientists and students from 90 institutions and 19 countries participate in the RHIC research program. These four detectors (described in the Site Descriptions) provide complementary measurements, but with some overlap in order to cross-calibrate the measurements.

▪ **Other Operations**..	**15,585**	**17,496**	**14,360**

As steward for Brookhaven National Laboratory (BNL), the Nuclear Physics program provides General Plant Project (GPP), General Purpose Equipment (GPE) and other funding for minor new construction, other capital alterations and additions, and for buildings and utility system, for needed laboratory equipment and other expenses. Funding of this type is essential for maintaining the productivity and usefulness of Department-owned facilities and in meeting its requirement for safe and reliable facilities operation. In FY 2003 funding for GPP remains at the same level as FY 2002 while GPE and other costs are reduced.

Total, Heavy Ion Nuclear Physics	**152,112**	**155,618**	**167,977**

Explanation of Funding Changes from FY 2002 to FY 2003

	FY 2003 vs. FY 2002 ($000)
Research	
▪ **University Research**	
▸ FY 2003 funding for grants for University Research increases by 2.2%, maintaining a comparable effort to FY 2002. Lower priority activities will be reduced in order to focus efforts on those activities at RHIC identified as providing the most promising physics opportunities.	+245
▪ **National Laboratory Research**	
▸ **BNL RHIC Research:** Research support is increased by $100,000 (1.6%) to effectively carry out research with the enhanced detectors at full luminosity at RHIC. Capital equipment is decreased by $1,012,000.	- 912
▸ **Other National Laboratory Research:** Research support for operations is increased by $638,000 (7.0%) to enhance effort compared to FY 2002. Capital equipment increases by $1,144,000 compared with FY 2002.	+1,782
Total, National Laboratory Research	+870

	FY 2003 vs. FY 2002 ($000)
▪ **Other Research:**	
▸ Estimated SBIR and other obligations increase.	+388
Total, Research	+1,503
Operations	
▪ **RHIC Operations**	
▸ **Accelerator Operations:** An increase of $10,205,000 (+14.0%) in operating funds provides an estimated 3,300 hours for research, providing 1,650 hours more than in FY 2002. An increase of $400,000 is provided for Accelerator Improvement Project funding (to a total of $2,900,000) to a level that can sustain operations.	+10,605
▸ **Experimental Support:** Funding is increased by $2,290,000 (+9.5%) compared to FY 2002. An increase of $1,097,000 is provided in capital equipment to support operations at full luminosity.	+3,387
Total, RHIC Operations	+13,992
▪ **Other Operations**	
▸ FY 2003 funding for General Plant Projects to Brookhaven National Laboratory is approximately constant compared with FY 2002. Funding for General Plant Equipment decreases by $972,000. Other operations decrease by $2,164,000 compared with FY 2002	-3,136
Total, Operations	+10,856
Total Funding Change, Heavy Ion Nuclear Physics	+12,359

Low Energy Nuclear Physics

Mission Supporting Goals and Objectives

The Low Energy Nuclear Physics subprogram supports research directed at understanding the structure of nuclei, nuclear reaction mechanisms, and experimental tests of fundamental symmetries, including neutrino oscillations. The forefront of nuclear structure research lies in studies of nuclei at the limits of energy, deformation, angular momentum, and isotopic stability. The properties of nuclei at these extremes are not known and such knowledge is needed to test and drive improvement in nuclear models and theories about the nuclear many-body system. Knowledge of the detailed nuclear structure, nuclear reaction rates, half-lives of specific nuclei, and the limits of nuclear existence at both the proton and neutron drip lines is crucial for understanding the nuclear astrophysics processes responsible for the production of the chemical elements in the universe, and the explosive dynamics of supernovae. Progress in both nuclear structure and astrophysics studies depend upon the availability of exotic beams, or beams of short-lived nuclei, to produce and study nuclei that lie in unstudied regions of the nuclear chart and that are involved in important astrophysics processes. While the U.S. today has facilities with limited capabilities for these studies, it was already noted in the 1996 NSAC Long Range Plan for Nuclear Science that a facility with next generation capabilities for short-lived radioactive beams will be needed in the future for the U.S. to maintain a leadership role. In FY 1999 a NSAC Taskforce established the optimal technical option for such a facility, the Rare Isotope Accelerator (RIA) facility. The ongoing 2001 NSAC long-range planning process is identifying RIA as the highest priority for a major new construction project. Starting in FY 2000, R&D activities have been supported in preparation for a request for approval for construction. Continued pre-conceptual funding for these R&D activities is supported in FY 2003.

The research of this subprogram is generally conducted using beams provided by accelerator facilities either operated by this subprogram or at other domestic or foreign facilities. The Low Energy Nuclear Physics subprogram supports the operation of three national user facilities: the Holifield Radioactive Ion Beam Facility (HRIBF) at Oak Ridge National Laboratory, the Argonne Tandem Linac Accelerator System (ATLAS) facility at Argonne National Laboratory, and the 88-Inch Cyclotron facility at the Lawrence Berkeley National Laboratory. These facilities are utilized by DOE-, NSF-, and foreign-supported researchers whose experiments undergo peer review prior to approval for beam time. Capital equipment funds are provided for detector systems, for data acquisition and analysis systems, and for accelerator instrumentation for effective utilization of all the national accelerator facilities operated by this subprogram. Accelerator Improvement Project (AIP) funds are provided for additions, modifications, and improvements to the research accelerators and ancillary equipment facilities to maintain and improve the reliability and efficiency of operations, and to provide new accelerator capabilities.

University-based research is an important feature of the Low Energy subprogram. Accelerator operations are supported at Texas A&M University (TAMU), the Triangle Universities Nuclear Laboratory (TUNL), University of Washington, and Yale University. Each of these university centers of excellence has a critical mass of nuclear physics faculty involved in research that is conducted both on and off campus, about 15-25 graduate students at different stages of their education, and historically has produced a large fraction of the leaders in the field. Many of these scientists, after obtaining their Ph.D.s, contribute to a wide variety of nuclear technology programs of interest to the DOE.

The Low Energy subprogram also supports studies of fundamental interactions and symmetries in selected nuclei, "laboratories" that allow exquisite measurements to test the present understanding of the Standard Model. Some experiments use accelerators in conjunction with special apparatus to study fundamental nuclear and nucleon properties, as for example the ultra-cold neutron trap at the Los Alamos Neutron Science Center (LANSCE) at Los Alamos National Laboratory. Other experiments in low energy nuclear physics do not require the use of accelerators. The study of neutrinos from the sun is an example. The Sudbury Neutrino Observatory (SNO) detector is studying the production rate and properties of solar neutrinos. The Kamioka Large Anti-Neutrino Detector (KamLAND) will study the properties of anti-neutrinos produced by nuclear power reactors. Both of these experiments address the important and interesting question of whether neutrinos have a mass. The answer to this very fundamental question has profound implications for our understanding of the basic building blocks of matter and the evolution of the universe, and the dynamics of "core collapse" supernovae.

Funding Schedule

	(dollars in thousands)				
	FY 2001	FY 2002	FY 2003	$ Change	% Change
Research					
University Research	17,856	16,849	17,591	+742	+4.4%
National Laboratory Research	20,017	19,883	20,044	+161	+0.8%
Other Research	3,044	3,830	4,743	+913	+23.8%
Subtotal Research	40,917	40,562	42,378	+1,816	+4.5%
Operations	21,733	21,860	23,780	+1,920	+8.8%
Total, Low Energy Nuclear Physics	62,650	62,422	66,158	+3,736	+6.0%

Detailed Program Justification

	(dollars in thousands)		
	FY 2001	FY 2002	FY 2003
Research	**40,917**	**40,562**	**42,378**
▪ **University Research**	**17,856**	**16,849**	**17,591**

Support is provided for the research of 140 scientists and 90 graduate students at 29 universities in 21 states. Nuclear Physics university scientists perform research as user groups at National Laboratory facilities, at on-site facilities and at other specifically fabricated experiments. These activities address a broad range of fundamental issues as diverse as the properties of nuclei, the nature of the weak interaction and the production mechanisms of the chemical elements in stars and supernovae. FY 2003 funding for university accelerator facilities, and for researchers and students is increased by ~3.6% compared to FY 2002. Funding for capital equipment projects is increased by $189,000. Research activities include:

	(dollars in thousands)		
	FY 2001	FY 2002	FY 2003

- Research programs conducted using the low energy heavy-ion beams and specialized instrumentation at the national laboratory user facilities supported by this subprogram (the ANL-ATLAS, LBNL – 88-Inch Cyclotron and ORNL – HRIBF facilities). The effort at the user facilities involves about two-thirds of the university scientists supported by this subprogram.
- Accelerator operations at four universities: the University of Washington, the Triangle Universities Nuclear Laboratory (TUNL) facility at Duke University, Texas A&M University (TAMU) and at Yale University. Each of these small university facilities has a well-defined and unique physics program, providing light and heavy ion beams, specialized instrumentation and opportunities for long-term measurements which complement the capabilities of the National Laboratory user facilities. Equipment funds are provided for new instruments and capabilities, including an energy and intensity upgrade to the High Intensity Gamma-ray Source (HIγS) facility at TUNL.
- Involvement in other accelerator and non-accelerator experiments directed at fundamental measurements, such as measurements of solar neutrino rates and the neutrino mass at the Sudbury Neutrino Observatory (SNO) in Canada. The U.S. effort with the Kamioka Large Anti-Neutrino Detector (KamLAND) in Japan, is being supported jointly with the High Energy Physics program.

■ **National Laboratory Research**..	**20,017**	**19,883**	**20,044**

Support is provided for the research programs of scientists at six National Laboratories (ANL, BNL, LBNL, LANL, LLNL and ORNL).

► **National Laboratory User Facility Research**............	**14,394**	**13,851**	**14,455**

Scientists at ANL, LBNL, and ORNL have major responsibilities for maintaining, improving and developing instrumentation for research by the user communities at the user facilities, as well as playing important roles in carrying out research that addresses the program's priorities. In FY 2002 the three user facilities support the following research activities:

- At ORNL the research focuses on the use of radioactive beams from the HRIBF and specialized spectrometers to study the nuclear structure of nuclei far from stability. Measurements are made of reaction cross sections and nuclear properties, such as half-lives, which are crucial input to detailed astrophysics models that calculate the production of the elements in stars. Specialized equipment is employed, such as a system that integrates gamma-ray and charged-particle detectors with a recoil mass separator. The high-pressure gas target for nuclear astrophysics experiments has been built, and is undergoing commissioning and initiating its first experiments.
- At ANL the research focuses on the use of stable and selected radioactive beams from ATLAS, coupled to ion traps and the Fragment Mass Analyzer to study fundamental processes and properties of nuclei, and to study nuclei at the extremes of isotope stability. Studies are undertaken with traps to measure atomic masses with high precision and search for effects in beta decay outside the standard decay model. The Advanced Penning Trap is being commissioned and tested.

	(dollars in thousands)		
	FY 2001	FY 2002	FY 2003

– At LBNL the research focuses on the use of stable beams from the 88-Inch Cyclotron with Gammasphere and the Berkeley Gas-filled Spectrometer (BGS) to study nuclei at high angular momentum and deformation, and the heaviest of elements. The world-leading effort to search for and characterize new very heavy elements and isotopes will continue. Conceptual design of a high-sensitivity gamma-ray tracking detector, 1000 times more sensitive than Gammasphere, is continuing. Test modules, electronics and data analysis algorithms are undergoing development.

	FY 2001	FY 2002	FY 2003
▸ **Other National Laboratory Research**........................	**5,623**	**6,032**	**5,589**

Scientists at BNL, LBNL, LLNL and LANL play important roles in a number of high-priority accelerator- and non-accelerator-based experiments directed towards fundamental questions. These include:

– The Sudbury Neutrino Observatory (SNO) experiment in Canada. The SNO detector, jointly built by Canada, England and the U.S., addresses the question of whether the observed reduced rate of solar neutrinos reaching the earth results from unexpected properties of the sun, or whether it results from a fundamental property of neutrinos–namely that neutrinos produced in the sun change their nature (that is, oscillate to a new neutrino type) during the time it takes them to reach the earth. This latter explanation would imply that the neutrinos have mass. In FY 2001, the first results from SNO were reported, indicating strong evidence for neutrino oscillations. In FY 2001, the second phase of the SNO experiment began. This phase measures neutrino types to which the solar neutrino have been transformed; preliminary results from this phase are possible in late FY 2002.

– The KamLAND experiment in Japan will measure the rate and properties of anti-neutrinos produced by several distant nuclear power reactors in an attempt to establish and measure the mass of the neutrino. Although KamLAND is less sensitive than SNO to the variety of neutrino oscillations it has the advantage of comparing the measured fluxes to known sources. **Performance will be measured** by the collection of first data with the KamLAND detector in FY 2003.

– Neutron beams at the LANSCE facility at LANL are “cooled” to very low energies for new cold and ultra-cold neutron experiments, which will allow very precise measurements of fundamental neutron properties.

	FY 2001	FY 2002	FY 2003
▪ **Other Research**...	**3,044**	**3,830**	**4,743**
▸ **RIA R&D Activities**...	**2,844**	**2,800**	**3,500**

Funds are provided for R&D and pre-conceptual design activities directed at the development of an advanced Rare Isotope Accelerator (RIA) facility. A next-generation facility for beams of short-lived, radioactive nuclei for nuclear structure, reaction and astrophysics studies is identified in the 2001 Nuclear Science Advisory Committee (NSAC) Long Range Plan as a compelling scientific opportunity and as the highest priority for new construction. The proposed RIA facility is a new paradigm for producing intense beams of very short-lived nuclei that emerged from the 1998 NSAC Taskforce study involving international experts. This facility would position the U.S. to play a leadership role in an area of study with the potential for new discoveries about basic properties of nuclei and to significantly advance our understanding of astrophysical

	(dollars in thousands)		
	FY 2001	FY 2002	FY 2003

phenomena. The increased funding for FY 2003 supports some of the needed R&D activities in both critical accelerator components and detector development. **Performance will be measured** by the demonstration of the fast ion gas catcher at full beam energy, a critical capability for RIA.

	FY 2001	FY 2002	FY 2003
▸ **SBIR and Other**	**200**	**1,030**	**1,243**

In FY 2001 $639,000 was transferred to the SBIR program. This section includes $655,000 for SBIR in FY 2002 and $868,000 for SBIR in FY 2003 and other established obligations. The Lawrence and Fermi Awards, funded under this line, provide annual monetary awards to honorees selected by the Department of Energy for their outstanding contributions to science.

	FY 2001	FY 2002	FY 2003
Operations	**21,733**	**21,860**	**23,780**

Support has been provided for the operation of three National User Facilities, the Argonne Tandem-Linac Accelerator System (ATLAS) at ANL, the 88-Inch Cyclotron facility at LBNL and the Holifield Radioactive Ion Beam Facility (HRIBF) at ORNL, for studies of nuclear reactions, structure and fundamental interactions.

HRIBF has coupled the existing cyclotron and tandem accelerator to develop a focused radioactive-ion beam program. Both proton-rich and neutron-rich beams are provided to spectrometer systems such as CHARMS, designed for nuclear structure studies, and the Daresbury Recoil Separator and the Silicon Detector Array for nuclear astrophysics studies.

ATLAS provides stable heavy-ion beams and selected radioactive-ion beams for research. Experiments utilize ion traps, the Fragment Mass Analyzer, and advanced detectors to study the structure of nuclei at the limits of stability, and fundamental and decay properties of nuclei.

The 88-Inch Cyclotron facility provides primarily stable heavy-ion beams for research. Gammasphere and the Berkeley Gas-filled Spectrometer provide world-class instruments to study rapidly spinning nuclei, and search for and characterize the heaviest of elements and isotopes. An innovative BEARS (Berkeley Experiments with Accelerated Radioactive Species) system has been developed to provide selected light radioactive-ion beams for experiments.

Included in the funding shown are Capital Equipment and Accelerator Improvement Project (AIP) funds provided to each of the operating facilities for the enhancement of the accelerator systems and experimental equipment.

In FY 2003 these low energy facilities will carry out about 100 experiments involving over 360 U.S. and foreign researchers. Planned beam hours for research are indicated below:

	(hours of beam for research)		
	FY 2001	FY 2002	FY 2003
Total beam hours for research	12,175	9,500	10,500

	FY 2001	FY 2002	FY 2003
Total, Low Energy Nuclear Physics	**62,650**	**62,422**	**66,158**

Explanation of Funding Changes from FY 2002 to FY 2003

	FY 2003 vs. FY 2002 ($000)
Research	
▪ **University Research**	
▸ FY 2003 funding for researchers and students is increased by 3.6% from FY 2002. Priority will be given to effectively operating the university accelerator facilities, utilizing the national user facilities, and supporting those activities where recent investments have been made, such as SNO and KamLAND. Funding for equipment also increases by $189,000 compared to FY 2002 with the continuation of the HIγS (High Intensity Gamma Source) upgrade at TUNL.	+742
▪ **National Laboratory Research**	
▸ **National User Facilities Research:** FY 2003 funding provides an increase of about 4.4% to enhance research efforts and activities at the three user facilities.	+604
▸ **Other National Laboratory Research**: Research funding is about constant compared to FY 2002. Manpower and effort will be focused on the high priority activities at the national user facilities, SNO and KamLAND. Equipment funds are reduced by $454,000 as projects are completed with no new starts.	-443
Total, National Laboratory Research	+161
▪ **Other Research**	
▸ **RIA R&D:** In FY 2003 $3,500,000 is provided for R&D activities directed at the development of an advanced Rare Isotope Accelerator (RIA) facility. The R&D funding is directed at projects identified in a 3-year R&D plan that has been developed for work that will be performed at ANL, LANL, LBNL, LLNL, ORNL, TJNAF and Michigan State University.	+700
▸ **SBIR and Other:** Estimated SBIR and other obligations increase slightly.	+213
Total, Other Research	+913
Total Research	+1,816
Operations	
▪ In FY 2003 operations are increased by 8.8% compared to FY 2002 to operate the three user facilities providing an increase in an estimated 1,000 hours of beam time for research. Funding for capital equipment and accelerator improvement projects to support these operations increases by $70,000 (+1.7%).	+1,920
Total Funding Change, Low Energy Nuclear Physics	+3,736

Nuclear Theory

Mission Supporting Goals and Objectives

Progress in nuclear physics, as in any science, depends critically on improvements in the theoretical techniques and on the development of new insights that will lead to a theoretical foundation that can be used to predict and interpret experimental results. The goal of the Nuclear Theory subprogram is to make such progress in understanding the characteristics of atomic nuclei and nuclear matter and the fundamental forces involved, utilizing the new results that come from the experimental programs discussed previously and new capabilities that become available.

There are three major frontiers in nuclear theory today. The first involves understanding the properties and behavior of nuclei. In the past, significant progress had been made from the development of theoretical models that view nuclei as interacting ensembles of protons and neutrons. This paradigm of the nucleus is now being revolutionized as new calculational and conceptual tools are being developed which permit microscopic calculations that previously had not been possible. Similarly, collective models, in which the nucleus is treated as a drop of fluid or in which pairs of neutrons or protons are treated as single particles, have achieved great success in describing many aspects of nuclear behavior too complicated to treat with protons and neutrons. With the possibility of new experimental results for nuclei far from stability from studies with radioactive beams, there is hope for developing a “standard model” for nuclei that is applicable across the periodic table. With the establishment of Quantum ChromoDynamics as the fundamental theory of the strong nuclear interaction, a second frontier of nuclear theory is to understand nuclei and the nucleon in terms of their constituent quarks and gluons. This goal is pursued through scientific investigations at the Thomas Jefferson National Accelerator Facility (TJNAF). The third major frontier of nuclear theory is to understand the properties of hot, dense nuclear matter, the central topic of research at the Relativistic Heavy Ion Collider (RHIC). Various approaches from nuclear theory have recently been applied to nuclear astrophysics topics such as supernova explosions, nucleosyntheses of the elements, and properties of neutrinos from the sun, as well as topics from fundamental symmetry investigations.

The Nuclear Theory subprogram supports research carried out at universities and National Laboratories. Some of the investigations depend crucially on access to forefront computing, and to the development of efficient algorithms to use these forefront devices. A very significant component of the program is the Institute for Nuclear Theory (INT), where there is an ongoing series of special topic programs and workshops that includes experimentalists. The Institute is a seedbed for new collaborations, ideas, and directions in nuclear physics.

The program is greatly enhanced through interactions with complementary programs overseas, with efforts supported by the National Science Foundation, with programs supported by the High Energy Physics program and with the Japanese supported theoretical efforts related to RHIC at Brookhaven National Laboratory. Many foreign theorists participate on advisory groups as peer reviewers. There is large participation in the INT by researchers from Europe and Japan and by researchers in overlapping fields such as astrophysics, atomic and molecular physics and particle physics.

Included in this subprogram are the activities that are aimed at providing information services on critical nuclear data and have as a goal the compilation and dissemination of an accurate and complete nuclear data information base that is readily accessible and user oriented.

Funding Schedule

	(dollars in thousands)				
	FY 2001	FY 2002	FY 2003	$ Change	% Change
Theory Research					
University Research	11,797	10,475	11,045	+570	+5.4%
National Laboratory Research	6,948	8,120	8,590	+470	+5.8%
Subtotal Theory Research	18,745	18,595	19,635	+1,040	+5.6%
Nuclear Data Activities	4,877	4,890	5,010	+120	+2.5%
Total, Nuclear Theory	23,622	23,485	24,645	+1,160	+4.9%

Detailed Program Justification

	(dollars in thousands)		
	FY 2001	FY 2002	FY 2003
Theory Research	**18,745**	**18,595**	**19,635**
▪ **University Research**	**11,797**	**10,475**	**11,045**

The research of about 160 university scientists and 85 graduate students is supported through 54 grants at 41 universities in 25 States and the District of Columbia. The range of topics studied is broad, constantly evolving, and each active area of experimental nuclear physics is supported by nuclear theory activities. Graduate student and postdoc support is a major element of this program.

The Institute for Nuclear Theory (INT) at the University of Washington hosts three programs per year where researchers from around the world attend to focus on specific topics or questions. These programs result in new ideas and approaches, the formation of collaborations to attack specific problems and the opportunity for interactions of researchers from different fields of study. For example, recent programs have resulted in a new research effort that fuses modern shell model technology with effective field theory to potentially provide a tractable, rigorous solution for low-energy properties of nuclei.

▪ **National Laboratory Research**	**6,948**	**8,120**	**8,590**

Research programs are supported at six National Laboratories (ANL, BNL, LANL, LBNL, ORNL and TJNAF).

- The range of topics in these programs is broad, and each of the active areas of experimental nuclear physics is supported by at least some of these nuclear theory activities.
- In all cases, the nuclear theory research at a given laboratory provides support to the experimental programs at that laboratory, or takes advantage of some unique facilities or programs at that laboratory.
- The larger size and diversity of the National Laboratory groups make them particularly good sites for the training of nuclear theory postdocs.

	(dollars in thousands)		
	FY 2001	FY 2002	FY 2003

- Funding is provided for new activities to model and calculate complex astrophysical nuclear processes, for example, in stellar supernovae explosions, and the quark/gluon-based structure of nuclei using "lattice gauge" techniques. Both efforts require investments in new computational modeling and simulation research and show great promise in pushing our understanding of the physics of these disciplines to new levels.

Nuclear Data	**4,877**	**4,890**	**5,010**

The Nuclear Data program collects, evaluates, archives, and disseminates information on nuclear properties and reaction processes for the community and the nation. The focal point for its national and international activities is at the DOE-managed National Nuclear Data Center (NNDC) at Brookhaven National Laboratory.

The NNDC relies on the U.S. Nuclear Data Network (USNDN), a network of DOE supported individual nuclear data professionals located in universities and at other National Laboratories who perform data assessment as well as developing modern network dissemination capabilities.

The NNDC participates in the International Data Committee of the International Atomic Energy Agency (IAEA).

Total, Nuclear Theory	**23,622**	**23,485**	**24,645**

Explanation of Funding Changes from FY 2002 to FY 2003

	FY 2003 vs. FY 2002 ($000)
▪ **University Research**	
▸ FY 2003 funding level is increased by 5.4 % compared to FY 2002. This provides increased funding for students and focused funding for priority targeted research.	+ 570
▪ **National Laboratory Research**	
▸ FY 2003 funding level is increased by 5.8% compared to FY 2002. This will permit retention of productive researchers in existing groups and a minimal expansion of priority targeted research.	+ 470
▪ **Nuclear Data**	
▸ FY 2003 funding level is increased by 2.5% compared to FY 2002. Lower priority activities will be phased out in order to maintain manpower in the higher priority activities.	+120
Total Funding Change, Nuclear Theory	+1,160

Capital Operating Expenses & Construction Summary

Capital Operating Expenses

(dollars in thousands)

	FY 2001	FY 2002	FY 2003	$ Change	% Change
General Plant Projects	7,104	6,439	6,560	+121	+1.9%
Accelerator Improvement Projects	5,419	5,450	5,400	-50	-0.9%
Capital Equipment	31,505	30,162	30,220	+58	+0.2%
Total, Capital Operating Expenses	44,028	42,051	42,180	+129	+0.3%

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

(dollars in thousands)

	Total Estimated Cost (TEC)	Prior Year Approp-riations	FY 2001	FY 2002	FY 2003 Request	Accept-ance Date
PHENIX Muon Arm Instrumentation	12,897	11,535	1,362	0	0	FY 2002
BLAST Large Acceptance Detector	5,200	4,000	1,200	0	0	FY 2001
STAR EM Calorimeter	8,600	2,100	2,897	3,000	603	FY 2003
STAR EM Calorimeter Enhancement	4,700	0	0	0	2,400	FY 2004
G0 Experiment Detector	3,965	2,890	1,016	59	0	FY 2002
Total, Major Items of Equipment		20,525	6,475	3,059	3,003	