High Energy Physics

Program Mission

The mission of the High Energy Physics (HEP) program is to understand the universe at a more basic level by investigating the elementary particles that are the fundamental 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 high energy physics and related fields, including particle astrophysics and cosmology, executing a long-range strategy for high energy physics research and technology.

Overview:

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

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

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

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

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

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

Major Advances:

The DOE HEP program has indeed been extremely successful. Since the Department of Energy and its predecessors began supporting the research in this field around 1950, our understanding of the fundamental nature of matter has deepened profoundly, generating a stream of Nobel Prizes that are a source of national pride, prestige and scientific leadership:

- 1957 Nobel Prize: Prediction by Columbia University physicists that parity is not conserved in weak interactions
- 1960 Nobel Prize: Invention of the bubble chamber by a physicist at Lawrence Berkeley National Laboratory (LBNL)
- 1968 Nobel Prize: Many discoveries by a physicist at LBNL using the bubble chamber
- 1969 Nobel Prize: Quark model of elementary particle physics proposed by a Cal Tech physicist
- 1976 Nobel Prize: Discovery of the charm quark at Stanford Linear Accelerator Center (SLAC) and Brookhaven National Laboratory (BNL)
- 1980 Nobel Prize: Discovery of charge-parity (CP) violation in K mesons at BNL
- 1988 Nobel Prize: Discovery of the muon neutrino at BNL
- 1990 Nobel Prize: Experimental basis for up and down quarks at SLAC
- 1995 Nobel Prize: Discovery of the electron neutrino by Los Alamos scientists using the Savannah River Plant and discovery of the tau lepton at SLAC

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 smaller constituents called the up quark and the down quark. Four other quarks were also discovered, for a total of six. The last one, and by far the heaviest, called the top quark, was 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 CERN, the European center for HEP research, in 1983. The photon, which carries the electromagnetic force familiar in our everyday lives, has been known since 1905.

The discoveries of the quark structure of matter was 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 the Standard Model, our theory of the fundamental particles and their interactions. The Standard Model includes twelve fundamental constituents of matter called fermions: six quarks and six leptons (familiar examples are the electron and the neutrino). The fermions occur in three families, each containing two quarks and two leptons. Each family has a similar pattern of particle properties, except for mass, which varies widely from one family to the next. All six quarks and three of the leptons were discovered at DOE accelerator laboratories. There is strong evidence that no more families of quarks and leptons exist beyond these three.

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 are subject to all except the strong force. Only two of the quarks are needed to make protons and neutrons. Thus two quarks and just one lepton—the electron—are sufficient to form all the stable matter we observe on Earth.

Another interaction, not yet observed, is also an essential component of the Standard Model. Called the Higgs field, it would be carried by its own special boson, and is believed to be the source of mass for the W and Z bosons, the quarks, and the charged leptons, and hence for all matter.

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 essentially all of them. It explains an amazing array of experimental data. Yet 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 distinct families of fermions (quarks and leptons)? Are these fermions truly the fundamental constituents of matter, or are they made of still smaller particles? Are fermions related somehow to bosons (force particles like the photon, the W boson, and the gluon)? Why do neutrinos change their identities? Do they violate the symmetry of charge exchange/mirror reflection (CP violation), as the quarks do? Can gravity be incorporated into a complete quantum theory of all particles and forces? Are there extra dimensions of space, beyond the three we know? Why is there so little antimatter in the universe, when we expect equal amounts of each were created in the Big Bang? What is the dark matter that provides most of the mass in the universe? What is the dark energy that causes the recently observed acceleration in the expansion of the universe? Is there a consistent cosmology based on a fundamental theory that explains the history and evolution of the universe?

Unique Opportunities:

In FY 2004, the U.S. High Energy Physics (HEP) program is focused on unique opportunities for great discoveries in physics, utilizing the world-class facilities built for this purpose here in the U.S., including the Tevatron facility at the Fermi National Accelerator Laboratory (Fermilab), and the B-factory at the Stanford Linear Accelerator Center (SLAC). The HEP program also makes use of other unique experiments and facilities worldwide to build a diverse and substantial program that has discovery potential in many areas.

The source of mass in elementary particles is one of the principal mysteries of the Standard Model, our theory of the fundamental constituents of matter and their interactions. The theory explains most observations of particles and forces, but not the wide range of particle masses observed, from the nearly massless neutrino to a top quark that is hundreds of billions of times heavier. The Standard Model proposes that an interaction called the Higgs Field permeates the universe and gives mass to elementary particles. Finding evidence of the Higgs Field has been a principal goal of high energy physics for years, with searches underway at accelerator facilities around the world.

The Large Electron-Positron Collider (LEP) at the European Organization for Nuclear Research (CERN) left a tantalizing hint of a Higgs when LEP ceased operations in late 2000. The LEP data suggest a Higgs mass of about 115 GeV, well within reach of the Tevatron. 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 2008. Thus the Tevatron at Fermilab, with substantial upgrades completed in 2001 and further improvements in progress, will have a chance to discover the Higgs before the LHC can get fully underway.

In order to maximize this window of opportunity, 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 underway, interleaved with intensive data runs. If it is successful, by the time LHC produces its first results, the Tevatron should have supplied enough data to find direct evidence of the Higgs if its mass is less than 165 GeV. Tevatron data will also give much more information about the surprisingly heavy top quark discovered there in 1995, and could reveal entirely new classes of particles or even undiscovered space-time dimensions that have been predicted by new theories that seek to complete the unification of fundamental interactions.

At SLAC, the highly successful B-factory and its BaBar detector use electrons colliding at several billion electron volts (GeV) to study a phenomenon known as Charge-Parity (CP) violation in B mesons, which causes an asymmetry in their decays. 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 at Brookhaven National Laboratory using much lighter mesons made of strange quarks. Its accommodation within the current theory has only recently been established through extremely difficult and exquisitely precise measurements at Fermilab and CERN. CP violation has now been observed in the B mesons at SLAC and the big question is whether it will follow theoretical predictions or will indicate a different source of the phenomenon. The B-factory will need a progressive series of upgrades to both the detector and the accelerator in order to be competitive with a similar facility now operating in Japan.

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 perform as expected, be strongly utilized, and eventually be significantly upgraded. Therefore, the FY 2003 budget focused on the utilization and upgrades of these facilities together with support for the research groups (primarily university based) performing the research. 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 the Tevatron and B-factory, there are other unique opportunities in the near-term program. A long baseline neutrino detection experiment, Main Injector Neutrino Oscillation Search (MINOS), is currently being fabricated in Minnesota, and the Neutrinos at the Main Injector (NuMI) beamline construction project at Fermilab will provide a dedicated beam of neutrinos for MINOS. Fermilab has also begun operating a smaller neutrino oscillation experiment called MiniBoone. With NuMI/MINOS and MiniBoone, Fermilab has an opportunity to directly confirm or refute early indications of neutrino oscillations and to make precise mass measurements. Positive results could inaugurate a new era of precision experiments to explore neutrino properties, including the possibility of observing CP violation with neutrinos.

Theory and Accelerator-Based Experiments:

Theoretical research in high energy physics seeks to understand elementary particles and forces. A theorist may pursue established ideas or invent new ones, but each one must be thoroughly explored and developed. A theory is expressed in mathematical form and provides a way to calculate particle properties and interactions, which can be tested experimentally. The theory may also predict new phenomena that can be sought by experimenters. Experimental work tests specific theoretical predictions and also explores for new phenomena not predicted by any theory. 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 more than 100 U.S. universities. In addition, there are participating university scientists supported by the National Science Foundation (NSF), scientists at DOE laboratories (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, they 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 FY 2003, HEP research was also conducted at the Alternating Gradient Synchrotron at BNL. 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 CERN, near Geneva, Switzerland, and those facilities will be even more important to the DOE program in the future. CERN is building the LHC, which will begin commissioning in 2007. Under an international agreement established in 1997, DOE in collaboration with the 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 used telescopes to discover 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 antimatter in space, and the Gamma-ray Large Area Space Telescope (GLAST/LAT) will be placed in earth orbit to study high energy gamma rays from "gamma ray bursters" and other astrophysical sources, using particle physics detection techniques. This class of astrophysical phenomena is particularly interesting because it indicates that out in space there are particle acceleration mechanisms (and hence forces) far greater than any encountered here on earth. The scientific topics studied will include those of interest to both particle physicists and cosmologists, such as the "dark matter" responsible for large-scale galactic structures: new fundamental particles are a popular candidate for such dark matter.

The proposed SuperNova Acceleration Probe (SNAP) would put an advanced imaging telescope in space to follow-up on the discovery of the accelerating universe with a detailed study of the Dark

Energy that is postulated to be responsible for pushing the universe apart. This mysterious Dark Energy makes up about two-thirds of the energy budget of the Universe, and does not fit into our current model of fundamental matter and forces. Measurements of the nature of Dark Energy will lead to an understanding of the history of the expansion of the Universe, from about 10 billion years ago until the present.

Technology Development:

High energy physics research deals with very high particle energies and very small distance scales. Experimenters must make precision measurements of phenomena buried in a background of noise or search for very rare processes. Such research demands particle beams of great intensities and detectors with the sensitivity to see the rare events and the selectivity to pull these out of background noise. The HEP program supports advanced technology research and development aimed at developing higher energy accelerators and more sensitive and selective detectors.

It is essential to accumulate, store, process, and transmit to hundreds of researchers worldwide the increasingly large data sets produced by modern experiments. Some theoretical problems also require massive computing resources. For example, the theory of strong interactions (called "Quantum Chromodynamics (QCD)") can be solved to high precision only using advanced, high-performance computers. Development of suitable computing resources for experiment and theory is supported by the program and additional resources are provided through the *Scientific Discovery through Advanced Computing* (SciDAC) program (see below).

Operating in these extreme domains requires substantial time and expense to design, build, maintain, operate, and upgrade the complex and technically advanced research apparatus. A new accelerator or colliding beam device now requires 10 to 20 years of intensive research and development work to bring 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 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 for their research. Fortuitously, it is from this technology R&D that many of the spin-offs to other sciences and the marketplace originate. See "Benefits to Other Sciences and Citizens" below for examples.

The technology R&D program supported by the DOE High Energy Physics program includes studies of the fundamental science principles underlying the design and operation of accelerators, storage rings, and detectors that are the principal tools of the research, the invention and reduction to practice of new devices and technology, and the development of designs for devices essential to the research capabilities of the future.

The research in accelerator science includes studies in nonlinear dynamics of particle beam optics, applications of chaos theory to the behavior of space charge dominated particle beams, new computational techniques, and computer modeling of accelerator storage ring and detector systems. An essential part of the research is the search for new accelerator concepts and methods. Excellent progress has been made in the use of lasers and plasmas in the acceleration of electrons and positrons (anti-electrons) and in the exploration of alternate radio frequency acceleration techniques. A significant R&D effort is development of superconducting wire and cable for use in superconducting magnets. The development of niobium tin and niobium aluminum as well as the application to the newer high temperature superconductors is done in collaboration with U.S. industry through direct grants and the

Small Business Innovation Research (SBIR) program. This work together with development of new magnet geometries for the generation of very magnetic fields sustains and advances this essential core competency of the technology R&D used in high energy physics.

The Department is continuing research and development directed toward accelerator facilities that will be needed for the future. The 2002 HEPAP long range planning report recommends "that the highest priority of the U.S. program be a high energy, high-luminosity, electron-positron linear collider." Work is directed toward achieving a center-of-mass energy for a Linear Collider (LC) in the TeV range 500 to 1000 GeV, expandable to 1.5 TeV. (A GeV is one billion electron volts of energy). The LC 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 LC may well be international, and research and development on linear colliders is also underway in other countries, primarily Germany and Japan.

For energies well beyond the LHC, a next-generation, very high energy hadron collider is a natural candidate for a possible future accelerator with great discovery potential. Its research program may include investigations of new particles, extra dimensions, quantum gravity, or phenomena not even thought of today. Such an accelerator might have a collision energy greater than 100 TeV, much higher than that of the LHC (14 TeV). Work is underway at several laboratories and universities toward designing magnets that could make such a hadron collider affordable. This basic research into production-quality high-field magnets is a long-term effort that may pay dividends to other fields of science and technology as well.

Benefits to Other Sciences and to Citizens:

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

Technology that was developed in response to the demands of high energy physics has become exceedingly useful to other fields of science, and thus has helped science to advance on a broad front. Synchrotron light sources, an outgrowth of electron accelerators and storage rings, have become invaluable tools for materials science, structural biology, chemistry, 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 large teams. Many of them go into careers in high-tech industries, contributing to our country's economic strength.

How We Work:

The High Energy Physics program coordinates and funds high energy physics research. The program is responsible for planning and prioritizing all aspects of supported research, conducting ongoing assessments to ensure a comprehensive and balanced portfolio, regularly seeking advice from stakeholders, supporting core university and national laboratory programs, and maintaining a strong infrastructure to support high energy physics research.

Advisory and Consultative Activities:

To ensure that resources are allocated to the most scientifically promising experiments, the Department of Energy and its national laboratories actively seek external input using a variety of advisory bodies.

The ***High Energy Physics Advisory Panel (HEPAP)*** provides advice to the Department of Energy and the National Science Foundation on a continuing basis regarding the direction and management of the national high energy physics research program. In FY 2002, the DOE HEP program provided about 90% of the federal support for high energy physics research in the nation. The National Science Foundation (NSF) provided most of the remaining support. HEPAP regularly meets to advise the agencies on their research programs, assess their scientific productivity, and evaluate the scientific case for new facilities.

Laboratory directors seek advice from ***Program Advisory Committees (PACs)*** to determine the allocation of a scarce scientific resource—the available beam time. Committee members, mostly external to the laboratory, are appointed by the director. PACs review research proposals requesting time at the facilities and technical resources; judging each proposal's scientific merit, technical feasibility, and manpower requirements and recommending whether the proposal should be approved, conditionally approved, deferred, or rejected. Non-accelerator research proposals to DOE and NSF are reviewed by a special advisory committee called SAGENAP (Scientific Assessment Group for Experiments in Non-Accelerator Physics).

Review and Oversight:

The High Energy Physics program provides review and oversight for its research portfolio. All ***university*** research proposals are subjected to an intensive and multistage review process to ensure high quality research and an appropriate mix of experiments in the national program. A university proposal to perform an experiment at a laboratory facility is reviewed by the laboratory PAC as described above. Its proposal to DOE for support is peer-reviewed by a group of external technical experts. Once a university group is funded, regular site visits and peer reviews are performed to ensure that the quality of the research is maintained.

The program also conducts annual in-depth reviews of the high energy physics program at each ***laboratory***, using a panel of external technical experts. These on-site reviews examine the institutional health of the laboratory, its high energy physics research program, and, as appropriate, the state of its user facilities. The results are used in setting priorities both at the laboratory and within the national program. HEPAP meets once a year at one of the major high energy physics laboratories and devotes one-third of its time to a review of that laboratory's program. Findings and recommendations are transmitted to DOE. In addition, the HEP program participates in the annual SC Institutional Reviews for each of its laboratories and semi-annual reviews of each of its ongoing construction projects conducted by the Construction Management Support Division in the Office of Science.

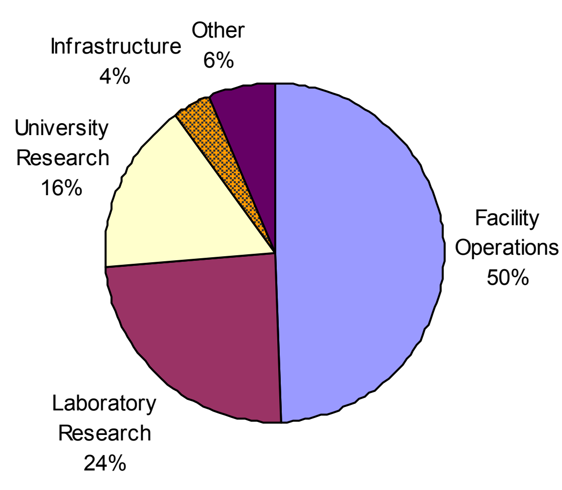
Planning and Priority Setting:

One of the most important functions of HEPAP is development of long-range plans that express community-wide priorities for future research. The most recent such plan was submitted in January 2002 and presented a roadmap for the field, laying out the physics opportunities the planning subpanel could envision as possibilities for the next twenty years. As part of this roadmap, the panel recommended that the highest priority of the U.S. program be a high energy, high-luminosity electron-positron linear collider to be built as a fully international effort. A Linear Collider Steering Group has been formed, comprised of eminent members of the field, to coordinate U.S. efforts toward a linear collider. HEPAP further recommended vigorous long-term R&D toward future accelerators as a high priority.

How We Spend Our Budget:

The High Energy Physics budget has five major components by function. About 50% of the program funding was provided to HEP laboratories (Fermilab and SLAC) for facility operations; a total of 24% was provided to laboratories, including multipurpose laboratories, in support of their HEP research activities; 16% was provided for university-based research; 4% for infrastructure improvements (construction plus GPP and GPE); and 6% for other activities (including SBIR and STTR). The FY 2004 budget request is focused on facility operations and upgrades at Fermilab and SLAC to advance research with the CDF and D-Zero detectors at the Tevatron and the BaBar detector at the B-factory.

HIGH ENERGY PHYSICS
FY 2004



Research:

The DOE High Energy Physics program supports approximately 2450 researchers and students at over 100 U.S. universities located in 36 states, Washington, D.C., and Puerto Rico, and 8 laboratories located in 5 states. These physicists conceive and carry out the high energy physics research program. Funding for university and laboratory research is held essentially flat compared to FY 2003 in order to support high-priority facility operations. National laboratory research scientists work together with the experimental collaborations to collect and analyze data as well as support and maintain the detectors. The laboratories provide state-of-the-art resources for detector and accelerator R&D for future upgrades and new facilities. The division of support between national laboratories and universities is adjusted to maximize productivity.

- ***University Research:*** University researchers play a critical role in the nation's research effort and in the training of graduate students. During FY 2002, the DOE High Energy Physics program supported approximately two-thirds of the nation's university researchers and graduate students engaged in fundamental high energy physics research. Typically, about 120 Ph.D. degrees are granted annually to students for research supported by the program.

  The university grants program is proposal driven, and funds the best and brightest of those ideas submitted in response to grant solicitation notices. Proposals are reviewed by external scientific peers and competitively awarded according to the guidelines published in Office of Science Regulation 10 CFR 605. Thereafter, the research is monitored to ensure quality of research is maintained (see Review and Oversight, above).

- ***National Laboratory Research:*** The High Energy Physics program supports research groups at the Fermi, Lawrence Berkeley, Lawrence Livermore, Argonne, Brookhaven, and Los Alamos National Laboratories, Princeton Plasma Physics Laboratory, and the Stanford Linear Accelerator Center. The directions of laboratory research programs are driven by the needs of the Department and are tailored to the major scientific facilities at the laboratories. Laboratory researchers collaborate with academic users of the facilities and are important for developing and maintaining the large experimental detectors and computing facilities for data analysis.

  The High Energy Physics program funds field work proposals from the national laboratories. Performance of the laboratory groups is reviewed annually by program staff assisted by an external panel of technical experts (see Review and Oversight, above), to examine the quality of their research and identify needed changes, corrective actions, or redirection of effort. Individual laboratory groups have special capabilities or access to laboratory resources that can be profitably utilized in the development of the scientific program.

Program Strategic Performance Goals

SC1-1: Manage a program that provides world-class, peer-reviewed research results in the scientific disciplines encompassed by the High Energy Physics mission areas, cognizant of the needs of DOE and of the wider scientific community. (Proton Accelerator-Based Physics, Electron Accelerator-Based Physics, Non-Accelerator Physics, Theoretical Physics and Advanced Technology subprograms)

Performance Indicators

Validation of results by merit review with external peer evaluation; Validation of program directions by the High Energy Physics Advisory Panel.

Annual Performance Results and Targets

FY 2002 Results	FY 2003 Targets	FY 2004 Targets
		At least 80% of all new research projects will be peer reviewed and deemed excellent (of highest quality) and relevant, and annually 30% of all ongoing projects will be subject to peer review with merit evaluation. (SC1-1-1) Respond to priorities and recommendations for the DOE High Energy Physics program in the 2002 High Energy Physics Advisory Panel Long Range Plan: • support R&D for a high-energy, high-luminosity electron-positron linear collider as the next major facility in the field, and prepare the U.S. to bid to host the facility; • respond to advice from the Particle Physics Project Prioritization Panel concerning possible future HEP projects. (SC1-1-2)

SC7-1: 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. (Proton Accelerator-Based Physics subprogram and Electron Accelerator-Based Physics subprogram).

Performance Indicator

Percent on time/on budget; Percent unscheduled downtime; Validation of results by merit review with external peer evaluation.

Annual Performance Results and Targets

FY 2002 Results	FY 2003 Targets	FY 2004 Targets
Complete and deliver A Toroidal LHC ApparatuS (ATLAS) detector barrel cryostat and feedthroughs to CERN. *[Met goal]*		Complete installation of CMS calorimeter in surface building.

FY 2002 Results	FY 2003 Targets	FY 2004 Targets
Complete prototype Large Hadron Collider quadrupole and dipole magnets. *[Met goal]*		Begin vertical integration tests of CMS subsystems. Complete production of Large Hadron Collider beam separation dipole magnets.
The completion targets for the U.S. portion of the Large Hadron Collider project are: CMS 77% ATLAS 72% Accelerator 85% *[Mixed Results]*(SC7-1-1)	The completion targets for the U.S. portion of the Large Hadron Collider project are: CMS 78% ATLAS 78% Accelerator 86% (SC7-1-1)	The completion targets for the U.S. portion of the Large Hadron Collider project are: CMS 84% ATLAS 83% Accelerator 90% (SC7-1-1)
	Conduct, using outside experts, a review (1) of the operations and performance of the HEP–supported accelerator facility at Fermilab (Tevatron) to identify opportunities to optimize efficiency and performance. (SC7-1-2)	Conduct, using outside experts, a review (1) of the operations and performance of the HEP–supported accelerator facility at SLAC (B-factory) to identify opportunities to optimize efficiency and performance. (SC7-1-2)
Maintain and operate HEP facilities such that unscheduled downtime is less than 20% of the total scheduled operating time. *[Met goal]* (SC7-1-3)	Maintain and operate HEP facilities such that unscheduled downtime is on average less than 20% of the total scheduled operating time. (SC7-1-3)	Maintain and operate HEP facilities such that unscheduled downtime is on average less than 20% of the total scheduled operating time. (SC7-1-3)

Program Assessment Rating Tool (PART) Assessment

The High Energy Physics program participated in the PART review conducted by the Office of Management and Budget. The program scored highly in the Purpose and Management sections primarily as the result of a well-defined mission and merit-based reviews for awarding contracts and grants. Lower scores in Planning and Results/Accountability were attributed primarily to the program’s lack of adequate long-term and annual performance measures; however, it was noted that the program has made significant strides toward developing such measures despite the problems inherent in measuring and predicting scientific progress. Further contributing to the lower Results score was the fact that two construction projects were under-performing or over budget/schedule, partly because the program is undertaking several high-risk projects simultaneously. Reviews of the program are conducted by HEPAP, and also the Division of High Energy Physics conducts annual reviews, using independent consultants, of the HEP programs at its five laboratories. However, it was called out that the program does not currently have regular reviews of its research portfolio and processes by ad hoc panels of outside technical experts.

As a result of the above findings, the High Energy Physics program will take the following actions in FY 2004. The program will work further to reform its performance measures and goals while being sensitive to the problems that basic research programs face in attempting to predict future scientific progress. Also, the FY 2004 budget focuses resources on addressing construction and upgrade problems at Fermilab while simultaneously operating the laboratory at 82 percent of maximum capacity (compared to 87 percent in FY 2003 and 78 percent in FY 2002). The program has formed a committee, called the Particle Physics Project Prioritization Panel (P5), to prioritize its medium and large ($50-600M TEC) construction projects and MIEs within the program that have not yet reached the full construction phase. The first meeting of P5 is scheduled for late January 2003. In addition, the program will institute a process, by September 2003, for reviewing its research portfolio by a formal committee of visitors.

Significant Program Shifts

- A number of planned upgrades to the Tevatron and the B-factory 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.
- The operation of the Tevatron collider complex has been disappointingly slow in achieving the desired beam intensities in the early phase (FY 2001-2002) of its major datataking run ("Run II"), perhaps diminishing some of the opportunities described above. Fermilab has assigned its highest priority to rectifying this situation. Internal resources have been redirected to solve the Tevatron performance issues, slowing progress on longer-term accelerator R&D projects that are not essential to the near-term goal of maximizing the Tevatron's ability to discover new physics.
- The extra resources needed to meet Tevatron Run II luminosity goals are mostly the efforts of accelerator physicists at Fermilab, and are not incurring "extra" costs to the program. Costs for materials and hardware needed to upgrade the Tevatron had already been planned and budgeted as noted above. A few SLAC, LBNL and BNL accelerator physicists with specialized expertise relevant to Run II problems have been recruited to help as well.
- DOE has established an exciting and expanding partnership with NASA in the area of Particle Astrophysics and Cosmology. The Alpha Magnetic Spectrometer (AMS) and Gamma-ray Large Area Space Telescope (GLAST/LAT) experiments have been underway for some time, and there is an exciting new proposal for an interagency experiment – the SuperNova Acceleration Probe (SNAP) -- to explore the nature of the recently-discovered "dark energy" which appears to be causing an accelerating expansion of the universe. These experiments, and others that may be proposed, will provide important new information about the birth, evolution and ultimate fate 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/LAT experiments, which are joint DOE-NASA projects, have received NASA mission approval.
- The Neutrinos at the Main Injector (NuMI) project has overcome 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.
- The HEP budget structure has changed significantly to realign the subprograms, allowing the budget to be presented more clearly in terms of the major physics thrusts in the overall program.

Scientific Discovery through Advanced Computing

The Scientific Discovery through Advanced Computing (SciDAC) activity is a set of coordinated investments across all Office of Science mission areas with the goal to achieve breakthrough scientific advances through computer simulation that were impossible using theoretical or laboratory studies alone. The power of computers and networks is increasing exponentially. By exploiting advances in computing and information technologies as tools for discovery, SciDAC encourages and enables a new model of multi-discipline collaboration among the scientific disciplines, computer scientists and mathematicians. The product of this collaborative approach is a new generation of scientific simulation codes that can fully exploit terascale computing and networking resources. The program will bring simulation to a parity level with experiment and theory in the scientific research enterprise as demonstrated by major advances in climate prediction, plasma physics, particle physics, astrophysics and computational chemistry.

Scientific Facilities Utilization

The High Energy Physics request supports the Department's scientific user facilities. This investment will provide significant research time for several thousand scientists based at universities and other Federal laboratories. It will also leverage both Federally and privately sponsored research, consistent with the Administration's strategy for enhancing the U.S. national science investment.

The proposed funding will support operations at the Department's two major high energy physics facilities: the Tevatron at Fermilab, and the B-factory at the Stanford Linear Accelerator Center (SLAC). These facilities provided a total of 74 weeks of beam time in FY 2002 for a research community of about 2,200 U.S. scientists in HEP and related fields. A comparable number of users come from foreign countries, testifying to the fact that these are unique, world-leading experimental facilities. The FY 2004 President's Budget Request will support facility operations that will provide ~75 weeks of beams for research. This plan will maintain the FY 2003 level at SLAC and a slight decrease at Fermilab associated with required shutdown for facility modification and upgrades.

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

	Estimated maximum utilization	FY 2002	FY 2003	FY 2004 Request
Tevatron Collider at Fermilab				
Maximum hours = 5400				
Scheduled running weeks	45	39	39	36
Unscheduled Downtime		18%	<20%	<20%
Number of Users = 2160				
B-factory at SLAC				
Maximum hours = 5850				
Scheduled running weeks	45	35	39	39
Unscheduled Downtime		14%	<20%	<20%
Number of Users = 1100				

In FY 2003, the Alternating Gradient Synchrotron at Brookhaven National Laboratory ceased its program of High Energy Physics research.

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

	FY 2000	FY 2001	FY 2002	FY 2003	FY 2004 Request
Major milestones completed or committed to	Completed Central Detector Facility (CDF) Run II upgrade at Fermilab Completed Large Hadron Collider accelerator dipole model magnet program	Completed D-Zero Run II upgrade at Fermilab Completed U.S. Compact Muon Solenoid (CMS) hadron calorimeter absorber and delivered to CERN	Completed construction of U.S. A Toroidal LHC Apparatus (ATLAS) tile calorimeter sub-modules Completed fabrication of first half of Main Injector Neutrino Oscillation (MINOS) experiment	Complete Neutrinos at the Main Injector (NuMI) excavation Complete AntiMatter in Space (AMS) upgrade Complete first inner triplet quadrupole magnet for LHC accelerator	Complete NuMI civil construction Complete U.S. ATLAS Transition radiation tracker module production Complete U.S. CMS Hadron calorimeter readout test Complete Pierre Auger project construction

Construction and Infrastructure:

Funding for construction and capital equipment is down significantly compared to FY 2003 as several construction projects are ramping down, and R&D activities directed at NLC are kept constant. The High Energy Physics program as part of its responsibilities as the landlord for Fermilab, SLAC, and Lawrence Berkeley National Laboratory provides funding for general plant projects (GPP) and general purpose equipment (GPE).

Workforce Development

The High Energy Physics program supports development of the R&D workforce through support of graduate students working toward a doctoral degree and post-doctoral associates developing their research and management skills. The R&D workforce developed under this program not only provides new scientific talent in areas of fundamental research, but also provides talent for a wide variety of technical, medical, and industrial areas that require the finely honed thinking and problem solving abilities and computing and technical skills developed through an education and experience in a

fundamental research field. Scientists trained as High Energy Physicists can be found in such diverse areas as hospitals (radiation therapy, medical imaging, and medical physics), national security, space exploration, software and computing, telecommunications, and many more fields.

About 1,200 post-doctoral associates and graduate students supported by the High Energy Physics program in FY 2002 were involved in a large variety of theoretical and experimental research, including advanced technology R&D. About one-fifth are involved in theoretical research. Those involved in experimental research utilize a number of scientific accelerator facilities (~90%) supported by the DOE, NSF, and foreign countries as well as participating in non-accelerator research (~10%).

Details of the High Energy physics manpower are given below. These numbers include people employed by universities and laboratories. The University grants include Physics Research and Accelerator Technology grants. In FY 2001, there were 140 University grants with an average funding of $850,000 per year. Most of these are multi-task grants with an average of three tasks. The duration of the grants is three years. The number of laboratory groups is an estimate of the number of distinct HEP research groups (experiment, theory, accelerator R&D) at the laboratories, which is a collection of single and multi-task efforts.

Human Resources (Full-Time Equivalent) in High Energy Physics

at Laboratories and Universities, DOE supported

	FY 2001	FY 2002	FY 2003 est.	FY 2004 est.
University Grants	145	140	140	140
Lab Groups	51	51	50	50
Ph.D.'s with permanent positions	1265	1255	1255	1255
Postdoctoral Associates	575	565	565	565
Graduate Students	615	605	610	610
# Ph.D.'s awarded	125	120	120	120

Funding Profile

(dollars in thousands)

	FY 2002 Comparable Appropriation	FY 2003 Request	FY 2004 Request	$ Change	% Change
High Energy Physics					
Proton Accelerator-Based Physics	388,117	387,886	399,494	+11,608	+3.0%
Electron Accelerator-Based Physics	148,232	150,148	159,486	+9,338	+6.2%
Non-Accelerator Physics	39,115	37,420	43,000	+5,580	+14.9%
Theoretical Physics	43,005	42,490	42,256	-234	-0.6%
Advanced Technology R&D	67,514	86,953	81,242	-5,711	-6.6%
Subtotal, High Energy Physics	685,983	704,897	725,478	+20,581	+2.9%
Construction	11,400	20,093	12,500	-7,593	-37.8%
Total, High Energy Physics	697,383[a][b]	724,990	737,978	+12,988	+1.8%

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 $14,521,000 which was transferred to the SBIR program and $871,000 which was transferred to the STTR program.

[b] Excludes $395,000 for the FY 2002 rescission contained in Section 1403 of P.L. 107-226, Supplemental Appropriations for further recovery from and response to terrorist attacks on the United States.

Funding by Site [a]

	(dollars in thousands)				
	FY 2002	FY 2003	FY 2004	$ Change	% Change
Albuquerque Operations Office					
Los Alamos National Laboratory	984	825	825	0	0.0%
Chicago Operations Office					
Argonne National Laboratory	9,849	10,293	10,043	-250	-2.4%
Brookhaven National Laboratory	39,117	23,319	21,161	-2,158	-9.2%
Fermi National Accelerator Laboratory	306,782	313,200	304,663	-8,537	-2.7%
Princeton Plasma Physics Laboratory	268	364	364	0	0.0%
Chicago Operations Office	83,465	74,527	72,804	-1,723	-2.3%
Total, Chicago Operations Office	439,481	421,703	409,035	-12,668	-3.0%
Oakland Operations Office					
Lawrence Berkeley National Laboratory	43,284	32,530	39,183	+6,653	+20.4%
Lawrence Livermore National Laboratory	1,221	429	429	0	0.0%
Stanford Linear Accelerator Center	161,587	163,887	169,845	+5,958	+3.6%
Oakland Operations Office	38,152	44,000	36,228	-7,772	-17.7%
Total, Oakland Operations Office	244,244	240,846	245,685	+4,839	+2.0%
Oak Ridge Operations Office					
Oak Ridge Inst. for Science & Education	80	130	130	0	0.0%
Oak Ridge National Laboratory	673	660	660	0	0.0%
Total, Oak Ridge Operations Office	753	790	790	0	0.0%
Richland Operations Office					
Pacific Northwest National Laboratory	54	0	0	0	0.0%
Washington Headquarters	11,867	60,826	81,643	+20,817	+34.2%
Total, High Energy Physics	697,383[bc]	724,990	737,978	+12,988	+1.8%

[a] On December 20, 2002, the National Nuclear Security Administration (NNSA) disestablished the Albuquerque, Oakland, and Nevada Operations Offices, renamed existing area offices as site offices, established a new Nevada Site Office, and established a single NNSA Service Center to be located in Albuquerque. Other aspects of the NNSA organizational changes will be phased in and consolidation of the Service Center in Albuquerque will be completed by September 30, 2004. For budget display purposes, DOE is displaying non-NNSA budgets by site in the traditional pre-NNSA organizational format.

[b] Excludes $14,521,000 which was transferred to the SBIR program and $871,000 which was transferred to the STTR program.

[c] Excludes $395,000 for the FY 2002 rescission contained in Section 1403 of P.L. 107-226, Supplemental Appropriations for further recovery from and response to terrorist attacks on the United States.

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 in the past 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 was 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 two large multi-purpose detectors, 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 commissioning in 2007. With the shutdown of the LEP machine at CERN in Switzerland in 2000, the Tevatron became the only operating particle accelerator at the energy frontier. The Tevatron complex also includes the Booster and the Main Injector, pre-accelerators 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. The Booster is used to accelerate low-energy protons, and a small part of the beam that is not used for Tevatron collider operations is provided to produce neutrinos for short-baseline oscillation experiments. 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 advanced 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.

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 B-factory and its detector, BaBar, and a small program of fixed target experiments. The B-factory, a high energy electron-positron collider, was constructed to support a search for and high-precision 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.

All Other Sites

The High Energy Physics program supports about 260 research groups at more than 100 colleges and universities located in 36 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 (NIST), Naval Research Laboratory (NRL), the Smithsonian Institution), and a few small companies. Through its participation in the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs, the DOE HEP program also supports advanced technology R&D at over 70 small businesses located throughout the U.S.

Facilities Summary

Fermilab

In FY 2004, Fermilab plans 36 weeks of running to achieve a performance goal of 400 pb-1 of data delivered to the major Tevatron experiments. Approximately 850 people are involved in day-to-day Tevatron operations, which include operation of the Tevatron accelerator complex and the CDF and D-Zero detectors. This is one of the major data collection periods for the experiments searching for the Higgs and other signals of new physics at the world's energy frontier facility as described in more detail in the Unique Opportunities section above.

Fully achieving the physics goals of the Tevatron program over the next five years requires a series of performance enhancements to the accelerator and the CDF and D-Zero detectors. These efforts are proceeding in parallel with current Tevatron operations and research and are more fully described in the Detailed Justification sections that follow.

Tevatron operations also include the running of the Tevatron complex in fixed target mode in parallel with Tevatron collider operation. This will be for the physics data taking of the MiniBooNE experiment (8 GeV protons extracted from Booster ring) and for test beam runs (120 GeV protons extracted from Main Injector). In FY 2004, the MiniBooNE experiment will be operating its beam line and detector to collect data. Test beam runs will be scheduled as needed. These functions are non-interfering with the high-priority Tevatron collider operations.

SLAC

In FY 2004, SLAC plans 39 weeks of running to achieve a performance goal of 50 fb^{-1} of data delivered to the BaBar experiment. Approximately 450 people are involved in day-to-day B-factory and BaBar operations. This will be the priority research program at SLAC in FY 2004. It is anticipated that the collected data will exceed the total collected in FY 2003, providing a significant enhancement to the BaBar dataset for precision studies of CP violation in the B-meson system, as described above.

Fully achieving the physics goals of the B-factory program over the next five years requires a series of performance enhancements to the accelerator and the BaBar detectors. 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. These efforts are proceeding in parallel with current B-factory operations and research and are more fully described in the Detailed Justification sections that follow.

AGS

Operations at BNL for HEP experiments using the AGS facility were terminated in FY 2003.

HEP facilities operations funding and running weeks are summarized in the table below for the Tevatron, B-factory and Alternating Gradient Synchrotron (AGS):

	(dollars in thousands)		
	FY 2002	FY 2003	FY 2004
Tevatron Operations	191,958	181,638	190,955
Tevatron Improvements[a]	49,677	51,589	57,240
Total, Tevatron	241,635	233,227	248,195
Running Weeks	39	39	36
B-factory Operations	97,334	97,275	104,225
B-factory Improvements[b]	20,595	19,810	21,618
Total, B-factory.	117,929	117,085	125,843
Running Weeks	35	39	39
AGS Operations	5,917	0	0
AGS Support	95	0	0
Total, AGS	6,012	0	0
Running Weeks	18	0	0

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

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

Proton Accelerator-Based Physics

Mission Supporting Goals and Measures

The Proton Accelerator-Based Physics subprogram exploits U.S. leadership at the energy frontier by conducting experimental research that will determine whether the Standard Model correctly predicts the mechanism that generates mass for all fundamental particles, or provide clear evidence for physics beyond the Standard Model. The Proton Accelerator subprogram also includes support for the facilities and research groups to perform decisive controlled measurements of basic neutrino properties, including neutrino oscillations that will provide important clues and constraints to the theory of matter and energy beyond the Standard Model.

Introduction

Proton accelerators are capable of producing the highest-energy particle beams made by man, and by colliding proton beams into targets, large samples of other particles like antiprotons, *K* mesons, muons, and neutrinos can be produced and formed into beams for experiments. The proton accelerator subprogram uses both of these aspects of proton accelerators.

The Tevatron at Fermilab is the highest-energy particle accelerator in the world. It produces collisions of 1 TeV protons with 1 TeV antiprotons. Because of the high energy of the collisions and the fact that the particles interact via three different interactions, the collisions can be used to study a wide variety of physics topics. All of the six different types of quarks are produced in these interactions with the heaviest, the top and bottom quarks, being of the most interest. Most of the force carrying particles are also directly produced, and if the masses of predicte – but as yet unobserved – particles, like the Higgs boson or supersymmetric particles are low enough, they will also be produced at the Tevatron. Two large general-purpose detectors, CDF and D-Zero, have been built to mine this rich lode of physics.

The Higgs boson is a crucial missing piece of the puzzle underlying the interactions of quarks and leptons. While the Standard Model predicts its existence, the mass of the Higgs boson is not known. Very general theoretical arguments point to the conclusion that collisions of quarks or leptons with energies in the ballpark of 1 TeV are likely to produce the Higgs. The current physics program at the Proton Accelerator-Based facilities will be focused on the unique opportunity for the discovery of the Higgs boson, which has been a principal goal of high energy physics for years and may explain the source of mass for all elementary particles. A unique opportunity exists at Fermilab to search for a Higgs boson. This opportunity results from recent DOE investments in the construction of the Fermilab Main Injector and the upgrades of the collider detectors. Other areas with great discovery potential include the search for supersymmetric particles, the hypothetical heavier "twins" of all known elementary particles, and the search for evidence of extra space-time dimensions that are hidden in everyday life. Either of these discoveries, or any of a number of other possibilities, would be key elements in understanding the physics beyond the Standard Model. These energy frontier programs will be carried out at the Tevatron at Fermilab, followed by the LHC program at CERN over the next decade. In parallel, there will be other wide varieties of very interesting physics to pursue. The number of top quarks – the most massive fundamental particle known – discovered and studied during the previous Tevatron collider run was less than 100. The new run will produce an order of magnitude more top quarks, which will allow a serious study of its properties. A variety of B meson studies will be done, including independent confirmation of CP violation, which has been observed at the B-factories at

SLAC and in Japan. Other processes, inaccessible to the B-factories, can also be measured. These measurements provide vital pieces of the theoretical framework used to explain CP violation, and an explanation of CP violation is necessary to understand why matter (and not antimatter) is what makes up the universe we live in. A precision measurement of mass of the W boson and detailed studies of the charm quarks will also be carried out.

Neutrino physics presents today one of the most promising avenues to probe for extensions of the Standard Model. *A priori*, no fundamental reason exists why neutrinos should have zero mass or why there should be no mixing between different neutrino species. In the past few years, a number of interesting new results have been reported by several different experiments, including the Liquid Scintillation Neutrino Detector (LSND) experiment at Los Alamos, the Super-K and KamLAND experiments in Japan and the Sudbury Neutrino Observatory experiment in Canada. These experiments provide compelling evidence that neutrinos do have mass and that they do change their identities (the different neutrino species "mix") as they travel. Unfortunately, the neutrinos used by these experiments have a wide range of energies and are produced in insufficient numbers to precisely measure their oscillation parameters. One of the unique opportunities in the Proton Accelerator subprogram is exploring and making precision measurements of the neutrinos, which will be generated by using dedicated proton beam facilities in a well-controlled environment (e.g., the Neutrinos at the Main Injector or NuMI project at Fermilab).

The major activities under the Proton Accelerator subprogram are the broad research programs using the CDF and D-Zero detectors at the Tevatron at Fermilab; the neutrino research program using the NuMI/MINOS and MiniBooNE facilities at Fermilab and at the Soudan Mine site in Minnesota; the LHC program, and maintenance and operation of these facilities. The Tevatron collider programs will determine whether the Standard Model accurately predicts the mechanism that breaks the symmetry between natural forces and generates mass for all fundamental particles or whether an alternate theory is required. The NuMI/MINOS and MiniBooNE programs will perform decisive controlled measurements of fundamental neutrino properties, including neutrino oscillations, which will provide important clues and constraints to the theory of matter and energy beyond the Standard Model. The LHC program will insure that the U.S. high energy physics research program will be one of the key players at the next energy frontier. There are much smaller specialized efforts involving the HERA accelerator machine at DESY in Germany, and the KEK proton accelerator in Japan.

Research and Facilities

The Research category in the Proton Accelerator subprogram supports the university and laboratory based scientists performing experimental research at proton accelerator facilities in the U.S. and abroad. Experimental research activities are collaborative efforts by research groups from ANL, BNL, Fermilab, LBNL, LANL, LLNL, and about 60 colleges and universities and include: planning, design, fabrication and installation of experiments and associated computing infrastructure; preparation for experimental operations and conduct of experiments; analysis and interpretation of data; and publication of results. These research programs are carried out at various facilities where the accelerators and detectors are located. The university program also includes a small amount of funds at national laboratories (so-called "university service accounts") to allow university groups to perform specific tasks connected with the experimental research program, such as purchasing needed equipment from laboratory stores.

The Facilities category in the Proton Accelerator subprogram supports the maintenance and operations of, and technical improvements to, proton accelerator facilities in the U.S. In addition, this category supports the U.S. share of operations, software and computing infrastructure, and directed technical

R&D for international proton accelerator facilities such as the LHC at CERN. Facilities activities include: installation, commissioning, maintenance and operations of accelerators and experiments; providing computing hardware and software infrastructure to support the experiments and the accelerators, and provide platforms for data analysis; and directed R&D for accelerator and detector enhancements and performance improvements. Since physicists are often involved in these activities as well as research activities, some are partially supported by both categories of funding where appropriate.

The proton accelerator facilities support personnel are based primarily at ANL, BNL, Fermilab, and LBNL, working together with experimental groups from various universities and foreign institutions.

Highlights

Recent accomplishments include:

- The CDF and D-Zero detectors at Fermilab have been largely rebuilt for Run II of the Tevatron collider. The collaborations have announced initial results based on first collisions observed in 2001. These detectors have much greater sensitivity than before and will search for the Higgs or other new physics, and will make numerous precision measurements.
- The Tevatron completed commissioning of the new Main Injector, and the two upgraded detectors (CDF and D-Zero) were brought into operation in FY 2001.
- A new accelerator-based neutrino program in the U.S. was launched in 2002 when the MiniBooNE detector at Fermilab began taking data using a low-energy proton beam to confirm or refute hints of neutrino oscillations discovered at Los Alamos in the LSND experiment.
- A formal program has been initiated to develop, design and implement a computing system to process, store and support the analysis of the huge amount of data anticipated after the LHC begins commissioning in FY 2007. A parallel effort to test, commission, and eventually operate the U.S.-supplied systems that are part of the LHC detectors has also been initiated, and significant pre-operations activities will begin in FY 2004.
- The 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 did not quite agree with the Standard Model, suggesting perhaps new physics. However, a mistake in the theoretical calculation was found, bringing theory and experiment into much closer agreement. The measurement precision has recently improved by a factor of two due to analysis of additional data, but the comparison with theory is still cloudy due to theoretical uncertainties. Work continues on both fronts: analyzing more data and reconciling theoretical questions.

The major planned research efforts in FY 2004 are:

- 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 physics issues to be addressed include searches for the Higgs boson, supersymmetry or other new phenomena; B meson studies including CP violation; and precision measurements of the top quark and the W boson properties.

- THE RESEARCH PROGRAM USING THE TEVATRON/D-ZERO FACILITY AT FERMILAB. This research program is being carried out by a collaboration including scientists from Fermilab, BNL, LBNL, 33 U.S. universities and institutions in 16 foreign countries. The physics issues to be addressed include searches for the Higgs boson, supersymmetry or other new phenomena; B meson studies including CP violation; and precision measurements of the top quark and the W boson properties.

- THE RESEARCH PROGRAM USING THE MINIBOONE AND NUMI/MINOS FACILITIES AT FERMILAB AND THE SOUDAN MINE. These research programs are being carried out by a collaboration including scientists from Fermilab, ANL, BNL, LANL, LLNL, 26 U.S. universities, and institutions in 10 foreign countries. The major efforts in FY 2004 will be data taking and analysis (MiniBooNE) and developing computing and data analysis tools (MINOS).

- PLANNING AND PREPARATION FOR THE U.S. PORTION OF THE RESEARCH PROGRAM OF THE LHC. A major effort in FY 2004 will continue to be the design and implementation of the U.S. data handling and computing capabilities needed for full participation in the LHC research program. Pre-operations of U.S.-supplied detectors for LHC experiments will begin at CERN.

The major planned facilities efforts in FY 2004 are:

- OPERATIONS OF THE TEVATRON AT FERMILAB. Fermilab plans 36 weeks of running to achieve a performance goal of 400 pb-1 of data delivered to the major Tevatron experiments. Approximately 850 people are involved in day-to-day Tevatron operations, which include operation of the Tevatron accelerator complex and the CDF and D-Zero detectors.

- PLANNING AND PREPARATION FOR TEVATRON/CDF/D-ZERO PERFORMANCE ENHANCEMENTS. Fully achieving the physics goals of the Tevatron program over the next five years requires a series of performance enhancements to the accelerator and the CDF and D-Zero detectors. As discussed above, these efforts are proceeding in parallel with current Tevatron operations and research.

- OPERATION OF THE MINIBOONE AND MINOS FACILITIES AT FERMILAB AND THE SOUDAN MINE. The MiniBooNE experiment will be operating its beam line and detector to collect data. The MINOS far-detector at Soudan Mine will be in its final commissioning and pre-operations phase.

- FABRICATION AND SUPPORT FOR THE U.S. PORTION OF THE LHC PROJECT. The fabrication of the U.S. portion of the ATLAS and CMS detector components will continue along with the support for these detector activities. The production of the U.S. portion of the LHC accelerator components will also continue.

Subprogram Goals

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.

Performance Indicator

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

Annual Performance Results and Targets

FY 2002 Results	FY 2003 Targets	FY 2004 Targets
Deliver data as planned (80 pb-1) to CDF and D-Zero detectors at the Tevatron. *[Met Goal]*	Deliver data as planned (225 pb-1) to CDF and D-Zero detectors at the Tevatron.	Deliver data as planned (400 pb-1) to CDF and D-Zero detectors at the Tevatron.
Collect data with the CDF and D-Zero detectors and begin analysis. *[Met Goal]*		Collect data using CDF and D-Zero detectors with high efficiency; record over 60% of available data and continue analysis.
		Using CDF and D-Zero data collected to this point, confirm or rule out some theoretical models of physics beyond the Standard Model (e.g., supersymmetry, large extra dimensions of space-time).

Develop high-intensity, accelerator-based neutrino beams, and specialized detectors, to perform decisive controlled measurements of fundamental neutrino properties, including neutrino oscillations, that will provide important clues and constraints to the theory of matter and energy beyond the Standard Model.

Performance Indicator

Validation of results by merit review with external peer evaluation.

Annual Performance Results and Targets

FY 2002 Results	FY 2003 Targets	FY 2004 Targets
Complete design of beamline components. Continue excavation of NuMI tunnels and halls. *[Met goal]*		Begin installation of beamline components.
		Complete installation of MINOS far detector.
Commission new MiniBooNE beamline and detector; begin data collection *[Met Goal]*.		Analyze MiniBooNE data to confirm or refute claims of neutrino oscillations observed in Los Alamos experiment.

Funding Schedule

	(dollars in thousands)				
	FY 2002	FY 2003	FY 2004	$ Change	% Change
Proton Accelerator-Based Physics					
Research	71,948	74,369	72,765	-1,604	-2.1%
Facilities	316,169	313,517	326,729	+13,212	+4.2%
Total, Proton Accelerator-Based Physics	388,117	387,886	399,494	+11,608	+3.0%

Detailed Program Justification

	(dollars in thousands)		
	FY 2002	FY 2003	FY 2004
Research	**71,948**	**74,369**	**72,765**
▪ **University Research**	**43,996**	**46,139**	**45,305**

The university program consists of groups at more than 60 universities doing experiments at proton accelerator facilities. These university groups plan, build, execute, analyze and publish results of experiments; develop the physics rationale and preliminary designs for future experiments; and train graduate students and post-docs. University physicists typically constitute about 75% of the personnel needed to create, run, and analyze an experiment, and they usually work in collaboration with other university and laboratory groups. University-based research efforts will be selected based on peer review. Proton accelerator activities concentrate on experiments at the Tevatron complex at Fermilab; development of the physics program for the Large Hadron Collider, under construction at CERN; and the HERA accelerator complex at DESY in Germany.

In FY 2004, the university program is slightly decreased in order to provide support for high-priority Tevatron Operations, as part of the initiative to exploit the "window of opportunity" for exciting new physics results described in the introductory sections, particularly searches for the Higgs boson and for supersymmetric particles. To the extent possible, the detailed funding allocations will take into account the involvement of university based research groups in the targeted physics research activities. These include research efforts related to the high-priority experiments such as CDF and D-Zero, work to support the fabrication of the LHC detector components, and work on the preparation for U.S. participation in the LHC research program.

▪ **National Laboratory Research**	**27,131**	**26,843**	**26,073**

The national laboratory research program consists of groups at several laboratories participating in experiments at proton accelerator facilities. These groups participate in all phases of the experiments, with the focus of the physics program being similar to that of the university groups described above. Although they lack the specific educational mission of their colleagues at universities, they are imbedded in the laboratory structure, and therefore they provide invaluable service to the research program in detector design, construction, and operations. The DOE HEP program office reviews laboratory research groups annually with input from independent peer reviewers. Proton accelerator activities concentrate on experiments at the Tevatron complex at Fermilab; the Large Hadron Collider, under construction at CERN; and the HERA accelerator complex at DESY in Germany.

In FY 2004, the national laboratory research program is modestly decreased in order to provide support for high-priority Tevatron Operations, as part of the initiative to exploit the "window of opportunity" described above. Lower priority research efforts will be de-emphasized. The laboratory experimental physics research groups will be focused mainly on data-taking with the upgraded CDF and D-Zero collider detector facilities, and analysis of data taken in the FY 2003 collider run; preparation for operation of the MINOS detector; data taking with the MiniBOONE detector; support for the fabrication of the ATLAS and CMS detectors for the LHC; and for physicists working on preparation for U.S. participation in the LHC Research Program.

The Fermilab research program ($8,500,000) includes data taking and analysis of the CDF, D-Zero, and MiniBooNE experiments, CMS research and computing program, and commissioning of the MINOS detector. Being imbedded at the host laboratory, these activities provide the close linkages between the Research and the Facilities categories in the Proton Accelerator subprogram.

Research activities at LBNL ($5,300,000) will include data taking and analysis of the CDF and D-Zero experiments, and ATLAS research and computing program.

Activities by the BNL research group ($7,764,000) will cover data taking and analysis of the D-Zero experiment, ATLAS research and computing program, and a small effort on the MINOS experiment.

The research group at ANL ($4,509,000) will be working on data taking and analysis of the CDF experiment, ATLAS research and computing program, commissioning of the MINOS detector, and data taking and analysis of the ZEUS experiment at HERA.

	FY 2002	FY 2003	FY 2004
▪ **University Service Accounts**...	**821**	**1,387**	**1,387**

University Service Accounts facilitate the support of university groups working at accelerator facilities, providing funding for these groups to purchase needed equipment and services from the laboratories with a minimum of time and cost overhead. Currently 45 university groups maintain service accounts at U.S. proton accelerator facilities.

	(dollars in thousands)		
	FY 2002	FY 2003	FY 2004
Facilities	**316,169**	**313,517**	**326,729**

Facilities			
Tevatron Operations	191,958	181,638	190,955
Tevatron Improvements	49,677	51,589	57,240
Large Hadron Collider Project	49,000	60,000	48,800
Large Hadron Collider Support	5,775	6,730	15,400
AGS Operations/Support	6,012	0	0
Other Facilities	13,747	13,560	14,334
Total, Facilities	316,169	313,517	326,729

- **Tevatron Operations** **191,958** **181,638** **190,955**

Operations at Fermilab will include operation of the Tevatron accelerator complex in collider mode and operations of two collider detectors for about 36 weeks. This will be a major physics run with the higher intensity available from the Main Injector and with the upgraded D-Zero and CDF detectors to exploit the discovery "window of opportunity." This is to be one of the major data collection periods for the experiments searching for the Higgs and other physics topics from the energy frontier facility as described in more detail above. *The increased funding will provide support for the operations of the Tevatron and two detectors with an increased operations staffing to enhance the reliability and efficiency of the planned operations.*

The operation of the Tevatron collider complex has been disappointingly slow in achieving the desired beam intensities in the early phase (FY 2001-2002) of its major datataking run ("Run II"), perhaps diminishing some of the opportunities described above. Fermilab has assigned its highest priority to rectifying this situation. Internal resources have been redirected to solve the Tevatron performance issues, slowing progress on longer-term accelerator R&D projects that are not essential to the near-term goal of maximizing the Tevatron's ability to discover new physics. Due to this effort, the Tevatron is expected to meet its base luminosity goals in FY 2003-2004.

The extra resources needed to meet Tevatron Run II luminosity goals are mostly the efforts of accelerator and experimental research physicists at Fermilab, and are not incurring "extra" costs to the program. A few SLAC, LBNL and BNL accelerator physicists with specialized expertise relevant to Run II problems have been recruited to help as well.

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

Tevatron Operations

	(in weeks)		
	FY 2002	FY 2003	FY 2004
Tevatron Operations	39	39	36

	(dollars in thousands)		
	FY 2002	FY 2003	FY 2004
▪ **Tevatron Improvements**	**49,677**	**51,589**	**57,240**

The funding will include the improvement of Tevatron operations as well as support for new and upgraded detectors associated with the Tevatron complex. The chance to discover the Higgs boson and other new physics before the LHC program is fully underway can be substantially increased with further improvements of the performance of the Tevatron and replacements of some of the components in the two collider detectors. Programs for improvement of the Tevatron performance are underway and the replacements of the detector components are being designed for installation in 2006. The funding will also provide the cost for the various utility improvement projects in order to operate Tevatron facilities with higher reliability and efficiency.

Plans for luminosity upgrades involve several steps toward increasing the number of antiprotons in the Tevatron, since that is the factor that limits the luminosity. Detector upgrades are needed to cope with the very high radiation load, or dose, on the inner tracking systems of the two collider detectors, that will result from the increased luminosity. The silicon tracker subsystem replacements will be necessary, since in the normal course of operation the silicon in the detectors will be damaged by radiation and will need to be replaced. The technology involving radiation-hard silicon has improved significantly since the design for the last upgrades to the detectors was completed five years ago. This will allow them to better withstand the higher intensities needed in the search for the Higgs. In addition, the large quantity of data from these experiments will require additional computing resources to carry out the data analysis. These enhancements will enable the Tevatron to run extensively with increased luminosity and therefore be able to provide enough data to find evidence of the Higgs if its mass is less than 165 GeV.

Funding in the amount of $33,300,000 is included for the program to increase the Tevatron luminosity, fabricate Run IIb 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 $5,600,000 over FY 2003. This includes capital equipment for continuation of the two projects including the replacement of the silicon tracker subsystems with new state-of-the-art radiation-hard silicon for both the CDF Detector ($8,396,000; TEC of $24,987,000) and D-Zero Detector ($8,588,000; TEC of $20,621,000). The TEC of the two Run IIb detector upgrade projects has increased since last year as conceptual designs have been developed and engineering estimates made. These TECs have now been finalized as an outcome of the baseline review in fall 2002.

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

MINOS is the detector part of the NuMI project that will provide a major new capability for neutrino research. *Capital equipment for the MINOS Detector is included at $2,000,000 (TEC $44,510,000). This is reduced from FY 2003 by $3,490,000 following the planned profile. Operating funding for the MINOS project is completed in FY 2003 leading to a decrease of $224,000 in FY 2004.*

(dollars in thousands)		
FY 2002	FY 2003	FY 2004

Funding for Other Tevatron Improvement activities is increased (+$3,765,000) from FY 2003. Activities in this category includes support for ongoing Tevatron and detector operations, not related to identified upgrades, including: accelerator and detector maintenance activities, repair and replacement of failing or obsolescent components, and minor improvements and upgrades to existing systems. Also included is R&D for approved accelerator or detector upgrade projects. Activities included in this effort are design of an electron cooling system to improve the quality of an antiproton beam passed through the recycler ring. GPP funding is unchanged at $4,800,000 to assist with urgent ES&H and infrastructure needs.

	FY 2002	FY 2003	FY 2004
▪ **Large Hadron Collider Project**	**49,000**	**60,000**	**48,800**

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

Construction and technical difficulties in the CERN funded portion of the LHC project on the CERN site in Geneva, Switzerland have led to delays in the project. The problems are being overcome and the latest CERN schedule has first collisions in April 2007.

The detailed schedules of the three U.S. LHC projects have been reviewed in the context of this schedule revision by CERN. The U.S. LHC Accelerator Components Project will go forward without modification. The U.S. detector projects (ATLAS and CMS) will complete ~97% of their planned work by the previously scheduled end-date (4^{th} quarter FY 2005), but for each a small amount of work is intimately tied to the late stages of the CERN schedule. This is primarily work directly related to the final assembly, testing, and installation of the full detectors, as well as purchase of computing hardware for data acquisition. Under the current schedule, this work will occur in 2006 and 2007, changing the final project completion date. The increased costs arising from the delay are modest and will be contained within the projects contingency allowances. **The final cost of each detector is unchanged.**

The result of these changes is a stretch out of the planned U.S. contributions to the LHC by two years. *The FY 2004 funding for the detectors is reduced and the funds rescheduled in FY 2006 and FY 2007.*

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

Participation by the U.S. in the LHC program is extremely important to U.S. High Energy Physics program goals. The LHC will become the foremost high energy physics research facility in the world when it begins commissioning in 2007. With the LHC at the next energy frontier, American scientific research at that frontier depends on participation in LHC. The High Energy Physics Advisory Panel (HEPAP) Subpanel on Vision for the Future of High Energy Physics strongly endorsed participation in the LHC, and this endorsement has been restated by HEPAP on several occasions.

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

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

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

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

The total cost of the LHC on a basis comparable to that used for U.S. projects is estimated at about $6,000,000,000. Thus the U.S. contribution represents less than 10% 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 600 U.S. scientists have joined the U.S.-ATLAS detector collaboration, the U.S.-CMS detector collaboration, or the U.S.-LHC accelerator consortium, and are hard at work helping to design the initial physics research program to be carried out at the LHC, helping to specify the planned physics capabilities of the LHC accelerator and detectors, and helping to design and fabricate accelerator and detector components and subsystems.

U.S. LHC Accelerator and Detector Funding Profile

(dollars in thousands)

Fiscal Year	Department of Energy Accelerator	Department of Energy Detector	Department of Energy Total	National Science Foundation[a] (Detector)
1996[b]	2,000	4,000	6,000	0
1997[b]	6,670	8,330	15,000	0
1998[b]	14,000	21,000	35,000	0
1999	23,491	41,509	65,000	22,150
2000	33,206	36,794	70,000	15,900
2001	27,243	31,627	58,870	16,370
2002	21,303	27,697	49,000	16,860
2003	22,100	37,900	60,000	9,720
2004	29,330	19,470	48,800	0
2005	20,657	11,053	31,710	0
2006[c]	0	7,440	7,440	0
2007	0	3,180	3,180	0
Total	200,000[d]	250,000	450,000	81,000

[a] The NSF funding 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] At the end of FY 2005 approximately 97% of the U.S. CMS and U.S. ATLAS projects will be completed on schedule. The remaining 3% of the project scope is integrally connected to the CERN portion of the project. As such, the recent slip in the CERN project schedule will significantly impact our ability to complete the remaining 3% of this project on the present schedule. The 97% portion of this project that will be complete at the end of FY 2005 will be closed out at that time. The remaining 3% of the project will continue, consistent with all DOE project management policies and practices. Based on CERN's current schedule, it is anticipated that the remaining work will be completed by the end of FY 2008, with no change in the total estimated cost of the project.

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

LHC Accelerator and Detector Funding Summary

	(dollars in thousands)		
	FY 2002	FY 2003	FY 2004
LHC			
Accelerator Systems			
Operating Expenses	1,900	1,850	1,830
Capital Equipment	8,196	6,850	4,300
Total, Accelerator Systems	10,096	8,700	6,130
Procurement from Industry	11,207	13,400	23,200
ATLAS Detector			
Operating Expenses	2,865	7,282	4,280
Capital Equipment	7,642	10,134	4,710
Total, ATLAS Detector	10,507	17,416	8,990
CMS Detector			
Operating Expenses	11,190	11,000	6,550
Capital Equipment	6,000	9,484	3,930
Total, CMS Detector	17,190	20,484	10,480
Total, LHC	49,000	60,000	48,800

Changes have been made by each of the three U.S. projects, and approved by DOE project management, based on actual expenditures and progress during FY 2002, and updated planning based on the FY 2002 experience.

In FY 2004, funding will be used for the fabrication of accelerator magnets and equipment and the 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.

	FY 2002	FY 2003	FY 2004
	(dollars in thousands)		
► **Accelerator Systems**	**10,096**	**8,700**	**6,130**

In FY 2004, funding will support continued production of quadrupole magnets, cryogenic/ electrical power feedboxes, and beam absorbers for the LHC beam interaction regions. Shipments to CERN 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. *Funding is reduced by $2,570,000 as production activities continue to ramp down.*

► **Procurement from Industry**	**11,207**	**13,400**	**23,200**

In FY 2004, 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 $9,800,000 to support the current estimate of actual CERN payments to U.S. industrial suppliers which are expected to peak in 2004.*

► **ATLAS Detector**	**10,507**	**17,416**	**8,990**

In FY 2004, 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 barrel, the silicon inner tracker and the muon drift test chambers will be completed. The delivery to CERN of various detector components will continue. Fabrication of the detector trigger and data acquisition system will begin. *Funding is decreased by $8,426,000 to follow the ramp-down on production of detector components.*

► **CMS Detector**	**17,190**	**20,484**	**10,480**

In FY 2004, 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 and production assembly of the silicon detector layers will continue in the U.S. *Funding is decreased by $10,004,000 to follow the ramp-down on production of detector components.*

	(dollars in thousands)		
	FY 2002	FY 2003	FY 2004
▪ **Large Hadron Collider Support**	**5,775**	**6,730**	**15,400**

In FY 2004, LHC Support work will concentrate on the preparation for U.S. participation in the LHC research program. The main use of the resources will be for LHC software and computing, and pre-operations for the U.S.-built systems that are part of the LHC detectors. The U.S. LHC effort is one of the high priority components of the HEP program and has been repeatedly endorsed by HEPAP. *Significant increases in this area are planned for FY 2004 to meet the urgent and growing need for LHC support activities in advance of LHC turn-on in 2007.*

The LHC software and computing effort will enable U.S. physicists to analyze the vast quantity of LHC data in a transparent manner, and empower them to take a leading role in exploiting the physics opportunities presented by the LHC. In FY 2004 the U.S. software efforts will be focused on "data challenges" where a significant fraction (~10%) of the hardware needed for full LHC data analysis will be tested with professional-quality software on simulated data. These systems need to grow rapidly from prototypes, capable of handling a few percent of the eventual data in 2002, to fully-functional 10%-scale systems in 2004 (comparable to the full data analysis systems for the CDF or D-Zero experiments at Fermilab).

Funding for pre-operations and operations of the LHC detector subsystems built by U.S. physicists will also start to ramp-up significantly in FY 2004 as LHC turn-on approaches. U.S. CMS collaborators will be performing vertical integration tests of the major detector subsystems that they built, using functional prototypes of the final data acquisition system, in advance of their final installation in the underground cavern. U.S. ATLAS collaborators will be performing testing and commissioning of most detector subsystems. A small effort focused on R&D for specific possible LHC accelerator and detector upgrades will continue.

▪ **AGS Operations/Support**	**6,012**	**0**	**0**

Operations at BNL for HEP experiments using the AGS facility were terminated at the end of FY 2002.

▪ **Other Facilities**	**13,747**	**13,560**	**14,334**

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

Includes $1,624,000 for General Purpose Equipment and $3,500,000 for General Plant Projects at LBNL for landlord related activities.

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

Total, Proton Accelerator-Based Physics	**388,117**	**387,886**	**399,494**

Explanation of Funding Changes

	FY 2004 vs. FY 2003 ($000)
Research	
▪ In University Research, a decrease of $834,000 is taken in order to provide support for maintaining high priority Tevatron improvements and operations	-834
▪ In National Laboratory Research, a decrease of $770,000 is taken in order to provide support for maintaining high priority Tevatron improvements and operations.	-770
Total, Research	-1,604
Facilities	
▪ In Tevatron Operations, an additional $9,317,000 is provided for increased support for operations of the Tevatron Complex. This includes significant additional personnel to handle the demands of high-luminosity Tevatron running, as well as preparation for the NuMI/MINOS program using the Main Injector in fixed-target mode beginning in 2005	+9,317
▪ In Tevatron Improvements, $5,600,000 is provided for increased support for the high priority upgrades of the Tevatron complex. This is offset by decreases of $3,490,000 in capital equipment and $224,000 in operating funding for the MINOS project as reflected in the approved profile, increases in support activities of $3,990,000, and a decrease of $225,000 in motor vehicle purchases.	+5,651
▪ In the Large Hadron Collider project, a decrease of $11,200,000 follows the new funding profile that reflects the changes to the CERN LHC completion date and its impact on the U.S. portions of the LHC detector sub-projects. These funds are restored in FY 2006 and FY 2007 so that the total project cost is unchanged. The accelerator funding ramps down as it nears completion	-11,200
▪ In Large Hadron Collider Support, an increase of $8,670,000 is provided in part for significantly increased effort in providing the computing systems and networks needed to effectively handle and process the large volume of LHC data. The support for the detector pre-operations is also significantly increased, as detector testing and commissioning activities are ramping up in 2004. A small accelerator R&D effort focused on LHC machine improvements also increases	+8,670
▪ In Other Facilities, an increase of $1,100,000 in funds is held pending completion of peer review and/or programmatic review, offset by a reduction of $326,000 in GPE at LBNL related to motor vehicle purchases.	+774
Total, Facilities	+13,212
Total Funding Change, Proton Accelerator-Based Physics	**+11,608**

Electron Accelerator-Based Physics

Mission Supporting Goals and Measures

The Electron Accelerator-Based Physics subprogram utilizes the high data rates achievable at the SLAC B-factory and other electron-positron colliding beam facilities to perform an experimental program to understand Charge-Parity (CP) violation in electroweak interactions, and therefore the excess of matter over antimatter in the universe.

Introduction

While electron accelerators can be used to study a wide variety of physics topics, and historically have been so used, the current electron accelerator subprogram is focused on the study of charm and bottom quarks and the tau lepton. These particles are all heavier than the particles of everyday matter and well suited for studying rare processes. The most interesting of these processes is CP violation, which is needed to explain the fact that our universe is mostly made of matter and not antimatter.

CP violation has been observed in the decays of particles containing strange quarks (*K* mesons) and most recently in particles containing bottom quarks (B mesons). This most recent observation has been made at the SLAC B-factory and the KEK-B accelerator in Japan. Now that the first observations of CP violation in B mesons have been made, it is possible to do a systematic study of the process and test whether our current theoretical explanation of CP violation, the Standard Model, is correct. This systematic study will require both new measurements of CP violation in other B meson decays, and measurements of other properties of particles containing bottom or charm quarks. The measurements of these other properties are used as inputs to the theoretical calculations of CP violation, and our limited current knowledge of those properties also limits our understanding of CP violation.

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

Research and Facilities

The Research category in the Electron Accelerator subprogram supports the university and laboratory based scientists performing experimental research at electron accelerator facilities in the U.S. and abroad. Experimental research activities are collaborative efforts by research groups from LBNL, LLNL, SLAC, and about 40 colleges and universities and include: planning, design, fabrication and installation of experiments and associated computing infrastructure; preparation for experimental operations and conduct of experiments; analysis and interpretation of data; and publication of results. These research programs are carried out at various facilities where the accelerators and detectors are located. The university program also includes a small amount of funds at national laboratories (so-called "university service accounts") to allow university groups to perform specific tasks connected with the experimental research program, such as purchasing needed equipment from laboratory stores.

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

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

Highlights

Recent accomplishments include:

- In 2002, physicists using the BaBar detector at the SLAC B-factory announced new, improved measurements 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 their earlier results announced in 2001. The BELLE experiment also reported a new observation of CP violation in the B-meson system (via a different B-decay channel), but BaBar has not confirmed this result. All data collected to date are consistent with the current Standard Model description of CP violation. Data collection continues at a high rate to improve the precision of the results, look for evidence in new modes, and resolve any discrepancies.

The major planned research efforts in FY 2004 are:

- THE RESEARCH PROGRAM AT THE B-FACTORY/BABAR FACILITY AT SLAC. This research program is being carried out by a collaboration of approximately 550 physicists including scientists from LBNL, LLNL, ORNL, SLAC, 35 U.S. universities, and institutions from 7 foreign countries.
- THE RESEARCH PROGRAM AT OTHER ELECTRON ACCELERATOR FACILITIES. This program complements the B-factory/BaBar efforts and consists of a group of experimental research activities using the Cornell Electron Storage Ring (CESR) and the KEK-B electron accelerator facilities. A total of 4 U.S. university groups work at KEK-B, and 19 U.S. university groups work at CESR.

The major planned facilities efforts in FY 2004 are:

- OPERATIONS OF THE B-FACTORY AT SLAC. SLAC plans 39 weeks of running to achieve a performance goal of 50 fb^{-1} of data delivered to the BaBar experiment. Approximately 450 people are involved in day-to-day B-factory operations.

- PLANNING AND PREPARATION FOR B-FACTORY/BABAR PERFORMANCE ENHANCEMENTS. Fully achieving the physics goals of the B-factory program over the next five years requires a series of performance enhancements to the accelerator and the BaBar detectors. These efforts are proceeding in parallel with current B-factory operations and research.

Subprogram Goal

Explain the observed absence of antimatter in the universe through understanding of the phenomenon of Charge-Parity (CP) Violation.

Performance Indicator

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

Annual Performance Results and Targets

FY 2002 Results	FY 2003 Targets	FY 2004 Targets
Increase the total data delivered to BABAR at the SLAC B-factory by delivering 35 fb-1 of total luminosity. *[Met Goal]*	Increase the total data delivered to BABAR at the SLAC B-factory by delivering 45 fb-1 of total luminosity.	Increase the total data delivered to BABAR at the SLAC B-factory by delivering 50 fb-1 of total luminosity.
	Add one new RF station to allow for increased beam intensity	Add one new RF station to allow for increased beam intensity.
Collect data using the BaBar detector with high efficiency; record over 90% of delivered data and continue analysis. *[Met Goal]*		Collect data using the BaBar detector with high efficiency; record over 90% of delivered data and continue analysis.
Using the BaBar dataset, measure CP violation in a single class of decay process ("golden modes") of B mesons with an uncertainty of +/- 0.12. *[Met Goal]*	Using the BaBar dataset, measure CP violation in a single class of decay process ("golden modes") of B mesons with an uncertainty of +/- 0.06.	Using the BaBar dataset, begin measuring CP violation (CPV) in new classes of rare decay modes with an uncertainty of +/- 0.4. Compare with existing measurements in other areas (e.g., B meson "golden modes," CPV in K mesons) to search for non-Standard Model CPV in the B meson system.

Funding Schedule

	(dollars in thousands)				
	FY 2002	FY 2003	FY 2004	$ Change	% Change
Electron Accelerator-Based Physics					
Research	30,303	33,063	33,643	+580	+1.7%
Facilities	117,929	117,085	125,843	+8,758	+7.5%
Total, Electron Accelerator-Based Physics	148,232	150,148	159,486	+9,338	+6.2%

Detailed Program Justification

	(dollars in thousands)		
	FY 2002	FY 2003	FY 2004
Research	**30,303**	**33,063**	**33,643**
▪ **University Research**	**20,160**	**22,777**	**23,007**

The university program consists of groups at about 40 universities doing experiments at electron accelerator facilities. These university groups plan, build, execute, analyze and publish results of experiments; develop the physics rationale and preliminary designs for future experiments; and train graduate students and post-docs. The current electron accelerator subprogram is focused on the study of charm and bottom quarks and the tau lepton which are all heavier than the particles of everyday matter and well suited for studying rare processes. The most interesting of these processes is CP violation, which is needed to explain the fact that our universe is mostly made of matter and not antimatter. The BaBar experiment at the SLAC B-factory will pursue a broad program of physics studies on particles containing bottom or charm quarks with CP violation measurements being its highest priority, but other measurements that support or complement the CP violation program will also be pursued.

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

The university program also supports nine groups that work at the Cornell Electron Storage Ring at Cornell University; and four groups that work at the KEK-B accelerator complex at KEK in Japan. The CLEO-C experiment at the Cornell Electron Storage ring is concentrating on certain precision measurements of particles containing charmed quarks, which are difficult to do at the B-factory. There is regular cooperation as well as competition between the SLAC and KEK experiments, which has led to a better understanding of how to run the accelerators and detectors and do the data analysis leading to physics results that are more precise than they would be otherwise. University-based research efforts will be selected based on peer review.

	(dollars in thousands)		
	FY 2002	FY 2003	FY 2004

In FY 2004, the university program is increased slightly 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, particularly to support analysis of the unprecedented amount of physics data generated by the B-factory and other electron accelerators. To the extent possible, the detailed funding allocations will take into account the involvement of university based research groups in the targeted physics research activities. These include research efforts related to the high priority experiments such as BaBar.

▪ **National Laboratory Research**	**9,992**	**9,981**	**10,331**

The national laboratory research program consists of groups at several laboratories participating in experiments at electron accelerator facilities with a physics program similar to the university program described above. In FY 2004, the laboratory experimental physics research groups will be focused mainly on data-taking with the BaBar detector, analysis of data taken in earlier runs, and planning for detector enhancements needed for future runs. The laboratory research program is increased slightly to provide support for those groups involved in the initiative to exploit the “window of opportunity” for exciting new physics results described in the introductory sections, particularly to support analysis of the unprecedented amount of physics data generated by the B-factory and other electron accelerators.

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

The experimental research group from SLAC ($7,058,000) participates in all phases of the experiments. Because they are imbedded in the laboratory structure, they provide invaluable service in the design, construction, and calibration, and operations of the detector, as well as the reconstruction and analysis of the data.

The experimental research group at LBNL ($2,975,000) has broad responsibilities on the BaBar experiment. The group is second in size with only the SLAC group being larger. They were responsible for constructing and commissioning significant portions of the charged particle tracking detectors and their electronics. Now they contribute to operating, maintaining and calibrating the detector. They also make significant contributions to the computing system used to control the detector and acquire the data, and the computing system used to reconstruct the data into physics quantities used for analysis.

The efforts from LLNL ($298,000) are much smaller, limited to only a handful of scientists working on the BaBar experiment.

▪ **University Service Accounts**	**151**	**305**	**305**

University Service Accounts facilitate the support of university groups working at accelerator facilities, providing funding for these groups to purchase needed equipment and services from the laboratories with a minimum of time and cost overhead. Currently 16 university groups maintain service accounts at U.S. electron accelerator facilities.

	(dollars in thousands)		
	FY 2002	FY 2003	FY 2004
Facilities	**117,929**	**117,085**	**125,843**
▪ **B-factory Operations**	**97,334**	**97,275**	**104,225**

Funding for operations supports running the accelerator for 39 weeks, the operation of the BaBar detector for data collection, and computing support to analyze the collected data. This will be the priority research program at SLAC in FY 2004. It is anticipated that the collected data will significantly exceed the total collected in FY 2003. *Funding increases due to the higher luminosity running.* More electric power is required to run the accelerator at higher luminosity, so power costs are up.

The fixed target research program in End Station A is not planned to run in FY 2004, due to overall budget constraints and the high priority assigned to B-factory operations.

SLAC Operation

	(in weeks)		
	FY 2002	FY 2003	FY 2004
Fixed Target[a]	8	8	0
B-factory Operation	35	39	39
Total, SLAC Operation	35	39	39

▪ **B-factory Improvements**	**20,595**	**19,810**	**21,618**

An important component of the FY 2004 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.

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 $12,200,000. *This is an increase of $4,500,000 over FY 2003.* The projects include upgrades to B-factory vacuum and acceleration systems, and continuous enhancement of computing capabilities to keep pace with the flood of data the B-factory provides.

Funding for Other B-factory Improvement activities is decreased (-$2,692,000) from FY 2003. Activities in this category include support for ongoing B-factory and detector operations, not related to identified upgrades, including: accelerator and detector maintenance activities, repair and replacement of failing or obsolescent components, and minor improvements and upgrades to existing

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

	(dollars in thousands)		
	FY 2002	FY 2003	FY 2004

systems. Also included is R&D for approved accelerator or detector upgrade projects. This effort includes design of a new interaction region for the B-factory that would allow the electron and positron beams to cross at an angle instead of head-on, which has the potential to significantly increase machine luminosity. GPP funding is unchanged at $4,200,000 to assist with urgent ES&H and infrastructure needs.

In FY 2004, the emphasis will be on work to support and improve performance of the BaBar detector and upgrade the associated computing systems to handle the unprecedented data volumes being generated by the excellent performance of the B-factory.

	FY 2002	FY 2003	FY 2004
Total, Electron Accelerator-Based Physics	**148,232**	**150,148**	**159,486**

Explanation of Funding Changes

	FY 2004 vs. FY 2003 ($000)
Research	
▪ In University Research, an additional $230,000 is provided for maintaining effort on the BaBar research program.	+230
▪ In National Laboratory Research, an additional $350,000 is provided for maintaining effort on the BaBar research program.	+350
Total, Research	+580
Facilities	
▪ In B-factory Operations, an additional $6,950,000 is provided for operation of the B-factory complex to help address projected increased in power costs and meet performance targets.	+6,950
▪ In B-factory Improvements, $4,500,000 is provided for increased support for the upgrades of the B-factory complex. This is partially offset by a reduction of $2,540,000 for other B-factory support activities including maintenance and repair, reflecting the high priority of B-factory upgrades, and a decrease of $152,000 for motor vehicle purchases.	+1,808
Total, Facilities	+8,758
Total Funding Change, Electron Accelerator-Based Physics	**+9,338**

Non-Accelerator Physics

Mission Supporting Goals and Measures

The Non-Accelerator Physics subprogram provides U.S. leadership in the study of those aspects of elementary particles and their interactions that cannot be determined solely through the use of accelerators. These activities have the capability of probing beyond the Standard Model of particle physics in many areas, enriching the accelerator-based subprograms with complementary experimental data, new ideas and techniques.

Introduction

Non-Accelerator Physics is playing an increasingly important role in High Energy Physics, using ever more sophisticated techniques to probe fundamental physics questions using naturally occurring particles. University and laboratory scientists in this subprogram pursue searches for rare and exotic particles or processes, such as dark matter, dark energy, Majorana neutrinos, proton decay, the highest energy cosmic rays, or primordial antimatter. They also study the properties of neutrinos from the sun, galactic supernovae, and cosmic rays in the earth's atmosphere. In addition, high energy gamma ray observations probe the highest energy phenomena observed in nature and yield information about possible black holes or active nuclei at the centers of galaxies. These areas of research probe well beyond the Standard Model of particle physics and offer possibilities for discovery of significant new physics. Using particle physics techniques and in some cases the infrastructure of our national laboratories, most of the experiments are located at remote sites, such as in deep underground laboratories, on mountain tops, spread over expansive deserts, or in space, either as dedicated satellites or as instruments attached to the International Space Station.

Research and Facilities

The Non-Accelerator Physics subprogram supports the university and laboratory scientists performing experimental particle physics and astrophysics research in the U.S. and abroad that does not directly involve the use of high energy accelerator particle beams. The research groups are based at about 35 colleges and universities. This program is carried out in collaboration with physicists from five DOE national laboratories (Fermilab, SLAC, LBNL, ANL, and LANL) and other government agencies including NASA, NSF, NRL, and the Smithsonian Astrophysical Observatory. Strong interagency coordination and collaboration is one of the hallmarks of the projects in this subprogram. As with the rest of the HEP portfolio, most projects involve international collaboration in all phases of the experiment.

The Non-Accelerator Physics subprogram includes support for special facilities and research groups to perform these experimental measurements. While research groups are covered under the Research categories, the Projects category in the Non-Accelerator Physics subprogram supports the technical R&D, engineering and design, detector apparatus, and remote site operations of Non-Accelerator Physics projects. Remote sites include the Soudan Mine in Minnesota, the Kamiokande Mine in Japan, the Whipple Observatory in Arizona, the Pierre Auger Laboratory in Argentina, the Stanford Underground Facility at Stanford University, and the Gran Sasso Laboratory in Italy. Other operations include the ground-based laboratories for Gamma-ray Large Area Space Telescope (GLAST) Large Area Telescope (LAT) at SLAC and for AMS at Massachusetts Institute of Technology (MIT).

Highlights

Recent accomplishments include:

- The Pierre Auger Project in Argentina to observe ultra-high energy cosmic rays completed an engineering array in FY 2002 consisting of 40 air-shower detectors and 2 resonance fluorescence detectors. The full array of 1600 air-shower detectors and 4 fluorescence detectors will be completed in 2005 by an international collaboration, but physics measurements will commence in 2002.
- In December 2002, after six months of running, KamLAND's first results were announced, showing a deficit in the flux of neutrinos. KamLAND is an underground neutrino experiment in Japan which detects neutrinos generated by several Japanese nuclear reactors. This result indicates that neutrinos have mass and are not stable in time, oscillating into other types of neutrinos. The KamLAND results make the case for oscillations and neutrino mass seemingly inescapable, since neutrinos were directly measured "disappearing" after leaving the nuclear reactors on their flight to the detector.

The major planned efforts in FY 2004 are:

- FABRICATION OF THE GLAST/LAT TELESCOPE. DOE and NASA are partners on the LAT, the primary instrument to be flown on the space-based NASA-GLAST Mission, scheduled for launch in 2006. Its goals are to observe and understand the highest energy gamma rays observed in nature and yield information about extreme particle accelerators in space, including possible black holes or active nuclei at the centers of galaxies, using particle physics detection techniques. This research program is being carried out by a collaboration, which includes scientists from SLAC, NASA, NRL, U.S. universities, and institutions from Italy, France, Japan, and Sweden. The LAT's high energy gamma ray observations will probe the highest energy phenomena in nature and yield information about a variety of scientific topics of interest to astrophysicists, cosmologists and particle physicists, including high-energy, extragalactic light sources and dark matter.
- FABRICATION OF THE VERITAS TELESCOPE ARRAY. VERITAS is a new multi-telescope array that will study astronomical sources of high energy gamma rays, from about 100 GeV to about 10 TeV. This facility will complement the GLAST/LAT telescope which does the same physics up to about 100 GeV. There is particular interest in gamma rays from poorly-understood astronomical sources such as Active Galactic Nuclei and Gamma Ray Bursters, and searches for signatures of supersymmetric dark matter. The experimental technique was developed by the DOE-supported researchers at the Harvard-Smithsonian Whipple Observatory on Mt. Hopkins in Arizona, and the project is supported by a partnership between DOE, NSF and the Smithsonian Institution. Fabrication will begin in FY 2004 and be completed in three years.
- COMPLETE FABRICATION AND BEGIN OPERATION OF THE PIERRE AUGER OBSERVATORY. The Southern Auger Observatory is a very large area cosmic ray detector, covering about 3,000 square kilometers, whose goal is to observe, understand and characterize the very highest energy cosmic rays. The southern array is under construction on the pampas of Mendosa, Argentina. This research program is being carried out by an international collaboration including scientists from U.S. universities, Fermilab, and institutions from 19 foreign countries. The

U.S. part of the project is funded jointly with NSF and a significant contribution from the University of Chicago. Fermilab provides the project management team.

- COMPLETE FABRICATION AND BEGIN OPERATION OF THE CRYOGENIC DARK MATTER SEARCH (CDMS). CDMS-II is the most sensitive direct search for super-symmetric dark matter undertaken to date. It consists of specially developed cryogenic silicon and germanium detectors with dual ionization and phonon signal capabilities. These detectors must operate at very low temperature (25 milliKelvin) in a cryostat located deep underground at the Soudan Mine Laboratory in Northern Minnesota. This research program is being carried out by a collaboration including scientists from U.S. universities, Fermilab, and LBNL. The project is funded jointly with NSF and Fermilab provides the project management team.
- RESEARCH, DEVELOPMENT, AND CONCEPTUAL DESIGN FOR THE PROPOSED SUPERNOVA ACCELERATION PROBE (SNAP) EXPERIMENT. LBNL is leading an effort to develop a dedicated satellite experiment to discover and precisely measure thousands of type Ia supernovae, which will be studied to determine the equation of state of the universe and the mechanism responsible for the accelerating expansion of the universe. The goal of this experiment is to understand the phenomena of "dark energy." The research is carried out by a collaboration including scientists from U.S. universities and LBNL.

Subprogram Goal

Develop a world-class, peer-reviewed research program of non-accelerator-based research in particle astrophysics and cosmology that builds on unique capabilities developed for HEP**.**

Performance Indicators

Validation of results by merit review with external peer evaluation.

Annual Performance Results and Targets

FY 2002 Results	FY 2003 Targets	FY 2004 Targets
Approve preliminary project baseline range (CD-1) for the Large Area Telescope (LAT) to be flown on the NASA GLAST mission The mission goals are to observe and understand high-energy gamma ray emissions using technology developed for HEP research. Launch is scheduled for FY 2006. *[Met goal]*		Complete mechanical support structure ("flight grid") for LAT instrument.

FY 2002 Results	FY 2003 Targets	FY 2004 Targets
Continue R&D in pre-conceptual planning phase for SuperNova Acceleration Probe (SNAP). Determine project plan for R&D phase. The goal of this experiment is to understand the phenomena of "dark energy" that is causing the accelerating expansion of the universe. *[Met Goal]*		R&D work in Preliminary Design Phase towards Conceptual Design Report for SNAP experiment.

Funding Schedule

(dollars in thousands)

	FY 2002	FY 2003	FY 2004	$ Change	% Change
Non-Accelerator Physics					
University Research	9,741	10,935	11,539	+604	+5.5%
National Laboratory Research	14,136	12,900	11,800	-1,100	-8.5%
Projects	14,378	13,230	19,306	+6,076	+45.9%
Other	860	355	355	0	0.0%
Total, Non-Accelerator Physics	39,115	37,420	43,000	+5,580	+14.9%

Detailed Program Justification

(dollars in thousands)

	FY 2002	FY 2003	FY 2004
University Research	**9,741**	**10,935**	**11,539**

The university program consists of groups at more than 35 universities doing experiments at Non-Accelerator Physics facilities, using ever more sophisticated techniques to probe fundamental physics questions using naturally occurring particles. Scientists in this subprogram pursue searches for rare and exotic particles or processes, such as dark matter, dark energy, Majorana neutrinos, proton decay, the highest energy cosmic rays, or primordial antimatter. They also study the properties of neutrinos from the sun, galactic supernovae, and cosmic rays in the earth's atmosphere. In addition, high energy gamma ray observations probe the highest energy phenomena observed in nature and yield information about possible black holes or active nuclei at the centers of galaxies. These areas of research probe well beyond the Standard Model of particle physics and offer possibilities for discovery of significant new physics.

These university groups plan, build, execute, analyze and publish results of experiments; develop the physics rationale and preliminary designs for future experiments; develop new theoretical models and provide interpretations of existing experimental data; and train graduate students and post-docs. University physicists in this research area often work in collaboration with other university and laboratory groups. University-based research efforts will be selected based on peer review.

	(dollars in thousands)		
	FY 2002	FY 2003	FY 2004

In FY 2004, the university program in non-accelerator physics will provide increased support for those universities involved in projects that may yield exciting new physics. To the extent possible, the detailed funding allocations will take into account the discovery potential of the proposed research. One notable example is the AMS experiment, whose goal is to detect sources of extra-galactic antimatter, using an instrument attached to the International Space Station. In FY 2004, the AMS collaboration will continue preparation for the planned 2006 launch. This project is led by scientists at MIT and consists of a collaboration of NASA, multiple U.S. universities, and numerous international institutions.

Other research efforts that will be continuing in this subprogram include: KamLAND, an underground neutrino oscillation detector which detects reactor-produced neutrinos in Japan; Super-Kamiokande, a proton decay, solar and atmospheric neutrino detector located in the Kamioka Underground Laboratory in Japan; and Zeplin-II, a Xenon dark matter detector located in an underground laboratory in Boulby, United Kingdom.

National Laboratory Research	**14,136**	**12,900**	**11,800**

The national laboratory research program consists of groups at several laboratories participating in Non-Accelerator Physics experiments similar to the university physics program described above. With strong laboratory technical resources, they provide invaluable service to the research program in detector design, construction, and operations. The DOE HEP program office reviews laboratory research groups annually with input from independent peer reviewers.

In FY 2004, the laboratory experimental physics research groups (including groups at LBNL, Fermilab and SLAC) will be focused mainly on supporting the fabrication of the GLAST/LAT telescope and analysis of previous experimental data (SLAC); analysis of initial data from the prototype Auger array and the CDMS-II detector and continuing data analysis from the Sloan Digital Sky Survey (Fermilab); and research and development for the SNAP experiment proposal and continued analysis of data from KamLAND (LBNL).

Projects	**14,378**	**13,230**	**19,306**

In FY 2004, this effort will be focused mainly on fabrication of the GLAST/LAT telescope, deployment of the prototype Auger array, installation of the Phase-I CDMS detector, R&D for the proposed SNAP experiment, and initial fabrication of VERITAS, a ground-based telescope to study high energy astrophysical gamma ray emissions, complementary to GLAST/LAT.

The FY 2004 GLAST/LAT program ($7,900,000; TEC of $37,000,000) will focus on the fabrication of the LAT instrument, and integration of components in preparation for launch on the GLAST mission in 2006, and development of the data analysis capability at SLAC. Project baseline cost range was finalized in FY 2002.

The FY 2004 CDMS program ($550,000; TEC of $4,918,000) will focus on completion of the cryogenic detector towers, taking data with already completed towers, and on the development of the data analysis and publication of preliminary results.

	(dollars in thousands)		
	FY 2002	FY 2003	FY 2004

The FY 2004 program for VERITAS ($1,600,000; TEC of $4,799,000) will concentrate on completion and final certification of the telescope prototype built in FY 2003, and beginning the fabrication phase for the full telescope array.

In FY 2004, the U.S. effort on the Pierre Auger project may take an additional scope to assist in completion of the full detector array. Funding for this effort ($1,000,000; TEC of $3,250,000) is planned pending completion of peer review and programmatic decisions.

The FY 2004 SNAP program ($8,256,000) will focus on developing a conceptual design, the beginning of engineering design, and fabrication and testing of prototypes for the principal SNAP instrument. *The goal of this R&D effort is to produce a complete Conceptual Design Report by 2006, and funding is increased by $6,876,000 to provide the significant resources needed to successfully begin the detailed design and prototyping phase. This increase is consistent with the 2002 HEPAP Subpanel recommendation that the physics of SNAP (the "dark energy" phenomenon) is exciting and relevant to HEP, and that the R&D effort should be supported; and the recent National Research Council report ("Quarks to the Cosmos") which identified this interdisciplinary research area as a high priority for an interagency initiative.* DOE is actively engaged with NASA to develop a successful research effort in this new and exciting field.

	FY 2002	FY 2003	FY 2004
Other	**860**	**355**	**355**

Includes funding for private institutions and other government laboratories and institutions that participate in non-accelerator based physics research. This category also includes funding for conferences, studies, and workshops, funding for research activities that have not yet completed peer review, and to respond to new and unexpected physics opportunities.

	FY 2002	FY 2003	FY 2004
Total, Non-Accelerator Physics	**39,115**	**37,420**	**43,000**

Explanation of Funding Changes

	FY 2004 vs. FY 2003 ($000)
University Research	
▪ An increase of $604,000 for university groups to increase effort on Non-Accelerator projects.	+604
National Laboratory Research	
▪ A decrease of $1,100,000 at Fermilab reflecting a reduced involvement in Non-Accelerator projects.	-1,100

	FY 2004 vs. FY 2003 ($000)
Projects	
▪ An increase of $6,876,000 is provided for the SNAP R&D program to begin conceptual design and fabrication and testing of detector prototypes, and an increase of $1,600,000 is provided to initiate VERITAS. This is offset by a $750,000 decrease reflecting the completion of funding for the AMS project; decreases in GLAST/LAT ($-1,010,000) and CDMS ($-250,000) are consistent with the planned profiles. The decrease of $1,250,000 due to completion of Phase I of the Auger project is partly offset by the set aside of $1,000,000 pending clarification and review of the proposed increase in the U.S. responsibilities in the Auger project. There is also a decrease of $140,000 in funds held for programmatic consideration, for a net increase of $6,076,000 in Projects.	+6,076
Total Funding Change, Non-Accelerator Physics	**+5,580**

Theoretical Physics

Mission Supporting Goals and Measures

The Theoretical Physics subprogram provides the framework for interpreting and understanding the results of high energy physics measurements. It includes activities ranging from detailed calculations of the predictions of the Standard Model of elementary particles to the investigation of informed speculations about what new phenomena may await discovery and how to search for them most efficaciously. The Theoretical Physics subprogram also includes strong components engaged in trying to extend the understanding achieved into the realm of cosmology in order to illuminate the history and early evolution of the universe.

Introduction

Though they are typically not directly involved in the planning, design, fabrication or operations of experiments, theoretical physicists play key roles in determining *what kinds* of experiments would likely be the most interesting to perform, and in *explaining* experimental results in terms of a fundamental underlying theory that describes all of the components and interactions of matter, energy, space and time. The research activities supported by the Theoretical Physics subprogram include calculations in the quantum field theories of the elementary particles that constitute the Standard Model and developing other models for elementary particle processes; interpreting results of measurements in the context of these models; identifying where new physical principles are needed and what their other consequences may be; developing and exploiting new mathematical and computational methods for analyzing theoretical models; and constructing and exploiting powerful computational facilities for theoretical calculations of especial importance for the experimental program. Major themes are symmetry and unification in the description of diverse phenomena.

Research at Universities and National Laboratories

The University and National Laboratory categories of the Theoretical Physics subprogram support scientists performing research in theoretical high energy physics and related areas of theoretical physics. The research groups are based at approximately 75 colleges and universities and at 6 DOE High Energy Physics and multiprogram laboratories (Fermilab, SLAC, BNL, ANL, LBNL, LANL).

The Theoretical Physics subprogram involves collaborations between scientists based at different universities and laboratories, and also collaborations between scientists supported by this program and others whose research is supported by other Offices of the DOE and by other federal agencies, including NASA and NSF. There are also many international collaborations in theoretical physics research. These collaborations are typically smaller and more informal than the efforts required to mount large experiments.

The Theoretical Physics subprogram also includes support for special facilities for numerical and algebraic computation of developed theories, and for research groups to carry out these activities.

SciDAC

The SciDAC program within the High Energy Physics program supports the major computational efforts inherent in evaluating the predictions of theories of fundamental particles, in performing detailed and accurate simulations of complex accelerator designs, and in developing the software tools needed to store, retrieve and analyze the huge quantities of data generated by current and future experiments over widely-distributed networks. These activities will play a key role in understanding the significance of current and future precision measurements, in optimizing the design and operations of current and future accelerator facilities, and in performing the physics analysis from many current and future experiments. These activities also include the design and construction of parallel computers optimized for high energy physics problems, and the development of software to exploit them most efficiently. This program is a close collaboration between university- and laboratory-based research groups supported by the High Energy Physics and the Nuclear Physics programs of the DOE, by the DOE Advanced Scientific Computing Research program, and by the National Science Foundation.

Highlights

Recent accomplishments include:

- 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.

By its nature, progress in theoretical physics cannot be predicted in advance. Thus quantitative annual performance goals and targets are inappropriate for this subprogram. Nevertheless, there are some current major thrusts in theoretical physics that we expect to continue in FY 2004:

- LATTICE QCD. Quantum Chromodynamics (QCD) is a very successful theory that describes the strong interactions between quarks and gluons. Although the equations that define this theory are in principle exact, none of the analytical methods that are so successful elsewhere in theoretical physics are adequate to analyze it. The reason that QCD is so intractable is that it is a strongly-coupled gauge field theory. The lack of precision in current QCD calculations is now limiting the understanding of many experimental results. It has long been known that QCD can be analyzed to any desired precision by numerical methods, given enough computational power. Recent advances in numerical algorithms coupled with the ever-increasing performance of computing have now made a wide variety of QCD calculations feasible with relatively high precision (errors of a few percent). Some of the computational tools for this effort are provided through the SciDAC program, and there will be a major effort to fabricate the necessary computer hardware.

- NEUTRINO PHENOMENOLOGY. The accumulating evidence that neutrinos have mass raises a host of fundamental and timely questions: whether neutrinos might be their own anti-particles; whether there might be CP violation, or even CPT violation (the combination of CP-and Time-invariance violation), in the neutrino sector; the role of neutrinos in supernova explosions; and whether neutrinos might be the origin of the matter-antimatter asymmetry in the universe. In turn these questions have strong connections to astrophysics, cosmology, and other sectors of particle physics, so that new developments have wide-ranging impacts. New theories of neutrinos are being developed, and the active world-wide program of neutrino experiments can be expected to clarify this interesting domain of elementary particles.

- NEW IDEAS. Theoretical physicists are speculating on whether there might be additional space dimensions that are normally hidden from us. It is even possible that some of these dimensions and their consequences are accessible to experiment, perhaps manifesting themselves in the production of mini-black holes at the LHC. Perhaps they can explain the nature of dark matter, or dark energy, or even suggest new cosmologies explaining the history and evolution of the universe.

Funding Schedule

(dollars in thousands)

	FY 2002	FY 2003	FY 2004	$ Change	% Change
Theoretical Research					
University Research	22,855	23,855	23,795	-60	-0.3%
National Laboratory Research........	13,999	14,112	13,762	-350	-2.5%
SciDAC……………………	4,919	4,410	4,600	+190	+4.3%
Other...	1,232	113	99	-14	-12.4%
Total, Theoretical Physics	43,005	42,490	42,256	-234	-0.6%

Detailed Program Justification

(dollars in thousands)

	FY 2002	FY 2003	FY 2004
University Research..	**22,855**	**23,855**	**23,795**

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

In FY 2004, the university theory program will address problems across the full range of theoretical physics research. There is currently a "window of opportunity" to interpret and understand the exciting new physics results expected from the Fermilab Tevatron regarding the Higgs boson and supersymmetric particles and the SLAC B-factory experiments studying CP violation and the matter-antimatter asymmetry, as described in previous sections. To the extent possible, the detailed funding allocations will take into account the involvement of university based research groups in these targeted physics research activities.

	(dollars in thousands)		
	FY 2002	FY 2003	FY 2004
National Laboratory Research	**13,999**	**14,112**	**13,762**

The national laboratory research program consists of groups at several laboratories. The scientists in these groups pursue a research agenda quite like that pursued at universities. In addition, those at the laboratories are a general resource for the national research program. Through continuing interaction with a diverse set of experimental scientists, they provide a clear understanding of the significance of measurements from ongoing experiments. It is also through such discussions that they help to shape and develop the laboratory's experimental program. The DOE HEP program office reviews laboratory research groups annually with input from independent peer reviewers.

In FY 2004, the laboratory theoretical research groups will address problems across the full range of theoretical physics research, including the analysis and interpretation of the new data expected from both the Tevatron Collider detectors, CDF and D-Zero, and the B-factory's detector, BaBar.

SciDAC	**4,919**	**4,410**	**4,600**

Following upon the successful completion and installation of the uniform software environment on both types of parallel computer platforms being developed for this program, in FY 2004 there will be two principal SciDAC efforts. The prototype computers developed the previous year will be run under the new software environment for the most urgently needed research computations. This will also be the year in which the bulk of the fabrication of the large QCDOC ("QCD On a Chip") computer at BNL is planned, building on the infrastructure of the dedicated QCD computing facilities provided by the Japanese for Relativistic Heavy Ion Collider (RHIC). In addition, further R&D will be undertaken on the optimization of commercial cluster computers for Fermilab (and, in Nuclear Physics, for Thomas Jefferson National Accelerator Facility). The goal of this R&D effort is to provide an efficient design for a large QCD computing cluster based on commercial components to address the hardware challenges of lattice QCD computing, as noted above. Both the customized and the commercial component approaches are viewed as important and useful in addressing the magnitude of the QCD computational problem; however, if both R&D efforts are successful, only the most cost-effective option will be pursued.

Other	**1,232**	**113**	**99**

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

Total, Theoretical Physics	**43,005**	**42,490**	**42,256**

Explanation of Funding Changes

	FY 2004 vs. FY 2003 ($000)
University Research	
▪ An decrease of $60,000 is taken in order to provide support for maintaining high priority facility operations	-60
National Laboratory Research	
▪ An decrease of $350,000 is taken in order to provide support for maintaining high priority facility operations	-350
SciDAC	
▪ An increase of $190,000 for the SciDAC program to maintain its level of effort.	+190
Other	
▪ A decrease of $14,000 in other research activities.	-14
Total Funding Change, Theoretical Physics	**-234**

Advanced Technology R&D

Mission Supporting Goals and Measures

The Advanced Technology R&D (ATRD) subprogram has as its goals providing the scientific and technological base for the development of new and improved accelerators, storage rings, and detectors, which lead to more advanced capabilities to carry out the experimental part of the high energy particle physics research program. The resulting technologies also provide significant benefits to other science and technology fields that use particle beams or particle detectors.

Introduction

High Energy particle physics research remains now, and for the foreseeable future, strongly dependent on the use of high energy particle beams provided by charged particle accelerators and storage rings. The research demands beams of great intensities and particle detectors with both the sensitivity to see the rare events and the selectivity to pull the signals for such events out of a cacophony of background noise. Operating in the extreme domains essential for successful particle physics research demands very specialized technology that takes substantial time and expense to invent, design, build, maintain and upgrade. The R&D programs that support such technology development are unavoidably costly and long term.

Since few of the core technologies used in high energy physics research are directly marketable, industry has no motivation to develop the necessary expertise or to do the essential R&D. Consequently, the DOE HEP program has supported a very successful program of technology R&D that has ensured the availability of the most technically advanced research facilities and a world-class U.S. HEP Program.

The High Energy Physics Advisory Panel (HEPAP), consisting of leading members of the high energy physics community, provides advice to the Department of Energy and the National Science Foundation on a continuing basis regarding the direction and management of the national high energy physics research program. The recommendations of their 2002 long range planning report state in part:

We recommend that the highest priority of the U.S. program be a high-energy, high-luminosity electron-positron linear collider, wherever it is built in the world. This facility is the next major step in the field and should be designed, built and operated as a fully international effort.

and:

We recommend that vigorous long-term R&D aimed toward future high energy accelerators be carried out at high priority within our program.

The FY 2004 budget maintains a significant U.S. effort focused on Linear Collider R&D, consistent with the first HEPAP recommendation, and progress towards a truly international Linear Collider proposal will continue. However, the emphasis on exploiting current unique opportunities through operations of forefront HEP facilities in the U.S. precludes a positive response to the latter recommendation. In fact, most areas of accelerator and detector R&D decrease in FY 2004 in order to provide support for high-priority facility operations. Details are provided in the following sections.

The Advanced Technology Research and Development subprogram includes both R&D to bring new accelerator concepts to the stage where they can be considered for use in existing or new facilities (General Accelerator R&D), and advancement of the basic sciences underlying the technology (Accelerator Science). A third topic, Other Technology R&D, describes Advanced Detector Research and Detector Development. Most of the technology applications useful to other science programs flow from the work carried out in the Advanced Technology R&D subprogram.

Accelerator Science

The Accelerator Science category in the ATRD subprogram focuses on the science underlying the technologies used in accelerators and storage rings. There is an emphasis on future-oriented, high-risk R&D, particularly in the development of new accelerating concepts, but essential infrastructure to support the HEP technology R&D programs is also addressed. Examples of this include standards for testing of advanced superconducting materials, instrumentation standards, and user facilities for general support of accelerator research, such as the Accelerator Test Facility at BNL.

Accelerator Development

Discovery and proof of principle of new concepts are funded under Accelerator Science R&D, described above. The larger task of reducing new concepts and technical approaches to the stage of proven engineering feasibility, so that they can be incorporated into existing or new facilities, is done under Accelerator Development. When concepts develop enough to be viewed as part of a larger system or as leading to a possible future proposal for a construction project, they are given special attention. The Muon Accelerator/Neutrino Source and the Linear Collider, whose funding is included in this section of the budget, are the two current R&D activities in this special category.

Other Technology R&D

This category includes funding at universities under Advanced Detector Research and primarily at national laboratories under Detector Development. Advanced Detector Research is similar to Accelerator Science in that it addresses the development and application of the underlying science to new particle detection, measurement, and data processing technologies. The Detector Development program provides funding to national laboratories and some universities to bring new detection and data processing concepts to an engineering readiness state so that they can be incorporated into an existing detector or into a new experiment.

Highlights

Recent accomplishments include:

- Researchers continue to make major evolutionary progress in high field magnets for the next generation of both electron and hadron colliders. The critical current of high field Niobium-3-Tin superconductors continues to set new records in performance. Work at the national laboratories and at universities has shown interesting approaches in the fabrication of very high field accelerator magnets that address both the need for strain management within the windings and the handling of the brittle superconducting materials.

- Progress has been made on alternate methods of charged particle acceleration. In particular, it appears that this may be reduced to practice at SLAC in Experiment E187, the "afterburner." In this project the energy of the linac may be significantly increased by placing a plasma wakefield channel at the far end of the linac.

The major Advanced Technology research and development efforts in FY 2004 are:

- THE ACCELERATOR SCIENCE RESEARCH PROGRAM. This program supports studies in scientific topics such as laser and radiofrequency driven accelerating means, plasma-based accelerators, superconducting material development and applications, and nonlinear dynamics and chaos at some 27 universities and 6 DOE national laboratories (ANL, BNL, LANL, LBNL, PPPL, and SLAC). The programs of research at the universities and national laboratories are complementary and collaboration between the national laboratories and the university research groups is strongly encouraged.
- THE RESEARCH AND DEVELOPMENT PROGRAM IN GENERAL TECHNOLOGY R&D. A component of the technology R&D at BNL, Fermilab, LBNL, and SLAC is focused on “reduction of practice” of new ideas and in general areas of technology important to that laboratory, but not directly relevant to an operating facility or a new facility under construction. The principal activities funded are R&D on advanced superconducting magnets, radiofrequency acceleration systems, and new beam instrumentation.
- SUPPORT FOR LINEAR COLLIDER R&D. A TeV scale linear electron-positron collider has been identified by the international high energy particle physics community, including various national laboratories, international advisory committees, and the U.S. High Energy Physics Advisory Panel (HEPAP), as an essential international facility to extend particle physics research into precision measurements not feasible at the LHC. A U.S. National Collaboration, including SLAC, Fermilab, LBNL, LLNL, and BNL, is funded to develop new technologies that enable a higher performance, lower cost machine, focusing on systems engineering, value engineering and risk analysis studies of applicable technologies.

Subprogram Goal

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 (Advanced Technology R&D subprogram).

Performance Indicator

Demonstration of R&D milestones and prototype components.

Annual Performance Results and Targets

FY 2002 Results	FY 2003 Targets	FY 2004 Targets
Demonstrate that 50MV/m accelerating gradients in the Next Linear Collider (NLC) accelerating structures are sustainable without significant structural damage. *[Met Goal]*	Demonstrate operation of advanced design accelerating structure for the NLC at 70 MV/m.	Complete the full prototype test of the “8 pack” radio-frequency power source with the power compression system. This is the last major “proof-of-principle” system test for the NLC design.

FY 2002 Results	FY 2003 Targets	FY 2004 Targets
Demonstrate operation of liquid mercury jet target hit by an intense proton beam as a first step in proving technology components for muon accelerators .*[Met Goal]*		Demonstrate operation of liquid mercury jet target hit by an intense proton beam in a strong (20 Tesla) magnetic field as a second step in proving technology for a muon accelerator source.
Continue R&D with industry to improve performance of superconducting cable; improve current-carrying capacity by 50% with respect to FY 2000. *[Met Goal]*	Begin engineering development program at LBNL and Fermilab for fabrication of prototype accelerator magnets with a goal of operating at fields greater than 16 Tesla. Begin industrial R&D program to develop large-scale capacity for producing high-performance Superconducting cable.	Produce 3-4 model magnets with selected key design parameters. Test and analyze performance.

Funding Schedule

(dollars in thousands)

	FY 2002	FY 2003	FY 2004	$ Change	% Change
Advanced Technology R&D					
Accelerator Science	17,892	19,905	20,836	+931	+4.7%
Accelerator Development	41,234	37,337	33,208	-4,129	-11.1%
Other Technology R&D	8,388	14,082	9,919	-4,163	-29.6%
SBIR/STTR	0	15,629	17,279	+1,650	+10.6%
Total, Advanced Technology R&D ..	67,514	86,953	81,242	-5,711	-6.6%

Detailed Program Justification

(dollars in thousands)

	FY 2002	FY 2003	FY 2004
Accelerator Science..	**17,892**	**19,905**	**20,836**
▪ **University Research**	**8,796**	**9,701**	**9,401**

In FY 2004, funding will provide for a program of accelerator physics and related technologies at some 27 universities. The research program includes development of new applications of niobium-tin and similar superconductors as well as high temperature superconductors; investigations of the use of plasmas and lasers to accelerate charged particles; development of novel high power radio frequency sources for driving accelerators; development of advanced particle beam instrumentation; theoretical studies in advanced beam dynamics, including the study of non-linear optics; space-charge dominated beams and plasmas; and development of new computational and simulation methods and programs. The largest programs are at the University of Maryland and University of California, Los Angeles, but substantial activities are also supported at Stanford, Texas A&M and

	(dollars in thousands)	
FY 2002	FY 2003	FY 2004

the University of Wisconsin. University based research programs are selected based on review by well-qualified peers, and progress is monitored through a system of formal site visits, presentations at appropriate workshops, and participation in conferences, and publications.

	FY 2002	FY 2003	FY 2004
▪ **National Laboratory Research**	**7,736**	**8,543**	**8,813**

There are areas of Accelerator Science research that require the more extensive or specialized research facilities located at DOE national laboratories. Funding for this work is provided to six national laboratories, ANL, BNL, LANL, LBNL, PPPL, and SLAC. National laboratory research efforts are selected based on review by appropriate peers, laboratory program advisory committees, and special director-appointed review committees. Measurement of progress is by these means, the annual HEP Program review supported by well-qualified peers, and publications in professional journals and participation in conferences and workshops.

BNL ($2,326,000) is the home of a very successful user facility, the Accelerator Test Facility (ATF), supporting research that HEP funds at universities and in industry (particularly through the SBIR Program). In FY 2004, the ATF will carry out an internal program of testing advanced accelerator concepts, developing new instrumentation, and developing next generation high brightness electron sources based on laser-driven photocathodes.

The Center for Beam Physics at LBNL ($3,663,000) is supported in FY 2004 for research in laser-driven plasma acceleration, advanced radiofrequency systems, laser manipulation and measurement of charged particle beams, and a broad program in acceleration theory and computation.

An advanced accelerator R&D program is supported at SLAC ($1,000,000) in FY 2004 to explore particle-driven plasma accelerators, direct laser acceleration, ultra high-frequency microwave systems for accelerating charged particles, very advanced electron-positron colliders concepts, and theoretical studies in advanced beam dynamics methods and new computer computation and simulation codes. Much of the work on advanced accelerator concepts at SLAC is done in collaboration with universities funded by the ATRD subprogram.

Other activities in FY 2004 include theoretical studies of space-charge dominated beams is supported at PPPL. At ANL the research addresses new means of generating high-brightness electron beams, and the use of charged particle wakefields to generate microwaves for particle acceleration. Maintenance and development of standard accelerator, storage ring, and beam optics computer codes is supported at the Accelerator Code Group at LANL, which also maintains an online encyclopedia of accelerator-related computer codes developed throughout the U.S.

	FY 2002	FY 2003	FY 2004
▪ **Other**	**1,360**	**1,661**	**2,622**

This category includes funding for Accelerator Science at sites other than universities and national laboratories. These include interagency agreements with NRL and NIST and funding of industrial grants. Also included is funding for Accelerator Science activities that are awaiting approval pending the completion of peer review and program office detailed planning.

	(dollars in thousands)		
	FY 2002	FY 2003	FY 2004
Accelerator Development	**41,234**	**37,337**	**33,208**
▪ **General Accelerator Development**	**17,198**	**14,574**	**10,374**

This research includes R&D to bring new concepts to a stage of engineering readiness wherein they can be incorporated into existing facilities, used in upgrading existing facilities, or applied to the design of new facilities. The work is almost all done at BNL, Fermilab, LBNL and SLAC. The major areas of R&D are superconducting magnet and related materials technology, high-powered radiofrequency acceleration systems; instrumentation; stochastic and electron cooling technologies; beam dynamics, both linear and nonlinear; and development of large simulation programs. *In FY 2004 this general research area is significantly reduced in order to provide support for high-priority facility operations.* Progress in many of the areas listed above will be slowed, particularly those which do not have near-term impact on improvements or upgrades for those facilities.

Work at BNL in FY 2004 will focus on superconducting magnet R&D and related materials development. The R&D program at Fermilab in FY 2004 will address a broad spectrum of technology needs for that facility, including advanced superconducting magnet R&D, stochastic cooling for the antiproton source, electron cooling, advanced beam instrumentation, and simulation codes to provide improved modeling of all aspects of Tevatron operations. The LBNL R&D supported in FY 2004 includes work on very high field superconducting magnets using niobium-tin and possibly niobium-aluminum, on development of superconducting wire and cable for their magnet R&D, on new beam instrumentation for use at Fermilab and SLAC, and on an extensive beam dynamics and simulation studies program with particular emphasis on electron cloud and related efforts in proton and electron colliders. The FY 2004 program at SLAC encompasses high-powered radiofrequency systems, beam instrumentation, generic electron-positron collider R&D, and advanced beam dynamics and machine simulation code development. Simulation codes for modeling radiofrequency system components and high-powered microwave tubes will receive special R&D focus.

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

The need for an electron-positron linear collider as a complement to and precision augmentation of the research program that will be carried out at the LHC now under construction at CERN has been reviewed in the last year by the International Committee of Future Accelerators (ICFA), the European Committee on Future Accelerators (ECFA), and the Asian Committee on Future Accelerators (ACFA). These bodies all have identified a TeV scale linear collider as the highest priority facility following the LHC to address the broad range of physics questions about the standard model, the Higgs boson that is believed to give rise to mass, supersymmetry, and the postulated hidden dimensions of space itself.

The result of the international R&D Program is that there are now two principal, viable technical approaches to constructing a high energy linear collider. One of these approaches, developed by a collaboration led by the German high energy physics laboratory, Deutsches Elektronen-Synchrotron (DESY), is based on the use of a superconducting radiofrequency acceleration system cooled to approximately 452 degrees Fahrenheit below zero. DESY submitted a proposal to the German government in March of 2000 to build their project, called the TeV-Energy Superconducting Linear Accelerator (TESLA), at a site adjacent to the DESY site. The other approach, developed by a U.S.

collaboration, led by SLAC and including Fermilab, LBNL and LLNL and in collaboration with the Japanese high energy physics laboratory, KEK, is developing a design based on room temperature radiofrequency accelerating system similar in principle to the one used in the SLAC Linear Collider. This R&D project is called the "Next Linear Collider" (NLC). All funding in this budget category is directed towards NLC-related R&D.

In FY 2004, the Next Linear Collider Collaboration will continue the systems engineering, value engineering, risk analysis, and cost studies that have been used to guide the R&D. A particular focus will be on assembly and operation of the so-called "Eight Pack Test." This will be a demonstration of a complete radiofrequency accelerating module for the NLC, including power supply, eight klystron tubes, pulse compressor, and the 70 MeV per meter accelerating structure needed to produce the 0.5 TeV on 0.5 TeV electron-positron colliding beams that give a 1 TeV center-of-mass energy. In addition work will continue with KEK on the injection damping ring technology using the prototype ring built at KEK and on design of the electron and positron sources and final focus beam optics systems. A U.S. national collaboration was formed in 2002 to begin developing a physics research agenda and to begin advanced R&D on technologies to be used in a linear collider detector with which to carry out the physics studies.

	FY 2002	FY 2003	FY 2004
▪ **Muon Accelerators/Neutrino Source**...........................	**4,836**	**3,563**	**3,634**

The technical requirements for a muon accelerator/neutrino source force the consideration of new technologies that do not yet exist. The three principal areas are ultra high intensity muon targets, transverse and longitudinal phase space cooling (to reduce beam size), and special high-powered but low-frequency accelerating structures. The latter are especially important for capturing the muon bunches from the target and rapidly accelerating them to high energy so as to take advantage of the relativistic time dilation that lengthens the muon decay time so the short-lived muons survive long enough to store.

In FY 2004, the major focus of the research will be on completing the muon production target feasibility studies at the BNL AGS and on preparing to participate in the Muon International Cooling Experiment (MICE) to test the concept of ionization cooling of transverse phase space. System studies looking for alternate technologies, particularly radiofrequency systems, will continue as will studies of conventional and superconductor radiofrequency cavities operating in the special environment that allows the acceleration and cooling of the muon beams to be superimposed.

	FY 2002	FY 2003	FY 2004
Other Technology R&D..	**8,388**	**14,082**	**9,919**
▪ **Advanced Detector Research**..	**461**	**0**	**500**

The Advanced Detector Research (ADR) program supports university physicists to develop new detector technologies. The chosen technologies are motivated by the needs of foreseen but not yet approved experiments. Approximately six to eight grants a year are awarded through a competitive peer review program. This program complements the detector development programs of the national laboratories.

	(dollars in thousands) FY 2002	FY 2003	FY 2004
▪ **Detector Development**	**7,921**	**11,773**	**8,993**

New experiments frequently depend on advancements in technologies. This funding supports detector development work at the national laboratories to advance these technologies to a point where there is reasonable chance that an experiment can adopt the technology successfully. Technology choices are based on the needs of foreseen experiments. In FY 2004, this research area is also significantly reduced in order to meet high-priority needs for facility operations.

	FY 2002	FY 2003	FY 2004
▪ **Other**	**6**	**2,309**	**426**

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

	FY 2002	FY 2003	FY 2004
SBIR/STTR	**0**	**15,629**	**17,279**

The two activities funded are the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) set asides mandated by Congress. The High Energy Physics Program runs four technical topics related to accelerator science and technology and two topics related to detector science and technology in the annual procurement solicitation. The contents of each topic are closely related to the R&D work funded in Advanced Technology, and consist of material provided in response to an annual HEP solicitation for suggestions from scientists and engineers working in support of the HEP Advanced Technology R&D programs. In FY 2002, $14,521,000 was transferred to the SBIR program and $871,000 was transferred to the STTR program.

	FY 2002	FY 2003	FY 2004
Total, Advanced Technology R&D	**67,514**	**86,953**	**81,242**

Explanation of Funding Changes

	FY 2004 vs. FY 2003 ($000)
Accelerator Science	
▪ An increase of $931,000 provides support for long-term R&D efforts focused on developing new particle acceleration techniques.	+931
Accelerator Development	
▪ A decrease of $4,200,000 in General Accelerator R&D, reducing effort in near-term R&D and "reduction to practice" is taken in order to maintain support for high-priority facility operations. This is slightly offset by an increase of $71,000 provided to the Muon Accelerators/Neutrino Source R&D program to continue progress towards two key experiments that are needed to demonstrate the feasibility of the muon accelerator concept.	-4,129

	FY 2004 vs. FY 2003 ($000)
Other Technology R&D	
▪ A decrease of $2,780,000 is taken in Detector Development, reducing R&D efforts on future experiments, in order to maintain support for high-priority facility operations. A net decrease of $1,383,000 is taken in funds held pending completion of peer review and/or program considerations.	-4,163
SBIR/STTR	
▪ An increase of $1,650,000 for the SBIR and STTR programs.	+1,650
Total Funding Change, Advanced Technology R&D	**-5,711**

Construction

Mission Supporting Goals and Measures

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 2002	FY 2003	FY 2004	$ Change	% Change
Neutrinos at the Main Injector...........	11,400	20,093	12,500	-7,593	-37.8%

Detailed Program Justification

(dollars in thousands)

	FY 2002	FY 2003	FY 2004
Neutrinos at the Main Injector (NuMI)	**11,400**	**20,093**	**12,500**

This project provides for the construction of new facilities at Fermilab that are specially designed for the study of the properties of the neutrino and in particular to search for neutrino oscillations. The FY 2004 funding is for construction and installation of the neutrino beam line in the underground tunnel. The project is proceeding well within the schedule and cost baselines established with the FY 2003 request.

Performance will be measured by accomplishment of scheduled milestones as detailed in the revised benchmark plan.

Total, Construction	**11,400**	**20,093**	**12,500**

Explanation of Funding Changes

	FY 2004 vs. FY 2003 ($000)
Neutrinos at the Main Injector (NuMI)	
▪ Funding needs decrease as project nears completion in FY 2005. Sufficient funds provided for completion of the Fermilab NuMI project on the current approved profile.	-7,593
Total Funding Change, Construction	**-7,593**

Capital Operating Expenses & Construction Summary

Capital Operating Expenses

(dollars in thousands)

	FY 2002	FY 2003	FY 2004	$ Change	% Change
General Plant Projects	9,569	12,500	12,500	0	0.0%
Accelerator Improvements Projects	10,835	18,790	15,170	-3,620	-19.3%
Capital Equipment	82,177	85,313	80,708	-4,905	-5.7%
Total, Capital Operating Expenses	102,581	116,603	108,378	-8,225	-7.1%

Construction Projects

(dollars in thousands)

	Total Estimated Cost (TEC)	Prior Year Approp-riations	FY 2002	FY 2003	FY 2004	Unapprop-riated Balance
98-G-304 Neutrinos at the Main Injector	109,242	64,749	11,400	20,093	12,500	500

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

(dollars in thousands)

	Total Estimated Cost (TEC)	Prior Year Approp-riations	FY 2002	FY 2003	FY 2004 Request	Accept-ance Date
Large Hadron Collider — Machine	85,672	64,506	8,196	6,850	4,300	FY 2005
Large Hadron Collider — ATLAS Detector[a]	54,099	26,756	7,642	10,134	4,710	FY 2008
Large Hadron Collider — CMS Detector	67,051	41,905	6,000	9,484	3,930	FY 2008
MINOS	44,510	21,245	15,275	5,490	2,000	FY 2005
GLAST/LAT	37,000	8,689	8,080	8,910	7,900	FY 2005
Cryogenic Dark Matter Search (CDMS)	4,918	2,598	970	800	550	FY 2004
Auger[b]	3,250	0	1,000	1,250	1,000	FY 2004
Alpha Magnetic Spectrometer (AMS) Upgrade	4,756	2,228	1,778	750	0	FY 2003
Run IIb D-Zero Detector[c]	20,621	0	3,460	7,500	8,588	FY 2006
Run IIb CDF Detector[c]	24,987	0	3,460	7,500	8,396	FY 2006
VERITAS	4,799	0	0	0	1,600	FY 2006
Total, Major Items of Equipment		167,927	55,861	58,668	42,974	

[a] At the end of FY 2005 approximately 97% of the U.S. CMS and U.S. ATLAS projects will be completed on schedule. The remaining 3% of the project scope is integrally connected to the CERN portion of the project. As such, the recent slip in the CERN project schedule will significantly impact our ability to complete the remaining 3% of this project on the present schedule. The 97% portion of this project that will be complete at the end of FY 2005 will be closed out at that time. The remaining 3% of the project will continue, consistent with all DOE project management policies and practices. Based on CERN's current schedule, it is anticipated that the remaining work will be completed by the end of FY 2008, with no change in the total estimated cost of the project.

[b] The TEC for this project has been revised with an addition of funds in FY 2004 in anticipation of additional U.S. efforts being undertaken at that time.

[c] The TEC for this project is based on the estimate developed late in 2002 as part of a baseline readiness review, including the complete conceptual design and the latest machine performance information. This estimate will be updated further and finalized in Spring of 2003, upon completion of Title I design. The funding profile shown is still preliminary, based on FY 2002 actual expenditures and the FY 2003 President's Budget.

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

(Changes from FY 2003 Congressional Budget Request are denoted with a vertical line [|] in the left margin.)

Significant Changes

None.

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
FY 2004 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	21,489
2003	20,093	20,093	24,000
2004	12,500	12,500	14,000
2005	500	500	7,926

3. Project Description, Justification and Scope

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

The primary element of the project is a high flux beam of neutrinos in the energy range of 1 to 40 GeV. The technical components required to produce such a beam will be located on the southwest side of the Fermilab site, tangent to the Main Injector accelerator at the MI-60 extraction region. The beam components will be installed in a new tunnel of approximately 1.5 km in length and 6.5 m diameter. The beam is aimed at two detectors (MINOS), which will be assembled in two new experimental halls located along the trajectory of the neutrino beam. One such detector will be located on the Fermilab site, while a second will be located in the Soudan Underground Laboratory. Two similar detectors in the same neutrino beam and separated by a large distance are an essential feature of the experimental plan. The FY 2004 funding is for construction and installation of the neutrino beam line in the underground tunnel.

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	12,265	12,228
Special Equipment	20,902	20,902
Other Structures	40,184	41,265
Construction Management (8.6% of TEC)	9,379	6,846
Project Management (4.1% of TEC)	4,430	4,788
Total, Construction Costs	87,160	86,029
Contingencies		
Construction Phase (13.6% of TEC)	14,902	16,033
Total, Contingencies (13.6% of TEC)	14,902	16,033
Total, Line Item Cost (TEC)	109,242	109,242

5. Method of Performance

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

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

6. Schedule of Project Funding

(dollars in thousands)

	Prior Years	FY 2002	FY 2003	FY 2004	Outyears	Total
Project Cost						
Facility Cost						
Total, Line item TEC	41,827	21,489	24,000	14,000	7,926	109,242
Other Project Costs						
Capital equipment [a]	17,198	14,216	9,443	2,000	1,653	44,510
R&D necessary to complete construction[b]	1,768	0	0	0	0	1,768
Conceptual design cost[c]	1,928	0	0	0	0	1,928
Other project-related costs[d]	10,045	1,783	983	800	383	13,994
Total, Other Project Costs	30,939	15,999	10,426	2,800	2,036	62,200
Total Project Cost (TPC)	72,766	37,488	34,426	16,800	9,962	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. Prior year totals have been adjusted to more accurately account for actual R&D costs.

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

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

7. Related Annual Funding Requirements

(FY 2003 dollars in thousands)

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

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

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

Nuclear Physics

Program Mission

The mission of the Nuclear Physics 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 Department of Energy'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 Nuclear Physics mission areas under the mandate provided in Public Law 95-91 that established the Department.

Overview:

Nuclear science began by studying the structure and properties of atomic nuclei as assemblages of protons and neutrons. Research focused on nuclear reactions, the nature of radioactivity, and the synthesis of new isotopes and new elements heavier than uranium. Great benefit, especially to medicine, emerged from these efforts. But today, nuclear science is much more than this. Today, its reach extends from the quarks and gluons that form the substructure of the once-elementary protons and neutrons, to the most dramatic of cosmic events—supernovae. At its heart, nuclear physics attempts to understand the composition, structure, and properties of atomic nuclei. The field is driven by the following broad questions as stated recently by the Nuclear Sciences Advisory Committee in the ***Opportunities in Nuclear Science: A Long-Range Plan for the Next Decade***.

- *What is the structure of the nucleon?* Protons and neutrons are the building blocks of nuclei and neutron stars. But these nucleons are themselves composite objects having a rich internal structure. Connecting the observed properties of the nucleons with an underlying theoretical framework, known as quantum chromodynamics (QCD), is one of the central goals of modern nuclear physics.
- *What is the structure of nucleonic matter?* Nuclear physics strives to explain the properties of nuclei and of nuclear matter. The coming decade will focus especially on unstable nuclei, where we expect to find new phenomena and new structure unlike anything known from the stable nuclei of the world around us. With new theoretical tools, we hope to build a bridge between the fundamental theory of strong interactions and the quantitative description of nuclear many-body phenomena, including the new and exotic properties we expect in unstable nuclei and in neutron stars.
- *What are the properties of hot nuclear matter?* The quarks and gluons that compose each proton and neutron are normally confined within the nucleon. However, QCD predicts that, if an entire nucleus is heated sufficiently, individual nucleons will lose their identities, the quarks and gluons will become "deconfined," and the system will behave as a plasma of quarks and gluons. With the Relativistic Heavy Ion Collider (RHIC), the field's newest accelerator, nuclear physicists are now hunting for this new state of matter.

Other major questions identified by NSAC, of equal importance for nuclear physics as those above, overlap with major questions that drive the fields of astrophysics and particle physics. These are:

- *What is the nuclear microphysics of the universe?* A great many important problems in astrophysics—the origin of the elements; the structure and cooling of neutron stars; the origin, propagation, and interactions of the highest-energy cosmic rays; the mechanism of core-collapse supernovae and the associated neutrino physics; galactic and extragalactic gamma-ray sources—involve fundamental nuclear physics issues. The partnership between nuclear physics and astrophysics will become ever more crucial in the coming decade, as data from astronomy's "great observatories" extend our knowledge of the cosmos.
- *What is to be the new Standard Model?* The resolution of the solar and atmospheric neutrino puzzles by the Sudbury Neutrino Observatory (SNO) and the SuperKamiokande Detector may require the addition of Super-Symmetry to the Standard Model. Precision experiments by nuclear physicists deep underground and at low energies are proving to be an essential complement to searches for new physics in high-energy accelerator experiments.

How We Work:

The Nuclear Physics program uses a variety of mechanisms for conducting, coordinating, and funding nuclear physics research. The program is responsible for planning and prioritizing all aspects of supported research, conducting ongoing assessments to ensure a comprehensive and balanced portfolio, regularly seeking advice from stakeholders, supporting core university and national laboratory programs, and maintaining a strong infrastructure to support nuclear physics research.

Advisory and Consultative Activities:

To ensure that resources are allocated to the most scientifically promising research, the Department of Energy and its national user facilities actively seek external input using a variety of advisory bodies. The Nuclear Physics research program needs to produce the scientific knowledge, technologies and trained manpower that underpin the Department's missions in national security, energy, and environmental quality.

The ***Nuclear Sciences Advisory Committee*** (NSAC) provides advice to the Department of Energy and the National Science Foundation on a continuing basis regarding the direction and management of the national basic nuclear sciences research program. In FY 2002, the DOE Nuclear Physics program provided about 90% of the federal support for fundamental nuclear physics research in the nation. The National Science Foundation (NSF) provided most of the remaining support. NSAC regularly conducts reviews of the operations of individual university and national laboratory facilities to assess their scientific productivity, major components of the Division's research program, and evaluates the scientific case for new facilities. One of the most important functions of NSAC is development of long-range plans that express community-wide priorities for the upcoming decade of nuclear physics research.

Facility directors seek advice from ***Program Advisory Committees*** (PACs) to determine the allocation of scarce scientific resources – the available beam time. The committees comprise members mostly external to the host lab who are appointed by the director. PACs review research proposals requesting time at the facilities and technical resources; they provide advice on a proposal's scientific merit, technical feasibility, and manpower requirements. The PAC also provides a recommendation for the proposal to be approved, conditionally approved, deferred, or rejected.

Facility Operations Reviews:

The Nuclear Physics program has undertaken a series of operations reviews of its two largest national user facilities: Relativistic Heavy Ion Collider (RHIC) and Continuous Electron Beam Accelerator Facility (CEBAF). Conducted by the Office of Science's Construction Management Support Division, these reviews enlisted experts from DOE National Laboratories and NSF-supported university nuclear physics facilities to evaluate present performance and costs of operations. The Division has also conducted an operations review of the Holifield Radioactive Ion Beam Facility (HRIBF) using similar external experts. Annual reviews of the RHIC and CEBAF programs with external reviewers are conducted to access the performance and scientific productivity of the facility.

Program Reviews:

NSAC, on a rotating schedule, reviews the major elements of the nuclear physics program. These reviews examine scientific progress in each program element against the previous long-range plan, assess the scientific opportunities, and recommend reordering of priorities based upon existing budget profiles. In 1998, the Medium Energy program was reviewed. In 2001, the Low Energy program was reviewed. Results of these reviews are discussed later in the context of the requests for the Medium Energy and Low Energy physics programs. Continuing the cycle of reviews, it is planned that the Theory and Heavy Ion programs will be reviewed. Quality and productivity of university grants and laboratory groups performing research are peer reviewed on an approximately three-year basis.

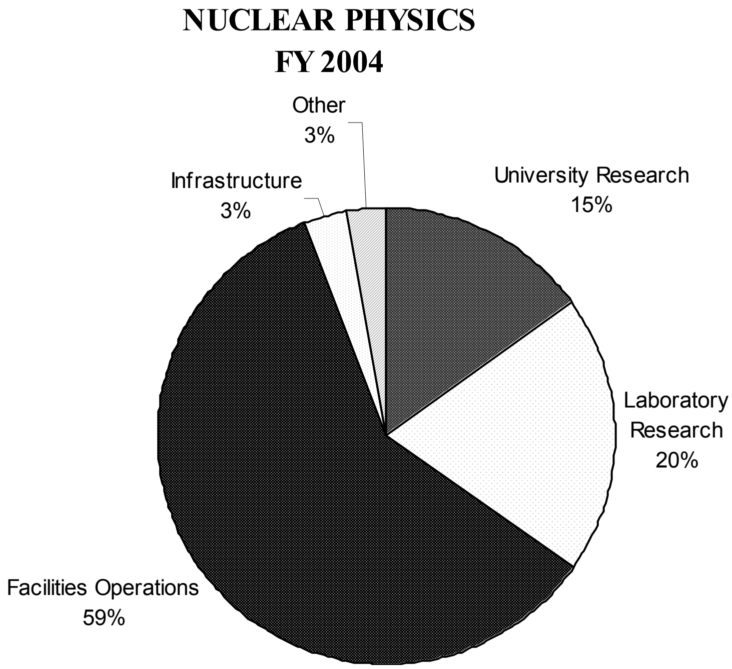
Planning and Priority Setting:

One of the most important activities of NSAC is the development of long-range plans that serve as a framework for the coordinated advancement of the field for the coming decade. These plans are undertaken every 5-6 years to review the scientific opportunities in the field, perform retrospective assessments of the major accomplishments by the field, and set priorities for the future. NSAC has identified increased support for the operations of the recently completed facilities as one of the highest priorities for DOE's Nuclear Physics program, as well as increased support for Nuclear Theory and computation. In the President's FY 2004 budget, funding supports operations at the newer major nuclear physics scientific user facilities. Operations are terminated at the 88-Inch Cyclotron at Lawrence Berkeley National Laboratory as a nuclear physics user facility in order to provide enhanced support for the remaining Low Energy user facilities and to make investments in instruments and to enhance capabilities. Theory support is enhanced and experimental research efforts are maintained at FY 2003 levels to collect and analyze data, at the operating facilities. The long-range plan also identifies the Rare Isotope Accelerator (RIA) as the highest priority for major new construction; the President's FY 2004 budget requests continuing funding of $3.5 million for RIA R&D.

How We Spend Our Budget:

The Nuclear Physics budget has three major components: research, facility operations and experimental support, and construction and laboratory infrastructure support. The FY 2004 budget request is focused on optimizing the utilization of its major user facilities and increasing the support for Nuclear Theory. Facility operations are provided a 1.1% increase in funding in FY 2004 that will result in a 5% increase in beam hours for research compared to FY 2003. With the completion of RHIC construction in FY 1999, no major nuclear physics projects are under construction.

Research:



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 Nuclear Physics 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. Funding for university and national laboratory research (excluding capital equipment) is increased about 4.2% compared to FY 2003, providing a small restoration to the recent erosion of effort. National laboratory research scientists work together with the experimental collaborations to collect and analyze data as well as support and maintain the detectors. The laboratories provide state-of-the-art resources for detector and accelerator R&D for future upgrades and new facilities. The division of support between national laboratories and universities is adjusted to maximize scientific productivity.

- ***University Research***: University researchers play a critical role in the nation's research effort and in the training of graduate students. During FY 2002, the DOE Nuclear Physics program supported approximately two-thirds of the nation's university researchers and graduate students doing fundamental nuclear physics research. Among the 85 academic institutions DOE supports researchers in five university laboratories with local accelerators (Texas A&M Cyclotron Laboratory, Triangle Universities Nuclear Laboratory (TUNL) at Duke University, MIT Laboratory for Nuclear Science, University of Washington, and Yale University). DOE also supports the Institute for Nuclear Theory at the University of Washington. Typically about 90 Ph.D. degrees are granted annually to students for research supported by the program. One-half of those who received nuclear science Ph.D.'s between 1980 and 1994 are pursuing careers outside universities or national labs in such diverse areas as nuclear medicine, medical physics, space exploration, and national security.

  The university grants program is proposal driven, in much the same way as is the nuclear physics program at the NSF. The Nuclear Physics program funds the best and brightest of those ideas submitted in response to grant solicitation notices (see http://www.sc.doe.gov/ production/grants/grants.html). Proposals are reviewed by external scientific peers and competitively awarded according to the guidelines published in 10 CFR 605.

- ***National Laboratory Research***: The Nuclear Physics program supports National Laboratory-based research groups at Argonne, Brookhaven, Jefferson, Los Alamos, Lawrence Berkeley, Lawrence Livermore, and Oak Ridge National Laboratories. The directions of laboratory research programs are driven by the needs of the Department and are highly tailored to the major scientific facilities at the laboratories. Laboratory researchers collaborate with academic users of the facilities and are important for developing and maintaining the large experimental detectors and computing facilities for data analysis. At the weapons laboratories, Nuclear Physics program funding plays an important role in supporting basic research that can improve the applied programs, such as proton radiography, neutron-capture reaction rates, properties of radioactive nuclei, etc.

The Nuclear Physics program funds field work proposals from the National Laboratories. Proposals are reviewed by external scientific peers and awarded according to a modified version of the 10 CFR 605 guidelines used for the grants program. Performance of the laboratory groups is reviewed every year to examine the quality of their research and identify needed changes, corrective actions or redirection of effort. Individual laboratory groups have special capabilities or access to laboratory resources that can be profitably utilized in the development of the scientific program.

Nuclear physics has made important contributions to our knowledge about the natural universe and has had great impact on human life. Knowledge and techniques developed in pursuit of fundamental nuclear physics research are extensively utilized in our society today. The understanding of nuclear spin enabled the development of magnetic resonance imaging for medical use. Radioactive isotopes produced by accelerators are used for medical imaging, cancer therapy, and biochemical studies. Particle beams are used for cancer therapy and in a broad range of materials science studies. Advances in cutting-edge instrumentation developed for nuclear physics experiments, such as high-resolution gamma ray detectors, have relevance to technological needs in combating terrorism.

The DOE Nuclear Physics program focuses its scientific thrusts along the high priority nuclear science questions identified by NSAC. To most effectively address these topics, the Nuclear Physics program is structured into four subprograms: the Medium Energy Nuclear Physics subprogram seeks to understand the structure of the nucleon; the Heavy Ion Nuclear Physics subprogram studies the properties of hot nuclear matter; the Low Energy Nuclear Physics subprogram focuses on the structure of nucleonic matter, the nuclear microphysics of the universe and addresses the possibility of new physics beyond the Standard Model; the Nuclear Theory subprogram provides the fundamental theories, models and computational techniques to address these science topics.

Program Strategic Performance Goals

SC2-1: Manage a productive and sustainable program that provides world-class research results in the scientific disciplines encompassed by the Nuclear Physics mission areas cognizant of DOE needs as well as the needs of the broad scientific community. (Medium Energy Nuclear Physics, Heavy Ion Nuclear Physics, Low Energy Nuclear Physics and Nuclear Theory subprograms)

Performance Indicators

Validation of results by merit review with external peer evaluation; validation of program directions by Nuclear Science Advisory Committee.

Annual Performance Results and Targets

FY 2002 Results	FY 2003 Updated Targets	FY 2004 Targets
		At least 80% of all new research projects will be peer reviewed and deemed excellent (of highest quality) and relevant, and annually 30% of all ongoing projects will be subject to peer review with merit evaluation. (SC2-1-1) Respond to priorities and recommendations for the DOE Nuclear Physics program in the 2002 Nuclear Science Advisory Committee Long Range Plan: • increase support for research and operations in order to exploit the opportunities made possible by recent investments at the new and upgraded facilities, for university research and infrastructure, and for nuclear theory; • maintain support for R&D activities to prepare for the future construction of the possible major new facility, the Rare Isotope Accelerator (RIA); • maintain R&D funding and prepare for the upgrade of the Continuous Electron Beam Accelerator Facility at Jefferson Lab to 12 GeV. (SC2-1-2)

SC7-2: Manage all Nuclear Physics 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.

Annual Performance Results and Targets

FY 2002 Results	FY 2003 Updated Targets	FY 2004 Targets
Maintain and operate Nuclear Physics scientific user facilities so the unscheduled operational downtime will be kept to less than 20%, on average, of total scheduled operating time. (SC7-2-1) [Met Goal]	Maintain and operate Nuclear Physics scientific user facilities so the unscheduled operational downtime will be kept to less than 20%, on average, of total scheduled operating time. (SC7-2-1)	Maintain and operate Nuclear Physics scientific user facilities so the unscheduled operational downtime will be kept to less than 20%, on average, of total scheduled operating time. (SC7-2-1)

FY 2002 Results	FY 2003 Updated Targets	FY 2004 Targets
		Conduct annual reviews of the Thomas Jefferson National Accelerator Facility and the Relativistic Heavy Ion Collider facility; use results of reviews to identify areas where increased efficiency and scientific productivity can be obtained. (SC7-2-2)
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). (SC7-2-3)	Upgrade the RHIC cryogenics system by replacing turbine oil skids and removing seal gas compressor, eliminating a single point failure. (SC7-2-3)	
Meet the cost and schedule milestones for the PHENIX Muon Arm Instrumentation (Major Item of Equipment) within 10% of baseline estimates. (SC7-2-4) [Met Goal]	Meet the cost and schedule milestones for the construction of facilities and Major Items of Equipment within 10% of baseline estimates. Complete the Solenoidal Tracker at RHIC (STAR) Electro-Magnetic Calorimeter (EMCAL). (SC7-2-4)	Fabrication of the STAR EMCAL Enhancement, the Fundamental Neutron Physics Beamline at the Spallation Neutron Source, and the Gamma-Ray Energy-Tracking In-beam Nuclear Array (GRETINA) (Major Items of Equipment) will not exceed 10% of cost and schedule baseline estimates. (SC7-2-4)

Program Assessment Rating Tool (PART) Assessment

The Nuclear Physics program was evaluated with the OMB Program Assessment Rating Tool (PART). It was found that, “The program received a perfect score in the purpose section and a high score in the management section, mainly as a result of standard management practices within the Office of Science that lead the Nuclear Physics program to have a well defined mission, merit-based reviews for awarding contracts and grants, and highly-regarded large project management practices. The primary cause for the lower scores for planning and results is the program’s current lack of adequate long-term and annual performance measures. Nevertheless, the program has made significant strides toward developing such measures despite the problems inherent in measuring and then predicting scientific progress.” Other findings include, “The program is well-managed with a strong focus on training nuclear scientists and utilizing existing facilities in order to maximize scientific results,” and, “The program coordinates its research strategy with the National Science Foundation through a jointly sponsored advisory committee (NSAC); however, the program does not yet have regular reviews of its research portfolio and processes by ad hoc panels composed of outside experts external to its advisory committee.”

To address these findings, 1) The Nuclear Physics program will work with OMB to improve the performance goals and measures for the FY 2005 Budget request utilizing the Research and Development Investment Criteria developed by OMB; 2) Towards maximizing scientific productivity the FY 2004 Budget request provides funds to operate the program’s user facilities at 83 percent of maximum capacity (compared with 80 percent in FY 2003 and 72 percent in FY 2002), while ceasing operations at one of its smaller user facilities; and 3) The Nuclear Physics program will institute a formal committee of visitors process by September, 2003.

Significant Program Shifts

In the FY 2004 budget request the scientific scope of the nation's nuclear physics program is maintained. The FY 2004 budget request terminates operations of one of the program's productive user facilities (the LBNL 88-Inch Cyclotron) in order to provide resources to optimize the utilization and science productivity of the remaining user facilities (BNL/RHIC, TJNAF/CEBAF, MIT/Bates Linear Accelerator Center, ANL/ATLAS, and ORNL/HRIBF). Facility operations at the remaining five facilities are provided a 2.7% increase in funding in FY 2004 that will result in a 29% increase in beam hours for research at these five facilities compared to FY 2003, (but only a 5% increase in beam hours overall because of the termination of the 88-Inch Cyclotron operation). 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 scientific productivity of the facilities. Funding for university and national laboratory research is increased about 4.2% compared to FY 2003, maintaining approximately constant effort for experimental efforts and enhancing theory efforts. Support for theory groups at the National Laboratories has been increased significantly at BNL, TJNAF, and ANL, by reallocation of some experimental support funds. The necessity for this increased support was identified in the 2002 NSAC Long Range Plan and is critical for the interpretation of the extensive new data coming from RHIC and TJNAF. Recognizing the exciting developments in research at the interface of nuclear physics and astronomy, the program increases support for non-accelerator-based research in the Low Energy subprogram. Funding for capital equipment will address opportunities identified in the recently completed 2002 NSAC Long Range Plan, while R&D activities for RIA are kept constant.

Scientific Discovery through Advanced Computing

The Scientific Discovery through Advanced Computing (SciDAC) activity is a set of coordinated investments across all Office of Science mission areas with the goal to achieve breakthrough scientific advances through computer simulation that were impossible using theoretical or laboratory studies alone. The power of computers and networks is increasing exponentially. By exploiting advances in computing and information technologies as tools for discovery, SciDAC encourages and enables a new model of multi-discipline collaboration among the scientific disciplines, computer scientists and mathematicians. The product of this collaborative approach is a new generation of scientific simulation codes that can fully exploit terascale computing and networking resources. The program will bring simulation to a parity level with experiment and theory in the scientific research enterprise as demonstrated by major advances in climate prediction, plasma physics, particle physics, astrophysics and computational chemistry.

Scientific Facilities Utilization

The Nuclear Physics request for FY 2004 supports the Department's scientific user facilities. In FY 2002 Nuclear Physics operated seven National User Facilities, which provide research time for scientists in universities and other Federal laboratories. In FY 2003 the program supports operations at:

- The Relativistic Heavy Ion Collider (RHIC) complex and the Alternating Gradient Synchrotron (AGS) at Brookhaven National Laboratory. (The AGS is not operating in FY 2003 and FY 2004 for Nuclear Physics.);
- The Continuous Electron Beam Accelerator Facility (CEBAF) at Thomas Jefferson National Accelerator Facility;

- The Bates Linear Accelerator Center at Massachusetts Institute of Technology;
- The Holifield Radioactive Ion Beam Facility (HRIBF) at Oak Ridge National Laboratory;
- The Argonne Tandem Linac Accelerator System (ATLAS) at Argonne National Laboratory; and
- The 88-Inch Cyclotron at Lawrence Berkeley National Laboratory. (The 88-Inch Cyclotron terminates operation in FY 2004.)

These facilities provide beams for research for a user community of about 2,400 scientists. The FY 2004 President's Budget Request will support operations of five facilities that will provide ~21,760 hours of beams for research, an increase of ~5% over the anticipated beam hours in FY 2003.

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

(hours)	FY 2000	FY 2001	FY 2002	FY 2003 Request	FY 2004 Request
Number of Facilities	7	7	7	6	5
Maximum Hours	31,500	31,600	31,600	32,275	26,260
Planned Operating Hours	23,150	20,285	17,510	20,700	21,760
Achieved Operating Hours	19,365	24,575	26,750	–	–
Unscheduled Downtime – Major user facilities	18%	18%	13%	–	–
Number of Users*	2,976	3,020	2,440	2,355	2,230

* Due to use of multiple facilities some users may be multiple counted.

In FY 2002, the achieved operating hours have well exceeded the planned operating hours for several reasons: increased operation of the Alternate Gradient Synchrotron for the Medium Energy program in order to finish experiments prior to termination of operations for this program, doubling the running hours of the MIT/Bates Electron Linear Accelerator to allow completion of the SAMPLE experiment prior to shutdown of this facility, and significantly increased operation of Low Energy facilities to take advantage of scientific opportunities by deferring maintenance.

Nuclear Physics will meet the cost and schedule milestones for construction of facilities and fabrication of Major Items of Equipment (MIE) within 10% of baseline estimates. Earned-value tracking is not maintained for MIE projects under $20,000,000; however, quarterly progress reviews are used to help ensure that projects remain on track.

Construction and Infrastructure:

Funding for capital equipment is reduced by ~5% compared to FY 2003 and R&D activities directed at RIA are kept constant. The Nuclear Physics program as part of its responsibilities as the landlord for Brookhaven National Laboratory and Thomas Jefferson National Accelerator Facility (TJNAF) provides funding for general plant projects (GPP) to both sites and general purpose equipment (GPE) to BNL only.

Workforce Development

The Nuclear Physics program supports development of the Research and Development (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, security 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, and national security. The Outstanding Junior Investigator (OJI) program, initiated in FY 2000, through ~5 new awards each year, has been very successful in identifying, recognizing, and supporting promising young faculty. About 800 postdoctoral research associates and graduate students supported by the Nuclear Physics program in FY 2002 were involved in a large variety of experimental and theoretical research projects. About 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. The FY 2004 funding level will support approximately the same number of postdoctoral research associates and graduate students as supported in FY 2003. Details of the DOE nuclear physics human capital are given below. In FY 2002 there were about 302 faculty researchers supported at the universities (~1.7 per grant), with an average award of ~$183,000 per faculty researcher. Almost all grants have a duration of three years.

	FY 2000	FY 2001	FY 2002	FY 2003, est.	FY 2004, est.
# University Grants*	171	180	181	185	185
Average size (excl. CE)	$314,000	$310,000	$306,000	$294,000	$307,000
# Lab groups	27	28	28	28	28
# Permanent Ph.D.'s	676	683	702	700	700
# Postdocs	363	362	364	360	360
# Graduate students	408	408	442	440	440
# Ph.D.'s awarded	87	67	100	~90	~90

*Tasks in multitask grants to university laboratories are counted separately.

Funding Profile

	(dollars in thousands)				
	FY 2002 Comparable Appropriation	FY 2003 Request	FY 2004 Request	$ Change	% Change
Nuclear Physics					
Medium Energy Nuclear Physics ..	111,218	123,590	124,198	+608	+0.5%
Heavy Ion Nuclear Physics	151,273	167,977	167,805	-172	-0.1%
Low Energy Nuclear Physics	62,769	66,158	69,289	+3,131	+4.7%
Nuclear Theory	25,329	24,645	28,138	+3,493	+14.2%
Total, Nuclear Physics	350,589 [a] [b]	382,370	389,430	+7,060	+1.8%

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 $7,777,000 that has been transferred to the SBIR program and $467,000 that has been transferred to the STTR program.

[b] Excludes $202,000 for the FY 2002 rescission contained in Section 1403 of P.L. 107-226, Supplemental Appropriations for further recovery from and response to Terrorist attacks on the United States.

Funding by Site [a]

	(dollars in thousands)				
	FY 2002	FY 2003	FY 2004	$ Change	% Change
Albuquerque Operations Office					
Los Alamos National Laboratory	9,652	9,123	9,104	-19	-0.2%
Chicago Operations Office					
Argonne National Laboratory	18,453	17,548	18,709	+1,161	+6.6%
Brookhaven National Laboratory	140,108	149,004	149,588	+584	+0.4%
Fermi National Accelerator Laboratory	231	0	0	0	--
Chicago Operations Office	53,029	52,111	52,655	+544	+1.0%
Total, Chicago Operations Office	211,821	218,663	220,952	+2,289	+1.0%
Oakland Operations Office					
Lawrence Berkeley National Laboratory	19,943	18,615	15,840	-2,775	-14.9%
Lawrence Livermore National Laboratory	664	507	700	+193	+38.1%
Oakland Operations Office	16,682	16,278	16,258	-20	-0.1%
Total, Oakland Operations Office	37,289	35,400	32,798	-2,602	-7.4%
Oak Ridge Operations Office					
Oak Ridge Institute for Science & Education	607	189	194	+5	+2.6%
Oak Ridge National Laboratory	15,974	16,870	19,330	+2,460	+14.6%
Thomas Jefferson National Accelerator Facility	74,761	79,138	82,247	+3,109	+3.9%
Total, Oak Ridge Operations Office	91,342	96,197	101,771	+5,574	+5.8%
Richland Operations Office					
Pacific Northwest National Laboratory	20	0	0	0	--
Washington Headquarters	465	22,987	24,805	+1,818	+7.9%
Total, Nuclear Physics	350,589 [bc]	382,370	389,430	+7,060	+1.8%

[a] On December 20 2002, the National Nuclear Security Administration (NNSA) disestablished the Albuquerque, Oakland, and Nevada Operations Offices, renamed existing area offices as site offices, established a new Nevada Site Office, and established a single NNSA Service Center to be located in Albuquerque. Other aspects of the NNSA organizational changes will be phased in and consolidation of the Service Center in Albuquerque will be completed by September 30, 2004. For budget display purposes, DOE is displaying non-NNSA budgets by site in the traditional pre-NNSA organizational format.

[b] Excludes $7,777,000 that has been transferred to the SBIR program and $467,000 that has been transferred to the STTR program.

[c] Excludes $202,000 for the FY 2002 rescission contained in Section 1403 of P.L. 107-226, Supplemental Appropriations for further recovery from and response to Terrorist attacks on the United States.

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 possible 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 Nuclear 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 ion-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 possible Rare Isotope Accelerator (RIA) facility. The combination of versatile beams and powerful instruments enables the ~230 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 uses 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 Van de Graaff, Booster Synchrotron, 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. 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 underway for the RHIC Spin program, with completion in FY 2004. 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 spectrometer arms that can track charged particles within a magnetic field especially to higher momentum; it provides excellent discrimination among photons, electrons, and hadrons. A Silicon Multiplicity Vertex Detector is used to locate the precise location of the collision point (different for each event), essential for measurement of the particle momenta with the spectrometer arms. 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 can be rotated to scan the broadest range of angles. It is especially designed to study the charged particle distributions in the forward and backward directions. Significant contributions (~$60,000,000) have been made by foreign institutions to these RHIC detectors and to implement the polarized proton capability.

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. 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 for medium energy physics experiments is terminating in FY 2003; however, the AGS will still be utilized to produce beams for tests of proton radiography for NNSA and for radiation damage studies to electronic systems for NASA supported work, among a variety of uses, with the support for these activities being provided by the relevant agencies.

The **Booster** Synchrotron, part of the RHIC injector, will provide heavy-ion beams to a dedicated beam line (Booster Application Facility, TPC~$33,900,000) for biological and electronic systems radiation studies funded by NASA as a Work-for-Others project to be completed in FY 2003. Upon completion operational costs will be supported by NASA.

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 (LE) subprogram, has been the operations and the research program of the 88-Inch Cyclotron, a national user facility. A major activity of this Low Energy group is the development of a next-generation gamma-ray detector system. 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 the KamLAND detector in Japan that are performing neutrino studies; (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. Operation of the 88-Inch Cyclotron as a Nuclear Physics user facility will be terminated in FY 2004.

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, in relativistic heavy ion experiments 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 162 acres in Newport News, Virginia. Constructed over the period FY 1987-1995 at a cost of $513,000,000, TJNAF began operations in FY 1995. Support for the research and operations of TJNAF are provided by the Medium Energy subprogram. The centerpiece 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 has a user community of ~1200 researchers and is used annually by ~700 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 of the strange quark contribution to nucleon structure, was completed during FY 2002. 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). The proposed upgrade to

CEBAF is one of the highest priority recommendations in the recently completed 2002 NSAC Long Range Plan for Nuclear Science.

All Other Sites

The Nuclear Physics program funds 181 research grants at 85 colleges/universities located in 35 states. Among these is a cooperative agreement 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 is the Bates Large Acceptance Spectrometer Toroid (BLAST) detector, whose fabrication was completed in FY 2001, underwent commissioning in FY 2002, and will begin its research program in FY 2003. BLAST will be used to observe collisions of polarized electrons in thin polarized gas targets located in the South Hall Pulse Stretcher Ring. The Bates experimental program is planned to terminate in 2005 with the completion of the BLAST program.

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. A new facility for producing intense photon beams using a free-electron laser (High Intensity Gamma Source) for studying photonuclear processes is just beginning its experimental program. ***The Texas A&M (TAMU) Cyclotron Institute*** operates a 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 the 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.

Medium Energy Nuclear Physics

Mission Supporting Goals and Measures

The Medium Energy Nuclear Physics subprogram supports fundamental research directed primarily at answering the first of the five broad questions listed in the 2002 Nuclear Science Advisory Committee Long Range Plan:

What is the structure of the nucleon? A quantitative understanding of the internal structure of the nucleons (protons and neutrons) requires a description of their observed properties in terms of the underlying quarks and gluons of Quantum Chromo-Dynamics (QCD), the theory of 'strong' interactions. Furthermore, this understanding would allow the nuclear binding force to be described in terms of the QCD interactions among the quarks.

To achieve the experimental description, the Medium Energy program supports different approaches that focus on:

(1) determining the distribution of (up, down, and strange) quarks in the nucleons,

(2) determining dynamic degrees of freedom of the quarks by measuring the excited states of hadrons (any composite particle made of quarks, such as nucleons),

(3) measuring the effects of the quark and gluon polarizations within the nucleon,

(4) determining the role of the "sea" of virtual quarks and gluons which also contributes to the properties of protons and neutrons, and

(5) measuring the properties of simple, few nucleon systems, with the aim to describe them in terms of the basic components.

Most of this work is done at this subprogram's primary research facility, Thomas Jefferson National Accelerator Facility (TJNAF), but the program also supports research at the MIT/Bates Linear Accelerator Center and the Relativistic Heavy Ion Collider at Brookhaven National Laboratory. Individual experiments are supported at the National Synchrotron Light Source at Brookhaven, the High Intensity Gamma Source at Triangle University Nuclear Laboratory, Fermilab, and at several facilities in Europe. All these facilities produce beams of sufficient energy (small enough wavelength) that they can probe at a scale within the size of a nucleon.

The operations of the two national user facilities, TJNAF and MIT/Bates, supported by 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. 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 European Center for Nuclear Research (CERN) member states. At TJNAF foreign collaborators have made significant investment in experimental equipment. Allocation of beam time at both Bates and TJNAF are based on guidance from Program Advisory Committees that review and evaluate proposed experiments regarding their merit and scientific priority.

The DOE Nuclear Physics program has made important discoveries in the past decade. 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. Advances in both theory and experiment have spurred this interest. The recent long-range plan singled out three significant achievements of the Medium Energy program related to the important central question of the structure of the nucleon:

- The combined discovery that the spins of the quarks alone account for only one third of the proton's overall spin and the observed increasing density of gluons inside the proton with increasing beam resolving power has increased the importance of the role of gluons in understanding nucleon structure.
- The discovery of a significant imbalance between antiquarks of different types inside the proton suggests that particles of quark-antiquark pairs called pions play as important a role inside the nucleon (via the virtual "sea" of quarks) as they do in theories of the nuclear force.
- The discovery in a new high-resolution spatial map of the proton points to an unexpected depletion of charge near its center, a fact not yet explained by current models.

These discoveries have been further extended by these recent highlights:

- *New precision results on the charge distribution of the neutron will test different models of the quark structure of the neutron:* Although a neutron has no net charge, it does have an internal distribution of charge due to the charged quarks inside. The precise determination of this charge distribution has been a major goal of nuclear physics for many years. Two dedicated experiments at TJNAF have obtained precise, high-resolution data on this distribution providing, for the first time, strong constraints for quark models of the neutron.
- *Data from disintegration of the deuteron by photons show a transition from quark to hadronic degrees of freedom:* New data from TJNAF on the breakup of the deuteron using gamma rays provide evidence that with increasing spatial resolution (power of magnification) one can see how the deuteron evolves from looking like a proton and a neutron bound together to an assembly of six quarks (the proton and neutron each containing three quarks). This result is important for scientists trying to understand when the individual quarks become important in describing the properties of the deuteron, the simplest compound nucleus.
- *Role of the strange quark in the proton's spin:* It had been thought that the strange quark should provide a negative contribution to the proton's internal "spin," or rotational angular momentum, of about 10%. Recent results from HERMES indicate that the contribution is consistent with zero or perhaps slightly positive. The near zero result rejects the hypothesis that the negative contribution of the strange quarks to the proton's spin could explain why the contribution of the 3 core quarks' spin does not add up to the proton's overall spin value.

Facility and Technical Accomplishments:

- *Fabrication of the BLAST Detector at the MIT/Bates facility is complete*: In FY 2002 the BLAST detector began commissioning activities; a unique research program will be initiated in FY 2003 to study the structure of the nucleon and few-body nuclei.
- *Fabrication of the G0 Detector is complete*: At the Thomas Jefferson National Accelerator Facility (TJNAF) the G0 Detector is complete and initiated commissioning at the end of FY 2002. 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 kinematic range.

- *The MiniBooNE detector fabrication is completed and operations begin:* Running of this jointly supported high-energy and nuclear physics experiment at Fermilab began in FY 2002 to look for the disapperance of muon neutrinos in an attempt to confirm the earlier result of the LSND experiment's observation of the disapperance of muon anti-neutrinos. With the observation of electron neutrino oscillations by the SNO experiment, this experiment becomes important for determining whether or not 'sterile' or non-interacting neutrinos exist.
- *The first Hydrogen-Deuterium frozen spin target is successfully demonstrated by the LEGS collaboration:* The LEGS collaboration at Brookhaven National Laboratory has demonstrated for the first time that an "ice" target made of hydrogen and deuterium can be polarized and operated in a beam of photons. This development is important for experiments on the structure of the proton and neutron for such "ice" targets have significantly cleaner experimental signatures than conventional polarized targets.

Subprogram Goal

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.

Performance Indicators

Validation of results by merit review with external peer evaluation.

Annual Performance Results and Targets

FY 2002 Results	FY 2003 Updated Targets	FY 2004 Targets
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. [Mixed Results]	As elements of the electron beam program, (a) collect first data with the BLAST detector at MIT/Bates, studying the structure of nucleons and few body nuclei and (b) collect first data to map out the strange quark contribution to nucleon structure using the G0 detector, utilizing the high intensity polarized electron beam developed at TJNAF.	At MIT/Bates complete high-priority experiments with BLAST studying structure of nucleons and few body nuclei. At Thomas Jefferson National Accelerator Facility perform experiments, analyze data, and/or publish results by carrying out a peer-reviewed and prioritized research program directed towards determining the structure of nucleons, including: • the first experiment to study new theoretical functions that describe the proton structure (Generalized Parton Distributions), • measurements of the form factor of the pion and of the charge distribution of the ^{4}He nucleus, and • measurements to complete the first phase of the study of the excited states of the nucleon.

FY 2002 Results	FY 2003 Updated Targets	FY 2004 Targets
Commission polarized protons at RHIC. [Met Goal]	Collect first data with polarized protons with the RHIC STAR, PHENIX and pp2pp detectors.	At the Brookhaven Relativistic Heavy Ion Collider, perform experiments, analyze data, and/or publish results by carrying out a peer-reviewed research program studying the internal structure of the proton, including: • asymmetry measurements of pion production in collisions of polarized protons at high energy.

Funding Schedule

	(dollars in thousands)				
	FY 2002	FY 2003	FY 2004	$ Change	% Change
Research					
University Research	15,670	15,575	15,432	-143	-0.9%
National Laboratory Research	14,554	16,815	15,708	-1,107	-6.6%
Other Research	315	5,405	5,405	0	0%
Subtotal, Research	30,539	37,795	36,545	-1,250	-3.3%
Operations					
TJNAF Operations	67,200	72,513	75,128	+2,615	+3.6%
Bates Operations	12,424	13,282	12,525	-757	-5.7%
Other Operations	1,055	0	0	0	0%
Subtotal, Operations	80,679	85,795	87,653	+1,858	+2.2%
Total, Medium Energy Nuclear Physics	111,218	123,590	124,198	+608	+0.5%

Detailed Program Justification

	(dollars in thousands)		
	FY 2002	FY 2003	FY 2004
Research	**30,539**	**37,795**	**36,545**
▪ **University Research**	**15,670**	**15,575**	**15,432**

These activities comprise a broad program of research, and include support of about 165 scientists and 110 graduate students at 35 universities in 17 states and the District of Columbia. 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.

	(dollars in thousands)		
	FY 2002	FY 2003	FY 2004
▸ **Bates Research**	**2,130**	**2,835**	**2,500**

MIT scientists along with other university researchers are beginning a new program of research, starting in FY 2003, 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 and the South Hall Ring. Effort at Bates remains essentially constant.

▸ **Other University Research**	**13,540**	**12,740**	**12,932**

Most of the university research supports the activities associated with our main facilities at Bates, TJNAF and RHIC. At TJNAF the 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 neutron and the pion. The latter will provide new information to better understand the transition from the quark degrees of freedom to the hadronic degrees of freedom. Hall B will complete its initial experimental program on the excited states of the nucleon and focus on two new experiments, one to determine the half-life of the neutral pion and the other to explore a new technique called Deeply Virtual Compton Scattering (DVCS) for measuring quark structure functions called "Generalized Parton Distribution Functions". In Hall C, the G0 experiment, which will begin its experimental program in FY 2003, 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. Support is provided for data analysis from BLAST precision polarization measurements of the proton and nuclear structure measurements on light nuclei.

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.

In FY 2004 other university research funds are effectively increased by 2.3% compared to FY 2003 after correcting for shifts ($430,000) in grants in FY 2003 to the Theory and Low Energy subprograms. This will maintain an approximately constant effort for university research.

▪ **National Laboratory Research**	**14,554**	**16,815**	**15,708**

Included is: (1) the research supported at the Thomas Jefferson National Accelerator Facility (TJNAF), that houses the world's most powerful 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 2002	FY 2003	FY 2004
▸ **TJNAF Research**	**5,770**	**5,945**	**5,405**

Scientists at TJNAF, with support of the user community, assembled the large and complex new experimental detectors for Halls A, B, and C. TJNAF scientists provide experimental support and operate the detectors 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. When a planned shift in FY 2003 of funds ($685,000) to the Theory Subprogram for enhanced theoretical effort at TJNAF is taken into account the FY 2004 funding provides a 2.8% increase from FY 2003.

As of FY 2002, Hall A will have completed 25 experiments and Hall C will have completed 17. The complex large-acceptance spectrometer in Hall B will have completed 65% of the data taking for 54 experiments. TJNAF researchers participate in all of these experiments.

TJNAF scientists are participating in the running of a new detector for the G0 experiment, in cooperation with the National Science Foundation. Beginning commissioning in FY 2002, the G0 detector will map out the contribution of the strange quark to the nucleon.

▸ **Other National Laboratory Research**	**8,784**	**10,870**	**10,303**

Support for research activities at accelerator and non-accelerator facilities at National Laboratories provides constant effort relative to FY 2003. These activities include:

- Argonne National Laboratory scientists will pursue research programs at TJNAF and at the DESY Laboratory in Germany. 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 new search for an electric dipole moment of the neutron.
- 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, the role of gluons. In FY 2003-2004, 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 completing a new spectrometer and a recently developed polarized "ice" target for a program of spin physics at low energies. This unique facility produces polarized gamma-rays by back scattering laser light from the circulating electron beam at the National Synchrotron Light Source (NSLS).

	FY 2002	FY 2003	FY 2004
	(dollars in thousands)		

– 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 Mini Booster Neutrino Experiment (MiniBooNE), uses neutrinos generated from the Fermi National Accelerator Laboratory Booster proton beam; data collection began 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 2002	FY 2003	FY 2004
▪ **Other Research**	**315**	**5,405**	**5,405**

In FY 2002 $4,219,000 was transferred to the SBIR program and $467,000 was transferred to the STTR program. This section includes $4,346,000 for SBIR and $510,000 for STTR in FY 2003 and $3,802,000 for SBIR and $1,048,000 for STTR in FY 2004 and other established obligations that the Medium Energy Nuclear Physics subprogram must meet.

	FY 2002	FY 2003	FY 2004
Operations	**80,679**	**85,795**	**87,653**
▪ **TJNAF Operations**	**67,200**	**72,513**	**75,128**

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 2002	FY 2003	FY 2004
▸ **TJNAF Accelerator Operations**	**43,040**	**46,413**	**48,753**

Funding for accelerator operations in FY 2004 supports a 4000 hour running schedule. In FY 2002, the accelerator routinely delivered beams of differing energies and currents simultaneously to the three experimental halls. This funding level provides approximately constant effort in operations.

	(hours of operation with beam)		
	FY 2002	FY 2003	FY 2004
TJNAF	3960	4200	4000

Funding of $1,000,000 is provided for R&D activities that include $500,000 for the proposed upgrade of CEBAF to 12 GeV. This upgrade is recommended as one of the highest priorities for Nuclear Physics in the 2002 NSAC Long Range Plan for Nuclear Science. AIP funding includes polarized injector and beam handling components as well as other additions and modifications to the accelerator facilities. GPP funding is increased by $20,000 from FY 2003 providing for minor new construction and utility systems.

	(dollars in thousands)		
	FY 2002	FY 2003	FY 2004
▸ **TJNAF Experimental Support**	**24,160**	**26,100**	**26,375**

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

In FY 2004 support is maintained 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 and for cooling, radiation shielding, and special equipment for specific experiments. When a proposed shift in FY 2003 of funds ($315,000) for enhanced theoretical effort at TJNAF is taken into account, the FY 2004 funding level will provide a ~3% increase compared to FY 2003.

The G0 detector fabrication was completed in FY 2002. TJNAF is shifting their base capital equipment ($6,100,000) 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.

▪ **Bates Operations**	**12,424**	**13,282**	**12,525**

Funding for operations of the MIT/Bates Linear Accelerator Center are provided in FY 2004 to complete the BLAST scientific program. Termination of Bates is planned for FY 2005. During FY 2004 an evaluation will be made of the options for disposition of this facility and equipment, and of the associated Decommissioning and Decontamination cost and schedule.

	(hours of operation with beam)		
	FY 2002	FY 2003	FY 2004
Bates	5560	2700	4000

▪ **Other Operations**	**1,055**	**0**	**0**

Operation of the Alternating Gradient Synchrotron (AGS) at Brookhaven National Laboratory for a limited fixed-target program in medium energy physics was funded in FY 2002. No funds are provided for operation of the AGS in FY 2003 or FY 2004.

Total, Medium Energy Nuclear Physics	**111,218**	**123,590**	**124,198**

Explanation of Funding Changes

	FY 2004 vs. FY 2003 ($000)
Research	
▪ **University Research**	
▸ Funding maintains the MIT/Bates research effort focused on effective collection and analysis of BLAST data. The level of effort remains essentially constant at Bates.	-335
▸ The research support at Other Universities is increased by 1.5% from FY 2003. As a result of transfer ($430,000) in FY 2003 of grant activities to Theory and Low Energy subprograms, this funding provides an approximately constant level of effort that is focused on the TJNAF and RHIC spin-physics research programs.	+192
Total, University Research	-143
▪ **National Laboratory Research**	
▸ Funding for capital equipment decreases by $691,000 from FY 2003 as projects are completed. Funding research support decreases by $416,000. The FY 2004 funding level for research support is effectively a ~2.6% increase from FY 2003 when the proposed shift of operating funds (~$835,000) to the Theory subprogram for enhanced theoretical effort in FY 2003 is taken into account.	-1,107
Total Research	-1,250
Operations	
▪ **TJNAF Operations**	
▸ **TJNAF Accelerator Operations:** Funding for accelerator operations is increased by $1,520,000 (3.4%) relative to FY 2003 in order to provide a 4000 hour running schedule. While the increase provides for somewhat less operating hours, actual scientific productivity is expected to increase due to higher beam reliability resulting from the increased funding. Funding for R&D is increased from FY 2003 by $500,000 (to $1,000,000, with $500,000 provided for the proposed 12 GeV upgrade) to maintain needed accelerator R&D manpower. AIP/GPP is increased by $320,000 compared to FY 2003 to maintain accelerator/physical infrastructure.	+2,340
▸ **TJNAF Experimental Support:** The increase of $275,000 for Experimental Support is effectively a ~3.0% increase relative to FY 2003 (after accounting for the proposed shift in FY 2003 of $315,000 to the Theory subprogram) in order to provide an approximately constant effort for supporting the experimental program. Overall capital equipment funding ($6,100,000) remains the same as FY 2003.	+275
Total, TJNAF Operations	+2,615

	FY 2004 vs. FY 2003 ($000)
▪ **Bates Operations**	
▸ The funding for Bates operations is decreased from FY 2003 since FY 2004 will be the last year of running to complete the BLAST program. Operating funds are increased (+$818,000) and capital equipment and accelerator improvement projects (AIP) funds are decreased (-$1,575,000).	-757
Total Operations	+1,858
Total Funding Change, Medium Energy Nuclear Physics	+608

Heavy Ion Nuclear Physics

Mission Supporting Goals and Measures

The Heavy Ion Nuclear Physics subprogram supports research directed at answering one of the central questions of nuclear science identified in the Nuclear Science Advisory Committee (NSAC) 2002 Long Range Plan:

(1) *What are the properties of hot nuclear matter?* At normal temperatures and densities, nuclear matter contains individual protons and neutrons (nucleons), within which the quarks and gluons are confined. At extremely high temperatures, however, such as those that existed in the early universe immediately after the "Big Bang," the quarks and gluons become deconfined and form a quark-gluon plasma. It is the purpose of this research program to recreate this phase of matter in the laboratory by colliding heavy nuclei at relativistic energies. The distributions and properties of particles emerging from these collisions are studied for the predicted signatures of the quark-gluon plasma to establish its existence and further characterize its properties experimentally. At much lower temperatures, nuclear matter passes through another phase transition from a Fermi liquid to a Fermi gas of free roaming nucleons; understanding this phase transition is also a goal of this program.

Historically, 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 (RHIC) at Brookhaven National Laboratory. First gold-gold collisions were observed at RHIC in 2000. The Heavy Ion research program, now almost exclusively performed at RHIC, 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." Limited studies of the conditions for inducing the liquid-to-gas phase transitions in nuclear matter are also going on at the National Superconducting Cyclotron Laboratory (NSF funded) at Michigan State University, at Texas A&M University, and at foreign laboratories.

The Heavy Ion Nuclear Physics subprogram supports operation of the RHIC facility at Brookhaven National Laboratory. 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. Two successful running periods have been completed, Run 1 in FY 2000 and Run 2 which spanned the end of FY 2001 and the beginning of FY 2002. The RHIC facility is utilized by over 1,100 DOE, NSF, and foreign supported researchers. capital equipment and accelerator improvement project (AIP) funds are provided for additions, modifications, and improvements to the various accelerators that make up the RHIC complex and to the ancillary experimental facilities, in order to maintain and improve the reliability and efficiency of operations, and to provide new experimental capabilities. The allocation of beam time at RHIC is made with the guidance of a Program Advisory Committee, consisting of distinguished scientists, that reviews and evaluates proposed experiments regarding their merit and scientific priority. An annual peer review of the effectiveness of RHIC operations and its research program is conducted by the program office; the recommendations from these reviews are used to improve RHIC operations.

The recent NSAC long-range plan identified several recent discoveries that support the goals of the Heavy Ion Program:

- Production of small regions of space with energy densities more than twenty times that of atomic nuclei. Matter under these extreme conditions is believed to be in the quark-gluon plasma phase.
- Observation of a strong "flow" of matter in relativistic heavy-ion collisions, that indicates that the initial kinetic energy of the beams is rapidly converted to heating the nuclear matter created in the collision zone, putting it under immense internal pressure.
- Observation of a deficit of high transverse-energy particles in relation to proton-proton collisions. This result indicates that high-energy particles suffer energy losses much larger than those expected for the partons (making up the particles) passing through normal nuclear matter – hinting at the formation of the plasma phase in the collision.
- Measurements of anti-matter to matter ratio. Since the number of anti-baryons (anti-matter) is almost equal to the number of baryons (matter), it is concluded that the collision zone immediately after the collision consists of almost only pure energy, out of which the particles are produced.

These discoveries have been further extended by these recent highlights:

- *First lepton measurements – open charm:* First measurements of high-energy electrons at RHIC show that their yields are consistent with the electrons originating from decays of D-mesons, which contain a single heavy charm quark. The study of charmed quark production and the survival probability of J/ψ-mesons (consisting of a pair of charm and anti-charm quarks) in the hot collision zone is expected to be a critical signal for demonstrating that the quark-gluon plasma has been formed.
- *Observation of the liquid-gas phase transition in nuclear matter* – At low temperatures nuclear matter behaves like a quantum mechanical (Fermi) liquid, but it is expected that it will go through a phase transition (start to boil) when heated to sufficiently high temperatures and assume the characteristics of a (Fermi) gas. Recently, this long-predicted phase transition has been observed in experiments where gold nuclei are heated by absorbing anti-protons or pions from the AGS into gold nuclei. The results show that this phase transition occurs in nuclear matter at a temperature of 4-6 MeV.

Facility and Technical Accomplishments:

- *The Relativistic Heavy Ion Collider (RHIC) reaches full luminosity:* At Brookhaven National Laboratory commissioning of RHIC 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) and beam energies of 65 GeV per nucleon, as planned. RHIC operated at full beam energies of 100 GeV per nucleon for gold-gold collisions in late FY 2001 and in early FY 2002 full luminosity (collision rate) was achieved. Both running periods supported very successful physics research programs.
- *RHIC obtains first collisions of polarized protons from two colliding beams:* The RHIC Spin program at Brookhaven National Laboratory successfully accelerated polarized protons in the two RHIC rings with about 25% polarization at energies of 100 GeV in early CY 2002. The polarization

was between 80-100% of injection polarization. This demonstrated that polarized protons can be successfully accelerated in the rings and set a new record for the highest energy polarized proton beam ever achieved as well as the first collisions of polarized protons.

- *RHIC detector enhancements remain on cost and schedule:* In FY 2002, a Critical Decision-4 (CD-4, Start of Operations) was approved for the STAR Silicon Vertex Detector (SVT), a high resolution, high granularity, charged-particle tracking system very close to the collision region. A CD-4 was also obtained for the first PHENIX muon arm (MIE); the second arm (funded substantially by the Japanese collaborators) was completed in FY 2002. The Electromagnetic Calorimeter (EMCAL) of STAR is on schedule for completion of the planned system in FY 2003.

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 that are needed for effective laboratory operations.

Subprogram Goal

Determine the behavior and properties of hot, dense nuclear matter as a function of temperature and density; establish whether a quark-gluon plasma can be created in the laboratory and, if so, characterize its properties.

Performance Indicators

Validation of results by merit review with external peer evaluation.

Annual Performance Results and Targets

FY 2002 Results	FY 2003 Updated Targets	FY 2004 Targets
Complete first round of experiments at RHIC at full energy; achieve the full design luminosity (collision rate) of 2×10^{26} cm^{-2} s^{-1} for heavy ions. [Met Goal]	Initiate first round of experiments with collisions with other ions to compare to results of gold-gold collisions.	At the Relativistic Heavy Ion Collider, perform experiments, analyze data, and/or publish results by carrying out a peer-reviewed and prioritized research program directed towards determining the behavior and properties of hot, dense nuclear matter, including: • Measurements of the thermodynamic and hydrodynamic properties of hot nuclear matter; and • Measurements of the yields of high transverse momentum particles through hot and cold nuclear matter.

Funding Schedule

	(dollars in thousands)				
	FY 2002	FY 2003	FY 2004	$ Change	% Change
Research					
University Research	11,530	11,635	12,083	+448	+3.9%
National Laboratory Research	18,903	21,194	18,873	-2,321	-11.0%
Other Research	0	3,291	3,902	+611	+18.6%
Subtotal, Research	30,433	36,120	34,858	-1,262	-3.5%
Operations					
RHIC Operations	103,344	117,497	121,057	+3,560	+3.0%
Other Operations	17,496	14,360	11,890	-2,470	-17.2%
Subtotal, Operations	120,840	131,857	132,947	+1,090	+0.8%
Total, Heavy Ion Nuclear Physics	151,273	167,977	167,805	-172	-0.1%

Detailed Program Justification

	(dollars in thousands)		
	FY 2002	FY 2003	FY 2004
Research	**30,433**	**36,120**	**34,858**
▪ **University Research**	**11,530**	**11,635**	**12,083**

Support is provided for the research of about 130 scientists and 75 graduate students at 26 universities in 18 states. *There is a $448,000 increase compared to FY 2003 that provides a 3.9% increase in grant funding.*

- Researchers using relativistic heavy ion beams are 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.
- Researchers using primarily the NSF supported National Superconducting Cyclotron Laboratory at Michigan State University, at the DOE supported 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.

▪ **National Laboratory Research**	**18,903**	**21,194**	**18,873**

Support is provided for scientists from five National Laboratories (BNL, LBNL, LANL, LLNL and ORNL). These scientists provide essential manpower for the operations of the RHIC detectors and in analyzing data. 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.

	FY 2002	FY 2003	FY 2004
	(dollars in thousands)		
▸ **BNL RHIC Research**	**9,177**	**9,153**	**8,696**

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 contribute to the search for signatures of any new forms of nuclear matter produced in heavy-ion collisions. *In FY 2004 funding for capital equipment decreases by $703,000 to $2,300,000, with the completion of projects, while support for manpower increases 4.0%.* Funding for production of modules for the Electromagnetic Calorimeter Enhancement for the STAR RHIC-spin program is beginning in FY 2003; the enhancement will be completed in FY 2004. The survey work with gold ions at the full energy will be substantially complete by FY 2004 and measurements of the yields of rarer signals, such as J/ψ suppression due to its breakup by the quark-gluon plasma, will dominate the experimental program. Two new major detector subsystems will be ready for these investigations in FY 2004:

- The muon instrumentation for PHENIX allows measurement of the yields of muons ("heavy electrons") that (1) probe the early stages of quark-gluon plasma formation in heavy-ion collisions, and (2) perform critical measurements in the PHENIX RHIC Spin program. Completed in FY 2002, this system will be used for the FY 2003 Run-3 running period. Japanese and French collaborators are contributing substantial support for the muon arms.
- The Electromagnetic Calorimeter for STAR provides capability to distinguish electrons from photons, and extends the measurement to higher particle 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 and be completed in FY 2004.

▸ **Other National Laboratory Research**	**9,726**	**12,041**	**10,177**

Researchers at LANL, LBNL, LLNL, and ORNL provide leadership in the commissioning of the PHENIX muon arms 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 decrease in funding of $2,065,000 to $275,000 for capital equipment compared to FY 2003 reflects the completion of projects; support for manpower increases by 2.1% for about constant effort.

▪ **Other Research**...	**0**	**3,291**	**3,902**

In FY 2002 $2,903,000 was transferred to the SBIR program. This section includes $3,291,000 for SBIR in FY 2003 and $3,902,000 for SBIR in FY 2004.

	(dollars in thousands)		
	FY 2002	FY 2003	FY 2004
Operations	**120,840**	**131,857**	**132,947**
▪ **RHIC Operations**	**103,344**	**117,497**	**121,057**

The Relativistic Heavy Ion Collider (RHIC) program nearly reached its full planned capabilities by the end of the planned running period Run 2 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 described theoretically. Already during the first runs in FY 2000 (Run 1) and FY 2001/FY 2002 (Run 2), new features were observed in the data indicating that conditions are favorable for quark-gluon plasma formation and hints of some characteristic signatures of its existence. The scientific papers that have been published from these results have generated much attention in the community. During the Run 2, operation with 100 GeV polarized protons was accomplished and some initial measurements for the spin-physics program were completed.

▸ **RHIC Accelerator Operations**	**75,823**	**86,950**	**90,232**

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. Operations in FY 2003 are expected to increase to 22 weeks (3300 hours) from the 18-week operating schedule (2110 hours) in FY 2002. *FY 2004 funding will support a 29-week schedule (3480 hours) for research, about a 5% increase in hours from FY 2003. After accounting for an anticipated shift of $400,000 to the Theory subprogram in FY 2003 for enhanced theoretical effort, in response to the NSAC Long Range Plan recommendation, there is a 4.3% increase in FY 2004 for operations. Capital equipment funding is increased from FY 2003 by $100,000 to $1,100,000* and AIP funding of $2,900,000 is maintained at the same level as FY 2003, providing for needed improvements especially to legacy systems such as the AGS main magnet power supply as well as for design efforts for the Electron Beam Ion Source (EBIS).

RHIC Operations

	(hours of operation with beam)		
	FY 2002	FY 2003	FY 2004
RHIC	2110	3300	3480

	FY 2002	FY 2003	FY 2004
▸ **RHIC Experimental Support**......................................	**27,521**	**30,547**	**30,825**

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) nearly reached their initial planned potential by FY 2002. About 1,100 scientists and students from 82 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. After accounting for a proposed shift of $200,000 in FY 2003 to the Theory subprogram there is a 1% increase in support in FY 2004. Capital equipment is increased by $228,000 from FY 2003.

	FY 2002	FY 2003	FY 2004
▪ **Other Operations**	**17,496**	**14,360**	**11,890**

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 2004 funding for GPP and GPE is decreased by $50,000 (-0.3%) relative to FY 2003, by reducing usage of motor vehicles.

(dollars in thousands)	FY 2002	FY 2003	FY 2004
Total, Heavy Ion Nuclear Physics..	**151,273**	**167,977**	**167,805**

Explanation of Funding Changes

	FY 2004 vs. FY 2003 ($000)
Research	
▪ **University Research**	
▸ FY 2004 funding for grants for University Research increases by 3.9%, maintaining an approximately constant effort relative to FY 2003 focused on carrying out an effective and productive research program at RHIC..	+448
▪ **National Laboratory Research**	
▸ **BNL RHIC Research:** Research support is increased by $246,000 (+4.0%) to effectively carry out research with the enhanced detectors at full luminosity at RHIC. Funding for capital equipment is decreased by $703,000 because of completion of projects..	- 457

	FY 2004 vs. FY 2003 ($000)
▸ **Other National Laboratory Research:** Research support for operations is increased by $201,000 (+2.1%) compared to FY 2003, maintaining approximately constant manpower. Funding for capital equipment decreases by $2,065,000 compared with FY 2003, with the completion of projects.	-1,864
Total, National Laboratory Research	-2,321
▪ **Other Research:**	
▸ Estimated SBIR and other obligations increase.	+611
Total, Research	-1,262
Operations	
▪ **RHIC Operations**	
▸ **Accelerator Operations:** An increase of $3,182,000 (+3.8%) in operating funds provides an enhancement of effort resulting in ~3,480 hours of beam for research, about 5% greater than in FY 2003. Funding of capital equipment is increased $100,000 relative to FY 2003 to maintain accelerator capabilities.	+3,282
▸ **Experimental Support:** The increase provides a funding level for experimental support that is needed to carry out the RHIC experimental program.	+278
Total, RHIC Operations	+3,560
▪ **Other Operations**	
▸ FY 2004 funding for general plant projects to Brookhaven National Laboratory is increased by $60,000 (+1%) compared with FY 2003. Funding for general purpose equipment is decreased by $110,000 (-2.4%). Other operations decrease by $2,420,000.	-2,470
Total, Operations	+1,090
Total Funding Change, Heavy Ion Nuclear Physics	-172

Low Energy Nuclear Physics

Mission Supporting Goals and Measures

The Low Energy Nuclear Physics subprogram supports research directed at understanding three of the central questions of nuclear science identified in the NSAC 2002 Long Range Plan:

(1) *What is the structure of nucleonic matter?* 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.

(2) *What is the nuclear microphysics of the universe?* 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.

(3) *Is there new physics beyond the Standard Model*? Studies of fundamental interactions and symmetries, including those of neutrino oscillations, are indicating that our current Standard Model is incomplete, opening up possibilities for new discoveries by precision experiments.

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 2002 NSAC Long Range Plan identified RIA as the highest Nuclear Physics priority for a major new construction project. Starting in FY 2000, R&D activities have been supported in preparation for a possible request for approval for construction. Continued funding for these pre-conceptual R&D activities is supported in FY 2004.

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. In FY 2004 the Low Energy Nuclear Physics subprogram supports the operation of two national user facilities: the Holifield Radioactive Ion Beam Facility (HRIBF) at Oak Ridge National Laboratory and the Argonne Tandem Linac Accelerator System (ATLAS) facility at Argonne National Laboratory. Operations at the 88-Inch Cyclotron (LBNL) are terminated as a nuclear physics user facility in order to provide resources to optimize the utilization and science productivity of the remaining user facilities. These facilities are utilized by DOE-, NSF-, and foreign-supported researchers. The allocation of beamtime is made with the guidance of Program Advisory Committees, consisting of distinguished scientists, who review and evaluate proposed experiments regarding their merit and scientific priority. 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. These students historically have become 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 Sudbury Neutrino Observatory (SNO) detector is studying the production rate and properties of solar neutrinos, while the Kamioka Large Anti-Neutrino Detector (KamLAND) is studying the properties of anti-neutrinos produced by nuclear power reactors.

Research in the Low Energy subprogram continues to evolve to address forefront scientific questions. The 1990's began with research efforts at the 88-Inch 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, conceived in the late 1980's to search for neutrino flavor oscillations due to their having mass, was designed and built in the 1990's. In 2001, SNO reported its first physics results, which together with other experimental results, made a persuasive case for neutrino oscillations among their different types (or "flavors") and that neutrinos have mass. These results have been confirmed by new measurements reported in 2002 from SNO that are sensitive to the different types of neutrinos, and from the first KamLAND results with reactor produced anti-neutrinos. Both of these experiments have shown that neutrinos "oscillate" or change flavor as they propagate from the source to detector – this property requires that they have mass. These results have stimulated an increasing interest in non-accelerator experiments, particularly those that study neutrino properties. A priority in the FY 2004 request is increased support for this research area.

The 2002 Long Range Plan identified significant achievements of the Low Energy subprogram that are related to the important central questions about nuclear structure, nuclear astrophysics, and fundamental interactions and symmetries:

- Studies of nuclei at extreme conditions are pointing to alterations of the nuclear shell structure, the ability of heavy nuclei to sustain rapid rotation demonstrating unexpected stability, and evidence for phase transitional behavior between spherical and deformed nuclei.
- Nuclear measurements of very neutron-rich, unstable nuclei, combined with new computational techniques, are leading to a better identification of the *r*-process site or sites for nucleosynthesis and to quantitative models for the production of heavy elements.

- Measurements of solar neutrinos have indicated that neutrinos change their identity on the way to earth, implying that they have mass, and providing a key to the fundamental structure of the forces of nature.

The basic knowledge and understanding in these areas have been further extended by these recent highlights:

- *Identification of hyper-intruder states*: Scientists at LBNL have identified the gamma-ray decay of nuclear states based on very extended shapes in ^{108}Cd. These structures may correspond to the most deformed nuclei observed to date. Microscopic calculations suggest that the proton orbitals that are the basis of the new structures in ^{108}Cd are the same as those involved in superdeformed structures of the much heavier mass 150 nuclei and the ground states of much heavier uranium nuclei. These newly discovered "hyper-intruder" states are thought to be a key ingredient for stabilizing football-like shapes with a 3:1 axis ratio in some nuclei.
- *First studies with re-accelerated neutron-rich radioactive ion beams*: Beams of re-accelerated radioactive tin and tellurium have been used at ORNL's Holifield Radioactive Ion Beam Facility to perform Coulomb excitation and transfer reaction studies of nuclear structure in the vicinity of ^{132}Sn, a nucleus with closed shells of both protons and neutrons. The initial Coulomb excitation results suggest that present theoretical models may not be able to adequately describe the low-lying structure of ^{136}Te, a nucleus with just two neutrons beyond the closed N = 82 shell.
- *First neutral current results from SNO:* Researchers at the Sudbury Neutrino Observatory reported the first neutral current measurements of neutrinos from the sun, a measurement made possible by the SNO detector's heavy water medium. The neutral current results show for the first time that the measured solar neutrino flux agrees with theoretical estimates. These results, together with the charged current results (sensitive to only the electron neutrino) SNO reported last year, provide evidence that the electron neutrinos originating in the sun change to one or both of the other neutrino types (muon and tau) by the time they are detected on earth, and indicate that neutrinos have a mass.

Facility and Technical Accomplishments:

- *Performance of the gas cell fast ion catcher:* The gas cell fast ion catcher is an essential component of the Rare Isotope Accelerator that will allow that facility to combine the best features of the fragmentation and isotope-separator-on-line techniques for production of exotic nuclei. At ANL a quarter-scale version of the gas cell has provided an efficiency of about 45% for stopping, collecting, and delivering charge 1+ radioactive ions for further study. A mean delay time of 10 milliseconds has been demonstrated for this device. A full-scale version of the gas cell fast ion catcher has been fabricated for high power tests to be conducted at the GSI accelerator facility in Germany.
- *Kamioka Large Anti-Neutrino Detector (KamLAND) begins operations*: The construction of this joint Japanese/U.S. detector project was completed and began operation in FY 2002. This experiment will detect anti-neutrinos from Japanese nuclear power plants and will provide complementary information regarding neutrino properties to the recent Sudbury Neutrino Observatory (SNO) results. U.S. participation in KamLAND is supported jointly with the High Energy Physics program
- *Development of segmented Germanium detectors:* Preconceptual design of a detector cluster module consisting of three Ge crystals in a cryostat was completed. The crystals are divided into 36 electrically isolated segments. This represents the final step in developing the technology for a 4π array that will be up to 1000 times more sensitive than Gammasphere, presently the most powerful gamma-ray detector in the world.

Subprogram Goal

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.

Performance Indicators

Validation of results by merit review with external peer evaluation.

Annual Performance Results and Targets

FY 2002 Results	FY 2003 Updated Targets	FY 2004 Targets
		Perform experiments, analyze data, and/or publish results by carrying out a peer-reviewed and prioritized research program, including: • at the Argonne Tandem Linac Accelerator System (ATLAS) measure masses with high precision of nuclear astrophysically important radioactive nuclei, identify collective excitations in actinide nuclei, and develop new exotic beams for nuclear astrophysics and structure studies; • at the Holifield Radioactive Ion Beam Facility (HRIBF), use stable and radioactive ion beams (RIBs) to measure the properties of reactions that are important for understanding the synthesis of elements in stellar explosions and necessary for interpretation of solar neutrino experiments, and measure shapes of neutron-rich nuclei.
Collect the first data from neutral current interactions from the Sudbury Neutrino Observatory (SNO). [Met Goal]	Collect the first data from the Kamioka Large Anti-Neutrino Detector (KamLAND), a joint U.S.-Japan experiment measuring neutrinos produced in nuclear reactors.	With KamLAND, perform experiments, analyze data, and publish results, completing the first measurement of reactor-produced neutrinos with this detector.
Construct a prototype high energy, high power gas catcher for the possible Rare Isotope Accelerator. [Met Goal]	Deliver the prototype high energy, high power gas catcher to the GSI facility in Germany and prepare it for testing. Complete tests of prototype targets for RIA. Complete prototype Electron Cyclotron Resonance ion source and fabricate prototypes of the high-beta superconducting radio frequency (RF) cavities for RIA.	As part of R&D for the possible RIA, complete test of the high-beta superconducting RF cavities.

Funding Schedule

	(dollars in thousands)				
	FY 2002	FY 2003	FY 2004	$ Change	% Change
Research					
University Research	17,123	17,591	18,312	+721	+4.1%
National Laboratory Research	20,109	20,044	23,244	+3,200	+16.0%
Other Research	3,150	4,743	4,903	+160	+3.4%
Subtotal Research	40,382	42,378	46,459	+4,081	+9.6%
Operations	22,387	23,780	22,830	-950	-4.0%
Total, Low Energy Nuclear Physics	62,769	66,158	69,289	+3,131	+4.7%

Detailed Program Justification

	(dollars in thousands)		
	FY 2002	FY 2003	FY 2004
Research	**40,382**	**42,378**	**46,459**
▪ **University Research**	**17,123**	**17,591**	**18,312**

Support is provided for the research of about 140 scientists and 90 graduate students at 32 universities in 23 states. Nuclear Physics university scientists perform research as users 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, the production mechanisms of the chemical elements in stars and supernovae, and the properties of neutrinos. FY 2004 funding for operation of university accelerator facilities, and for researchers and students is increased by 6.8% compared to FY 2003, with priority given to non-accelerator research. Funding for capital equipment projects is decreased by $353,000. Research activities include:

- 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 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 that 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.

	(dollars in thousands)		
	FY 2002	FY 2003	FY 2004

- 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**	**20,109**	**20,044**	**23,244**

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**............	**14,123**	**14,455**	**14,345**

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 2004 funding is increased ~0.6% for manpower while investments in equipment decrease by $200,000 from FY 2003. In FY 2004 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 being utilized in an experimental program in nuclear astrophysics.
- At ANL the research focuses on the use of stable and selected radioactive beams from ATLAS, coupled to ion traps, Gammasphere and the Fragment Mass Analyzer to study fundamental processes and properties of nuclei, and to study nuclei at the extremes of excitation energy, angular momentum, deformation and 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 tested and the experimental program initiated.
- At LBNL the research focuses on the completion of data analysis from the terminated research program at the 88-Inch Cyclotron and the use of DOE user facilities to study nuclei at high angular momentum and deformation. Development and 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.

► **Other National Laboratory Research**	**5,986**	**5,589**	**8,899**

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. *FY 2004 funding for manpower increases by ~2.6% from FY 2003 with priority given to non-accelerator research. Capital equipment investments increase from FY 2003 by $3,176,000 to $3,641,000.* These activities include:

	(dollars in thousands)	
FY 2002	FY 2003	FY 2004

– 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 and 2002, the first results from SNO with the heavy water detector were reported, indicating strong evidence for neutrino oscillations. Results from the second phase measurements of neutrino types to which the solar neutrinos have been transformed will be reported in FY 2003. In FY 2003, the third phase of SNO began; it will provide additional detail and confirmatory information on neutrino oscillations. Results from this phase are expected to be reported in FY 2004-2005.

– The KamLAND experiment in Japan will measure the rate and properties of anti-neutrinos produced by several distant nuclear power reactors to study neutrino "oscillations." KamLAND has the advantage of comparing the measured fluxes to known sources. Commissioning of the KamLAND detector began in FY 2002, with data collection continuing in FY 2003 and FY 2004. The U.S. participation in KamLAND is supported jointly with the High Energy Physics program.

– 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. Commissioning of neutron experiments with these beams will begin in FY 2004. Funds ($500,000) are provided in FY 2004 to begin development of a beamline for neutron studies at the Spallation Neutron Source (SNS) (an MIE).

– Development and fabrication of a segmented germanium gamma-detector array, the Gamma-Ray Energy-Tracking In-beam Nuclear Array (GRETINA) begins, that is especially useful for the study of the nuclear decay and structure of exotic nuclei in fast fragmentation beams, and a smaller version of the proposed GRETA detector for the Rare Isotope Accelerator. The improved position resolution and higher efficiency for high-energy gamma rays compared with presently available gamma-ray detector arrays will allow this new detector system to utilize fragmented nuclear beams to open up a new frontier for understanding exotic nuclei that may exist in stars and supernovae, but live only briefly (fractions of a second). In FY 2004 funding of $1,000,000 is provided to begin fabrication of GRETINA (a Major Item of Equipment).

	FY 2002	FY 2003	FY 2004
▪ **Other Research**	**3,150**	**4,743**	**4,903**
▸ **RIA R&D Activities**	**2,800**	**3,500**	**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 2002 Nuclear Science Advisory Committee (NSAC) Long Range Plan as a compelling scientific opportunity and as the highest priority for new construction. The possible RIA facility is a new paradigm for producing intense beams of very short-lived nuclei that emerged from the 1999 NSAC Taskforce study involving international experts. This facility would position the

	(dollars in thousands)	
FY 2002	FY 2003	FY 2004

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 phenomena. Funding for FY 2004 supports some of the needed R&D activities in both critical accelerator components and experimental station development.

	FY 2002	FY 2003	FY 2004
▸ **SBIR and Other**	**350**	**1,243**	**1,403**

In FY 2002 $655,000 was transferred to the SBIR program. This section includes $868,000 for SBIR in FY 2003 and $1,028,000 for SBIR in FY 2004 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 2002	FY 2003	FY 2004
Operations	**22,387**	**23,780**	**22,830**
▪ **User Facility Operations**	**22,387**	**23,780**	**22,680**

Support is provided for the operation of two National User Facilities, the Argonne Tandem-Linac Accelerator System (ATLAS) at ANL 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. Accelerator improvement project funding is increased from FY 2003 by $1,000,000 in order to fabricate a platform for development and testing targets and ion sources.

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.

Operations at the 88-Inch Cyclotron as a Nuclear Physics user facility are terminated in FY 2004 to provide resources to optimize the utilization and science productivity of the remaining user facilities and to be consistent with the recommendations of the NSAC Low Energy Program Review in 2001. In FY 2003 options for this facility will be evaluated and the estimated cost and schedule for the appropriate Decommissioning and Decontamination (D&D) activities will be developed. Funds of $3,000,000 are provided in FY 2004 for these phaseout activities. While the final D&D cost and schedule have not been established, it can be anticipated that these activities will continue for 2-4 years.

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.

	(dollars in thousands)		
	FY 2002	FY 2003	FY 2004

In FY 2004 these low energy facilities will carry out about 95 experiments involving over 360 U.S. and foreign researchers. Planned hours of operation with beam are indicated below:

	(hours of operation with beam)		
	FY 2002	FY 2003	FY 2004
ATLAS	5,485	4,050	6,500
HRIBF	4,250	2,600	3,780
88-Inch Cyclotron	4,480	3,850	0
Total Beam Hours for Low Energy Facilities	14,215	10,500	10,280

	(dollars in thousands)		
	FY 2002	FY 2003	FY 2004
▪ **Other Operations**	**0**	**0**	**150**
Funding is provided for maintenance of the Oak Ridge Electron Accelerator (ORELA) for criticality measurements supported by DOE/NNSA.	0	0	150
Total, Low Energy Nuclear Physics	**62,769**	**66,158**	**69,289**

Explanation of Funding Changes

	FY 2004 vs. FY 2003 ($000)
Research	
▪ **University Research**	
▸ FY 2004 funding for researchers and students is increased by 6.8% ($1,074,000) from FY 2003. Priority will be given to supporting non-accelerator research activities such as SNO and KamLAND. Additional support is provided for operating university accelerator facilities and utilizing national user facilities. Funding for capital equipment decreases by $353,000 compared to FY 2003 as projects are completed.	+721
▪ **National Laboratory Research**	
▸ **National User Facilities Research:** FY 2004 funding provides about constant funding of +0.6% ($90,000) for research efforts and activities at the user facilities while capital equipment funds are reduced by $200,000. Because of the proposed transfer in FY 2003 of $380,000 to the Theory subprogram from this funding category, the effective increase for research efforts is $450,000 (+3.4%).	-110

	FY 2004 vs. FY 2003 ($000)
▸ **Other National Laboratory Research**: Research funding increases about 2.6% ($134,000) in FY 2004 compared with FY 2003. Manpower and effort will be focused on the high priority non-accelerator research activities including SNO and KamLAND. Equipment funds are increased by $3,176,000 to address scientific opportunities identified in the NSAC 2002 Long Range Plan for Nuclear Science, such as the Fundamental Neutron Physics Beamline at the Spallation Neutron Source and the GRETINA gamma-ray tracking detector.	+3,310
Total, National Laboratory Research	+3,200
▪ **Other Research**	
▸ **SBIR and Other:** Estimated SBIR and other obligations increase.	+160
Total, Other Research	+160
Total Research	+4,081
Operations	
▪ In FY 2004 operating funds are increased by ~6.1% ($900,000) compared to FY 2003 for ATLAS and HRIBF operations to provide an estimated 10,280 hours of beam time. Funding for capital equipment and accelerator improvement projects at these facilities increases by $1,300,000 compared to FY 2003. Operations of the 88-Inch Cyclotron at LBNL is terminated with a reduction of $3,300,000 in operations and equipment costs.	-1,100
▪ Other operations are increased by $150,000 to provide maintenance of the Oak Ridge Electron Accelerator (ORELA) for criticality measurements supported by DOE/NNSA.	+150
Total Operations	-950
Total Funding Change, Low Energy Nuclear Physics	+3,131

Nuclear Theory

Mission Supporting Goals and Measures

Progress in nuclear physics, as in any science, depends critically on improvements in the theoretical techniques and on new insights that will lead to new models and theories that can be applied to interpret experimental data and predict new behavior. The Nuclear Theory subprogram supports research directed at understanding the five central questions identified in the NSAC 2002 Long Range Plan:

(1) *What is the structure of the nucleon?* Protons and neutrons are the basic components of all observable matter in the universe that are themselves made-up of lightweight, point-like particles, called quarks and gluons. The fundamental theory governing the dynamics of quarks and gluons is known as Quantum Chromodynamics (QCD). A key goal of modern theoretical nuclear physics is to comprehend the intricate structure and properties of the nucleon and ultimately nuclei, in terms of the interactions between the quarks, gluons and the extraordinarily complex vacuum.

(2) *What is the structure of nucleonic matter?* Nuclear theorists strive to understand the diverse structure and remarkable properties of the nucleus. With the possibility of obtaining new experimental results for unstable nuclei from studies with radioactive beams, theorists will be able to probe nuclei at limits of high excitation energy, deformation, and isotopic stability. Ultimately, this major frontier of research will permit the development a “comprehensive model” for nuclei that is applicable across the entire periodic table.

(3) *What are the properties of hot nuclear matter?* The properties of hot, dense nuclear matter, is the central topic of research at the new Relativistic Heavy Ion Collider (RHIC) facility. Lattice QCD theory predicts that the physical vacuum “melts” at extremely high temperatures and the underlying symmetries of QCD restored. Under these conditions, normal nuclear matter should transform into a plasma of nearly massless quarks and gluons – a new form of matter that is believed to have pervaded the primordial universe a few microseconds after the Big Bang. Theoretical research provides the framework for interpreting the experimental measurements for evidence of the quark-gluon plasma and other new phenomena. A key goal of the theoretical program is to establish knowledge of the QCD phase diagram of bulk nuclear matter.

(4) *What is the microphysics of the universe?* The theory subprogram attempts to understand the nuclear microphysics of the universe that involve fundamental nuclear physics processes, such as the origin of elements; the structure and cooling of neutron stars; the properties of neutrinos from the sun and the mechanism of core-collapse supernovae.

(5) *Is there new physics beyond the Standard Model?* The search for a single framework describing all known forces of nature – the so-called ‘Standard Model’ represents a formidable challenge. The current version of the Standard Model has been tested with impressive precision in experiments with atoms, in various nuclear experiments testing Standard Model symmetries, and in high-energy experiments. However, despite its successes, recent experimental observations of neutrino behavior and studies of fundamental symmetries present some conceptual difficulties that lead physicists to believe a more fundamental theory must exist.

The research of this program is conducted entirely by groups and individual researchers located at universities and DOE national laboratories. The researchers utilize the high performance computational facility at the National Energy Research Scientific Computing Center (NERSC) at the Lawrence Berkeley National Laboratory and other specialized computers at other institutions. This subprogram sponsors the national Institute for Nuclear Theory (INT), based at the University of Washington, in Seattle, Washington, where visiting scientists focus on key frontier areas in nuclear physics, including those crucial to the success of existing and future experimental facilities and the education of postdoctoral researchers and graduate students.

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 the RIKEN Center 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 the theory 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. Progress in Nuclear Theory is reviewed as a component in reviews of the three other major program components of the Nuclear Physics program.

The 2002 Long Range Plan highlights many significant theoretical advances in all of the five major frontiers of research in nuclear physics today. A few of the most recent accomplishments are:

- *Structural phase transitions in nuclei:* Nuclei are known to exhibit exotic shapes, but describing the detailed properties of nuclei in the phase-transition region has been a long standing challenge. An analytical model, called the X(5) symmetry, has been developed to predict the properties of various spherical nuclei that transform into a rugby-ball shape during a phase transition. This theory could also be applied to metallic clusters, molecules and polymers. Recently, experimenters have found ^{152}Sm co-exists as a spherical and rugby-ball nucleus; an observation that is in agreement with the X(5) symmetry model. This exciting confirmation could lead to a new direction in nuclear physics research when more exotic nuclei becoming readily available at radioactive beam facilities.
- *Left-handed nuclei:* Nuclear theorists have predicted that triaxial nuclei with odd numbers of both protons and neutrons could have handedness. In particular, observing the so-called chirality would provide solid evidence for stable triaxial shapes, while also establishing handedness as a new property of nuclei. Recently, experimenters and nuclear structure theorists using 3D tilted axis cranking calculations have found evidence for handedness in odd-odd nuclei in ^{55}Cs, ^{57}La, and ^{61}Pm, N = 75 isotones (same number of neutrons) of ^{134}Pr.
- *New Theoretical Tool Ties Together Many Different Phenomena:* A new comprehensive framework, called the Generalized Parton Distributions (GPD's) has been developed that allow for the first time, to describe and relate a large variety of complex high-energy electromagnetic reactions to the internal quark and gluon structure of the nucleon.
- *Indicators of quark-gluon plasma formation:* Theoretical calculations using a hydrodynamic model appear to be in excellent agreement with the first and second year RHIC data on "elliptic flow." When two heavy nuclei collide, the initial fireball created in the "little bang" has the shape of an almond or more precisely, the fireball is said to be elliptically deformed. The subsequent near light-speed explosion of this 'deformed' fireball results in an anisotropy of the final transverse momentum distribution of the emitted particles. This effect is called elliptic flow. It is remarkable that the majority of the data (low momentum particles) are seen to coincide with the upper limit of the hydrodynamical calculations. This unexpected agreement suggests that a significant thermal pressure existed on a time scale too short to be explained by conventional collision dynamics, but rather it

seems plausible that the early stage of the nuclear collision might implicate the appearance of a new phenomenon.

- *Origin of elements*: Spectacular core-collapse supernovae explosions represent the violent end of a massive star's life, and create and disperse many elements – but the explosion mechanism remains elusive. Theoretical nuclear astrophysics, coupled with results from a variety of nuclear physics measurements represents the foundation of an emerging generation of sophisticated, computationally intensive models of astrophysical phenomena. For example, nuclear theorists working on the DOE Scientific Discovery through Advanced Computing (SciDAC) program on simulations of exploding stars are continuing to make rapid progress on many fronts. Neutrino transport is now being utilized in one-dimensional (spherical) models of stars. Recent progress has also been made in calculating electron-capture rates crucial to the understanding stellar collapse. Multi-dimensional stellar models are now able to explore effects such as convention induced by neutrino heating. These new computational tools could also be applied to other fields of research.

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, to 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.

Subprogram Goal

Provide a theoretical program that supports the Medium Energy, Heavy Ion, and Low Energy strategic goals, by developing models, computational techniques, interpreting data, and finding new directions for profitable investigation; provide reliable nuclear data in formats that are useful for a wide range of activities in nuclear and astrophysics research, nuclear medicine, nuclear stockpile stewardship, national security and space exploration.

Performance Indicators

Validation of results by merit review with external peer evaluation.

Annual Performance Results and Targets

FY 2002 Results	FY 2003 Updated Targets	FY 2004 Targets
		Develop models, interpret data, and find new research directions relevant to the Nuclear Physics mission, and publish results. At the National Nuclear Data Center, complete database migration project, performing a generational step to a modern relational database management system.

Funding Schedule

	(dollars in thousands)				
	FY 2002	FY 2003	FY 2004	$ Change	% Change
Theory Research					
University Research	10,923	11,045	11,811	+766	+6.9%
National Laboratory Research	7,618	6,590	9,165	+2,575	+39.1%
Scientific Computing (SciDAC)*	2,000	2,000	2,000	0	0%
Subtotal Theory Research	20,541	19,635	22,976	+3,341	+17.0%
Nuclear Data Activities	4,788	5,010	5,162	+152	+3.0%
Total, Nuclear Theory	25,329	24,645	28,138	+3,493	+14.2%

*In FY 2002 funding for the NP portion of the SciDAC program was distributed between University ($854,200) and National Laboratory Research ($1,145,800).

Detailed Program Justification

	(dollars in thousands)		
	FY 2002	FY 2003	FY 2004
Theory Research	**20,541**	**19,635**	**22,976**
▪ **University Research**	**10,923**	**11,045**	**11,811**

The research of about 170 university scientists and 80 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. *Support increases by 4.7% from FY 2003, after accounting for shifts of $241,000 in grants from the Medium Energy and Low Energy subprograms.*

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**	**7,618**	**6,590**	**9,165**

Research programs are supported at six National Laboratories (ANL, BNL, LANL, LBNL, ORNL and TJNAF). *The increase in the request for Nuclear Theory in FY 2004 is in direct response to the recommendation in the 2002 Nuclear Science Advisory Committee Long Range Plan. These increased funds will be used to hire additional theorists to work on high priority topics and to expand computing. It is proposed that redirection of $2,155,000 to theory will be made in FY 2003 in order to respond effectively to this recommendation. When this is taken into account there is an effective 4.8% increase in funding in FY 2004 compared to FY 2003.*

	(dollars in thousands)	
FY 2002	FY 2003	FY 2004

- ▸ 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.

	FY 2002	FY 2003	FY 2004
▪ **Scientific Computing**	**2,000**	**2,000**	**2,000**

The Scientific Discovery through Advanced Computing (SciDAC) program is an Office of Science program to address major scientific challenges that require advances in scientific computing using terascale resources. An effort managed by the High Energy and Nuclear Physics (HENP) programs 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 FY 2001 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 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.

	FY 2002	FY 2003	FY 2004
Nuclear Data	**4,788**	**5,010**	**5,162**

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).

	FY 2002	FY 2003	FY 2004
Total, Nuclear Theory	**25,329**	**24,645**	**28,138**

Explanation of Funding Changes

	FY 2004 vs. FY 2003 ($000)
University Research	
▸ FY 2004 funding level is increased by 4.7% compared to FY 2003 once shifts of $241,000 in grants from the Medium Energy and Low Energy subprograms are taken into account. This provides increased funding for students and focused funding for priority research that was identified in the NSAC 2002 Long Range Plan for Nuclear Science.	+766
National Laboratory Research	
▸ FY 2004 funding level is increased by 4.8% compared to FY 2003, once proposed shifts of $2,155,000 in FY 2003 are accounted for. This addresses the need for enhanced theoretical efforts to interpret the results obtained at our new facilities. Such enhanced support was strongly recommended in the NSAC 2002 Long Range Plan for Nuclear Science.	+2,575
Nuclear Data	
▸ FY 2004 funding level is increased by 3.0% compared to FY 2003 to enhance efforts to effectively disseminate nuclear data needed for basic and applied research.	+152
Total Funding Change, Nuclear Theory	+3,493

Capital Operating Expenses & Construction Summary

Capital Operating Expenses

(dollars in thousands)

	FY 2002	FY 2003	FY 2004	$ Change	% Change
General Plant Projects	6,649	6,560	6,640	+80	+1.2%
Accelerator Improvement Projects	5,450	5,400	5,800	+400	+7.4%
Capital Equipment	29,617	30,220	27,727	-2,493	-8.2%
Total, Capital Operating Expenses	41,716	42,180	40,167	-2,013	-4.8%

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

(dollars in thousands)

	Total Estimated Cost (TEC)	Prior Year Approp-riations	FY 2002	FY 2003	FY 2004 Request	Accept-ance Date
STAR EM Calorimeter	8,600	4,997	3,300	303	0	FY 2003
STAR EM Calorimeter Enhancement	4,700	0	0	2,400	2,300	FY 2004
G0 Experiment Detector	3,965	3,906	59	0	0	FY 2002
GRETINA gamma-ray detector	15,000	0	0	0	1,000	TBD
Fundamental Neutron Physics Beamline	9,800	0	0	0	500	FY 2011
Total, Major Items of Equipment		8,903	3,359	2,703	3,800	