FERMILAB INSTITUTIONAL PLAN

2001

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Fermilab Institutional Plan

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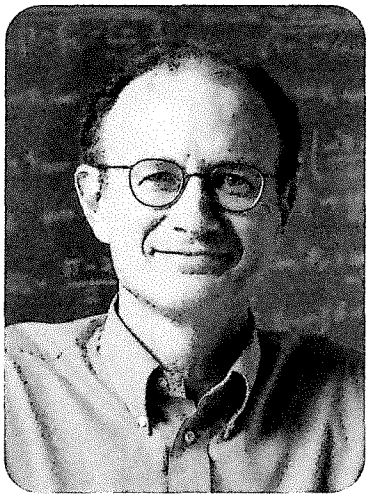
From the Director



Fermilab Director Michael S. Witherell

Fermilab research is exciting science, and it competes with research done in any field, anywhere in the world.

As America's largest high-energy physics facility, Fermilab's people and facilities represent an incalculably valuable asset to U.S. science. Thousands of physicists in the U.S. and abroad depend on our lab to carry on their research. The Fermilab program is addressing the most important issues in our field, with experiments that are among the best in the world.

With the beginning of Collider Run II in March, 2001, the Tevatron—the world's highest-energy particle accelerator—will embark upon what should be the best period in the collider's history. We might have the Higgs boson within our reach—postulated as the source of all mass.

With the addition of the new Main Injector, our upgraded accelerator complex will deliver 100 times the integrated luminosity (or total number of particle collisions) produced in the earlier incarnation that discovered the top quark in 1995. Our two massive detectors—CDF and DZero—are newly configured to recognize and collect collision data at unprecedented rates and volumes. New particles, supersymmetry, CP violation, precision measurements—we see a glowing horizon of new developments.

With the NUMI/MINOS long-baseline project and the on-site MiniBooNE experiment, we are building the world's best neutrino program. Neutrinos represent the clearest part of our immediate future. MINOS is pushing toward starting to see neutrinos in early 2003. And MiniBooNE, using the booster beam, is on a very fast track to start taking data in 2001. Neutrinos are hot, and we're going to know a lot more about them in five or six years than we know now.

And along with our exciting experimental prospects, we hope to build the next collider on the energy frontier here at Fermilab. Unlike 15 years ago in this country, there is not yet a clear consensus in the field on what that facility will be. We must play a leading role in research and development on accelerators for the future, to lead the way toward that future in our field.

Fermilab has a great past, a great present, and—with the talent, the industry and the good will of the people at our lab—a great future as a world leader in high-energy physics.

Michael S. Witherell
Director
Fermi National Accelerator Laboratory

Mission and Roles

I. Mission Statement

As is the case from its founding in 1968, Fermilab's mission is to advance the understanding of the fundamental nature of matter and energy, by providing leadership and resources for qualified researchers to conduct research at the frontiers of high-energy physics and related disciplines.

Fermilab leads the nation in the construction and operation of large facilities

II. Core competencies

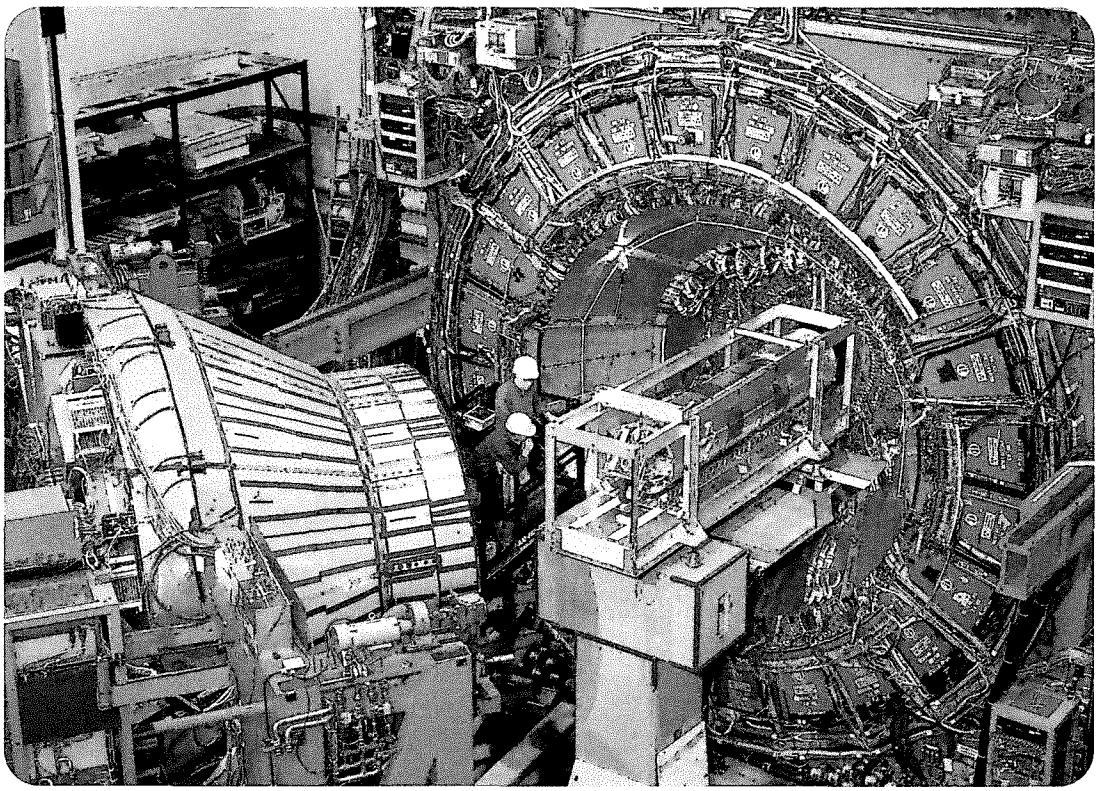
Fermilab leads the nation in the construction and operation of large facilities for particle physics research, and in developing the underlying technology for high-energy physics research. The Lab's mission is built on a foundation of eight core competencies:

1. Operation of the world's highest-energy user facility—the Tevatron collider— for university scientists investigating the fundamental structure of matter and energy;
2. Accelerator research, design and development of the frontier machines that are necessary to keep the U.S. among the world leaders in high energy physics;
3. Magnet research, design and development with particular emphasis and expertise extending to leading-edge technology in both superconducting magnets and permanent magnets;
4. Detector design and development for the tracking and recording of trillions of high energy particle collisions;
5. High performance computing and networking to support high-energy physics in on-line data taking, storage, analysis and world-wide data sharing and physics collaboration (the World Wide Web was born from this last requirement by physicists);
6. International scientific collaboration, both at Fermilab and as a contributor to foreign laboratories such as CERN, in particular in assisting in the construction of the Large Hadron Collider;
7. Construction and management of large scientific and technical projects, including the seven-year, $260 million Main Injector accelerator, completed on time and on budget;
8. Scientific education of graduate students, and additional science education programs for undergraduates and for K-12 students, with major support from non-DOE sources

III. Major User facilities

Fermilab, the world's highest-energy particle physics facility, welcomes more than 2,700 users (defined as "qualified researchers") from 224 institutions in 38 states and 23 foreign countries. These users have access to the world's best tools for particle physics research:

- The Tevatron, the world's most powerful particle accelerator, creating high energy proton-antiproton collisions and proton beams for fixed-target experiments, where the Bottom Quark was discovered in 1977 and the Top Quark was discovered in 1995;
- The Main Injector, another powerful and efficient accelerator which can supply experiments on its own, as well as dramatically increase the number of collisions possible in the Tevatron;
- The Antiproton Recycler, the world's largest use of permanent magnet technology, which also increases the number of possible collisions in the Tevatron by recovering antiprotons that would previously have been discarded;
- The Antiproton Source, the world's largest producer of antimatter, used for proton-antiproton collisions and research on antimatter;
- Two 5,000-ton collider detectors, CDF and D Zero, each serving as an international collaboration of nearly 0500 university physicists;
- Fixed-target experiments, including the MINOS (Main Injector Neutrino Oscillation Search) and MiniBooNE experiments now being built to resolve the question of neutrinos mass.



Technicians align the Silicon Vertex detector for installation at CDF, one of the two collider detectors each serving international collaborations of nearly 600 physicists.

Scientific Vision and Strategic Plan

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I. Collider Run II of the Tevatron at higher energy and luminosity will pave the way for new discoveries: Higgs particles, Supersymmetry signals, matter-antimatter anomalies

Scientists envision breakthroughs into new physics beyond the Standard Model of Elementary Particles

In Collider Run II of the Tevatron, Fermilab sees the promise of discoveries at or beyond the scale of discovering the top quark at in 1995, which made headlines around the world.

With the $260 million Main Injector and Antiproton Recycler, and some $110 million in upgrades for the CDF and DZero detectors, Fermilab has essentially transformed itself into a much more powerful physics facility. Scientists envision breakthroughs into new physics beyond the Standard Model of Elementary Particles, with the Main Injector enabling increased luminosity levels at the Tevatron (at least 20 times the rate of proton-antiproton collisions as in Run I); and with improved data-handling and tracking capabilities at the CDF and DZero detectors (at least 20 times the data generated in Run I). The greater the number of collisions, the greater the chances for new discoveries; the greater the data-handling and detector sophistication, the greater the ability to record those discoveries and analyze them in exquisite detail.

When it begins operating sometime around 2006, the Large Hadron Collider at CERN, the European particle physics laboratory in Geneva, Switzerland will pre-empt Fermilab as the world's highest-energy particle physics laboratory. But Fermilab will occupy the frontier of high-energy physics for much of this decade, contemplating the ultimate challenge–finding the Higgs boson with a collider that wasn't designed to find it. The most-wanted yet undiscovered particle, the Higgs is crucial to the theoretical framework of the Standard Model. It is the key element of the mechanism that gives mass to quarks and leptons, and to the W and Z bosons. And it is essential in deriving a consistent, meaningful quantum field theory, for which Gerardus t'Hooft and Martinus Veltman received the 1999 Nobel Prize.

Nobel laureate and Fermilab Director Emeritus Leon Lederman has dubbed the Higgs boson the "God Particle," acknowledging its all-pervasive presence and ability to impart mass to particles. At Fermilab, a 75-member working group drawn from the Theoretical Physics Department and from the CDF and DZero detectors spent a year studying the question of whether the Tevatron is capable of discovering the Higgs. The group's conclusion: current measurements of top quark mass and other Standard Model parameters predict a fairly light Higgs, probably lighter than the top itself. If the number of collisions in the Tevatron can be nudged just beyond the Main Injector's capabilities, finding the Higgs during Collider Run IIb is not outside the realm of possibility.

The first part of the collider run (Run IIa) is projected as a two-year excursion into the realm of new physics. It will also serve as a test run for the new configuration of Fermilab's accelerator complex, and a measurement of the experimental reach with the increased luminosity at the Tevatron. Discoveries in new physics could serve as an open-ended invitation for an extended Run IIa. Additional upgrades to further increase the Tevatron's luminosity during the continuing experimental run, leading to the start of Run IIb in 2004, could take this scientific expedition into even more exciting new territory:

New b physics: This area could be the most fertile for discoveries in physics beyond the Standard Model. The bottom quark (b) is the next heaviest quark after the top. As the world's highest-energy particle accelerator, the proton-antiproton collisions of the Tevatron allow for b physics research in realms inaccessible to the lower-energy "B-factories" (which manufacture B-mesons, bound b quark states, using electron-positron machines). In particular, the Tevatron can produce the heavy Bs meson. It is thus uniquely suited to investigate instances of CP violation (anomalies between matter and antimatter) related to the b. If present hints for CP violation in the b sector get confirmed and more aspects are investigated, it is far from certain whether the Standard Model will be able to accurately describe the observed phenomena.

New particle discoveries: Increasing the Tevatron's luminosity also increases the possibility of creating higher-energy collisions that could produce particles heavier than the top, opening the door to Supersymmetry. The many different models within the Supersymmetry (SUSY) framework all propose that every particle in the Standard Model has one or two superpartner particles, which are much heavier and have a different spin. If Supersymmetry evolves as the correct way to extend the Standard Model, opening the door to what could become a Grand Unified Theory of particle interactions, there are many particles waiting to be discovered–possibly during Run II, if their masses are within reach of the Tevatron.

The Main Injector (foreground), two miles in circumference, will greatly enhance the discovery potential of the four-mile Tevatron (background) during Collider Run II.

More top quarks: Producing thousands of top quarks, instead of just a hundred or so, means achieving a new level of detail in studying the most massive elementary particle known to physicists. More precise measurements of the top and of the W boson (one of the force-carriers in the Standard Model) might point the way toward the discovery of the Higgs.

Even if the Tevatron does not produce direct evidence of the Higgs, results from Run II could point the way and show LHC experimenters where to look. But observing the Higgs at the Tevatron would be a great discovery for particle physics everywhere, and a triumph for Fermilab.

The Main Injector Neutrino Oscillation Search collaboration will chronicle the journey of an accelerator-driver neutrino beam traveling through nearly 450 miles of rock between Fermilab in Batavia, Illinois and a former iron mine a half-mile underground in Soudan, Minnesota.

II. MiniBooNE and MINOS will discover the truth behind nature's most elusive particles, studying the neutrinos' role in the evolution of the universe

Do neutrinos have mass? Does a fourth flavor, the sterile neutrino, exist? What is the neutrino's role in the evolution of the universe.

Neutrino experiments at Fermilab provide the chance of answering these and other surprising questions on neutrinos and their properties, which increasingly command our attention. The MiniBooNE experiment, scheduled to take data in 2002, and the MINOS experiment, starting at the end of 2003, will help to resolve conflicting experimental findings of the past and provide the means to expand our knowledge of neutrinos at an unprecedented level.

Neutrinos and the universe

Neutrinos are strange little particles that were originally observed in the decay of radioactive elements. Neutrinos are everywhere, and they are plentiful. The subject of scientific measurements for half a century, they were assumed to be massless until recently–and if they do have mass, their ubiquity could alter our view of the very makeup of the universe and how it holds together. Recent results suggest that neutrinos could make up several percent of the entire mass of the universe—enough to play an important part in its evolution immediately after the Big Bang. They are still all around us, the relics of that distant past, with 300 neutrinos per cubic centimeter everywhere in the universe. In contrast to the cosmic microwave background, another relic of the early universe, scientists are not yet able to directly measure the cosmic neutrino background.

In addition to this neutrino background, we are constantly bombarded by neutrinos from extraterrestrial sources: from the sun, from cosmic ray interactions in the atmosphere, from distant supernovae, from violent astrophysical events. Worldwide, many experiments aim at measuring these neutrinos and studying their sources. Because of their extremely weak interaction, neutrinos offer a new window on the outer edges of the universe. They are messengers from realms which do not send us light in a direct and observable fashion: the interior of the sun, the center of our galaxy, and possibly, objects not yet discovered by conventional telescopes. Neutrinos may even contribute to the unseen dark mass in our universe.

But studying neutrinos represents a challenge: they are uncharged and antisocial. They rarely interact with other members of the subatomic world. Billions can pass through the earth leaving barely a trace. Only by producing billion billions of neutrinos using proton accelerators are we able to capture a few of them and study their properties.

Neutrinos (so far) come in three varieties, or flavors: electron, muon and tau. In 1956, Fred Reines and Clyde Cowan observed the first neutrino interactions. Then in 1962, Leon Lederman, Mel Schwartz and Jack Steinberger discovered that muon neutrinos are different from electron neutrinos. Both discoveries produced Nobel prizes. In July 2000, the DONUT collaboration at Fermilab announced the first evidence for the direct observation of tau neutrinos.

If neutrinos have mass, they undergo transformations from one flavor to another ("neutrino oscillations") as they travel through space. A variety of present and future experiments aim at studying oscillation and related phenomena.

To maximize the chances of observing neutrino interactions, physicists have designed some of their biggest experiments. Japan's Super-Kamiokande experiment uses a 50,000-ton detector filled with 12.5 million gallons of ultra-clean water. The detector is lined with 13,000 photomultiplier tubes so sensitive to light that they can detect a single photon. The Super K experimenters have been collecting data for several years, and their results—including hints at an "atmospheric neutrino anomaly"—are so far the strongest evidence that neutrinos have mass. As impressive as Super-Kamiokande's data are, however, there is still a long way to go to demonstrate conclusively that the elusive particles oscillate, and hence have mass. Physicists agree that only accelerator experiments can precisely measure the masses and mixings of neutrinos.

The Soudan mine in Minnesota houses experimental apparatus for both the Main Injector Neutrino Oscillation Search and the Cryogenic Dark Matter Search.

Fermilab's neutrino experiments

At Fermilab, the MiniBooNE experiment will be the first to gain worldwide attention as physicists will unambiguously confirm or deny the existence of the neutrino oscillation signal seen by the Liquid Scintillating Neutrino Detector at Los Alamos. In combination with other neutrino data, the LSND results cannot be explained by Standard Model interactions. A new kind of neutrino, dubbed the sterile neutrino, could explain those data. MiniBooNE will show whether an extension of the Standard Model is necessary. If this is the case, experimenters plan to upgrade their detector to study the new phenomenon in more detail.

In October, 2003, the MINOS (Main Injector Neutrino Oscillation Search) experiment at Fermilab will send its first beam of neutrinos speeding through the earth to a detector 730 km away at the bottom of a mine a half-mile below the surface in Soudan, Minnesota, attempting to resolve the question of whether neutrinos have mass. MINOS is a major component of the NuMI (Neutrinos at the Main Injector) Project. Fermilab's Physics Advisory Committee has stated that the $136.5 million NuMI/MINOS project should be "pursued with high priority . . . second only to Run II." Construction of the NuMI tunnels, needed to create the intense neutrino beam for the MINOS experiment, started in April 2000.

Beginning with a precisely measured neutrino beam makeup, and capable of generating large numbers of events, the NuMI/MINOS project can produce definitive and extended results.

Atmospheric neutrino experiments, like Super-K, have a major limitation: They measure the disappearance of muon neutrinos, and a reduction in the number of neutrino interactions, but give no indication of where, or as what, the missing neutrinos ended up. Proof of oscillation would lie in showing that one neutrino type changes into another as function of neutrino energy and distance from the original neutrino source. Future experiments, like MINOS, are designed to look for the appearance of neutrino flavors not present in the original neutrino beam. Specifically, the MINOS experiment starts with a virtually unadulterated beam of muon neutrinos and determines whether tau neutrinos appear down the line–incontrovertible proof that neutrinos have oscillated.

NuMI's neutrino beam will travel 730 kilometers (about 438 miles) on an underground path between Fermilab's new Main Injector accelerator and an 8,000-ton detector in a mineshaft at Soudan, Minnesota. The long baseline gives neutrinos the time and space they need to oscillate, or change identities. MINOS will cash in on the capabilities of Fermilab's new Main Injector to deliver an intense beam of protons in rapid pulses. The intensity and repetition at the Main Injector are major improvements over its predecessor accelerator, the Main Ring, an important factor given the rarity of sighting neutrino interactions.

If neutrino experiments are seeing oscillations, scientists believe that at least one flavor of neutrino has a finite mass, and neutrinos with different masses must mix to form the electron, muon and tau neutrinos. How neutrinos mix has immediate bearing on large and unresolved questions in particle physics: whether quarks and leptons are distinct families of fundamental particles, or are instead related in ways suggested by a grand unified theory; why there are three generations of particles instead of two or four; and why neutrino masses—if they are non-zero—are over a billion times smaller than their charged partners, the electron, muon and tau leptons.

The MiniBooNE experiment will be the first to gain worldwide attention

III. Non-particle-physics experiments

Mapping the sky

Fermilab has special capabilities to mine the growing convergence between particle physics and astrophysics. The Particle Physics Division's Astrophysics Group has a track record of making a big impact with modest resources.

Sloan Digital Sky Survey, the most ambitious astronomical survey project ever undertaken

Fermilab is responsible for overall project management and for data handling of the Sloan Digital Sky Survey, the most ambitious astronomical survey project ever undertaken. During its five-year mission, the survey will map in detail one-quarter of the entire sky, determining the positions and absolute brightnesses of more than 100 million celestial objects. It will also measure the distances to more than a million galaxies and quasars.

The SDSS with its Apache Point Observatory in New Mexico addresses fascinating, fundamental questions about the universe. With the survey, astronomers will be able to see the large-scale patterns of galactic sheets and voids in the universe. Scientists have varying ideas about the evolution of the universe, and different patterns of large-scale structure point to different theories of how the universe evolved. The Sloan Digital Sky Survey will tell us which theories are right—or whether we have to come up with entirely new ideas.

The Sloan Digital Sky Survey has already observed three of the four most distant quasars ever recorded. Analysis of data covering 225 square degrees indicates that the unseen dark matter "halos" that surround galaxies are about twice as large as had been previously believed. And data suggest that our Milky Way galaxy may have engaged in "galactic cannibalism." SDSS astronomers have found evidence that our galaxy's halo contains huge clumps of stars that appear to be the remains of smaller galaxies assimilated by the Milky Way more than a billion years ago.

Understanding highest-energy cosmic rays

Fermilab is also project manager for the Pierre Auger Observatory, an international collaboration building an array of detectors to track and analyze high-energy cosmic rays that, though extremely rare, exhibit energy levels 100 million times higher than the Tevatron.

Physicists of the Pierre Auger project study the masses of ionizing radiation that are constantly striking the earth. Due to high occurrence, low-energy cosmic rays have become relatively well understood in the 80 years since their discovery. However, cosmic rays at higher energies are much rarer and poorly studied.

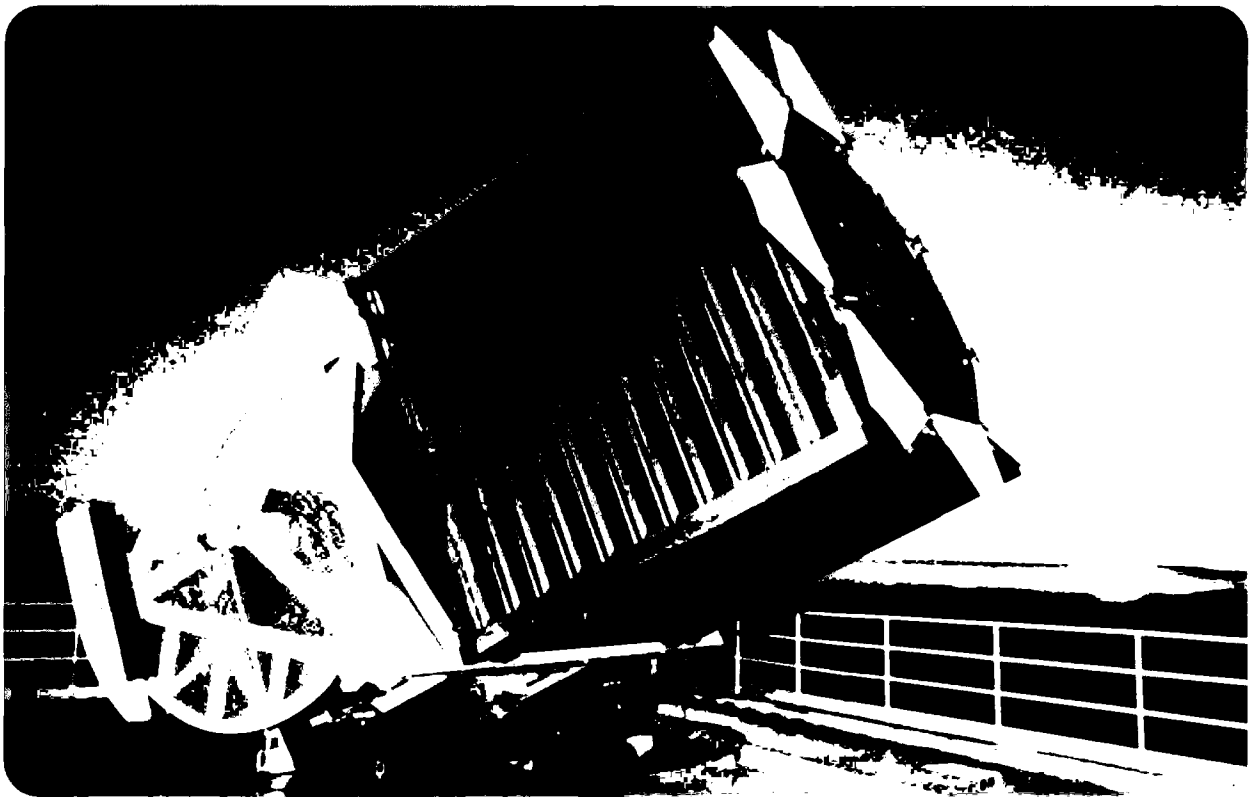
Two giant detector arrays, each covering 3000 square kilometers, will be constructed in the Northern and Southern Hemispheres. Each will consist of 1600 particle detectors and an atmospheric fluorescence detector. The objective of the arrays is to measure the arrival direction, energy, and mass composition of cosmic ray air showers above 10^{19} eV. Primary cosmic rays can never be directly observed: They must be researched instead through the properties of the air showers that they cause in our upper atmosphere.

The search for dark matter

The Cryogenic Dark Matter Search (CDMS) is looking for dark matter in the form of Weakly Interacting Massive Particles, or WIMPS. These hypothetical particles could account for the invisible mass, observed indirectly by its influence on the formation and motion of galaxies and other heavenly objects. Assuming that WIMPS were in thermal equilibrium with the very early universe, one can calculate the abundance of these particles left in the universe today. If these particles are to provide the mass necessary to close the universe, their mass should be in the range 10 GeV to 10 TeV. (The proton mass is 1 GeV.)

The CDMS experiment aims at identifying WIMPS using a low background cryogenic detector. A large Germanium crystal is cooled down to about 20mK. A dark matter particle interacting with a nucleus in the crystal will produce both heat and ionization. The crystal is outfitted with NTD thermistors to measure the temperature elevation, and with charge collection pads. Signal redundancy is used to reject background, which would produce a different heat/ionization ratio. A special low background cryostat (called Ice Box) has been designed to host the detectors.

The experiment's first stage is located at Stanford's Underground Facility. This shallow site has the advantage of being close to lab facilities, which will make improvements to the system easier. The second stage of the experiment will be carried out at the Soudan mine in Minnesota.



The Sloan Digital Sky Survey uses the Apache Point, New Mexico observatory for its effort to map the large-scale structure of one-fourth of the sky in three dimensions.

Major Program Initiative

I. Making the Most of the Tevatron: Collider Run IIb

Fermilab must put a strong emphasis on achieving the highest achievable integrated luminosity during Run II

Though its reality remains unconfirmed, the tantalizing prospect of a Higgs boson spotlights the importance of Run II. With indirect experimental indications of a light mass for the Higgs boson holding firm, and with even the faintest of hints of the Higgs at the Large Electron Positron at CERN, a successful Collider Run II at the energy frontier must remain Fermilab's highest priority.

The Tevatron collider will resume operation in March 2001 adding the increased capabilities of the new Main Injector. The detectors have been upgraded to operate at instantaneous luminosities of 2 x 10^{32} cm^{-2} sec^{-1}, an increase from the earlier run of over a factor of ten. The laboratory's goal for Run IIa is to deliver 2 fb-1 to each detector. This goal should be reached in several years of operation, at which time the capabilities of the detectors will begin to deteriorate due to radiation damage to the inner layers of silicon trackers.

Continued progress toward revolutionary new physics will require further increases in the collider luminosity, along with upgrades to the detectors to accommodate these increases. The lab has adopted what it regards as a realistic goal for this subsequent Run IIb of the collider: achieving an integrated luminosity of 15 fb^{-1} over the full Run II. Fermilab must develop the accelerator upgrades necessary for Run IIb to maximize the collider luminosity, before the LHC experiments begin running.

Every increment of integrated luminosity increases the likelihood of thrilling discoveries in the Tevatron Run II program.

Run IIb Detectors

The CDF and DZero collaborations have begun developing plans for replacing radiation-damaged silicon detectors, and for other upgrades to ensure effective operation during the higher luminosity Tevatron Run IIb. Careful planning and implementation of the detector upgrades, and close coordination with accelerator upgrade projects, will be essential for success. The new detector components must be designed with the confidence that they will operate effectively throughout Run IIb, with anticipated integrated luminosity of at least 15 fb-1. Installation of all detector upgrades must occur during a single shutdown of no more than six months' duration, with roll-out and roll-in tentatively scheduled between October, 2003 and March, 2004.

The Run IIb Accelerator Complex

To exploit the unique physics window that is open before 2006, the Tevatron must deliver as many high-energy particle collisions as possible. The integrated luminosity goal of 15 fb^{-1} per experiment reaches into the region of revolutionary new physics. Any substantial increase beyond this goal significantly increases the physics discovery reach.

Fermilab must put a strong emphasis on achieving the highest achievable integrated luminosity during Run II. The Beams Division has developed ambitious plans and concepts for increasing Run II luminosity far above levels previously attained. These include improvements in antiproton production, antiproton collection efficiency, and beam cooling in the Recycler, among other promisingl ideas.

II. CP Violation in the B system: A Dedicated Program of Physics of the Bottom Quark at the Tevatron

On February 5, 1999, after more than a year of painstaking analysis of data collected from particle collisions at the Tevatron, CDF scientists cautiously reported finding "tantalizing," but not "ironclad," evidence of CP violation in B mesons (quark-antiquark pairs involving the b or bottom quark)—the first observation outside the neutral kaon system.

Fermilab has been the historic leader in the physics of the bottom quark—in fact, the lab inaugurated the field with the 1977 discovery of the b quark, or upsilon particle. Nearly a quarter-century later, much of the buzz in particle physics comes from B's and B-bars—B mesons and anti-B mesons. Experiments in B physics promise dramatic new insights into the enigmatic asymmetry between matter and antimatter.

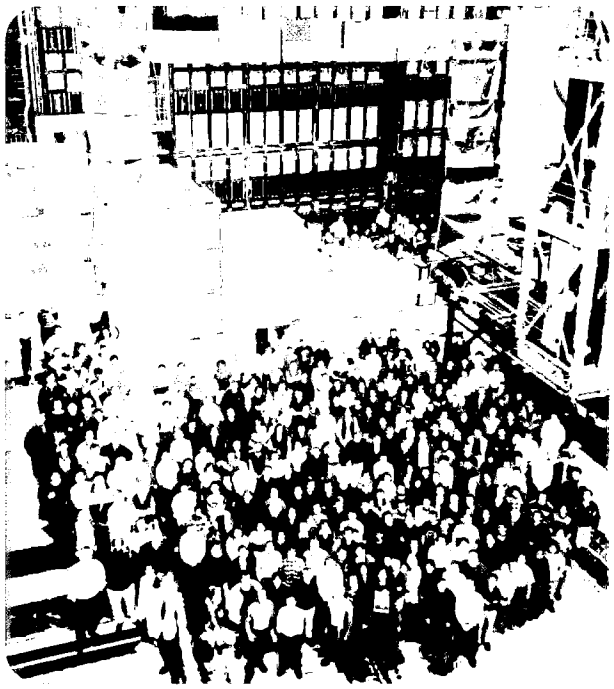
Now Fermilab proposes to initiate an ambitious experimental program to extend the study of CP violation in the B system, using B and Bs mesons in a new detector at the CZero intersection region of the Tevatron Collider. The BTeV experiment has the potential to make the measurements that will not be completed by the programs currently underway. BteV can be the definitive experiment that finally clarifies the picture of CP violation.

The main goals of BTeV are:

- tests of the Standard Model and searches for new physics through the precise measurement of CP asymmetries with B and B_s decay modes that have minimal theoretical uncertainty;
- measurement of rare B and B_s decays to search for effects of new physics;
- measurement of a broad range of B_s decays that become accessible with the particle identifiation and photon measurement capabilities of the BTeV detector.

We know much more about B_d meson decays than about the B_s meson, largely because of a long program of high-statistics B_d measurements, at the °(4S) and the Z resonances, at SLAC and CERN.

BTeV will be a central part of an excellent Fermilab physics program in the era of the LHC. Impressed by the science potential and by the elegant and challenging detector design, the laboratory granted Stage I approval for BTeV after receiving a positive recommendation at the June 2000 meeting of its Physics Advisory Committee.



The DZero collaboration at Fermilab numbers nearly 600 scientists, symbolizing both the complexity and the international nature of particle physics experiments.

Discovering asymmetries

James Cronin and Val Fitch led experimenters into the new realm of CP violation in 1964 with their discovery of asymmetries in the neutral kaon system (kaons are mesons containing strange quarks). Andrei Sakharov showed in 1967 that CP violation was necessary to explain the preponderance of matter over anti-matter in the universe.

But CP asymmetries in the neutral kaon system did not pin down the origin of the effect. They were interpreted as individual occurrences of interference between complex amplitudes that arise in neutral kaon mixing. In 1972, Makoto Kobayashi and Toshihide Maskawa pointed out that, with three quark generations, CP violation could arise in the standard model as a consequence of a single, CP-violating phase in what is now called the Cabibbo-Kobayashi-Maskawa quark-mixing matrix. Although neutral kaon decays have produced important progress in CP violation studies (notably in the measurement of direct CP violation in $K \rightarrow \pi+ \pi-$ decays), these measurements have not determined whether CP violation originates entirely within the Standard Model framework of the CKM matrix; or in CP-violating phases introduced by new physics outside this framework.

The Standard Model CKM framework predicts very large CP asymmetries (on the order of unity) in some B and B_s decays, and the confirmation of CP violation in the B system may well occur within the next year. This would start a new era in our understanding of CP violation, possibly leading us to and new physics beyond the Standard Model.

The parameters describing CP violation include the magnitudes and phases of weak-interaction couplings of quarks and the magnitudes and phases of the loop diagrams that contribute to meson mixing amplitudes. The contributions from new physics potentially affect both the magnitudes and the phases of the mixing amplitudes. Only when the full set of parameters is accurately measured can we be convinced either that the CKM model completely describes CP violation or that all the possible non-standard sources of CP violation have been probed.

The origin of CP violation is one of the fundamental questions in high-energy physics. A tremendous effort to measure precisely the basic parameters of CP violation has begun at the e+e- B-factory experiments (BaBar, Belle, and CLEO) and at hadron experiments (CDF, DZero, HERA-B). There should be results over the next five years. But these experiments won't produce a complete and comprehensive set of measurements in the B_d and B_s systems. New experiments will be needed at the end of this decade to provide crucial pieces of information. One of those experiments is BteV.

The BTeV Initiative

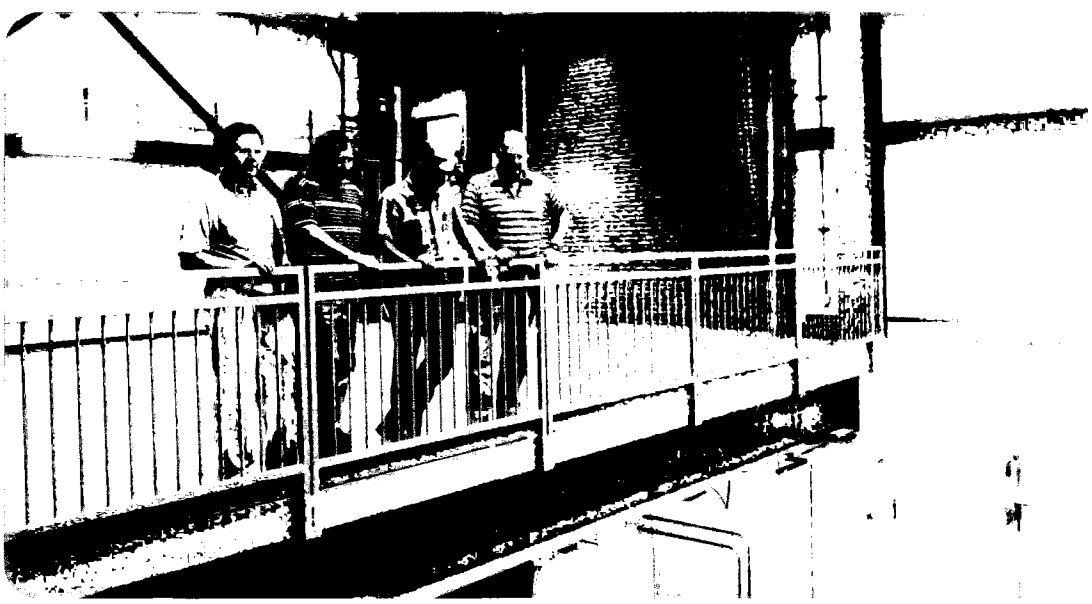
Noting the crowded current roster of B experiments, the laboratory and its advisory committee set the bar high for approval of BTeV: it had to be competitive with all these experiments and superior to each of them in some key measurement. BTeV cleared the bar.

The collaboration designing BTeV has proposed a very powerful detector. Its pixel-based tracker, detached-vertex Level 1 trigger, RICH particle identification system, and lead tungstate electromagnetic calorimeter make it capable of measuring the full suite of CP violation parameters in the B system. BTeV's physics reach exceeds that of all other experiments in many of the important measurements. The BTeV collaboration has done excellent work in developing advanced technologies needed to make the experiment possible, and in deploying the simulation and analysis tools needed to make its physics case.

The BTeV experiment will exploit the enormous proton-antiproton cross section (100 μb) at the Tevatron, which yields $2x10^{11}$ proton-antiproton events per year. The existing Tevatron experiments, CDF and DZero, have significant capabilities for B physics, notably from silicon microstrip detectors and new, detached vertex triggers. But the BTeV detector is optimized for B physics rather than for the study of high-Pt events. It has sophisticated particle ID and photon-detection capabilities, as well as a pixel-based vertex detector/trigger system with pixels extending down to 6 mm from the beam axis. It is designed to record 1 kHz of b-bbar events and 1 kHz of $c\text{-}c_{bar}$ events, with a 4 kHz total event rate. BTeV's capabilities should give it a significantly greater B physics reach than either CDF or DZero.

While the experiments at the e+e B factories have some advantages for B_d studies, including very clean and kinematically constrained events, B_s mesons are not produced at the °(4S), and any B_s physics program at such experiments would be quite limited. In addition, the large rate of B_d production at the Tevatron, together with the capabilities of the BTeV detector, should allow it to perform measurements of B_d decays that are completely inaccessible or very difficult at the B factories.

Note: *Cost estimates for the BTeV project are based upon conceptual designs and a detailed work breakdown structure. These estimates include funding for the detector, data acquisition electronics, computing for offline analysis, equipment for the interaction region and experimental facilities. These estimates total about $190M in then year dollars and anticipate construction funds in FY2004 through FY2007.*



Looking over the new CZero assembly hall are (from left) Peter Garbincius, Tom Lackowski, Ron Foutch and Paul Lahn, all instrumental in constructing the facility. The new assembly hall will help diversify future experiments at the Tevatron.

III. Accelerator R&D: Reclaiming the post-LHC energy frontier is the challenge of the future

Fermilab and the U.S. high-energy physics community will be full partners in the international success when the first collisions are recorded at the LHC

Fermilab has a $167-million stake in the high-energy frontier that the Large Hadron Collider will establish at CERN. With oversight responsibility for both the US/CMS Detector Project and the US/LHC Accelerator Project, Fermilab and the U.S. high-energy physics community will be full partners in the international success when the first collisions are recorded at the LHC. That day will also begin a new era, with the Tevatron surpassed as the world's highest-energy particle accelerator—yet remaining a vital world-class experimental facility.

Fermilab has two goals for the LHC era:

1. To provide forefront facilities for the U.S. high energy physics program;
2. To achieve an eventual return to the energy frontier.

Pursuing these two goals means striving to share resources for accelerator research and development, simultaneously with the all-out effort to produce the most significant results possible from Run II of the Tevatron. Pursuing these two goals represents a challenge to our priorities and our funding.

Fermilab is currently involved in research and development on three concepts for a frontier facility beyond LHC—a second-generation electron-positron linear collider, a first-generation muon storage ring, and a fifth-generation hadron collider—all within the context of national collaborations.

Hadrons and higher energies

Hadrons are particles composed of more fundamental constituents called "partons." Protons, neutrons and their antiparticles are all hadrons; their constituent partons are the quarks, antiquarks, and gluons.

In the four-mile circumference Tevatron, currently the world's largest hadron collider, counter-circulating bunches of protons and antiprotons are tightly focused and brought into collision in two massive detectors located in the accelerator ring. Scientists observe the collision energy as it produces different forms of matter ($E=mc^2$), or use it to probe the shortest distances separating the particles—distances as small as 10^{-17} cm, or about 1/10,000 the size of a proton. As the energy of the hadron collider increases, the increased energy of the parton-parton collisions allows scientists to see deeper into inner space, in a process analogous to using increasingly powerful microscopes. The LHC, under construction at CERN, is 16 miles (27 km) in circumference, and will reach an energy level seven times that of the Tevatron when it begins operations around 2006.

The greater the energy produced in the collider accelerator, the greater the mass of the particles that may be produced. The Tevatron's pre-eminence as the world's highest-energy particle accelerator led directly to the 1995 discovery of the top quark, which is 185 times more massive than a proton. Physicists anticipate that higher energy and more intense beams will allow the discovery of particles such as the Higgs boson and supersymmetric particles. The LHC will allow more massive

particles to be produced, and particles such as the top quark can be created in much greater numbers.

But taking the next step beyond LHC means building bigger accelerators with higher energies. Cornell University, Brookhaven National Laboratory and Lawrence Berkeley National Laboratory are collaborating with Fermilab in exploring concepts and technologies for a Very Large Hadron Collider (VLHC). The VLHC would reach a center of mass energy of roughly 100 TeV (50 times the current energy of the Tevatron's trillion electron volts, and 7 times the energy of the LHC), with a luminosity of 10^{34} $cm^{-2}sec^{-1}$, or 100 times the number of collisions that the Tevatron currently produces.

Muons, neutrinos, and precision measurements

Neutrinos are produced through the decays of heavier particles: neutrons, pions and muons. Because of the weakness of their interactions with matter, very intense sources are required to do meaningful experiments. Current sources of neutrinos are nuclear reactors and secondary beams produced by targeting high-energy protons.

A much more intense source could be formed by using a muon storage ring. R&D aimed at the development of technologies that could enable the construction of such a novel device has begun. A longer-term potential payoff for this research is the development of the technology needed for a very-high-energy muon collider based on the knowledge gained from pursuing a muon storage ring.

Along with Brookhaven, Lawrence Berkeley Lab and significant participation from universities, Fermilab is pursuing muon storage ring R&D within the context of a national collaboration. The performance goal for a neutrino source based on a muon storage ring (also known as a "neutrino factory") is to produce at least 10^{20} decays per year from muons at 20-50 GeV.

While it would fit comfortably within Fermilab's existing site, a neutrino factory presents major challenges in design. Muons have a short lifetime (2.2 microseconds at rest) during which they have to be collected into a beam and accelerated. The lifetime is too short for existing stochastic and/or electron cooling systems to be effective, or for a conventional synchrotron to accelerate the beams. Novel ideas based on ionization cooling, and high-gradient, wide-aperture accelerating cavities are being pursued to overcome these issues.

Fermilab is building half of the final focusing high-gradient quadrupole magnets for the the Large Hadron Collider at CERN, the European Particle Physics Laboratory in Geneva, Switzerland. Here, Paul Mayer of the Engineering and Fabrication department in Fermilab's Technical Division works on the coils for an LHC quadrupole.

The linear collider

The concept of a linear collider is being developed by a number of laboratories throughout the world. A linear collider achieves collisions between electrons and positrons by accelerating these particles in two linear accelerators aimed at each other. The physics studied is very similar to that of hadron colliders, but the technique is complementary. The electron is a fundamental particle, not a composite particle like the proton, making certain aspects of the study of high energy phenomena more accessible to this sort of facility. The performance goal for a linear collider would be a center-of-mass energy of 500-1500 GeV with a luminosity of 10^{34} $cm^{-2}sec^{-1}$.

The Stanford Linear Accelerator Center has taken the lead within the U.S. on the development of this technology. SLAC has built and operated the first and only linear collider ever constructed, and is pursuing a second-generation design. Fermilab has joined in the U.S. collaboration on Next Linear Collider (NLC) R&D that is led by SLAC with LBNL and LLNL as the other collaborators. The critical design issues for the linear collider are the creation of high accelerating gradients and the control of beams measuring tens of nanometers across. Similar efforts are being undertaken in Japan (with a similar technology) and in Germany.

Charting the course

Looking ahead at the future of Fermilab and the U.S. high-energy physics program, our planning should grow from a set of realistic priorities and an understanding of the critical role of accelerator R&D. Making the discoveries of tomorrow requires:

- Building a new generation of accelerators and detectors;
- Undertaking the research and development needed for new and cheaper tools;
- A sustained effort over many years to develop the technology for a frontier facility.

We begin by establishing our physics goals, then letting those physics goals determine our programmatic goals, while keeping a close eye on the technology involved. These goals then translate into accelerator R&D goals, while maintaining flexibility and working within the context of a coherent national and international program.

Our challenges will lie in balancing the competing demands of these opportunities; balancing these opportunities relative to our ongoing experiments and experimental goals; and balancing our resources to allow planning for the future while maximizing our scientific results from our new and upgraded accelerator components. Our strength will lie not only in our scientific knowledge, but also in the well-developed system of big-project management that allowed us to bring in the Main Injector on time and on budget.

Our wisdom will lie in letting our discoveries tell us which way to go, and in recognizing that the discoveries of tomorrow require R&D today.

Operations and Infrastructure

01 06

Strategic Facilities Plan: Infrastructure management to meet 21st century needs

Fermilab is preparing to become the model for infrastructure management within the SC laboratory complex, ensuring that this laboratory continues as an efficient and effective world-class scientific research facility well into the 21st Century.

While much of Fermilab's infrastructure has reached, or is nearing, the end of its original design life, infrastructure management initiatives over the past few years have significantly moved the lab toward achieving the objectives for the Laboratory Complex recently published by the Office of Science. Most significant are the ongoing use of third party investments, through partnerships with Fermilab's gas and electric utilities; and the Wilson Hall Safety Improvements Project.

These newly published objectives set guidelines for improvements and modernization, and recognize infrastructure management as critical to sustaining the SC laboratory complex. The Fermilab Strategic Facilities Plan (SFP) was developed to identify the needed framework and actions in these areas of infrastructure management:

Mission: Making facilities precisely meet the type and quality of space and equipment requirements for the lab's mission, including shared activities, minimization of leased space and adaptability to changing research requirements.

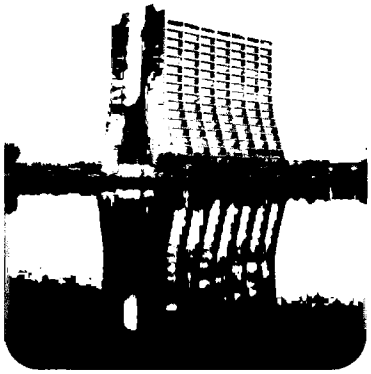
Working Environment: Creating a "preferred" working environment to attract and retain high quality staff and users, by including the latest advances in information technology.

Environment, Safety, Health and Security: Satisfying all necessary ES&H and Security elements for workers, visitors and neighbors.

Operations and Maintenance: Funding, operating and maintaining all infrastructure—including facilities, roads, utilities and equipment—from a life-cycle asset management standpoint.

The SFP considers infrastructure issues, such as inventory and condition assessment; and the Office of Science paramaters for modernization, within the context of Fermilab's mission. It then identifies the projects needed to meet the objectives, and the resources needed for the projects. Finally, the plan outlines lab management's efforts to implement a capital allocation and prioritization process, and identifies change indicators for performance measurement.

The following table summarizes the $60.3 million in project requirements for continuing this effort:



Wilson Hall, Fermilab's headquarters building, was inspired by the design of a Gothic cathedral in Beauvais, France.

Project Requirements

FY	FY '02	FY '03	FY '04	FY '05	FY '06	FY '07	FY '08	FY '09	FY '10
$M	15.1	6.42	5.05	9.69	8.0	7.62	1.57	4.34	2.58

Environment, Safety and Health

Safety: The emphasis continues, and the record continues to improve.

With a continuing emphasis on safety, Fermilab surpassed its goal for the 1998 lost workday case rate.

Fermilab surpassed its goal for the 1998 lost workday case rate.

The goal set for 1998 was less than 2.1 lost workday cases per 100 man-years; the final figure was 1.98 per 100 man-years. The Lab's goal for 1999 was to reduce the rate to 1.6, or not more than 34 lost-time injuries for the yearæa reduction of 20 percent. We had 27 lost workday cases in 1999 (20 were employees and 7 were subcontractors). We achieved a lost workday case rate of 1.2.

The lost workday case rate measures the number of injuries that are serious enough to cause someone to lose a day of work, or to return to work with duties that are limited in some way. The laboratory-wide score over the previous three years averaged about 3.0, meaning that the 1998 statistics show a significant and welcome drop.

In addition, the lost workday case rate statistics include both Fermilab personnel and contractorsæboth service contractors and construction contractorsæindicating that the message has spread to all activities over the entire site, through stepped-up communication and stepped-up oversight.

For the year 2000, the Lab's goal is to halve the rate, to 0.8æor a total of just 17 lost-time injuries.

The active leadership of top-level management, and the tailoring of the training sessions to individual work sites, underscored the message of Integrated Safety Management: that safety is inseparable from doing the best work and turning out the best product. Making safety an everyday issue is as important as the everyday issues of quality and planning.

Implementing a Fermilab-specific ISM

The laboratory's contract with the Department of Energy stipulated the development of an Integrated Safety Management Plan. A Department of Energy verification team visited Fermilab in October, 1999 and Fermilab passed the review. The team verified that we have adequately implemented ISM principles.

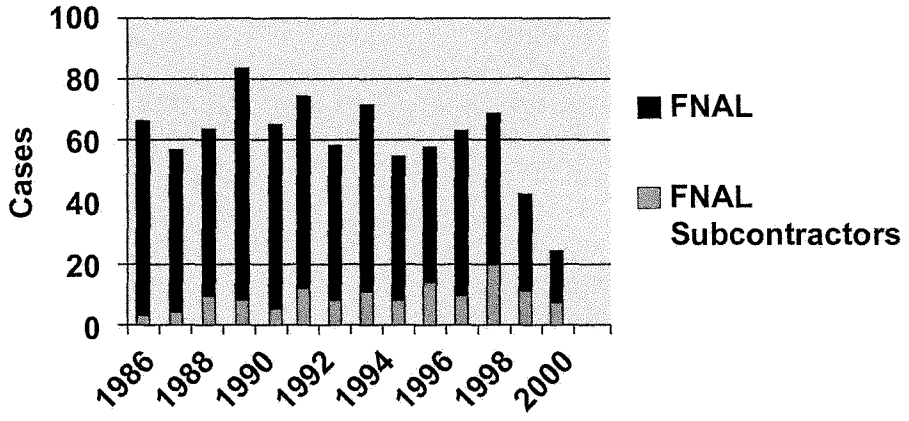
Dedication to waste minimization

The laboratory's Environmental Protection Subcommittee and the ES&H section are formulating procedures for peer reviews in an award system based on merit, in apportioning funds earmarked for highly effective waste minimization efforts ranging from low-mercury lamps to refurbished 10-foot magnets, from packaging waste to chemical waste, from environmental clean-up to pollution prevention.

Lost Work Day Cases

	FNAL Subcontractors	FNAL	Total
1986	3	63	66
1987	4	53	57
1988	9	55	64
1989	8	76	84
1990	5	60	65
1991	12	63	75
1992	8	51	59
1993	11	61	72
1994	8	47	55
1995	14	44	58
1996	9	54	63
1997	20	49	69
1998	11	32	43
1999	7	17	24
2000		**Goal: <17**	**Goal: <17**

Lost Workday Cases



FERMILAB LIBRARY

Communication and Trust

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06

Fermilab Community Outreach Issues and Initiatives

"Focus Group": Fermilab's first-ever community public opinion survey, to determine current local community knowledge of and attitudes toward Fermilab

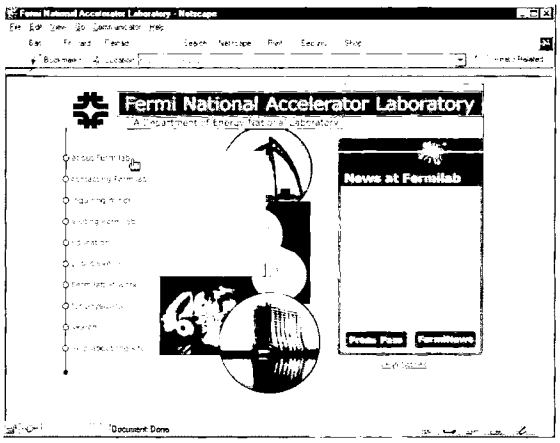
The proposed northern extension of Eola Road by DuPage County continues to have a high profile in the community and in local media. Fermilab and the Department of Energy have made clear that they would be highly unlikely to approve a road along the eastern boundary of the laboratory, because such a road would jeopardize Fermilab's ability to attract and build future accelerators at the site. Fermilab and DOE have said that, if the community decides a north-south route is needed, they would consider allowing the widening of Kirk Road along Fermilab's western boundary, because such a route would have the least impact on our present and future scientific program. However, DuPage County continues to press for an east-side route.

As called for in the NuMI Communication Plan, the Fermilab Office of Public Affairs and NuMI Project staff has had extensive interaction with community groups and local media before and during blasting for the project. Public Affairs and NuMI project staff met with neighborhood associations, federal, state and local officials, city councils, the Kane County Board, the press and others to explain the project, to let residents know what to expect from the blasting phase of the project and to answer questions. The Public Affairs staff and project management followed up promptly and vigorously on all questions, concerns and complaints related to NuMI blasting.

The Fermilab Future Accelerators Siting Committee has an active subcommittee on Communication and Community Outreach, which is examining and reporting on community relations issues associated with future facilities that might be built at Fermilab. In connection with the Committee's work, the Public Opinion Laboratory of Northern Illinois University has recently completed the first, "focus group," phase of Fermilab's first-ever community public opinion survey, to determine current local community knowledge of and attitudes toward Fermilab. The survey is being funded by a grant from the State of Illinois.

The Fermilab Office of Public Affairs has contracted with the Chicago firm Xeno Media for a complete overhaul of the "public" pages of the Fermilab World Wide Web site. The new Web site will be unrolled early in 2001.

The Office of Public Affairs has launched a number of recent collaborative efforts with employees and users, to leverage available laboratory resources for community outreach. An ongoing series of "mini Open Houses" has brought members of the public to CDF, DZero and NuMI/MINOS for Saturday experiment tours led by collaborating scientists. On Sunday, September 2, "Ask a Scientist" began its program: each Sunday from 1:00 to 3:00 p.m., two volunteer Fermilab scientists are available in the public areas of Wilson Hall to talk with visitors about the laboratory and the science that they do. So far, both scientists and visitors are enthusiastic in their responses.



Fermilab launched a new website design on March 1, 2001 to coincide with the start of Collider Run II of the Tevatron.

In the fall of 2000, Fermilab will collaborate with Rick Borchelt and Bill Valdez of the Office of Science in hosting a workshop to define metrics and benchmarking for successful lab public affairs activities in the national laboratory context. Our hope is to generate a short white paper outlining desirable outcomes for public affairs (media, community, government) and reasonable measures of success in meeting those outcomes. It is our intention that this white paper become a document that can inform goals-setting and contract language for management of the DOE national laboratories, and help bring order to the current patchwork of expectations for each laboratory. It could also provide a sound basis for effective peer review of public affairs operations at the labs. Fermilab plans to use the results of the workshop in a pilot peer review (open to interested Public Affairs staff of other labs as observers) of the laboratory Public Affairs effort.

Students in the QuarkNet program coordinated by Fermilab's Education Office represent one of many educational and outreach efforts that have always been integral to the mission of the laboratory.

Tight market, tight budget: Challenges in recruiting and retaining employees

Some of our advertising money has been spent on image-building, enhancing the view of our laboratory as the scene of exciting challenges for technical professionals

We are the world's leading high-energy physics research institution, but we are also part of the U.S. job market—which is experiencing it lowest unemployment rates in decades. We are thus buyers in a sellers' market, facing strong competition for anyone we wish to hire as well as for the many people we wish to keep—and doing it with limited budget resources.

As The New York Times has reported ("Technology Boom Too Tempting for Many Government Scientists," Sept. 18, 2000):

"The lure of the private sector and its many start-up companies is so strong that national research laboratories are losing their best and brightest in growing numbers. Senior scientists...can go to private companies and increase their salaries by 50 percent. Add a lucrative stock-option package and the appeal can be irresistible."

Our first obvious hurdle is trying to compete on salaries. With this tight labor market, the salaries for engineers and computer professionals are escalating each year. Often when we make an offer, our candidate also has another three to five offers. We have none of the bargaining chips that private industry can offer such as bonuses or stock options. Our tight budget exacerbates this drawback. In some cases, the Fermilab Section or Division simply cannot afford to pay what the competition is offering for vital but hard-to-find talent.

A second all-too-obvious hurdle: Our total benefits package is now average, not outstanding, as it once was in comparison to private industry. This consistently puts us "one-down" when competing with high-tech industries which are constantly improving their own benefits packages. Meanwhile, we are striving to maintain the competitive level of our benefits package, at a time when most of private industry is looking to increase its own benefits packages to gain a competitive edge and become more attractive for potential hirees. Some examples: We are seeking initiatives to address the two-year waiting period our employees face for vestiture in the retirement plan; to make our relocation benefits more competitive; and to make career paths more clearly defined, so that potential candidates can see the possibilities for future promotions.

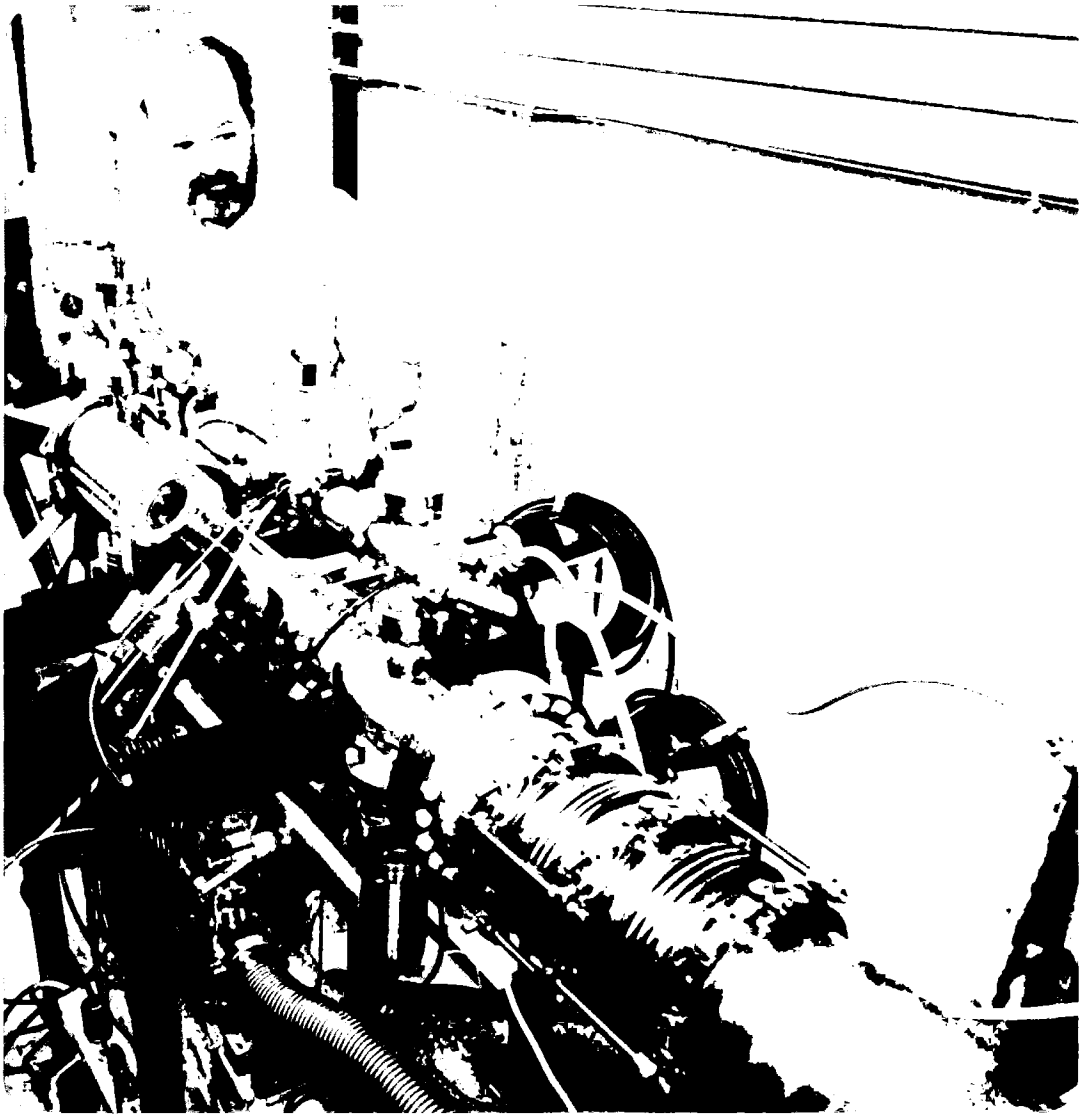
In the past, we have faced a less-obvious hurdle in the unavailability of H - 1B visas. Often the only candidates available to us are foreign nationals, either because of their unique skills or because the economic factors leaving us at a competitive disadvantage. Getting visas allowing these foreign nationals to work for us often posed a hurdle.

Now, however, we look forward to working under new conditions, thanks to the new law passed by Congress giving research labs no limit on H-1 visas for the next three years.

Finally, image represents a hidden yet highly significant hurdle. While scientists perceive the Lab as a world-class research institution, computer professionals, engineers and technicians often view the Lab as an unknown quantity. We often lose out in recruiting to household name companies seen as being on the cutting edge—yet we occupy the high-energy physics frontier. Some of our advertising money has been spent on image-building, enhancing the view of our laboratory as the scene of exciting challenges for technical professionals. We've increased our

attendance at job fairs. We are planning an "open house" recruiting event for engineers and computer professionals. We have considered having some of our engineers represent us on college campuses to give guest lectures and other presentations. Extending our creativity in recruiting methods, we also use Internet advertising, and we will soon announce a pilot employee referral program that has been approved by DOE.

Competition is fierce for people with in-demand skills, and especially for diversity candidates. While we have some successes, we find they are immediately followed by more challenges.



Physicist Jim MacLachlan with electron cooling development at Lab G. Skills in technology are always in demand at Fermilab.

Laboratory Mission Profile

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Laboratory Information

Name:
Fermi National Accelerator Laboratory

Location:
Batavia, IL

No. of Full-Time Employees: 2,186 (407 PhDs/1 JD - 415 BS/MS)

Contractor:
Universities Research Assoc., Inc.

Accountable Program Office: High Energy and Nuclear Physics

Field Office:
Chicago Operations Office

Web Site:
http://www.fnal.gov

Funding Sources:
Office of Science (FY99 - $282 M)

Description

Fermilab was founded in 1967 as a truly national laboratory to lead the nation in the exploration of the fundamental nature of matter, using high-energy proton beams to probe subatomic structure at the smallest scale. Today, Fermilab operates the Tevatron, the world's first superconducting syn-chrotron creating proton-antiproton collisions with the highest energy of all the "high-energy" physics labs in the world. It is the nation's largest and most active user facility in particle physics, with 2,700 scientific users from 38 states and 23 countries. Fermilab's mission remains what it has been from its founding: to advance the understanding of the fundamental nature of matter and energy by pro-viding leadership and resources for qualified researchers to conduct research at the frontiers of high-energy physics and related disciplines.

Distinctive Competencies and Major Facilities

Fermilab leads the nation in the construction and operation of large facilities for particle physics research, and in the underlying technology for high-energy physics research.

Capabilities include:

1. Operation of the world's highest-energy user facility for research by university scientists into the fundamental structure of matter;
2. Accelerator research, design and development of the frontier machines that are necessary to keep the U.S. among world leaders in high-energy physics;
3. Magnet research, design and development with particular emphasis on and expertise in leading-edge superconducting magnet technology;
4. Detector design and development for the detection and recording of trillions of high-energy particle collisions;
5. High-performance computing and networking to support high-energy physics in online data-taking, storage, analysis and world-wide data sharing and physics collaboration. (The World Wide Web was born from this last requirement.);
6. International scientific collaboration, both at Fermilab and as a contributor to foreign laboratories such as CERN;
7. Construction and management of large scientific and technical projects, including the $230M Main Injector accelerator, now being completed on time and on budget;

8. Scientific education of graduate students; and additional science education programs for undergraduates and K-12.

Major user facilities

1. The Tevatron, the world's most powerful particle accelerator, creating high-energy proton-antiproton collisions and proton beams.
2. The Antiproton Source, the largest supply of antimatter in the world, used for proton-antiproton collisions and research on antimatter.
3. Two large collider detectors, CDF and DZero. Each serves an international collaboration of nearly 500 university physicists.
4. Fixed-target experiments, including the NuMI project, now under construction, to explore the question of neutrino mass.

Fermilab was founded in 1967 as a truly national laboratory to lead the nation in the exploration of the fundamental nature of matter

Founding director Robert Wilson (left) and chairman Glenn T. Seaborg of the Atomic Energy Commission celebrate the 1968 groundbreaking for the National Accelerator Laboratory, renamed for Enrico Fermi in 1974.

Fermilab provides the capability for the U.S. to remain a world leader at the frontiers of the science of particle physics

Key Research and Development Activities

Science and Technology

Fermilab provides the capability for the U.S. to remain a world leader at the frontiers of the science of particle physics. Together with Stanford Linear Accelerator Center, Fermilab provides U.S. scientists with the accelerators; detectors, computing and support facilities they need to carry out research at the forefront of high-energy physics.

Key R&D activities include:

- Experimental particle physics research into the fundamental structure of matter;
- Accelerator physics research, to conceive, design and build the physics research tools of the future;
- Particle physics theory;
- Experimental and theoretical particle astrophysics, to exploit the convergence of particle physics and cosmology;
- Science education, to train the next generation of particle physicists and to increase the nation's science literacy.

Significant Accomplishments

Discoveries made at Fermilab in the three decades of its operation have played a significant role in characterizing the current understanding of the fundamental structure and nature of matter.

- Energy Frontier: In 2000, Fermilab provided 2,281 university scientists from 34 states (plus the Commonwealth of Puerto Rico) and 25 countries with the opportunity to work at the high-energy frontier, the Tevatron particle accelerator. Of Fermilab users, roughly half are funded by DOE, one tenth by the National Science Foundation, and the remainder by foreign funding sources.
- Tau neutrino: On July 21, 2000 scientists of Fermilab's DONUT collaboration announced the first direct evidence for the tau neutrino, the third kind of neutrino known to particle physics.
- CP violation: In February 1999, Fermilab scientists announced the observation of the first signs of matter-antimatter asymmetry in the physics of subatomic particles called b quarks.
- Beam to Main Injector: In November 1998, Fermilab first accelerated beam in the new Main Injector accelerator: This $230 million construction project was completed on time and under budget.
- Time Reversal Symmetry Violation: In October 1998, Fermilab scientists announced the direct observation of time reversal symmetry violation in rare kaon decays.
- Discovery of B_c Meson: In March 1998, Fermilab scientists announced the discovery of the last of the mesons, the B_c, a combination of bottom and charm quarks.
- W Boson Measurements: Throughout the 1990's, Fermilab collider and fixed-target experiments have produced the world's best measurements of the W boson, the particle that carries the weak force.
- Top Quark Discovery: In March, 1995, Fermilab scientists announced the discovery of the top quark, the last of the fundamental building blocks of matter in the Standard Model.
- Science Education: In September 1992, Fermilab dedicated the Lederman Science Education Center to house its award-winning education program.

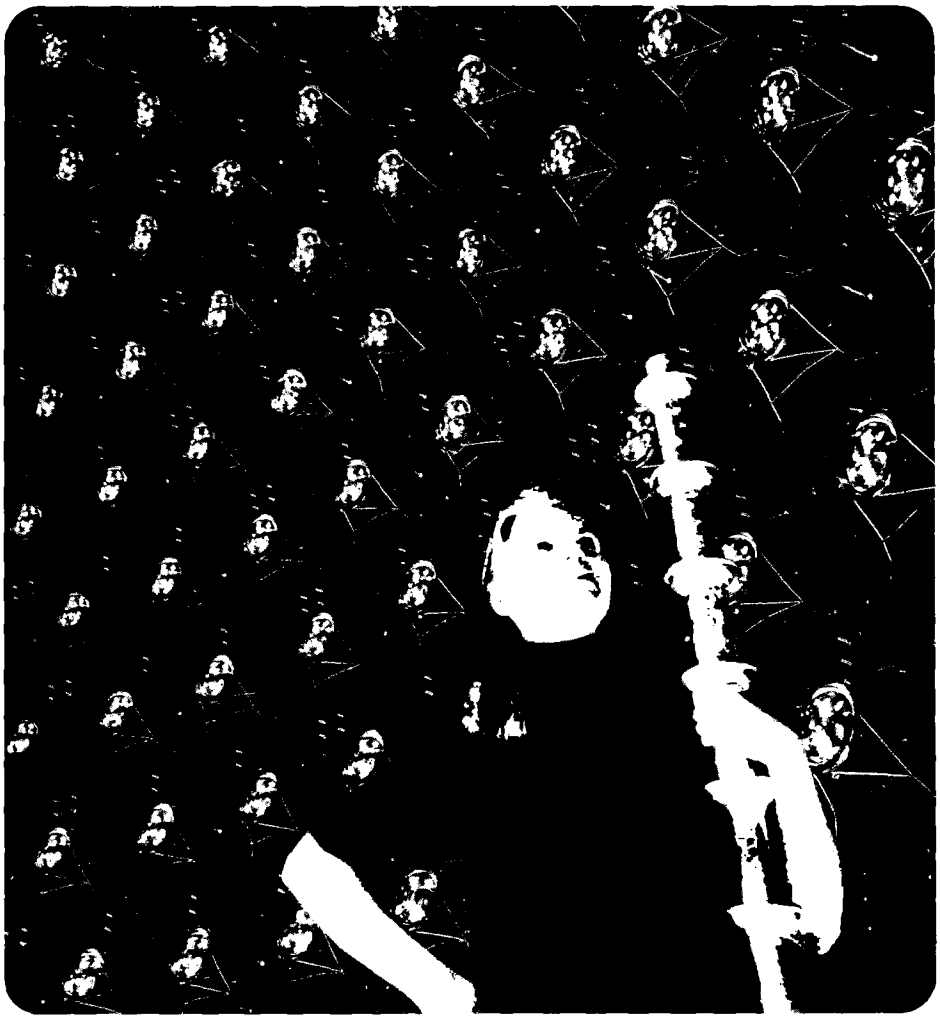
■ Proton-Antiproton Collisions: In 1985, Fermilab scientists observed the first proton-antiproton collisions at 1.6 TeV center-of-mass energy in the Tevatron.

■ Quantum Chromodynamics: In the 1970's, Fermilab experiments provided some of the first evidence for the theory that describes the strong force that acts between particles in the atom's nucleus.

■ Bottom Quark Discovery: The third generation of quarks was born at Fermilab with the discovery of the bottom quark in June 1977.

■ Beam Energy Doubled: On December 14, 1972, the energy of the Main Ring proton beam reached 400 GeV.

■ Proton Beam: On March 1, 1972, Fermilab first accelerated 200 GeV protons through the original accelerator, the Main Ring.



Janet Conrad of Columbia University hopes the MiniBooNE experiment will soon add neutrino discoveries to the long list of Fermilab research milestones.

Major Partnerships, Collaborations, and Cooperative Research and Development Agreements

Partnerships and collaborations with university scientists are the essence of Fermilab's reason for being.

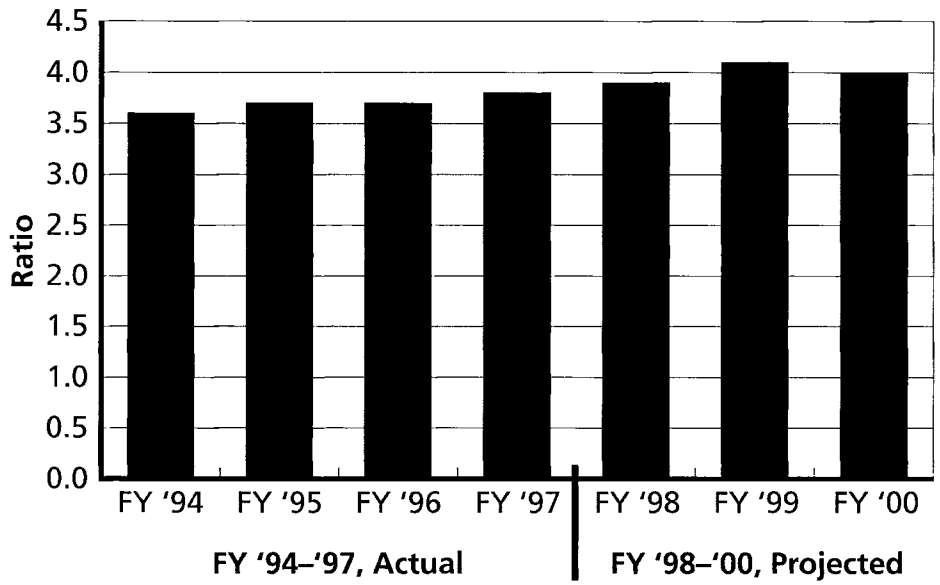
Category/Mission: Science and Technology

Partner	Description
Universities	Fermilab is operated by Universities Research Association, Inc., a consortium of 90 research universities in the U.S., Canada, Europe and Japan. In 1998, 112 U.S. universities in 38 states and 112 foreign universities in 23 countries sent users to Fermilab. Fermilab collaborates with four universities in the Sloan Digital Sky Survey, an astrophysics collaboration. Fermilab collaborates with universities from 18 countries in the Pierre Auger Project, studying cosmic rays.
DOE Laboratories And Facilities	Fermilab users include scientists from Argonne National Laboratory, Brookhaven National Laboratory, Lawrence Berkeley National Laboratory, Los Alamos National Laboratory, and Lawrence Livermore National Laboratory.
International	Of Fermilab's 2,717 users, 1,014 come from 112 institutions in 23 foreign countries. Fermilab is playing a leading role in the U.S. effort for the Large Hadron Collider at CERN, both for the LHC accelerator and for the Compact Muon Solenoid (CMS), one of the two major detectors. Fermilab is a member of the Pierre Auger Project, a cosmic ray collaboration with membership from 18 countries. The Sloan Digital Sky Survey, the MINOS collaboration and the Cold Dark Matter Search are all international collaborations.

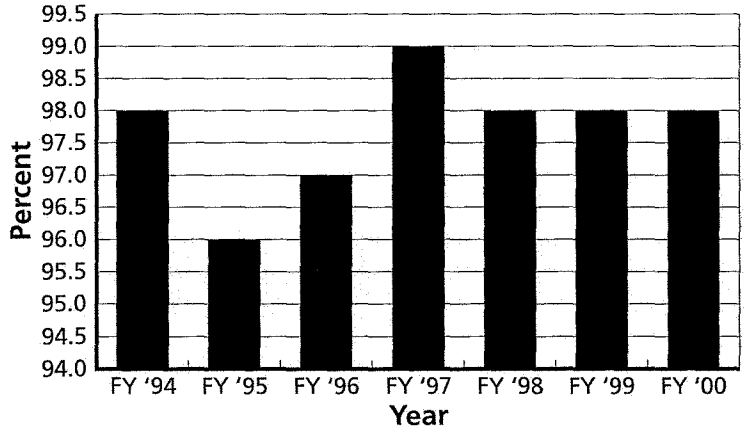
Performance Metrics

	FY '94–'97 Actual:				FY '98–'00 Projected:		
Reasearch-to-Support	**FY '94**	**FY '95**	**FY '96**	**FY '97**	**FY '98**	**FY '99**	**FY '00**
Ratio	3.6	3.7	3.7	3.8	3.9	4.1	4
Percent of Technical Labor on Research							
Percent	98	96	97	99	98	98	98
Average Cost per Reasearch FTE							
Thousand $	125	120	121	135	131	135	139
Constant FY 94$	125	116	114	123	116	116	116

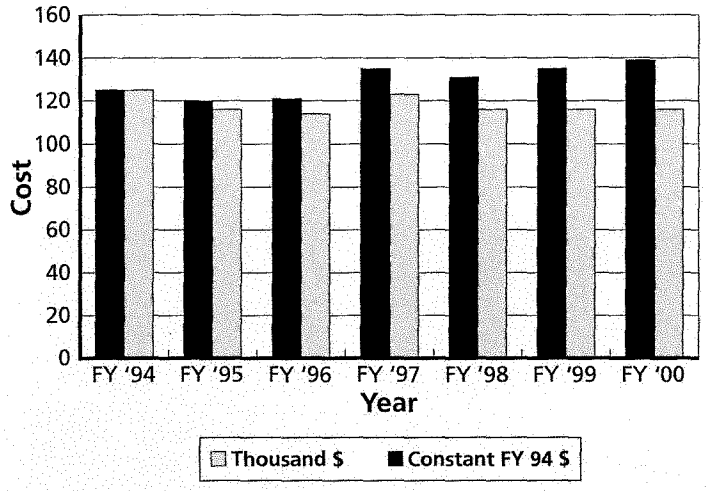
Research to Support FY



Percent of Technical Labor on Research



Average Cost per Research FTE



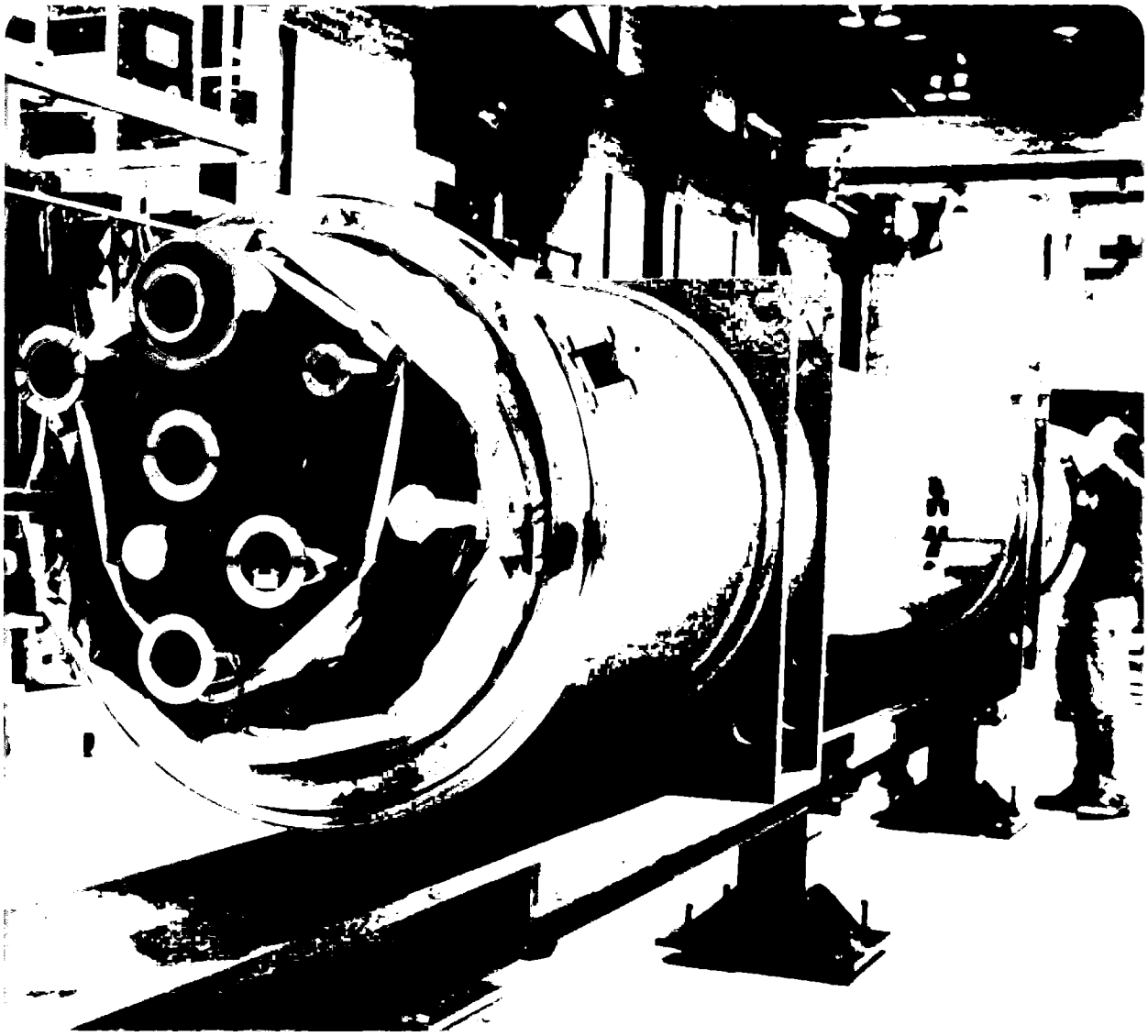
Performance Assessment Results

Category	FY '94	FY '95	FY '96	FY '97	FY '98	FY '99	FY '00
Science and Technology	outstanding	outstanding	outstanding	outstanding	outstanding	outstanding	outstanding
Industrial Competitiveness	outstanding	outstanding	gd-excl	NA	NA	NA	NA
Environmental Quality	outstanding	excellent	excellent	excellent	excellent	NA	NA
Communication and Trust	excellent	excellent	excellent	outstanding	outstanding	outstanding	NA
Human Resources	excellent	excellent	excellent	outstanding	excellent	good	outstanding
ES&H	gd-excl	outstanding	outstanding	good	excellent	excellent	excellent
Management Practices	excellent	excellent	excellent	outstanding	excellent	NA	NA
Financial Management				good	outstanding		
Overall	excl-out	outstanding	excl-out		excellent		

Funding by Activity

Use millions of dollars, rounded to one decimal place

	FY '96	FY '97	FY '98	FY '99	FY '00
R&D and Operations	177.1	191.8	184.4	211.5	208.4
Construction	52	52	41.5	28.4	38.2
Capital	35.2	29	56.1	50.2	56.5
Non-DOE Funds					
External Performers					
Total	264.3	272.8	282	290.1	303.1



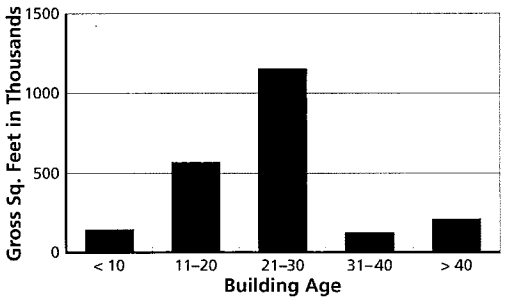
Q2P1, also known as "Jessica," is a full-scale prototype of the advanced superconducting quadrupole magnets being built at Fermilab for the Large Hadron Collider at CERN. Superconducting magnet technology represents a vibrant research and development effort at Fermilab.

Resource Projections

Age of Laboratory Buildings

Building Age	Gross Sq. Ft. in Thousands
<10	143.5
11-20	569.442
21-30	1153.606
31-40	123.754
>40	210.075
Total	2200.447

Age of Laboratory Buildings



Use of Laboratory Space

(All space judged "adequate")

Space	Sq. Ft.
Office	612,562
H. Lab	274,193
L. Lab	677,201
Misc.	214,867
Computer	89,833
Shop	109,981
Storage	221,810
Total	2,200,447

Use of Laboratory Space

(in sq. ft)

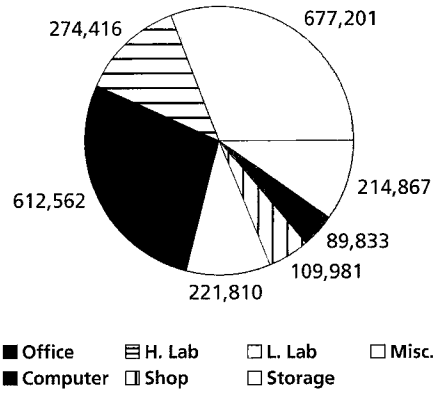


Table 2. Laboratory Funding Summary ($ in Millions)

	FY98	FY99	FY00	FY01	FY02	FY03	FY04	FY05
DOE Effort								
Fermilab	177.2	195.8	211.7	213.1	243.2	262.3	273.6	292.0
LHC	4.1	11.5	6.7	11.5	12.1	11.6	10.3	2.9
Work for Others	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0
Total Operating	181.5	207.5	218.6	224.6	255.3	273.9	283.9	294.9
Capital Equipment								
Program Capital Equipment	35.8	35.4	30.0	27.2	31.0	31.6	32.3	33.0
LHC Capital Equipment	11.6	25.6	11.2	12.7	11.6	12.1	8.1	3.4
Subtotal	47.4	31.0	41.2	39.9	42.6	43.7	40.4	36.4
Program Construction								
Main Injector	31.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NuMI	5.5	14.3	22.0	23.0	11.4	0.0	0.0	0.0
Wilson Hall Safety Project	0.0	6.7	4.7	4.2	0.0	0.0	0.0	0.0
CZero Experimental Hall	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AIP/GPP	8.7	7.4	8.4	7.1	15.5	14.0	14.3	14.4
Subtotal	50.2	28.4	35.1	34.3	26.9	14.0	14.3	14.4
Total Laboratory Funding	279.1	296.9	294.9	298.8	324.8	331.6	338.6	345.7

Table 4. Resources by Major DOE Program (1)

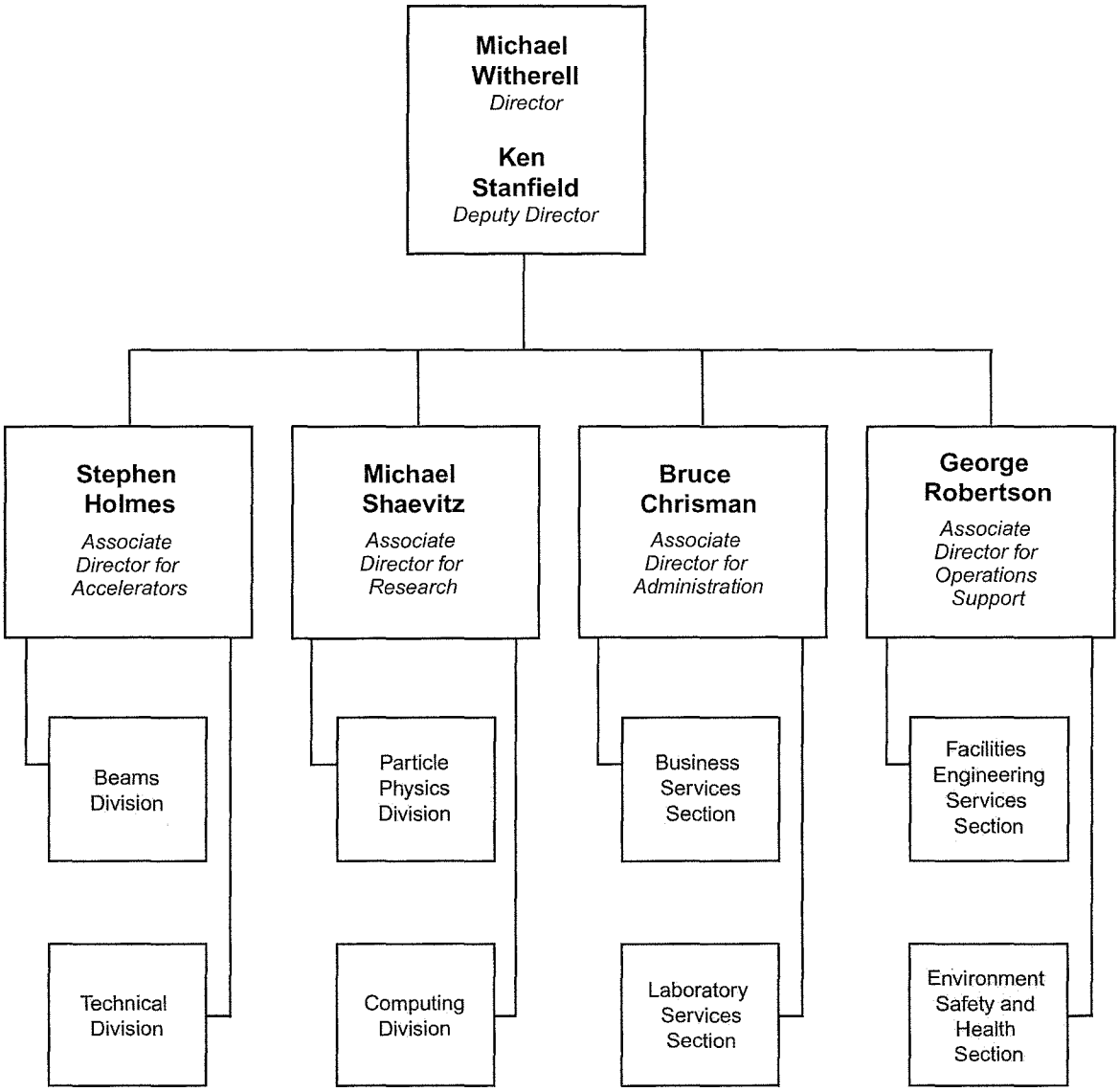
($ in Millions) (Personnel in FTE)

Program	FY98	FY99	FY00	FY01	FY02	FY03	FY04	FY05
KA - High Energy Physics								
Operating	181.3	207.3	218.4	224.6	255.3	273.9	283.9	294.9
Capital Equipment	47.4	61.0	41.2	39.9	42.6	43.7	40.4	36.4
Construction	50.2	28.4	35.1	34.3	26.9	14.0	14.3	14.4
Total KA	278.9	296.7	294.7	298.8	324.8	331.6	338.6	345.7
Program 60 - Work for Others								
Operating	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0
Miscellaneous								
Operating (3)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Capital Equipment	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Construction	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Misc.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Direct Personnel	1,537	1,632	1,660	1,660	1,660	1,660	1,660	1,660

Table 11. Major Construction Projects ($ in Millions)

	TEC	FY98	FY99	FY00	FY01	FY02	FY03	FY04	FY05
Funded Construction									
Program Line Item Projects									
Wilson Hall			6.7						
NuMI Project	15.6	5.5	14.3						
General Plant Projects (KA)		4.1	3.9						
Accelerator Improvement Projects (KA)	76.2	4.6	3.5						
Total Funded		14.2	28.4						
Budgeted Construction									
Program Line Items									
NuMI Project				22	23	11.4			
Wilson Hall				4.7	4.2				
Total Budgeted				26.7	27.2	11.4			
Total Funded and Budgeted		14.2	28.4	26.7	27.2	11.4			
Proposed Construction									
General Plant Projects				4.9	5.2	5.3	5.5	5.6	
Accelerator Improvement Projects (KA)				6.6	5.6	5.8	5.9	5.9	
Total Proposed			12.8	11.5	10.8	11.1	11.4	11.7	
Total Funded, Budgeted, and Proposed		14.2	41.2	38.2	38	22.5	11.4	11.7	

Supplemental Information



Supplemental Table 3
EEO Utilization Analysis Within Major Job Groups

Total Laboratory 30-Mar-95

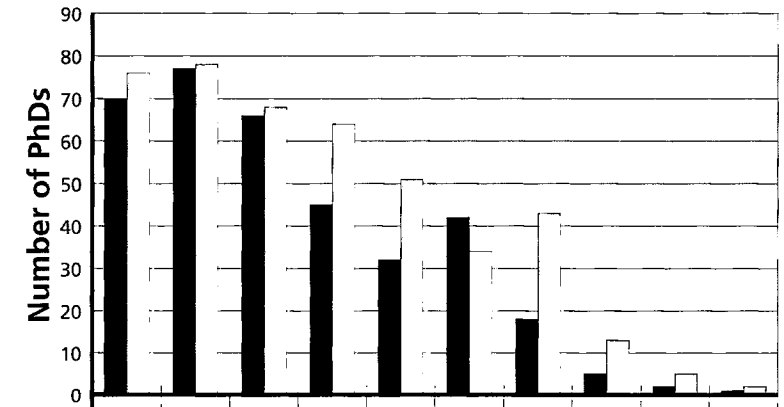
	US SOC Total	Male	Female	Amer. Black Male	Amer. Asian Male	Amer. Indian Male	Amer. Hispanic Male	Amer. Black Female	Amer. Asian Female	Amer. Indian Female	Amer. Hispanic Female	Total Minority	Female
Officials and Managers													
Executives and Managers	98	82	16	1	1	0	0	1	0	0	0	3	16
Percent			16.3	1	1	0	0	1	0	0.	0.	3.1	16.3
Unit Supervisors	89	79	10	3	1	0	1	1	0	0	0	6	10
Percent			11.2	3.4	1.1	0	1.1	1.1	0	0	0	6.7	11.2
Skilled Supervisors	26	23	3	3	0	1	1	0	0	0	0	5	3
Percent			11.5	11.5	0	3.8	3.8	0	0	0	0	19.2	11.5
Total Officials and Managers	**213**	**184**	**29**	**7**	**2**	**1**	**2**	**2**	**0**	**0**	**0**	**14**	**29**
Percent			**13.6**	**3.3**	**0.9**	**0.5**	**0.9**	**0.9**	**0**	**0**	**0**	**6.6**	**13.6**
Professionals													
Administrative Support	114	38	76	4	1	0	1	6	4	0	7	23	76
Percent			66.7	3.5	0.9	0	0.9	5.3	3.5	0	6.1	20.2	66.7
Engineering Physicists	67	59	8	3	3	0	0	0	0	0	1	7	8
Percent			11.9	4.5	4.5	0	0	0	0	0	1.5	10.4	11.9
Physicists	221	200	21	1	17	0	3	0	4	0	1	26	21
Percent			9.5	0.5	7.7	0	1.4	0	1.8	0	0.5	11.8	9.5
Research Associates	154	135	19	0	25	0	3	0	4	0	4	37	19
Percent			12.3	0	16.2	0	1.9	0	2.6	0	2.6	24	12.3
Engineering/Elec./Mech.	210	201	9	4	20	0	13	0	3	0	0	40	9
Percent			4.3	1.9	9.5	0	6.2	0	1.4	0	0	19	4.3
Computing	175	119	56	7	10	0	1	4	7	0	2	31	56
Percent			32	4	5.7	0	0.6	2.3	4	0	1.1	17.7	32
Technical Aides	166	157	9	10	1	0	4	1	0	0	1	17	9
Percent			5.4	6	0.6	0	2.4	0.6	0	0	0.6	10.2	5.4
Total Professionals	**1,107**	**909**	**198**	**29**	**77**	**0**	**25**	**11**	**22**	**0**	**16**	**181**	**198**
Percent			**17.9**	**2.6**	**7**	**0**	**2.3**	**1**	**2**	**0**	**1.4**	**16.4**	**17.9**
Technicians													
Drafting	43	36	7	3	1	0	1	0	0	0	1	6	7
Percent			16.3	7	2.3	0	2.3	0	0	0	2.3	14	16.3
Technicians/Elec./Mech.	396	329	67	29	8	0	18	7	0	0	14	76	67
Percent			16.9	7.3	2	0	4.5	1.8	0	0	3.5	19.2	16.9
Operations Support	45	33	12	3	0	0	1	2	0	0	0	6	12
Percent			26.7	6.7	0	0	2.2	4.4	0	0	0	13.3	26.7
Total Technicians	**484**	**398**	**86**	**35**	**9**	**0**	**20**	**9**	**0**	**0**	**15**	**88**	**86**
Percent			**17.8**	**7.2**	**1.9**	**0**	**4.1**	**1.9**	**0**	**0**	**3.1**	**18.2**	**17.8**
Office and Clerical													
Clerical	61	11	50	3	0	0	1	4	1	0	5	14	50
Percent			82	4.9	0	0	1.6	6.6	1.6	0	8.2	23	82
Secretarial/Computing	63	0	63	0	0	0	0	3	0	0	9	12	63
Percent			100	0	0	0	0	4.8	0	0	14.3	19	100
Total Office and Clerical	**124**	**11**	**113**	**3**	**0**	**0**	**1**	**7**	**1**	**0**	**14**	**26**	**113**
Percent			**91.1**	**2.4**	**0**	**0**	**0.8**	**5.6**	**0.8**	**0**	**11.3**	**21**	**91.1**
Craft Workers (Skilled)													
Misc. Crafts/Apprentices	91	87	4	7	1	0	11	0	0	0	0	19	4
Percent			4.4	7.7	1.1	0	12.1	0	0	0	0	20.9	4.4
Machining	34	34	0	5	0	0	1	0	0	0	0	6	0
Percent			0	14.7	0	0	2.9	0	0	0	0	17.6	0
Total Craft Workers/Skilled	**125**	**121**	**4**	**12**	**1**	**0**	**12**	**0**	**0**	**0**	**0**	**25**	**4**
Percent			**3.2**	**9.6**	**0.8**	**0**	**9.6**	**0**	**0**	**0**	**0**	**20**	**3.2**
Operatives (Semi-Skilled)													
Miscellaneous Operatives	47	40	7	10	0	0	5	1	0	0	0	16	7
Percent			14.9	21.3	0	0	10.6	2.1	0	0	0	34	14.9
Total Operatives (Semi-Skilled)	**47**	**40**	**7**	**10**	**0**	**0**	**5**	**1**	**0**	**0**	**0**	**16**	**7**
Percent			**14.9**	**21.3**	**0**	**0**	**10.6**	**2.1**	**0**	**0**	**0**	**34**	**14.9**
Service Workers													
Service Workers	18	2	16	0	0	0	0	1	0	0	1	2	16
Percent			88.9	0	0	0	0	5.6	0	0	5.6	11.1	88.9
Total Service Workers	**18**	**2**	**16**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**1**	**2**	**16**
Percent			**88.9**	**0**	**0**	**0**	**0**	**5.6**	**0**	**0**	**5.6**	**11.1**	**88.9**
Overall Total	**2,118**	**1,665**	**453**	**96**	**89**	**1**	**65**	**31**	**23**	**0**	**46**	**352**	**453**
Percent			**21.4**	**4.5**	**4.2**	**0**	**3.1**	**1.5**	**1.1**	**0**	**2.2**	**16.6**	**21.4**

Supplemental Table 4. Fermilab Staffing

1/1/1991 through 1/1/2000

	2000	1999	1998	1997	1996	1995	1994	1993	1992	1991	Change 00-91
Engineers and Scientists	700	663	626	613	619	610	616	616	596	597	103
Technicians and Tech Support	650	659	663	681	711	740	792	819	930	942	–292
Computer Professionals	225	209	191	185	187	183	189	196	156	152	73
Other	576	563	547	572	611	618	674	685	707	704	–128
Total Lab	**2151**	**2094**	**2027**	**2051**	**2128**	**2151**	**2271**	**2316**	**2389**	**2395**	**–244**

Dist. FNAL PhDs '95 & 00



	0–5	6–10	11–15	16–20	21–25	26–30	31–35	36–40	41–45	46+
■ 1995	70	77	66	45	32	42	18	5	2	1
□ 2000	76	78	68	64	51	34	43	13	5	2

5 Year Bins

Supplemental Table 5: Subcontracting and Procurement

($ in millions obligated within each fiscal year)

	FY98	FY99	FY00	FY01 (Est.)
Subcontracting and procurement from:				
Universities	10.0M	15.6M	18.0M	15.0M
All Others	1.0M	110.6M	127.5M	113.5M
Transfers to other DOE Facilities	118.5M	1.3M	0.5M	0.5M
Total External Subcontracts and Procurement	**$129.5M**	**$127.5M**	**$146.0M**	**$129.0M**

Supplemental Table 6: Small and Disadvantaged Business Procurement

	FY98	FY99	FY00	FY01 (Est.)
Small and Disadvantaged Business Procurement ($ in millions–B/A)				
Total Procurement from S&DB	72M	68M	65M	64M
% of Annual Procurement	**64**	**56**	**56**	**56**

Supplemental Table 7: Fermilab Users in 2000—Totals

A. US	Physicists	Students	FY00	FY01 (Est.)
University	708	348	1056	80
Industry	0	0	0	0
National Lab	398	15	413	17
Sub Total	**1106**	**363**	**1469**	**97**
B. Non-US				
University	360	153	513	80
Industry	0	0	0	0
National Lab	285	14	299	17
Sub Total	**645**	**167**	**812**	**97**
TOTAL	**1751**	**530**	**2281**	**198**

1. Data on Fermilab users are updated annually, generally about January of each year.
2. Fermilab experiments included on the list are those approved by the Laboratory. They are in one of the following stages: detailed design, construction, data-taking or data analysis (listed in Sections B-G in the Experimental Program Situation Report on Pages 30-31). The experiment personnel is supplied by the experiment spokespersons, and is divided into physicists or graduate students. Also included are Fermilab physicists who are involved in significant experimental physics activities which are not particle physics experiments at Fermilab accelerators and are listed in the Situation Report; this includes such activities as collaboration in astrophysics experiments and on the CMS experiment at the CERN LHC.
3. Although a user or an institution may be involved in more than one experiment, he/she/it is counted only once in any totals.
4. When experiments pass into the data analysis stage, students may graduate and move to other institutions, as also may more senior researchers. For experiments in the data analysis stage, we list users and institutions as of the data-taking phase.

Supplemental Table 8: Education '00

Program	Part S	Par T	#Min	#Fem
FERMILAB				
Cryogenic Show	4,576			
Daughters and Sons to Work	250			
Fermilab ARISE		25	3	11
Fermilab LInC Online		148		
Fermilab Teacher Fellowship		1		
Hands-on-Science	30			
Lederman Center	1065			
Museum Partners		56	51	43
Phriendly Physics		13	1	10
Physics Science Experience	1869	24		
Prairie Science Experience	9062	32		
Professional Networks		865		
QuarkNet		141		
Saturday Morning Physics	325			
Schramm Memorial Lecture	75			
Science Adventures	1476			
sciencelines		####		
Symposium		425		
Target	17		17	5
Teacher Resource Center		738		
Tours	2690	152		
TRAC		10	1	2
Workshops/Presentational		1430		
Totals	**21435**	**7260**		

Supplemental Table 8A: Education: Minority Programs

	FY 1999:			FY 2000:		
Pre-College Programs	**Total**	**Minorities**	**Women**	**Total**	**Minorities**	**Women**
Student Programs: TARGET	16	15	717	17	5	0
Undergraduate Programs						
Student Programs: Summer Internships	17	15	11	18	18	7
in Science and Technology						
Graduate Programs						
Student Programs: GEM PhD	4	4	1	2	2	1
fellowships for minority students						