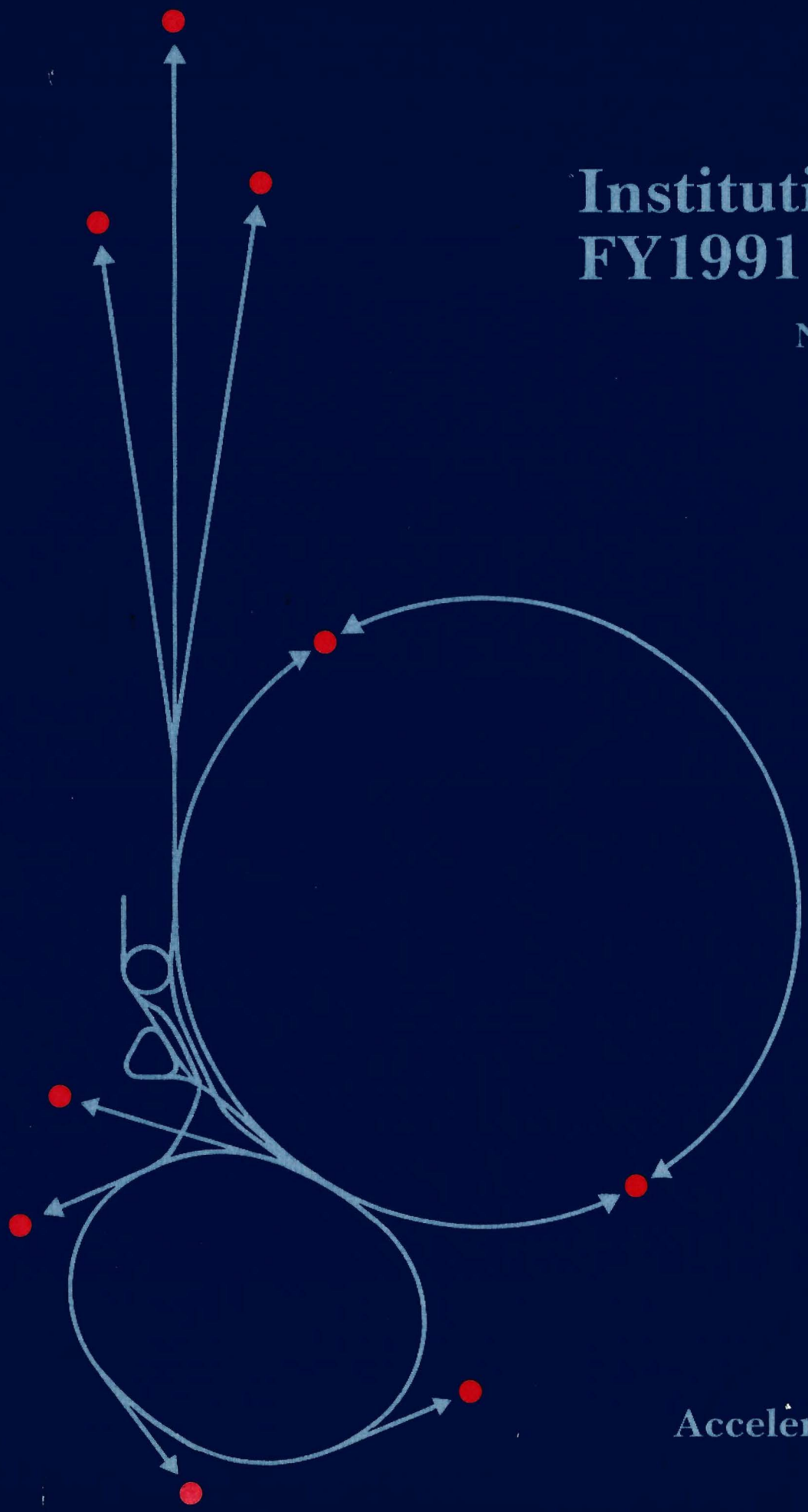

# Fermilab Institutional Plan FY1991 – FY1996

November 1, 1990

Fermi National Accelerator Laboratory

Batavia, Illinois

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Fermi National Accelerator Laboratory
Batavia, Illinois

Operated by Universities Research Association, Inc.
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# TABLE OF CONTENTS


I. Laboratory Director's Statement ..... 1

II. Laboratory Mission ..... 4

III. Laboratory Strategic View ..... 6

A. Planning Assumptions ..... 6
B. Activities at Fermilab ..... 11
C. Managerial Implications ..... 15

IV. Initiatives ..... 21

A. The Tevatron: Path to the Top ..... 21
B. CDF and D0: The Observation of the Top ..... 22
C. Fixed-Target Physics with the Main Injector ..... 23
D. The Search for the Origin of Matter in Beauty ..... 24
E. Participation in the Large Solenoidal Detector Collaboration for the SSC ..... 25
F. Experimental Astrophysics ..... 27
G. Environmental Safety and Health ..... 28
H. The Education and Conference Center ..... 30

V. Scientific Programs ..... 32

A. Current Programs ..... 32
B. Work for Others ..... 35

VI. Issues ..... 36

A. Fermilab Collaboration Efforts on SSC Detectors ..... 36
B. Magnet Technology Effort ..... 36
C. The Pursuit of New Directions within the Laboratory Mission ..... 37
D. DOE Orders and the Application of Nuclear Standards to Fermilab ..... 37

VII. Education and Technology Transfer Programs ..... 39

A. Support of Scientific and Technical Education ..... 39
B. Technology Transfer ..... 39

VIII. Human Resources ..... 41

A. Laboratory Personnel Summary ..... 41

IX. Site and Facilities Improvements ..... 46

A. Laboratory Description ..... 46
B. Facilities Plant and Options ..... 46
C. Facilities Resource Requirements ..... 49

X. Resource Projections ..... 51

A. Laboratory Organization Chart ..... 51
B. Laboratory Funding Summary ..... 52
C. Laboratory Personnel Summary ..... 54

Appendix 1 Details of Scientific Program ..... 55

Appendix 2 Cooling Water Improvements ..... 71

Appendix 3 Details of Education and Technology Transfer Programs ..... 72

Appendix 4 Universities Research Association, Inc. Member Institutions, ..... 83

Appendix 5 Institutions Currently Participating in the Fermilab Program ..... 84

# I. LABORATORY DIRECTOR'S STATEMENT

The Tevatron is the highest energy collider in the world and its energy creates a unique opportunity to search for elementary particles more massive than the Z°, such as the top quark. Fermilab will maintain its energy supremacy until the end of the decade when more energetic colliders come into existence. While the most powerful collider of them all, the SSC, will begin operation at that time, it will not be the end of the line for the Tevatron because researchers will pursue lines of investigation which either cannot be pursued at the SSC or which will not be pursued at the SSC during its first decade of operation.

Since the past may offer some guidance for the future, it is worth considering the events of the past decade. Ten years ago, the European Laboratory for Particle Physics (CERN) had overtaken Fermilab simply because it had far greater resources. At that moment, it was clear that the fastest path to the discovery of the W and Z° particles was the transformation of the big proton synchrotrons into proton-antiproton colliders. While CERN and Fermilab had the same basic ingredient, a 400 GeV synchrotron, it was clear that CERN could travel that path far more rapidly. Fermilab abandoned this race and chose to make a bold new initiative: the construction of a 2 TeV center-of-mass proton-antiproton collider made entirely of superconducting magnets. It was a great risk, but it promised three times the energy that could be achieved in the CERN Super Proton Synchrotron (SPS). When the discoveries of the W and Z° were made in 1983, CERN reached its primary goal. Four years later, these results were duplicated at the Tevatron and the data from 1988-89 collider run is ample evidence that the Tevatron had given the U.S. a collider that had overtaken CERN. During that run, the Tevatron design luminosity was exceeded by a factor of two and an integrated luminosity of nearly 10 $pb^{-1}$ was delivered to the Collider Detector at Fermilab (CDF). This large step in integrated luminosity and increased energy allowed the CDF collaboration to make very precise measurements of the properties of the W and Z° and to raise the lower bound of the top quark mass to 90 $GeV/c^2$.

Fermilab took its first step on the path to these accomplishments in 1974 when it started the development of superconducting accelerator magnets. When the Tevatron accelerated its first beam in 1983, Fermilab was the first and only laboratory to succeed in the extremely difficult technological tasks of producing one thousand accelerator quality superconducting magnets and constructing a working collider from them. Fermilab's basic approach has been adopted by the builders of HERA and UNK. In addition, this pioneering work provides the technological basis for the SSC.

As magnificent as the Tevatron is, its moment of supremacy will be very brief unless its parameters are significantly extended in the next five years. The two parameters that can be extended are the energy and luminosity. Increasing

the luminosity presents the fastest and most cost effective path for Fermilab to follow. Because the mass reach of the Tevatron may be extended beyond the most likely mass of the top quark, an important discovery is assured.

Fermilab has developed a sensible, cost-effective plan for increasing the luminosity of the Tevatron by more than a factor of fifty above its design. The plan, Fermilab III, includes the upgrade of the Linac from 200 MeV to 400 MeV, the construction of the Main Injector, and substantial improvements to the two large, general purpose detectors, CDF and D0. The latter will make it possible to observe 100 times the number of collisions in each detector per year compared to the number that the CDF detector observed in the 1988-89 run. With this increased number of collisions, D0 and CDF would be able to observe CP violation in the decay of neutral B mesons. While the increase in luminosity will make it possible to observe CP violation, it is likely that a new collider detector which is dedicated to detecting B mesons will be needed by the year 2000 to make precise measurements.

Fermilab III also makes provision for new fixed-target facilities that will make it possible to provide opportunities for discovery in the twenty-first century that are complementary to the opportunities that will be afforded by the SSC.

Throughout the 1990's Fermilab III is the only opportunity for the U.S. high-energy physics community to carry out research at the forefront of the field in the U.S. It also provides the only opportunity for U.S. physicists to gain experience in the design, construction and operation of hadron collider detectors in a high luminosity environment, experience that is essential to use the SSC. Fermilab will provide vital training for the students who will receive their Ph.D.'s in high-energy physics and accelerator physics. That experience will insure that, when the SSC comes on near the beginning of the twenty-first century as the highest energy collider in the world, the U.S. will have the trained research manpower necessary to make the SSC a stunning success. The futures of the SSC and Fermilab are inextricably intertwined. Fermilab physicists in collaboration with physicists from other U.S. institutions and institutions in Europe and Japan are planning the design of a major SSC detector. Fermilab is committed to supporting that effort, should its construction be approved by the SSC Laboratory. Fermilab will continue to make its unique test beam facilities available to the SSC detector R&D program. Fermilab is making significant contributions to the design of the SSC accelerators and superconducting magnets and the laboratory looks forward to making further contributions.

When the SSC begins operation, the Tevatron will still provide unique opportunities for forefront high-energy physics research. It is likely that a series of evolutionary experiments will be required to advance the technology needed to do precision B physics and CP studies at high luminosity hadron colliders. The Tevatron will provide a unique laboratory both for these technology improvements and for the physics experiments themselves. Precision vertex

detectors are already planned for CDF/D0 and these efforts will provide a technology base from which to design and build the detectors needed to make CP violation measurements. Although the SSC could in principle be used for such studies, the higher machine energy is unnecessary and it is likely that the Tevatron offers an operationally less expensive more flexible machine for these studies. We expect that this physics program, combined with a continuing 800 GeV fixed-target physics/test beam program, will occupy the bulk of those U.S. high-energy physicists not active on one of the two large SSC detectors (~1000). Physicists will be pursuing the source of CP violation in the decays of the neutral K meson and the neutral B mesons, searching for evidence of neutrino oscillations and making direct observations of the tau neutrino. These are some of the lines of research that cannot be pursued at the SSC but can be pursued at Fermilab after Fermilab III is completed.

Looking still further ahead, Fermilab will remain in the forefront of high-energy accelerators if, during the next decade, it takes another bold leap toward a new technology, as it did in the mid-seventies. This document does not contain a blueprint for that leap, but it does contain a prescription to keep Fermilab in the forefront of elementary physics for at least the next two decades.

## II. LABORATORY MISSION

Fermilab is a program-dedicated national laboratory managed by the Universities Research Association, Inc. (URA) for the U.S. Department of Energy. URA is a consortium of 77 universities in the U.S. and Canada (see Appendix 4). Fermilab's mission is to provide the resources necessary for qualified researchers to conduct frontier basic research in the field of high-energy physics and related disciplines. The Laboratory carries out this mission in a variety of ways which include:

1. Providing a 2 TeV center-of-mass proton-antiproton collider and two general purpose collider detectors.

2. Operating an 800 GeV proton synchrotron and the associated external beamlines (primary, secondary, tertiary) which provide a variety of high-energy beams to an array of fixed-target experiments. The Laboratory provides areas to assemble fixed-target apparatus and the general purpose equipment used to carry out the experiments.

3. Operating an 8 GeV antiproton source which, in addition to providing antiprotons for the collider program, is also used for internal fixed-target experiments.

4. Developing imaginative and unique accelerator techniques that are implemented here at Fermilab and at other Laboratories like the SSC.

5. Developing new techniques for designing and fabricating superconducting magnets and expanding the technology base of superconductivity in adjacent areas in high-energy physics and beyond.

6. Developing state-of-the-art particle detector techniques that can be employed to utilize presently operating high-energy physics facilities more fully and also developing the sophisticated new detectors that will be a part of future facilities like the SSC.

7. Pioneering new computing applications to solve specific problems of high-energy physics. This includes parallel computing for the on-line and off-line analysis of experimental data and sophisticated machines necessary for doing theoretical lattice gauge calculations.

8. Assisting scientists in closely related disciplines to exploit unique opportunities that may arise as a result of programs that constitute our main mission goals as stated above.

9. Providing a valuable national resource for the development and stimulation of science education and science literacy through the

Education and Conference Center. The Laboratory's education mission spans the spectrum from elementary students to graduate research scientists in training.

# III. LABORATORY STRATEGIC VIEW

## A. PLANNING ASSUMPTIONS

### Past and Prologue

It is worth briefly recounting the past to provide the context from which Fermilab's view of the future springs. Prior to 1989 Fermilab pursued the design of hadron colliders which promised the highest energy collisions that could be made in the laboratory with the available technology. In 1975, Fermilab proposed POPAE, a 1 TeV on 1 TeV proton-proton collider, as a way of exploring the electroweak mass scale. The superconducting magnets then under development for the Tevatron, a 1 TeV proton synchrotron for fixed-target physics, were intended to be the heart of this collider. When POPAE was not approved, Fermilab proposed a less expensive collider; a proton-antiproton collider using the as yet unbuilt Tevatron. The physics goals were to explore the electroweak mass scale with proton-antiproton collisions. The construction of the Tevatron, renamed as the Energy Saver project, began in 1979 and by 1983 it had accelerated protons to 512 GeV. Within a few months, the energy was raised to 800 GeV and the higher energy gave immediate benefits to the fixed-target experiments. The very precise measurements of the lifetimes of particles containing charmed quarks were one of the consequences of the higher energy and precise measurements of high-energy neutrino and antineutrino cross sections were another. Soon after it was clear that the Energy Saver would be successful, the proton-antiproton collider project, Tevatron I, was included in the DOE long-range plans for High Energy Physics and funds for its construction were first appropriated by Congress in FY 1981. Collisions between protons and antiprotons were first observed in 1985 and the first Collider run began in January of 1987. The design goals of the project were reached and exceeded in 1988. In 1982, the Tevatron II project (the adaptation of the existing fixed-target areas to the doubled energy) was started and the first extensive use of these facilities began in 1987.

In 1982, Fermilab proposed the Dedicated Collider, a 5 TeV center-of-mass proton-antiproton collider. During the same year, Fermilab physicists were the driving force behind the Desertron, a 20 TeV pp collider. In 1983 when the U.S. high-energy physics community recommended that the SSC be the next high-energy facility in the U.S., Fermilab joined the effort to develop a conceptual design for the SSC. For the next five years, Fermilab's long-range plan was focussed on the possibility that the SSC might be sited at Fermilab.

When Texas was selected as the site for the SSC in 1988, Fermilab focussed on the development of plans for Fermilab III, the project that would allow the Tevatron to be the premiere particle physics facility throughout the 1990's and to continue as a forefront research facility even after the SSC comes into operation. During the ten years remaining in this century, Fermilab III must move ahead rapidly if the U.S. is to prevent the high-energy physics program from sliding

into mediocrity. The strategic view that follows focusses primarily on the next ten years which can easily be Fermilab's finest. The view is set by the high-energy facilities landscape throughout the world.

## FACILITIES IN EUROPE AND ASIA: 1990-2000

### CERN

LEP is the major research facility in Europe and it completely dominates electron-positron vistas of the landscape. During the fall and winter of 1989 the LEP staff brought it into operation so rapidly and efficiently that the four general purpose detectors received enough luminosity in the first year of operation to make very precise measurements of the Z° mass, width and visible cross section. These measurements have established that the number of light neutrinos is equal to 3 to a precision of a few percent. The mass range up to 45 GeV has been thoroughly surveyed for the existence of the Higgs and supersymmetric particles, because all particles couple to the Z° in the Standard Model. While no surprising discoveries have emerged from this data, they, along with present results from the Tevatron, establish the validity of the Standard Model below the mass scale of the Z°. Each of the LEP collaborations expects to observe $10^6$ events during the next two years. A precise determination of $\sin^2\theta_W$ will be derived from the measurement of the forward backward asymmetry.

With these data, LEP experiments will complete the initial program in electroweak physics that had been envisioned for $e^+e^-$ colliders operating at the Z°. With this goal in sight, the LEP experimental collaborations are adding microvertex detectors to their detectors so that they can detect the decays of particles containing b quarks. While LEP is not the ideal place to search for B's, it has some advantages. At the Z° pole, the cross section for B production is 5 nb compared to 1 nb at the at the $\Upsilon$ (4S), the favored energy for asymmetric $e^+e^-$ B factories.

During shutdowns over the next four years, CERN will install sufficient superconducting RF in LEP to allow it to reach an energy of 180 GeV. The additional RF will also allow it to increase the luminosity to near $10^{32}cm^{-2}sec^{-1}$, when the energy is appropriate for Z° production. Since a center-of-mass energy of 180 GeV is well above the threshold for W pair production, LEP II will be the sole electron-positron collider in the world that can produce W bosons as well as Z° bosons. Once the first step in Fermilab III (the Linac Upgrade) is completed, the Tevatron will be able to equal in one year the best that can be done at LEP. When the final step in Fermilab III (the Main Injector) is completed the Tevatron will produce an order of magnitude more W's than can be produced at LEP. LEP will run for only six months out of the year but the annual shutdowns will provide the time needed to improve both the accelerator and the four detectors.

The CERN Super Proton Synchrotron (SPS) will be operated as a proton-antiproton collider (Sp$\bar{p}$S) in the fall and winter of 1990. This will very likely be the last run in that mode of operation. During its nearly ten years of spectacularly successful operation it brought the discoveries of the W and Z° to CERN. Nevertheless, the results from the 1988-89 Tevatron have been of such high quality that CERN has elected not to continue operations after 1991. Even today, the Sp$\bar{p}$S with its modest advantage in luminosity cannot compete with the Tevatron in the mass region beyond 100 GeV/$c^2$. By the summer of 1992 the Tevatron luminosity will significantly exceed the Sp$\bar{p}$S luminosity.

The SPS is used to provide 450 GeV proton beams for fixed-target experiments when it is not used for collider experiments. In this mode, it is used to produce secondary beams ($K_L^o$, $\pi$, hyperons) or tertiary beams ($\nu$, $\mu$, $\gamma$) for a few very high quality fixed-target experiments. Because CERN concentrates superior resources in a few well chosen experiments, their experiments have remained competitive with Tevatron fixed-target experiments in spite of the lower energy of the primary protons. After 1993, it is likely that the SPS fixed-target effort will emphasize heavy ion physics, a field of physics that could provide a special insight into the strong force that binds nucleons into nuclei. Because the SPS must be maintained as an injector for LEP (and the Large Hadron Collider, LHC, if it is built) and because high-energy collider detectors need fixed-target test beams, the SPS fixed-target capability will be preserved. It is worth noting that fixed-target operation is compatible with LEP operation.

CERN is considering the construction of LHC, a proton-proton collider in the LEP tunnel. In order to achieve a center-of-mass energy of 16 TeV, 10 Tesla dipoles suitable for LHC must be developed and mass produced. CERN has already built and tested 1m model dipoles that achieve this field. While the CERN Council has not given the approval to build the LHC, it has approved an aggressive R&D program. Nevertheless, if LHC were approved in 1992, it is likely that it could be brought into operation between 1998 and the year 2000. Should it be built, it would be a more powerful instrument for exploring the mass scale beyond the electroweak scale than the Tevatron, although it would not be nearly as powerful as the SSC.

**DESY**

The Hadron Electron Ring Accelerator (HERA) will begin operation in 1991. It will be the first electron-proton collider and only the second superconducting proton synchrotron. It will open a new window on physics for which there will be no comparable facility in the U.S. HERA experiments will be able to probe a far greater range of kinematic variables relevant to the proton

structure function than can be done in fixed-target experiments at CERN and Fermilab. Nevertheless the motivation to do these experiments in fixed-target beams will remain because of the superior precision over the smaller range of $\nu$ and $q^2$. The measurement of spin structure functions and structure functions of complex nuclei can also be done at HERA with gas jet targets.

**Soviet Union**

UNK in the U.S.S.R. should come into operation by 1995 as a 3 TeV fixed-target proton accelerator. If quality heavy-quark experiments are mounted at UNK, the factor of 3.5 in energy will make the UNK heavy-quark experiments superior to their counterparts at Fermilab. When this happens, UNK should be the preeminent high-energy fixed-target machine in the world. Fermilab's fixed-target program will continue to carry out important fixed-target experiments if Fermilab III is completed in a timely fashion.

KEK

Tristan, the 60 GeV center of mass $e^+e^-$ collider at KEK in Japan, probably will exhaust its scientific potential sometime during the next two or three years. KEK is developing a design for a two ring asymmetric $e^+e^-$ collider that will use the Tristan injector. It should be known within a year whether this machine will be built at KEK. KEK would be able to build such a B factory very rapidly since the Japanese could choose to focus their entire resources on this machine.

**FACILITIES IN THE UNITED STATES AND PLANS FOR FUTURE FACILITIES: 1990-2000**

SLAC

SLC, the first single pass collider, began operation in 1989 at a luminosity of $10^{28}cm^{-2}sec^{-1}$. At this time the integrated luminosity of LEP summed over all four of its detectors exceeds that achieved by SLC by more than a factor of 1000. In order for the SLC to reach its design luminosity of $6x30^{30}$, a significant number of major improvements must be made and an even greater effort will have to be made if the luminosity of the SLC is to approach that of LEP II. Throughout this period, it is likely that the SLC, with its single collision region occupied by the new SLD detector, will have significantly less luminosity than will be available at LEP. Since the $e^-$ beam can be polarized, the SLC is being modified to allow collisions of polarized electrons with unpolarized positrons. Once this is completed and commissioned, a precise value of the weak mixing angle could be obtained from measurements of the cross section. This result would be

competitive with the data sample of far greater statistical power obtained with unpolarized beams at LEP.

SLAC will continue to explore the feasibility of a linear collider in the 1 TeV center-of-mass energy region by improving SLC and by its dedicated R&D facility for the final focus. Without this research, a 1 TeV linear collider will be too risky to build. Accelerator R&D on linear colliders done in the next decade at SLAC and elsewhere, notably Japan, will set the stage for the construction of high-energy linear colliders early in the twenty-first century.

In the past year SLAC began the development of a proposal for a B factory, based on an asymmetric $e^+e^-$ collider designed to operate at a luminosity in excess of $3x10^{33}cm^{-2}sec^{-1}$. It would make use of the existing PEP accelerator and tunnels. SLAC will carry out a vigorous R&D effort in order to eliminate the uncertainty in those accelerator parameters that appear to limit the B factory luminosity. It intends to submit a proposal for the construction of such a B factory to the DOE in 1991.

**Cornell: CESR/CLEO**

It is likely that CESR will reach a luminosity of $5x10^{32}cm^{-2}sec^{-1}$ by 1993. With the new CLEO detector in operation, the CESR-CLEO combination should be a formidable force in the exploration of the physics of the b quark. While it will be the most versatile facility for measuring the wide variety of b quark decays in the next five years, it will not be able to get enough B decays to approach the threshold of detecting CP violation in the b quark system. To clearly establish CP violation in the b quark system, a luminosity of $5x10^{33}cm^{-2}sec^{-1}$ (or more) is needed. Cornell proposes to press ahead in this field by building a two ring symmetric collider and then, as experience is gained, transform this into an asymmetric collider that can achieve a luminosity of $5x10^{33}cm^{-2}sec^{-1}$.

**AGS**

The AGS is an old and venerable machine with an enormously successful past. The next round of its rare K decay experiments, its principal programmatic thrust in high-energy physics, should be completed by the middle of the decade. While the Brookhaven neutral K decay experiments are comparable to similar experiments at Fermilab, the stopping charged K experiments have no peer. The future of the AGS will be in nuclear physics through its value as a heavy ion injector into RHIC, Brookhaven's proposed Relativistic Heavy Ion Collider. Already, Brookhaven's heavy ion program which uses the AGS has made it possible to study relativistic heavy ion collisions. The Brookhaven heavy ion program will be an important factor in the development of our understanding of the nucleus.

### SSC Laboratory

The SSC is the highest priority of the U.S. high-energy physics program and the enthusiasm for it is very high. That enthusiasm is tempered by the realization that SSC will not fulfill its physics promise until at least the year 2000. The base program of U.S. high-energy physics must be healthy and competitive during this decade to provide the scientific and technological base needed to exploit the SSC when it becomes available. In order to assure this, the base program must allow full utilization of existing facilities including cost effective upgrades of those facilities.

### HEPAP Subpanel Recommendations

During the past year the DOE asked the High Energy Physics Advisory Panel (HEPAP) to review the needs of the base program during the period of transition to the SSC. The HEPAP Subpanel on the U.S. High Energy Physics Research Program for the 1990's was appointed and it examined how the national HEP program could go forward vigorously during the decade of construction of the SSC. It concluded that a viable and productive research program was essential for the HEP community to continue to attract and educate scientists of great creativity. The Subpanel made nine recommendations which if followed would allow the program to exploit existing opportunities, while undertaking some new initiatives. The two highest priority recommendations in order of priority are repeated below (the remaining recommendations were not priority ordered):

1. Strongly recommends the immediate commencement and speedy completion of construction of the Tevatron Main Injector at Fermilab.

2. Recommends strong exploitation of the existing high-energy physics facilities to take advantage in a timely way of the many physics opportunities available.

## B. ACTIVITIES AT FERMILAB

### The Rhythm of the Schedule

The Fermilab experimental physics program alternates between collider experiments and fixed-target experiments on an annual basis. Experience has shown that the experimental runs must be at least nine months long if the startup and calibration efforts are to be no more than 25% of the run. A three to four month shutdown is needed each year to carry out major accelerator maintenance and improvements. Detector upgrades and data analysis require a minimum of one year between runs. Thus, these efforts fit very naturally into an

annual alternation of collider and fixed-target cycles. In practice the two year cycle has had to be stretched to three years to allow funding resources to match equipment needs.

**Fixed-Target**

Fermilab has a very broad and strong fixed-target program, based on detectors that were constructed over the past seven years. Nearly all of the detectors that were used in 1990 and that will be used in 1991 were used during the 1987-88 fixed-target run. The initial objectives of all but a few of the eighteen approved experiments will be achieved when the 1991 fixed-target run ends. Eight of these experiments will measure the properties of hadrons containing charmed quarks and b quarks. The goals of the remainder of these experiments include a search for the origin of CP violation, measurements of nucleon structure functions, and measurement of the properties of hyperons.

Based on the experience from the 1990 run, the experiments designed to observe charm-particle decays should meet their objective of observing $10^5$ fully reconstructable charm decays. No other facility can approach this number of charmed particle decays, although the general purpose detector at the Beijing Electron Positron Collider (BEPC) can in principle obtain samples of charm decays in excess of a few times $10^4$. The Beijing experiments will complement the Fermilab experiments very nicely since inclusive decays are best done in an $e^+e^-$ collider and the detection of charmed particles through their lifetime is best done at Fermilab.

The fixed-target experiments, together with two dedicated B experiments, should observe enough fully reconstructed B decays to determine the cross sections for B particles. Because the cross section for producing B's in an 800 GeV proton beam is expected to be about 20 nb, the ability to produce a sufficient number of B's to observe mixing or CP violation is somewhat controversial. The first results from the dedicated B experiments should resolve the controversy and establish the extent to which the properties of b quarks can be measured in Tevatron fixed-target experiments.

After the 1990-91 run the fixed-target program will be focussed on fewer, more sharply defined objectives. The most promising directions that emerge out of the data of the 1990-1991 run will be pursued in the subsequent run by using existing detectors with some improvements. The understanding gained from this data will point the way to the design of new detectors that can better exploit the increased intensity of the Tevatron and the very high intensity of the Main Injector. In particular, experiments using beams from the Main Injector will provide better measurements of neutrino properties and CP violation in the neutral K system than can be done in any existing machine or any other proposed machine. The R&D for the first of these detectors should start in 1992 so that the

first detector can be completed by 1996. Because these detectors will have very demanding properties, the challenge in building them will be great. However, the rewards will be commensurate with these efforts. Because the study of the detailed properties of charm and beauty will still be at an early stage, the best of the existing large fixed-target detectors will still be engaged in programmatic physics in 1996.

It is very likely that the population of fixed-target experimenters will undergo a significant change during the next five years. Following the 1990-91 run, some experimenters can be expected to move into the Fermilab collider program because they will find it the logical next step in their research. Some will work on SSC detector development because they see this as the new opportunity. While more than half will still be engaged in fixed-target experiments in 1996, the remainder will be using the fixed-target beams for detector development and calibration.

Nuclear physicists and medium-energy physicists have begun to participate in the fixed-target program and this trend should accelerate. The study of the strong interaction, the common ground between nuclear and particle physics, at energies made possible by the Tevatron is of great interest to nuclear physicists and medium-energy physicists. As that trend gathers momentum, it will be more than offset by high-energy physicists who transfer their interests to collider programs at Fermilab and the SSC. When the Main Injector begins operation, there will be fewer experimenters engaged in the fixed-target program than there are today, but there will be many more using the fixed-target beam lines for detector development for collider experiments at Fermilab and the SSC Laboratory.

This state will continue even after the SSC becomes operational near the start of the next century. When that happens, one might expect a fixed-target program consisting of four or five sharply focussed experiments using state-of-the-art detectors and perhaps another four or five beams dedicated to detector development. As a result, the need for fixed-target beams is not likely to decline from the present. In fact, the demand may exceed the Laboratory's resources.

## Colliding Beams

Of all colliders in operation, only the Tevatron has a real chance of making a major new discovery in the decade of the 1990's. The Tevatron is the only collider that can access the high-mass region between 200 GeV/$c^2$ and 1000 GeV/$c^2$. This region almost certainly contains the threshold for pair production of top quarks. It may also contain the lightest supersymmetric particles or the lightest technipions if such particles exist. In order to thoroughly explore this region Fermilab has proposed to increase the luminosity of the Tevatron by a factor of 50 over the next five to six years. During the next collider run, scheduled

to begin in the fall of 1991, the luminosity will increase to $5 \times 10^{30} cm^{-2} sec^{-1}$ and when the upgraded Linac is available, the luminosity will increase to $10^{31} cm^{-2} sec^{-1}$. When the Main Injector is available the luminosity will increase by yet another factor of five.

The D0 detector will be commissioned in the fall of 1991 and thus a second powerful detector will join CDF in searching for new physics in 2 TeV proton-antiproton collisions. By 1995 when Fermilab III is complete, the search for quarks as massive as 250 GeV and vector bosons up to eight times more massive than the W and Z° will be possible. CDF and D0 could make observations of new phenomena, like the top quark, if nature allows. They will certainly make very accurate measurements of fundamental quantities such as the W mass, W width, and the weak mixing angle. Given the power of CDF and D0, the potential for discovery will remain high throughout the decade.

The top quark is not the only clear opportunity for Tevatron Collider experiments. The data from the 1988-89 Collider run showed that B decays are detectable at the collider. In particular, clear signals of B's decaying semileptonically into $D^\circ + e + \nu$ and B's decaying into $\Psi + K^\pm$ and $\Psi + K^{*o}$ were observed by CDF. The roughly 100 fully or partially reconstructed B events that were seen came from a sample in excess of $10^8$ B's that were produced and decayed in the CDF detector. While the selection of events that were recorded for subsequent analysis lead to this rather low efficiency, there are several improvements that can substantially improve the efficiency, some of which are already underway. In the Collider run that will begin in the fall of 1991, CDF will be equipped with a microvertex detector that will allow more efficient identification of B's through their finite decay length. Changes in the electronic event selection will allow events with lower momentum leptons and $\Psi$'s to be recorded. Because the cross section for B production at the Tevatron Collider is 45,000 times bigger than it is at an asymmetric $e^+e^-$ factory, there will be an active collider program to study B's. It will have to be tempered by a realization that to fully exploit the large B cross section and ultimately observe CP violation, it may be that a detector dedicated to B physics will have to be built. The results to date are very promising and suggest that continued improvement of CDF and D0 can come close to reaching this distant goal.

Since an exposure of 1000 $pb^{-1}$ will produce enough B mesons to allow a sensitive search for CP violation in the B system, the construction of a detector dedicated to B decays seems like a natural step once the goals of CDF and D0 have been achieved. Until this is done, the CDF and D0 detectors will be the B detectors at the Tevatron and the results from these detectors will shape the future of B physics at the Tevatron. Fermilab has begun to assess the feasibility of designing a detector with the sensitivity needed to carry out a search for CP violation in the B system. The successful completion of the R&D for any subsystem of this detector will be a valuable contribution to the design of a second-generation B detector for

a hadron collider. The construction of such a detector could begin as early as 1996. It is also possible that improvements to CDF and D0 could make a more cost effective path to efficient B detection. The full program of B physics at Fermilab leading to an understanding of CP violation will continue well into the first decade of the twenty-first century.

### Work for the SSC

Fermilab is assisting the SSC Laboratory in the design of accelerator systems, fixed-target beam lines, and superconducting collider magnets. It is playing the major role in the development of the 50mm diameter collider dipole. It is also making significant contributions to the design of the SSC Medium Energy Booster (MEB) and the SSC High-Energy Booster (HEB). This help will probably be needed for most of the next three years.

Until the SSC MEB and its associated test beams are in operation, physicists working on SSC detectors in the U.S. will be dependent on Tevatron fixed-target beams. Even after the MEB work gets underway, the Tevatron will still be the highest energy beams for calibration of calorimetry. The CDF experience is that this need will exist almost indefinitely while the SSC collider detectors run. Already, five groups participating in the SSC generic R&D program have used the facilities of four of Fermilab's fixed-target beams on a part-time basis during 1990. Groups working on the systems level R&D for SSC detectors will make even greater use of these beams in 1991. The SSC has requested that Fermilab dedicate two complete beams to SSC detector development during the subsequent fixed-target runs, in addition to the facilities requested for generic and systems level R&D. The ability to fulfill these demands and maintain a strong high-energy physics program at Fermilab depends on whether the Main Injector is built in a timely way. Near the end of the century, the SSC will have its test beam capability in place in Texas and the need for Fermilab fixed-target beams will be reduced but not eliminated. For the foreseeable future, the Tevatron will remain as the only source of fixed-target beams with energies exceeding 200 GeV in the United States.

## C. MANAGERIAL IMPLICATIONS

### 1. Response to Fermilab III

Fermilab III, the plan for keeping the Tevatron as the forefront facility in the U.S., has been developed. Two elements of this plan require line-item construction funds: the Linac Upgrade and the Main Injector. The need for increasing the Linac energy was accepted by the Department two years ago and the Linac Upgrade is now under construction, with completion expected at the end of FY 1992. The Main Injector was submitted to the Department by Fermilab at the beginning of 1989. It has subsequently been validated by DOE and reviewed by two panels of technical experts. One panel examined the Main Injector design for

technical feasibility and the other examined it for the feasibility of the proposed cost and schedule. Both panels stated that the Main Injector was ready for construction. The HEPAP Subpanel on the U.S. High Energy Physics Research Program for the 1990's gave the Main Injector the highest priority in the base program. In fact, under the constant budget scenario, it was the only initiative to be recommended for new construction.

The Fermilab staff is capable of carrying out Fermilab III and its commitments to the SSC. Because of the similarity of the Main Injector to the SSC Medium Energy Booster (MEB), Fermilab has contributed to the design of that machine without adding staff. .It could also contribute to prototype development and thus make a greater contribution to the MEB if SSC staff members choose to work with Fermilab in this effort. If the MEB and the Main Injector shared a common magnet design, magnet power supplies, diagnostics, RF, and controls, then both Fermilab and the SSC would derive savings.

Fermilab will need $180M of construction funds, funds in addition to its base budget, during FY 1992 through FY 1994 in order to construct the Main Injector. For the years FY92, FY93, and FY94, the optimum rate of funding would be about $60M per year. The details of the funding requirements can be found in Table IX-1, Table X-1, and Table X-2.

Now that the HEPAP Subpanel on the U.S. High Energy Physics Research Program in the 1990's has completed its work, discussions of Fermilab's plans for the 1990's and beyond should not be postponed. There are three important reasons for doing this as soon as possible. First, Fermilab III is the only way that the U.S. can have an operating forefront facility in high-energy physics during the period of the SSC construction. Second, if the start of construction of the Main Injector, a major element of Fermilab III, is postponed for several more years, then LHC can overtake the Tevatron and compete for the discovery of the top quark. Third, the existence of a fully comprehensive U.S. HEP program and experienced high energy physicists once the SSC comes into operation is dependent on having an agreed-upon plan for Fermilab for the next ten years.

## 2. Impact of the SSC on Fermilab

The SSC impacts Fermilab in four ways: first, a significant number of key Fermilab staff have left to join the SSC and more will follow; second, the SSC has asked Fermilab to provide personnel and facilities, such as its Magnet Test Facility, for the design and development of its laboratory; third, the SSC has requested that Fermilab make some of its fixed-target beams available to experimenters engaged in the development of equipment for SSC detectors; and fourth, the SSC physics program can create an opportunity for Fermilab to study 40 TeV center-of-mass hadron collisions in the twenty-first century. Fermilab views the first of these impacts as inevitable, but important to the SSC program.

If the brain drain is gentle and not a torrent, Fermilab believes that the staff that remains can train replacements in time. The second impact will not be as easy to handle. In the event that the Main Injector is delayed beyond 1992, there will be little incentive for Fermilab to commit its most valuable resource, its scientific staff, to the SSC Medium Energy Booster. Instead, Fermilab will focus its efforts on alternative, less effective ways of relieving the limitations that the existing Main Ring imposes on the Physics program. Since these alternatives are not likely to have anything in common with the MEB, the Fermilab staff will not be able to participate in SSC MEB design.

The SSC request for dedicated use of fixed-target beams is manageable only if the Tevatron continues to operate in the fixed-target mode, since extracted beams from the Tevatron are not feasible during Collider operation. As one of its benefits, the Main Injector will allow fixed-target beams to be operated simultaneously with collider operations. If the scheduling of the use of Fermilab facilities for SSC detector development is not to come into conflict with the higher priority collider program, then the base program needs to continue at the present level of funding and the Main Injector should move forward in a timely way.

The fourth impact is welcome. Because it can be expected that some fraction of the Fermilab staff will want to work on an SSC detector, it should be possible to direct some resources into such an effort after 1991 when the analysis of the data from the 1990 fixed-target run is nearly complete.

## 3. The Twenty-First Century

### Physics with the Tevatron

A complete plan for the first decade of the twenty-first century cannot be forecast with any degree of certainty at this time, because it depends on the results that will be obtained over the next ten years. Indeed there are many instances where unexpected discoveries have altered our long-term outlook. Nevertheless, certain elements of a Fermilab plan are beginning to emerge. The studies of CP violation in neutral B mesons and neutral K mesons are likely to be at the top of that plan. The search for neutrino oscillations will be in the plan as long as the neutrino flux emerging from the sun remains inexplicably low in experimental measurements.

Assuming a constant level of annual funding throughout the period FY 1997-FY 2005 equal to the level requested for FY 1996, the following program would be possible: Beginning in FY 2000, a collider detector dedicated to studying CP violation in B decays would be put into operation in one of the two collision regions; prior to that time, CDF and D0 detectors would be used in the collider. The design of this new detector would be based on the experience gained by the CDF and D0 collaborations during the next five years. A luminosity of

$5x10^{31}$ $cm^{-2}$ $sec^{-1}$ would make it possible to produce 20 billion B's each year in the dedicated detector. The second collision region would be used for specialized but dedicated experiments. These experiments would be used to follow up on results obtained by CDF and D0. One likely experiment would be the measurement of dilepton pairs in the forward or backward direction. Since the Tevatron hadron collider will be the only collider operating in the center of mass energy range of 300 GeV to 2000 GeV, it would be surprising if there was nothing of interest to explore. It is unlikely that the definitive B experiments will be done at the SSC during its first decade of operation because to do so would require compromising detectors dedicated to searching for ultra high energy phenomena such as Higgs bosons which will be the unique province of the SSC.

The study of CP violation in the neutral K system is a direction of research that Fermilab will continue to follow. It will probably take until at least the year 2005 to complete the program of measurements on the neutral K system that now appear to be feasible with the Main Injector. These are experiments that cannot be done at the SSC if the SSC Laboratory is to keep to its present scope and budget. In addition to neutral K experiments there will be a neutrino physics program. As long as the mystery of the missing flux of neutrinos emanating from the sun remains, there will be an incentive to carry out neutrino experiments with the Main Injector. Considering that the strange quark has been the object of intense study since V particles were first discovered forty years ago, it is likely that the charm quark will be an object of interest in the year 2005. The high energy photon beams at Fermilab can produce in excess of $10^6$ detectable charmed particle decays per year with the Main Injector. A new detector would have to be built to exploit this harvest of charmed particles.

On the basis of the number of physicists who have participated in the preparation of Letters of Interest (LOI) to the SSC, about half of the U.S. high-energy physicists can be expected to participate in the SSC program. Since somewhat less than half of the physicists who do their research at Fermilab have participated in the preparation of the LOI's, it is reasonable to assume that the other half will continue to work at Fermilab if research opportunities continue to exist at Fermilab in the twenty-first century.

**Physics at the SSC and Beams for the SSC**

Fermilab is deeply committed to participating in the SSC physics program. Already it is participating in the preparation of a proposal for one of the major collider detectors. Should this proposal be approved, in excess of 25% of the Fermilab physics staff could be expected to participate in the design, construction of utilization of this detector. While utilization of this detector is not likely to begin before the year 2000, if the experience with such detectors as CDF is appropriate the detector will be used for more than a decade.

Even after the SSC begins operation the SSC may need the high-energy beams of Fermilab for its detector calibration program. It is worth noting that the current scope of the SSC does not have fixed-target beams emanating from its High Energy Booster (HEB), the only accelerator other than the collider itself that can produce beams with an energy greater than 200 GeV. Since the replacement cost of the Fermilab fixed-target areas probably exceeds $250M (inflation adjusted to the year 1999), the decision to replicate Fermilab in Texas should not be taken carelessly. As long as the Tevatron is operated in the fixed-target mode such beams would be available to experimenters developing and calibrating detectors for the SSC. Note that CDF used its original test beam in 1984-85 but still continues to need a dedicated test beam today for continued R&D, calibration and tests required by the physics in progress. Even after the year 1999, one might expect the SSC to need 1 TeV test beams for many years.

## Long-Range Planning

Since the Tevatron will not last forever, Fermilab must make a bold programmatic leap if it is to remain in either the forefront of accelerator technology or the forefront of high-energy physics. The old proverb that one must "look before one leaps" is instructive here. Fermilab will be engaged in this "looking" process during the next two years.

In order to focus the planning effort of the laboratory leadership on the crucially important issues of the twenty-first century, a formal long-range planning mechanism has been put into place. A Long-Range Planning Committee (LRPC) has been formed. The membership of this committee includes the Chairmen of various subcommittees. The following subcommittees were formed early in 1990:

- Advanced accelerator research and development beyond the Tevatron
- Experimental astrophysics and particle physics experiments that do not require accelerators
- Fermilab participation in experiments at other laboratories exclusive of the SSC
- Site Development Plan Task Force

The Directorate and the Division Heads are included in the membership of the LRPC. The LRPC meets as necessary to charge its subcommittees and consider their reports. It is responsible for the preparation of the Laboratory's Institutional Plan. This planning process has already brought results. The Laboratory has decided to participate in a major collaboration to prepare an Expression of Interest for an SSC detector.

Despite the uncertainty, Fermilab intends to move toward the twenty-first century aggressively, driven by the presupposition that it will continue to be in the forefront of high-energy physics even after the SSC begins operation.

# IV. INITIATIVES

## A. THE TEVATRON: PATH TO THE TOP

The major initiative of the Laboratory is Fermilab III. The accelerator upgrade portion of Fermilab III is not a single project: rather, it consists of a series of projects or steps, each of which makes a useful increase in the luminosity. These steps, in rough chronological order, are:

- Antiproton source improvements,
- Matched low-β insertion at B0 (CDF) in the Tevatron,
- Matched low-β insertion at D0 in the Tevatron,
- Electrostatic beam separators in the Tevatron,
- Collider abort system at A0 in the Tevatron,
- New antiproton injection kickers in the Tevatron,
- Tevatron energy upgrade using cold compressors,
- Linac energy upgrade, and the
- Main Injector.

Some of the Antiproton Source improvements have already been completed and are being commissioned; others will continue through the entire duration of the accelerator upgrade. The fabrication of the new low-β quadrupoles for the B0 and D0 straight sections, the electrostatic beam separators, and the colliding beam abort system at A0 are all in progress. These systems will be completed by the middle of FY 1991. R&D and prototyping are underway for the new Tevatron antiproton injection kickers and for the cold compressor system; these are expected to be completed during FY 1993.

Two steps in the collider luminosity upgrade require line-item construction projects: the Linac energy upgrade and the Main Injector. The Linac energy upgrade construction project received its first funding in FY 1990. Funding for the second year of the project is included in the FY1991 President's Budget at a level sufficient to complete the project (assuming the requested FY 1992 funding) by the end of FY 1992.

Fermilab has requested that the Main Injector project receive its initial funding in FY1992, with completion anticipated by the end of calendar year 1994. "Immediate commencement and speedy completion of construction" of the Main Injector was the highest priority recommendation of the 1990 HEPAP Subpanel on the U.S. High Energy Physics Research program for the 1990's. A more detailed description of these steps is given in Appendix I.

The schedule for Fermilab III has been arranged so that each successive collider run will have three to four times the integrated luminosity of the preceding collider run. Since the schedule for these collider runs is dependent on

the level of annual appropriations, the collider runs have been numbered. Collider run 1 is defined to start in the fall of 1991 when both CDF and D0 will take data. The expectation for luminosity in the next four collider runs is given in the following table:

**Luminosity Projections by Run for the Tevatron Collider**

| Collider Run | Peak Luminosity | Integrated Luminosity | top quark Sensitivity |
|---|---|---|---|
| 1* | $5x10^{30}/cm^2/sec$ | 25 $pb^{-1}$ | 120 $GeV/c^2$ |
| 2 | $10^{31}/cm^2/sec$ | 75 $pb^{-1}$ | 170 $GeV/c^2$ |
| 3 | $5x10^{31}/cm^2/sec$ | 350 $pb^{-1}$ | 210 $GeV/c^2$ |
| 4 | $>5x10^{31}/cm^2/sec$ | >500 $pb^{-1}$ | 250 $GeV/c^2$ |

*Run 1 begins in the fall of 1991; subsequent runs are expected to follow at intervals of 2 years.

The sensitivity to the undiscovered top quark is a significant measure of the performance of a proton-antiproton collider, and as the table shows, the Tevatron collider can search for the top quark over the full mass range permitted by the Standard Model. The annual funding requests for the Linac Upgrade and the Main Injector Project are given in Table X-2.

## B. CDF AND D0: THE OBSERVATION OF THE TOP

Analysis of the CDF data from the 1988-89 run is now almost complete. From their top quark search, they have a published limit, top mass > 77 GeV, and a more recent preliminary limit based on further analysis, top mass > 89 GeV. Measurements of width and mass, $\sin^2 \theta w$ from neutrino scattering experiments and limits on the direct contribution to CP violation in neutral K decay place the mass in the range of 100 GeV to 180 GeV. Various theoretical speculations suggest that the mass could be as large as 200 to 250 GeV.

The CDF and D0 collaboration are both planning upgrades to their detectors so that they can keep pace with the steadily increasing luminosity of the Tevatron. While most of the improvements are intended to handle the increased luminosity, many of the improvements are intended to extend the detection capability for processes that cannot be detected with the present detectors. One of the most important of these additions will be precision vertex detectors which will allow b quarks from Top decays to be identified by observing

their decay a fraction of a millimeter from the point where the top quark is produced.

Once upgraded, CDF and D0 will have the sensitivity to discover the top quark over the entire range allowed by the Standard Model. If it is observed, then they will provide confirmation that the particle discovered is indeed the top quark. An accurate measurement of the top quark mass is very important to precision tests of the Standard Model and the search for deviations from it. It is of prime importance that the top quark be found or that its absence within the limits imposed by the Standard Model be clearly established. In addition, it is quite possible that there will be real surprises in the properties of the top quark. This particle is already an oddity by virtue of its extremely large mass.

## C. FIXED-TARGET PHYSICS WITH THE MAIN INJECTOR

The properties of the Main Injector which will make it an efficient producer of antiprotons for the collider program also present a unique opportunity for fixed-target physics at Fermilab using very high intensity (2μA), medium energy (120 GeV) proton beams. The potential value of the Main Injector for this type of physics was examined both at a dedicated "Workshop on Physics at the Main Injector" in May 1989 and at the Breckenridge "Workshop on Physics at Fermilab in the 1990s" in August 1989. Many interesting areas of study were identified at Breckenridge including: rare and CP violating neutral K decays, precision measurements of Standard Model parameters such as $\sin^2\theta_W$ and $V_{cd}$, very long baseline neutrino oscillations, neutrino oscillations involving the appearance of the tau neutrino, and initiatives based on antiproton beams to study charmonium states, charmed baryons, and CP violation in hyperon decays. The design of the Main Injector will allow delivery of beam to such experiments concurrent with either Tevatron collider or fixed-target operations at 1 TeV.

The $K_L^0$ beams produced by the Main Injector will make the measurement of $K_L^0$ branching ratios as small as a few x $10^{-13}$ possible. The detection of decay modes such as $\pi^0 e^+ e^-$ and $\pi^0 \mu^+ \mu^-$ are sensitive to the presence of "direct" CP violation and are expected to be observed with branching ratios at a level of $10^{-12}$ while others, such as $\mu e$, are forbidden at any level in the Standard Model. Experiments at this level of sensitivity will provide precision tests of the Standard Model and perhaps even lead to the discovery of new phenomena. The best of today's experiments are a thousand times less sensitive and are not sufficiently sensitive to challenge the Standard Model. A conceptual design for an Intense Kaon Facility is in progress. This facility will make use of existing facilities in the fixed-target areas. While some new enclosures will be needed, the existing infrastructure of utilities, roads, and controls will be used. It would be desirable to start this project in FY 1992.

A neutrino beam derived from the Main Injector could extend the sensitivity for $\nu_\mu \rightarrow \nu_\tau$ oscillations by nearly two orders of magnitude beyond the best experiment done to date. It may be possible to do complementary experiments of this type by directing an intense neutrino beam at the underground IMB detector near Cleveland. A precision measurement on $\nu_\mu$ elastic scattering off electrons would result in an accurate, systematic free measurement of $\sin^2\theta_W$. Such a measurement will be possible with the intense $\nu_\mu$ beams that can be generated with the Main Injector. Fermilab is developing plans to build suitable beam lines and experimental areas for Main Injector neutrino experiments. At this time it is believed that the neutrino experiments that will use Tevatron beams could be done by modifying existing facilities in the Neutrino Area.

## D. THE SEARCH FOR THE ORIGIN OF MATTER IN BEAUTY

The study of b-quark production and decay will be an important field of research through the 1990's and beyond. One major goal of this research will be to test whether the three generations of quarks lead to a unitary Cabibbo Kobayashi Maskawa matrix. The measurement of the production cross section of b quarks could provide additional insights into perturbative Quantum Chromodynamics (QCD) and the observation of a large number of b decays could provide additional tests of the standard electroweak weak interactions. The ultimate goal is a search for the many possible manifestations of CP violation in B-decays.

The B-physics program at Fermilab is already building on the experience gained with detecting charm particles. Charm physics has been a particularly fruitful area of research at Fermilab; initially, precise measurements of charmed particle lifetimes were made and in the near future the results will lead to a detailed picture of the hadronic form factor that govern the semi-leptonic decays. The production of heavy quarks is predicted by perturbative QCD, and the agreement for charm is very encouraging considering the relatively light mass of the charm quark. These calculations for B meson production are expected to be much more reliable and thus the measurement of the cross-section should provide an accurate test of the basic production processes.

B-production cross sections are high in both fixed-target and collider experiments when compared to $e^+e^-$ production. The main problem encountered in hadron experiments is the difficulty in isolating the B-decays from the much larger background. For typical fixed-target experiments the background is more than a million times the signal. In this respect the collider has a factor of 1000 advantage over fixed-target experiments. However, for the moment, the B-decay vertex is better separated and more easily measured in the fixed-target

configuration. Thus, while fixed-target experiments will certainly contribute to the study of B-particles, the collider will provide the highest yields.

Very large data-sets will be required to observe $B_S$-mixing and CP-violation. Achieving the high data-rates and background rejection of such experiments will require an extensive R&D effort in detectors and data-acquisition systems, and in off-line data-handling techniques. The initial exploitation of the very high B-production rate available at the Tevatron will require upgrades to CDF and D0 and the complete exploitation may require new detectors dedicated to B-physics. Our approach at Fermilab is not only to pursue R&D in these areas, but to develop the detector technology and to test new ideas in experiments which address increasingly challenging B-physics topics. In a sense, the heavy flavor program at Fermilab is both an R&D program to learn how to reach rarer processes, as well as an ongoing (and highly productive) physics program. The study of B-physics presents both a rich reward, and a serious technical challenge. We are very optimistic about the potential for success considering the recent announcement by CDF that B mesons have been reconstructed in the $\Psi$ + K final state.

## E. PARTICIPATION IN THE LARGE SOLENOIDAL DETECTOR COLLABORATION FOR THE SSC

Fermilab has recently made a major, coherent, institutional commitment to an international collaboration called SDC, the Solenoid Detector Collaboration, whose goal is to construct and operate a detector at the SSC. The role of Fermilab is to provide a strong concentration of technical resources and hence serve as a regional center for coordinating and supporting the development of SDC. Indeed, Fermilab is already active in the detector R&D program of the SSC Laboratory. At present there are about 35 physicists devoting at least 20% of their research time to SSC work. The planned Upgrades of the existing Tevatron Collider Detectors, CDF and D0, will provide invaluable "intermediate experience" on the path towards the higher energy (20 times) and higher luminosity (20 times after Fermilab III is complete) SSC environment.

Since the SSC program is a natural extension of the Fermilab Collider program, there is much interest on the part of the Fermilab staff in participation in the SSC. During 1989, with the support of the Director, some decided to pursue research opportunities at the SSC. After discussions internal to the Fermilab staff in July and August, Fermilab hosted a workshop on Solenoidal Magnetic Detectors in September. As an outgrowth of this workshop, an international collaboration was formed which had its first organizational meeting at Fermilab in December, 1989. This collaboration, SDC, consists of 400 Ph.D. physicists from 65 institutions, 5 from Europe and 20 from Japan.

The experience of FNAL physicists and technical support staff in the construction and operation of both CDF and D0 for the Tevatron Collider is unique and ideally suited to the design and participation in a large multipurpose detector for the SSC. At present there are roughly 70 Ph.D. Fermilab physicists working on CDF and D0. The Fermilab III improvement projects for these detectors offer a unique chance to train the physicists who will work at the SSC as they learn how to operate a hadron collider detector at high luminosity. The experimental environment expected at the SSC (luminosity of $10^{33}$ $cm^{-2}$ $sec^{-1}$) has not been approached in any existing hadron collider. It is expected that it will be difficult to build a workable detector for full SSC luminosities without gaining experience at intermediate values. While the start of the construction of the SSC detectors cannot wait until the experience of working with luminosities approaching $10^{32}$ $cm^{-2}$ $sec^{-1}$ is obtained, the experience can influence the detector subsystems that will still be evolving five or six years from now. The plan for increasing the Tevatron Collider luminosity to > $5x10^{31}$ $cm^{-2}$ $sec^{-1}$ presents a natural stepping stone for physics measurements and detector operation in the SSC environment.

Many of the same Fermilab physicists are participating in the generic R&D program supported by the Division of High Energy Physics as well as specific subsystem proposals for SSC detectors. The latter include work on solenoid magnet designs, scintillating fibers, tile and fiber calorimetry, front-end electronics, trigger electronics, muon detection, and data acquisition electronics. All of this is done in collaboration with physicists from universities. On a broader scale Fermilab is functioning as a regional center for university physicists who are pursuing common R&D goals by utilizing the facilities at Fermilab. This work will lead to the evaluation of full scale prototypes in the fixed-target beams at Fermilab. It is inevitable that beams will play an important role in prototyping and calibrating detectors for the SSC. In addition, the results of some of this work will be directly applicable to upgrades for both CDF and D0 for the higher luminosities expected in Fermilab III collider and fixed-target (Main Injector) programs.

The four areas of collider detector expertise that have been gained in building the CDF and D0 detectors are:

1. Solenoid design and operation.

2. High rate scintillator based detectors (including tracking and calorimetries).

3. Triggering and data acquisition systems in a hadron collider environment.

4. Offline computing and data handling.

These areas naturally dovetail with the existing program, most particularly with the CDF and D0 upgrades. The incorporation of SSC detector development and planning at FNAL provides a natural way to achieve a vigorous high-energy program in the United States in the 1990's while building experience for the SSC.

## F. EXPERIMENTAL ASTROPHYSICS

The mission of Fermilab is to discover the fundamental particles, and to explore the forces by which they interact and compose everything in our physical universe. It has become increasingly clear that the accomplishment of this mission must ultimately involve tools beyond the traditional one of high-energy physics, the particle accelerator. In particular, it is recognized that the confluence of high-energy physics and astrophysics provides opportunities for each discipline to pursue common projects within the scope of their traditional, separate missions.

Along with particle physics, astrophysics is a frontier science, dedicated to answering the most basic questions about the Universe. There is a new, vigorous connection between astrophysics and particle physics, both in experimental techniques, and most importantly, in the underlying physics issues. It has become clear in the past few years that the input of particle physics will have as large an impact upon cosmology as the infusion of nuclear physics into astrophysics in the 1950's and 1960's. It is likely that further advances in cosmology and astrophysics will incorporate the latest developments in particle physics. Likewise, it has become obvious that the early Universe and various contemporary astrophysical sites can provide conditions that are complementary to terrestrial accelerators to test the ideas of particle physics. For example, the limits on the axion mass from red-giant stars and the early Universe have guided the direction for research on this important topic in particle physics. No single accelerator, terrestrial nor astrophysical, will give the complete answer. Only a partnership of high energy physics and astrophysics will lead to the ultimate understanding of the Universe. A few major areas of common ground in physics issues that come to mind in the Inner Space/Outer Space connection are large-scale structure in the Universe, microwave background measurements, dark-matter searches, and high-energy cosmic rays.

There are fields of experimental astrophysics that utilize the techniques and talents of high-energy physicists. These include production and operation of large-scale detector arrays, low-noise electronics, cryogenic techniques, acquisition and computer analysis of very large data bases, and more generally, the rapid application of leading-edge technologies to research in physics. Some indication of the confluence of the fields of particle physics and astrophysics is the number of prominent particle physicists who have become involved in experimental astrophysics.

In other fields of astronomy (for instance, optical astronomy) where particle physicists have not yet played a role, we anticipate that they soon will. Although traditionally astronomy has been a data-starved science, many planned observations will reverse this trend and face situations familiar to particle experiments, namely the generation of enormous data bases that have to be stored, archived, and analyzed. For instance, the proposed Chicago-Princeton-Institute for Advanced Studies "Map of the Universe" project will generate 10 terabytes of data. Traditional astronomers have little experience in handling such data bases, but they are of a size familiar in particle experiments.

In November 1989 the Director appointed a long-range planning group with the charge of considering the feasibility of Fermilab involvement in some aspect of particle astrophysics. In April of 1990, the planning group submitted a report to the Director endorsing the concept of a program in experimental particle astrophysics. The committee found many areas in astrophysics consistent with the particle physics mission of the Laboratory, and where Fermilab could play a leading role. The committee further endorsed the idea that Fermilab should gain experience by becoming involved in a modest-sized project before embarking on a major program of its own.

The Laboratory is currently exploring a possible collaboration in the "Map of the Universe" project started by The University of Chicago, the Institute for Advanced Study, and Princeton University. The project will produce the first uniform, contiguous map of the Universe within a volume hundreds of times larger than any probed up to this time. This map will allow us for the first time to learn if the dark matter in the Universe is provided by some elementary particle, such as a massive neutrino or a supersymmetric particle. The Fermilab role would be in data acquisition, processing, computing, and analysis.

## G. ENVIRONMENTAL SAFETY AND HEALTH

Fermilab has traditionally taken an aggressive approach to ES&H issues. These efforts have resulted in a safe and environmentally sound program. The Department of Energy over the last few years has embarked on a program of increasing the emphasis in this important area. This has included the Environmental Survey of 1987, the Factory Mutual Fire Protection Survey of 1985, and the development of the Five Year Plan for Environmental Restoration and Waste Management. Other DOE efforts which shape the Fermilab program consist of an extensive review of existent DOE Orders and other documents of guidance. A major effort is required to adapt the policies of the Laboratory to these new initiatives. In addition, our continued pursuit of excellence in this area has resulted in initiatives arising from our own experience. Continued improvement is expected both by Laboratory management and by DOE. The

ES&H initiatives which will be pursued in the next five years are described in this section.

## 1. DOE Five Year Plan for Environmental Restoration and Waste Management

This major effort by DOE has resulted in the identification of 15 project items to be funded under this program. These projects incorporate items identified in the 1987 Environmental Survey as well as new ones identified thereafter. Also included are Fermilab's routine programs for handling the disposal of radioactive, hazardous and regulated chemical wastes. The direction of this activity by DOE, particularly in the area of reporting and budgeting, is still evolving.

Concerning environmental restoration activities, the most important issue in terms of cost and operational impact is the possible need to clean up the PCB contamination adjacent to the 24 service buildings around Fermilab's Main Accelerator Ring. A comprehensive assessment of two of the 24 sites being conducted in FY1990 will further direct this activity. Other projects in the area of environmental restoration are characterizations of various spills which have occurred due to past actions. These include a PCB spill near the Capacitor Tree, an oil spill in the Master Substation area, two leaking underground gasoline tanks which were removed during CY1990 and an evaluation of the need to remove soil contaminated with low levels of chromates in an old tile field.

The routine handling of both radioactive and regulated chemical wastes is an important matter. New laws and regulations continue to enlarge this program with respect to both radioactive and regulated chemical wastes. This program is now funded separately under DOE-EM. The Laboratory presently has Resource Conservation and Recovery Act (RCRA) interim status for its hazardous waste storage facility and is applying for the final permit from the State of Illinois to operate this facility. Radioactive wastes are generated in the course of operation of the accelerator complex and this material is handled in accord with DOE requirements. The effective implementation of a waste minimization program will be an important ingredient in the progress of this program.

## 2. General Environmental Protection

New laws, regulations and DOE Orders in the area of environmental protection mandate continued improvement in this area. In the near future, improved monitoring programs will be needed to comply with the regulations. Also, a heightened emphasis on detailed reviews of projects for compliance with the National Environmental Policy Act will require improved definition of projects and, unfortunately, longer lead times. Such reviews must consider environmental impacts of a given action comprehensively.

### 3. Industrial Safety, Industrial Hygiene and Fire Protection Activities

An important area of emphasis is the continued improvement of industrial safety. DOE has declared that it will emphasize complete compliance with all national industrial safety standards and state laws in a manner consistent with those enforced on industry by OSHA. As a result, Fermilab will take measures to modify the "culture" of the institution to assure such compliance. This effort will manifest itself in more inspections, appraisals and corrective actions. A more vigorous effort in the area of industrial hygiene surveys will be needed and undertaken. A particular point of interest will be the review of all buildings for compliance with the Life Safety Code.

During the last several years, the fire protection program at Fermilab has yielded significant improvements in the level of protection afforded to personnel and property through an extensive improvement program of equipment upgrades. Efforts in this area will continue throughout the Laboratory. The ever-changing nature of the experiments often requires adjustment of the fire protection equipment and procedures. The institution of a Laboratory standard for managing flammable gases used in experimental apparatus is an example.

### 4. Radiation Protection Activities

Radiation protection has been and will continue to be a high priority activity at Fermilab. A very strong program for controlling this hazard is in place. A continuing initiative will be to maintain all radiation exposures as low as reasonably achievable (ALARA). New DOE Orders will require the Laboratory to strengthen all aspects of this program, with particular emphasis on training of personnel. A major initiative is to better characterize the radiation fields at Fermilab, especially those involving neutrons. A strong effort is underway to assure compliance with DOELAP, the DOE-required dosimetry accreditation program.

## H. THE EDUCATION AND CONFERENCE CENTER

The Education and Conference Center (ECC), the new home for Fermilab's precollege science education programs, is scheduled to open late in 1991. The ECC will also provide the long needed space for meetings and conferences for up to two hundred participants. The ECC will offer educational programs for students, teachers and Fermilab visitors year round in a rich and stimulating environment for science education. Programs will include teacher training, an out-of-school program for students and their parents, hands-on-science, and adult education. Fermilab, through its new Education Office, and in a partnership with Friends of

Fermilab and the private sector, will equip the ECC for educational use. Funds from the DOEOER, NSF, the State of Illinois, and the private sector will be sought for new programs that are not self-supporting.

# V. SCIENTIFIC PROGRAM

## A. CURRENT PROGRAMS

Elementary particle physics, the science of the ultimate constituents of matter and the interactions among them, has undergone a remarkable development during the past two decades. A synthesis of our current understanding, the Standard Model, consists of the following elements: The basic constituents of matter are particles with spin 1/2 that can be placed in two distinct categories called quarks and leptons. Quarks are the constituents that define the properties of the neutrons and protons which form the nuclei of atoms. The force of attraction among quarks is so strong that an isolated quark has never been observed while the forces between leptons are rather weak. Examples of leptons are the electrons and the neutrino emitted in nuclear beta decay. The forces between these particles are communicated by another set of particles called gauge bosons, each of which has spin 1. The gauge bosons are: gluons (strong force), the photon (electromagnetic force), and the W and $Z^\circ$ (weak force responsible for nuclear decay). The Standard Model allows at least three different families of quarks, with each family consisting of a quark with a charge equal to 1/3 of the electron and one with a charge 2/3 of the proton. Each family of quarks appears to have a counterpart family of leptons. Each lepton family consists of a charged lepton with the same charge as the electron and a neutrino with zero charge.

At the present time, we stand at a cross-road in physics, near the end of the very dramatic period of the development of the Standard Model. Yet we are awaiting important discoveries which would complete the Model such as the discovery of the top quark and the direct observation of the Tau neutrino. The most intriguing ingredient of the Standard Model is the feature which gives it mathematical self consistency, the Higgs sector. If the Higgs sector consists of one elementary particle, it has spin zero and it is very massive. Whatever the Higgs sector is, it is closely connected with the spectrum of the gauge boson masses. Looking to the future, there is the possibility that quarks have internal structure, that there is a fourth generation of quarks and leptons (with neutrino mass greater than one-half the mass of the $Z^\circ$ boson), and that a fundamental understanding of CP violation (which is only parameterized in the Standard Model) is possible. Ironically, the Standard Model which is so successful in linking many different particles and forces, is on closer inspection too complicated. The desire for simplification and elegance persists. Various attempts at a further unification of the forces of nature lead to speculations about the existence of other families of particles, such as supersymmetric particles and techni-quarks. In addition, there are exotic possibilities such as axions and monopoles. In order to proceed further and find the right theoretical models to simplify our understanding, more experimental data is essential.

The major thrust of the Fermilab program is to build, operate, and improve the accelerator and experimental facilities necessary to reach this deeper understanding of the particles and forces that constitute the physical world. At present, this program uses the Tevatron with the collider and fixed-target experimental facilities. In order to keep this complex at the forefront of particle physics, an upgrade program called Fermilab III is planned. What follows is an enumeration of the major program activities at the Laboratory. A discussion of the details of each activity can be found in Appendix 1. In addition, a list of approved experiments, including the number of collaborating institutions and the number of physicists working on each experiment is given at the end of Appendix 1.

## 1. The Fermilab III Program

The Tevatron has achieved a peak luminosity of $2x10^{30}cm^{-2}sec^{-1}$, twice the design luminosity. A major goal of Fermilab III is to increase the luminosity of the Tevatron collider to greater than $5x10^{31}cm^{-2}sec^{-1}$.

## 2. Colliding Beam Program

Four collider experiments were completed in 1989, including the initial major use of CDF, a large general purpose detector. Each experimental collaboration has published results based on the data taken since 1987. CDF has already published 13 papers and submitted three additional articles for publication. These include results on precision measurements of the W and Z° masses from the 1988-89 data. A second large general purpose detector, D0, is under construction and will be operated for the first time in 1991. CDF and D0 have the unique opportunity to explore the mass region beyond the W and Z° and to make precision measurements of the properties of the W. These detectors will be upgraded to handle the increased luminosity promised by Fermilab III. A major objective of these detectors is the discovery and study of the top quark.

## 3. Fixed-Target Program

Eighteen fixed-target experiments will take data in eleven beams during 1990 and 1991. The initial objectives of almost all of these experiments will be completed. The goals of these experiments include measurements of the properties of the charmed quark and the beauty quark, a search for the understanding of the origin of CP violation, measurements of the properties of hyperons and charmed baryons, and the measurements of nucleon structure functions. In addition, four beams will be dedicated to testing sub-systems for

seven collider detectors or generic R&D tests for the SSC. The overall level of activity is not expected to change for the foreseeable future.

## 4. Computing Program

This program is directed at developing and implementing parallel computing and data handling techniques that will allow affordable solutions for the event-by-event data analysis problem and also the calculations of the properties of hadrons from the basic theory of QCD in the lattice approximation. There is also anticipated to be a program of research into analysis visualization tools and software engineering tools to aid the development of software for the analysis of data by large, dispersed physics collaborations.

## 5. HEPNET

In response to DOE's HEPNET Review Committee recommendations, the DOE has made Fermilab responsible for HEPNET management. The increased growth in the size, complexity and new technological opportunities mandated a more coherent, full time dedicated effort to get the most of the resources used for this networking. Fermilab's role will be to implement, monitor and speak for the capabilities provided to the U.S. high-energy physics community and to expand on these services by providing higher level services to the users, e.g., directories, video conferencing and networking tools.

## 6. Theoretical Particle Physics

The Theoretical Particle Physics Group works on a broad range of problems extending from the phenomenology of high-energy hadron collisions, perturbative QCD and nonperturbative field theory to lattice gauge theory and superstrings. An active visitors program allows visitors an opportunity to carry out research in a setting close to experiments.

## 7. Theoretical Astrophysics

The Theoretical Astrophysics Group is exploring the connections between particle physics and astrophysics. The main emphasis of the group's work has been the study of the very early universe. Part of the group's support comes from the Office of Space Sciences and Applications of NASA.

## B. WORK FOR OTHERS

Fermilab carries out work for others. It operates the Linac for the Rush Presbyterian St. Luke's Medical Center in order to provide a source of neutrons suitable for treating certain types of cancers. This program is expected to continue indefinitely. Fermilab has built a 250 MeV proton synchrotron for the Loma Linda University Medical Center. The Accelerator has been shipped to Loma Linda and will be used at the Loma Linda University Medical Center for cancer therapy and other diseases which respond to proton therapy. Details of this program can be found in Appendix 1.

# VI. ISSUES

## A. FERMILAB COLLABORATIVE EFFORTS ON SSC DETECTORS

Our initiative to participate in the R&D, conceptual design and proposal preparation for one of the SSC detectors requires the participation of Fermilab engineers and technicians. Fermilab has already taken a major role in one EOI and has allowed a few physicists to contribute their research time to a second EOI. In both cases the DOE has provided funds to Fermilab, among others, for generic R&D and systems R&D that were relevant to these EOI's. The salary costs of certain engineers, computer scientists and technicians, together with materials costs, were paid for from these funds. The preparation of proposals for the detectors will require both software and hardware engineering. It would be natural if these people continued their efforts. We seek guidance from the Department on the extent to which High Energy Physics funds allocated to Fermilab may be expended for this purpose.

## B. MAGNET TECHNOLOGY EFFORT

Designing, developing, constructing, and operating the first superconducting accelerator in the world placed Fermilab in a position to make essential contributions to the SSC R&D program.

Fermilab was asked by the SSC Central Design Group and then later by the SSCL to make a major contribution to the SSC Magnet R&D. Fermilab responded by expanding its superconducting magnet fabrication and testing capability to meet the needs of the SSC magnet program during the past six years, using funds provided by the SSC. Recently the SSC Laboratory requested that Fermilab take a lead role in the design and construction of the first full length 50mm SSC dipole magnets. In addition, Fermilab was asked to assist in the transfer of this technology to an SSC industrial contractor. This transfer is to be achieved at the laboratory site using Fermilab developed magnet tooling. The ultimate goal of this program is the construction of SSC dipoles by the industrial contractor using the Fermilab tooling and facilities.

Over the years the size of the SSC program at Fermilab has grown to the point where it will require roughly $20M per year to achieve the objectives set by the SSC. It is reasonable to presume that in three to four years the SSC will not need the support of Fermilab. Given the possible importance of superconductivity to the nation, it would be a mistake to allow the program to diminish once again. Fermilab's capabilities in these areas should be preserved for the benefit of the Fermilab program, and to contribute to a strong capability in applied superconductivity within the overall DOE Laboratory system.

In addition to the superconducting magnet effort, Fermilab also has a significant capability in the area of conventional magnets. Maintenance of this capability is essential for the success of the Main Injector project and the ongoing Fermilab program.

## C. THE PURSUIT OF NEW DIRECTIONS WITHIN THE LABORATORY MISSION

As has been noted earlier, the future health of the Fermi National Accelerator Laboratory depends on 1) the implementation and utilization of the Fermilab III program, 2) making preparations to make another bold leap toward a new accelerator technology, 3) preparing for the participation in the utilization of the SSC and 4) seeking new directions within the laboratory mission. By early in the twenty-first century the highest energy accelerator in the world will be in Texas. In order for Fermilab to remain in the forefront of particle physics it must fulfill its mission in ways other than providing accelerator facilities at the energy frontier of hadron colliders.

The fourth ingredient is an essential one. Progress in the related fields of High Energy Physics, Cosmology and Astrophysics has led to a growing interrelationship and interdependence among them. Experimental and theoretical advances in any one of the subfields has potentially profound consequences on the others. It is therefore natural and desirable for Fermilab to pursue research on topics in Cosmology and Astrophysics which impact on the major questions of particle physics. Through the efforts of the Fermilab Theoretical Astrophysics Group we have already seen the positive consequences of investment in this new direction.

We seek a dialogue with the Department which will clarify and address possible concerns as we pursue new directions within the mission which could lead, for example, to the support of experimental activity in Particle Astrophysics. It is noteworthy in this context that the HEPAP Subpanel on the U.S. High Energy Physics Research Program for the 1990's "recommends that both nonaccelerator and foreign-based experiments continue to be strongly supported."

## D. DOE ORDERS AND THE APPLICATION OF NUCLEAR STANDARDS TO FERMILAB

Accelerators do not pose the risk of nuclear reactors. There are quantitative physics differences between the risks posed by accelerators and nuclear reactors or waste repositories. Application of nuclear reactor standards would increase substantially the costs of operating accelerator laboratories without a commensurate benefit in safety. It is suggested that a more efficient and appropriate approach would involve a graded standard for accelerator laboratories

which properly considers the benefits and risks at these institutions. Fermilab would welcome the opportunity to assist in the development of such standards.

# VII. EDUCATION AND TECHNOLOGY TRANSFER PROGRAMS

## A. SUPPORT OF SCIENTIFIC AND TECHNICAL EDUCATION

Fermilab is committed to the goal of stimulating science education and scientific literacy. The scope of the programs presently operating at the Laboratory span the spectrum from elementary students to graduate research scientists in training. This effort also includes an international program aimed at Latin American countries.

Currently, Fermilab offers 34 precollege education programs. The proposed Education and Conference Center (ECC) will provide a home within the Laboratory for the many educational programs that reach elementary and secondary school students and teachers. These programs have been developed on a voluntary basis at Fermilab over the past ten years. The ECC will also provide visitors with information about Fermilab. It will offer all who participate in its programs actual experiences through interactive science materials and education programs. These experiences will foster an understanding of the elementary particles and forces that constitute our universe and the relationship of these phenomena to the origin of the universe itself.

Other dimensions of Fermilab's commitment to education are expressed with programs geared for undergraduates. The two undergraduate programs include summer employment for a select group of 20-25 science students by the Physics Department, and participation in GEM, a consortium of industry and universities whose objective is to increase the number of minority students in graduate engineering studies.

On the graduate and post-graduate level, Fermilab sponsors a joint University-Fermilab graduate program in accelerator physics to train an additional supply of Ph.D. accelerator physicists. Fermilab's Latin American Program is designed to extend the pool of available accelerator physicists internationally by collaborating with Latin American universities to the train experimental particle physicists.

Also, in collaboration with other laboratories and U.S. universities, Fermilab helps sponsor the U.S. Particle Accelerator School which is conducted annually at various locations around the U.S. This program was motivated by a recommendation of HEPAP in 1979-80. The goal of the program is to encourage more scientists and students to work in the field of accelerator physics.

## B. TECHNOLOGY TRANSFER

The Office of Research and Technology Applications (ORTA), located within the Director's Office, is the focal point for technology transfer, licensing

and commercialization activities at Fermilab. The activities of the ORTA fall into five broad areas. These include the Fermilab Industrial Affiliates organization, a technology assessment activity, the patent and copyright licensing program, coordination of industry-laboratory joint programs such as technology exchanges, and operation of a State of Illinois funded Technology Center. In addition, the ORTA, publishes a technology newsletter called FermiTec about ten times per year. FermiTec is directed at the Industrial Affiliates and primary technology news outlets.

Major programmatic technology transfer efforts are the responsibility of the Divisions or Sections involved in the specific program. Examples of significant technology transfers that have occurred include the dissemination of know-how related to SSC magnet fabrication, medical applications for particle accelerators, and the development and use of parallel computing architecture and software exemplified by the award-winning ACP system.

# VIII. HUMAN RESOURCES

## A. LABORATORY PERSONNEL SUMMARY

Fermilab has benefitted from a relatively stable workforce and has a basic complement of people at every level. Increasing demands for persons with accelerator and/or cryogenic technology experience is generating pressure on our retention rate for skilled staff members. The Laboratory Organization Chart is shown in Chapter X. Our major human resource issues are twofold: 1) the replacement of existing skilled workers as a result of retirements and 2) the loss of staff through recruitment activities outside the Laboratory. The average age of the Fermilab staff is 40.0 years which maintains an optimum blend of mature experience and youthful enthusiasm. While there are a number of issues associated with the Laboratory's human resources, this section will only discuss two of the most crucial ones. First, Fermilab's use of superconducting magnets throughout the facility has forced it to develop cryogenics and controls technologies on a scale that does not exist in industry. The labor pool to support this activity did not exist over a decade ago. To meet this demand, the Laboratory acquired people with general technical skills and trained them in the tasks of developing, maintaining, and improving cryogenic technologies and facilities. The Laboratory has also met this need by upgrading the skills of the existing technical staff. Tables VIII-1 and VIII-2 show the basic personnel data for Fermilab.

The second major personnel resource was driven by the high level of technology needed to commission and operate the Tevatron. Staffing needs have increased the requirements for engineers, programmers, electronics technicians, and accelerator physicists, both in the numbers of people needed and in their level of training. The number of scientists and engineers relative to support staff continues to increase, reflecting an adjustment to these technological advancements. The most crucial part of Fermilab's personnel planning strategy involves the training of replacements for some of the highest skills, a task which often requires years of overlap. Because the Tevatron drove major advances in superconducting accelerator magnet fabrication and cryogenics, the builders of the Tevatron are in demand for new projects using these technologies. For example, most of the fifty Fermilab employees that have joined the SSC have experience in these areas. Anticipation of retirements also has an impact on manpower planning. An important point to note here is that there are few people with the necessary experience in accelerator technology in industry. This scenario is not likely to change.

Major near-term changes included in our projections reflect a shift in Laboratory needs caused by the completion of several major construction projects and the subsequent emphasis on the operation of these newly constructed

facilities for physics. Our projections are also focussed on the personnel needed to carry out facilities improvements.

The Laboratory has a number of on-going programs aimed at improving the skill levels of existing staff. These include the Academic Lecture Series, seminars, cooperative education efforts in-house (IITV program), and a tuition reimbursement program. A major component of the Laboratory's response to maintaining a technically capable workforce includes "on-the-job training", post-doctoral appointments, and encouraging training through programs available in relevant industries. This broad spectrum of programs has improved the level of technical skills of Laboratory employees, and helped to ensure a continuity of quality and capabilities of the overall staff.

While the Laboratory has lost some key personnel to the SSC Laboratory and other major accelerator projects, a solid base of technically skilled workers has allowed the absorption of these losses.

In order for Fermilab to carry out its physics mission, we will continue our vigorous program of recruiting and training. Laboratory policy will constantly be reviewed to maintain Fermilab as an attractive place for technical people to work. In addition to benefiting the Laboratory, this approach will ultimately contribute to the technical resources in the field of particle physics. With regard to the scientific and engineering staff, special attention will be paid to maintaining forefront R&D efforts and the associated technical challenges. The Laboratory salary structure must provide the opportunity to attract the very best and brightest in all relevant fields with comparisons made on a national basis. One area of concern in this regard is that at the present time the average salaries for Fermilab scientists continue to be low. This is an area that demands ongoing attention. The Laboratory and the DOE must continue to work together to assure success in these areas.

The following tables reflect the impact of increasing the technological skills represented by the Laboratory staff. Note the increased numbers of scientists and engineers while the total employee count is lower. The recruiting networks and appointment framework which were developed to produce these recent results are intact and will be continued in order to assure scientific vitality.

## TABLE VIII-1

## LABORATORY STAFF COMPOSITION

| Professional Staff | Ph.D. | MS/MA | BS/BA | Other |
|---|---|---|---|---|
| Scientists | 237 | 44 | | |
| Technical Support | 31 | 40 | 81 | 31 |
| Engineers | 4 | 65 | 110 | 2 |
| Admin. & Mgmt. | 9 | 20 | 90 | 285 |
| **Support Staff** | | | | |
| Technicians | | 11 | 93 | 595 |
| Others | | | 17 | 395 |
| Laboratory Total | 281 | 180 | 391 | 1308 |

TABLE VIII-2

PROFESSIONAL STAFF EXPERIENCE
FY (Year End)

| YEARS SINCE B.S. DEGREE | SCIENTISTS 1984 | SCIENTISTS 1989 | ENGINEERS 1984 | ENGINEERS 1989 |
|---|---|---|---|---|
| Less than 10 | 34 | 37 | 47 | 55 |
| 11 - 20 | 77 | 91 | 34 | 45 |
| 21 - 30 | 53 | 67 | 27 | 30 |
| 31 - 40 | 16 | 25 | 20 | 19 |
| 41 + | 3 | 4 | 1 | 1 |
| TOTAL | 183 | 224 | 129 | 150 |

PHYSICIST AVERAGE AGE: 43.7 (1984), 43.8 (1989)

## EQUAL EMPLOYMENT OPPORTUNITY

The Laboratory maintains an active recruiting program to encourage minority and female participation in the workforce. In addition to recruiting efforts, a designated Equal Opportunity Office was established very early in the history of the Laboratory. The presence of minority and female personnel on the Fermilab staff plays a significant role in the human resource activities of the Laboratory. The Table below shows this distribution.

## TABLE VIII-3

## EQUAL EMPLOYMENT OPPORTUNITY
**FY (Year End)**

| FULL & PART-TIME EMPLOYEES | 1979* | 1984* | 1989 |
|---|---|---|---|
| White | 1268 | 1814 | 1803 |
| Black | 169 | 205 | 174 |
| Hispanic | 59 | 118 | 113 |
| Asian | 32 | 55 | 67 |
| American Indian or Alaskan Native | 1 | 0 | 0 |
| TOTALS | 1529 | 2192 | 2157 |
| Foreign Nationals | 76 | 127 | 180 |

| EMPLOYMENT - FY (Yr End) | 1979* | | 1984* | | 1989 | |
|---|---|---|---|---|---|---|
| | M | F | M | F | M | F |
| Professional Staff | | | | | | |
| Scientists & Engineers | 272 | 11 | 362 | 11 | 431 | 24 |
| Technical Support | 183 | 9 | 315 | 33 | 363 | 45 |
| Administration | 109 | 38 | 104 | 60 | 108 | 62 |
| Support Staff | | | | | | |
| Technicians | 467 | 70 | 742 | 123 | 625 | 91 |
| Others | 217 | 153 | 269 | 173 | 182 | 226 |
| LAB TOTALS | 1248 | 281 | 1792 | 400 | 1709 | 448 |

*Excludes janitorial group members subcontracted subsequent to 1984

# IX. SITE AND FACILITIES IMPROVEMENTS

## A. LABORATORY DESCRIPTION

In this chapter, we discuss the existing Laboratory facilities and their evolution over time to meet the needs of the projected Tevatron program. Fermilab's facilities are traditionally broken into three areas: 1) accelerator systems, 2) beam lines and experimental facilities, and 3) support facilities. Areas 2) and 3) encompass such things as computers, electronic data systems, Laboratory shops and fabrication areas. This breakdown reflects the Laboratory organization chart which is shown in Section X.

The Fermilab site is 21 years old. The original facilities were constructed between 1969 and 1972. Since that time, the Laboratory has made major improvements to the facilities, including the Tevatron I and Tevatron II Projects, the Computer Upgrade Project, and the construction of several large water collection ponds for the support of plant and experimental activities. We are currently in the midst of the Linac Upgrade Project and are requesting funding for the Fermilab Main Injector Project. However, there are some parts of the original facility that need additional improvements. The Laboratory machine shops and many of the Laboratory support shops are located in eight small industrial buildings in the Fermilab village. These industrial buildings in the village are now about twenty years old and should be replaced with newer facilities at a location more convenient to the present Laboratory operations. This action would also serve to separate the functions of visitor housing and light industrial manufacturing presently intermixed in the village. Also needed are more warehouse facilities and space for support services and administrative personnel.

## B. FACILITIES PLANT AND OPTIONS

### Line Item Construction

The facilities improvement budgets shown in Table IX-1 reflect the plan to further exploit the upgraded Tevatron. This includes two line item construction projects to be funded by the Office of Energy Research: the Linac Upgrade Project of $22.8 million and the Main Injector of $173.4 million. The Linac Upgrade, which is a funded project beginning in FY 1990, is scheduled to be completed in FY 1992. The Main Injector Project, proposed to begin in FY 1992, will replace the present Fermilab Main Ring accelerator. Details of both projects are discussed at length in Appendix 1.

## General Plant Projects

The General Plant Projects (GPP) lines of the budgets shown in Table IX-1 are for miscellaneous small construction projects funded by the Office of Energy Research which cannot be identified beforehand and whose total estimated costs do not exceed $1.2 million per project. The Laboratory keeps a current list of such project requests which is updated annually and whose priorities are assigned at the beginning of each fiscal year in order to be responsive to the needs of the Laboratory. The FY 1990 list includes such projects as cooling water improvements by enlarging the Casey's Pond reservoir and connecting Casey's Pond and Lake Law with a pipeline (additional details of these two projects are discussed in Appendix 2), construction of an education center, construction of additional parking to supplement the parking at Wilson Hall, installation of a second water connection to Warrenville in order to have a backup supply for the village water, the installation of an alternate gas supply line to the Central Utility Building, completion of the Facilities Management building, and various fire protection projects. The proposed lists for FY 1991 and FY 1992 include various building additions, various remodeling building projects, more fire protection improvements, a new fueling station, and a new gas and flammable liquid storage building. The amounts shown for FY91-FY96 are based on escalating the base year FY90 at a 5% annual rate. One project is requested from the Office of Environmental Restoration and Waste Management in FY 1992 for a new radioactive waste sorting and packaging facility.

## Accelerator Improvement Projects

The Accelerator Improvement Projects (AIP) line of the budgets shown in Table IX-1 are for small projects funded by the Office of Energy Research which either improve the performance of the existing accelerators or allow for the better utilization of the existing accelerators which are too small to be proposed as a line item. The Laboratory keeps a current list of such project requests which is updated annually and whose priorities are assigned at the beginning of each fiscal year in order to be responsive to the needs of the program. The FY 1990 list includes such projects as Tevatron cold iron quadrupole improvements, a new Tevatron abort system, separated orbit harmonic corrector magnets, control system improvements for both consoles and front ends, beamline controls improvements, and improvements to the P Center beamline. The proposed lists for FY 1991 and FY 1992 include new Tevatron fast kicker magnets, some new cold compressors for the Tevatron cryogenic system, a central computer upgrade for the Tevatron controls system, a stacktail kicker upgrade for the antiproton source, improvements to both the B0 and D0 beampipes, improvements to the beamline controls CAMAC system, Meson Area shielding improvements, Tevatron power systems upgrade, Main Ring beam profile monitor improvements, a Tevatron refrigerator cryogenic antiproton source, modifications to the beam switchyard for 900 GeV operation, and a possible new

150 GeV primary beamline in the experimental areas. The amounts shown for FY91-FY96 are based on escalating the base year FY90 at a 5% annual rate.

**In House Energy Management Projects**

The In House Energy Management (IHEM) budgets shown in Table IX-1 fund various energy retrofit projects proposed as energy conservation measures. These projects are funded by the Office of Energy Research. The main source of these funding requests is the analysis of our energy usage needs by the Fermilab Facility Management staff and suggestions arising from the Fermilab Energy Conservation Award Program. The FY 1990 projects are to provide a chilled water free cooling heat exchanger and a direct digital control system for the HVAC at the CDF experimental hall. The proposed FY 1991 project would convert the Technical Support industrial building complex from electric to natural gas heat. The FY 1992 list includes various lighting conversion projects.

**General Purpose Facilities**

The General Purpose Facilities budgets shown in Table IX-1 are line item construction projects funded by the Office of Energy Research estimated to cost more than the GPP limit of $1.2 million and which are required to support the long-term administrative and technical needs of DOE operated laboratories and facilities. Fermilab recently became eligible to receive such funds. Previously these funds had been restricted for use at the DOE multipurpose laboratories. FY 1992 is the first year that such funds have been requested by Fermilab. The intention is to use such funds for light or heavy duty laboratories, administrative offices, machine shops, electrical utilities, roads, and warehouses.

The FY 1992 request includes as the highest priority a request for $3.3 million for a Science Conference Center. This would be located adjacent to the Fermilab Science Education Center (FY90 GPP project) and would, together with the Science Education Center, form a much needed complex where we could handle scientific meetings in the 100-300 person range. It would be equipped with state of the art teleconferencing equipment so that it could form the node for connection to other conference facilities anywhere in the U.S. or abroad. It is anticipated that this center would be heavily used by both the education community and the scientific community. Other proposed projects for FY 1992 are a Support Services Building for $1.5 million that would allow various service groups now located around the site to be collected in one location at Site 39 and Industrial Building 6 for $3.75 million which would provide a heavy laboratory for construction of experimental equipment. The increasing size and weight of HEP equipment requires a 50 ton crane bay and many detector component assembly operations require relatively clean, temperature controlled work conditions. Such a building

would be used to support both the Fermilab HEP program and the SSC detector test program as it becomes operational at Fermilab.

Anticipated requests in FY 1993 include $6.8 million for a new office building adjacent to Wilson Hall which would house both business services and accelerator personnel, $2.5 million for a third warehouse at Site 38, and $3.94 million for Industrial Building 7 which would replace Lab 2 and Lab 5 presently located in the Fermilab village. FY 1994 shows anticipated requests for $2.75 million to fund a new accelerator control room, $1.5 million to relocate the outdoor storage area from the railhead to Site 38 for better material control, and $4.13 million for Industrial Building 8 which would replace the village machine shop and cut shop. FY 1995 and FY 1996 show Industrial Buildings 9, 10, 11, and 12 which would replace Village Labs 3, 6, 7, and 8, thus completing the move of technical areas from the village to the Technical Support industrial area.

## C. FACILITIES RESOURCE REQUIREMENTS

Table IX-1 shows the costs for all plant projects either under construction or currently planned for the FY 1989 to FY 1996 period.

## TABLE IX-1

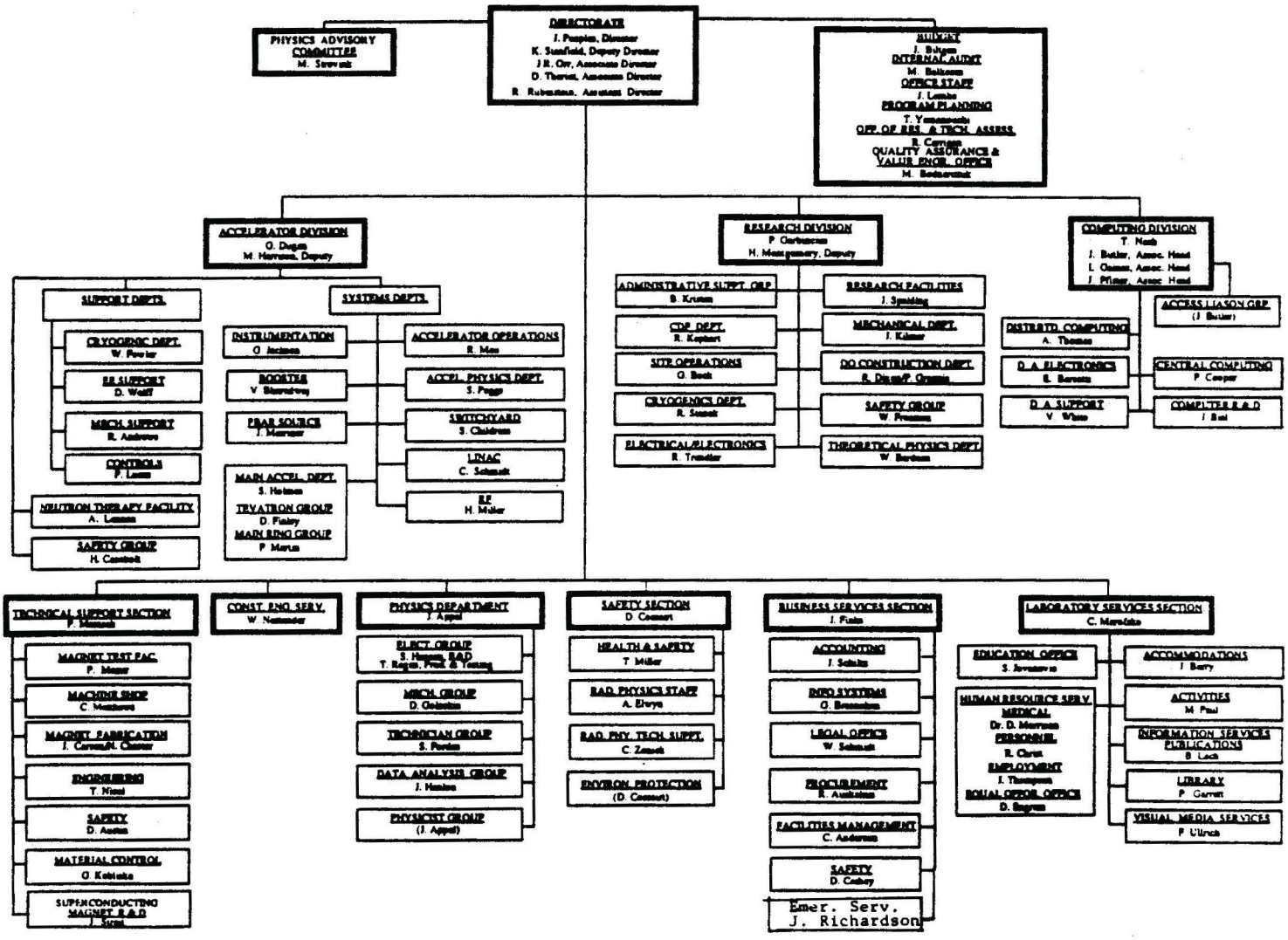
### Major Construction Projects

| | TEC | FY89 | FY90 | FY91 | FY92 | FY93 | FY94 | FY95 | FY96 |
|---|---|---|---|---|---|---|---|---|---|
| Funded Construction | | | | | | | | | |
| Program Related Projects | | | | | | | | | |
| Central Computing Upgrade | 24.6 | 3.6 | | | | | | | |
| Linac Upgrade (KA) | 22.8 | | 4.6 | 12.0 | 6.2 | | | | |
| General Plant Projects (KA) | | 3.0 | 3.6 | | | | | | |
| Accel. Improvement Projects (KA) | | 6.1 | 6.9 | | | | | | |
| In House Energy Management (WB) | | 1.4 | 0.2 | | | | | | |
| Total Funded | | 14.1 | 15.4 | 12.0 | 6.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| Budgeted Construction | | | | | | | | | |
| General Plant Projects (KA) | | | | 3.8 | | | | | |
| Accel. Improvement Projects (KA) | | | | 7.3 | | | | | |
| In House Energy Projects (WB) | | | | 1.1 | | | | | |
| Total Budgeted | | | | 12.2 | | | | | |
| Total Funded and Budgeted | | 14.1 | 15.4 | 24.2 | 6.2 | | | | |
| Proposed Construction | | | | | | | | | |
| Program Related Projects | | | | | | | | | |
| Main Injector (KA) | 173.4 | | | | 51.1 | 79.5 | 42.8 | | |
| General Plant Projects (KA) | | | | | 4.0 | 4.2 | 4.4 | 4.6 | 4.9 |
| General Plant Projects (EX) | | | | | 1.2 | | | | |
| Accel. Improvement Projects (KA) | | | | | 7.6 | 8.0 | 8.4 | 8.8 | 9.2 |
| In House Energy Management (WB) | | | | | 0.3 | 0.8 | 0.8 | 0.8 | 0.8 |
| General Purpose Facilities (KG) | | | | | | | | | |
| Science Conference Center | 3.3 | | | | 3.3 | | | | |
| Support Services Building | 1.5 | | | | 1.5 | | | | |
| Industrial Building 6 | 3.8 | | | | 3.8 | | | | |
| West Office Building | 6.8 | | | | | 0.4 | 4.0 | 2.4 | |
| Warehouse 3 | 2.5 | | | | | 2.5 | | | |
| Industrial Building 7 | 3.9 | | | | | 3.9 | | | |
| New Accelerator Control Room | 2.8 | | | | | | 2.8 | | |
| Relocate Outside Storage Yard | 1.5 | | | | | | 1.5 | | |
| Industrial Building 8 | 4.1 | | | | | | 4.1 | | |
| Industrial Building 9 | 4.3 | | | | | | | 4.3 | |
| Industrial Building 10 | | | | | | | | 4.3 | |
| Industrial Building 11 | | | | | | | | | 4.6 |
| Industrial Building 12 | 4.6 | | | | | | | | 4.6 |
| Total Proposed | | | | | 72.8 | 99.3 | 68.8 | 25.3 | 24.0 |
| **Total Funded, Budgeted, and Proposed** | | **14.1** | **15.4** | **24.2** | **79.0** | **99.3** | **68.8** | **25.3** | **24.0** |

# X. RESOURCE PROJECTIONS

## A. LABORATORY ORGANIZATION CHART

THE FERMI NATIONAL ACCELERATOR LABORATORY ORGANIZATION CHART APRIL 1990



## B. LABORATORY FUNDING SUMMARY

The distribution of Laboratory resources by major DOE program is given in the table below.

**TABLE X-1**

**Resources by Major DOE Program (1)**
**($ in Millions)**
**(Personnel in FTE)**

| PROGRAM | FY89 | FY90 | FY91 | FY92 | FY93 | FY94 | FY95 | FY96 |
|---|---|---|---|---|---|---|---|---|
| KA - High Energy Physics | | | | | | | | |
| Operating | | | | | | | | |
| Fermilab (2) | 147.0 | 154.6 | 154.3 | 185.5 | 199.2 | 197.4 | 204.0 | 212.2 |
| SSC | 12.2 | 0.3 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Capital Equipment | | | | | | | | |
| Fermilab | 30.3 | 29.9 | 29.8 | 36.5 | 40.2 | 41.0 | 46.7 | 43.9 |
| SSC | 1.6 | 0.5 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Construction | 12.7 | 15.2 | 23.1 | 78.7 | 98.5 | 68.0 | 24.5 | 23.2 |
| TOTAL KA | 203.8 | 200.5 | 207.5 | 300.7 | 337.9 | 306.4 | 275.2 | 279.3 |
| WN - Work for Others | | | | | | | | |
| Operating | 3.3 | 2.4 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 |
| Miscellaneous | | | | | | | | |
| Operating | 0.5 | 1.3 | 1.7 | 2.1 | 2.2 | 2.3 | 2.3 | 2.4 |
| Construction | 1.4 | 0.2 | 1.1 | 0.3 | 0.8 | 0.8 | 0.8 | 0.8 |
| TOTAL Misc | 1.9 | 1.5 | 2.8 | 2.4 | 3.0 | 3.1 | 3.1 | 3.2 |
| DIRECT PERSONNEL | 1,233 | 1,270 | 1,290 | 1,293 | 1,293 | 1,293 | 1,293 | 1,293 |

(1) Base programs, including submitted projects.
(2) Research Support (KA 01-02) excluded

## TABLE X-2

### Laboratory Funding Summary
### ($ in Millions)

| | Fiscal Years | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | FY89 | FY90 | FY91 | FY92 | FY93 | FY94 | FY95 | FY96 |
| DOE Effort | | | | | | | | |
| - Fermilab | 147.5 | 155.9 | 156.0 | 187.6 | 201.4 | 199.7 | 206.3 | 214.6 |
| - SSC | 12.2 | 0.3 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Subtotal | 159.7 | 156.2 | 156.1 | 187.6 | 201.4 | 199.7 | 206.3 | 214.6 |
| Work for Others | 3.3 | 2.4 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 |
| TOTAL OPERATING | 163.0 | 158.6 | 156.8 | 188.3 | 202.1 | 200.4 | 207.0 | 215.3 |
| Capital Equipment | | | | | | | | |
| - Fermilab | 30.3 | 29.9 | 29.8 | 36.5 | 40.2 | 41.0 | 41.7 | 38.9 |
| - SSC | 1.6 | 0.5 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Subtotal | 31.9 | 30.4 | 30.0 | 36.5 | 40.2 | 41.0 | 41.7 | 38.9 |
| Program Construction | | | | | | | | |
| Central Computing Upgrade | 3.6 | - | - | - | - | - | - | - |
| Linac Upgrade | - | 4.6 | 12.0 | 6.2 | - | - | - | - |
| AIP/GPP (KA) | 9.1 | 10.6 | 11.1 | 11.6 | 12.2 | 12.8 | 13.4 | 14.1 |
| GPP (EX) | 0.0 | 0.0 | 0.0 | 1.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| GPF (KG) | 0.0 | 0.0 | 0.0 | 8.6 | 6.8 | 12.4 | 11.1 | 9.1 |
| In-House Energy Mgmt. | 1.4 | 0.2 | 1.1 | 0.3 | 0.8 | 0.8 | 0.8 | 0.8 |
| Subtotal | 14.1 | 15.4 | 24.2 | 27.9 | 19.8 | 26.0 | 25.3 | 24.0 |
| TOTAL LABORATORY FUNDING | 209.0 | 204.4 | 211.0 | 252.7 | 262.1 | 267.4 | 274.0 | 278.2 |
| PROPOSED CONSTRUCTION | | | | | | | | |
| Main Injector | - | - | - | 51.1 | 79.5 | 42.8 | - | - |
| PROPOSED MAJOR EQUIPMENT | | | | | | | | |
| Computer Systems | - | - | - | - | - | - | 5.0 | 5.0 |
| **TOTAL FUNDING** | **209.0** | **204.4** | **211.0** | **303.8** | **341.6** | **310.2** | **279.0** | **283.2** |

## C. LABORATORY PERSONNEL SUMMARY

The table below represents a Laboratory personnel summary:

**TABLE X-3**

**Laboratory Personnel Summary**
(Personnel in FTE)

| | FY89 | FY90 | FY91 | FY92 | FY93 | FY94 | FY95 | FY96 |
|---|---|---|---|---|---|---|---|---|
| Direct | 1,233 | 1,270 | 1,290 | 1,293 | 1,293 | 1,293 | 1,293 | 1,293 |
| Charge-Back | 357 | 354 | 355 | 355 | 355 | 355 | 355 | 355 |
| Indirect | 550 | 560 | 561 | 562 | 563 | 564 | 566 | 567 |
| TOTAL Laboratory Personnel | 2,140 | 2,176 | 2,206 | 2,210 | 2,202 | 2,202 | 2,202 | 2,202 |

# APPENDIX 1

# DETAILS OF SCIENTIFIC PROGRAM

## A. CURRENT PROGRAMS

### FERMILAB III

The starting point for Fermilab III is the upgrade of the Tevatron collider and fixed-target facilities. During the 1987-88 fixed-target run, the Tevatron delivered a total of $2.2 \times 10^{18}$ protons at 800 GeV to the experimental areas and the peak intensity in the extracted beam reached $1.8 \times 10^{13}$ protons per cycle. This was the largest number of protons delivered to the fixed-target program since the Tevatron started operations in 1984. Since the fixed-target experimental program could efficiently use a factor of three more protons per cycle, a greater extracted beam intensity would lead to a more productive research program. During the 1988-89 collider run, the Tevatron collider achieved a peak luminosity of $2.1 \times 10^{30}$ $cm^{-2}sec^{-1}$, twice the design luminosity. This was achieved at an energy of 1800 GeV in the center-of-mass, nearly three times greater than the energy of the CERN $Sp\bar{p}S$ which is the only other high-energy hadron collider now in operation. Almost 10 $pb^{-1}$ of integrated luminosity was delivered by the Tevatron to CDF. This stunning achievement was greater than the integrated luminosity delivered by the CERN $Sp\bar{p}S$ between 1981 and 1987 and it was achieved after only two years of operation.

The Tevatron, supported by the whole Fermilab complex of accelerators, provides a sound base upon which to increase the luminosity and energy. The luminosity increase will occur in a series of steps, each of which provides a factor of at least two to three increase in luminosity at the beginning of each collider run. Each step is carefully matched to improvements in the ability of the CDF and D0 detectors to use the increased luminosity. The upgrade, when completed, will provide a peak luminosity of $>5 \times 10^{31} cm^{-2}sec^{-1}$ at 2 TeV center-of-mass. The accelerator improvements will also benefit the fixed-target physics experiments, because it will produce a much higher intensity primary beam than is currently available.

### 1. Tevatron Improvements

Improvements currently underway for the Tevatron consist of 1) the implementation of the D0 low-beta quadrupole system, a requirement for delivering high luminosity to the D0 Detector, 2) a beam separator system, a prerequisite for increasing the luminosity, 3) the new B0 low-beta quadrupole

system which will be identical to the D0 low-beta system, a requirement for simultaneously achieving high luminosity at B0 and D0, and 4) a new Tevatron abort system at A0. All four improvements will be completed in FY 1991 prior to the start of the 1991 Collider run, collider run 1.

The beam separator system consists of twenty-three pairs of electrostatic plates that deflect the counter-rotating antiproton-proton beams onto spiral orbits so that they collide only at the B0 and D0 interactions regions. At present, the six bunches of protons and six bunches of antiprotons collide in twelve locations. By separating the beams at the other ten locations, the strength of the destabilizing beam-beam interaction will be reduced by a factor of 6. The separators make it possible to store up to thirty-six bunches of each particle type and still have only two collision points. Because the strength of the beam-beam interaction will be made independent of the number of bunches, the luminosity can be increased. The number of bunches can be increased to 36 after a new injection kicker is built. The R&D for this kicker will be started in 1991 and completion could be as early as 1992. The number of bunches will not be increased until the CDF and D0 detectors have been upgraded to handle the shorter bunch spacing. This could be either collider run 2 or 3.

An increase in the Tevatron center-of-mass energy to ~2.0 TeV will also be undertaken. By reducing the operating temperature of the Tevatron cryogenic system by about 0.5 degrees Kelvin with a system of cold compressors located in the satellite refrigeration buildings, the collider energy will be increased to 1000 GeV per beam. Since this improvement could be completed soon after the Linac Upgrade is completed it could be used in collider run 2.

These improvements (initiated in FY 1987), began as accelerator R&D projects. The R&D effort, which is nearly complete, has demonstrated that each improvement will work and that the prototype components will perform as intended. The production of the final components is being carried out as a set of Accelerator Improvement Projects (AIP).

Beyond these improvements additional increases in luminosity could be achieved by decreasing the bunch spacing by a factor of two and developing bunched beam cooling. These are examples of modest projects that could be completed near the end of the 1990's and thus lead to an enhancement of the Collider Program in the twenty-first century.

## 2. Antiproton Source Improvements

A number of improvements are under way in the Antiproton Source which will increase the antiproton production rate from $2\times10^{10}$/hr to $3.5\times10^{10}$/hr during Collider run 1. The aperture of the Debuncher Ring has been increased from $20\pi$ to $30\pi$ (mm-mr) by increasing the separation of the cooling electrodes.

Additional beam cooling system power has been installed to compensate for the reduced sensitivity caused by separating the electrodes. The momentum acceptance of the Debuncher has been increased from 3% to 4% by installing a momentum cooling system. A planned 25% increase in average targeting repetition rate will increase the number of protons striking the antiproton target by 25% and hence 25% more antiprotons will be produced and subsequently delivered to the Debuncher. A 4-8 GHz core cooling system has been implemented in the accumulator, thereby allowing a greater stacking rate, and more importantly, a smaller antiproton beam emittance when intense beams of up to $10^{12}$ antiprotons are stored in the Accumulator.

As is the case with the Tevatron improvements, these were first initiated as R&D projects to demonstrate feasibility. When a large number of identical components needed to be fabricated or purchased, the remainder of the work was carried out as an Accelerator Improvement Project. These projects should be completed in FY 1990 and FY 1991 in time for the 1991 collider run.

Starting in FY 1991, additional improvements will be made to the Antiproton Source target station. These include a beam sweeping system to mitigate the destructive heating caused by the proton beam as it strikes the Antiproton target and improvements to the Accumulator stack-tail cooling system. These improvements should be ready for collider run 2, which follows the collider run that begins in fall of 1991.

## 4. Linac Upgrade

This project is a $22.7M line-item construction project which received $4.7M of funds in FY 1990 and $12M has been appropriated for FY 1991. If funding for FY 1992 is as expected the project will be completed at the end of FY 1992. The energy of the Linac will increase from 200 MeV to 400 MeV by replacing the downstream half of the present 201 MHz Drift Tube Linac with an 805 MHz side coupled cavity accelerating structure. The new structure will provide three times the present accelerating gradient. By increasing the Booster injection energy from 200 MeV to 400 MeV, the beam emittance growth that takes place at injection will be reduced. As a result, it will be possible to inject either smaller emittance beams at present intensities or present emittance beams at higher intensities into the Main Ring. Because this project can increase the intensity of the maximum emittance that can be captured in the Main Ring by a factor of 1.7, it will increase antiproton production by the same factor. The transverse emittance of a beam with a bunch intensity of 1.5 to $2.0 \times 10^{10}$ protons delivered by the Booster to the Main Ring should be smaller than it is now by the same factor. The smaller emittance will allow the formation of more intense proton bunches for Collider operation. Each of these effects will contribute to an increase in the luminosity and the entire Linac Upgrade is expected to increase the luminosity of the collider

beyond $10^{31}$ $cm^{-2}$ $sec^{-1}$. The upgraded Linac will be used for the first time in collider run 2, which follows the collider run that begins in the fall of 1991.

## 5. The Main Injector

This project is a line-item construction project which was submitted by Fermilab to the DOE in January 1990. A diagram at the end of this appendix shows the physical lay-out of the Main Injector relative to the existing facilities. Fermilab has requested that funding start in FY 1992 and continue at a rate that will allow completion in FY 1994. The project provides for the construction of a new accelerator, the Main Injector. It is about 3.3 km in circumference and is capable of accelerating protons to 150 GeV. In addition to a new accelerator enclosure, the project includes 300 conventional iron-core dipole magnets for the guide field, and five beam transfer lines that tie the Main Injector into the existing accelerator complex and transport slow extracted beam to the A0 Transfer Hall. From there it can be directed through the present Switchyard toward existing fixed-target areas. Many of the technical components in the existing Main Ring including quadrupole magnets, some power supplies, correction magnets, RF systems, some controls components, and diagnostic devices will be reused in the Main Injector. All of the Main Ring Components except for magnets between F0 and A0 will be removed. These magnets will be used to transfer the slow extracted beam from the Main Injector to A0.

The purpose of this project is to increase the luminosity of the Tevatron when it is operated as a proton-antiproton Collider, thereby increasing the data collection rate of the CDF and D0 detectors. A major source of experimental background in the D0 and CDF detectors caused by the proximity of the Main Ring to the detectors will be eliminated through its removal. It will also increase the number of protons which can be delivered to the Tevatron for acceleration and delivery to the fixed-target experimental areas. Because the Main Injector is in a separate tunnel, it will be possible to provide 120 GeV protons to the fixed-target experimental areas during collider operation without inducing unacceptable backgrounds in CDF and D0.

Substantially improved performance, relative to the existing Main Ring, is expected to result from improved magnetic field quality at injection and the shorter cycle time. Calculations show that the Main Injector should be capable of accelerating $3x10^{13}$ protons when filled with six Booster batches. The Main Injector is designed to cycle to 120 GeV in 1.5 seconds for antiproton production, as compared to 2.6 seconds in the existing Main Ring. As a result, the total number of protons that are extracted from the Main Injector per hour should increase by a factor of five times higher than can be achieved with the existing Main Ring. With the Main Injector, the Tevatron will be able to reach a luminosity in excess of $5x10^{31}cm^{-2}sec^{-1}$.

## COLLIDING-BEAM PHYSICS

The initial, very successful run of the Tevatron Collider took place in spring of 1987. The Tevatron delivered an integrated luminosity of about 10 $pb^{-1}$ to CDF during the second run, which extended from mid-1988 to mid-1989. This data has already provided the most precise measurements of the W mass and width; it has provided a test of Quantum Chromodynamics at the highest momentum transfer achieved in any laboratory; it has allowed the observation of B meson decays that are useful for searching for CP violation in B decays; and it has established that the top quark mass is greater than 90 $GeV/c^2$. When the Collider luminosity is increased by a factor of 50 (thus permitting the accumulation of an integrated luminosity in excess of 500 pb-1 during a 1-year run ($10^7$ sec)), each of the measurements will be significantly improved. For example, jet pairs with mass of up to 800 $GeV/c^2$ will be observed, the error in the mass of the W will be reduced below 50 MeV, and the top quark will be found if it conforms to the Standard Model. This will lead to a far greater sensitivity in searching for possible quark substructure than can be achieved at HERA in e-p collisions.

Six x six bunch operation will continue throughout the Collider run scheduled to begin in the fall of 1991. With the improvements mentioned earlier, a peak luminosity in excess of $5x10^{30}cm^{-2}sec^{-1}$ (exceeding the original design luminosity by over a factor of 5) should be obtained. The front-end electronics, trigger system, and data acquisition system of the CDF detector will be modified in order to handle six bunch operation at this luminosity without excessive dead-time. The tracking chamber closest to the beam pipe will be replaced with one that can withstand the higher luminosity. Part of this vertex system will consist of precision silicon strip detectors to thereby provide the ability to separate B decays from QCD background. The muon detection system will also be substantially improved. This will also be the first run with the complete D0 detector. D0 and CDF will extend the search for the top quark to higher masses.

Thirty-six x thirty-six bunch operation will be used for the first time during a subsequent Collider run, Collider run 2. Peak luminosities in excess of $10^{31}cm^{-2}sec^{-1}$ should be obtained by that time. CDF and D0 will incorporate electronic pipelines into their data acquisition systems in order to handle events from beam-beam crossing separated in time by as little as 400 nano-seconds, a condition that will exist with thirty-six x thirty-six bunch operation. The R&D has been started to develop the pipeline and related systems. D0 will also upgrade their trigger and data acquisition electronics to handle the higher luminosity and bunch structure. The increasing luminosity will require CDF to replace their gas calorimetry with a scintillator-based design that is faster and more radiation-hard technology. CDF also plans to extend their muon coverage as part of a calorimetry replacement package at the same time. The schedule for completing

these detector upgrades is dependent on the level of the annual appropriations. The number of bunches will not be increased to 36 until the detector upgrades are completed. When the luminosity climbs to greater than $2x10^{31}$ $cm^{-2}$ $sec^{-1}$, further upgrades to D0 and CDF track detection systems will be required. While the proposed upgrades are within the realm of current technology, the limits are pushed. Much of the technology that will be developed and tested in a real hadron collider environment is that relevant for future SSC experiments.

## 1. Top Quark Search

The data of 1988-89 run allowed CDF to place the most sensitive lower bound on the top quark mass at 89 GeV. The upgrade through the Main Injector would extend the sensitivity for top discovery to 250 GeV in a standard run of > 500 $pb^{-1}$ integrated luminosity, or would allow detailed study of a lower mass ~150 GeV top.

## 2. Bottom Quark Physics

The discovery of $B/\bar{B}$ quark mixing by UA-1 showed that it was possible to study the physics of the b quark at the Tevatron Collider. The very large cross section for producing pairs of b quarks, 45μ barns at 2 TeV in the center of mass, was already a strong incentive for searching B meson decays. The observation of fully reconstructed B decays from the data that CDF obtained in the 1988-89 run strengthened that incentive by showing that it was feasible to observe $B_d$ and $B_s$ mixing in the CDF detector if a microvertex detector was added. Even the observation of CP violation appears plausible because a 10 month collider run at a peak luminosity of $5x10^{31}cm^{-2}sec^{-1}$ will produce 20 billion hadrons containing b quarks at each collision point. The challenge is to be able to select these events from a background that is a thousand times larger. It is very likely that the intermediate goals of measuring the B production cross section and separately observing the mixing of the $B_s$ and $B_d$ mesons will be achieved in either Collider run 2 or 3. When these goals are achieved, the path will be clear to design a detector dedicated to B physics at the Tevatron Collider. The program of physics with this detector will continue after the SSC turns on.

## 3. $W^{\pm}$ and $Z^{\circ}$ Physics

The 4.7 $pb^{-1}$ data sample from the 1988-89 run allowed CDF to make a precision measurement of the $Z^{\circ}$ mass. The measurement of the $Z^{\circ}$ (although it has since been superseded by a more accurate measurements at SLAC and LEP) demonstrated the capability of the CDF detector to make this type of very precise measurement. The sample of 5000 W's yielded the most precise measurements

of the $W^{\pm}$ mass and a ratio of W to $Z^{\circ}$ width done to-date. These measurements provide the most critical test of the predicted relationships among the electroweak gauge boson masses and the weak mixing angle. The major other unknown in the Standard Model is the mass of the undiscovered sixth quark, the top. Accurate measurements of the W and $Z^{\circ}$ mass together with a measured mass for the top quark will provide an important test of the higher-order corrections of the Standard Model. As noted earlier, the only collider currently in operation that can produce the top quark is the Tevatron.

### 4. Physics Beyond the Standard Model: New Quarks, Gauge Bosons, Technicolor, Supersymmetry, and Compositeness

Tevatron energies are high enough to be sensitive to new physics at the electroweak scale. Additional gauge bosons, partners of the W and $Z^{\circ}$, are required in almost any theory which extends the Standard Model beyond the minimum model. At present, the strongest limits on the masses of such new gauge bosons come from the data of the 1988-89 Tevatron collider run. This data will be sensitive to gauge bosons that decay leptonically with Standard Model couplings of leptons to the gauge bosons if their masses are less than 400 GeV. Once the Fermilab III program is in place, bosons with masses up to 1000 GeV can be detected. This represents a very significant window on new physics.

Technicolor, supersymmetry and quark compositeness are three major possible departures from the Standard Model which have received considerable theoretical attention. In each of these models, new physics is proposed for which the Tevatron Collider program can make an important contribution by significantly extending the range of masses accessible to experiment.

In summary, the Tevatron Collider will provide a vast wealth of physics opportunities within the Standard Model and could provide physics beyond the Model. The Fermilab III program is required to exploit the Tevatron's capability to discover the top quark. Detailed studies will be possible for the electroweak gauge bosons, jets, and heavy quarks. This will guarantee a successful physics program for at least the next ten years if the Fermilab III program proceeds as planned. Although a full understanding of the physics of the 1-TeV mass scale will require the SSC, the Tevatron may provide important clues to the character of this new physics and thereby point the way for early SSC explorations.

## FIXED-TARGET PHYSICS

The approved program of fixed-target experiments for the Tevatron addresses a broad range of physics topics, and includes both particle searches and detailed measurements. The present program is summarized in the table at the end of this appendix. Experiments will be carried out which will add to our

knowledge of the properties of the strange and charm quarks and perhaps the bottom quark, probing the soft territory where theoretical progress requires guidance from experiment. There may well be surprises in this territory. Other experiments will explore the properties of neutrinos and search for conditions under which neutrinos may change flavors. Previous experiments studied the Standard Model on a broad front with results ranging from the discovery of the fifth quark in its quarkonium state, the Upsilon, to the best measurements of important charm particle lifetimes. A published analysis of a measurement of the CP violating parameter $\varepsilon'/\varepsilon$ in the kaon system, based on one-fifth of the data sample, is comparable to the best previous measurement. As this data sample is fully analyzed, it will yield the most accurate measurement of this important parameter. The largest sample of $\Omega^-$s was observed and its magnetic moment was measured.

The fixed-target program surveyed and tested the Standard Model with experiments in (1) the nature of the electroweak interactions, (2) studies of the strong force (QCD) and constituent structure of hadrons, (3) studies of hadrons containing heavy quarks, (4) precision measurements of weak decays (including CP-violating decays), and (5) searches for unexpected phenomena. The major thrust of this program was associated with the Tevatron II Upgrade program which made a new energy range accessible for the first time.

It is expected that after the current set of fixed-target experiments are completed in 1991, a strong program of fixed-target experiments will continue with fewer, more focussed efforts. Among the possibilities to be included in this program are high-statistics charm particle production dynamics and spectroscopy, precision measurements of charmonium states, studies of bottom quarks produced in photon and hadron collisions, polarization phenomena, precise, high-sensitivity rare kaon decays emphasizing the study of the origin of CP violation, neutrino oscillations, and structure functions.

## COMPUTING PROGRAM

### 1. Data Processing Requirements

Computing has been a pacing item in the production of physics results for many experiments. Some recent trends and efforts at Fermilab and in the computing industry should give rise to something more than cautious optimism. First, Fermilab made a successful transition from a mainframe-only computing "solution" to a functional problem oriented solution using the computation tools suited to specific requirement parallel processing for track reconstruction, workstations for CAD/CAM and small scale analysis, mainframes for larger analysis, intermediate processor systems for large software development and communications. The integration (albeit loose) of these tools has been a combination of intercomputer and local area networks. On the technology side

the cost of computing increments continue their downward slide while the range of potential data exchange media increases in number and is also going down in cost. The major challenge will be to define an opportunistic model of computing for the Laboratory which addresses the growing analysis requirement by taking advantage of the new technologies offered in the marketplace in an evolutionary way. The process of defining an approach is underway.

The computing resources acquired and used between 1986 and 1990 have increased to approximately 1000 MIPS dominated by track reconstruction capability. Over the next five years we anticipate an additional requirement for another 10,000 MIPS but of a more balanced capability utilizing RISC and mainframe architectures which addresses the physics analysis through publication. The technical solution lies in reduced data handling by experimenters and computer operations and greater reliance on networks and terabytes of robotic storage centrally managed. Distributed computing and physics analysis workstations are supported on the spurs of the network. The key element in this scheme is data serving hardware and software.

The current system of Vax-Amdahl-farm processing will continue to be augmented as the basis for the transition to the new architecture. We anticipate this transition beginning in 1991.

## 2. Advanced Computer Program and New Approaches

A major part of the computing load dedicated directly to high-energy physics is production processing of independent event data. The data are divided into pieces which are natural candidates for a distributed parallel processing environment. Because of this, Fermilab established an Advanced Computer Program (ACP), now the Computer R&D Department, to develop systems tuned precisely to this kind of computing. The initial project was the development of a system consisting of 50 nodes of interconnected microprocessors. Each microprocessor, rated at 0.7 MIPS, was intended to carry out the reconstruction of a single event. Moving this kind of capacity from an R&D environment into a major production role is a crucial part of the Laboratory strategy. Following a very successful test of the first 50 node system, there are now over 400 microprocessors installed in six production systems which are processing data from the 1987 fixed-target and the 1988-89 Collider runs. This contribution is expected to grow. A second generation ACP system based on a RISC microprocessor provides 20 times more computing power per node than the original system.

In addition to more powerful hardware, the ACP group has developed a software system, COOPERATING PROCESSES SOFTWARE, which is designed to facilitate the distribution of a software task among a collection of heterogeneous processors. This software allows Fermilab to bring to bear, on a single problem,

farms of processors developed in-house or farms of commercially available processors or even a mixture from each source. This software is already successfully running at Fermilab. It is the basis of several farms of commercial UNIX and VMS processors whose total capacity will be well beyond 1000 MIPS by the end of the year and will likely approach 3000 MIPS by the end of 1991.

Attention is beginning to turn to the problem of developing new tools to facilitate the stages of physics analysis which follow the "event reconstruction" on the parallel processing farms. Problems under investigation include 1) "data-serving" of large data sets to personal workstations, 2) the development of graphics tools for event and statistical displays, correlation studies, etc, and 3) the development of better techniques for the design and creation of the physics software itself. Parallel processor activity in the theoretical area is discussed below.

### 3. Trigger, On-Line, and Data Acquisition Computing

In the area of online acquisition and monitoring computers, the value of a single acquisition is not expected to exceed $1M. The trend towards networked collections of microprocessors, mini-computers and workstations continues. Every experiment has, as part of its data acquisition and on-line system, at least one VAX or Microvax class machine. Most experiments have clusters of local VAX computers. The availability of a VME based data acquisition system has opened up the possibilities of incorporating numerous different processors and/or workstations into the data acquisition path. Similarly the availability of very high performance workstations, often running under the UNIX operating system, clearly offers the opportunity to perform a greater amount and more extensive analysis and monitoring of data, as the data is being taken and recorded. Projections of requirements for computing capability, both for performing analysis of data directly in the datapath (i.e., triggering) and for analyzing data online, show a need for substantial expansion in these areas.

The incorporation of the new, powerful workstations into online systems will require new ways of interfacing them to the traditional CAMAC systems, which remain in heavy use in experiments both for data acquisition and monitoring, either via the much used SCSI bus or via the local area network.

The once ubiquitous 6250 bpi 9 track magnetic tape has largely been replaced by the new 8mm tape and helical scan technology. This is true for data written from a VAX system as well as data written from a VME based system. However, the 8mm technology will certainly not enjoy such a long reign of supremacy. New technologies are expected to present themselves as candidates for use in the recording of massive amounts of data, reliably, fast and cheaply. This will certainly necessitate a major investment in data recording and reading

hardware throughout all systems on-line and off-line; the interchangeability of data between machines and institutions being a prime consideration.

## THEORETICAL PARTICLE PHYSICS

Members of the Theoretical Physics Department contribute to a broad spectrum of research on the current issues of elementary particle physics. The Department provides the opportunities for young theoretical physicists to participate in postdoctoral research in a setting close to experiments. Fermilab supports an active Theory Visitors Program which attracts theoretical physicists from around the world, making Fermilab a central crossroads for the exchange of the newest ideas and results in theory and experiment.

The Fermilab research program ranges from fundamental problems in field theory and superstrings to supercollider phenomenology. A particularly active area of research involves the application of quantum chromodynamics (QCD), the theory of strong interactions, to relevant physical problems using the techniques of perturbative field theory, including heavy quark production processes and jet production in the hadron collider environment. A diverse program of research in applications and tests of the Standard Model of electroweak interactions is maintained. The more formal aspects of particle physics research are also well represented with projects including integrable systems, conformal field theory, and matrix models.

The lattice formulation of quantum chromodynamics (QCD) provides a unique method for the systematic analysis of strong dynamics in the non-perturbative domain. The Theoretical Physics Department and the Computing R&D Department are collaborating on the ACPMAPS project to develop a special-purpose supercomputer for lattice gauge theory calculations. The anticipated completion of a 256-node lattice gauge engine with 5 gigaflops of computing power will make Fermilab the central focus of realistic calculations in nonperturbative QCD and its applications to the solution of many important physics issues. The possibility of a quick upgrade beyond 50 gigaflops is presently under investigation by Computing R&D Department.

## THEORETICAL ASTROPHYSICS

Fermilab is unique among National Laboratories in having a group devoted to exploring the connections between particle physics and astrophysics. The Fermilab Theoretical Astrophysics Group was started in 1983, and is jointly funded by the Office of Space Science and Applications of NASA. The main emphasis of the group is the study of the very early Universe, where the temperature and energies of particles in the Universe were comparable to the conditions produced in the high-energy collisions of particles at accelerators. By

studying the interactions of matter on small scales, we can learn something about the origin of the Universe and the structure of the Universe on the largest scales. There is no better example of the unity of various branches of science than this Inner Space/Outer Space connection.

## B. WORK FOR OTHERS

### NEUTRON THERAPY FACILITY (NTF)

In 1976, an experimental program of cancer treatment with beams of high-energy neutrons was started at Fermilab. This program was supported by the National Cancer Institute (NCI) of the U.S. Department of Health and Human Services under a grant to the Universities Research Association. In the 10-year period through September of 1985, more than 1500 patients were treated with neutron beams and the efficacy of this type of treatment was demonstrated.

By 1985, it was established that fast neutrons were an efficacious treatment for several types of tumors and the National Cancer Institute discontinued funding this type of therapy because it was no longer considered to be experimental. In an effort to keep this method of treatment available to patients in the eastern part of the U.S., a group of physicians formed a partnership called the Midwest Institute for Neutron Therapy (MINT) and entered into a contract with URA to operate the facility on a fee-for-service basis, with MINT guaranteeing full cost recovery.

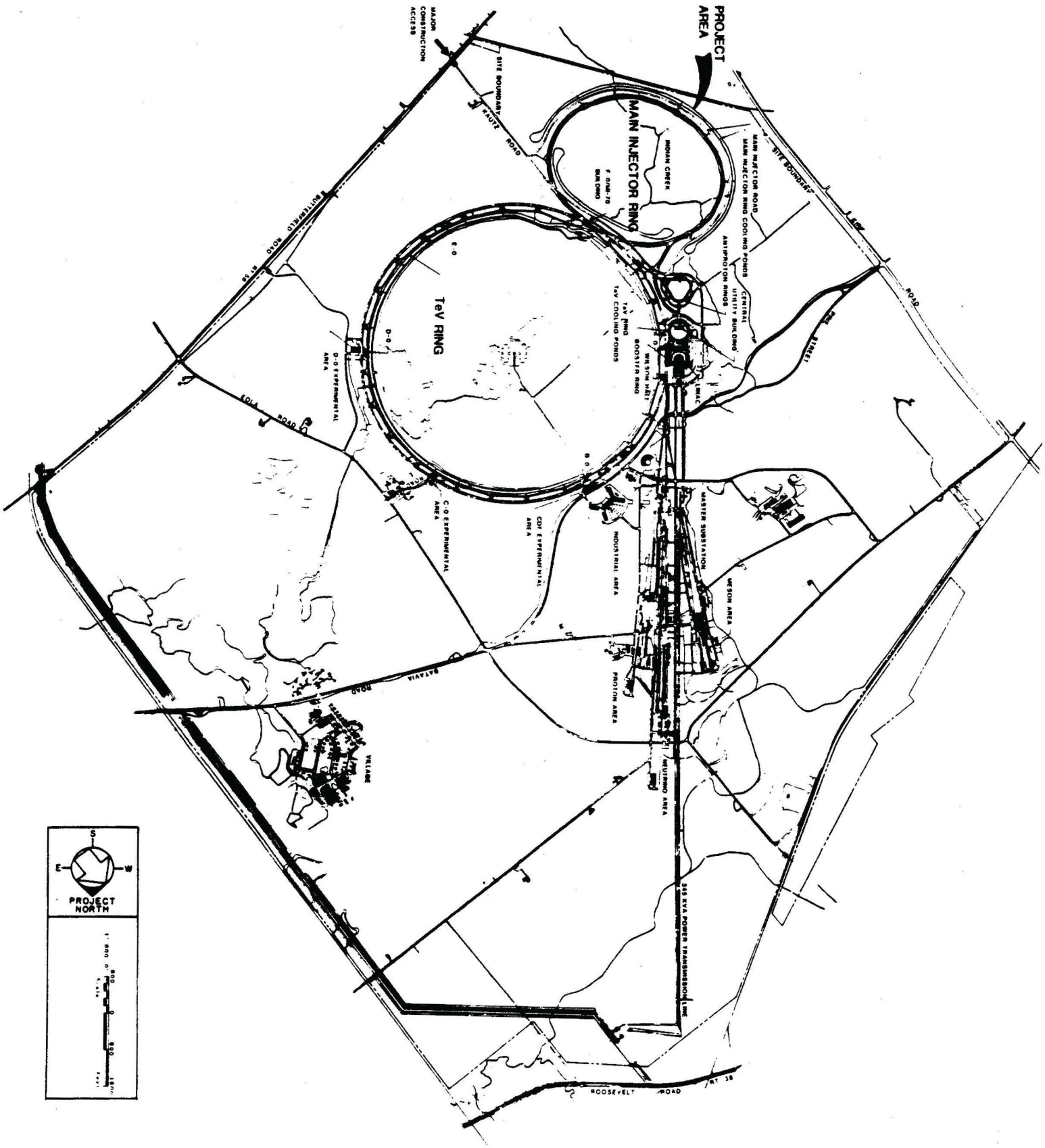
When the contract between URA and MINT expired in 1988, URA entered into another contract with Rush Presbyterian St. Luke's Medical Center to continue operating the Neutron Therapy Facility. This was done because the cost of professional liability insurance was becoming prohibitive and Rush was willing to provide the insurance to cover the therapy given at Fermilab. Also, by this time NTF had demonstrated that the fees collected from patients were sufficient to cover all operating costs. The annual budget for the facility is $500K.

### LOMA LINDA MEDICAL ACCELERATOR

Early in 1986, the Loma Linda University Medical Center of Loma Linda, California asked Fermilab to design and build a synchrotron for proton therapy to be installed at Loma Linda. The Department of Energy agreed that Fermilab could do this work as a technology-transfer activity under the provisions of the Stevenson-Wydler Act and under the provisions of the DOE Order concerning work for others. Work began on the design of a 250 MeV proton synchrotron in 1986. The accelerator was completed in 1989 and during the commissioning at Fermilab it reached the design energy of 250 MeV and an intensity of $2 \times 10^{10}$ protons/cycle. The accelerator was moved to Loma Linda in October, 1989 where

the facilities under construction were ready for partial occupancy. After recommissioning at Loma Linda, an intensity of $4 \times 10^{10}$ protons/cycle was reached. Patient treatment commenced during 1990. Fermilab has no plans to continue this type of work.

# FERMILAB TEVATRON ACCELERATOR WITH MAIN INJECTOR



## CURRENTLY APPROVED FERMILAB EXPERIMENTS

| FIXED- TARGET | |
|---|---|
| **CP VIOLATION AND RARE DECAYS** | |
| E-761 ( Vorobyov ) | Hyperon Radiative Decays ( 9 / 43 ) |
| E-773 ( Gollin ) | Phase Difference Between $\eta_{00}$ and $\eta_{+-}$ ( 5 /17 ) |
| E-774 ( Crisler ) | Electron Beam Dump Particle Search ( 4 / 9 ) |
| E-799 ( Wah / Yamanaka ) | Search for $K_L \rightarrow \pi^0 e^+ e^-$ ( 5 / 21 ) |
| **PARTON DISTRIBUTIONS AND HARD COLLISIONS** | |
| E-683 ( Corcoran ) | Photoproduction of Jets ( 11 / 44 ) |
| E-704 ( Yokosawa ) | Experiments with Polarized Beam ( 18 / 83 ) |
| E-706 ( Slattery ) | Direct Photon Production ( 10 / 77 ) |
| E-665 ( Geesaman ) | Muon Scattering with Hadron Detection ( 13 / 82 ) |
| E-782 ( Kitagaki ) | Muon Scattering with Tohoku Bubble Chamber ( 8 / 26 ) |
| **CHARM AND BEAUTY** | |
| E-672 ( Zieminski ) | High Mass Dimuons and High $P_t$ Jets ( 7 / 30 ) |
| E-687 (Butler ) | Photoproduction of Charm and Beauty ( 12 / 92 ) |
| E-690 ( Knapp ) | Hadronic Production of Charm and Beauty ( 5 / 28 ) |
| E-760 ( Cester ) | Charmonium States ( 7 / 72 ) |
| E-771 ( Cox ) | Beauty Production by Protons ( 20 / 94) |
| E-781 ( Russ ) | Large-X Baryon Spectrometer ( 8 /43 ) |
| E-789 ( Kaplan / Peng ) | Production and Decay of B-Quark Mesons and Baryons ( 6 / 26) |
| E-791 ( Appel / Purohit ) | Hadronic Production of Beauty and Charm Particles ( 10 / 60 ) |
| **STATIC PROPERTIES OF ELEMENTARY PARTICLES** | |
| E-800 ( Johns / Rameika ) | $\Omega^-$ Magnetic Moment ( 4 / 13 ) |

| COLLIDER | |
|---|---|
| E-740 ( Grannis ) | D0 Detector ( 23 / 187 ) |
| E-775 ( Shochet / Tollestrup ) | Collider Detector at Fermilab ( 21 / 188 ) |

| DETECTOR TESTS | |
|---|---|
| E-790 ( Sciulli ) | ZEUS Calorimeter Module Tests ( 8 / 28 ) |
| E-795 ( Pripstein ) | Warm Liquid Calorimetry ( 6 / 16 ) |
| E-797 ( Gustafson / Thun ) | SSC R&D ( Fine-grained EM Calorimeter ) ( 1 / 6 ) |
| E-798 ( Cushman / Rusack ) | SSC Detector Tests ( Synchrotron Radiation ) ( 2 / 4 ) |
| E-807 ( Teige) | Calorimeter R&D ( Tetra-Bromo-Ethane ) ( 1 / 7 ) |

| OTHERS | |
|---|---|
| E-667 ( Wolter ) | Emulsion / $\pi^-$ at 500 GeV (1 / 8 ) |
| E-754 ( Sun ) | Channeling Tests ( 4 / 7 ) |
| E-778 ( Gerig / Talman ) | Study of SSC Magnet Aperture Criterion ( 6 / 21 ) |
| E-793 ( Lord ) | Emulsion Exposure ( 3 / 4 ) |
| E-802 ( Chatterjee / Ghosh ) | Emulsion Exposure ( 2 / 3 ) |

Note: Numbers in parentheses denote total number of institutions and physicists, respectively.

## PENDING PROPOSALS

| | |
|---|---|
| P-682 ( Underwood ) | Polarized Beam |
| P-688 ( Ditzler ) | Polarized Beam |
| P-699 ( Stanek ) | Polarized Beam |
| E-784 ( Lockyer )# | Bottom Collider Detector |
| P-794 ( Van Bibber )* | Axion Helioscope |
| P-796 ( Thomson )* | CP Violation |
| P-803 ( Reay )* | Neutrino Oscillation |
| P-804 ( Winstein )* | Kaon Physics at Main Injector |
| P-805 ( Gajewski )* | Long Baseline $\nu$ Oscillation |
| P-808 ( Goldberg )* | B Physics with E706/672 Spectrometer |
| P-809 ( Yokosawa / Nurushev / Masaike ) | Spin Dependence in Direct-Gamma Production |
| P-810 ( Wilson )* | Nucleon Structure Function with E665 Apparatus |
| P-811 ( Orear ) | Physics at E0 for the 1991-92 Collider Run |
| P-812 ( Smith )* | Tests of CPT and Gravity using Low Energy |
| P-813 ( Jones )* | Landau-Migdal-Pommeranchuk Effect, etc. |
| P-814 ( Chaloupka )* | Primakoff Production of Hybrid Mesons |
| P-815 ( Shaevitz )* | Neutrino Experiment with the Upgraded Tevatron |
| P-816 ( Lubatti ) | SSC Detector Muon Sub-System Tests |
| P-817 ( Alexander ) | Silicon Strip Detector Test for CLEO |

* Letter of Intent.

# Research and Development for this proposal has been approved.

# APPENDIX 2

## COOLING WATER IMPROVEMENTS

The recent Midwest drought has caused two problems. Normally, the Laboratory can pump water from the Fox River nine months out of the year (from October through June). The flow of the Fox River is controlled by gates releasing water from the Chain-of-Lakes region along the Wisconsin border. With the drought conditions of 1988 and 1989, the quantity of water released was severely reduced and the length of time during which we are not allowed to pump is being expanded. The natural rainfall on the Fermilab site is generally spread out over the year, with some peaking in the spring and fall. In normal years, sufficient rainfall is available to keep Fermilab's eastern lakes full and allow some water to escape over the dams. This water is used to supplement the water stored in Casey's Pond when we are not allowed to pump water from the Fox River. In 1988, these eastern lakes were pumped dry. Almost no rain fell in the period from May through August. During this same period, we were not allowed to draw water from the Fox River. This caused a severe shortage of industrial cooling water and almost caused a suspension of accelerator operations in July and August, 1988.

The solution to these water problems is expanded water storage capacity. Casey's Pond needs to have its capacity increased so that we can store more water during the periods the Laboratory is allowed to pump water from the Fox River. In addition, the eastern lakes need to be deepened to increase their water storage capacity for the periods when rainfall is plentiful and to be connected.

# APPENDIX 3

## DETAILS OF EDUCATION AND TECHNOLOGY TRANSFER PROGRAMS

## A. SUPPORT OF SCIENTIFIC AND TECHNICAL EDUCATION

### 1. Precollege Programs

In 1990, 34 precollege education programs are currently being offered. They are primarily sponsored by the Education Office and Friends of Fermilab, a not-for-profit corporation whose mission is to support precollege programs based on Fermilab's commitment to enhance science education. A listing of the various programs follows:

### HIGH SCHOOL TEACHERS

Chemistry West: Network of Chicago area chemistry teachers who meet monthly during the school year to share skills, materials, etc. from Fermilab programs. Four hundred teachers are on the mailing list.

DOE Teacher Research Associates Program (TRAC): Eight to ten week summer research program for about twenty secondary school teachers per year. Teachers are selected both nationally and regionally. Over 100 have participated. Some teachers return for additional years of employment through the TRAC Graduate Program.

Latin American Collaboration: Provides materials and speakers in support of efforts in Latin America to enhance precollege science instruction.

Physics Mini-Courses: Teams of physicists and teachers present modern physics topics as developed in Fermilab programs to high school and/or college teachers. Over 3000 teachers have attended.

Physics West: Network of Chicago area physics teachers who meet monthly during the school year to share skills, materials, etc. from Fermilab programs. One hundred twenty teachers are on the mailing list.

Summer Institute for Science and Mathematics Teachers: Four-week enhancement program for 60 high school teachers per year. Three hundred sixty teachers are graduates of the program.

Summer Institute for Science and Mathematics Teachers at Chicago: A special three week enhancement program for 60 Chicago high school teachers is co-sponsored with Chicago State University.

Topics in Modern Physics: Program includes a three-week institute to train 26 lead teachers, in-service programs for other physics teachers and the publication of a Teacher Resource Manual. Over 150 teachers have used the materials.

## HIGH SCHOOL STUDENTS

DOE High School Honors Research Program in Particle Physics: Part of the DOE National High School Honors Program. Sixty students (one per state, D.C. and Puerto Rico plus foreign countries) per year spend two weeks at Fermilab attending lectures and working in particle physics experimental groups. Over 240 students have participated.

EAL: A one-week pilot science careers' program for 12 minority high school students involved in the Educational Assistance Ltd. COP program.

Explorer's Post: A computer post operated year round for approximately 15 students.

Guided Tours: The Public Information Office offers guided tours to high school groups. Over 3000 students and 300 teachers have this introduction to Fermilab each year.

IMSA: Fermilab scientists give special lectures and serve as mentors for students in the Illinois Mathematics and Science Academy.

INTECH: Fermilab scientists serve as judges and as mentors for high school students who participate in this science fair.

JPTA Jobs Program: Summer training opportunities for economically disadvantaged and handicapped young people ages 16-21.

Saturday Morning Physics: A ten-week lecture program given in three sessions to 300 students per year. Over 3000 students have graduated.

Target: Science and Engineering: Research participation program for 25 gifted minority students who spend half their time on the job and half their time on individual research projects. Over 200 students have participated.

## ELEMENTARY AND JUNIOR HIGH SCHOOL TEACHERS

Beauty and Charm at Fermilab - Introduction to Particle Physics: A workshop for junior high school science teachers to prepare them to teach a unit of "particle physics." Over 130 teachers have been trained to teach the program.

Chicago Science Explorers: Teachers are developing and piloting classroom materials to make the Fermilab prairie accessible to students. The project. organized by Argonne National Laboratory, is keyed to a new New Explorer videotape, "Yellowstone", produced by Bill Kurtis.

Down to Earth: A workshop to familiarize teachers with instructional materials that allow students to visit Fermilab for a geology field trip.

Hands-On Science: A workshop to train lead teachers to use traveling collection of hands-on activities. Sixty teachers have been trained; the collection stays at 32 schools for two weeks each year.

Summer Science Project: Three-week enhancement program for 45 junior high/middle school teachers per year.

TIMS: Three year program to train 39 lead teachers and introduce Teaching Integrated Mathematics and Science into ten school districts and a parochial school. The program is offered in partnership with the University of Illinois at Chicago.

## ELEMENTARY AND JUNIOR HIGH SCHOOL STUDENTS

Beauty and Charm at Fermilab - Introduction to Particle Physics: Junior high school classes may visit Fermilab for a special tour and visit with a scientist. Over 1500 students per year visit the Laboratory as part of the program.

Classes for Kids: Out-of-school program for elementary students. Pilot program includes two sessions of two or three classes that meet for eight hours and include eleven students each.

Down to Earth: Students come to Fermilab for geology field experiences.

Ecology Field Trips: School groups can schedule field trips to visit the Fermilab prairie savannah.

Hands-On Science: Traveling collection of hands-on science activities for elementary school classrooms.

Wonders and Magic of Science: Held during National Science and Technology Week for third through sixth graders selected by their school. Some 1200 students and parents attend each year.

**K-12 TEACHERS AND/OR STUDENTS**

Academy for Mathematics and Science Teachers (Chicago): Design workshop held February, 26-28, 1990 to develop a proposal for the Academy.

Classroom Materials: Variety of classroom materials developed in conjunction with Fermilab programs are made available free of charge or at cost to teachers.

Cryogenic Magic Show: Fermilab engineers put on liquid nitrogen demonstrations for teachers and students of all ages. Some 3000 students attend per year.

Resources for the Science Classroom: Resource manual listing over 150 opportunities for Chicago area teachers to enhance their teaching of science.

Weird Science: Program to promote the use of demonstrations in the classroom and interest students in studying science. Over 5000 students and teachers attend each year.

**2. Undergraduate Programs**

Physics Department Summer Program for Undergraduates: Every summer, the Fermilab Physics Department employs a select group of 20 - 25 undergraduate science students. The widely respected reputation of Fermilab draws hundreds of applications for these positions from both inside and outside the United States.

Minority Programs: The Laboratory participates in GEM, a consortium of industry and universities whose objective is to increase the number of minority students in graduate engineering studies. GEM offers fellowships in conjunction with summer employment opportunities. The Laboratory also offers a program of summer employment for undergraduate minority students majoring in physics and related subjects. This program has existed for a number of years and provides student exposure to a working research and development environment.

**3. Graduate, Post Doctoral and Faculty Programs**

Joint University-Fermilab Graduate Program in Accelerator Physics: The motivation for this program is the current shortage of accelerator physicists. Our colleagues in nuclear physics and materials science need, as high priority facilities,

large high-energy accelerators; examples are the 4 GeV CEBAF electron accelerator and a 6 GeV synchrotron light source. There are also plans for medical accelerators, kaon factories, and synchrotron light sources, all in addition to HEP demands for new accelerators and upgrades of existing facilities. The output of accelerator physicists from the few university Ph.D. programs that do exist is insufficient to meet the anticipated needs.

Currently there are seven students in the program. Their research topics are in the following areas: non-linear dynamics, synchrotron magnet aperture studies, third-order beam optics, Linac Upgrade studies, Booster efficiency and emittance, Tevatron luminosity lifetime, and Accumulator beam properties. The first Ph.D. was awarded under this program in June 1987.

Fermilab Latin American Program: For a number of years, Fermilab has been actively encouraging the development of physics, and especially particle physics, in Latin America. Recent activities are as follows:

Four groups of Latin American particle physics experimenters, two from Brazil, one from Mexico and one from Colombia, have been formed with active assistance from Fermilab. All have participated in, or will soon participate in, experiments at the Laboratory.

In 1985 and 1986, Fermilab administered, for the American Physics Society, a $300,000 NSF grant to aid Latin American physics. The grand paid for per diem expenses of physicists visits to the U.S., page charges for publications in U.S. journals, subscriptions to U.S. journals, and purchase of equipment items for Latin American physics projects. A $100,000 new grant for the same purpose was received from the Department of Energy in 1987.

A collaboration is underway with CINVESTAV (Mexico) to train experimental particle physicists; the university currently has no facilities or staff in this field, so students who have passed their Ph.D. qualifying exams in Mexico come to Fermilab to join experiments here. Fermilab staff members supervise them and guide their Ph.D. research. One student received his Ph.D. from CINVESTAV in January 1989 and two other students are currently at Fermilab.

Fermilab has been host to several engineers from Latin America who came to work with the advanced facilities available here. Currently, we have two electronics engineers from Argentina and three from Brazil.

Among other areas of Fermilab activity are visits by staff members to Latin American institutions for seminars, conferences and collaboration discussions. A program exists to donate books and journals to Latin American universities and co-sponsorship of conferences in Latin America. Among the latter are the very successful series of Symposia on Pan American Collaboration in Experimental

Physics. The fourth in this series of symposia was held in Bariloche (Argentina) in November 1989.

Post Doctoral Program: Postdoctoral Research Associates are hired and trained in experimental particle physics, theoretical particle physics, astrophysics and accelerator physics. At present, the four programs train 26, 10, 7, and 7 postdoctoral associates, respectively. It is expected, as Fermilab evolves into a mode of continuous data taking, that the number of Research Associates will increase.

A summary of the statistics for participation in all programs referred to in this section is given in Table AP-1.

# TABLE AP-1

## Educational Program Participation
## Fiscal year 1989

| | Pre-University Student/Teacher | | Under Graduate | Graduate Student/Postdoc/Faculty | | | Total |
|---|---|---|---|---|---|---|---|
| **DOE Programs** | | | | | | | |
| DOE High School Honors | 56 | 6 | | | | | 62 |
| TRAC/TRAC Grads | | 26 | | | | | 26 |
| **Other Programs** | | | | | | | |
| Beauty & Charm | 1310 | 62 | | | | | 1372 |
| National Science Week* | 1250 | | | | | | 1250 |
| Saturday Morning Physics | 300 | | | | | | 300 |
| Physics West | | 125 | | | | | 125 |
| Chemistry West | | 480 | | | | | 480 |
| TM Physics | | 6 | | | | | 6 |
| Teachers Institutes | | 120 | | | | | 72 |
| Target | 25 | 3 | | | | | 28 |
| EAL | 12 | | | | | | |
| TIMS | 39 | | | | | | |
| SSP | 45 | | | | | | |
| DOE Honors Grad | | | 0 | | | | 3 |
| DeVry Work Study | | | 9 | | | | 9 |
| Physics Department | | | 30 | | | | 30 |
| Minority Program | | | 20 | | | | 20 |
| Co-op Students | | | 30 | | | | 30 |
| GEM | | | | 3 | | | 3 |
| Accelerator PhD | | | | 7 | | | 7 |
| Graduate Fellowship Program | | | | 3 | | | 3 |
| Fermilab Postdocs | | | | | 51 | | 51 |
| Theory Visitors | | | | | | 120 | 120 |

*Students and Parents

## B. TECHNOLOGY TRANSFER

### The Current Program

Since its inception in the late 1960s, Fermilab has been actively involved in the development of technology that later spins out into industry. Technology transfer is a well established and familiar activity at the Laboratory. By way of illustration, there are several Fermilab technologies that have been transferred in the past - superconducting wire to help build a billion dollar medical imaging market, advanced computers to an Illinois business, and a medical accelerator to an internationally renowned hospital.

Since 1980 Fermilab has received twelve R&D 100 Awards recognizing specific, significant technological developments. In 1989 four Fermilab staff members [Rich Orr, Alvin Tollestrup, Helen Edwards (now at the SSC), and Dick Lundy (now a private consultant)] were awarded the National Medal of Technology by President Bush in recognition of their contributions in building and commissioning Fermilab's Tevatron - today the world's most powerful accelerator. By late FY1989 some 600 individual innovations had been disclosed, assessed for patent and market potential, and cataloged. Some of the more recent of these should become the technology transfer success stories of the future.

The heart of the technology transfer activities at Fermilab is the Fermilab Industrial Affiliates. The Affiliate organization consists of between 30 and 40 companies, ranging in size from industrial giants to vigorous, young startups, that are interested in the work being done at Fermilab. (A current listing of the Affiliates appears at the end of this section.) Both the Advanced Computer Project and the Proton Accelerator for Medicine mentioned above have involved interactions with members of the Affiliates.

The Fermilab Industrial Affiliates was formed to stimulate the transfer to private industry of the technical innovations born of the basic research done at Fermilab and to improve University-Industrial research communications. Affiliates receive tailored monthly mailings about Laboratory developments, early alerts on licensing opportunities, the opportunity to participate in staff exchanges, and an invitation to the Affiliate annual meeting. During the meeting an exchange of information takes place between Fermilab staff members and Affiliate top management representatives concerning Fermilab's technological developments in such areas as superconductivity, cryogenics, advanced computer hardware and software, accelerator controls, fast electronics, ion beams and sources, large vacuum systems and particle detectors. The 1989 annual meeting featured two roundtables, one on "Accelerator Applications" and the other on "New Initiatives for Computers and Electronics for Science." A number of distinguished speakers, including representatives from LeCroy Corporation, Sun Microsystems Inc., and Science Applications International Corporation, appeared on the program. Affiliates pay an annual membership fee.

An important new technology transfer activity at Fermilab is patent and copyright licensing. The Licensing Office in the ORTA, acting on behalf of Universities Research Association, Inc. (URA), is currently offering royalty-bearing licenses on the technology items listed below:

| TITLE | FAA No. | U.S. Patent No. |
|---|---|---|
| Cryogenic Support Member | 279 | 4,696,169 |
| Dead Time Compensation Circuit for a Logarithmic Display Ratemeter | 380 | 4,722,793 |
| Computer Controlled HV Supply for Drift Chambers | 381 | 4,888,693 |
| Laser Pulse Stretcher Electronic Pockels Cell Controller | 421 | 4,901,323 |
| DeBuncher RF Cavity Tuning Loop Control | 424 | Application Filed |
| Zero Heat Leak, Zero Contraction Magnet Anchor System | 430 | 4,781,034 |
| Technique for Fabricating a Multilayer Insulation Blanket | 472 | Application Filed |
| ACP Branch Bus Switch Backplane | 488 | Application Filed |
| $CeF_3$ as a Fast Scintillator | 519 | Application Filed |
| Di-Valent Dopants for Cerium Fluoride | 563 | Application Filed |

A modification of the Fermilab Prime Contract executed just over a year ago has resolved earlier uncertainties surrounding whether and how URA could copyright and then license software developed at Fermilab. Specific products currently available include:

| TITLE | FAA No. | Description |
|---|---|---|
| CANOPY, Site-Oriented Software for ACPMAPS | 529 | Multiprocessor software which facilitates development and coding of algorithms for problems thought of as existing on a collection of "sites" on a grid. |
| IBM 3812 Printer Utility | 590 | Menu-driven software that permits users to format and print line-printer-type reports/ documents on IBM3812 printers. |

A critical aspect of transferring technology from Fermilab is to first identify, then evaluate the technology. At Fermilab the ORTA evaluates 40 to 50 new innovations each year. This evaluation includes publication review, appraisal of patent or copyright cost vs. potential for commercialization and the creation of a formal assessment document. It may also include reviews by a Laboratory Patent Advisory Group and the patent counsel retained by Fermilab, a prior art search and a preliminary market study.

A little over a year ago Fermilab participated in and hosted week-long briefings and workshops aimed at 20 or so potential suppliers of SSC magnets. Partly because of the importance and the intensity of that activity to transfer superconducting magnet fabrication technology to industry and partly in anticipation of the new legislation granting DOE laboratories more freedom in arranging Cooperative Research and Development Agreements (CRADAs) with industry, this activity has not been emphasized during the past 18 months. It is now receiving renewed attention.

Finally, for the past several years Fermilab has been funded by the State of Illinois, through the Department of Commerce and Community Affairs (DCCA) to operate a Technology Center for the benefit of Illinois industry (about one third of the Affiliates are located in Illinois). This relationship has given the Laboratory both opportunity and leverage to forge new or strengthened relationships at the state and local level of government. The Director serves as a member of the Governor's Commission on Science and Technology and the Director Emeritus is the Governor's Science Advisor.

## Long Term Changes

Over two decades the most effective technology transfers out of Fermilab have come from large-scale technology development projects like the Tevatron and the ACP. Similar programs in the future should yield more technology returns.

The Laboratory is now actively looking for new ways to develop critical technology in concert with industry. The Director has instructed Division heads to identify specific opportunities related to the near-term physics program.

As far as technology transfer oversight is concerned, the ORTA has grown by almost a factor of two in the last several years. The office is still substantially over-committed. Ultimately, if the mismatch of resources continues, some important technology may not be transferred.

**FERMILAB INDUSTRIAL AFFILIATES**

AMP Incorporated
Air Products and Chemicals, Inc.
Allied-Signal Engineered Materials Research Center
Babcock & Wilcox
Commonwealth Edison Company
CVI, Incorporated
Digital Equipment Corporation
E. I. DuPont de Nemours & Company (Inc.)
General Dynamics
General Electric Company
W.W. Grainger, Inc.
Grumman Space Systems
Harza Engineering Company
Hewlett-Packard Company
Hutchinson Technology, Inc.
State of Illinois
Inland Steel Company
Intermagnetics General Corporation
Kinetic Systems Corporation
LeCroy Corporation
Major Tool & Machine, Inc.
Martin Marietta Denver Astronautics
NALCO Chemical Company
New England Electric Wire Corporation
NYCB Real-Time Computing, Inc.
Omnibyte Corporation
Oxford Superconducting Technology
Phillips Scientific
Plainfield Tool and Engineering, Inc.
Science Applications International Corporation
Sulzer Brothers, Inc.
Swagelok Companies
TradeWind Scientific
Westinghouse Electric Corp.

# APPENDIX 4

## UNIVERSITIES RESEARCH ASSOCIATION, INC. MEMBER INSTITUTIONS

University of Alabama
Arizona State University
University of Arizona
Boston University
Brown University
University of California at Berkeley
University of California at Irvine
University of California
at Los Angeles
University of California
at San Diego
California Institute of Technology
Carnegie-Mellon University
Case Western Reserve University
University of Chicago
University of Colorado at Boulder
Columbia University
Cornell University
Duke University
Florida State University
Harvard University
University of Hawaii at Manoa
University of Houston
University of Illinois at
at Urbana-Champaign
Indiana University
University of Iowa
Iowa State University
Johns Hopkins University
Louisiana State University
McGill University
University of Maryland
University of Massachusetts
at Amherst
Massachusetts Institute of Tech.
University of Michigan
Michigan State University
University of Minnesota
State University of New York
at Buffalo
State University of New York
at Stony Brook
University of North Carolina
University of North Texas
Northeastern University
Northern Illinois University*
Northwestern University
University of Notre Dame
Ohio State University
University of Oklahoma
University of Oregon
University of Pennsylvania
Pennsylvania State University
University of Pittsburgh
Prairie View A&M University*
Princeton University
Purdue University
Rice University
University of Rochester
Rockefeller University
Rutgers, The State University
of New Jersey
San Francisco State University*
University of South Carolina
Stanford University
Syracuse University
University of Tennessee at Knoxville
University of Texas at Arlington
University of Texas at Austin
University of Texas at Dallas
Texas A&M University
Texas Tech University
University of Toronto
Tufts University
Tulane University
University of Utah
Vanderbilt University
University of Virginia
Virginia Polytechnic Institute
and State University
Washington University
University of Washington
College of William and Mary
University of Wisconsin at Madison
Yale University

*Indicates Associate Member

# APPENDIX 5

## INSTITUTIONS CURRENTLY PARTICIPATING IN THE FERMILAB PROGRAM

FOREIGN INSTITUTIONS

IHEP, Academia Sinica (Taiwan)
University of Athens (Greece)
University of Bristol (England)
CEN-Saclay (France)
CBPF (Brazil)
CERN (Switzerland)
Delhi University (India)
University of Ferrara (Italy)
College De France (France)
Freiburg University (Germany)
University of Guanajuato (Mexico)
IHEP, Serpukhov (USSR)
Hiroshima University (Japan)
IHEP, Beijing (PRC)
INFN, Frascati (Italy)
INFN, Genova (Italy)
INFN, Milano (Italy)
INFN, Pisa (Italy)
INP, Krakow (Poland)
ITEP, Moscow (USSR)
Jadavpur University (India)
Kazakh State University, Alma-Alta (USSR)
KEK (Japan)
Kyoto Sangyo University (Japan)
Kyoto University (Japan)
Kyoto University of Education (Japan)
LAPP, D'Annency-Le-Vieux (France)
University of Lecce (Italy)
INP, Leningrad (USSR)
Universidad de Los Andes (Colombia)
Max-Planck (Germany)
McGill University (Canada)
University of Milano (Italy)
Nanjing University (PRC)
University of Occupational & Environmental Health (Japan)
University of Pavia (Italy)
Tashkent Physics & Technology Institute (USSR)
University of Puerto Rico
Rajasthan University (India)
University San Francisco de Quito (Ecuador)
University of Sao Paulo (Brazil)
Shandong University (PRC)
Sugiyama Jyogakuen University (Japan)
Tohoku Gakuin University (Japan)
Tohoku University (Japan)
University of Torino (Italy)
Trieste (Italy)
University of Tsukuba (Japan)
University of Udine (Italy)
University Federal Do Rio De Janeiro
Vanier College (Canada)
University of Wuppertal (Germany)

UNITED STATES INSTITUTIONS

Abilene Christian University
University of Southern Alabama
University of Alabama
Argonne National Laboratory
University of Arizona
Ball State University
Brandeis University
Brookhaven National Laboratory
Brown University
California Institute of Technology
University of California, Berkeley
University of California, Davis
University of California, Irvine
University of California, Los Angeles
University of California, Riverside
University of California, San Diego
Carnegie-Mellon University
University of Chicago
University of Colorado at Boulder
Columbia University
Cornell University
Duke University
Elmhurst College
Fermilab
Florida State University
University of Florida
General Electric R&D Center

Harvard University
University of Hawaii at Manoa
University of Houston
University of Illinois, Chicago Circle
Illinois Institute of Technology
University of Illinois, Champaign
Indiana University
University of Iowa
Johns Hopkins University
Lawrence Berkeley Laboratory
Lehigh University
Los Alamos National Laboratory
Louisiana State University
University of Louisville
University of Maryland
University of Massachusetts
Massachusetts Institute of Technology
Michigan State University
University of Michigan
University of Minnesota
University of Mississippi
SUNY at Albany
SUNY at Stony Brook
New York University
University of North Carolina
Northeastern University
Northern Illinois University
Northwestern University
Notre Dame University
Ohio State University
University of Oklahoma
Pennsylvania State University
University of Pennsylvania
University of Pittsburgh
Prairie View A&M University
Princeton University
Purdue University
Rice University
University of Rochester
Rockefeller University
Rutgers University
Sandia Laboratories
University of South Carolina
SSC Central Design Group
SLAC
SSC Laboratory
University of Tennessee, Knoxville
Texas A&M University
University of Texas at Austin
Tufts University
Valparaiso University
Vanderbilt University
Virginia Polytechnic Institute
University of Virginia
Washington Natural Philosophy Institute
University of Washington
University of Wisconsin-Madison
Yale University