Fermi National Accelerator Laboratory

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The Fermilab Program for the Next Decade
A Response to the Gilman HEPAP Subpanel

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THE FERMILAB PROGRAM FOR THE NEXT DECADE

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1 INTRODUCTION

As Fermilab approaches its thirtieth birthday, the Laboratory is in the midst of the most dynamic period in its life on the frontier of particle physics. For the next 10 years, Fermilab and its facilities offer the best opportunities to make important discoveries in particle physics.

As the Subpanel met at Fermilab, we were nearing the end of the last large (nine experiments and four test beam efforts) 800 GeV Fixed Target run which began just over a year ago in July, 1996. Our plans to complete and commission the new Main Injector allow the possibility to continue three or four of these fixed target experiments in a run of six months duration late in 1998 and early 1999. This may be particularly important for those experiments that first took data in the 1997 800 GeV run.

The next run of the Tevatron collider (Run II) will be the first collider run with the Main Injector and the Recycler. It will begin early in 2000 with the goal of accumulating more than 2 fb^{-1} with each of two upgraded detectors capable of operating at peak luminosity of 2×10^{32} cm^{-2} sec^{-1} and bunch spacing of 132 ns. It is expected that the duration of this run will be set by inevitable radiation damage which the inner layers of the silicon vertex detectors must sustain. An exposure of 2 fb^{-1} is believed to be safe and after an exposure of 4 fb^{-1} the inner layer should have sustained significant damage, although they may still be useful.

By the year 2001, the 120 GeV fixed target program should be utilizing beams from the Main Injector. For the first time at Fermilab, it will be possible to run the collider and the fixed target program simultaneously. The initial focus of this program will be the long and short baseline neutrino oscillation experiments in the NuMI area. In time the program could grow to include both charged and neutral kaon decay experiments in the Meson area and KTeV area.

Around the year 2003 a dedicated charm and beauty experiment could be installed in the new CZero hall - at a time when the LHC is still some years away. Beyond collider Run II, in a program called TeV33, we will continue to exploit the unique opportunity afforded at the Tevatron by pressing both the collider and the detectors to accumulate as much luminosity as possible, perhaps as much as an additional 25 fb^{-1} by the end of the year 2007. Additional improvements to the collider and the detectors will be needed to achieve this goal and R&D programs for both detector and accelerator components will receive greater emphasis once Run II begins. Throughout the decade Fermilab will maintain a modest research program in particle astrophysics.

Preparing for a facility that extends the energy frontier beyond the LHC is clearly important for the future of Fermilab and U.S. High Energy Physics. Alternatives to the technologies of the LHC or linear electron colliders may be needed to go beyond LHC. Fermilab is supporting R&D into two initiatives - a 100 TeV hadron collider and a 4 TeV Muon collider. A significant R & D program over the next few years is being planned to identify and resolve the major issues of each proposal so that we can make a wise and informed choice for the future.

1.1 ORGANIZATION OF THIS DOCUMENT

We have divided this description of our plans for the Laboratory program into seven parts. The first five sections describe the ongoing technical work and the broad range of physics opportunities available at Fermilab. These are organized into

- our plans for the accelerator complex
- our plans for facilities for performing experiments
- the program of experiments we presently foresee
- our plans for involvement with the LHC
- our plans for R&D towards a future facility which recaptures the energy frontier

The final sections summarize

- our priorities and our planning strategy for making choices for the future, and
- our budget request to support the Fermilab program as we approach the fundamental challenges of elementary particle physics over the next ten years.

1.2 PLANNING ASSUMPTION

In response to the Gilman Subpanel of HEPAP we have considered several budget scenarios which can be called “modestly up”, “flat”, and “modestly down.” In the “modestly up” scenario it is assumed that the FY 98 Fermilab budget is the one which was described to HEPAP at its March 13, 1997, meeting by the director of the DOE High

Energy Physics Division. This is what Fermilab could expect if the President's Budget request were approved by Congress. In subsequent years the Fermilab budget would increase in purchasing power by ~2% per year during the time of this exercise, out to FY2006. In the "flat" scenario FY98 is once again given by the President's budget request. FY 99 is taken to be ~$240M in FY 97 dollars, consistent with guidance given by the HEP program office for the preparation of the Fermilab FY 99 budget request. In subsequent years the "flat" scenario is taken to be flat in purchasing power at the FY 99 level though the duration of the planning period. A "modestly down" scenario is one in which purchasing power falls at about the rate of inflation until FY2002 and then remains at constant buying power thereafter.

The schedule for construction of the LHC will impact Fermilab resources through our involvement in both the Accelerator Project and the CMS detector project. It is assumed that the LHC will begin to operate near the end of this planning period in 2006.

The "up scenario" allows for a modest increase in staff to accomodate the program; however, the increase is less than 2% per year so that the staff will have risen in size by only 10% by 2006 to a size still smaller than the Fermilab employment level of 1991. The up scenario would accomodate the plans for the scientific program described in subsequent sections. In addition, any plan for Fermilab's program must invest in R&D for future facilities. The "up scenario" provides funding for this R&D and anticipates the start of the construction phase for such a facility beginning in FY2004 - 2005.

The details of the budget scenarios are given in Section 8

2 PLANS FOR THE ACCELERATOR COMPLEX

The major plans for the Accelerator Complex in the immediate future are based on the completion and commissioning of the Main Injector and the Recycler. The Main Injector will replace the old Main Ring and serves two major functions. It will support a factor of five-to-ten improvement in the luminosity of the Tevatron collider, and it allows simultaneous operation of the collider program with a new 120 GeV extracted beam capability. The Recycler is a fixed energy machine which allows the antiprotons available at the end of a collider store to be captured, recooled and reused in subsequent stores.

We give some parameters and a schedule for the Main Injector and Recycler, discuss the work to be done on the Tevatron and Antiproton Source in preparation for Collider Run II, and describe the extracted proton beams that will be available in the Main Injector era. We present the improvements that will allow us to achieve TeV33 using the existing Collider complex. Finally, we describe a long range plan for the evolution of the Proton Source.

2.1 THE MAIN INJECTOR (1992-1998)

The Main Injector has been under construction since March of 1993. It is a 3319 meter cirumference, 150 GeV, conventional-magnet accelerator designed to perform all duties currently assigned to the Main Ring, but with significantly improved performance. It also provides a new extracted beam capability which can operate *at the same time* as the Collider program.

A summary of operational modes is given below. Shown are the dedicated antiproton production cycle, Tevatron injection cycles for fixed target and collider operations, and Main Injector fixed target cycles.

Operational Mode	Energy (GeV)	Cycle Time (sec)	Flattop (sec)	Protons per cycle
Antiproton Production	120	1.5	0.04	5×10^{12}
Fixed Target (800 GeV)	150	2.4	0.25	3×10^{13}
Collider Injection	150	4.0	1.45	3×10^{11}
High Intensity Slow Spill	120	2.9	1.00	3×10^{13}
High Intensity Fast Spill	120	1.9	0.04	3×10^{13}

Mixed modes incorporating antiproton production and 120 GeV slow spill are also possible. For example, in running a mixed antiproton production/fast spill cycle, 3×10^{13} protons would be accelerated every 1.9 seconds with 5×10^{12} delivered onto the antiproton production target and 2.5×10^{13} delivered to a fixed target experiment, for example NuMI. The anticipated factor of five improvement in luminosity for the Collider program is achieved primarily by increasing the antiproton production rate, but also by improving the transmission of antiprotons into the Tevatron.

Commissioning of the completed Main Injector will start in late 1997 and is planned to be be completed by the end of 1998. The TEC for the Main Injector Project is $229.6M, and $198.6M has been appropriated through FY1997. The present estimated cost at completion is $219M, including the Recycler. To date, $190M has been obligated and $170M costed, leaving the project 78% complete by cost. Formal project completion is scheduled for March 1999.

2.2 THE RECYCLER (1995 - 1999)

The Recycler was approved for inclusion into the Main Injector project in FY1997. As mentioned, it is a fixed energy machine (kinetic energy = 8 GeV) which captures and recools the antiprotons available in the Tevatron at the end of a collider store, allowing them to be reused in subsequent stores. It brings several benefits to the program. It will improve the performance of the antiproton Accumulator by reducing the average stack current during stacking. By recycling the antiprotons available at the end of the Collider store, it also reduces the total load on the Main Injector for production of antiprotons thus increasing the availability of the Main Injector for extracted beams.

The Recycler sits in the same enclosure as the Main Injector and uses permanent magnets. The 8 GeV beamline between the Booster and the Main Injector has provided valuable experience with constructing such magnets, and it has given us confidence in our ability to complete and commission the Recycler Ring as planned. While the Recycler will start operations with stochastic cooling, it has been designed to accomodate the electron cooling system which is required to realize its full potential of a factor of ten increase in luminosity. Commissioning with stochastic cooling will take place over the period spring 1998 through winter 1999. Project completion is scheduled for March 1999.

The estimated cost is $12.5M (excluding contingency) without the electron cooling.

2.3 TEVATRON AND ANTIPROTON SOURCE IMPROVEMENTS FOR COLLIDER RUN II (1997 - 2003)

The goals of Run II require the Main Injector, the Recycler, and several upgrades in the capabilities of the existing accelerators to achieve 2 TeV center of mass energy with two detectors and a peak luminosity of 5 x 10^{31} cm^{-2} sec^{-1} at each detector.

Antiproton Source:

The Main Injector will achieve higher proton intensities and faster cycle times than the Main Ring. To take advantage of these features, the performance of the Antiproton Source also needs to be improved. To accomodate the higher Main Injector intensity ($5x10^{12}$ versus $3.5x10^{12}$ protons per pulse), the primary proton beam will be swept over the face of antiproton target to avoid exceeding the allowable energy deposition density. The stochastic cooling systems in both the Debuncher and Accumulator will have their cooling rates increased by a factor of 2 to accomodate the higher antiproton flux ($20x10^{10}$/hr versus the old value of $7x10^{10}$/hr) by increasing the bandwidth of the cooling systems. The 2-4 GHz bandwidth Debuncher cooling system will be replaced by 4 narrow-band systems operating between 3 and 8 GHz. The Accumulator stack tail cooling system bandwidth will be increased from 1-2 GHz to 2-4 GHz. Removal of some specific aperture restrictions in the Debuncher injection line to increase the antiproton acceptance will result in a further 20% increase in the antiproton yield.

The Tevatron:

The Tevatron will be modified to accommodate the increase in the number of bunches from 6 to 36, to allow antiproton recovery by the Recycler, and to allow operation at 1 TeV. A fast rise time kicker will be installed for the protons to allow loading proton bunches with a 396 nsec spacing for 36 bunch operation. This kicker will be designed so that the rise time can be decreased to 132 nsec. A system that will allow removal of the protons by scraping at the end of a store (while leaving the antiprotons in the Tevatron) will be installed during the 1997-8 shutdown and commissioned in 1999.

The major improvement that allows the Tevatron to achieve an operating energy of 1 TeV was made and demonstrated when the cold compressors were installed in 1993. This lowered the nominal operating temperature of the Tevatron from 4.6^0 K to 3.9^0 K, effectively raising the peak energy by about 70 GeV. At present, the maximum reliable energy of the Tevatron is limited by a few magnets that have lower than average quench currents. Since it is possible to allocate more or less of the central helium liquifier (CHL) capacity to each of the 24 “houses” which distribute helium to the Tevatron, a program of “magnet shuffling” is planned where low quench-current magnets will be placed in lower temperature locations. Improvements to the CHL will be made to increase the capacity and to provide an adequate backup system for the higher flow requirements of 1 TeV operation.

The controls and diagnostics will be updated for 36 and eventual 108 bunch operation and the "shot set-up time" (the time between periods of data taking) will be reduced from 2 hours to 1/2 hour.

As Run II matures, the ultimate luminosity of the Collider complex, namely 2×10^{32} cm^{-2} sec^{-1} may be reached. With 36 colliding bunches, the number of interactions per crossing will exceed 5 at this luminosity. Such a large number of overlapping interactions per crossing makes it difficult for the experiments to interpret the data. One technique for reducing the number of interactions per crossing is “luminosity levelling.” This technique reduces the peak luminosity at the beginning of a store, for example by running a larger β^* at the interaction regions at the beginning of the store and then reducing β^* as the store proceeds. Luminosity levelling extends the luminosity lifetime with only a small loss in integrated luminosity and with significantly lower demand on the detectors’ peak rate capability.

We plan to increase the number of bunches to ~100 with 132 nsec spacing when the experiments need this to reduce confusion from multiple interactions per crossing. To achieve the 132 nsec spacing, it appears necessary to introduce a crossing angle in order to avoid deleterious effects from the beam-beam interaction. The implementation of the crossing angle requires additional separators, minor modifications to the Main Injector rf system, and running the Tevatron injection kicker with 132 nsec rise time. The crossing angle results in a loss of almost 2 in luminosity, so that the maximum in Run II would be about 10^{32} $cm^{-2}sec^{-1}$. This reduction in luminosity can be recovered by adding a superconducting RF system at 4 times the frequency of the present system, but the superconducting system would not be installed before the TeV33 era, 2003 and on.

Improvements that will result in further increases in antiproton production include using “slip stacking” to double the proton intensity for antiproton production. Slip stacking injects two Booster batches into the Main Injector and combines them into a single batch. This technique is compatible with the concurrent operation of the collider program and the Main Injector fixed target program. We also plan to continue removing aperture restrictions in the antiproton source, improve alignment, reduce closed orbit errors, increase the lithium lens gradient, and to improve matching of the antiproton beam phase space to the Debuncher acceptance. However, we do not expect to be able to fully benefit from these improvements in antiproton collection without improving our ability to cool the higher antiproton flux. The most important bottle neck in the cooling is expected to occur in the Accumulator Stack Tail system. This bottleneck will be relieved by the implementation of electron cooling in the Recycler in the TeV33 era.

2.4 EXTRACTED PROTON BEAMS (1998 - 2003)

The Laboratory is planning a capability for extracted proton beams at both 120 GeV and 800 GeV. The 120 GeV beam in the Main Injector will be extracted into the remnant of the Main Ring at F0, from where it can be transported to the antiproton target or the Switchyard. These extraction lines are part of the Main Injector Project. Protons will also be extracted into the NuMI line from a different point in the Main Injector. This is part of the NuMI Project and the primary proton line from the Main Injector to the NuMI target has been fully designed.

The plans for fixed-target areas provide the capability of extracting 800 GeV beam after the year 2000 to the Proton Area and in the KAON line to KTeV/KAMI; the KAON line will also be capable of transporting 120 GeV beam. The Meson area will be served only by 120 GeV beams. The beam lines in the Neutrino area will be shut down and their components recycled. 120 GeV beam will not be sent to the Proton Area. A conceptual design for 120 GeV beam lines to the Meson Laboratory and the KAON line has been completed. The first part of the transport system to the Switchyard will be installed during the FY1998 construction shutdown as part of the Main Injector Project. It is anticipated that this can be commissioned during the 1999 fixed target run.

Transporting the 120 GeV beam cleanly to Meson and KAMI requires more frequent quadrupole focussing than exists at 800 GeV and both lines will require additional quadrupoles. In addition, the cryogenic left bend to Meson will be removed and replaced with conventional dipoles to reduce operating costs, and the geometry of the various bends will be simplified; both quadrupoles and dipoles will come from the existing inventory of beam line magnets. This work will not begin until late 1999, after any 800 GeV fixed-target run, and the design will not be finalized until the actual beam sizes at 120 GeV have been measured. These revised beam lines will be ready for use by the middle of the year 2000.

2.5 TEV33 - THE ACCELERATOR (2003 - 2007)

At the conclusion of Run II, we may have achieved a peak luminosity of 10^{32} cm^{-2} sec^{-1}, assuming the 132 nsec bunch spacing with a crossing angle. A continuation of Run II, referred to as TeV33, is scheduled to begin following a shutdown in 2003. By this time, we expect to have increased the proton beam for antiproton production by a factor of 2 by utilizing slip stacking and/or other improvements to the Main Injector and Proton Source. We also expect to have achieved or to be in the process of achieving another factor of 2 in antiproton yield (antiprotons produced per proton) with the several improvements discussed in the section on Run II (2.3). The increased antiproton flux should translate directly to 4 times higher luminosity and will make it possible to accumulate a further data sample of up to 20 fb^{-1} when the following improvements to the collider complex are implemented.

In Run II, we expect that the Accumulator Stack Tail will be the bottleneck in collecting antiprotons at a higher rate. The implementation of electron cooling in the Recycler will eliminate this restriction. In the initial part of Run II, we will use stochastic cooling in the Recycler. However, technical considerations make it difficult to increase the cooling system bandwidth in the Recycler. An alternative, which is particularly attractive for the high intensity beams in the Recycler, is electron cooling. One of the more important benefits provided by electron cooling is that it allows us to redesign the Accumulator stack tail cooling system in the Antiproton Source so that it can cool a larger antiproton flux, but not to such a high density; the extra cooling load is assumed by the electron cooling system in the Recycler. Even so, the Accumulator stack tail cooling system bandwidth will have to be increased from 2-4 GHz to 4-8 GHz.

To facilitate the frequent transfers from the Accumulator to the Recycler (about once per minute) a dedicated transfer line, AP-5, will be constructed from the Accumulator to the Recycler; this supercedes the initial Run II configuration which uses the Main Injector and the beam line that is used to transport 120 GeV protons to the antiproton production target.

A superconducting rf system in the Tevatron operating at 212 MHz and 20 MV will be used to shorten the bunches and increase the peak luminosity, more than compensating for the introduction of the crossing angle to achieve 100 bunch operation. This system will require a substantial R&D program to develop cavities at this frequency; it will also require new high power rf amplifiers, additional cryogenic cooling systems and some civil construction.

2.6 EVOLUTION OF THE FERMILAB PROTON SOURCE

Along with the scheme described above to achieve TeV33 luminosities, a more radical plan is being developed which considers the long term future of the Proton Source at Fermilab. This development is motivated by the expectation that with the advent of the Main Injector, and the capability for simultaneous operation of fixed-target and collider programs, the demand for protons will grow. Once NuMI is fully operational, its requirements together with the Run II Collider could saturate the capability of the present Proton Source. This, however, does not cover the full potential of the future program. There are other fixed-target experiments and programs approved or under serious consideration including the rare Kaon decay program, a narrow band beam for NuMI and a low energy neutrino program based on 8 GeV protons from the Booster. There are plans to increase the Tevatron collider luminosity beyond those of Run II. There is a program to understand the possible future siting of either a very large hadron collider or a muon collider at Fermilab. Support for all these activities simultaneously is beyond the capabilities of the present proton source - in the case of the muon collider by more than a factor of ten. The whole Fermilab research program will clearly benefit if the number of protons delivered per hour can be increased by a factor of 5 to 10.

The present Fermilab Proton Source is composed of a 750 kV ion source, a 400 MeV Linac, and an 8 GeV (kinetic energy) Booster synchrotron. This facility currently provides proton beams at intensities up to 5×10^{10} protons/bunch for injection into the Main Ring in support of the current Tevatron fixed target run. Following completion of the Main Injector project in 1999, the Proton Source is expected to provide protons to the Main Injector at an intensity of 6×10^{10} protons/bunch as required to achieve established performance goals for Tevatron Collider Run II.

The plan for the evolution of the Fermilab Proton Source takes place over the next ten years and more. While the plan is not yet complete, it is evident that its primary components are likely to include the following:

- Relocation of the Booster and an upgrade of the H^- source.
- Construction of a new Booster with higher energy and larger aperture.
- Upgrading of the Linac energy
- Construction of a new intermediate energy Pre-Booster

A staged implementation of these improvements is envisaged with benefits accruing to the Main Injector and Tevatron program at each stage, and with minimal disruption to the scheduled program from construction activities. The first stage allows the Booster to deliver more beam to the Main Injector, the second stage increases the protons/bunch delivered by a factor of 2. The timing of these stages will be dictated by normally scheduled program interruptions in the Fermilab program and by the availability of funding. Upon completion of the final stage, the new Fermilab Proton Source would have the following capabilities:

- A factor of five increase in protons delivered to the Main Injector
- A factor of five increase in the protons available for a low energy neutrino program
- Support for muon production sufficient to achieve a luminosity of 10^{33}cm^{2}sec^{-1} in a 500 GeV (center-of-mass) muon collider.

3 FACILITY PLANS

This section describes the plans to allow optimum use of the accelerator complex for experiments. These plans include providing a third interaction region in the Collider, designs for beams for a refined 120 GeV fixed-target program simultaneous with the collider program, and the plans for the NuMI project including the beam-line, the experiment halls for the near detectors and the hall for the far detector at the Soudan mine in Minnesota. A recent development is the proposal to explore the LSND signal region at Fermilab using beam from the Booster. A scenario for the evolution of the Proton source, including the Booster, was given in the previous section (2.6).

3.1 CZero Interaction Region (1997 - 1999)

The $5 million in funding included in the Budget for FY1998 provides for construction of a collision hall at CZero and thus affords the opportunity to create a third $\bar{p}p$ interaction region in the Tevatron where modestly sized experiments and detector R&D may be undertaken. Construction of the hall will begin in FY1998 and will be completed during the suspension of Tevatron operations for the tie-in to the Main Injector - thus avoiding any major interruption of operations during Collider Run II The project will provide an experiment hall appropriate for installing an experiment with maximum dimensions +/- 13m along the beam and +/- 2.5m transverse to the beams, along with a small staging area, counting room facilities, and minimum utilities. Additional funding will be required to complete the outfitting of this facility for the installation of experiments, and for the low-β^* focussing elements and electrostatic separators necessary to bring beams into collision at moderate luminosities.

3.2 The NuMI Beam and Experiment Facilities (1997-2001)

When the Main Injector is completed, it will provide for the first time the capability for simultaneous operation of both collider and extracted beam physics programs. In particular, it will be possible to create high intensity beams of neutrinos which provide unprecedented physics opportunities. The NuMI (Neutrinos at the Main Injector) project involves the designing and construction of such neutrino beams and the facilities for experiments to use the beams in search of neutrino oscillations. These facilities include two experiment halls at Fermilab and an experiment hall in the Soudan mine in Minnesota. The NuMI project also includes the construction of the detector for the MINOS long baseline experiment.

The 1998 President's Budget Request contains $5.5 million for A&E work for the NuMI beam line. This is an encouraging step towards funding for the conventional construction of the beam line and of the detector halls at Fermilab and in the Soudan mine (some 730 km from Fermilab) starting in FY1999.

The beamline for the NuMI neutrino oscillation experiments begins with the 120 GeV Main Injector beam extracted at MI-60. A detailed design exists for transporting the proton beam to the NuMI target and then aiming the neutrino beam properly towards Soudan Minnesota. A horn focused wide-band beam will be used in the first years of operation; provisions to allow change over to a narrow band beam are being included in the design. The target station will be surrounded by adequate shielding to reduce residual radiation in the enclosure and to prevent contamination of groundwater, thus ensuring that NuMI operations remain within regulatory limits. The target enclosure is followed by a 750 meter long decay pipe, two meters in diameter inside a six meter diameter tunnel. The decay pipe will be shielded for radiation by a liner of steel and concrete and a copper absorber at the end of the pipe will stop uninteracted protons and hadrons. Beyond the absorber, the NuMI tunnel follows an off-axis trajectory for 250 meters, thereby providing a rock muon shield upstream of the detector halls.

A muon neutrino beam with an average energy of 17 GeV can be used to search for oscillations in the channel $\nu_\mu \rightarrow \nu_\tau$ as well as the channel $\nu_\mu \rightarrow \nu_e$. The energy is significantly above the threshold for τ production from the charged current interaction $\nu_\tau + N \rightarrow \tau$. The NuMI beam design achieves a ν_e contamination of ~ 0.6%, and a combined $\bar{\nu}_e + \bar{\nu}_\mu$ contamination less than 0.9%. The purity, intensity and energy range of this beam is vastly superior to any other beams contemplated elsewhere.

The NuMI facility on the Fermilab site includes two experiment halls constructed off the NuMI tunnel; the upstream hall will be used for the COSMOS short baseline experiment. (The COSMOS experiment itself is not part of the NuMI project). Two hundred and fifty meters further downstream a second hall will house the near detector of the MINOS long baseline experiment. The halls are located between 70 and 90 meters below the surface.

The far detector for the MINOS experiment will be located more than 800 meters below the surface in a new cavern to be constructed in the Soudan Underground Laboratory in Minnesota. This hall will be approximately 85 meters long and 12 meters wide and oriented along the trajectory of the beam from Fermilab. As mentioned, construction of the MINOS detector itself is also part of the NuMI project. The aims of the MINOS and COSMOS experiments are described in section 4.3.

3.3 Kaon Beams from 120 GeV Protons (2001 - 2003)

The Main Injector also offers the opportunity to generate kaon beams of high intensity. KAMI (Kaons At the Main Injector) is a continuation of the neutral K_L experiments now running using 800 GeV protons from the Tevatron (KTeV). KAMI will use the 120 GeV proton beams from the Main Injector to make K_L beams and search for rare decays. The plans for the KAMI beam involve two stages. Initially the experiment will reconfigure for 120 GeV, the 120 GeV proton transport will be installed to the existing target station. This alone will produce an order of magnitude increase in the number of kaon decays available for study compared to KTeV. A second stage will involve upgrading the detector for higher rates and then moving the target station downstream, closer to the detector. This will gain another order of magnitude in decays.

Proposals for two new kaon experiments are being prepared for the 120 GeV Meson area. Both proposals rely on a new rf-separated charged kaon beam generated by cavities operating at 4-6 GHz. The time required for the R&D on the new superconducting cavities is about 3 years and Fermilab is already developing some expertise in this area. The charged kaon beam is designed to be switched between two experiments, CKM (Charged Kaons at the Main Injector) which uses the charged kaons directly and CPT which will make a pure K^0 beam using the charge exchange reaction from the K^+ beam striking a target. This will be a short beam in length and therefore dominated by K_s decays.

The time scale both for the second stage of the KAMI program, and for CKM and CPT is set by the availability of funding but is not foreseen before 2003.

3.4 8 GeV Extracted Beam for MiniBooNE

The MiniBooNE (Booster Neutrino) proposal asks for $5x10^{12}$ protons per pulse at an average rate of 5 Hz from the Booster. Since the NuMI program and antiproton stacking require only 6 Booster batches out of the 30 available each 2 sec Main Injector cycle, there are booster cycles available. A design for the extraction and extraction line has been made to direct the beam toward the BooNE target hall. The BooNE beam will leave the Main Injector tunnel at MI10 and be transported through approximately 100ft of tunnel to the BooNE target hall. The design uses a combination of new permanent magnets and existing electromagnets.

4 PLANS FOR THE PROGRAM OF EXPERIMENTS

This section describes plans for experiments over the next 10 years. It starts with a summary of the 96-97 fixed-target run and mentions the plans for a reduced fixed-target program to run in 1999 when the Main Injector is being commissioned. We describe the plans for the major collider experiments for Run II and the program of neutrino oscillation experiments. Proposals and initiatives for a rare Kaon decay program and a dedicated B collider experiment are also given. Looking further, we describe the opportunities offered by TeV33 and show how the Collider upgrades in progress provide a strong basis for detectors able to exploit these opportunities.

The upgrades for the Collider experiments CDF and DZero constitute the major experiment construction activity at the Laboratory for the next two to three years; both experiments were "baselined" earlier this year in a Lehman review. In broad overview, as the present Collider upgrades are completed, resources for detector development and construction will become available to the Neutrino program of MINOS and COSMOS and to other projects.

The sum of the plans outlined here exceeds our financial capability and the strategy for making decisions in the future is described in the summary, section 7.

4.1 800 GEV FIXED-TARGET PROGRAM (96-97 & 99)

Collider operation ended on February 28, 1996, and the excavation of the underground enclosure that connects the Booster Ring to the AP-4 line began that day. Starting in May, the Tevatron was recommissioned on weekends and evenings when it did not interfer with construction. Round-the-clock operation of the Tevatron resumed in late June with all of the planned construction accomplished within the aggressive schedule set at the end of 1995. The present run is the last full 800 GeV run.. The plans for the long-term future do not show any such accelerator operation except for a period in 1999 during Main Injector commissioning. (The ability to deliver 800 GeV beam to Proton and the KAON line is being preserved - see 2.4)

Overall, the performance of the beams and the detectors has met and even exceeded expectations.

The Neutrino experiment, **NuTeV**, received almost $3x10^{18}$ protons (three times the original commitment). The cleanliness of the sign-selected beam and the size of the data sample will allow precise measurements of $\sin^2\theta_w$ and $\alpha_s(Q^2)$ and a determination of the mass of the W boson with an uncertainty of ~100 MeV/c^2, comparable precision to the final measurements from CDF and DZero from Run I. These three Tevatron measurements should yield a measurement of the W mass to a precision of ~60 MeV, comparable to the four LEP experiments by the year 1999.

The neutral Kaon experiment, **KTeV** has had an outstanding run. The neutral K beam outperformed expectations with beam-created backgrounds substantially reduced compared to those in the previous experiment E731. The detector was completed within budget and within three months of the schedule date. While there were some problems with some new integrated circuits, the detector performance has more than met the demanding expectations of its designers. New observations on rare decays have already been presented with a 100 fold increase in signal over previous results and the statistical precision of the data set will allow a measurement of ε'/ε to better than 2 parts in 10^4.

The performance of the new tagged photon beam and the upgraded **FOCUS** detector has also proved very satisfying. With a new silicon vertex detector, new electromagnetic and hadronic calorimeters, new (rebuilt) wire chambers, a new muon system and a new data acquisition system, the collaboration more than met their goal of recording one million fully reconstructable charm decays, a full factor of 10 over their previous data set.

The **NuSea** experiment had a very succesful run, exceeding their anticipated sample of data for studying Drell Yan production from Hydrogen and Deuterium to determine differences in the u and d sea distributions. Preliminary analysis already shows a clear difference between $\bar{u}$ and $\bar{d}$.

The **DONUT** experiment, which is attempting the first direct observation of ν_τ, has overcome the problems of primary beam and muon-produced background and expects about 100 examples of ν_τ interactions in its emulsions.

The **SELEX** experiment which studies charm baryon production and spectroscopy using a novel vertex triggering technique is expected to have a large sample of charmed baryons. Though the rejection achieved with the vertex trigger was less than expected forcing the experiment to run at lower rates than planned, the experiment logged many more hours than orginally requested and should have close to its desired data sample.

The **HyperCP** experiment,which looks for CP violation manifested as a difference between the cascade-lambda and anticascade-antilambda decay asymmetry product, has the data to improve the current limit on this difference by a factor of almost 100. That the experiment did not achieve its design factor of 200 above the present limit is largely due to an unexpectedly low yield of $\overline{\Xi}$'s in the beam. The ambitious wire-chamber system and data-acquisition worked extremely well.

The **Charmonium** experiment which studies the spectroscopy of charmonium through resonant formation in proton-antiproton annihilation has been affected by some problems with the performance of the antiproton source but will receive about 70% of its 200 pb^{-1} requested luminosity. The detector as a whole has worked very well, including the first use in an experiment of a tracker based on scintillating fibers readout with VLPC's.

The **Antihydrogen** experiment which studies the formation of antihydrogen in the antiproton source using the Charmonium gas-jet as target for the process $\bar{p}p \rightarrow e^+\bar{p}pe^-$ where the positron and antiproton combine to an atom of antimatter, $\overline{H}$, has detected about 50 $\overline{H}$ atoms with essentially no background.

As is obvious, this last major 800 GeV Fixed-target run has been a considerable success. After this September, the 800 GeV fixed target physics program will proceed on two fronts: a major computing effort in support of the analysis of the 1997 data set and a modest effort of preparations for a 1999 fixed target run with a much reduced number of experiments.

1999 Fixed-Target Run

A fixed-target run at 800 GeV is envisaged to begin at the end of 1998 and continue for the first 6 months of 1999 for a few experiments where the increased data set will allow significant improvements in the physics reach and where developments for a future program can be tested. This time will also be used to commission the Main Injector, the upgraded Antiproton Source and Tevatron to the extent possible for Collider Run II.

The **DONUT** experiment, **KTeV,** and the **Charmonium** experiment have been invited by the Laboratory to submit proposals for this run. Other experiments may also submit proposals.

4.2 THE COLLIDER EXPERIMENTS FOR RUN II: CDF AND DZERO

Collider Run II is defined as a data set of at least 2 fb^{-1} on tape for each detector, with the run begining in the year 2000 and continuing through at least 2002. The data set sizes will be at least twenty times the size of the existing CDF and DZero data sets from Collider Run I (1992-96).

To illustrate the scale of Run II, consider the number of 'top' events observed with at least one tagged displaced vertex. (This is one of the preferred samples for measurement of the top mass.) Compared to Run I, the integrated luminosity will be 17 times higher, the production cross section will be 30% higher (at 2.0 TeV vs. 1.8 TeV), and two detectors will each have vertex tagging capability for the entire luminous region (a factor of 1.55 for CDF, an entirely new feature for DZero). This will give both detectors over 1000 vertex-tagged events to be compared to 34 such events observed by CDF in Run I. This top mass data sample will increase by a factor of 70, nearly two orders of magnitude. A similar analysis of top events with two tagged displaced vertices leads to an increase from 5 events at CDF in Run I to over 500 events in the two detectors in Run II.

The length of Run II and the total delivered luminosity will be determined by the ability of the detectors to operate efficiently with increasing instantaneous luminosity and increasing integrated luminosity in the Main Injector era. The maximum useful instantaneous luminosity may be set by the tracking and trigger confusion resulting from multiple interactions per crossing; the total integrated luminosity will probably be limited by degradations in detector performance, particularly of the silicon vertex detectors, due to radiation damage.

The Upgrades to the CDF and DZero Detectors

To achieve the physics goals of Run II, each detector is undergoing an extensive upgrade. The upgrades are well defined in scope, well understood in terms of total cost, and on a schedule to finish construction in November, 1999. Each upgrade will result in a detector which is capable of dealing with instantaneous luminosities of at least 2 x 10^{32} cm^{-2} sec^{-1} with 132 nsec between beam crossings. Our current understanding from the measured properties of the silicon vertex detectors indicates that they will suffer little deterioration in performance up to 2 fb^{-1} and may well function adequately up to 3- 5 fb^{-1}.

Working from the interaction region out to the data storage, the salient features of the **CDF** upgrade are :

- a new six/seven layer silicon strip vertex detector with double sided readout and a total of ~ 675k channels. The device will cover the range $|\eta| < 2.0$. The readout will be a third generation radiation hard ASIC (called SVX3) with a 42 stage pipeline for deadtimeless operation at trigger rates up to 50 kHz.

- a new drift chamber with smaller wire spacing capable of resolving individual beam crossings at 132 ns. The drift chamber will have 48 stereo measurements (twice the number of Run I) and 48 axial measurements for tracks in the range $|\eta| < 1.0$. The readout electronics include a new pre-amp and a new multihit TDC.
- new "plug" calorimeters in the forward directions, using scintillator tiles with waveshifting fibers and PMT readout to cover $1.1 < |\eta| < 3.6$, making the entire CDF calorimeter a scintillator based device. The calorimeter electronics will be replaced with a new version of the QIE (charge integrating and encoding) ASIC first deployed in KTeV.
- muon system upgrades including reduced gas gain in the original chambers ($|\eta| < 0.6$), patched acceptance in several azimuthal "holes" with additional chambers, a new system of chambers in the forward direction ($1.0 < |\eta| < 2.0$), and new scintillator counters throughout to tag beam crossings in the entire system.
- a rebuilt trigger system, maintaining the three level sorting system. The first level will be deadtimeless for 132 nsec crossings, operate in 5.5 microseconds and have a 50 kHz output. The second level will have four buffers to minimize deadtime, accept the full 50 kHz from Level 1, operate in 20 microseconds, and output up to 300 Hz to Level 3.
- a new front-end electronics and data acquisition system packaged in VME crates, each with a local processor which transfers data via a 5 MB/sec network switch for 300 Hz input to the Level 3 trigger processor farm. Level 3 output data at 30 - 50 Hz are logged to tape or directly to disk in the Feynman Computing Center.

The main features of the **DZero** upgrade are:

- a 2.0 Tesla solenoid magnet inserted inside the existing calorimeter. This adds the ability to measure all charged particle momenta to DZero for the first time.
- a new "barrel and disk" silicon strip vertex detector. The barrel has four layers, two layers with small angle stereo and two with large angle stereo. The disks provide tracking in the forward direction and help to accomodate the long luminous region.

The detector will have a total of ~ 795k channels and cover the range $|\eta| < 2.5$. The readout will be a second generation radiation hard ASIC (called SVX2) allowing Level 1 trigger accept rates up to 10 kHz.

- a scintillating fiber tracker with Visible Light Photon Counter and SVX2 readout located just outside the vertex detector, at radii from 19 cm to 52 cm. This tracker will have 77,000 channels in 8 axial and 8 stereo layers covering the range $|\eta| < 1.7$. The fibers are 835 microns in diameter and are staggered in doublets to give 100 micron resolution in each of the sixteen layers.

- two preshower detectors placed just outside the solenoid with strips of triangular cross section extruded scintillator using fiber and VLPC readout. The preshower detectors will cover the range $|\eta| < 1.2$ and $1.4 < |\eta| < 2.5$ and aid electron triggering and identification.

- modification of the liquid argon calorimeter electronics to achieve a shorter effective integration time (reducing 2.2 microseconds to 400 nanoseconds) and to reduce intrinsic and uranium pre-amplifier noise. The noise performance will be similar to that seen in Run I.

- muon system upgrades including new electronics for the central system ($|\eta| < 1.0$), 48,000 channels of mini-drift proportional tube detectors in the forward region ($1.0 < |\eta| < 2.0$), and new scintillator trigger counters throughout to tag beam crossings in the entire system.

- a rebuilt trigger system, now with three levels of sorting. The first level will be pipelined and buffered for deadtimeless operation, operate in 4.2 microseconds, and have 10^3 rejection for a 10 kHz output. The second level will be buffered to minimize deadtime, execute in about 100 microseconds, and output up to 1 kHz to Level 3.

- the same data acquisition architecture but with a new data collector/data distributor system to handle a rate of 160 Mbytes per second (about 800 Hz) to the Level 3 trigger. The Level 3 trigger processor farm will reconstruct events in 25 msec and output 20 Hz of data with less than 5% deadtime. The online computing will support data logging capacity of 5 MB/sec average, 25 MB/sec peak. As with CDF, the data will be logged directly in the Feynman Computing Center.

Details of the upgrades and a thorough discussion of their physics goals and capabilities are in : **"The DZero Upgrade: The Detector and Its Physics, the DZero Collaboration, Fermilab-Pub-96/357-E, October 1996".** & **"The CDF II Detector Technical Design Report, the CDF II Collaboration, Fermilab-Pub-96/360-E, November 1996".**

The large increase in data expected in Run II (twenty times that collected in Run I) will provide a major challenge in off-line computing and data access. Progress in the commercial computing world is expected to provide much of the extra capacity required to handle the increased data sets at a cost which is not significantly higher than the costs associatedwith the Run I computing systems. Nevertheless, the unprecedented size of the data sets and the associated computing demands will require a large effort from the Computing Division and both collaborations over the next few years.

4.3 NEUTRINO OSCILLATIONS (MINOS, COSMOS, MINIBOONE)

Two experiments have been proposed and approved to search for neutrino oscillations suing neutrino beams from the Main Injector.

MINOS is a long baseline experiment which will explore parameter space down to a Δm^2 of 10^{-3} $(eV)^2$ at large mixing angle and a few 10^{-2} $(eV)^2$ at $\sin^2(2\theta)$ of 0.02. The experiment is designed to fully cover the region indicated by the atmospheric neutrino deficit. The MINOS far detector will be located in a newly constructed cavern in the Soudan Underground Mine in northern Minnesota, 730 km from Fermilab. A smaller near detector of similar design will be located on the Fermilab site. The detector is composed of magnetized iron calorimeter modules of approximately three kilotons each. Though the MINOS proposal calls for three such modules, both funding limitations and evolving physics results in the neutrino sector, are leading the collaboration to construct the detector in stages and consider options for including a detector of extremely high resolution such as emulsion which would provide the capability of doing a true τ appearance experiment for the long baseline.

A short baseline experiment can explore the large Δm^2 region down to very small mixing angles. COSMOS is a ν_τ appearance experiment which focuses on the ability to demonstrate an unambiguous τ signal if oscillations exist. The sensitivity plot shows a reach down to 0.1 $(eV)^2$ at large mixing angle and sensitivity to $\sin^2(2\theta)$ as low as $3\text{x}10^{-5}$ for Δm^2 above 30 $(eV)^2$. The COSMOS apparatus is a hybrid emulsion & electronic spectrometer. Candidates for τ decays are directly observed in the emulsion target, and information from the electronic spectrometer is used both to select and locate events to be scanned, and to provide momentum, energy and particle identification for kinematic analysis of the τ candidates. COSMOS will have a 90% confidence level sensitivity an order of magnitude better than that aimed for by CHORUS and NOMAD, and two orders of magnitude better than the best present limit which was set by Fermilab E531.

Recently, a Letter of Intent has been received proposing to perform an experiment using a neutrino beam derived from protons from the Booster. The experiment, known as **MiniBooNe** (Booster Neutrino Experiment), is motivated by the data for neutrino oscillations from the LSND and atmospheric neutrino experiments. The proponents claim a factor of 10 greater sensitivity than the LSND experiment in both Δm^2 and $\sin^2(2\theta)$; for large mixing angles, the minimum Δm^2 reachable is about 10^{-2} and for Δm^2 above 1 $(\mathrm{eV})^2$ the experiment is sensitive to $\sin^2(2\theta)$ of $6\mathrm{x}10^{-4}$. The experiment expects a sample of 400 events if the LSND signal is due to $\nu_\mu \to \nu_e$ oscillations. If oscillations are observed the experiment plans a second phase with a second detector to determine the values of Δm^2 and $\sin^2(2\theta)$.

4.4 120 GeV Kaon Program (2001 and on)

A second use of the 120 GeV extracted beam is to serve a rare K decay program being planned. As mentioned, the Main Injector can provide the Meson area and the KAON line with 120 GeV protons concurrently with the delivery of 120 GeV protons to the antiproton target and to NuMI, and a powerful Kaon program would require only a fraction of the Main Injector flux.

The essential technical basis for the Kaon program is the capability of the Main Injector to furnish Kaon fluxes 100 times those currently available, with good duty cycle and round the year operation. The physics motivation includes the continued quest to understand the origin of CP violation, the search for CPT, and that the real test of the Standard Model will come by making measurements in *both* the kaon and the b system. Three experiments are in the conceptual design phase:

- KAMI which is aiming at the process $K_L^0 \to \pi^0 \nu\bar{\nu}$ and possibly $K_L^0 \to \pi^0 e^+ e^-$
- CKM which is aiming at the process $K_L^+ \to \pi^+ \nu\bar{\nu}$ and

- CPT which uses a K^+ beam to generate a fairly pure K^0 beam and looks for CPT violation in the K_L and K_S interference.

The KAMI experiment is based on the existing KTeV detector and experiment hall. Plans are being developed for the beams to the CKM and CPT experiments and for the detectors to be located in the Meson lab. The first phase of KAMI which uses the existing target station and the existing KTeV detector with small improvements could begin operation as early as 2000. The fully improved detector and extended beam line are not foreseen before 2003.

4.5 CHARM AND BEAUTY EXPERIMENT AT CZERO (2002 - 2005)

The CZero collision hall provides an opportunity to stage a third major collider experiment..

In June of 1997, the Program Advisory Committee reviewed the expression of interest by the BTeV collaboration to construct an experiment at CZero. It is currently expected that a Letter of Intent (LOI) will be submitted in time for consideration by the PAC at its spring meeting in 1998. The LOI is expected to include a conceptual design report for the detector. If the proponents show that the detector can be used to carry out a competitive and affordable heavy quark experiment, they will be invited to submit a proposal that includes a technical design report and a detailed cost estimate. The availability of engineering support will set the time scale for the proposal. The likely time frame for first operation of CZero for heavy quark physics is after 2002.

BTeV

The aim of BTeV is to design, build, and operate a dedicated B experiment at the Fermilab Tevatron collider. The experiment will follow the round of experiments (e^+e^- B factories, CDF, DZero, HERA-B) which will begin operation in 1998-2000 and which will most probably make the first observations of CP violation in the B system in decays to $J/\Psi\ K^0_s$. BTeV is being designed to take the next steps in these studies by making detailed measurements of $\sin(2\alpha)$, $\sin(2\gamma)$, x_s, and of rare B and charm decays. (BTeV is the only B experiment that also plans to make the study of rare charm decays one of its goals) In particular, BTeV aims to be the best experiment for studying mixing, CP violation, and rare decays of the B_s. BTeV will also be able to study b-baryon decays and the B_c meson. The experiment is being designed to run in the CZero experiment hall.

The key features of the experiment are :

- forward (and backward) coverage which makes the detector efficient for reconstructing high momentum B's. The reconstructed B decay vertex for high momentum B's is better defined because the decay products are also of high momentum and their tracks are less affected by multiple scattering. The spatial precision achievable with a powerful vertex detector gives the detector excellent lifetime resolution which is particularly important for B_s mixing studies. The forward coverage is achieved by placing a dipole directly on the IR, which provides good acceptance for pairs of B's going either forward or backwards.

- high precision vertexing based at present on planar arrays of silicon pixel detectors. The pixel detectors allow the experiment to run at high rate, make it resistant to radiation damage, provide excellent tracking. pattern recognition, and vertexing capability, and deliver fast signals to the Level I trigger.

- a Level I trigger based on the detection of tracks with large impact parameters with respect to the primary vertex or with secondary vertices. This permits the experiment to trigger on B or charmed states without leptons in them while leaving open the possibility of using non-leptonic tagging methods, such as kaon , jet charge, or soft pion tagging. It is the most general trigger that can be implemented for B physics and we have demonstrated that it can be efficient for triggering on a wide variety of B states while offering good rejection against minimum bias events. The trigger is based on a massively parallel system of computer processors interconnected with high speed switches.

- excellent particle identification based on a Ring Imaging Cerenkov Counter with momentum coverage from 3 to 70 GeV/c. This is important for nearly all studies of purely hadronic final states where incorrect identification of decay particles creates serious backgrounds. Moreover, the system provides the ability to tag kaons, a capability which simulation shows to be very effective in this kinematic region. Further particle identification is provided by an electromagnetic calorimeter and a muon system .

The BTeV collaboration is concentrating its efforts on detailed simulations to optimize the design of the experiment, especially the trigger, to help develop the pixel detector, and to develop the hardware for the trigger system. Conceptual design work is also proceeding on the RICH counter, the muon detector, the calorimeter, the conventional part of the tracking system, and the remainder (Level II, III) of the trigger and the data acquisition system. The group hopes to begin with tests on subsystems in CZero soon after the collider starts up for Run II and to have a large part of the experiment installed and doing physics by the years 2003-2004.

4.6 TEV33

The Fermilab community has studied the opportunities that a luminosity approaching 5×10^{32} cm^{-2} sec^{-1} would provide between the end of Run II and the time when the LHC clearly eclipses the Tevatron. The study identified excellent physics opportunities and concluded that the Laboratory should strive to deliver an integrated luminosity of 30 fb^{-1}.

The Physics Potential of TeV33

With the discovery of the top quark, the Tevatron Collider has begun to explore the scale of energy associated with electroweak symmetry breaking. At higher luminosity, the Tevatron Collider will continue the exploration of this new domain of physics. TeV33 describes the physics potential of a high-luminosity physics program following Run II of the Tevatron Collider. The program is largely based on studies made by the TeV 2000 Study Group which analyzed the physics opportunities associated with integrated luminosities of 2 fb^{-1}, 10 fb^{-1} and 100 fb^{-1} and the TeV33 studies which focused on accumulating a data sample of 30 fb^{-1} by the year 2006. The TeV33 program combines precision measurements of electroweak parameters with the potential for discovering physics beyond the Standard Model. Important elements of the physics program include detailed studies of the top quark with precision measurements of its mass, width and spin; precise measurements of the W-boson mass, width and couplings; potential discovery of the intermediate mass Higgs particle; exploration of light-scale supersymmetry; and sensitivity to a wide range of exotic physics.

The top quark provides a unique physics program at the Tevatron Collider. With 240,000 top quark pairs and 90,000 single top quarks produced during TeV33, a large number of tagged events can be accumulated in a variety of channels where precise measurements of the top-quark properties can be achieved. The top-quark mass will be measured to a precision of about 1 GeV (3 GeV) in TeV33 (Run II). The top-quark width can be inferred with a precision of 8-9% (27-28%). The branching ratios for top-quark decays can also be accurately measured. By observing the polarization of the W-boson in top decays and by measuring various asymmetries in top production and decay, detailed information on the spin structure of the top-quark couplings can be determined. Single top-quark production via the W* process will provide a unique opportunity for measuring the top-quark CKM matrix element, $|V_{tb}|$, to a precision of 4% (14%). Because of the large Q^2, this process is sensitive to signals for new physics associated with the top quark.

A prime example of the benefit of the increased sensitivity of TeV33 is the discovery potential for an intermediate mass Higgs boson in (W,Z)H (H->bb) final states. With an integrated luminosity of $30fb^{-1}$, the Tevatron Collider will be able to discover a Higgs particle with mass up to 120-130 GeV which encompasses the full range predicted in normal supersymmetric MSSM models. Measuring the W*WH vertex will complement a measurement of the Z*ZH vertex in lepton colliders and the measurement of the ($H\to\gamma\gamma$) channel required for observation of an intermediate mass Higgs at the LHC. The properties of a light Higgs particle can also be measured. A standard Higgs particle with a mass of 100 GeV will yield about 200 events in TeV33 allowing a measurement of the Higgs width to precision of about 1 GeV.

Precise measurements of electroweak parameters are possible with the large data samples of TeV33. The W-boson mass will be measured to a precision of 20-30 MeV compared to 40-50 MeV expected in Run II and LEP II. It may be possible to improve the precision of this measurement using (W/Z) cross section ratios and the high Z statistics available in TeV33. The precise W-boson and top-quark mass measurements imply a 30-40% estimate of the Higgs mass in the Standard Model. A direct measurement of the W-boson width will reach a precision of 15 MeV (30 MeV). TeV33 will also provide precise measurements of parton distributions using lepton asymmetries, and of $\sin^2\theta_W$, the strong coupling constant and anomalous vector boson vertices.

Low-mass supersymmetry will be probed in TeV33. While the higher luminosity provides only a modest increase over Run II in mass reach for super-partners, 250 GeV (200 GeV) for charginos and neutralinos and 400-500 GeV (300-400 GeV) for squarks and gluinos, the entire mass range of the lightest Higgs particle and the light stop are covered by TeV33. If supersymmetry is first discovered at LEP II or in Run II of the Tevatron, then large samples of supersymmetric particles could be available for study in TeV33. With these samples, various superparticle states can be identified allowing measurements of their masses, mass differences and cross sections.

The Tevatron has potential for discovering signals that may indicate thresholds for new dynamics other than supersymmetry, such as technicolor or topcolor. Discoveries in Run II of the Tevatron Collider could be exploited using the higher luminosities of TeV33.

A high luminosity Tevatron offers rich opportunities for exploring the physics of the Standard Model and beyond. It is the heart of the U.S. High Energy Physics Program for the next decade combining a program of precision measurements of electroweak parameters with the discovery potential for new physics.

The Collider Experiments & TeV33

Both CDF and DZero have considered the suitability of their Run II detectors to exploit the opportunities of TeV33; they have provided these statements.

CDF for TeV33

"CDFII, as built for TeV Run II, is a powerful general purpose detector which is well positioned to exploit the physics opportunities of 30 fb^{-1}. The main performance issues at the luminosities of TeV33 are radiation damage close to the beamline, and the effects of overlapping interactions on the trigger and the analysis. Radiation damage will force the replacement of the inner silicon layers long before the accumulation of the full 15 MRad expected after 30fb^{-1}. The lifetime of the Run II silicon system is under study, and may require measurement of the actual damage constants in Run II, but probably lies in the range of 2-6 fb^{-1}. The need to replace the inner layers motivates the consideration of ambitious radiation hard technologies under development for future detectors, such as diamonds or pixels, which could yield big performance payoffs. The uncertainties of cost and schedule for these technologies also leads to the consideration of fallback solutions based on silicon strips. Correlated design issues such as occupancy, pattern recognition, resolution, and optimal inner radius must also be studied. Once a technology is chosen, there needs to be a dedicated R&D program to have prototypes in a test beam by year 2000.

"Although CDF II is a much more capable detector than CDF I, the Run I data can be used to construct reliable models of CDF II performance as a function of $\overline{N}_{crossing}$ (the average number of interactions per crossing). $\overline{N}_{crossing} = 5$ at 5×10^{32} $\mathrm{cm}^{-2}\mathrm{sec}^{-1}$ with 132 nsec crossings. Preliminary studies of the tracking in the combined system of 7 silicon layers and central drift chamber suggest that the track finding, resolution, and b tagging efficiency are robust out to at least $\overline{N}_{crossing} = 5$. To ensure continued good linking, CDF would anticipate completing the 7th silicon layer in the central region, and some modifications to the inner layers of the drift chamber.

"Preliminary studies based in Run I data also suggest that the complete set of triggers for the high p_t and b physics programs can be accomodated with 90% livetime and no changes in the DAQ system up to L = 5×10^{32} $cm^{-2}sec^{-1}$, only requiring that the experiment can double the bandwidth of the Level 3 processor system. Straightforward upgrades to the secondary vertex trigger can ensure and even enhance its performance. The experience of the first data from CDF II will allow the implementation of significant parts of the offline analysis at Level 3, leading to compressed versions of part of the data set.

"The calorimeters continue to be useable, although strategies will have to be developed for coping with light loss at large rapidities of the plug scintillator system. A backup for the central preshower and shower max systems may also prove desirable. The muon chamber systems are expected to have no problems with ageing or occupancy..

"In summary, preliminary study suggests that the main detector plant of CDF II is robust at $5 \times 10^{32}cm^{2}sec^{-1}$with a small upgrade program of modest cost and reasonable timescale; the promise of the Tev33 physics program seems truly accessible at FNAL before 2007."

DZero for TeV33

"The DZero Upgrade Detector for Run II is designed for instantaneous luminosities of 2×10^{32} with a bunch spacing of 132 nsec. This corresponds to a mean number of interactions per crossing of between one and two. The integrated luminosity in Run II is expected to be of the order of 2-4 fb^{-1}. The TeV33 operating condition of 5×10^{32} which with luminosity levelling has the potential to yield 20-30 fb^{-1} represents an increase of a factor of 2.5 in instantaneous intensity over that envisaged for Run II.

"The two issues that need to be considered when discussing Run III are the integrated radiation damage and the impact of increased instantaneous rates. DZero has examined the DZero Upgrade detector and concludes that it has a very sound basis for further exploitation of the exciting possibilities for physics with samples corresponding to tens of inverse femtobarns.

"The calorimeter is radiation hard and can be operated essentially unchanged in Run III. Recent radiation damage studies indicate that the preshower detectors should operate satisfactorily in all except possibly the very high rapidity regions.

"The muon system at high rapidity is currently being modified with short drift time tracking detectors. The central region is expected to suffer at the higher luminosities from the long drift times of the existing chambers which are also expected to suffer aging. A replacement with the same technology mini drift tubes to be used in the forward muon system is straightforward.

"The inner tracking systems are each affected differently. The scintillating fiber outer tracker is expected to suffer only slight radiation damage in the inner layers. However the occupancy will reach 15% in the inner layers. This puts at risk standalone pattern recognition capability, and the reduction in rejection power of the Level 1 track trigger would be significant. The inner layers of the silicon system are expected to suffer significant radiation damage by an integrated luminosity of ~3 fb^{-1}. However, there are some uncertainties in the understanding of radiation damage coefficients and other operating parameters which may place the critical integrated luminosity somewhat higher.

"The DZero collaboration have been considering various solutions. One scheme is to redeploy the outer tracking elements of the scintillating fibers to larger radii. The silicon would be largely replaced with a combination of pixel and radiation-hard strip detectors. The actual design here depends on the progress of the R&D on both strip and pixel detectors and needs detailed study. The combination of these two measures would permit recovery of the trigger rejection power and provide a tracker matched to high p_t physics in Run III.

"The rejection power of the trigger system components in general is expected to degrade with increased luminosity. The tracking component was mentioned above. In addition we anticipate an increased role to be played by vertex triggering in order to target the Higgs associated production. Present studies indicate that with the detector upgrades mentioned above, the muon triggers are in good shape.

"In summary, the Run II DZero detector provides a very strong basis for 30 fb^{-1} of data. The changes considered could be achieved in a shutdown of not more than one year and a relatively modest investment would allow DZero to explore fully the exciting physics opportunities of TeV33."

4.7 ASTROPHYSICS

Experiments in particle astrophysics also offer exciting opportunities to increase our understanding of the universe. Fermilab is engaged in three astrophysics projects, each at a very different stage of definition. In each case a small number of Fermilab physicists are involved.

All of the ideas for extending the domain of validity of the Standard Model of particle interactions beyond the electroweak energy scale predict new particles. In the case of supersymmetry, the lightest of the new particles should be stable. If they are, then large numbers of them will have survived the moment of creation and will still be present. In that case, they could make up a significant fraction of the mass of the universe. Searches for these massive particles are underway. Fermilab has recently joined the **Cryogenic Dark Matter Search** of the UC Berkeley, Stanford and Case Western Collaboration. These collaborators have developed very sensitive solid-state detectors that can detect the recoils of germanium or silicon nuclei if they collide with one of these massive particles.

If the performance of the detectors meets expectations, the collaborators plan a larger experiment with greater sensitivity, deep underground in the same **Soudan Mine** in northern Minnesota where the **NuMI** project will locate its detector. Fermilab's principal contribution will be to build the cryogenics systems, the electronics and the shielding for this experiment in the Soudan mine. This second stage of the cold, dark matter experiment might answer the question whether there are stable particles with a mass of 150 GeV or more, with the expected properties of the lightest supersymmetric particles, filling the universe. This experiment could give another hint about the particle composition of dark matter and might even be the first evidence that nature is supersymmetric.

Fermilab is also engaged in a project that aims to find out how matter, both dark and luminous, is distributed. This project, the **Sloan Digital Sky Survey**, will measure the location and red shift of a million galaxies and a hundred thousand quasars in the northern galactic cap to a magnitude of 19. This corresponds to a red shift of about 0.2 for galaxies. Fermilab's contributions to this project are in the mechanisms for handling the cartridges and interfacing them to the telescope, in the interlock and operations control system, in the telescope motion control system, and in the construction of the data acquisition system and the software and hardware to process the expected 10 to 20 terabytes of data that will accumulate during the roughly five-year span of the survey. The other partners, Chicago, Johns Hopkins, Princeton, Tokyo University, the U.S. Naval Observatory and the

University of Washington, are building the 2.5 meter telescope itself and the light sensing elements. The information from observatories of this type, in conjunction with information from satellite observatories of the microwave background, may shed light on physics at energy scales of 10^{16} GeV.

A few Fermilab scientists are involved in the **Pierre Auger Project**, which will try to find the mysterious source of very high energy cosmic rays. This year, the collaboration chose the second of the two sites for its Rhode-Island-sized grids of detectors: one will be in Argentina and one in Utah. Jim Cronin, the project's leader, has submitted a proposal for the US contribution to this project to the NSF and DOE through the Universities Research Association, Inc.

Experimental astrophysics is a modest but important part of Fermilab's program, because it provides another approach in our search for an understanding of the fundamental questions still posed by particle physics.

5 FERMILAB AND THE LHC

The Large Hadron Collider will provide experimenters the opportunity to analyze collisions with seven times the Tevatron's center-of-mass energy, at a collision rate more than ten times greater. The LHC will address key questions in particle physics, and open a new energy domain. It also provides an opportunity for accelerator builders in the U.S. to work at the forefront of accelerator technology.

In December 1996, the CERN Council approved the construction of the LHC as a single-step project. The approved funding plan is designed to allow the start of the scientific program in the year 2005. The Department of Energy has proposed to commit $450 million over the seven-year construction period for construction of components for the LHC facility and two of the LHC detectors, CMS and ATLAS. The National Science Foundation plans to commit $81 million. Fermilab is involved in both the LHC machine and in the CMS experiment.

5.1 LHC MAGNETS (1995 - 2004)

A consortium of Brookhaven, Fermilab, and LBNL is taking signficant responsibility for the design and construction of magnets for all four interaction regions at the LHC. This work will allow Fermilab to continue to restore its superconducting accelerator magnet program. Fermilab is taking the lead in the project management and Jim Strait of Fermilab has been designated the project manager.

Fermilab is designing and now starting to build short model magnets of the 70 mm aperture, high gradient quadrupoles for the interaction regions. These are among the most challenging magnets in the LHC with an operating gradient of more than 200T/m, 50% higher than the Low Beta Quadrupoles in the Tevatron Collider. Their field quality must be excellent over a large fraction of the aperture, since under collision conditions these quadrupoles are expected to be the main determinant of the dynamic aperture of the LHC. In addition, these magnets will be subject to substantial heating due to the interaction of secondary particles from p-p collisions at the interaction point.

The R&D program for the high gradient quadrupole is underway. Construction of the first model magnet is expected to be complete in fall 1997, and two more models are planned to be built and tested during FY 1998; two more models are then planned for late FY 1998 and early FY 1999. A full scale prototype, including cryostat, is to be tested in early FY

2000 and production will begin later in FY 2000. Collaborations with industry and other Labs have been initiated to develop improved superconducting wire. The quadrupole development program is the base on which Fermilab is building a broader superconducting magnet R&D program looking at high field or low cost magnets for use in proposed future hadron or muon colliders.

The consortium will take major responsibility for all aspects of the interaction region construction, from the interaction point out through the beam separation-recombination dipoles including the integration of all components into the CERN accelerator system. This level of responsibility requires involvement in the accelerator physics as well as the technology of the IR's. Currently work is being done at Fermilab to study the beam-induced energy deposition in the magnets, to understand the field quality and physical aperture requirements for the IR quadrupole system, to evaluate anomalous dispersion and local chromaticity corrections, to evaluate the effects of the non-uniform end fields of the quadrupoles and to study the alignment requirements.

This program at Fermilab currently employs 30-35 people; this level of effort, with modest increases in the next couple of years and a modest decline in the last years of the progam, is expected to continue until the last quadrupoles are delivered to CERN in 2004.

5.2 CMS (1996 - 2005)

Fermilab has been designated as the Host Laboratory for the U.S. CMS collaboration. This means that Fermilab will not only provide technical support to specific projects in CMS but will also provide logistical and infrastructure support, and project management support to the U.S. CMS collaboration. The project management office will reside at Fermilab and Fermilab has been requested to provide management oversight for both the DOE and the NSF.

Fermilab technical resources will be used to support specific projects for CMS where there is special local expertise and/or infrastructure. In general, some technical oversight at existing facilities will be provided by Fermilab while fabrication labor and other support for production will be provided by U.S. CMS funds. Projects to be carried out at Fermilab include design and construction of the end-cap muon chambers, design and procurement of the absorber material and design and routing of the scintillator tiles for the hadron calorimeter, design and construction of the front-end electronics for the hadron calorimeter, and design and assembly of part of the trigger and DAQ system. Fermilab has also been asked to act as a computing center for U.S. CMS. The number of technical staff currently involved in supporting these activities is small at present (Aug 1997) and is expected to grow to about thirty people in 2000.

6 R & D FOR A FUTURE MACHINE

An essential part of the present Fermilab program is R&D for a future facility that will allow us to extend the high energy frontier beyond the LHC. The Laboratory recognizes that real effort on conceptual design and significant R&D must start now if the U.S. is to regain the high energy frontier after the LHC comes into full operation and we are concentrating on two candidate future facilities:

- a (very large) hadron collider with a center-of-mass energy of 100 TeV,
- a 4 TeV center-of-mass energy muon collider.

Both of these represent a true stage beyond the LHC. While the detailed physics justification has not been prepared, both these machines clearly take elementary particle physics into the realm of discovery beyond LHC.

Fermilab, together with laboratories around the nation, is starting now on the conceptual work and R & D for making the right choice of major facility to build; once this choice is clear, the necessary steps to prepare and submit a full fledged construction proposal will be taken.

Fermilab is engaged in a modest amount of accelerator R&D that is relevant to **electron linear colliders** and superconducting rf. Fermilab could certainly be a candidate for a linear collider either superconducting or conventional high frequency, and sites near the laboratory have been identified. Collaboration is on going with both SLAC and DESY. At SLAC, the effort has centered on aspects of the beam delivery system collimation and on beam tuning diagnostics for the final focus test beam. For the international TESLA collaboration work has centered on cavity input power couplers, RF modulators and cryogenics. The A0 PhotoInjector being built at Fermilab is a 15 MeV electron injector prototype for the TESLA Test Facility; a duplicate of the photogun and magnetic compressor will be installed at the TTF. Fermilab is gaining experience with the installation and operation of superconducting rf at the A0 installation and plans to further develop scrf proficiency by learning design, fabrication and processing methods with the aid of people at Cornell and Desy. This superconducting technology is relevant not only for linear colliders but also for muon colliders and for shorter term applications like rf separated beams and Tevatron bunch shortening.

For the immediate future, however, the Laboratory will commit most of its R & D efforts into the Muon Collider and the Very Large Hadron Collider. Both candidate machines require substantial R&D funds over the next several years. The Muon Collider needs funds to establish its feasibility and to conduct crucial experiments on specific components. The VLHC needs funds particularly for work on the different field strength options. For both the Muon Collider and the VLHC, R&D funds are needed to establish realistic and credible cost estimates. The decision on which machine to choose should be made four or five years from now, based on the results of these R&D efforts.

6.1 A VERY LARGE HADRON COLLIDER (VLHC)

The basic parameters for the VLHC are for a proton-proton collider with 100 TeV in the center-of mass, with a 2-stage injector chain: the existing Fermilab 150 GeV Main Injector and a 3 TeV "booster." Luminosity in the 100 TeV machine could be as high as $10^{34}\text{cm}^{-2}\text{s}^{-1}$.

The crucial technical issue with the VLHC is seen to be its cost. Apart from the well developed technologies of the Tevatron and LHC, promising avenues to explore are the low-field, superferric approach or the very high-field approach using new materials. The basic magnet technology is in place now for a VLHC using either superferric (low-field, $B = 2$ T) or NbTi (high field, $B \approx 10$ T) designs. Very high-field designs ($B \geq 12$ T) using Nb_3Sn or high-temperature superconductor (HTS) are at an earlier stage in their development. (By "high" field, one means a machine in which synchroton radiation damping plays a major role in the luminosity.)

Options using the three types of magnets each require significant R & D funding. A rough estimate, based on the cost of the LHC magnet R & D, is that to bring each style to the final prototype stage, if feasible, would require between $50 M and $150 M over several years.. Of course, the superferric (2 Tesla) magnet is much closer to realization than the very high field magnet and so the R&D costs for the latter will probably be higher.

Fermilab is pursuing the magnet issues on several fronts. Prototypes of the superferric magnets are under construction; the LHC magnet program is effectively the program for medium strength magnets. The performance potential of high temperature superconductor (HTS) has stimulated a serious R&D effort to understand its use and a project has been started with a view to using HTS leads in the Tevatron.

Since the length of the tunnel and the distance over which services need to be distributed is significantly greater for the low field option, Fermilab is also studying issues of tunneling, and distribution of power and cryogenics.

The VLHC Study Group at Fermilab plans to produce a design report by the end of 1998. This will include both low and high-field approaches as well as the physics justification for 100 TeV center of mass energy and the intermediate physics that could be done with the 3 TeV booster.

6.2 THE MUON COLLIDER

Work on the Muon Collider is in progress at Fermilab, Brookhaven, LBL, Argonne and UCLA, led by Bob Palmer of Brookhaven, Alvin Tollestrup of Fermilab, and Andy Sessler of Berkeley Lab. Until recently the focus of the effort was directed toward a 4 TeV center-of-mass collider, but both Brookhaven and Fermilab are now directing their efforts toward a 400 - 500 GeV center of mass collider. It is recognized that a muon collider will require advances in superconducting magnets, superconducting rf, and high intensity proton beams, all technologies with a wide range of application.

Fermilab is a member of an international collaboration of approximately twenty-five institutions studying the feasibility of the muon collider concept. The main thrust is a calculational program to clarify the most serious obstructions in the path of muon collider development. The Muon Collider Collaboration has an executive committee with representatives from the three laboratories where the majority of effort is centered: FNAL, BNL and LBNL. Planning for a muon cooling experiment has begun, and participants come from many institutions in the Collaboration based on their expertise. It is assumed that other muon collider R&D will also involve collaborative efforts between the national labs, universities and other international participants.

The nation wide Muon Collider group is developing a Research and Development 5 Year Plan, the overall goal of which is to reach a decision on the feasibility of a muon collider. This work entails the demonstration of critical collider components, extensive numerical and theoretical work, and detailed design of many components. The experimental program is centered on the cooling experiment at Fermilab.

The ionization cooling R&D consists of prototyping and testing all of the critical components in a cooling channel, including a prototype solenoid focussing transverse cooling section, a prototpye lithium lens focussing cooling section, and wedge (longitudinal) cooling prototypes. The prototypes will need to be tested at an ionization cooling test facility, consisting of a 100-300 MeV/c muon beam, and experimental enclosure, and instrumentation to precisely measure the incoming and outgoing muon coordinates in 6-dimensional phase-space. The complete R&D program is estimated to take 6-years, at the end of which the capabilities of all of the critical cooling hardware would have been demonstrated, and optimization studies would have been made. The Muon Collider group plans to submit a proposal with costs and assignment of responsibilities by the end of 1997.

The Laboratory will hold a workshop to assess the physics opportunities that the pieces of the muon collider, in particular the the proton source, could provide. The stages of development of a muon collider would benefit many physics programs. A new proton source with ten times the intensity of the present 8 GeV Booster would improve antiproton and neutrino production and enhance a kaon program. The muon cooling channel would provide spectacular intense low-energy muon beams for rare decay experiments. All these bring exciting opportunities on the path to the muon accelerator and collider.

National and International Collaboration

At this stage in their evolution, both the electron collider work, the VLHC and the Muon Collider span the U.S. in their collaborating laboratories and institutions. Fermilab already has a large user community from all over the world and this automatically provides a network to foster connections. International collaboration will be welcomed but it is probably premature to define the level of commitment that is necessary or desirable.

Schedule

It is too early to give a cost or a schedule for either of these facilities. The Muon Collider and the VLHC projects rely on innovative ideas designed to allow high energy physics to take the step beyond the LHC. These ideas need to be developed, tested and show promise of feasibility. Fermilab is determined to meet this challenge and is embarking with other laboratories and institutions on the R&D needed to establish the costs and a realistic schedule.

7 FERMILAB PRIORITIES & PERSPECTIVE ON A FUTURE FACILITY

Fermilab, and U.S. High Energy Physics, clearly faces two challenges over the next decade. The first is to make the optimal stategic choices for exploiting the Tevatron and the other Fermilab accelerators - how we take best advantage of the tremendous assets in existing machines and detectors. The second challenge we face is to develop and establish the plan for a collider machine and facility in the U.S. that will truely extend the energy frontier beyond the LHC - how to prepare boldly and effectively for our future.

To meet the first challenge, Fermilab has identified two periods - from now till 2002, and from 2003 to 2007. Our priorities and program for the first period are already set. Much of the program from 2002 on is also defined, but this separation allows us to retain flexibility in our longest range planning. We summarize our priorities here and show how those for the second part of the decade follow from what we learn in the first part.

PRIORITIES FOR THE YEARS 1997 - 2002

- complete the upgrades to CDF and DZero, complete and commission the Main Injector and Recycler and deliver 2 to 4 fb^{-1} to each experiment

- execute the NuMI project and initiate a program of neutrino oscillation experiments with the MINOS and COSMOS experiments

- complete the 800 GeV fixed-target program with a 6 month run in 1999 that will also help in commissioning the accelerator complex for collider operation

- sustain a modest program in experimental astrophysics, including the Sloan Digital Sky Survey (SDSS) and the Cryogenic Dark Matter Search (CDMS)

- support and host U.S. CMS and work on LHC interaction region magnets

- carry out vigorous R & D programs for the Muon Collider and the Very Large Hadron Collider so that by the year 2002 Fermilab can choose the path for recapturing the energy frontier in the following decade. The efforts on LHC and CMS are part of this strategy.

PRIORITIES FOR THE YEARS 2003 - 2007

- deliver > 20 fb^{-1} to one and preferably both of CDF and DZero by mid 2007 as part of TeV33, including the implementation of the first two phases of the new proton source

- exploit the MINOS and COSMOS experiments fully with the wide-band beam, and prepare for the round of experiments with a narrow band beam

- continue R&D for the future Fermilab collider chosen on the basis of the previous work and the results from Run II and LEP II

- pursue one or more new experimental initiatives from a list including a dedicated B detector at the Tevatron, a program of rare Kaon decay experiments using the Main Injector, and a program of μ and ν physics based on a high intensity proton source, initiatives which are synergistic with the path to the new energy frontier.

These priorities have a definite time line that allows us to make informed strategic choices. By the year 2001, 0.5 fb^{-1} of data will have been analyzed by CDF and DZero and the decision on whether to continue with one or both experiments can be taken. The value of a dedicated B experiment will be more clear in 2001 after the first years of operation of the e^+e^- colliders and of CDF and DZero, and the decision on continuing the R&D and initiating construction can be made at that time. By the year 2003, when more than 2 fb^{-1} of luminosity has been delivered to each detector, the decision can be taken whether to continue operating one or more high p_t detectors till 2006 or 2007.

AN ENERGY FRONTIER FACILITY AT FERMILAB

From the Director's Closing Remarks to the subpanel...

- In the past the energy frontier has been the leap into the unknown and the source of much new knowledge in particle physics. Fermilab proposes to leap beyond the energy scale of the LHC and the complementary lower energy linear colliders.

- The "cognoscenti" are in disagreement on the proposition that warm e^+e^- colliders can reach 4 TeV in the center-of-mass.

- The muon collider and the VLHC offer interesting, but uncertain possibilities for leaping beyond the LHC. It will be a long haul but the U.S. should head for the frontier and Fermilab is the best vehicle.

- The Fermilab plan will build on the facilities of the present as they will be in 2005.

- If the path to the energy frontier is through a 100 TeV center-of-mass collider, then the Tevatron does not have a long-range future after 2007. It should be replaced by a 3 TeV injector with the same technology as will be proposed for the 100 TeV collider.

- By 2007 the Tevatron will have been a glorious R&D experiment. And, it will have provided exciting physics results for nearly two decades.

- If the path to the energy frontier is through a 4 TeV c.m. muon collider then the Tevatron may have a slightly longer lifetime as a source of b hadrons for a dedicated B detector.

- The intermediate steps to a 4 TeV center-of-mass muon collider will include a high intensity muon beam and then a medium energy demonstration muon collider.

8 THE BUDGET

The Budget presented to the Subpanel addresses the near term and prepares for the long term future of Fermilab. In his closing remarks, the Fermilab Director proposed the answers to two questions

- **What does Fermilab want for its near-term future and a balanced U.S. Program for the next decade?** and
- **What does Fermilab want for its long-term future?**

For the near term, the budget we request provides that:

- Collider Run II can be started early in the year 2000 and concluded in a timely way during the year 2002.
- The NuMI project and the MINOS and COSMOS experiments can be underway by the middle of the year 2002.
- The final run of the 800 GeV fixed-target program can be carried out in FY1999 without delaying Collider Run II and NuMI.
- TeV33, the luminosity improvements required to reach and eventually exceed $5\times10^{32}cm^{-2}s^{-1}$, can begin in late 2003.

For the long-term future of Fermilab, we are requesting a budget that provides:

- Endorsement of TeV33 and NuMI.
- Encouragement of an exploration of the nature of CP violation and rare decays in s, c, and b hadrons and the recognition of the exceptional, cost effective opportunities presented by Fermilab to this physics.
- Encouragement of the concept that higher proton intensity is the way to more luminosity and more intense secondary beams. We seek recognition of the possibility that the new proton source is the first step on the path to a balanced U.S. program for the U.S. in the next decade and that it should be done early enough to benefit TeV33.

- Sufficient R&D funds so that Fermilab can wisely choose between the Muon Collider and the Very Large Hadron Collider option by the year 2002. This is the first step toward bringing the energy frontier back to Fermilab and the U.S.
- Recognition of our dream that Fermilab should lead the effort to build a collider in the U.S. that reaches well beyond the LHC.

8.1 SPECIFIC BUDGET SCENARIOS:

We discuss the two specific years for which we have budget guidance and then describe the various longer term scenarios mentioned by the sub-panel. These descriptions serve as a guide to the series of graphs and tables which give the actual numbers. Budget sheets B.1 to B.6 give some history of the Fermilab budget and the allocation of the current FY1997 budget.

FY1998

The FY 98 President's Budget for Fermilab is about constant in then year dollars relative to FY97 (Flat - Flat). This is the critical funding year for Run II detector upgrades; each detector needs $17M in FY 98 and the final year of funding will be FY 99. Funding for Run II Computing will begin in FY98 (~$2M first year with a total need of ~$20M). Funding for the NuMI project begins at $5.5M and the CZero Hall is funded ($5M). No machine operations saves ~ $15M in power and cryogens. The Wilson Hall Restoration project is funded at $1M in FY98 with a total need of ~$16M. The Central Utilities Building (CUB) Maintenance and Restoration project is funded at $2M in FY98 and the total need is $5M.

FY 1999

Fermilab's FY 99 Budgetary Guidance indicates a reduction in the total budget of ~$10M. Run II detector upgrade funding will be completed. Funding for Run II Computing must peak in this year so that it can be completed in FY2000. NuMI beam funding rises to $20M. This budget level would in fact not allow the FY99 800 GeV fixed target run to proceed and thus the US HEP program would fail to exploit the KTeV detector and complete the program begun in 1997. Wilson Hall ($5M) and CUB ($1.3M) funding continues.

LONGER TERM SCENARIOS

We characterize the various longer term scenarios below. Details of the "Modestly Up" and "Flat" scenario are in the tables and graphs attached.

"Modestly Up" Scenario (~2% growth per year)

The level of funding obtained in the later years of this scenario is comparable to the Fermilab budget of ten years ago. The 800 GeV Fixed Target Run could proceed as discussed. Collider Run II will begin in early 2000 as planned and it's computing needs would also be funded through 2000. The NuMI program can begin in late 2002 with detectors fully funded. Funding for other experimental initiatives can be accommodated and could begin in FY 2001 (eg $40M for TeV33 detectors could be allocated by FY2003). Initial phases of the Proton Source Upgrade are included.

"Flat" or Constant Level of Effort Scenario

There would be no further 800 GeV Fixed Target running. Collider Run II will begin slowly in CY 2000, and Run II computing will not be completely funded until 2002. The NuMI Beam will be complete late in 2002 and the detectors will be completed one year later. Funding for new experimental initiatives could not begin before FY 2003. Only one collider detector can be upgraded for TeV33. The Proton Source Upgrade cannot be funded at a constant level of effort budget even though it would allow following-up on Run II and/or NuMI discoveries.

"Modestly Down" Scenario

In this scenario the Fermilab budget would stay flat in then year dollars to FY2002 and then remain at constant buying power thereafter resulting in ~10% or $24M/year reduction in buying power in FY2002 relative to FY98. Staff reductions would continue (not in Beams Div. and therefore primarily in experiment support, PPD and CD). To maintain a viable Tevatron collider program we would have to stop one detector after 2002. The NuMI program would experience major delays. There would be no possibility for new initiatives either experimental or for accelerators.

"Immodestly Down"

We comment only briefly on a scenario which is Flat - Flat through FY2006. This is a 20% reduction or $50M per year in buying power in FY2006 relative to FY98. We have not prepared a detailed "Down" scenario for Fermilab. Neither of the down scenarios would represent a viable future for US High Energy Physics. NuMI would be cancelled. Run II would be stretched and we could afford to operate only one detector. TeV33 could not happen. Fermilab would not be strong enough to serve as host to CMS.

Budget Summary Statement.

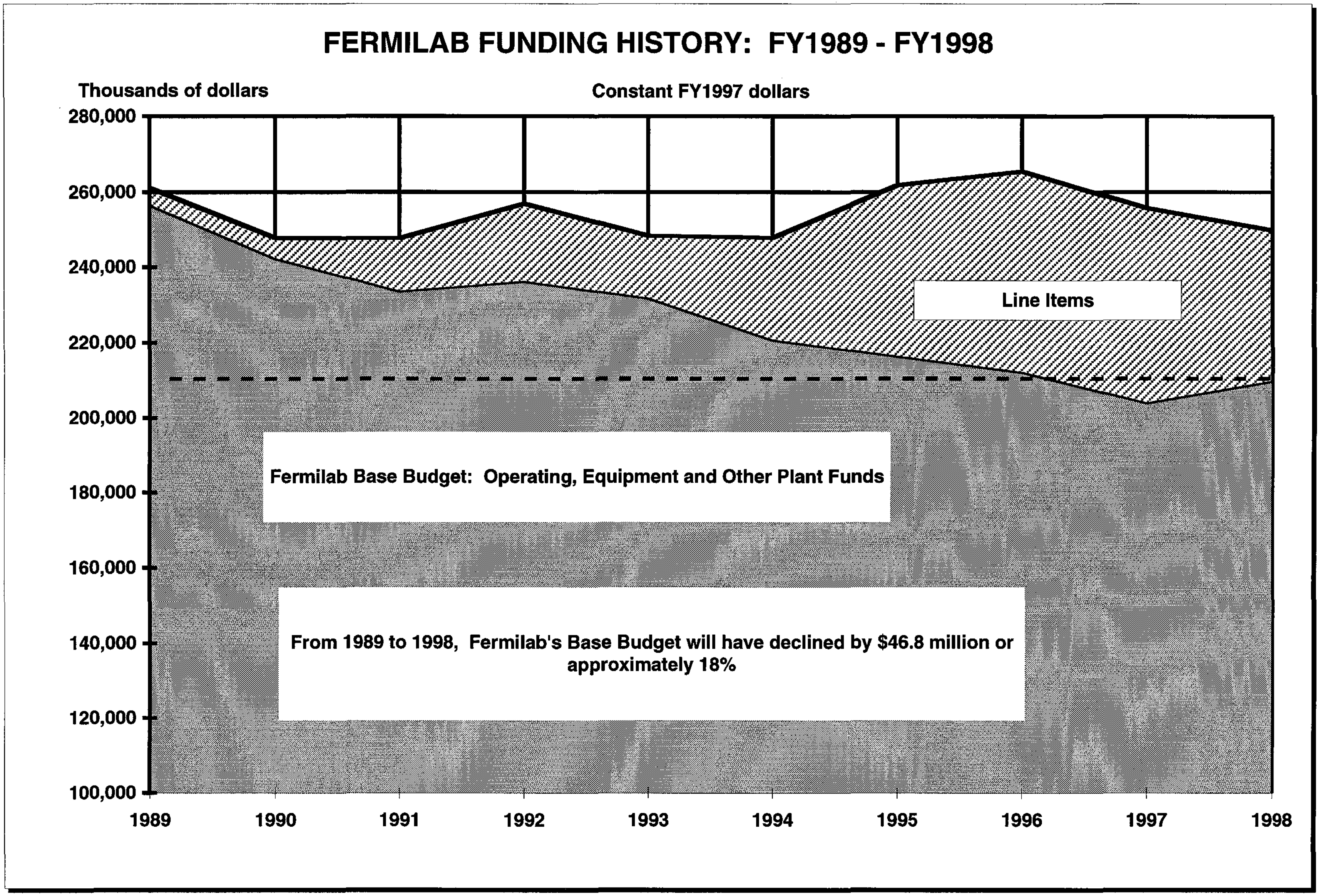
In the subpanel's visits to the national laboratories they heard about the compelling possibilities for the Fermilab program of the next decade.

This program includes the exciting discovery potential of the high p_t collider program and its evolution between now and LHC physics. It includes the neutrino oscillation program, rare decays and CP violation in Kaons and B's. And it includes the potential for these programs to evolve and for Fermilab to provide the basis for a future US accelerator facility with an upgraded proton source. It includes R&D for two possible facilities. These possibilities can be realized in a budget scenario which is "modestly up", reaching the buying power of the Fermilab budget of ten years ago. We urge the subpanel to endorse only this plan for a Fermilab future.

List of Tables and Graphs

HIGH ENERGY PHYSICS FUNDING HISTORY
of
FERMI NATIONAL ACCELERATOR LABORATORY
(BA : As Spent : dollars in thousands)

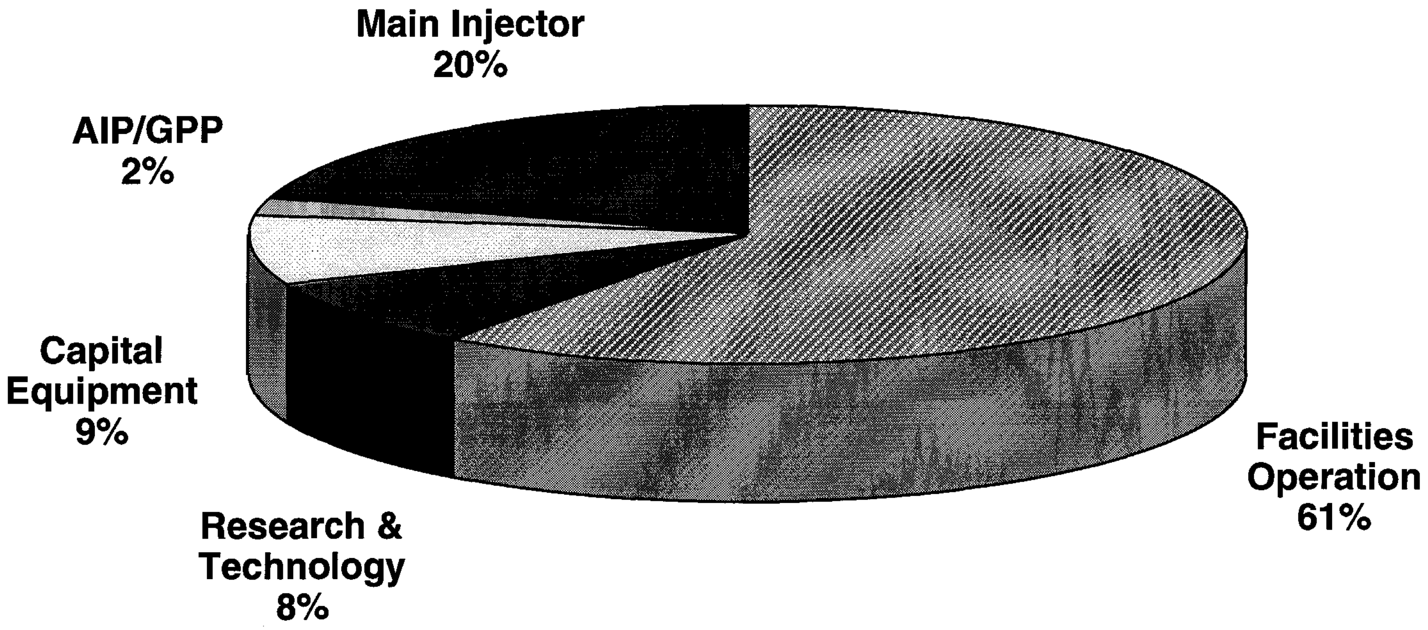
HIGH ENERGY PHYSICS *	FY1996	FY1997	FY1998
OPERATING			
Facilities Operation	145,310	153,490	151,120
Research & Technology	22,565	21,645	24,500
Subtotal	167,875	175,135	175,620
Capital Equipment	27,855	23,135	37,700
AIP/GPP	7,320	5,450	4,090
C0	0	0	5,000
BASE PROGRAM	203,050	203,720	222,410
LINE ITEMS			
Main Injector	52,000	52,000	30,950
NuMI/COSMOS/MINOS	0	0	5,500
TOTAL FERMILAB	255,050	255,720	258,860



FERMILAB FUNDING HISTORY: FY1989 - FY1998

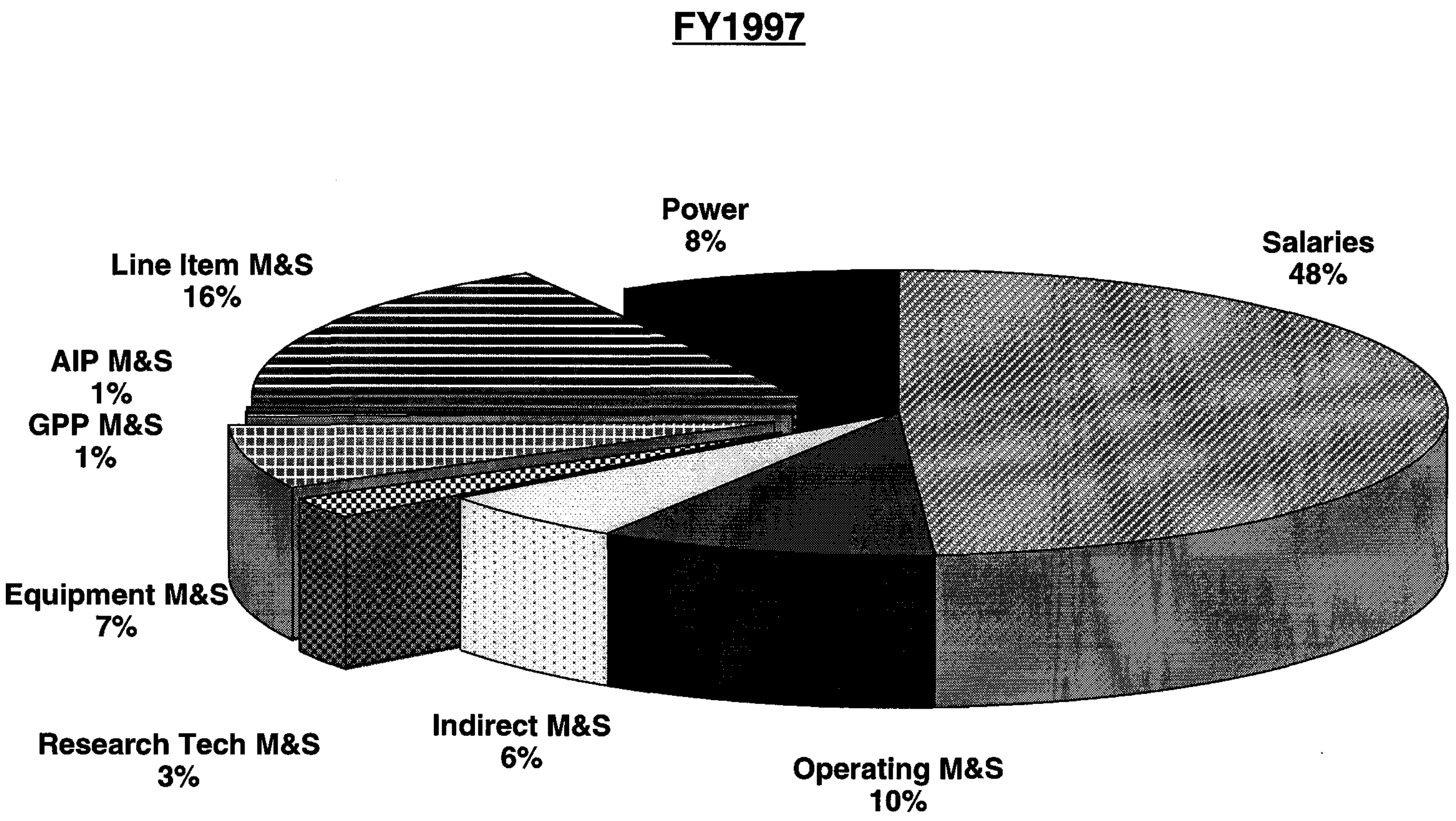
From 1989 to 1998, Fermilab's Base Budget will have declined by $46.8 million or approximately 18%

FY1997 Fermilab Funding



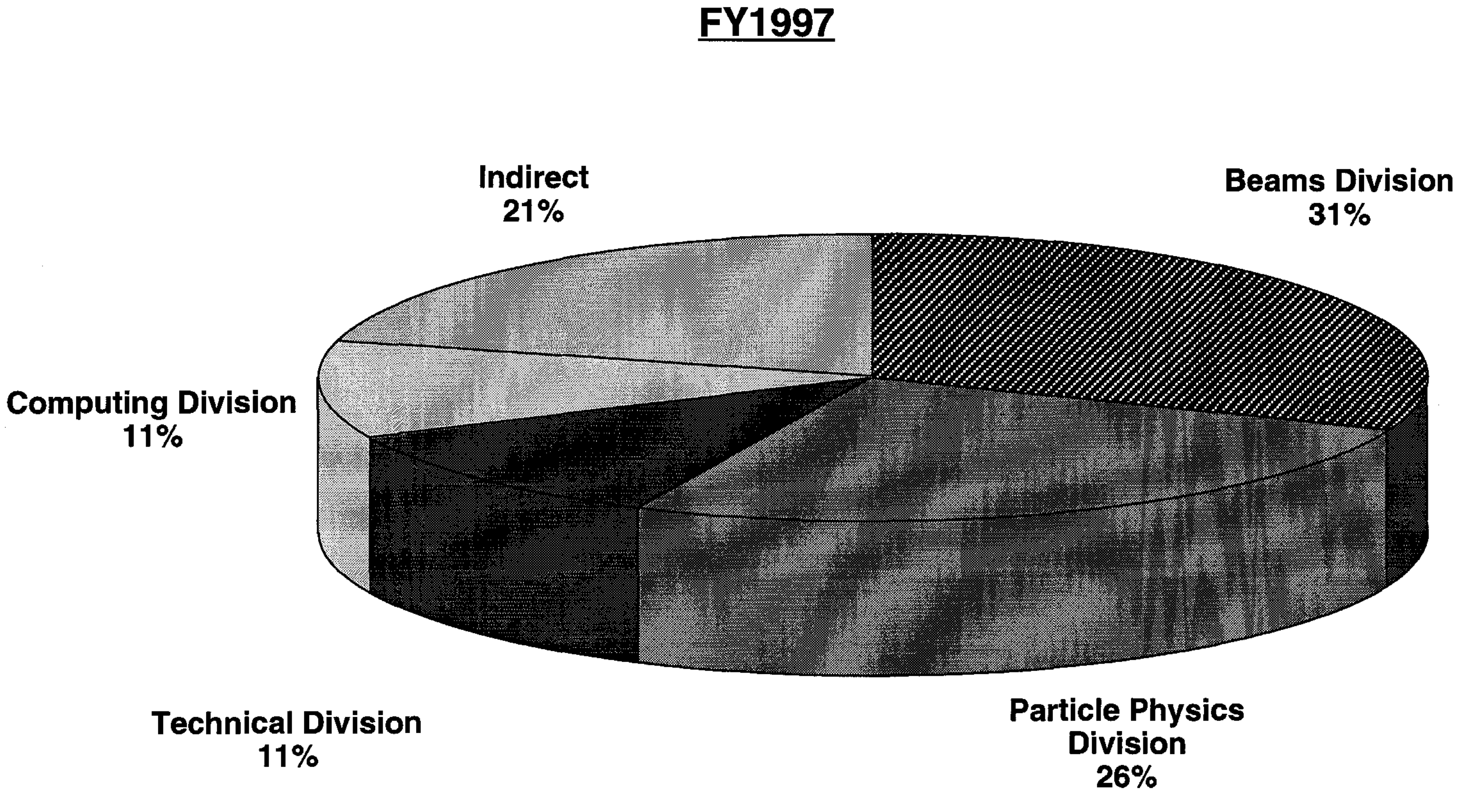
Total Funding: $255.7 million

Cost Distribution by Category



Total Amount: $255.7 million

SALARIES, WAGES, and FRINGES by DIVISION

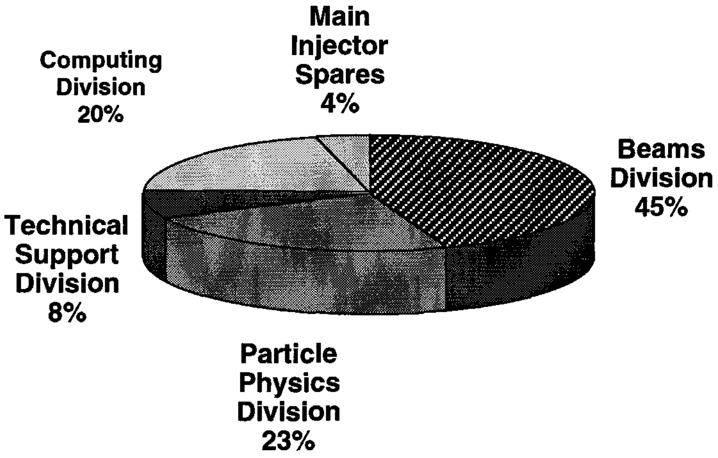


Total SWF: 125.2 million

Operating and R&D M&S Costs

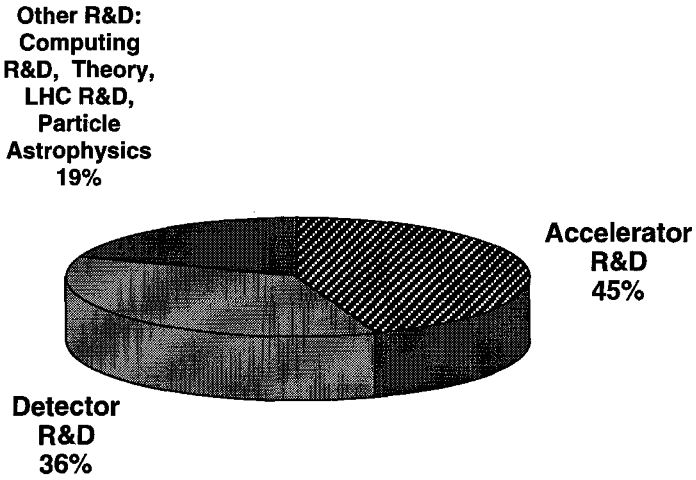
FY1997

Facilities Operations



Total Fac. Op. M&S: $25.7 Million

Research Technology



Total Research Tech R&D M&S: $6.4 million

HIGH ENERGY PHYSICS FUNDING HISTORY
of
FERMI NATIONAL ACCELERATOR LABORATORY
(BA : dollars in thousands: constant FY97 dollars)

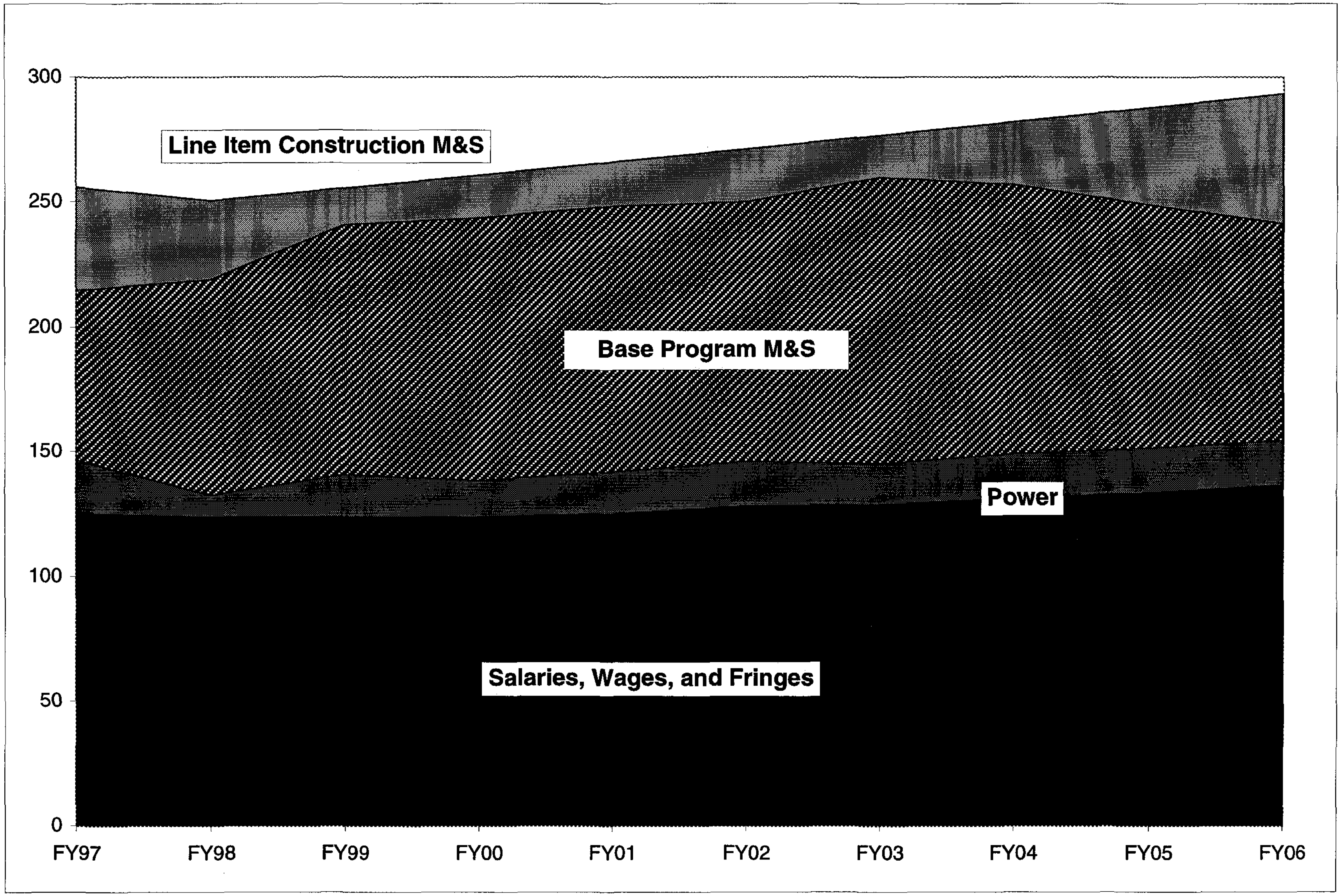
UP SCENARIO

HIGH ENERGY PHYSICS *	FY1997	FY1998	FY1999	FY2000	FY2001	FY2002	FY2003	FY2004	FY2005	FY2006
Facilities Operations	134,874	131,173	142,662	134,847	128,046	119,529	112,343	116,571	124,814	133,172
Research Technology	22,209	24,765	26,934	28,434	27,335	23,572	20,809	21,264	23,236	20,259
Capital Equipment	23,305	36,997	39,798	48,730	55,063	64,210	85,303	74,053	56,972	40,892
SWF	1,800	3,325	1,488	5,657	7,206	10,371	15,576	13,026	10,026	6,876
M&S (Eq)	17,955	28,028	32,296	35,710	39,537	44,137	56,837	49,837	38,337	27,837
CDF Upgrade	6,037	10,500	6,002	--	--	--	--	--	--	--
D0 Upgrade	6,340	10,500	5,199	--	--	--	--	--	--	--
Run II Computing	--	1,934	9,000	7,000	--	--	--	--	--	--
FY99 Fixed Target Experiments		500	--	--	--	--	--	--	--	--
COSMOS	--	--	--	4,000	4,000	1,000	--	--	--	--
MINOS	--	--	4,700	16,000	17,200	8,300	--	--	--	--
MINOS (Narrow Band Beam)	--	--	--	--	--	--	--	3,000	--	--
New Experiment Initiatives	0	0	0	2,000	8,500	25,000	47,000	37,000	28,500	18,000
Mini-BooNE	--	--	--	2,000	2,000	--	--	--	--	--
K^+ Experiments & Beam	--	--	--	--	500	2,000	8,500	6,000	4,000	--
KAMI	--	--	--	--	500	3,000	5,500	4,000	--	--
Other 120 GeV Experiments		--	--	--	--	--	1,000	2,000	5,000	5,000
BTeV	--	--	--	--	--	5,000	17,000	20,000	15,000	13,000
TeV33 Detector Upgrades		--	--	--	5,500	15,000	15,000	5,000	4,500	--
Cryo Improvements	--	--	967	1,873	--	--	--	--	--	--
120 GeV Switchyard	--	--	1,873	--	--	--	--	--	--	--
Particle Astrophysics	85	235	200	200	200	200	200	200	200	200
All Other	5,493	4,359	4,355	4,637	9,637	9,637	9,637	9,637	9,637	9,637
Beams Division	500	484	468	468	468	468	468	468	468	468
Computing Division	3,210	2,183	2,218	2,500	7,500	7,500	7,500	7,500	7,500	7,500
Particle Physics Division	700	677	655	655	655	655	655	655	655	655
Technical Division	385	338	360	360	360	360	360	360	360	360
G&A Sections	698	677	654	654	654	654	654	654	654	654
Indirect Allocation	3,550	5,644	6,014	7,363	8,320	9,702	12,890	11,190	8,609	6,179
GPP	2,065	3,308	4,200	5,500	5,500	6,000	6,000	6,000	6,000	6,000
AIP	2,685	7,712	8,400	9,100	12,600	11,977	12,600	12,600	12,600	12,600
PROGRAMMATIC POWER	18,750	6,300	14,630	12,000	14,325	15,425	13,850	15,425	15,425	15,425
SUBTOTAL	203,888	210,255	236,624	238,611	242,869	240,713	250,905	245,913	239,047	228,348
Main Injector	52,000	29,932	--	--	--	--	--	--	--	--
NuMI	--	5,319	18,727	20,852	15,803	6,797	--	--	--	--
C0 Hall	--	4,836	--	--	--	--	--	--	--	--
Proton Source Upgrade	--	--	--	1,000	7,000	22,000	22,000	23,000	17,000	8,000
Muon Cooling Experiment						1,500	3,500	10,000	10,000	5,000
New Project (First Step)								3,000	21,500	52,000
TOTAL FERMILAB	255,888	250,342	255,351	260,463	265,672	271,010	276,405	281,913	287,547	293,348

Cost Distribution

Up Scenario

BA: dollars in millions : constant FY97 dollars



Summary Level Cost Distribution

Up Scenario

BA: dollars in millions : constant FY97 dollars

HIGH ENERGY PHYSICS	FY97	FY98	FY99	FY00	FY01	FY02	FY03	FY04	FY05	FY06
TOTAL Laboratory SWF	125.2	123.5	123.5	123.8	124.9	128.1	128.6	131.0	133.3	136.4
Base Program M&S	68.4	86.7	100.3	105.2	106.6	104.0	114.9	108.2	97.7	87.2
Operating	25.7	24.4	28.4	24.2	27.2	24.2	24.2	24.2	24.2	24.2
Research Technology	6.4	7.7	9.0	9.6	10.1	7.2	4.9	5.2	6.2	6.2
Equipment	18.0	28.0	32.3	35.7	39.5	44.1	56.8	49.8	38.3	27.8
GPP	1.7	3.1	3.4	4.4	4.4	4.9	4.9	4.9	4.9	4.9
AIP	1.7	5.5	6.0	6.5	9.0	8.6	9.0	9.0	9.0	9.0
Indirect	15.0	17.9	21.2	24.8	16.3	15.0	15.0	15.0	15.0	15.0
Line Item M&S	41.1	31.4	14.5	17.1	17.4	21.1	16.7	25.0	38.8	52.0
Total POWER	21.2	8.7	17.0	14.4	16.7	17.8	16.3	17.8	17.8	17.8
TOTAL FERMILAB	255.9	250.3	255.4	260.5	265.7	271.0	276.4	281.9	287.5	293.3

Operating and R&D Costs

Up Scenario

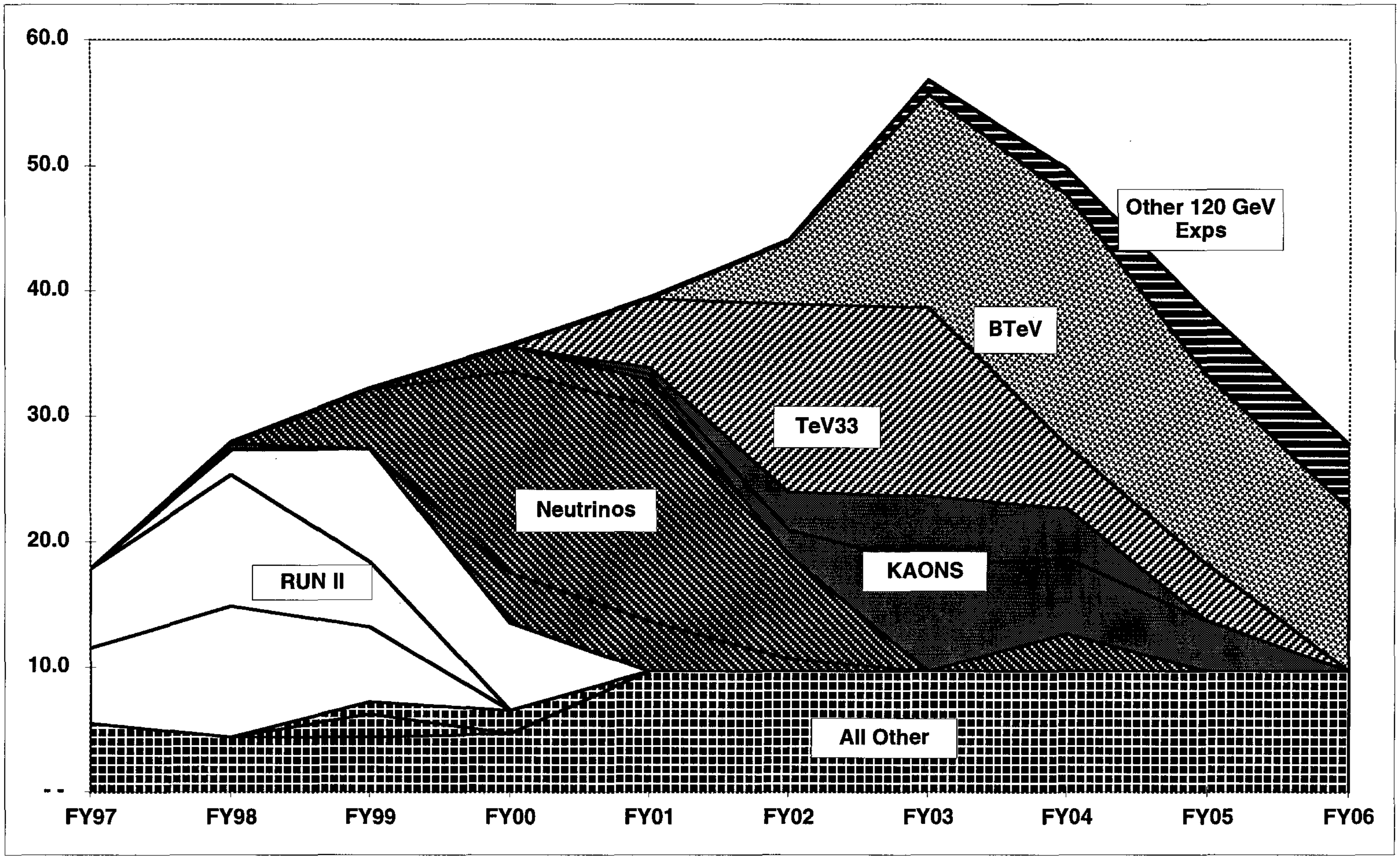
BA: dollars in millions : constant FY97 dollars

	FY97	FY98	FY99	FY00	FY01	FY02	FY03	FY04	FY05	FY06
Facilities Operations	**134.9**	**131.2**	**142.7**	**135.2**	**129.6**	**124.0**	**120.7**	**123.7**	**129.9**	**136.4**
SWF	75.6	74.5	80.1	76.1	75.9	76.4	74.8	76.6	77.7	81.5
M&S OP	25.7	24.4	28.4	24.2	27.2	24.2	24.2	24.2	24.2	24.2
Indirect Allocation	33.6	32.3	34.1	34.9	26.4	23.4	21.7	22.9	28.0	30.7
Research Technology	**22.2**	**24.8**	**26.9**	**28.4**	**27.3**	**23.5**	**20.7**	**21.2**	**23.1**	**20.2**
SWF	10.5	11.3	11.9	12.2	12.2	12.2	12.2	12.2	12.2	9.8
M&S (R&D)	6.4	7.7	9.0	9.6	10.1	7.2	4.9	5.2	6.2	6.2
Main Injector R&D	0.1	- -	- -	- -	- -	- -	- -	- -	- -	- -
RunII Accelerator Component R&D	0.4	0.7	0.9	- -	- -	- -	- -	- -	- -	- -
Stochastic Cooling R&D	- -	1.0	0.9	0.9	0.9	0.5	- -	- -	- -	- -
TeV33 Accelerator Component R&D	- -	- -	- -	1.4	1.4	1.0	- -	- -	- -	- -
R&D for Future Machine	2.3	2.0	3.0	3.0	3.0	3.0	3.2	4.0	5.0	5.0
Run II Detector R&D	1.7	1.2	- -	- -	- -	- -	- -	- -	- -	- -
NuMI(MINOS/COSMOS) R&D	0.5	1.0	2.0	1.0	0.5	- -	- -	- -	- -	- -
TeV33 Detector R&D	0.2	0.4	0.9	2.0	3.0	1.5	0.5	- -	- -	- -
Computing R&D	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Theory	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
LHC R&D	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Particle Astrophysics	0.6	0.9	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Indirect Allocation	5.2	5.7	6.0	6.7	5.1	4.2	3.6	3.8	4.8	4.2
TOTAL	**157.1**	**155.9**	**169.6**	**163.6**	**156.9**	**147.5**	**141.5**	**144.9**	**153.1**	**156.6**

Capital Equipment M&S

Up Scenario

BA: dollars in millions : constant FY97 dollars



Capital Equipment

Up Scenario

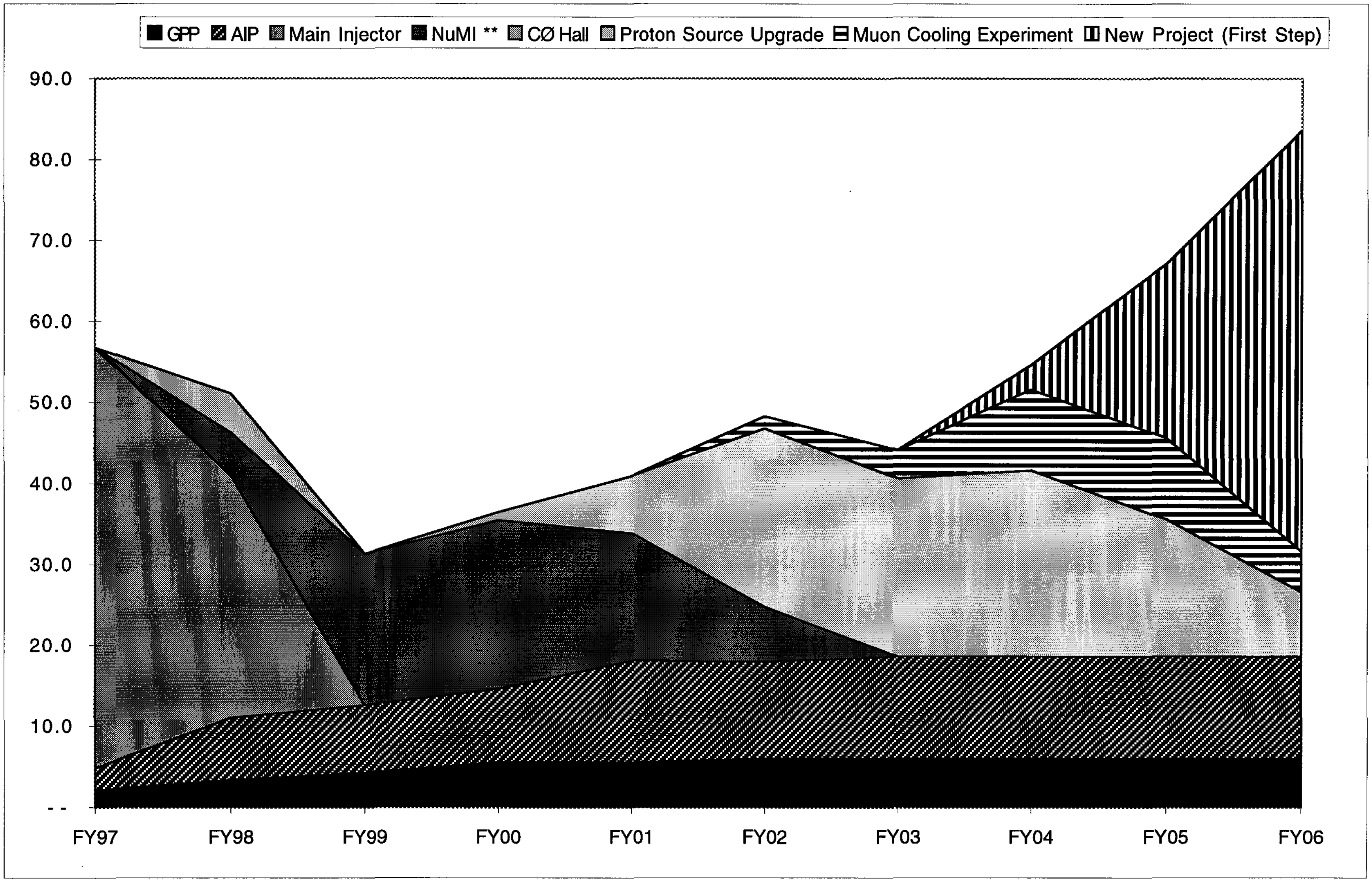
BA: dollars in millions : constant FY97 dollars

	FY97	FY98	FY99	FY00	FY01	FY02	FY03	FY04	FY05	FY06	Total
SWF	1.8	3.3	1.5	5.4	5.9	6.6	8.5	7.0	5.8	4.2	
M&S (Eq)	18.0	28.0	32.3	35.7	39.5	44.1	56.8	49.8	38.3	27.8	
CDF Upgrade	6.0	10.5	6.0	- -	- -	- -	- -	- -	- -	- -	
DØ Upgrade	6.3	10.5	5.2	- -	- -	- -	- -	- -	- -	- -	
Run II Computing	- -	1.9	9.0	7.0	- -	- -	- -	- -	- -	- -	
FY99 Fixed Target Experiments	- -	0.5	- -	- -	- -	- -	- -	- -	- -	- -	
COSMOS	- -	- -	- -	4.0	4.0	1.0	- -	- -	- -	- -	9.0
MINOS	- -	- -	4.7	16.0	17.2	8.3	- -	- -	- -	- -	46.2
MINOS (Narrow Band Beam)	- -	- -	- -	- -	- -	- -	- -	3.0	- -	- -	
New Experiment Initiatives	- -	- -	- -	2.0	8.5	25.0	47.0	37.0	28.5	18.0	166.0
Mini-BooNE	- -	- -	- -	2.0	2.0	- -	- -	- -	- -	- -	4.0
K+ Experiments & Beam	- -	- -	- -	- -	0.5	2.0	8.5	6.0	4.0	- -	21.0
KAMI	- -	- -	- -	- -	0.5	3.0	5.5	4.0	- -	- -	13.0
Other 120 GeV Experiments	- -	- -	- -	- -	- -	- -	1.0	2.0	5.0	5.0	13.0
(e.g. MECO)											- -
BTeV	- -	- -	- -	- -	- -	5.0	17.0	20.0	15.0	13.0	70.0
TeV33 Detector Upgrades	- -	- -	- -	- -	5.5	15.0	15.0	5.0	4.5	- -	45.0
Cryo Improvements	- -	- -	1.0	1.9	- -	- -	- -	- -	- -	- -	
120 GeV Switchyard	- -	- -	1.9	- -	- -	- -	- -	- -	- -	- -	
Particle Astrophysics	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	
All Other	5.5	4.4	4.4	4.6	9.6	9.6	9.6	9.6	9.6	9.6	
Indirect Allocation	3.6	5.6	6.0	7.3	8.1	9.0	11.6	10.1	7.8	5.7	
TOTAL Capital Equipment	**23.3**	**37.0**	**39.8**	**48.4**	**53.6**	**59.8**	**77.0**	**67.0**	**51.9**	**37.7**	

Plant

Up Scenario

BA: dollars in millions : constant FY97 dollars



Plant

Up Scenario

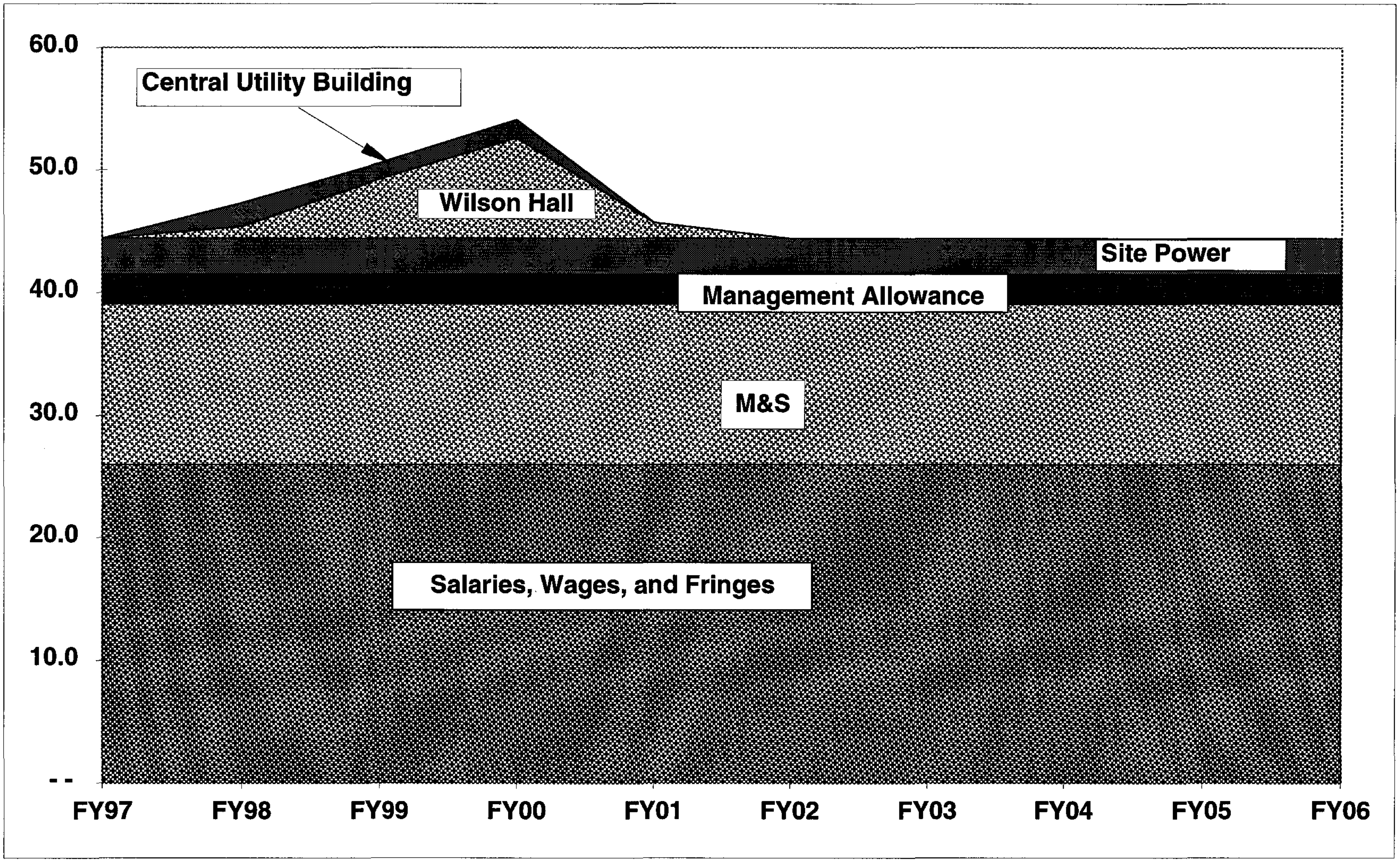
BA: dollars in millions : constant FY97 dollars

	FY97	FY98	FY99	FY00	FY01	FY02	FY03	FY04	FY05	FY06
GPP	2.1	3.3	4.2	5.5	5.5	6.0	6.0	6.0	6.0	6.0
AIP	2.7	7.7	8.4	9.1	12.6	12.0	12.6	12.6	12.6	12.6
Main Injector	52.0	29.9	- -	- -	- -	- -	- -	- -	- -	- -
NuMI **	- -	5.3	18.7	20.9	15.8	6.8	- -	- -	- -	- -
C0 Hall	- -	4.8	- -	- -	- -	- -	- -	- -	- -	- -
Proton Source Upgrade	- -	- -	- -	1.0	7.0	22.0	22.0	23.0	17.0	8.0
Muon Cooling Experiment	- -	- -	- -	- -	- -	1.5	3.5	10.0	10.0	5.0
New Project (First Step)	- -	- -	- -	- -	- -	- -	- -	3.0	21.5	52.0
Total	56.8	51.1	31.3	36.5	40.9	48.3	44.1	54.6	67.1	83.6

Indirect Costs

Up Scenario

BA: dollars in millions : constant FY97 dollars



Indirect Costs

Up Scenario

BA: dollars in millions : constant FY97 dollars

Indirect	FY97	FY98	FY99	FY00	FY01	FY02	FY03	FY04	FY05	FY06
Salaries, Wages & Fringes	26.0	26.0	26.0	26.0	26.0	26.0	26.0	26.0	26.0	26.0
M&S	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1
Wilson Hall	- -	1.0	4.9	8.3	1.3	- -	- -	- -	- -	- -
Centeral Utility Building	- -	1.9	1.3	1.5	- -	- -	- -	- -	- -	- -
Management Allowance	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9
Site Power	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
Total Indirect	44.4	47.3	50.6	54.1	45.7	44.4	44.4	44.4	44.4	44.4

HIGH ENERGY PHYSICS FUNDING HISTORY
of
FERMI NATIONAL ACCELERATOR LABORATORY
(BA : dollars in thousands: constant FY97 dollars)

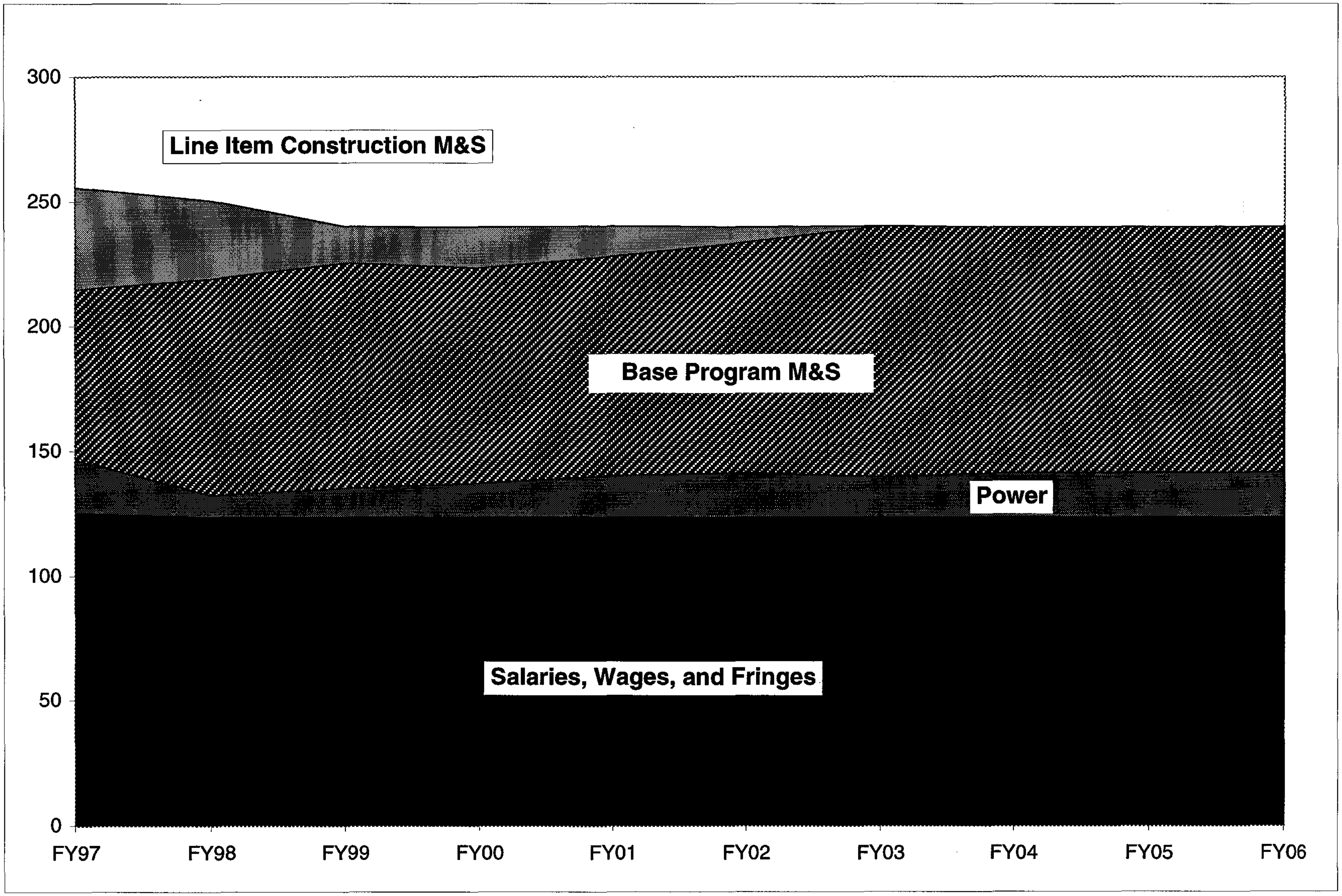
FLAT SCENARIO

HIGH ENERGY PHYSICS *	FY1997	FY1998	FY1999	FY2000	FY2001	FY2002	FY2003	FY2004	FY2005	FY2006
Facilities Operations	134,874	131,063	143,331	140,508	136,240	130,332	127,994	128,538	128,689	131,962
Research Technology	22,211	24,770	25,414	27,699	26,812	24,331	21,573	21,268	21,963	18,800
Capital Equipment	23,135	36,407	31,927	26,611	30,312	44,967	58,130	56,095	55,145	62,337
SWF	1,800	3,325	1,802	2,942	3,351	4,971	6,426	6,201	6,096	6,891
M&S	17,785	27,528	25,255	19,610	22,337	33,137	42,837	41,337	40,637	45,937
CDF Upgrade	6,037	10,500	7,182	--	--	--	--	--	--	--
DØ Upgrade	6,340	10,500	6,379	--	--	--	--	--	--	--
Run II Computing	--	1,934	5,400	5,500	5,100	--	--	--	--	--
FY99 Fixed Target Experiments		--	--	--	--	--	--	--	--	--
COSMOS	--	--	--	--	2,000	3,500	3,500	--	--	--
MINOS	--	--	800	8,000	10,000	16,500	8,000	--	--	--
MINOS (Narrow Band Beam)		--	--	--	--	--	--	3,000	--	--
New Experiment Initiatives		--	--	--	--	3,800	22,000	29,000	31,300	36,600
Mini-BooNE	--	--	--	--	--	3,000	1,000	--	--	--
K^+ Experiments & Beam		--	--	--	--	200	5,500	5,000	7,000	3,300
KAMI	--	--	--	--	--	200	2,500	5,000	4,000	1,300
Other 120 GeV Experiments (eg MECO)			--	--	--	--	--	--	--	14,000
* BTeV	--	--	--	--	--	200	6,500	9,500	16,500	18,000
* TeV33 Detector Upgrade		--	--	--	--	200	6,500	9,500	3,800	--
Cryo Improvements	--	--	967	1,873	--	--	--	--	--	--
120 GeV Switchyard	--	--	400	400	1,000	--	--	--	--	--
Particle Astrophysics	85	235	200	200	200	200	200	200	200	200
All Other	5,323	4,359	3,927	3,637	4,037	9,137	9,137	9,137	9,137	9,137
Indirect Allocation	3,550	5,554	4,870	4,059	4,624	6,859	8,867	8,557	8,412	9,509
GPP	2,065	3,308	3,720	3,780	5,500	6,000	6,000	6,000	6,000	6,000
AIP	2,685	8,412	7,700	9,100	11,200	11,977	12,600	12,600	12,600	5,600
PROGRAMMATIC POWER	18,750	6,300	9,212	11,261	14,325	15,425	13,850	15,425	15,425	15,425
SUBTOTAL	203,720	210,260	221,304	218,959	224,389	233,032	240,147	239,926	239,822	240,124
Main Injector	52,000	29,932	--	--	--	--	--	--	--	--
NuMI	--	5,319	18,727	20,852	15,803	6,797	--	--	--	--
CØ Hall	--	4,836	--	--	--	--	--	--	--	--
TOTAL FERMILAB	255,720	250,347	240,031	239,811	240,192	239,829	240,147	239,926	239,822	240,124
MAJOR UNFUNDED PROJECTS IN FLAT SCENARIO										
Proton Source Upgrade	--	--	--	1,000	7,000	22,000	22,000	23,000	17,000	8,000
Muon Cooling Experiment						1,500	3,500	10,000	10,000	5,000
New Project (First Step)								3,000	21,500	52,000

Cost Distribution

Flat Scenario

BA: dollars in millions : constant FY97 dollars



Summary Level Cost Distribution

Flat Scenario

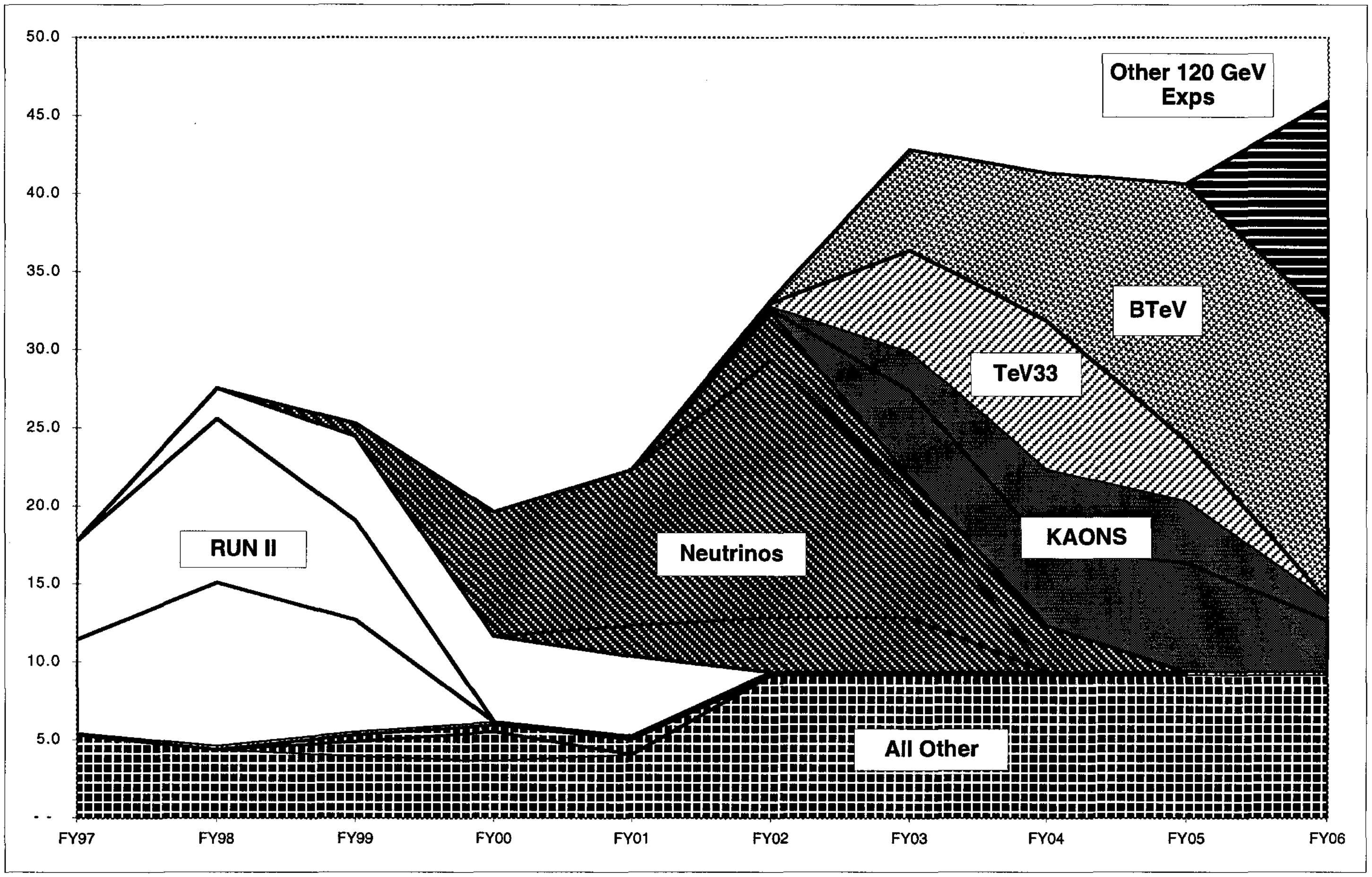
BA: dollars in millions : constant FY97 dollars

HIGH ENERGY PHYSICS	FY97	FY98	FY99	FY00	FY01	FY02	FY03	FY04	FY05	FY06
TOTAL Laboratory SWF	125.2	123.5	123.5	123.5	123.5	123.5	123.5	123.5	123.5	123.5
Base Program M&S	68.3	86.7	90.4	86.2	88.0	92.5	100.4	98.6	98.5	98.8
Operating	25.7	24.4	28.0	23.8	26.8	23.8	23.8	23.8	23.8	23.8
Research Technology	6.4	7.7	7.5	8.6	9.1	7.2	4.9	4.6	5.2	5.2
Equipment	17.8	27.5	25.3	19.6	22.3	33.1	42.8	41.3	40.6	45.9
GPP	1.7	3.1	3.0	3.0	4.4	4.9	4.9	4.9	4.9	4.9
AIP	1.7	6.0	5.5	6.5	9.0	8.6	9.0	9.0	9.0	4.0
Indirect	15.0	17.9	21.2	24.8	16.3	15.0	15.0	15.0	15.0	15.0
Line Item M&S	41.1	31.4	14.5	16.4	12.0	6.0	- -	- -	- -	- -
Total POWER	21.2	8.7	11.6	13.7	16.7	17.8	16.3	17.8	17.8	17.8
TOTAL FERMILAB	255.7	250.3	240.0	239.8	240.2	239.8	240.1	239.6	239.8	240.1

Capital Equipment M&S

Flat Scenario

BA: dollars in millions : constant FY97 dollars



Capital Equipment

Flat Scenario

BA: dollars in millions : constant FY97 dollars

	FY97	FY98	FY99	FY00	FY01	FY02	FY03	FY04	FY05	FY06	Total
SWF	1.8	3.3	1.8	2.9	3.4	5.0	6.4	6.2	6.1	6.9	
M&S	17.8	27.5	25.3	19.6	22.3	33.1	42.8	41.3	40.6	45.9	
CDF Upgrade	6.0	10.5	7.2	- -	- -	- -	- -	- -	- -	- -	
DØ Upgrade	6.3	10.5	6.4	- -	- -	- -	- -	- -	- -	- -	
Run II Computing	- -	1.9	5.4	5.5	5.1	- -	- -	- -	- -	- -	
FY99 Fixed Target Experiments	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	
COSMOS	- -	- -	- -	- -	2.0	3.5	3.5	- -	- -	- -	9.0
MINOS	- -	- -	0.8	8.0	10.0	16.5	8.0	- -	- -	- -	43.3
MINOS (Narrow Band Beam)	- -	- -	- -	- -	- -	- -	- -	3.0	- -	- -	
New Experiment Initiatives	- -	- -	- -	- -	- -	3.8	22.0	29.0	31.3	36.6	122.7
Mini-BooNE	- -	- -	- -	- -	- -	3.0	1.0	- -	- -	- -	4.0
K+ Experiments & Beam	- -	- -	- -	- -	- -	0.2	5.5	5.0	7.0	3.3	21.0
KAMI	- -	- -	- -	- -	- -	0.2	2.5	5.0	4.0	1.3	13.0
Other 120 GeV Experiments	- -	- -	- -	- -	- -	- -	- -	- -	- -	14.0	14.0
(e.g. MECO)											- -
BTeV	- -	- -	- -	- -	- -	0.2	6.5	9.5	16.5	18.0	50.7
TeV33 Detector Upgrade	- -	- -	- -	- -	- -	0.2	6.5	9.5	3.8	- -	20.0
Cryo Improvements	- -	- -	1.0	1.9	- -	- -	- -	- -	- -	- -	
120 GeV Switchyard	- -	- -	0.4	0.4	1.0	- -	- -	- -	- -	- -	
Particle Astrophysics	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	
All Other	5.3	4.4	3.9	3.6	4.0	9.1	9.1	9.1	9.1	9.1	
Beams Division	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	
Computing Division	3.0	2.2	1.8	1.5	1.9	7.0	7.0	7.0	7.0	7.0	
Particle Physics Division	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	
Technical Division	0.4	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	
G&A Sections	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	
Indirect Allocation	3.6	5.6	4.9	4.1	4.6	6.9	8.9	8.6	8.4	9.5	
TOTAL Capital Equipment	**23.1**	**36.4**	**31.9**	**26.6**	**30.3**	**45.0**	**58.1**	**56.1**	**55.1**	**62.3**	

Plant

Flat Scenario

BA: dollars in thousands : constant FY97 dollars