Physics Advisory Committee

June 18-23, 2005

Comments and Recommendations

FERMILAB'S FUTURE PLANS

Fermilab's current program in particle physics is being carried out at a time of great excitement and promise. The Tevatron is operating very well, delivering a steadily increasing luminosity characterized by a data-doubling time that is now one year and is expected to remain below two and a half years throughout the decade. The CDF and DZero experiments are producing a rapidly growing stream of new results based on Run II data. The discovery of neutrino oscillations is the first observation of physics beyond the Standard Model and has inspired new experiments aimed at exploring the nature of neutrino-flavor physics. The Laboratory's Booster and Main Injector facilities are functioning extremely well and are both now providing high-intensity proton beams for neutrino production. Data-taking for the MiniBooNE experiment is well advanced and the community eagerly awaits its results. The MINOS experiment has brought its construction phase to a successful conclusion and has begun to acquire data. Fermilab is also playing an essential role in the construction of the LHC accelerator and the CMS detector and is well along in establishing itself as a center for CMS physics analysis. Finally, the Laboratory is conducting a small, but well-motivated and successful, research program in astroparticle physics.

The Laboratory staff and their domestic and international collaborators can be justifiably proud of these accomplishments, which were made possible by years of sustained investment. The Committee commends the Laboratory on so effectively carrying out its mission as the central facility for particle physics in the U.S.

There are, however, dangers to the U.S. program. With no new investment, the number of high-energy physics opportunities in the U.S. will dwindle as we approach the end of the decade. This state of affairs threatens the vitality of the field just at a moment of great opportunity, when profound scientific mysteries still remain unresolved. Furthermore, the fiscal situation is such that this dilemma will not be easily remedied. Careful planning is essential, and difficult decisions will need to be taken.

The Laboratory presented a well considered plan that addresses these challenges and offers a path to keep the U.S. in a position of leadership. In particular, it proposes to carry through with Run II at the Tevatron, thus taking advantage of what will be unique opportunities to exploit the discovery potential at the energy frontier and to elucidate the important question of electroweak symmetry breaking. Taken together with the Laboratory's involvement in CMS, this plan will provide continuity in the collider physics program. Fermilab also proposes to build on its investment in NuMI/MINOS by constructing the NOνA experiment as the next logical step in a program to explore the neutrino-flavor puzzle.

Fermilab's plans also call for a significant ramp-up in International Linear Collider (ILC) R&D, aimed at hosting this important endeavor, and providing vital infrastructure whether or not the ILC is eventually built near Fermilab. The plan maintains an alternative path in the form of a Proton Driver that would be built in the event that the ILC is delayed or does not go forward. The overlap between ILC and Proton Driver technology allows the latter to be pursued in a way that will not materially detract from work on the ILC, but rather will offer synergistic advantages.

The Committee enthusiastically endorses the basic features of this plan, while recognizing that its successful implementation will require a highly disciplined approach. Indeed, even with such discipline, full realization of the Laboratory's core plans may not be possible without a temporary increase in funding toward the end of the decade.

TEVATRON COLLIDER PHYSICS

The Committee heard presentations about the status and prospects of the machine and experiment upgrades, as well as recent physics results from CDF and DZero.

The Committee congratulates the Accelerator Division and the Laboratory as a whole on the success in realizing the Run II luminosity goals over the past year. The major achievements were slip stacking in the Main Injector and combined shot operation using antiprotons from both the Accumulator and the Recycler. In addition, electron cooling was installed in the Recyler. The luminosity goals were accomplished while the NuMI beam was commissioned and operated.

The Tevatron peak luminosity record is now 1.27×10^{32} $cm^{-2}s^{-1}$; the FY05 integrated luminosity is running ahead of the design curve, with 0.37 fb^{-1} as of June 15; and the integrated luminosity for Run II exceeds 1 fb^{-1}. These achievements are significant, and are the payoff for outstanding efforts. Both CDF and DZero have recorded data from about 0.8 fb^{-1} integrated luminosity, resulting from efficient operation. Current efficiencies are 85-90%.

The CDF and DZero detectors are in good shape, with recent potential problems having been understood and managed. The CDF central tracker aging problem has been cured by increasing the gas flow rate, and adding 100 ppm of oxygen. The DZero magnet experienced anomalous quenching following the fall 2004 shutdown, and this problem appears to have been understood and corrective action taken. Both of these issues appear to be under control.

The CDF and DZero detector upgrades designed for the increased luminosities are being implemented. The CDF upgrades will be completed in the coming fall, and the DZero upgrades will mostly be completed this fall/winter, with the exception of the upgrade to the fiber tracker front-end board, which is scheduled to be completed by summer 2006.

The physics productivity of both collaborations is strong. About 60 papers from Run II data have been submitted for publication. Many of these have been published. Most of these papers are based on 0.2 – 0.4 fb^{-1}, indicating updated results are likely to be following soon. The Committee congratulates the collaborations on these impressive achievements.

Both the current and planned machine performance will provide short doubling times for integrated luminosity, thus ensuring a physics program which continues to break new ground. With the current performance, one expects 2 fb^{-1} by 2007 and 4 fb^{-1} in 2009, i.e. two doublings in the next four years. With the planned upgrades (e.g. electron cooling), one expects 4 fb^{-1} and 8 fb^{-1} over the same periods, i.e. three doublings.

The Tevatron Collider is the most powerful instrument available today to explore the high-energy frontier. It is used by the world-wide high-energy physics community and has the potential of discovering new physics in a well-motivated energy range. The experiments at the Tevatron are the result of a large international investment. The Committee is therefore pleased to see that every effort is being made to improve the machine luminosity performance with the prospects of delivering up to 8 fb^{-1} by 2009. The Committee believes that the collaborations should document their plans for human, computing and other technical resources to realize the experiments' physics goals.

Considering the present LHC schedule (machine commissioning with single and colliding beams starting in summer 2007), the expected LHC luminosity ramp-up scenario, and the time it will take to understand the complex LHC detectors, the LHC is not likely to take over the leadership in the exploration of the high-energy frontier much before 2009. The Committee believes that, until that time, the Tevatron will play a driving role. This is illustrated with a few examples below. The Committee also notes that the planning for future facilities, such as an International Linear Collider, would benefit a lot from the discovery and determination of the scale of new physics as early as possible.

With an integrated luminosity of 2 fb^{-1}, CDF and DZero have little sensitivity to a Standard Model Higgs boson beyond the LEP limit of 114.4 GeV. With 4 fb^{-1}, they may collect 3σ evidence for masses a few GeV above the LEP limit, while with 8 fb^{-1} they may extend the 3σ evidence up to masses as high as 130 GeV. This mass region is highly motivated by electroweak data and supersymmetry, and is especially challenging at the LHC because integrated luminosities of at least 10 fb^{-1} per experiment, very good control of the huge backgrounds, and well-understood and close-to-optimal detector performance are required. Also, the two machines have sensitivities to different physics channels in this mass range.

If SUSY is responsible for stabilizing the Higgs mass, SUSY mass scales might be accessible to the Tevatron. The discovery reach for squarks and gluinos, through the most powerful and most model-independent *jet + missing ET* signature, increases by more than 20 GeV when the accumulated luminosity increases from 2 fb^{-1} to 8 fb^{-1}. For other more model-dependent signatures (e.g. 3-lepton final states arising from gaugino pair production and decays) the gain is larger, namely 30 GeV for chargino masses when the integrated luminosity increases from 2 fb^{-1} to 4 fb^{-1} and by another 30 GeV from 4 fb^{-1} to 8 fb^{-1}. The Committee notes that these gains are larger than those that were offered by the energy increase throughout the whole LEP2 phase.

The Tevatron also has potential for the discovery of MSSM Higgs bosons at large $\tan(\beta)$, and Run II has already excluded some of this region for light Higgs bosons. With 1 fb^{-1}, the reach (3σ) is expected to be up to masses of 180 GeV for $\tan(\beta)=60$; with 8 fb^{-1} the reach extends up to 240 GeV. The discovery of such Higgs bosons would be stunning.

Among the wide range of B-physics measurements possible at the Tevatron, B_s mixing will give a unique contribution to test the Standard Model in the flavor sector. Throughout the range allowed by the Standard Model, and taking into account improvements to the analysis procedures, the Tevatron can increase its sensitivity from a 95% C.L. exclusion with 2 fb^{-1}, to a 3σ evidence with 4 fb^{-1}, to a 5σ discovery with 8 fb^{-1}. In addition, non-observation of B_s mixing with 8 fb^{-1} would be strong evidence for new physics.

The anticipated uncertainties on the W and top masses are expected to improve by about 20% when the integrated luminosity increases from 2 fb^{-1} to 4 fb^{-1}. The combination of these two measurements provides constraints on the Standard Model Higgs mass, which can be compared with bounds from other precision electroweak measurements. Once a Higgs (or some other agent of electroweak symmetry breaking) is discovered, these precision measurements will provide crucial tests of the theory.

Finally, the Committee notes that although some measurements and observations performed at the Tevatron will be repeated at the LHC with more statistics, in some cases the two machines probe different initial-state dynamics. In addition to the Higgs case discussed above, another example is single-top production, which may be observed at 5σ for the first time at the Tevatron with integrated luminosities of 5-7 fb^{-1}. The relative contributions of the t-channel and s-channel production processes, which have different sensitivities to new physics, vary between the Tevatron and the LHC.

On the basis of the Tevatron Collider's broad discovery potential, the Committee fully endorses the Laboratory's plan to make every effort to upgrade and run the Tevatron and, together with the collaborations, operate the experiments and exploit the full physics capabilities of the facility.

INTERNATIONAL LINEAR COLLIDER (ILC)

Since the last Aspen PAC meeting, tremendous progress has been made on the ILC efforts worldwide. In August 2004, the recommendation to use the "cold" technology for the linac was endorsed by the ILCSC and ICFA. In November 2004, the first ILC Workshop at KEK brought the whole community together and united it behind the project. In March 2005, the Director for the Global Design Effort (GDE) was announced, and now the three regional directors have been selected. The next important step will be the development of the baseline configuration for the machine by the end of 2005, following the second ILC Workshop at Snowmass in August 2005. GDE Director Barry Barish plans to produce a Reference Design Report ("CDR") by the end of 2006. This document will contain the first cost estimate for the accelerator and the detectors. It will include a range of infrastructure costs based on sample sites from all three regions. DOE has announced that the U.S. sample site will be near Fermilab.

Fermilab has been active in linear collider R&D for many years. As a member of both the TESLA and the NLC Collaborations, it successfully built and tested components for both competing technologies in collaboration with national and international partners. It now plays a major role in the coordinated activities of the GDE.

The Committee is pleased with the recent increased Fermilab efforts and plans for accelerator and detector R&D for the ILC. Fermilab intends to take a lead role in the global ILC project. In particular, it plans to lead the U.S. effort in the development of superconducting RF technology. It will also assume a leadership role in accelerator design and beam dynamics issues. As the U.S. candidate for the host laboratory site, Fermilab is leading the U.S. effort on site characterization. There is also an active public outreach effort. All these efforts are embedded and coordinated within the global scene, led by the GDE.

Incoming Director Pier Oddone presented the ILC as the Laboratory's highest priority initiative in his vision of the future of Fermilab. The goals are to establish the technical components to enable a decision by 2010 and to position the U.S. (and Fermilab) to host the ILC and to play a major role in detector development and future physics analysis. He re-emphasized the importance of integrating the Fermilab efforts into the GDE.

The Superconducting Module Test Facility (SMTF) at Fermilab has been proposed by all major U.S. institutions with significant superconducting RF experience and a number of international laboratories. This facility is important to establish the expertise in the fabrication of high gradient superconducting accelerator structures in the U.S. The Committee sees this as a very positive development, advancing the realization of the ILC.

The Committee heard the details of the timeline through 2009 for the fabrication and testing of four cryomodules in the SMTF. This plan seems to be limited by available resources, and could be too slow for the GDE plans, particularly in the optimistic scenario of a construction start in 2010.

In the past year, efforts at Fermilab on ILC detector R&D have focused on conceptual design of the SiD detector, in particular its silicon tracker and its 5 Tesla solenoid, and on scintillator-based muon systems. Additional effort has gone into the development of high resolution calorimetry. The Committee encourages Fermilab to continue its effort on ILC detector R&D.

The Committee reiterates its statement concerning test beams in the April report. Detector development for the ILC will require test beams both to probe and optimize characteristics of particular detector designs and to advance the associated simulation tools. There is a scarcity of test beams worldwide, and Fermilab is a natural site to host such efforts. The existing Fermilab test beam facilities can already satisfy many of the stated goals. Upgrades may in some cases be required. The Committee encourages Fermilab to make facilities available for well-motivated ILC detector tests. Proposals for beam time, particularly those that require upgrades to Laboratory facilities, will need to be considered in the broad context of the Fermilab and ILC programs. The Laboratory should interact closely with the ILC organization to prioritize requests, to optimize the use of its facilities and to plan possible upgrade paths.

The increased effort in the past year at Fermilab on ILC R&D is remarkable, and consistent with the Laboratory's aspirations. The Committee endorses strongly the overall strategy of the Laboratory towards the ILC.

NEUTRINO PHYSICS AND THE PROTON DRIVER

The Context

The discovery of neutrino mass and mixing has led to a number of very interesting questions: What are the (presently rather uncertain) neutrino mass splittings, Δm^2? Is the surprisingly large atmospheric mixing angle maximal? If so, is an underlying symmetry responsible? Is the neutrino mass spectrum normal, as favored by grand unified theories, or inverted? Do neutrino interactions violate CP symmetry, and if they do, is this violation related to the observed matter – antimatter asymmetry of the universe? How small is the presently unknown mixing angle θ_{13}, on which CP violation in neutrino interactions and our ability to determine whether the mass spectrum is normal or inverted both depend? To answer these questions, the APS multi-divisional neutrino study recommended that high priority be given to a timely accelerator neutrino experiment, and then to a Proton Driver in the megawatt class with more sensitive experiments. The Committee believes that the case for the recommended program is very strong. Timeliness is indeed important because of the complementary accelerator neutrino program being mounted in Japan and because of the probable timing of complementary, and related, reactor neutrino experiments. Fermilab has an active ongoing neutrino program relevant to these issues, and is well-poised to play a major role in future research in this area.

NuMI Operations and the Proton Plan

The NuMI beam involves use of the Main Injector (MI) to produce a muon neutrino beam for neutrino oscillation studies. During the last few months, commissioning and operation of the NuMI beam has been successfully accomplished. Although high intensity NuMI running has added another component to the already complex mix of accelerator operations, high levels of operational efficiency have been maintained, with minimal effect on Tevatron operations. In addition, MiniBooNE has received 5.7×10^{20} protons on target from the Booster (surpassing the original allocation), and with NuMI commissioned MINOS has successfully started data-taking. The Accelerator Division should be congratulated for the smooth and efficient turn-on of the NuMI beam.

To support the growing neutrino program and meet its increasing demands for protons over the course of the next decade, the Laboratory has embarked on an ambitious 3-year program to double the proton intensity and increase the operational reliability of the accelerator complex. At this point, the Laboratory is midway through the first year of the plan (Phase I). The Committee was very happy to hear that Phase I has made excellent progress. Progress includes commissioning NuMI, introducing slipstacking for antiproton production (with some loss issues still to be addressed), introducing 2+5 multi-batch operation to allow simultaneous NuMI and Tevatron operation, and increasing the Booster repetition rate to 7.5 Hz. The Committee also heard good news on related upgrades, which are aimed at Tevatron luminosity. Injection of combined shots is now standard practice, and the multi-batch operation proceeded without disturbing Tevatron experimental operations.

Looking beyond the scope of the Proton Plan, the Laboratory is studying options for further upgrades in proton delivery. The realization that the Main Injector RF upgrade may require only 1/3 as much RF as previously thought suggests that this upgrade could be advanced. With additional improvements to Main Injector fill-time and cycle-time, and possibly using the Recycler as a preloader, it might be possible to reach the megawatt range through upgrades alone. A study group has been formed to investigate these possibilities. The Committee urges the Laboratory to pursue these possible upgrades aggressively.

MINOS

The Committee was pleased to hear of the successful start of data-taking by the MINOS experiment. The beamline was commissioned, and events were observed in the near detector in January. The target developed a water leak which has been ameliorated by introducing helium gas into the vacuum region surrounding the target. A second target is being prepared for installation as a replacement. Despite this setback, the collaboration has observed over twenty in-time beam-induced events at the far detector in medium energy running, which indicates that the full MINOS experiment is working as expected. The Committee congratulates the MINOS collaboration on a successful start to a promising program of neutrino physics.

The MINOS collaboration was originally approved for four years of running and 8.4×10^{20} protons on target. The Proton Plan as presented offers substantial promise for more protons than anticipated at the time of the proposal, and the collaboration presented arguments at a previous PAC meeting which indicate that the experiment can make substantial gains in sensitivity up to at least 16×10^{20} protons on target before becoming limited by systematic uncertainties. The Committee strongly urges the Laboratory to proceed with the Proton Plan, independent of the status of NOνA, in order that MINOS can achieve its physics goals as efficiently and expeditiously as possible.

NOνA

NOνA presented updates on physics sensitivity studies, detector design technical progress, and project management issues, including answers to several questions raised by the PAC before the Aspen meeting.

Physics Sensitivity and Experimental Strategy

NOνA is considering a 5-year run strategy with a mixture of neutrino and anti-neutrino running. This strategy gives a 95% C.L. sensitivity on $\sin^2 2\theta_{13}$ of ~0.01, with relatively small dependence on the CP phase δ, for a total of 32×10^{20} protons on target. This reach is similar to that of the most sensitive proposed reactor experiments.

In addition to sensitivity to the angle θ_{13}, the approved NOνA experiment has modest but unique sensitivity to the mass hierarchy. Moreover, with a Proton Driver (PD) capable of delivering approximately a factor of four higher proton intensity, combined with a second detector at 30 km off-axis, the neutrino program can determine the mass hierarchy for any $\sin^2 2\theta_{13}$ greater than ~0.02. The upgraded configuration is also capable of a 3σ observation of

CP violation for more than 50% of the CP phase space if $\sin^2 2\theta_{13}$ is >0.02. These exciting prospects would address fundamental physics questions in the neutrino sector.

Matter effects (which depend on the hierarchy) and CP violation both produce an asymmetry between neutrino and antineutrino oscillation probabilities. However, because the Fermilab neutrino beamline is longer and of higher mean energy than its J-PARC counterpart, the contribution of matter effects to the neutrino – antineutrino asymmetry will be larger at Fermilab than at J-PARC. Thus, combining the results of measurements with upgraded facilities at the two places will significantly enhance the ability to separate genuine CP violation from matter-induced asymmetries.

NOνA presented several studies related to optimization of the experimental design. One of these studies indicates that a detailed optimization of the beam energy profile could improve statistics by ~10%. An updated study on cosmic ray background was presented. The cosmic muon and neutron backgrounds are easily distinguishable from ν_e signal events. The electron and photon backgrounds are not as easy to control, which led to a design preference to include an overburden of ~3m of rock. This adds ~11M$ of cost, but has the benefit of making it possible to use NOνA as a supernova detector with much better signal/background. The Committee notes the following remaining unanswered issues: a) extent to which MIPP/MINERνA can help estimate far-detector backgrounds by extrapolating from the near detector; b) energy reconstruction accuracy as a function of neutrino energy, down to the lowest relevant energy. The proposed mixture of running with neutrinos and antineutrinos also demands studies of backgrounds, which will be different for neutrinos and antineutrinos. The Committee hopes that NOνA will provide information regarding these issues to the Laboratory in time for the next PAC meeting.

Technical Progress

The collaboration has made good progress towards a final design for the extruded PVC tanks for the liquid scintillator. They have developed a new scalloped cell design with a larger radius of curvature (3/8") at the corners to reduce the stress by about a factor of two. They are planning to study short prototype cells, pressurizing them to simulate the additional pressure head associated with the tall structures to be employed in the full detector. The Committee encourages the collaboration to continue these technical studies and to address the various other detector design issues. Tests to ensure that there are no stress-related chemical effects due to the presence of liquid scintillator should also be undertaken.

The photoelectron (Pe) yield of a prototype liquid scintillator cell with wave-length shifting fiber attached to avalanche photodiode (APD) readout was measured. The design goal is 25 Pe per minimum ionizing particle at the end far from the APD, and the observed yield was 24 Pe. Further improvements in reflectivity of the PVC cell walls are anticipated to increase the yield further. However, the width of the observed distribution was significantly wider than expected from a 24 Pe yield. This width was apparently not well understood at the time of this meeting and is under further study.

Alternate Site

The collaboration is now considering an alternate site for the experiment. This alternate site may have more convenient road access and power availability. Feasibility studies and a choice of site should be accomplished in a timely fashion. If the alternate site is still under consideration at the next PAC meeting, the Committee would like to see its effects on the experimental sensitivity.

NOνA Summary

The Committee would like to reiterate the importance of timeliness in the implementation of NOνA. There is substantial value in starting the experiment as soon as possible to maintain a competitive position in discovering ν_e appearance and measuring θ_{13}. Reactor experiments, as well as T2K, are aiming to address the θ_{13} issue early in the coming decade. An initially quite modest beam power at T2K in 2009 will be gradually ramped up until 2013. Given the remaining work to be done and the extensive review process that lies ahead, it will be a great challenge to construct NOνA and begin taking data on a competitive time scale; nevertheless, it does appear possible at this point if substantial delays can be avoided. Timely execution of this important experiment will require serious attention from both the collaboration and Laboratory management.

In addition to the potential for discovering the important mixing parameter θ_{13}, NOνA will provide opportunities for studying both the mass hierarchy and CP violation in the neutrino mixing matrix. Indeed, the long baseline afforded by the NOνA experiment makes it uniquely sensitive to the mass hierarchy. Thus a large share of the future of neutrino physics will be accessible at Fermilab with the existence of NOνA and subsequently with suitable upgrades (e.g., Proton Driver and additional detector deployments). This program will provide the Laboratory with a unique and world-leading role in the exciting field of neutrino physics for many years to come, with substantial opportunities for important discoveries.

Proton Driver

The currently favored scheme for a Proton Driver at Fermilab (FPD) is based on a new 8 GeV superconducting linac. Feeding the Main Injector, this linac could produce a beam with an initial, upgradeable power of 2 MW at any energy from 40 to 120 GeV. This linac could simultaneously provide an 8 GeV beam with an initial power of 0.5 MW, upgradeable to 2 MW.

The Committee heard a progress report on Proton Driver R&D from the Technical Division. The proposal is to build an 8 GeV Proton Driver using Tesla technology, with the $\beta < 1$ sections using "squeezed" Tesla cavities and the $\beta \sim 1$ sections using cavities very similar to those proposed for the ILC. Possible locations for such a facility on the Fermilab site have been evaluated.

The Proton Driver project has substantial overlap with ILC development and industrialization. The β=1 section of the Proton Driver will consist of 36 ILC cryomodules, equivalent to 1.5% of a 500 GeV ILC. Due to the large overlap in accelerator technology, Proton

Driver development is closely tied to ILC R&D, and Fermilab is pursuing a strategy that emphasizes the ILC but also advances the Proton Driver. It is believed that the number of klystrons needed per GeV of acceleration can be reduced substantially relative to the number used at SNS by the use of phase shifters to independently control the phase and amplitude of the RF in each individual cavity. This technology still needs to be tested with beam but is vital to a low cost machine. Additional goals for the next two years are to establish a capability to fabricate and test high-gradient cavities and a facility for high-power tests of integrated cryomodules. The venue for this work will be the SMTF (Superconducting Module Test Facility). This R&D is essential for both the ILC and the proposed Proton Driver.

The physics case for a Fermilab Proton Driver, presented to the Committee by Stephen Geer, is compelling. To establish that neutrino interactions violate CP and to greatly improve sensitivity to the hierarchy question will require event rates substantially higher than will be available with NOνA at NuMI. The FPD would provide such higher event rates and thus play a key role in the exploration of neutrino mass, mixing, and CP violation. This role is the primary reason, and a convincing reason, for building the FPD. Although the neutrino event rates could also be raised by increasing detector mass, that approach offers no clear cost advantage. In addition, it would lack the versatility provided by an FPD, which could also produce variable energy neutrino and other beams as needed. The 8 GeV FPD proton beam would make possible precision studies of muons, while the higher-energy beam would make possible studies of rare kaon decays. Whether or not the LHC observes new physics beyond the Standard Model, studies such as these can provide important information about the existence and nature of new physics at higher mass scales. These studies will be particularly interesting if the LHC does see new physics, because they will be needed to help elucidate the characteristics of the new phenomena. Finally, it is important to note that an FPD would be a logical first step towards the development and implementation of a neutrino factory, which could provide a powerful new world-class capability in neutrino physics in the future.

The Paths Into The Future

As discussed above, a Fermilab Proton Driver would bring great benefits, including:

- The ability to establish the presence of CP violation in neutrino oscillations, and to determine the neutrino mass hierarchy, for any value of θ_{13} almost down to the 95% C.L. sensitivity on $\sin^2 2\theta_{13}$ (~ 0.01) achievable with conventional neutrino beams.

- Neutrino beams at several energies, enabling antineutrino cross section measurements at the low energies where they are needed.

- A window on new physics beyond the Standard Model via muon and kaon studies.

- An ILC technology developmental tool.

- A first component of a neutrino factory.

- Improved reliability of the accelerator complex.

However, if a decision is made to build an ILC without delay at Fermilab, then construction of the Fermilab Proton Driver is unlikely. In that case, one can still create more intense neutrino beams by upgrading the existing accelerator complex in steps. Each step involves uncertainties, which compound as one takes more steps. However, it appears likely that a proton beam power of at least 1 MW, corresponding to 10^{21} protons on target/yr at 120 GeV, can be achieved. This flux would provide NOνA with considerable physics reach, even without the FPD. Unfortunately, the benefits of a Fermilab Proton Driver discussed above would be lost in such a scenario.

This vision of possible neutrino physics futures at Fermilab, which has been presented by the incoming Fermilab Director, is one with which the Committee strongly concurs.

Summary

The Committee recommends continuing R&D on the very attractive Proton Driver possibility and investigation of the non-Proton-Driver upgrades to the proton beam intensity. The Committee notes that some of these latter upgrades, notably those involving modifications to the Main Injector, would also increase the beam intensity provided with a Proton Driver.

Even without the Proton Driver, a neutrino program with considerable reach and importance to the world's exploration of neutrino physics can be carried out. With the Proton Driver, the Fermilab neutrino program can determine the mass hierarchy and establish CP violation so long as $\sin^2 2\theta_{13} > (0.01\text{-}0.02)$. Should θ_{13} prove to be below this level, the Proton Driver can serve as a component of the neutrino factory that would then be required for future studies. As we have discussed, a Proton Driver will also yield many additional scientific, operational, and technical benefits.

ASTROPARTICLE PHYSICS

In recent years, the synergy between particle physics and astrophysics/cosmology has grown. The Committee believes this synergy will continue and further expand, and it is natural for the Laboratory to play a leading role in this area.

The Fermilab Long-Range Planning Committee (FLRPC) Report "The Coming Revolution in Particle Physics" recommended:

"Particle astrophysics provides important new probes of fundamental physics that complement accelerator experiments and Fermilab was the first particle physics laboratory to establish an astrophysics effort. Given the discovery potential of this field and the strong astrophysics program currently in place, the committee feels that Fermilab should strive to expand its leadership role and grow its program in Particle Astrophysics."

The PAC recommended in June 2003:

"The Laboratory has asked the Committee to recommend criteria that might guide an eventual larger involvement in astrophysics experiments over the long term. The Committee would like to put forward four criteria. First, the scientific motivation for any new effort should be very

strong. Second, the new efforts should build on special strengths of the Fermilab staff. Third, the new efforts should involve or support a community of physicists outside the Fermilab staff, in the ideal case, physicists from the community of traditional high energy physics university user groups. Finally, the new efforts should not compromise Fermilab's commitment to provide accelerator facilities for experiments in high-energy physics."

The current Committee endorses both of these recommendations, with more comments below.

The Committee heard a presentation on the overview of the current particle astrophysics program at the Laboratory. The following achievements are noteworthy:

1. The Sloan Digital Sky Survey (SDSS) has produced a high-quality catalogue of about a million galaxies both in photometric and spectroscopic surveys in addition to other data of astrophysical interest. It provides data to study the large-scale structure of the universe, probing the evolution of structure and providing independent constraints on dark matter, dark energy, and neutrino mass complementary to CMB and supernova data. The recent detection of baryon oscillation has been one of the key goals of the survey, and confirms the dark matter to baryon ratio at much lower redshifts than WMAP. The Fermilab group has roles in data acquisition, data processing, survey planning, data distribution, telescope support, and instrument systems. The group works very closely with the Theoretical Astrophysics Group.

2. The Cryogenic Dark Matter Search (CDMS-II) has successfully installed five towers in the Soudan mine. It aims at direct detection of a Weakly Interacting Massive Particle (WIMP) as dark matter in our galactic halo. It has already produced the world's best limits on the WIMP cross section, nearly an order of magnitude better than its competitors. The Fermilab group provides the project management, electronics, Soudan cryogenics and infrastructure, and computing support, and is working on data analysis.

3. The Pierre Auger Observatory (Auger) has deployed more than half of the tanks and fluorescence telescopes, on schedule for the completion of the entire array by July 2006. The air shower array will provide data on Ultra High-Energy Cosmic Rays (UHECR) above 10^{19}eV with cross calibration between the surface detectors and fluorescence telescopes. It is expected to settle the disagreement between AGASA and Hi-Res data, and provide insight into the origin of UHECR. They are reporting their first science results at the International Cosmic Ray Conference (ICRC) this summer. Fermilab has been involved since its inception and is providing key leadership and project management.

4. In addition to the above operational and support activities, the Fermilab group has been playing important scientific roles. To further integrate the various astrophysics experimental and theory efforts, the Fermilab Particle Astrophysics Center opened on January 1, 2005.

In addition to these recent achievements, there are new projects underway.

1. SDSS has been granted a three-year extension (SDSS-II) that aims at three areas: a) Legacy Survey will fill gaps in the current survey; b) Segue will study the structure of the Milky Way Galaxy; and c) Supernova survey will find ~200 Type-IA supernova in the redshift range z=0.05–0.35 where data are lacking.

2. The Dark Energy Survey (DES) was granted Stage I approval by the Laboratory. It proposes to build a camera based on LBNL CCDs for the Blanco Telescope at the Cerro-Toloro Inter-American Observatory (CTIO). Four approaches will be taken to study the nature of Dark Energy: a) galaxy cluster counting of ~20K clusters; b) weak lensing survey of ~300M galaxies; c) spatial clustering of ~300M galaxies; and d) Type IA supernova in the range z=0.3–0.8. In addition, it will provide photometric redshift data to the Sunyaev-Zeldovich survey at the South Pole Telescope (SPT). Cross correlation of different approaches will provide better understanding of the systematics that will be needed in later, larger surveys such as LST and JDEM.

3. CDMS is planning to expand to larger towers and a deeper site (e.g., SNOLab or DUSEL) and has proposed the R&D program to NSF (SuperCDMS and SNOBox). Currently the Laboratory is committed to supporting ongoing operation of the CDMS II detectors at Soudan and cryogenic engineering support for the R&D phase of the development proposal. The future role of the Laboratory is not yet defined.

4. The Chicagoland Observatory for Underground Particle Physics (COUPP) is developing a new technology for WIMP searches using a bubble chamber, with the superheat pressure tuned to nuclear recoil. Currently, a liter-scale prototype module is installed in the NuMI tunnel and is being tested. Potentially it may be a new WIMP detection technology scalable to the ton scale. It is a collaboration of the Laboratory and University of Chicago.

5. The Auger collaboration is planning to propose another site in the northern hemisphere.

6. SuperNova Acceleration Probe (SNAP) is a satellite experiment to study Type-IA supernova in the wide range of redshift z=0.5–1.7 to map out the expansion history and measure the property of dark energy precisely. It is a candidate for the JDEM mission. The Fermilab group works on electronics, radiation shielding, simulations, calibrations, science pipelines and data archive, and is getting involved in CCD packaging. It is also bringing weak lensing science to SNAP.

Comments

The science of DES is exciting and is also a good way to obtain better understanding of the systematics of various approaches on dark energy before LST and JDEM come online. The collaboration is making progress in securing needed funding and outside expertise to carry out the project. They have MOUs with UIUC and Chicago, and modest M&S and labor support from the Laboratory for FY 2005. UCL (UK) possesses needed expertise in optics and has applied for funding from PPARC. IEEC (Barcelona) has submitted a proposal, and IFAE (Barcelona) will follow. In addition, DES is discussing additional funding from Michigan and Portsmouth (UK). Much of the anticipated funding is subject to recommendation by the Dark Energy Task Force of DES as an intermediate dark energy project between now and JDEM/LST. The report of the Task Force is due at the end of this year. Meanwhile, the collaboration started working on CCDs, with a clear procurement plan, and has begun work on CCD packaging. The project represents expansion in the astrophysics program at the Laboratory as the Fermilab Long Range Planning Committee report envisioned. The PAC commends the collaboration for aggressively moving forward with tight funding, and urges the Laboratory to continue working closely with the collaboration to monitor the progress and to secure funding from outside sources.

At present, the Laboratory's commitment to the SuperCDMS proposal is limited to providing engineering support for R&D. If this project goes forward in the future, its scope will be much greater than CDMS-II. If Fermilab were to consider substantial responsibility for engineering, design, and project management, this role would likely be a much larger effort than for CDMS-II. Dark matter experiments are anticipated to proceed to ~1-ton scale in the future with project size in the ~$100M scale, and currently many different techniques are being studied. The impact of this effort in the context of other commitments will need to be considered.

The Auger project also intends to proceed with proposing a northern hemisphere site as the present southern site completes construction. Recently, the collaboration selected a site in Colorado for this project. As this site would be on U.S. soil, more of the infrastructure cost for this array would need to be borne by the U.S. If Fermilab were to consider substantial responsibility for the Auger North Project, this responsibility is likely to be a larger effort than the Laboratory's role in Auger South. Again, the impact of this effort in the context of other commitments will need to be considered, and any discussion most likely depends on the data from the southern array.

In general, the highly successful Fermilab astrophysics program is generating new and exciting proposals. As Fermilab is the only U.S. single-purpose national laboratory in particle physics and given its responsibility to the Tevatron, the neutrino program, and the future ILC, the Committee anticipates that the astrophysics program will remain a relatively small part of the Laboratory's activities. However, the Committee does believe that the synergy of astrophysics and particle physics will grow, and consequently there will likely be motivation for the program to grow. Appropriate use of the Laboratory's resources, attraction of additional outside funding, and effective collaborations with other institutions could enable such growth.

COMPUTING DIVISION

The Committee heard a report on the activities and plans of the Computing Division (CD). The CD has a well-articulated mandate that encompasses a broad program of work essential to the Laboratory's ability to fulfill its scientific mission. It provides dedicated resources and scientific and technical expertise to experiments, as well as a broad range of computing resources to the entire Laboratory. The CD regularly takes the lead in developing a large range of scientific computing tools, often securing funds for such work through competitive proposals. It also participates in planning for the Laboratory's future.

The CD's priorities are well-aligned with those of the Laboratory. Moreover, it uses its resources in an efficient manner by searching for ways to benefit from overlap between different projects and by being flexible about reallocating resources between various projects as their needs change. Currently, there are at least fifteen major projects that need computing support within the Lab. The majority of the CD's effort is directed toward common infrastructure needs, such as computing and communications, core support services, and physics applications development. The majority of the dedicated resources goes to running experiments (CDF, DZero, SDSS) and to developing the new LHC Physics Center at Fermilab, which will provide the core of an analysis structure being developed for the U.S. CMS experimental community. In addition, the CD has contributed accelerator instrumentation and simulation software.

The CD also provides leadership to two U.S. communities interested in developing advanced computing techniques. Together with the lattice QCD community, it is developing and providing access to major dedicated computing facilities. Moreover, with the international "Grid" community, it is developing Grid tools.

The Committee commends the CD on making invaluable contributions to a challenging and diverse range of endeavors, and also applauds its role in leading Fermilab's involvement in the world-wide Grid effort.

DETECTOR AND ACCELERATOR R&D

The Committee heard a presentation of detector R&D on a number of promising technologies. In addition to the R&D focused on ILC detectors discussed elsewhere, there are projects with possible applications to neutrino and WIMP detection and to CMS upgrades.

Among these projects is an effort by university and Fermilab scientists to scale up liquid-argon TPC technology. This approach to neutrino detection is promising by virtue of the bubble-chamber-like images that can be obtained and due to its potential to achieve a detector mass in the tens of kiloton range needed for long-baseline applications through the use of commercial storage tanks and purification units. The Committee believes that studying the challenges of scaling the technology is the correct focus for this group, and that Fermilab's level of effort on this project is appropriate.

Concerning WIMP detection, a Fermilab-Chicago collaboration called COUPP is developing a bubble-chamber device that is tuned to produce a single bubble from the nuclear recoil caused by a WIMP interaction, in contrast to neutrons, which tend to scatter more than once, producing multiple bubbles. This work is at an early stage, but could conceivably emerge as a competitive technology for a kiloton-scale WIMP detector.

The Laboratory is also working on radiation-hard silicon strip and pixel detectors for a future upgrade to CMS. This activity makes good use of existing infrastructure and expertise, and is well in line with the Laboratory's stated priorities.

The Laboratory has a vibrant accelerator R&D program beyond that focused on the ILC and FPD. The three U.S. laboratories (FNAL, BNL, and LBNL) working on the LHC interaction regions have been joined by SLAC to form the LARP collaboration to coordinate their further efforts. LARP has chosen Fermilab as its host laboratory. Commissioning of the LHC interaction regions will be an important task for LARP. Its member labs are building instrumentation for the LHC, and will help with beam commissioning, both at CERN and remotely from the U.S. LARP is also committed to the technically challenging task of R&D and fabrication of the second-generation LHC interaction region quadrupoles. This project will benefit from Fermilab's high-field magnet program, which is developing methods to build high-field magnets based on Nb_3Sn. Clearly Fermilab's effort within LARP is crucial to the success of the LHC project and is therefore appropriately viewed by the Laboratory as a high-priority activity. The likely application of R&D being performed by Fermilab's high-field magnet program to LHC upgrades underscores the importance of basic accelerator R&D to the future of our field. Finally, the Laboratory hosts a modest effort of muon-collider/neutrino-factory activities focused on developing the technology needed for muon ionization cooling.