The report of the Fermilab Physics Advisory Committee following its June meeting in Aspen, Colorado, is now available.

As expected, the Committee concentrated its attention on the experimental program based on the Fermilab accelerator complex while recognizing the importance of the Fermilab program of particle astrophysics experiments and its participation in the CMS experiment at CERN.

The PAC considered the Run IIb upgrades to the Tevatron collider detectors CDF and D0 and recommended Stage I approval, which was subsequently granted by the Fermilab Director. This will enable these upgrades to move forward to the Director's Technical, Cost and Schedule reviews, and then the DOE Technical, Cost and Schedule reviews over the upcoming months.

The flavor physics experiments BTeV and CKM were accorded Stage I approval in 2000 and 2001, respectively, and the approval of BTeV with reduced scope was enthusiastically recommended in April 2002. These will be the subject of further discussion with DOE, probably in the context of the P5 process.

At the Aspen meeting, the PAC considered two submissions addressing initiatives which go beyond the neutrino program consisting of the NuMI/MINOS and MiniBooNE experiments. The PAC response to a potential extension of the neutrino program was positive. Therefore, we will encourage a series of workshops and discussions, designed to help convergence on strong proposals within the next few years. These should involve as broad a community as possible so that we can accurately gauge the interest and chart our course. Understanding the demands on the accelerator complex and the need for possible modest improvements is also a goal. Potentially, an extension of the neutrino program could be a strong addition to the Fermilab program in the medium term. We hope to get started on this early in 2003.

Michael Witherell

Physics Advisory Committee

June 15-20, 2002

We follow cleft hoofprints
of a bull moose, you striding ahead, I lagging
you reading woods lore—ice-stripped bark, deer-nibble,
last winter's furry matter fisher-cat spoor; I distracted
musing …

-- *Rosanna Warren*

General Comments

Aided by a number of informative presentations and documents, the Committee reviewed the short- and long-term plans for the Laboratory's accelerators and experiments. The Laboratory has a strong physics program in place for the next decade at the energy frontier, in CP violation in the quark flavor sector, in neutrino oscillation measurements, and in astrophysics. The Laboratory also has several interesting possibilities for the future, the most prominent of which is the Linear Collider. Below the Committee outlines its view of the current program and the future options. This includes a recommendation for Stage I approval of the Run IIb detector upgrades proposed by the CDF and D0 collaborations.

Short-Term Program

The Run II collider program is currently the centerpiece of the Laboratory's physics program, with significant opportunity to make discoveries at the energy frontier. Following a disappointing start to Run IIa, the Laboratory has responded by diverting resources to attack the remaining problems. Meanwhile, upgrades to the detectors and to the accelerator are planned in order to maximize the discovery potential up to the start of LHC physics in the 2008-2009 time-frame.

MiniBooNE and MINOS represent a major neutrino program at the Laboratory. MiniBooNE, using the neutrino beam from the Booster, will definitively verify or refute the LSND evidence. With turn-on of the NuMI beam in 2005, MINOS will provide precision measurements on atmospheric neutrino oscillation parameters reported by SuperKamiokande. These experiments will be a crucial basis for future neutrino programs.

The BTeV experiment is designed to make definitive measurements on CP violation in the B sector. This experiment will be able to install and commission in parallel with RunII, and will start taking data once RunII is finished. The CKM experiment is designed to measure the rate for $K^+ \rightarrow \pi^+ \nu\bar{\nu}$, with about 100 events if the Standard Model expectation is correct. This will provide an important independent test of the unitarity triangle from the K sector. CKM will begin taking data late in the decade. Both CKM and BTeV have Stage I approval from the Laboratory, but await decisions by the Particle Physics Project Prioritization Panel (P5).

Beginning in the next year, test beams and small fixed-target experiments requiring few cycles will be able to run in the Meson 120 line.

Fermilab is the US host institution for the CMS experiment at CERN's LHC accelerator, which is a major part of the US program. Fermilab will continue to play a role in experimental astrophysics – in the Sloan Digital Sky Survey, CDMS, and Pierre Auger projects – addressing important questions in structure formation, dark matter, dark energy, and ultra-high-energy cosmic rays.

The Committee finds the current program of the Laboratory to be well balanced, very exciting, and ripe with discovery potential. In order to carry it out, continued upgrading of the accelerator complex is required, both to increase the number of protons and antiprotons accelerated, and to deliver them to the various experiments while maintaining acceptable radiation levels. The Committee supports the Laboratory's many efforts to execute this program in a timely manner.

One potential difficulty for this program of experiments is that of its funding. The Committee completely agrees with the Laboratory's assessment that a flat-flat budget would not allow this program to be completed. In contrast, a budget accounting for inflation would be roughly consistent with the program outlined above. The physics that will come out of this program is exciting and strongly justifies the expense. In the case of a budget keeping pace with inflation, Laboratory projections indicate that the Laboratory budget could begin to fund new experimental initiatives starting around 2008.

The Committee also notes that the Laboratory and its users have been engaged in public outreach efforts. Such efforts are important to convey to the public the knowledge gained at the Laboratory and in the field. It is also crucial in gaining support for particle physics and science from the general public. The Committee recommends that the Laboratory continue to enhance these important efforts.

Long-Term Program

The long-range plan depends crucially on global decisions about the funding and siting of a Linear Collider. If the Linear Collider is sited at Fermilab, this will bring a major opportunity. Other options include the Laboratory hosting a major program in long-baseline neutrino oscillation experiments. Significantly, the Laboratory has played an active role in bringing together its staff and user community to perform studies on the various options. A list of the studies commissioned by the Laboratory in the past three years together with their URLs is given at the end of these General Comments.

The Tunnel Vision, Circle Line, and Line Drive series were particularly instrumental in informing the community about Linear Collider physics and issues prior to the 2001 Snowmass meeting and the subpanel deliberations that led to the recommendation to build a Linear Collider.

If the Linear Collider becomes a reality, Fermilab will play a major role in its construction, even if it is not built in Illinois. If it is built near Fermilab, the Laboratory will play the leading role in its construction and operation, and be the host to an international facility. This will dominate the Laboratory program into the 3rd decade of this century.

Continuation of the neutrino program beyond MINOS is also an exciting option. Larger detectors with enhanced electron identification capabilities, operating in the beam of a new proton driver, could probe the full neutrino mixing matrix and perhaps detect CP violation in the neutrino sector.

In the very long term, high-energy physicists look forward to experiments far above the TeV energy scale with both proton and electron beams. Fermilab is now a world leader in the development of high-field magnets that would be needed for future proton colliders of much higher energies. The Committee strongly recommends that the Laboratory continue this program of R&D in collaboration with other world centers in this area.

List of Recent Studies of Future Physics Initiated by Fermilab

Neutrino Factory Physics Study Group and Superbeams
http://www.fnal.gov/projects/muon_collider/nu/study/study.html

Linear Collider Physics
P.F. Derwent, et al., FERMILAB-FN-701, hep-ex/0107044

FNAL Feasibility Study of a Neutrino Source Based on a Muon Storage Ring
http://www.fnal.gov/projects/muon_collider/nu-factory

Design Study for a Staged Very Large Hadron Collider
http://tdserver1.fnal.gov/tddoc/DesignStudyReport/upload/PDF

The Proton Driver Design Study
http://www-bd.fnal.gov/pdriver/reports.html

Proton Driver Study II
http://www-bd.fnal.gov/pdriver/8GEV

The Physics Potential of a Proton Driver
http://projects.fnal.gov/protondriver/summary

B Physics at the Tevatron: Run II and Beyond
http://www-theory.lbl.gov/Brun2/report/
(This was the last stage of the larger Run II physics studies. http://theory.fnal.gov)

In addition, the Laboratory hosted

International Workshop on Physics and Experimentation at Linear Colliders (LCWS 2000)
http://www-lc.fnal.gov/lcws2000/

New Initiatives for the NuMI Neutrino Beam
http://www-numi.fnal.gov/fnal_minos/new_initiatives/new_initiatives.html

and three special seminar series:

Tunnel Vision (see Alvin Tollestrup for more information)

The Circle Line Tours
http://theory.fnal.gov/CircleLine

Line Drive Series
http://www-lc.fnal.gov/Linedrive

Specific Comments and Recommendations

Run II

Run II is the most important component of the Fermilab research program, and much of the Aspen meeting was devoted to reviewing the status and plans for the accelerator complex and the D0 and CDF detectors. In preparation for the meeting the Committee reviewed updates from the collaborations on their current operations and their Run IIb upgrade plans, including answers to questions posed in the April PAC report. Additionally, the Committee received reports from the Technical Review Committee (TRC), chaired by Jim Pilcher, and the Director's Review Committee (DRC), chaired by Ed Temple. During the Aspen meeting the Committee heard reports from the Beams

Division on Run IIa accelerator performance and the Run IIa and Run IIb luminosity-improvement programs, and from the “132-ns” committee, chaired by David Finley, on bunch-spacing options for future Tevatron running. Status and planning for Run II computing were described in a written report received from the Run II Computing Review Committee, chaired by Ian Bird, and a summary presentation in Aspen from the Computing Division.

The Committee congratulates the Beams Division for the recent improvement in Tevatron luminosity and for the sharpened focus on the challenge of meeting Run II luminosity goals. This is the single most critical ingredient for the success of the Laboratory’s program, and the Committee looks forward to hearing of continuing rapid progress in the near future.

Maintaining the capabilities of the CDF and D0 detectors throughout the run is also essential for the success of Run II. The development of upgrade plans that will ensure adequate performance, while meeting the rigorous schedule and fiscal constraints that the Laboratory faces, has been a major challenge. While the Committee believes that this challenge has not yet been completely met, it also recognizes the necessity to proceed toward a full baseline review of the projects by late summer. On this basis, the Committee recommends Stage I approval for the CDF and D0 Run IIb upgrade projects.

(A) Physics of Run IIb

The Tevatron will be the world's energy frontier collider until the advent of the LHC. Run II will be the first comprehensive search for the new physics of the TeV energy scale. Strong theoretical arguments and experimental hints point towards new physics associated with electroweak symmetry breaking and the Higgs boson. This new physics could take the form of supersymmetry, new dynamics, or even extra dimensions of space. Understanding the new physics of the TeV scale is the key step towards attacking the most interesting and profound questions of our field, including the unification of forces, the “DNA of matter” that explains its rich flavor structure, the nature of dark matter and dark energy, and the evolution and origin of the universe.

Run IIb offers the extraordinary opportunity to discover the Higgs boson predicted by the Standard Model or its minimal supersymmetric extensions (MSSM). As shown in Figure 1, precision electroweak data, which are sensitive to virtual effects of the Higgs, strongly favor a Higgs boson lighter than about 200 GeV. Indeed the best fit mass is somewhat less than the current lower bound of 114 GeV obtained by the Higgs searches at LEP. The LEP experiments themselves reported several candidate Higgs events with masses close to 115 GeV. Furthermore, in the MSSM extension of the Standard Model, there is a hard theoretical upper bound of 135 GeV on the mass of the lightest Higgs. All of these considerations make the Higgs mass range 115 GeV $< M_H <$ 200 GeV of extreme interest.

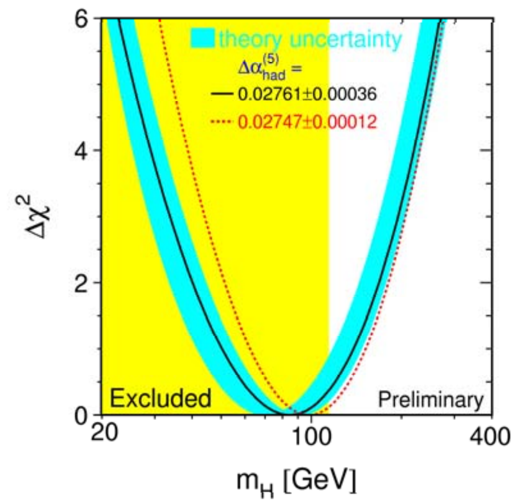

Figure 1

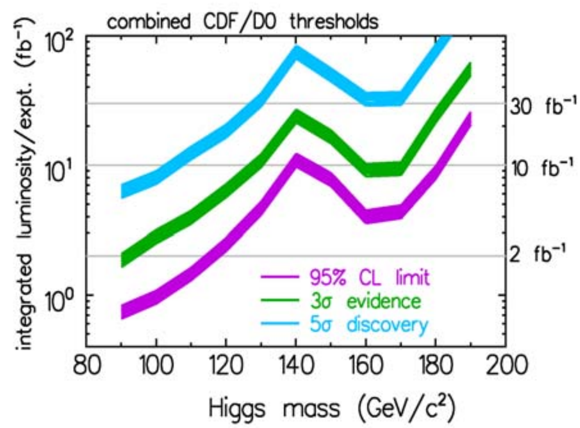

Figure 2

Figure 2 shows the projected combined sensitivity of the CDF and D0 Run II detectors for a Standard Model Higgs boson (M. Carena *et al.*, "Report of the Tevatron Higgs Working Group," (arXiv:hep-ph/0010338). With 10 fb^{-1} of integrated luminosity per detector, almost the entire Higgs mass range from 115 GeV to 200 GeV can be excluded at the 95% confidence level. With the same 10 fb^{-1}, a Higgs boson can be discovered at the 3-sigma level for the mass range 115 to 130 GeV, and in a higher mass window of 160 to 170 GeV. With 15 fb^{-1} of integrated luminosity, 5 sigma discovery and study of the Higgs boson properties become possible in the mass range near the LEP bound.

As noted by the recent HEPAP subpanel: "Discovery of the Higgs would be a revolutionary step for particle physics." In the lower part of Higgs mass range, the Tevatron experiments would observe the Higgs in *WH* and *ZH* associated production, channels which are very challenging for the LHC experiments.

Even non-observation of the Higgs in Run IIb would be a result of extreme importance. If the Higgs is not observed, 95% CL exclusion over the mass range required by the electroweak precision data would put the Standard Model in crisis. This is especially so since the Run II measurements of the *W* and top masses may tighten the precision electroweak constraints. If the Higgs is not observed, supersymmetry in the form of the MSSM will be excluded at the 95% CL or better over all but a tiny sliver of its parameter space.

While the Higgs search is not the only important physics opportunity for Run IIb, it is the one for which high-luminosity running is absolutely essential, since Higgs sensitivity begins for integrated luminosities above about 2 fb^{-1} per experiment, and requires a minimum of 10-15 fb^{-1} to accomplish the goals outlined above.

A Higgs search also makes stringent requirements on the performance of the D0 and CDF detectors. The Higgs search relies on the associated production channels *WH* and *ZH*, with the *W* decaying leptonically and the *Z* decaying to neutrinos. For Higgs mass less than 135 GeV, a Standard Model Higgs decays predominantly to $b\bar{b}$. The corresponding discovery signatures suffer from large backgrounds as a result of a variety of Standard Model processes. The detectors will need excellent *b*-tagging efficiencies (since the Higgs decays mostly to $b\bar{b}$), excellent $b\bar{b}$ dijet mass resolution (since the Higgs signal is on top of a large Standard Model background), excellent tracking capabilities (needed for the dijet mass resolution and to trigger on *WH* associated production), and excellent missing energy resolution (to detect *ZH* associated production where the *Z* decays to neutrinos). For Higgs mass greater than 135 GeV, the Higgs decays predominantly to WW^*, requiring sensitivity to dilepton channels.

All of these capabilities must be maintained in the context of the challenges of running at high luminosities. Triggering poses special challenges. The triggers must be highly efficient for the signal events, while maintaining strong rejection power against backgrounds and fakes, despite the high rates and high occupancies. In addition to a number of Higgs signal channels, the trigger menus must also allow the collection of data samples for calibration and for study of the irreducible Standard Model background processes.

The Committee notes that these same capabilities will allow CDF and D0 to explore other new physics targets that may be discovered in Run II. This is especially true for possible discoveries of super-partner particles, of new physics associated with top, and of evidence for extra spatial dimensions. While 2-4 fb^{-1} may well be enough integrated luminosity to make such discoveries, Run IIb will be essential to follow up and study the new physics, and to search for other new physics in related channels.

(B) Comments on the Run IIa and Run IIb Luminosity Programs and the Related Issue of Tevatron Bunch Spacing

1. Run IIa Progress and Plans

The Committee heard an update of progress and plans for accelerator operations in Run IIa. The Committee was encouraged by the substantial luminosity increases since its April meeting, and by recent improvements to reduce the antiproton emittance in the Accumulator. These include a new dual lattice, and a core cooling upgrade installed during the recent shutdown. The Committee commends the Beams Division for its aggressive response to the difficult Run IIa startup. The team now includes over 100 physicists and engineers.

Many challenges remain to meet the ambitious luminosity goals of Run IIa. The Committee heard plans for a sustained campaign, which will attack a number of accelerator performance issues in parallel. As part of this strategy, additional modifications of the Recycler, the Main Injector, and the Tevatron are planned for this year. The plan also includes integrating the Recycler into collider operations next year, with the goal of making antiproton recycling with electron cooling operational in 2004.

2. Run IIb Accelerator Upgrades

The Committee heard an update on the Run IIb accelerator upgrade project. Substantial progress has been made on electron cooling, to the extent that, as mentioned above, commissioning may occur during Run IIa. Progress has also been made on the antiproton target lithium lens, including a new collaboration with the University of Illinois. Other Run IIb projects are being delayed due to the diversion of key personnel to Run IIa activities. These delays jeopardize the Run IIb accelerator upgrades; this problem needs to be addressed as soon as possible.

In this regard, the Committee was encouraged by several recent examples of both Fermilab and outside physicists being recruited and integrated into Run IIa activities. The Committee encourages the Laboratory management to continue these efforts, and to expand them, where appropriate, to Run IIb projects.

3. Operation with 132 ns Bunch Spacing

The Committee received and heard a report concerning Tevatron operation with a bunch spacing of 132 ns. The Committee thanks David Finley and his panel for their report, which outlines a number of challenges of accelerator operation with a bunch spacing of 132 ns. An attractive alternative scheme of luminosity leveling with a bunch spacing of 396 ns was presented. If it works, the commissioning of the machine for Run IIb could be made simpler and faster.

The ultimate goal of Run II is to obtain the highest possible integrated luminosity under event pileup conditions that are acceptable to the experiments. The Run IIb detectors have been designed for a bunch spacing of 132 ns, and the decision on whether or not to operate in that mode does not need to taken immediately. In the meantime, the Beams Division and the two collaborations are encouraged to establish whether luminosity leveling and 396 ns operation can provide conditions that are acceptable to the experiments and maximize the integrated luminosity for Run IIb. Luminosity leveling should be tested during Run IIa.

(C) Run II Off-Line Computing

The Committee received the written report of the recent Run II Computing Review Committee and heard a summary presentation by Stephen Wolbers of the Computing Division (CD). The Committee congratulates the collaborations and CD on the successful completion of the Run IIa off-line computing project and the establishment of effective and timely processing of current data. The Committee notes the Review Committee's conclusion that the experiments' processing and storage needs can be met, at least initially, within the budgetary guidance of $2.5M per year per experiment.

Periodic reviews of off-line requirements by the Run II Computing Review Committee will be an important component of the Laboratory's continuing project management.

General Statement on Future Neutrino Program at Fermilab

Tremendous progress in neutrino physics during the past few years has led to a completely new paradigm. The old assumptions that neutrinos are massless and that lepton flavor is conserved have been overturned; neutrinos evidently do have mass, and the mass eigenstates are not diagonal in flavor, leading to oscillations. In analogy with the CKM matrix for quark flavor mixing, we have the MNS matrix $U_{\alpha i}$ for neutrinos:

$$\nu_\alpha = [\, U_{\alpha i} \,]\ \nu_i$$

where $\alpha = e, \mu, \tau$ are the flavor indices and $i = 1, 2, 3$ are the mass indices. It is informative to write this matrix as the product of three two-generation matrices,

$$U = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{+i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

where $c_{ij} = \cos\theta_{ij}$, $s_{ij} = \sin\theta_{ij}$ and θ_{ij} is the mixing angle.

Recent results from SNO using solar neutrinos, combined with all previous solar neutrino data, strongly favor a large mixing angle solution, $\theta_{12} \sim \pi/6$ and $m_2^{\ 2} - m_1^2 = +(2\text{-}10) \times 10^{-5}\ \text{eV}^2$ at 90% CL. In the next year this solution will be tested by KamLAND; if KamLAND confirms this result, they can improve the precision to better than $\pm 1 \times 10^{-5}\ \text{eV}^2$. The LSND experiment sees evidence for $\bar{\nu}_\mu \to \bar{\nu}_e$ oscillations at a much higher mass scale, $0.3 - 2\ \text{eV}^2$. The LSND result will be definitively tested by MiniBooNE, which will begin data-taking this summer.

Our best present knowledge for θ_{23} comes from atmospheric neutrino experiments, especially SuperKamiokande which favors maximal mixing, $\sin^2 2\theta_{23} \sim 1$ and $|\Delta m^2_{32}| = |m_3^{\ 2} - m_2^2| = (1.6 - 3.9) \times 10^{-3}\ \text{eV}^2$ at 90% CL. (Note that the sign of Δm^2_{32} is not determined.) The NuMI/MINOS experiment, expected to come on line in early 2005, will significantly improve the precision on these numbers.

In a striking analog to quark-flavor mixing, it appears that first-to-third generation mixing is suppressed in the neutrino sector. In contrast to the relatively large values favored for θ_{12} and θ_{23} , the best limits, from the Chooz experiment, indicate that $\sin^2 2\theta_{13} < 0.11$ (for $\Delta m^2_{32} = 2.5 \times 10^{-3}\ \text{eV}^2$). Chooz was a reactor experiment that searched for ν_e disappearance; a significant improvement of the Chooz limit will probably require a search for ν_e appearance in a ν_μ beam. NuMI/MINOS can improve these limits by approximately a factor of two. A future generation of neutrino experiments to measure $\sin^2 2\theta_{13}$ is now being formulated. Extensions of these experiments may be sensitive to matter effects, and hence be able to determine the sign of Δm^2_{32}. If $\sin^2 2\theta_{13}$ is not too small, it may also be possible to observe CP violation in the neutrino sector and measure its phase, δ. This is an especially tantalizing prospect.

The extended Fermilab community has been actively engaged in possibilities for future neutrino experiments for some time. The PAC believes that the question of future Fermilab experiments in neutrino physics is a timely one. This program naturally divides into two stages, an initial phase using the NuMI beam to measure or further constrain $\sin^2 2\theta_{13}$ and a second stage aimed at measuring CP violation and the sign of Δm^2_{32}, which would require a new Proton Driver.

The Committee was pleased to learn that a well-attended workshop on future neutrino experiments utilizing the NuMI beam was held at Fermilab in May. Prior to its June meeting, the Committee received a Letter of Intent for an experiment using the off-axis NuMI neutrino beam to search for $\nu_\mu \rightarrow \nu_e$ oscillations and measure or significantly constrain θ_{13}, an Expression of Interest for a near off-axis NuMI detector to measure neutrino cross sections and characterize the off-axis neutrino beam, and a report on "Physics Potential at FNAL with Stronger Proton Sources". The Committee is also aware of other LOIs or EOIs that are in preparation, as well as proposals to search for $\nu_\mu \rightarrow \nu_e$ oscillations using neutrino beams at Brookhaven, at the Japanese Hadron Facility (JHF), and at CERN.

Given the exciting recent results, the eagerly anticipated results from the present and near future program, and the worldwide interest in future experiments, it is clear that the field of neutrino physics is rapidly evolving. Fermilab is already well positioned to contribute through its investment in MiniBooNE and NuMI/MINOS. Beyond this, the significant investment made by the Laboratory in NuMI could be further exploited to play an important role in the elucidation of θ_{13} and the exciting possibility of observing CP violation in the neutrino sector. The Committee encourages the Laboratory to continue to engage with the neutrino community through workshops and colloquia in an ongoing exploration of the experimental possibilities utilizing Fermilab's unique resources. The Committee anticipates that the Laboratory may want to issue a Call for Proposals in a year or two if a compelling role for Fermilab is identified.

Specific Comments on Neutrino Program at Fermilab

Proton Economics

One of the most important constraints on the Laboratory's physics program is the availability of protons. The Committee received a briefing on this issue, which is referred to as "proton economics." This issue greatly affects the Laboratory's fixed-target program, although it is not presently a constraint on Run II Tevatron operations.

Discussed elsewhere is the fact that the NuMI beam will be capable of providing instantaneous flux that integrates to about 2.5×10^{20} protons/year. However, in addition to the machine limitations on the instantaneous flux there are limitations on total flux due to radiation. Thus, even if the per-pulse flux goals are met, the delivery of the desired integrated flux may not be possible.

The approved neutrino experiments, as well as any future uses of the NuMI and MiniBooNE beams, are in fact limited in total flux by the associated radiation dose. Increased shielding around the Booster has mitigated radiation-safety concerns to the point where the limiting factor is irradiation of the Booster itself. This limitation is at a level that has consequences for the planned program of neutrino experiments. Neither MiniBooNE nor MINOS will run at their anticipated intensities unless substantial progress is made toward reducing Booster losses and/or confining losses to non-sensitive components such as collimators.

These issues are a concern to the Committee, and the Committee was pleased to learn that work in these areas is underway. The Committee requests an update on progress.

Expression of Interest in Construction of an Off-Axis Near Detector to Measure Neutrino Cross Sections on Nuclear Targets in the Few GeV Region with the NuMI Beam (McFarland)

The Committee was presented with an Expression of Interest for a near off-axis detector in the NuMI beam. The physics goal for such an experiment would be the measurement of the charged-current and neutral-current neutrino cross sections and fluxes in the few GeV range as well as studies of particular detector configurations. Better knowledge of these quantities would reduce some sources of systematic errors in neutrino oscillation experiments.

The Committee is interested in the possibility of making such measurements as input for future electron-neutrino appearance experiments, but has a number of questions that need to be addressed in any future submissions:

1. How would this experiment determine neutrino fluxes and absolute neutrino cross sections, and to what precision can these quantities be determined independently?

2. The Committee would like to explore alternative sites for the measurement of these cross sections, which might be available before additional civil construction can be done in the NuMI tunnel. Please evaluate measurements with an active target detector

a) on-axis, just in front of the MINOS near detector;
b) using the Booster neutrino beam, either off-axis or on-axis;
c) off-axis from the JHF neutrino beam.

P-929 Letter of Intent to Build an Off-axis Detector to Study $\nu_\mu \rightarrow \nu_e$ Oscillations with the NuMI Neutrino Beam (Para)

The Committee thanks the proponents for their Letter of Intent for an experiment in the off-axis NuMI beam and appreciates this effort to flesh out an optimum experiment to measure θ_{13}. Such a measurement is the crucial next step towards the long-range goal of observing CP violation in neutrino oscillations. The Committee encourages continued discussion within the neutrino community on how best to achieve these ambitious goals. More detailed discussion of the off-axis experiment, which was also discussed in the proton-driver report, is given below.

Report on "Physics Potential at FNAL with Stronger Proton Sources"

The Committee thanks the authors for preparing this report, which provided a very useful reference and informed many of our discussions. The Committee believes that a Proton Driver offers a very interesting future physics program for the Laboratory. More detailed comments and questions regarding the potential for an off-axis detector to measure $\nu_\mu \rightarrow \nu_e$ oscillations are given below.

While the primary physics motivator for a proton Driver (PD) is neutrino physics, several other topics are mentioned in this and previous studies.

Since a permanent electric dipole moment (EDM) of any elementary particle or atom is a violation of T invariance (and P invariance), a discovery of one would have great consequence. The Standard Model prediction for the neutron EDM is 10^{-31} e-cm, well below the current experimental limit of 6.3×10^{-26} e-cm. Many extensions to the Standard Model enhance the expected value for the EDM of the neutron. The present limit on the neutron's EDM puts significant constraints on the parameter space of supersymmetric models. In addition, some models of baryogenesis (e.g., electroweak baryogenesis in the MSSM) also predict an enhanced neutron EDM, within two orders of magnitude of the current limit. The PD physics study suggests that an EDM search using a long-pulse high-intensity neutron source could lower existing limits on the neutron EDM by three orders of magnitude. The Committee finds this physics compelling.

The Committee notes that other high intensity neutron sources exist or are planned, PSI and SNS for example. At these and other facilities EDM measurements can be made with sensitivities that approach those predicted by the PD study. If neutron EDM is to be a significant physics motivator for a PD, a detailed comparison with other proposed experiments should be completed.

A second interesting application for an intense cold neutron beam is the search for neutron-antineutron oscillations. The limit on this process constrains models with B but not L violation, for example, R-parity violating supersymmetry.

An additional physics motivator in the PD study is a precision test of CPT. The study notes that the antiproton decelerator at CERN will be abandoned, leaving a physics opportunity for Fermilab. Clearly more work is needed on the prospects and relative merits of possible CPT tests with a PD.

The Committee notes that the above precision measurements are difficult and require lengthy and dedicated efforts. If these are to be a motivation for the Proton Driver, groups need to be identified that would be interested in carrying out these long-term programs.

Issues for Off-Axis Neutrino Oscillation Experiments

As has already been discussed, the next important problem in the study of neutrino mixing is to measure θ_{13}. It is especially interesting to search for θ_{13} in the parameter range within about a factor of 10 below the Chooz limit, because this is the region in which it may be feasible to detect CP violation in neutrino mixing with conventional ν_μ beams without having to build a muon storage ring.

However, the Committee notes that the measurement of θ_{13} in an off-axis experiment using the currently planned NuMI beam with 2.5×10^{20} protons/year is very challenging. For example, a 20 kton experiment would only observe 1 signal event per year if $\sin^2 2\theta_{13} = 0.01$, and a comparable number of background events.

The total number of protons available to NuMI is an important constraint on this program. The near-term program in the proton driver report assumed that the total number of protons delivered to NuMI would be 20×10^{20} for a five-year program. However, the current accelerator complex can only provide 2.5×10^{20} protons/year in dedicated running for NuMI. The proton driver report states that this level could be raised to 4×10^{20} protons/year with a modest program of accelerator improvements. The Committee would appreciate a report at the fall PAC meeting from the Beams Division on the Proton Driver project and on possible adiabatic accelerator improvements, including more detailed cost estimates. The Committee also suggests that the Laboratory issue guidance on the maximum proton flux that could be available to NuMI without replacing the Booster.

To help the PAC evaluate the prospects for an off-axis experiment, the Committee would appreciate answers to the following questions, which need to be addressed in any future submissions:

1. Can one confidently pick a location of the off-axis experiment today? What is the flexibility in optimizing the location of the detector once Δm^2_{23} is known better?
2. What is the optimum detector technology, for a fixed cost, to measure θ_{13}?
3. What is the discovery reach (as well as the 90%CL limit) in θ_{13} and the achievable precision in such a measurement?
4. What supporting measurements are critical to understand the background? In particular, can the nature and magnitude of all important backgrounds be determined experimentally?
5. If the MINOS on-axis near detector is the only one available to characterize the beam, how well can the flux at the off-axis far detector be understood?
6. How does the detector proposed fit into a longer term program to measure CP violation? Should one adopt in the first stage the technology most appropriate for the later stages?
7. In view of the low signal rates, how significant are the cosmic-ray backgrounds, and is it convincing that the detector can be on or near the surface? Is there other compelling physics that an underground version of the same detector could do?
8. Are there other important measurements that a 20 kton detector optimized for electron ID could perform?

The Committee understands that an off-axis NuMI experiment would be complementary, in its sensitivity to matter and CP violation effects, to other proposed experiments utilizing different baselines and/or neutrino energies. The Committee would like to understand whether there are unique or complementary aspects for the first phase NuMI experiment to measure θ_{13}. More generally, as the scale of neutrino mixing experiments increases, the Committee encourages the members of the Fermilab neutrino community to plan globally in collaboration with other laboratories.

Linear Collider Topics

The Committee commends the Laboratory's work already done in Linear Collider (LC) accelerator R&D, and in physics and detector studies. In parallel, a significant grassroots effort has begun within the broader Fermilab community which has already resulted in significant participation by university groups and two EOIs on LC detector and machine R&D with over 100 signatories combined. Fermilab plays an important role in this broader effort as host and coordinator and the Committee commends the Laboratory for its contributions to the broader program.

At this meeting the Committee heard a presentation on the status of LC machine R&D at Fermilab. Due to a funding cap of $3M/year, the Laboratory has concentrated on a small number of projects. Tasks appear to be well coordinated between Fermilab and the many universities and laboratories involved in LC accelerator projects. Within the Laboratory, both Beams and Technical divisions are involved. However the effort remains subcritical in scope.

If the Linear Collider project is to be the future of Fermilab, the Laboratory must pursue it aggressively. This requires a substantial R&D program at the Laboratory. It is important to point out that this program cannot be carried out under the current $3M/year cap on spending on Linear Collider R&D. It is imperative that this cap be lifted. The Committee fully supports efforts of the Laboratory management in this direction.

The Committee recommends three specific steps that the Laboratory should take as soon as possible:

First, the Laboratory must increase its effort on Linear Collider R&D. At present, the Laboratory is a member of the NLC and TESLA collaborations. The Laboratory is engaged in the industrialization of the manufacture of accelerating structures for the NLC, general site studies, the design of permanent magnets, photoinjectors, superconducting cavities and estimates of LC costs. If the Laboratory is to compete to be chosen as the site for the accelerator, it needs a much broader program. The Laboratory must raise the level of its expertise in RF technology, preferably in both the X-band and the superconducting technologies which are the alternatives for the 500 GeV Linear Collider. The Laboratory should improve its capabilities in accelerator simulation and automatic control.

Second, the Laboratory should set up an organization that will give staff members the ability to contribute to the Linear Collider R&D programs both in accelerator technology and in physics and detectors. In the Committee's opinion, this requires Laboratory programs in these two areas, with staff members associated with each as their primary research responsibility. The Committee also encourages members of the Laboratory staff to look into part-time participation in the Linear Collider activities.

Third, the Laboratory should strongly support the initiative for university-based R&D on LC accelerator and detector technology outlined in the recent EOIs. The Laboratory should provide both intellectual and engineering support to university researchers. The staff members associated with the LC R&D program can serve as liaisons to outside groups working in this area. The Laboratory can also provide logistical support, in organizing meetings and facilitating collaborations between universities. The Laboratory should look for synergy between university projects on Linear Collider instrumentation and beam instrumentation projects that might be helpful for the Tevatron Run II. The Laboratory should also support and expand the existing educational programs on the physics and technology of Linear Colliders that will be helpful to university physicists in beginning new efforts in this field.