Fermilab

July 10, 2002

Adam Para
MS 220

Dear Adam,

The Fermilab Physics Advisory Committee considered the Letter of Intent to Build an Off-axis Detector to Study $\nu_\mu \rightarrow \nu_e$ Oscillations with the NuMI Neutrino Beam (P-929) at its June meeting in Aspen CO. This stimulated a broad discussion of neutrino physics potential at Fermilab. Following are the Committee's comments on the neutrino program in general:

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 $m_2^2 - m_1^2 = +(2\text{-}10) \times 10^{-5}\ eV^2$ 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 $\pm 1 \times 10^{-5}\ eV^2$. The LSND experiment sees evidence for $\overline{\nu}_\mu \rightarrow \overline{\nu}_e$ oscillations at a much higher mass scale, $0.3 - 2\ eV^2$. 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 $|\Delta m^2_{32}| = |m_3{}^2 - m_2{}^2| = (1.6 - 3.9) \times 10^{-3}$ 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 $\Delta m^2_{32} = 2.5 \times 10^{-3}$ 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.

In addition, the Committee had the following comments specific to your Letter of Intent:

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.

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. Both the LOI and 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.

I agree with the PAC's comments that Fermilab could be a focal point for future neutrino experiments and, indeed, an ongoing healthy neutrino program would be very natural given the investments in the Main Injector and the NuMI Project. We appreciate the initiative taken by you and your collaborators. Through this letter, I would like to encourage a vigorous and broad exploration of this potential with a view to eventual convergence on a broadly supported proposal. To this end, we envisage supporting/sponsoring one or two workshops over the next twelve months.

Finally, while not all the signatories of the Letter of Intent are MINOS collaborators, it is important to recognize that the overarching prerequisite for a strong, long-baseline and long-term neutrino program at Fermilab is the successful mounting and completion of the NuMI/MINOS project which deserves the unstinting effort of all.

Sincerely,

Michael Witherell

cc: K. Stanfield
M. Shaevitz

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