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Future of Neutrino Program at FNAL

NuMI Off-Axis Meeting

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January 12, 2004

Neutrino Oscillations

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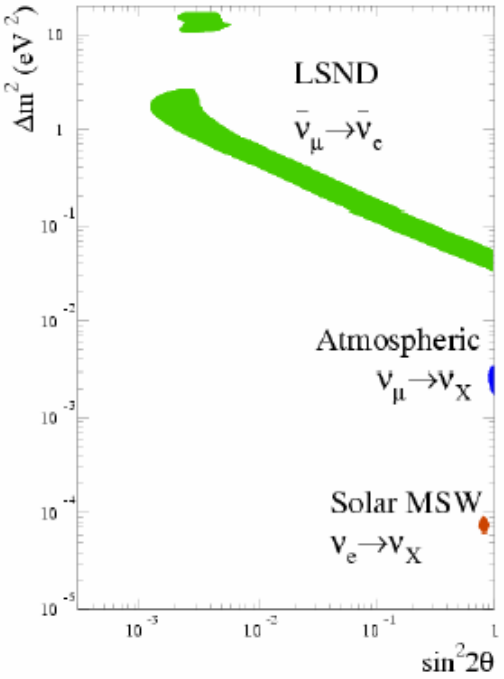
Current State of Neutrino Oscillation Evidence



Expt.	Type	Δm^2 (eV^2)	$\sin^2 2\theta$
LSND	$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$	~1	~3×10^{-3}
Atm.	$\nu_\mu \rightarrow \nu_\tau$	~2×10^{-3}	~1
Solar	$\nu_e \rightarrow \nu_{\mu,\tau}$	~7×10^{-5}	~0.8

MiniBooNE

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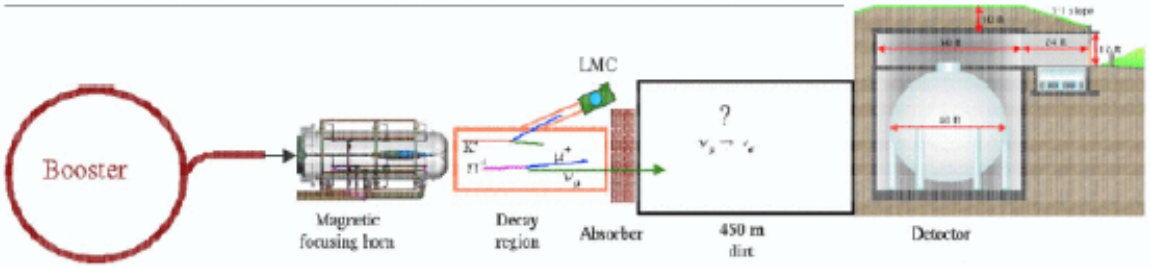
MiniBooNE - A Definitive Test of the LSND Evidence for ν Oscillations



- Booster - 8 GeV proton beam (5 x 10^{20} POT/y)
- Target - 71 cm Be
- Horn - 5 Hz, 170 kA, 143 μs, 2.5 kV, 10^8 pulses/y
- Decay Pipe - 50 m (adjustable to 25 m)
- Neutrino Distance - ~ 0.5 km
- $\langle E_\nu \rangle$ ~ 1 GeV
- (ν_e / ν_μ) ~ 3×10^{-3}
- Detector - 40' diameter spherical tank
- Mass - 800 (450) tons of mineral oil
- PMTs - 1280 detector + 240 veto, 8" diameter

MiniBooNE

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- First event September 2002
- Neutrino Beam operates well
- Neutrinos per proton as expected
- Events match Monte Carlo
- Currently > 1.6 10^{20} pot
- Limitation is from Booster losses and the Booster is key for all of the FNAL program.
- Potential for improvement is in place.
- Commitment to 5 10^{20} pot
- Goal is more through to NuMI start-up

Coverage of LSND

1×10^{21} POT: →

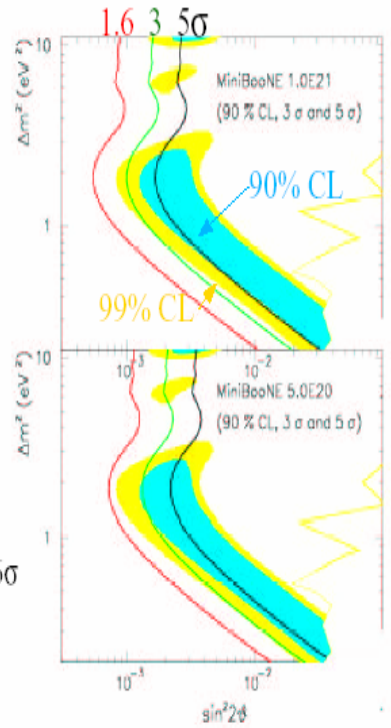
Good coverage:

90% LSND allowed at > 4σ

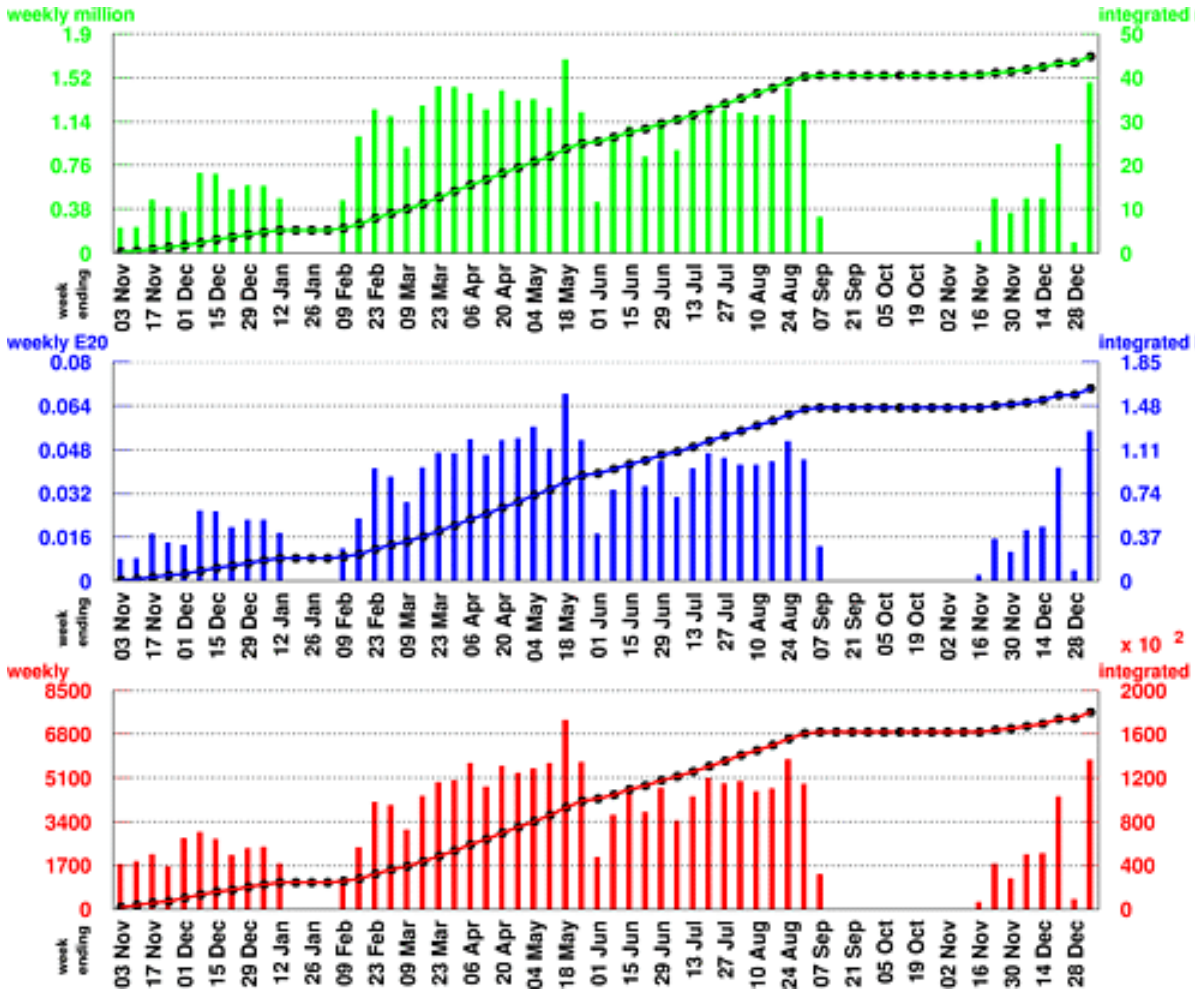
5×10^{20} POT: →

90% CL LSND @ ~3σ

Only just covers at LSND 99% CL at <1.6σ



MiniBooNE Operations



Number of Horn Pulses

To date: 44.89 million

Largest week: 1.68 million

Latest week: 1.47 million

Number of Protons on Target

To date: 1.629 E20

Largest week: 0.0682 E20

Latest week: 0.0546 E20

Number of Neutrino Events

To date: 179918

Largest week: 7334

Latest week: 5794

Status of the NuMI/MINOS Project

- **Tunnels and Halls construction finished**
- **Surface Buildings and Outfitting construction-finish February 2004**
- **MINOS far detector installed and operating**
- **Cosmic ray data taking**
- **Serious risk of being ready for beam in about 1 year**

NuMI/Minos Project

NuMI/Minos Project

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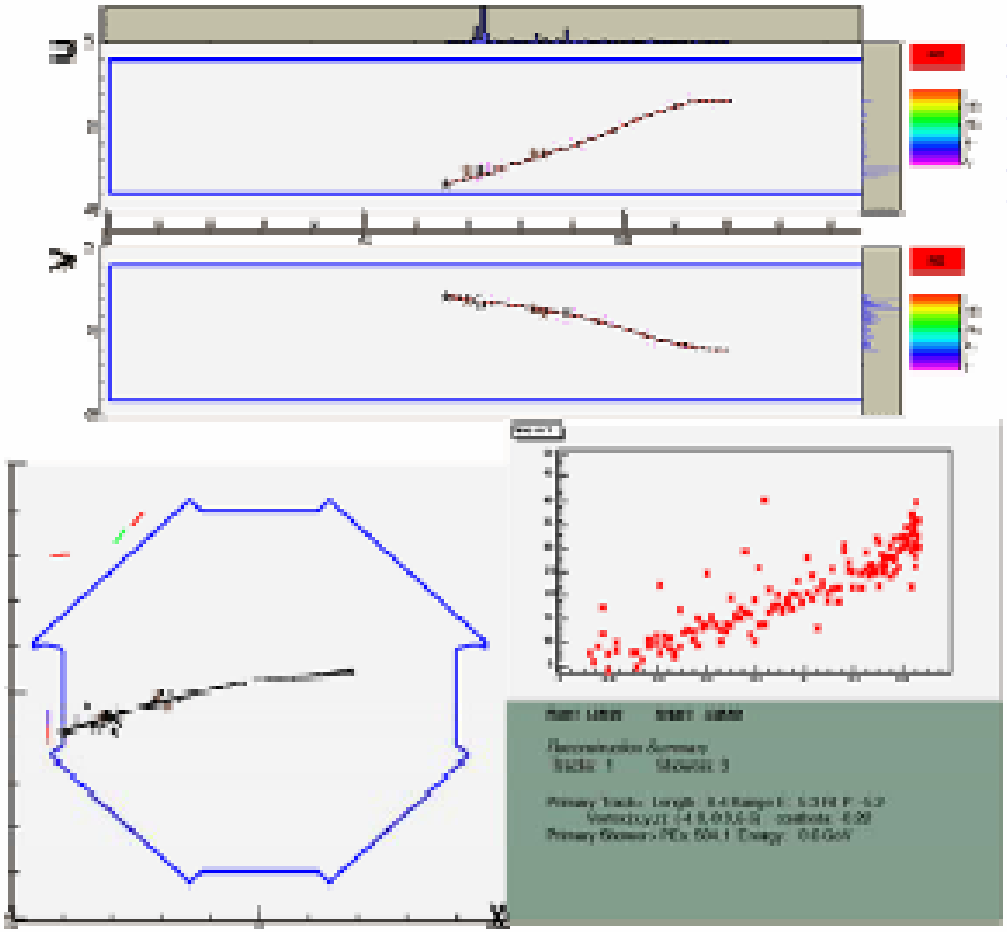

MINOS is the first large underground detector which has a magnetic field

We can directly compare whether atmospheric ν_μ and ν_μ oscillate in the same way.

Example Upward Muon

$p_{\mu+} = 5.3$ GeV/c

Fermilab PAC November 2002

2:00 - 2:20	Letter of Intent to Build an Off-Axis Detector to Study $\nu_\mu \rightarrow \nu_e$ Oscillations with the NuMI Neutrino Beam (A. Para)
2:30 - 2:50	Detector R&D for Future Experiments with the NuMI Beamline (D. Harris)
3:00 - 3:20	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 (K. McFarland)
3:30 - 3:45	Break
3:45 - 4:05	Expression of Interest to Perform a High-Statistics Neutrino Scattering Experiment Using a Fine-Grained Detector in the NuMI Beam (J. Morfin)
4:15 - 4:35	Expression of Interest: Physics with a Near Detector on the Booster Neutrino Beamline (B. Fleming/R. Tayloe)

PAC June 2002: P-929

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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.

PAC June 2002

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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.

Fermilab PAC, June 2002: Neutrino Initiatives

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

Fermilab PAC, December 2003

Neutrino Physics

Neutrino physics is an important component of the Laboratory's program, and its importance is likely to grow in the future. The NuMI/MINOS program is the highest priority after Run II. The Laboratory is currently going through a long-range planning process, and the Committee eagerly awaits its report. Any discussion of neutrino physics at the Laboratory should be consistent with the long-range plan. Moreover, future neutrino physics experiments will require high intensity proton beams, and the possible reach of and costs associated with the necessary improvement of the accelerator complex are not known at this moment. Recommendations in this report are made in this context.

DOE Office of Science: Facilities 20 yr Plan

Priority: Tie for 21
Super Neutrino Beam

The Facility: The Super Neutrino Beam will allow more comprehensive studies of neutrino properties by producing a neutrino beam 10 times more intense than those available with current accelerators.

Background: Neutrinos are the most poorly understood of the elementary particles but may be the most important for answering fundamental questions ranging from why there is any matter in the universe at all, to how all particles and forces in the universe "unify" into a simple picture. Because neutrinos rarely interact with matter (many billions pass through each of us every second), the ability to generate controlled beams containing large numbers of neutrinos greatly increases the ability to study them.

What's New: The Super Neutrino Beam will be powered by a new, megawatt class "proton driver" which will be able to provide an intense, well-controlled neutrino beam—with 10 times more neutrinos per second than are available from any existing facility—to detectors hundreds or thousands of miles distant.

Applications: The 2002 Nobel Prize in physics was shared by two scientists—one American and one Japanese—for their path-breaking measurements of solar and atmospheric neutrinos. Their research strongly suggested that neutrinos have mass and oscillate among three types as they travel through space. These oscillations have recently been confirmed, and the properties and behavior of neutrinos are now ripe for measurement. The results will have profound implications for our understanding of the fundamental properties of matter and the evolution of the early universe.

The Super Neutrino Beam will provide 10 times more neutrinos per second than any existing facility—to detectors hundreds or thousands of miles away. This new facility will build on current experiments such as the KEK to Kamiokande (K2K) long baseline neutrino oscillation experiment in Japan, shown above, which sends neutrinos along a beamline from KEK (High Energy Accelerator Research Organization) to the Super Kamiokande detector 250 km (~155 miles) away.

(From) Charge to the FNAL Long Range Planning Committee

- I would like the Long-range Planning Committee to develop in detail a few realistically achievable options for the Fermilab program in the next decade under each possible outcome for the linear collider. The goal in developing each option should be to optimize the opportunities available at Fermilab in this period for high energy physicists to answer the most important questions in our field. The options should be guided by the priorities for the field as laid out in the HEPAP Subpanel and in the HEPAP response to the Office of Science on the facilities plan.
- The committee should develop scenarios for each of the two cases spelled out by the HEPAP Subpanel.
  - A linear collider project will be built here, starting late in this decade with international support and organization.
  - The linear collider will be built offshore with substantial participation from U.S. High Energy Physics.
- In either case, you should make the following additional assumptions.
  - Fermilab will have a central role in an active U.S. research program at the LHC, both as host of the US-CMS collaboration and as developer of accelerator upgrade plans.
  - Fermilab will carry out the presently approved program of experiments following approval from the national program.

Neutrino Open Session

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- Issues in Neutrino Physics — S. Parke
- Off-Axis Experiment — G. Feldman
- Reactor Experiment — J. Link
- Neutrino Factory — S. Geer

- Prospects if MiniBooNE Has a Positive Signal — B. Kayser
- Non-Oscillation Physics — K. McFarland
- Proto-Recommendations — G. Feldman

Neutrinos - Long Baseline proto-recommendations

- That Fermilab proceed with the Off-Axis experiment as part of a step-by-step program to eventually measure all of the neutrino mixing parameters.
- That Fermilab proceed with the construction of a proton driver to provide a 2 MW 120 GeV beam.
- There will be other recommendations concerning Neutrino Factory work and possibly about the off-site reactor initiative.

Proton Driver (Peter Meyers)

- **Primary motivation is the Long Baseline Neutrino Program**
- **Proton Driver could support a broad physics program of its own**
  - **Two Fermilab studies**
  - **Short-baseline neutrino oscillation**
    - **if MiniBooNE confirms LSND**
    - **multiple sterile neutrinos?**
  - **Low-energy neutron source**
    - **optimize for elementary particle physics**
  - **Low-energy muon source**
- **Head-start for bigger projects?**
  - **SC Linac a warm-up (cool-down?) for LC**
  - **Neutrino Factory R&D/source**

Neutrinos and Fermilab

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- **Fermilab is operating a neutrino oscillation program NOW**
- **NuMI/MINOS Operations should start in about 1 Year**
- **The Fermilab PAC considers that the future possibilities for neutrino physics at Fermilab are interesting**
- **The Office of Science Facilities Report has "Neutrino-Superbeams as a recommended component.**
- **The Fermilab long range planning committee will feature neutrinos as a major component of the future physics program.**
- **Based on the physics of neutrinos, Fermilab will explore building a "Proton Driver" to provide "super-beam" capability.**
- **We would like to provide a coherent FNAL "white paper" as input to the "Freedman-Kayser" APS study.**
- **We are here.**