LA-UR- 04-0704

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Title: NEAR FUTURE ACCELERATOR-BASED EXPERIMENTS

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Submitted to: 5th International Workshop on Neutrino Factories & Superbeams
Columbia University, New York, NY
June 5-11, 2003

Near Future Accelerator-Based Experiments

December 3, 2003

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1. Introduction

This report covers accelerator-based neutrino oscillation experiments that will be conducted in the near future. The first section discusses the current state of neutrino oscillation evidence coming from solar experiments [1,2,3,4,5,6], atmospheric experiments [7,8,9], and the LSND experiment [10], and shows that, taken at face value, these experiments imply physics beyond the Standard Model, such as lepton number violating muon decay [11], light, sterile neutrinos [12], or CPT violation [13]. The next sections describe, in chronological order, the MiniBooNE short-baseline experiment at FNAL, the MINOS long-baseline experiment at FNAL/SOUDAN, and the OPERA and ICARUS long-baseline experiments at CERN/Gran Sasso. The results from these experiments will help provide answers to fundamental questions, such as: (i) What is the resolution of the $3-\Delta m^2$ paradox? (ii) What are the neutrino masses and hierarchy? (iii) What are the neutrino mixings? (iv) Do light, sterile neutrinos exist? (v) Is CP conserved in the neutrino sector? (vi) Is CPT conserved in the neutrino sector? and (vii) Are neutrinos Dirac or Majorana?

2. Current State of Neutrino Oscillation Evidence

Fig. 1 displays the current state of neutrino oscillation evidence coming from the solar experiments [1,2,3,4,5,6], the atmospheric experiments [7,8,9], and the LSND experiment [10]. As shown in Table 1, the solar and atmospheric experiments observe large mixing at relatively low Δm^2 values, while the LSND experiment observes small mixing at relatively high Δm^2 values. If all of these experiments are correct, then, taken at face value, they imply physics beyond the Standard Model because it is not possible to explain such disparate Δm^2 regions with only three neutrinos. Examples of such beyond the Standard Model physics include: (i) lepton number violating muon decay ($\mu^+ \to e^+ \bar{\nu}_\mu \bar{\nu}_i$), which will be tested by the TWIST experiment at TRIUMF [11]; (ii) light, sterile neutrinos, which could have a huge impact on astrophysics in terms of BBN, the r-process in supernovae neutrino bursts, cold dark matter, and possibly even dark energy [12]; and (iii) CPT violation, which is motivated by theories of extra dimensions and has the potential to explain the baryon asymmetry of the universe [13].

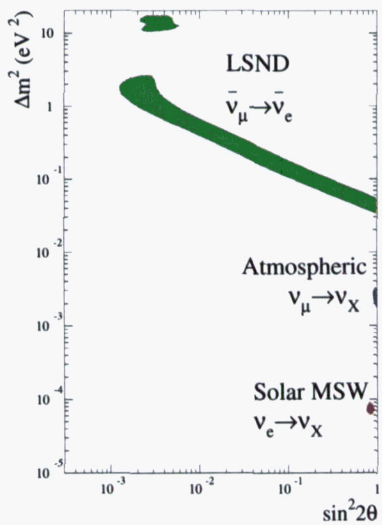

Figure 1: The current state of neutrino oscillation evidence coming from the solar experiments, the atmospheric experiments, and the LSND experiment.

Table 1: The current state of neutrino oscillation evidence coming from the solar experiments, the atmospheric experiments, and the LSND experiment.

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

3. The MiniBooNE Experiment at FNAL

A schematic drawing of the MiniBooNE experiment is shown in Fig. 2. MiniBooNE is fed by the 8-GeV protons from the Booster, which at full intensity will deliver approximately 5×10^{20} protons on target (POT) per year. The protons interact in a 71-cm long Be target located at the upstream end of a magnetic focusing horn. The horn pulses at 5 Hz (10^8 pulses per year), operates at a current of 170 kA and a voltage of 2.5 kV, and focuses the pions and kaons from the proton-Be interactions. (The horn can be operated at either positive polarity for neutrino running or negative polarity for antineutrino running.) The pions and kaons decay into neutrinos in a 50-m decay pipe located just downstream of the horn, and the neutrinos then pass through the detector tank positioned 500 m downstream of the decay pipe. The average neutrino energy is approximately 1 GeV, and the intrinsic ν_e background is

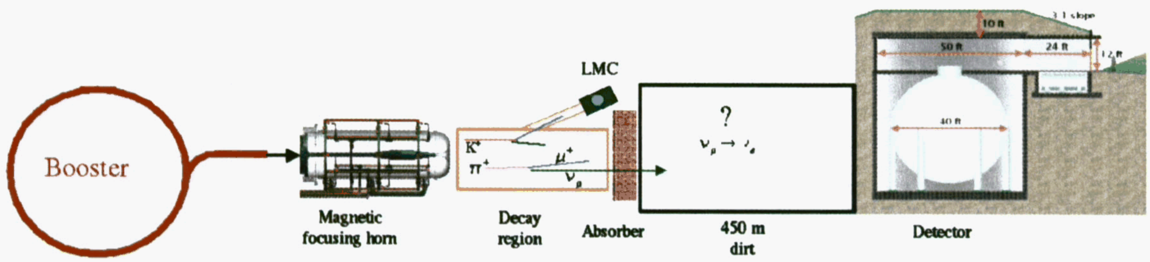

Figure 2: A schematic drawing of the MiniBooNE experiment.

about 0.4% of the primary ν_μ flux. The detector consists of a 40-ft diameter spherical tank filled with 800 tons of mineral oil (450 ton fiducial volume) and covered on the inside by 1520 8-inch phototubes (1280 detector phototubes and 240 veto phototubes). After 2 full years of data collection (10^{21} POT), MiniBooNE will be able to fully cover the entire LSND allowed region, as shown in Fig. 3.

After the first year of operation, MiniBooNE has collected about 162 K neutrino events, corresponding to 1.5×10^{20} POT (or about 30% of the yearly goal of 5×10^{20} POT.) The detector is working well with 99% of the phototube channels operational and a data acquisition livetime of about 99%. The time, charge, position, and angular resolutions, as well as the neutrino event rate, are consistent with expectations. Finally, the detector is clearly reconstructing charge-current μ^- events, neutral-current elastic events, and neutral-current π^0 events. Fig. 4 shows the π^0 mass distribution after requiring > 40 MeV per ring. The mass and width of the π^0 peak are consistent with expectations. Neutrino oscillation results are expected by the summer of 2005.

4. The MINOS Experiment at FNAL/Soudan

The MINOS experiment will be a definitive test of the atmospheric neutrino oscillation results and will be capable of making a precision measurement of the oscillation parameters, including a possible determination of θ_{13}. Neutrinos are produced by the 120-GeV protons from the Main Injector interacting in a 1-m long segmented graphite target, followed by a two horn focusing system and a 675 m long decay tunnel. The average neutrino energy can be varied from 3 GeV to 18 GeV by adjusting the locations of the two horns, and MINOS will start with the low-energy horn configuration. The intrinsic ν_e component in the neutrino beam is $< 1\%$. MINOS consists of two detectors, both consisting of a magnetized toroid and plastic scintillator strips. The near detector is located on site at FNAL at a distance of ~ 1 km from the neutrino source and has a mass of 1 kton, while the far detector, shown in Fig. 5, is located in the Soudan mine in northern Minnesota at a distance of 735 km and has a mass of 5.4 ktons. Both detectors have an energy resolution of $\sim 60\%/\sqrt{E}$ for hadronic energy and $\sim 25\%/\sqrt{E}$ for electromagnetic energy. Fig. 6 shows the measurement of oscillations in MINOS for $\nu_\mu \rightarrow \nu_\tau$ oscillation parameters of $\Delta m^2 = 0.0025$ eV^2 and

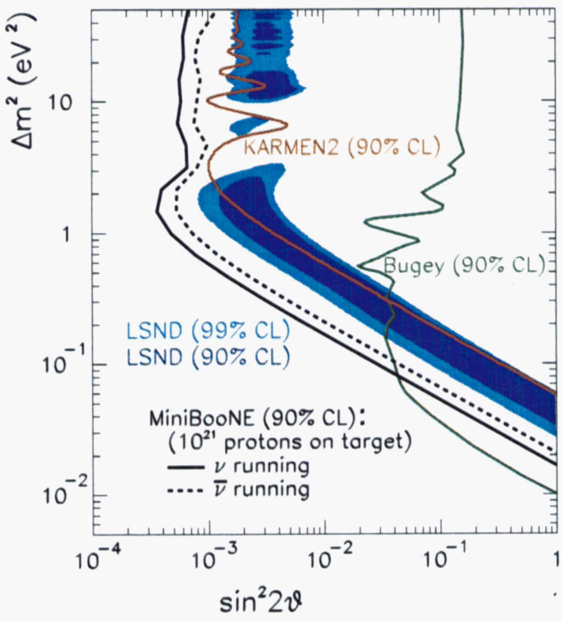

Figure 3: The expected MiniBooNE sensitivity after two full years of data collection.

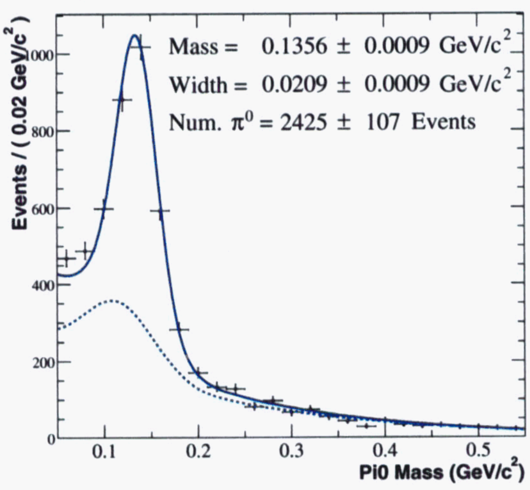

Figure 4: The π^0 mass distribution after requiring > 40 MeV per ring. The mass and width of the π^0 peak are consistent with expectations.

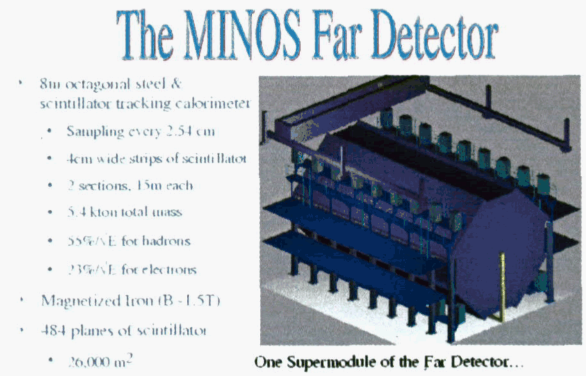

Figure 5: A schematic drawing of the MINOS far detector, located in the Soudan mine in northern Minnesota.

$\sin^2 2\theta = 1.0$. Finally, MINOS will have a θ_{13} sensitivity of < 7.1 degrees.

Construction of the MINOS far detector is complete, and the detector has begun making the world's first measurement of atmospheric ν_μ and $\bar{\nu}_\mu$ interactions separately. Construction of the NuMI beamline is nearing completion. The tunnel excavation is complete, and the outfitting and final civil construction is on schedule. First protons on target are planned for December 2004, and MINOS should be fully operational by September 2005.

5. OPERA and ICARUS at CERN/Gran Sasso

The OPERA and ICARUS experiments are both designed to be a definitive test of atmospheric $\nu_\mu \rightarrow \nu_\tau$ oscillations and ν_τ appearance. The experiments are located in the Gran Sasso underground laboratory and will detect neutrinos produced by the CNGS beam at CERN. The CNGS beamline, shown in Fig. 7, is fed by the 400 GeV protons from the SPS, which should be able to supply 4.5×10^{19} POT/y. The protons interact in a target made of graphite rods, and downstream of the target are magnetic focusing horns and a decay volume. The average neutrino energy is 17 GeV, the distance from CERN to Gran Sasso is 732 km, and the intrinsic ν_e background is $\sim 8 \times 10^{-3}$. First beam to Gran Sasso is scheduled for May 2006.

The OPERA experiment, shown in Fig. 8, consists of 1.8 ktons of emulsion interleaved with Pb plates. There are a total of 206,336 bricks, where each brick consists of 56 emulsion and PB layers. The detector lies in a 1.6 T magnetic field transverse to the neutrino beam, and an electronic target tracker determines the locations of neutrino events, so that candidate bricks can be removed for subsequent analysis. The energy resolution of the detector is $\sim 40\%/\sqrt{E}$, and the efficiency for neutrino oscillation events is $\sim 9.1\%$. After 5 years of data collection, OPERA should

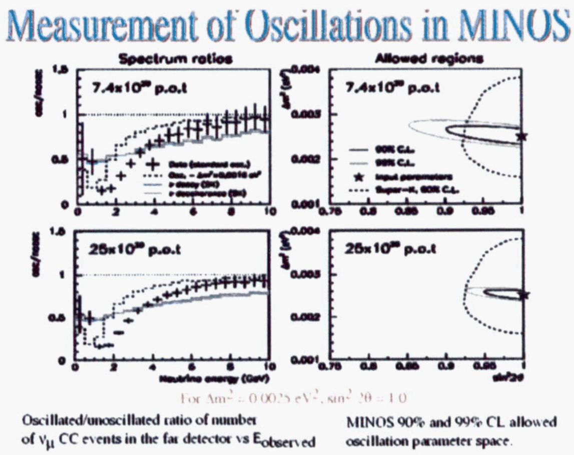

Figure 6: The measurement of oscillations in MINOS for $\nu_\mu \to \nu_\tau$ oscillation parameters of $\Delta m^2 = 0.0025$ eV^2 and $\sin^2 2\theta = 1.0$.

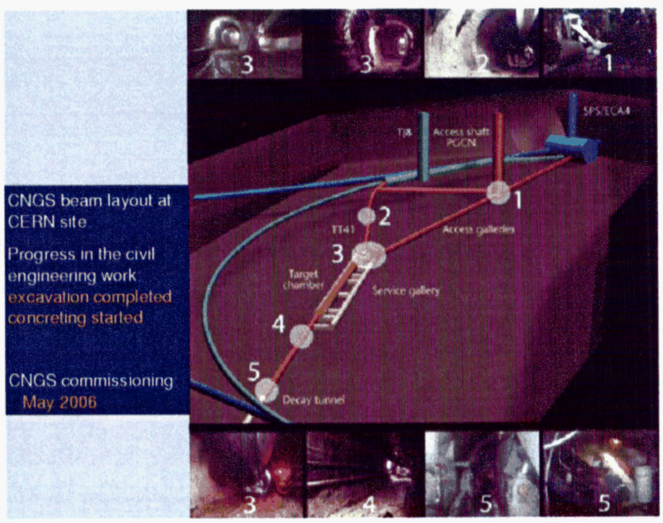

Figure 7: A schematic drawing of the CNGS beamline.

OPERA

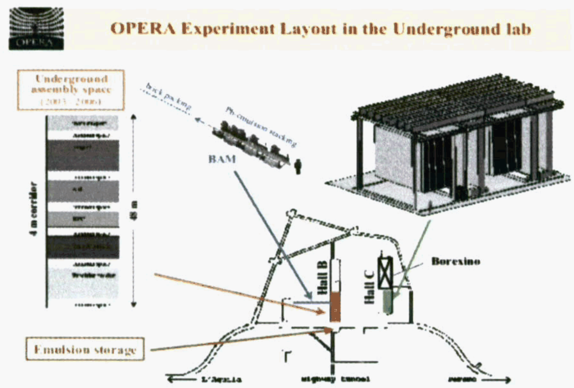

Figure 8: A schematic drawing of the OPERA detector, consisting of 1.8 ktons of emulsion interleaved with Pb plates.

be able to observe a signal of 19.8 clean ν_τ events (for $\nu_\mu \rightarrow \nu_\tau$ oscillation parameters of $\Delta m^2 = 2.5 \times 10^{-3}$ eV^2 and $\sin^2 2\theta = 1.0$) on top of a background of only 0.67 events. Furthermore, OPERA will have a θ_{13} sensitivity of < 7.1 degrees, which is similar to MINOS.

A schematic drawing of the ICARUS detector is shown in Fig. 9. ICARUS is a 3 kton liquid Ar TPC, consisting of ten 300-ton half-modules. Each half module is a $4 \times 4 \times 20$ m^3 cryostat. The expected momentum resolution is $\sim 20\%$ at 10 GeV, and the expected efficiency for oscillation events is about 5.9%. After 5 years of data collection, ICARUS should observe an oscillation signal of 11.9 events (for oscillation parameters of $\Delta m^2 = 2.5 \times 10^{-3}$ eV^2 and $\sin^2 2\theta = 1.0$) on top of a background of only 0.7 events. In addition, ICARUS will have an excellent θ_{13} sensitivity of < 5.8 degrees.

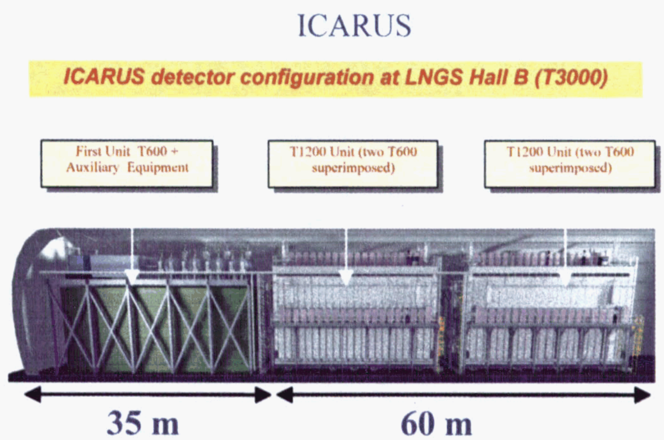

Figure 9: A schematic drawing of the ICARUS detector, consisting of a 3 kton liquid Ar TPC.

6. Conclusions

This report summarizes the accelerator-based neutrino experiments that are planned for the near future: MiniBooNE, MINOS, OPERA, and ICARUS. The MiniBooNE experiment at Fermilab will be a definitive test of the LSND oscillation evidence, and if it confirms LSND, it will be able to probe new physics beyond the Standard Model. The MINOS experiment at Fermilab and Soudan will be a definitive test of the atmospheric oscillation evidence and will be capable of making precision measurements of the oscillation parameters. Finally, the OPERA and ICARUS experiments at CERN/Gran Sasso will be a definitive test of atmospheric $\nu_\mu \to \nu_\tau$ oscillations and will be capable of measuring ν_τ appearance. We can confidently conclude that the results from these experiments will lead to a rich program at a future Neutrino Factory.

7. References

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