Proposal to Build an Off-Axis Detector to Study $\nu_\mu \rightarrow \nu_e$ Oscillations in the NuMI Beamline

NOνA

NuMI Off-Axis ν_e Appearance Experiment

(P929)

Fermilab PAC

12 December 2003

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Name

- In Spanish and Italian, no va = it does not go
- In Latin, nova = new, fresh, young, novel, or extraordinary
- In English and most other languages, nova = a star that has become suddenly brighter

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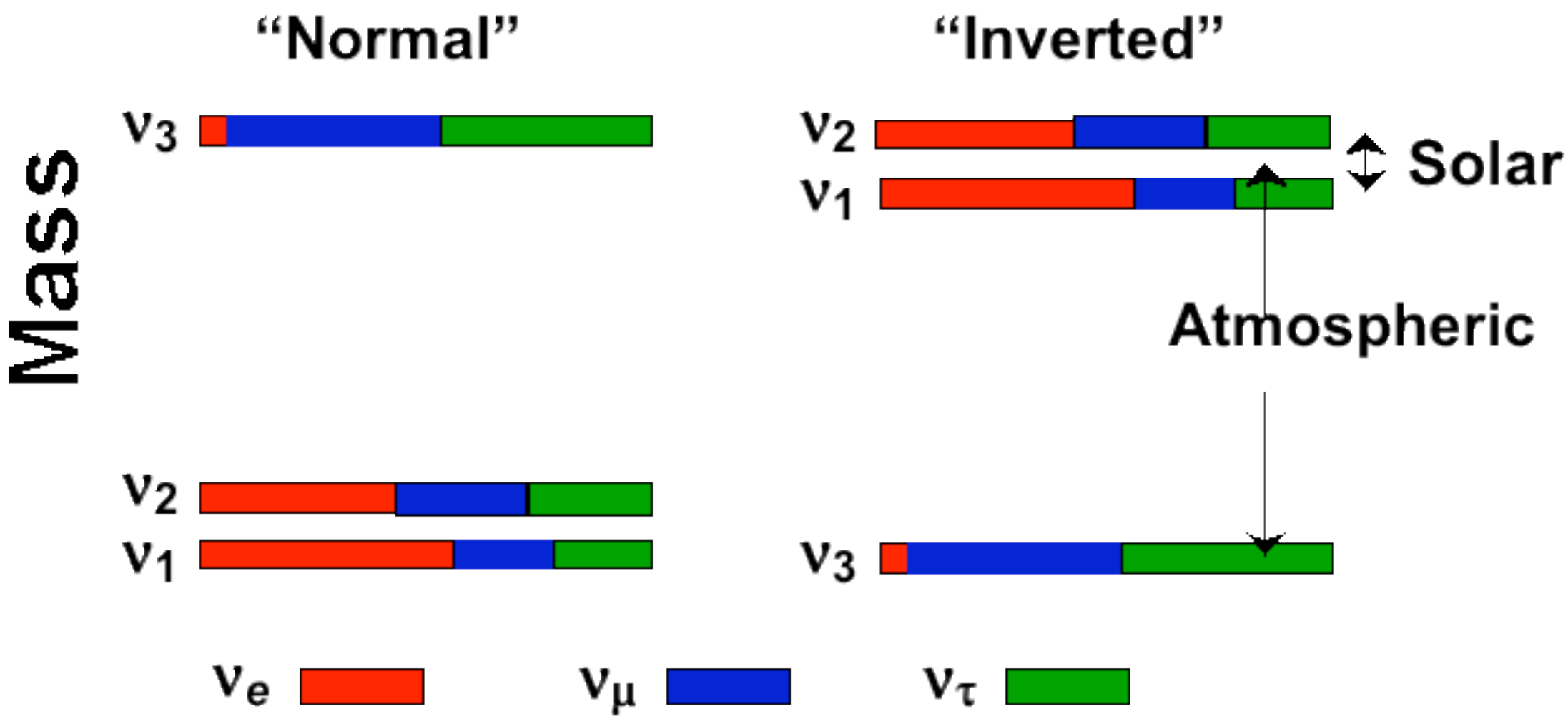
Outline

- Very brief review of the proposal
- What is new in the proposal
  - Collaboration organization
  - Simulations
  - Near Detector
  - Active Shield
  - Cost Estimate
  - Schedule
- Requests
- Final Thoughts

What Do We Know?



Physics Goals

- MINOS
  - Verify the oscillation paradigm
  - Improve measurements of Δm_{23}^2 and $\sin^2(2\theta_{23})$
  - Search for evidence of sterile neutrinos
  - Search for $\nu_\mu \rightarrow \nu_e$ at factor of 2 better sensitivity than CHOOZ
- NOνA
  - Extend the $\nu_\mu \rightarrow \nu_e$ search by an order of magnitude
  - Resolve or contribute to the resolution of the mass hierarchy
  - Start to gather information on CP violation
  - Improve on other MINOS measurements

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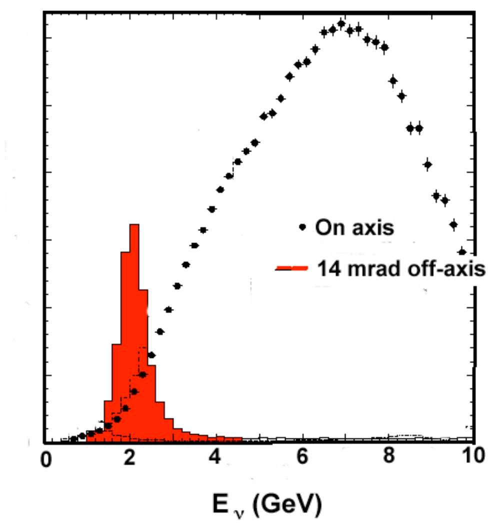
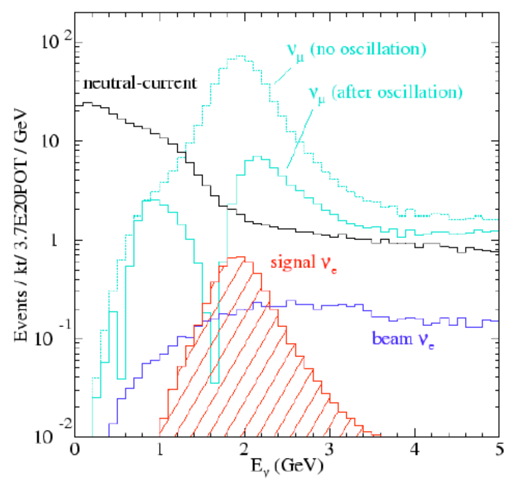
How Does NOνA Do This? (1)

- **Move ~12 mrad off axis to obtain a narrow band beam**
  - **Increase in neutrino flux in the region of interest**
  - **Sharp reduction of higher-energy NC background**
  - **Separation of ν_e background from kaons**





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How Does NOνA Do This? (2)

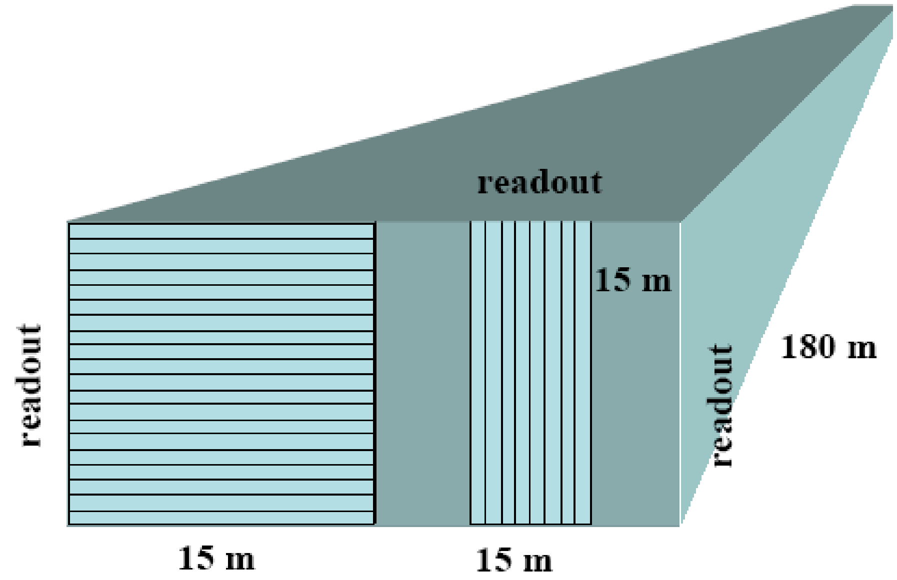
- Increase the detector mass by a factor of 9 over MINOS (at a cost/kt reduction of 3)
- Build a detector optimized for electron detection
  - Sandwich detector with 0.3 X_0 depth segmentation vs. 1.5 X_0 for MINOS
  - Allows an electron to be seen as a fuzzy track
  - Allows π^0's to be seen as more diffuse objects with conversion gaps

Baseline Detector

Monolithic structure

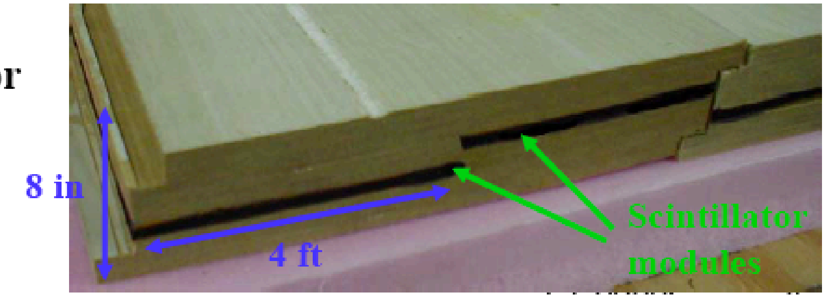
Liquid Scintillator:
1.2 m x 3 cm x 14.4 m
30-cell PCV extrusions,
24 extrusions/plane,
750 planes
= 18,000 extrusions
= 540,000 channels
U-shaped WLS fiber into
APD readout

Absorber:
20 cm particleboard/
plane (~1/3 X_o)



800 planes X, absorber, Y, absorber, … = detector

tor



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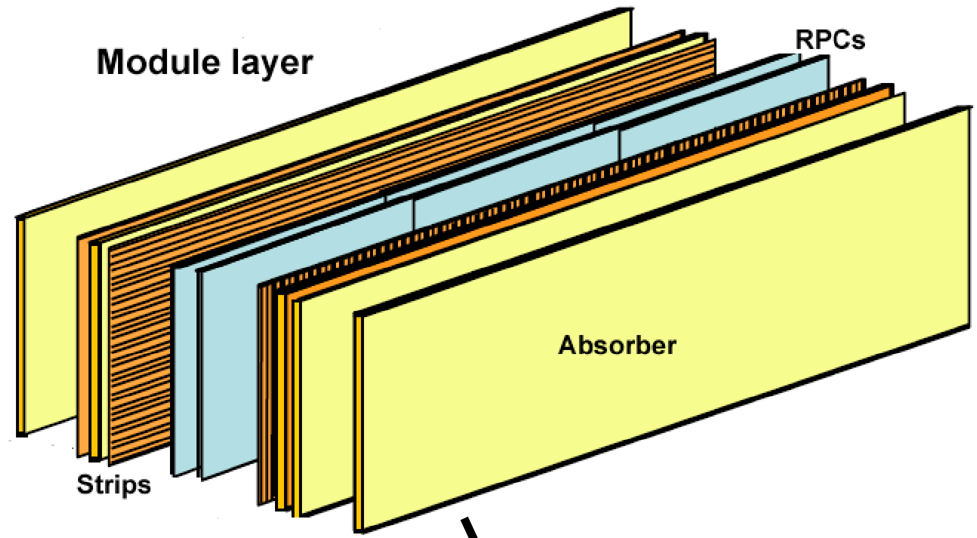
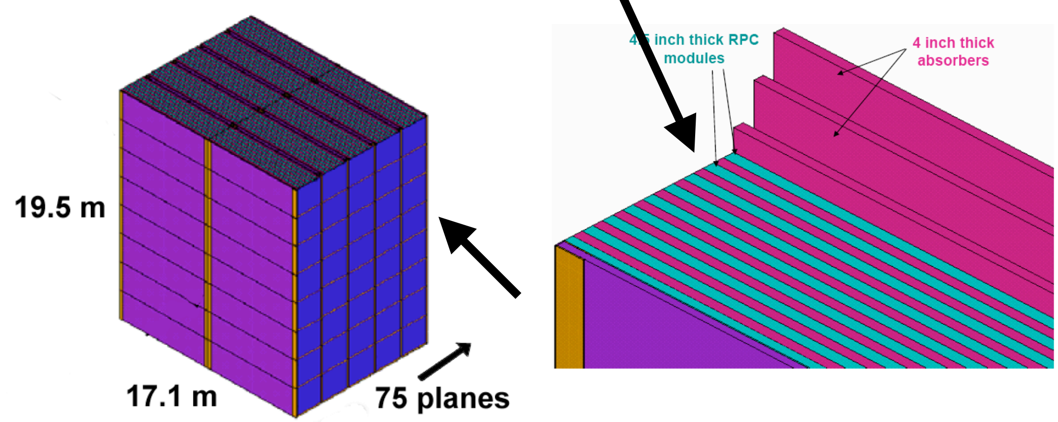
Alternative Detector

Container Structure

RPCs:
2.4 m x 2.8 m chambers
~4 cm readout strips
3 double-gap chambers/ module layer
12 module layers/module
16 modules/plane
75 planes
= 86,400 chambers
= 3,686,400 channels





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Technology Choice

- Liquid scintillator was chosen largely on the basis of cost. RPCs appear more expensive because they require more labor to assemble.
- Physics tradeoffs:
  - Liquid scintillator allows pulse height measurement.
  - RPCs allow 2-dimensional readout at each layer.
  - We are still studying these tradeoffs. They are probably not large.
- Optimization: TASD being studied.
- We would like to make a final technology decision in less than a year.

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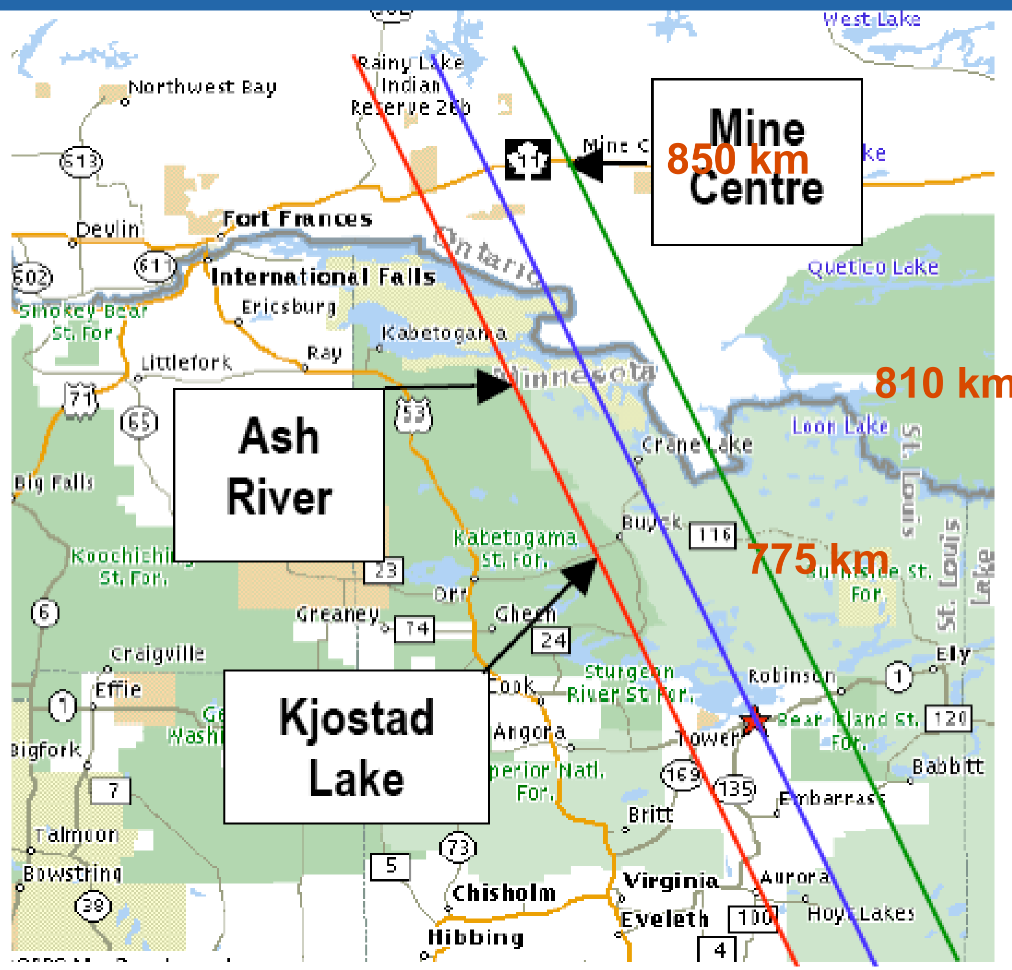
Possible Sites



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Collaboration Organization

- Proposal has 160 authors from 34 institutions.
- At the February collaboration meeting a temporary organization established for 6 months:
  - IB Chair: Peter Litchfield
  - Co-spokespersons: John Cooper and Gary Feldman
  - Executive Council: Carl Bromberg, Ken Heller, Mark Messier, Doug Michael, Ron Ray, Alfons Weber, and Stan Wojcicki

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$P(\nu_\mu \rightarrow \nu_e)$
(in Vacuum)

- $P(\nu_\mu \rightarrow \nu_e) = P_1 + P_2 + P_3 + P_4$
  - $P_1 = \sin^2(\theta_{23}) \sin^2(2\theta_{13}) \sin^2(1.27\ \Delta m_{13}^2\ L/E)$
  - $P_2 = \cos^2(\theta_{23}) \sin^2(2\theta_{12}) \sin^2(1.27\ \Delta m_{12}^2\ L/E)$
  - $P_3 = \sqsubset J \sin(\delta) \sin(1.27\ \Delta m_{13}^2\ L/E)$
  - $P_4 = J \cos(\delta) \cos(1.27\ \Delta m_{13}^2\ L/E)$

  where $J = \cos(\theta_{13}) \sin(2\theta_{12}) \sin(2\theta_{13}) \sin(2\theta_{23})$ x

  $\sin(1.27\ \Delta m_{13}^2\ L/E) \sin(1.27\ \Delta m_{12}^2\ L/E)$

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$P(\nu_\mu \rightarrow \nu_e)$ (in Matter)

- In matter, P_1 will be approximately multiplied by $(1 \pm 2E/E_R)$ and P_3 and P_4 will be approximately multiplied by $(1 \pm E/E_R)$, where the top sign is for neutrinos with normal mass hierarchy and antineutrinos with inverted mass hierarchy.

$$E_R = \frac{\Delta m^2_{13}}{2\sqrt{2} G_F \rho_e} \approx 11 \text{ GeV for the earth's crust.}$$

About a ±23% effect for NuMI, but only a ±10% effect for JPARC .

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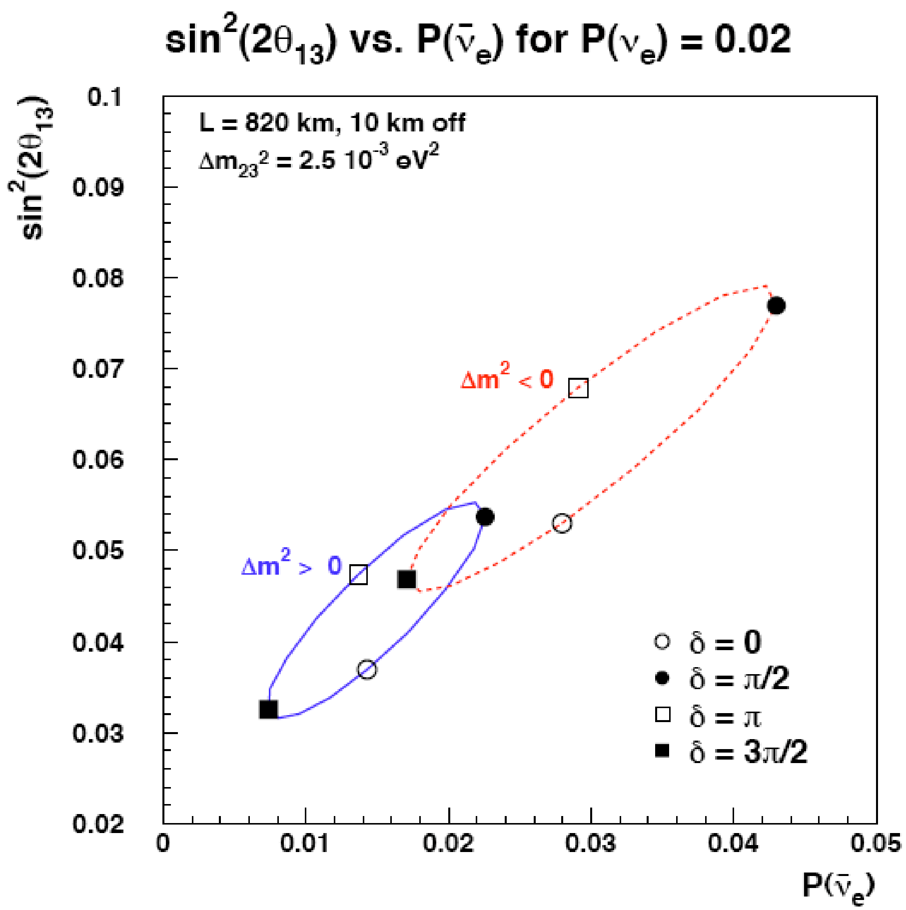
$P(\nu_\mu \rightarrow \nu_e) = 0.02$ at 820 km



Note

(1) Effect of $\cos(\delta)$ term

(2) Ambiguities

(Hidden ambiguity: P1 $\propto \sin^2(\theta_{23})$; if $\sin^2(2\theta_{23}) = 0.95$, $\sin^2(\theta_{23}) = 0.39$ or 0.61)

(1) Rough equivalence of reactor and antineutrino measurements

New Simulations

- Simulations of the baseline detector have been redone with better beam and physics descriptions, including coherent π^0 production and a better treatment of duality in the resonance region. The improvements caused a reduction in our sensitivity, but it is still about an order of magnitude better than MINOS.
- These simulations do not use sophisticated event classification techniques, so I hope that we will be able to improve upon them.

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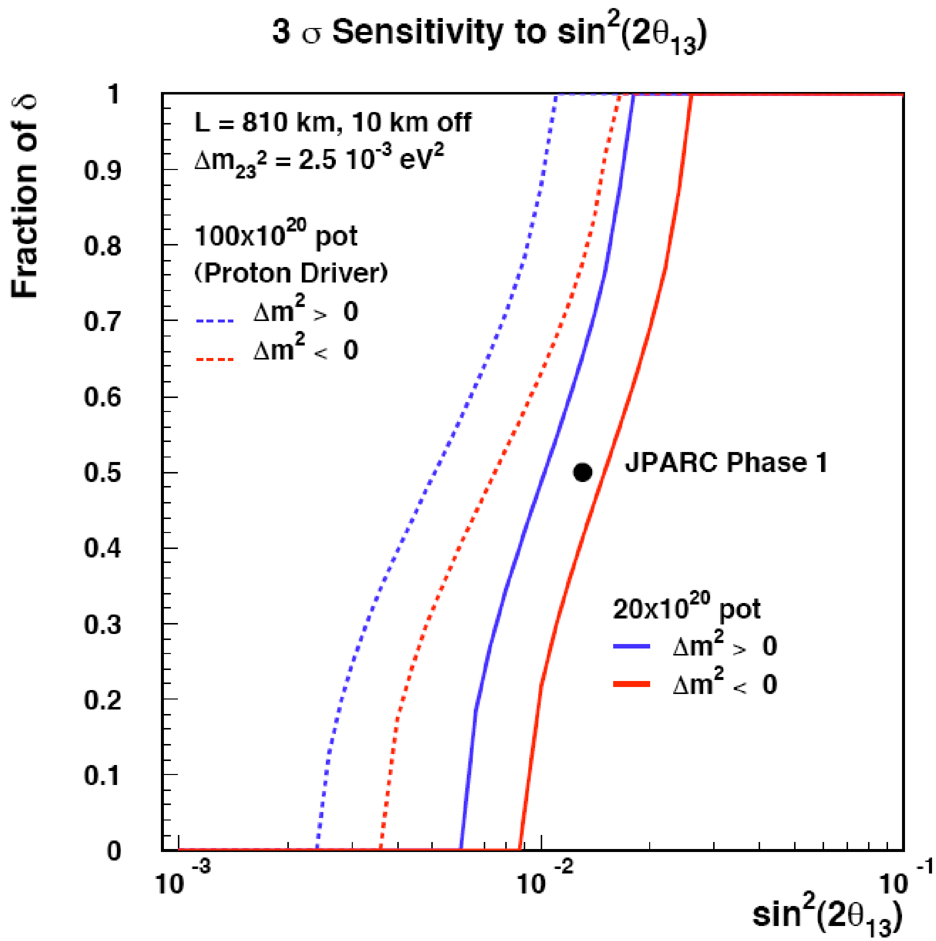
3 σ Discovery Potential for $\nu_\mu \rightarrow \nu_e$



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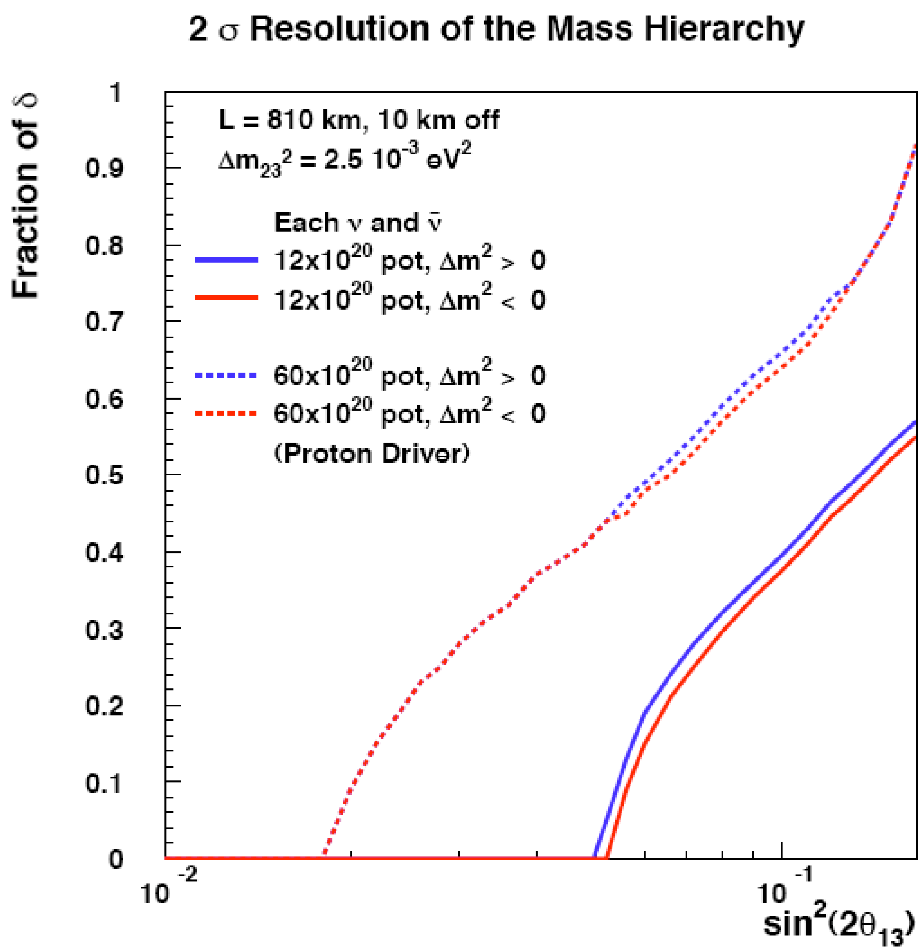
95% CL Resolution of the Mass Hierarchy



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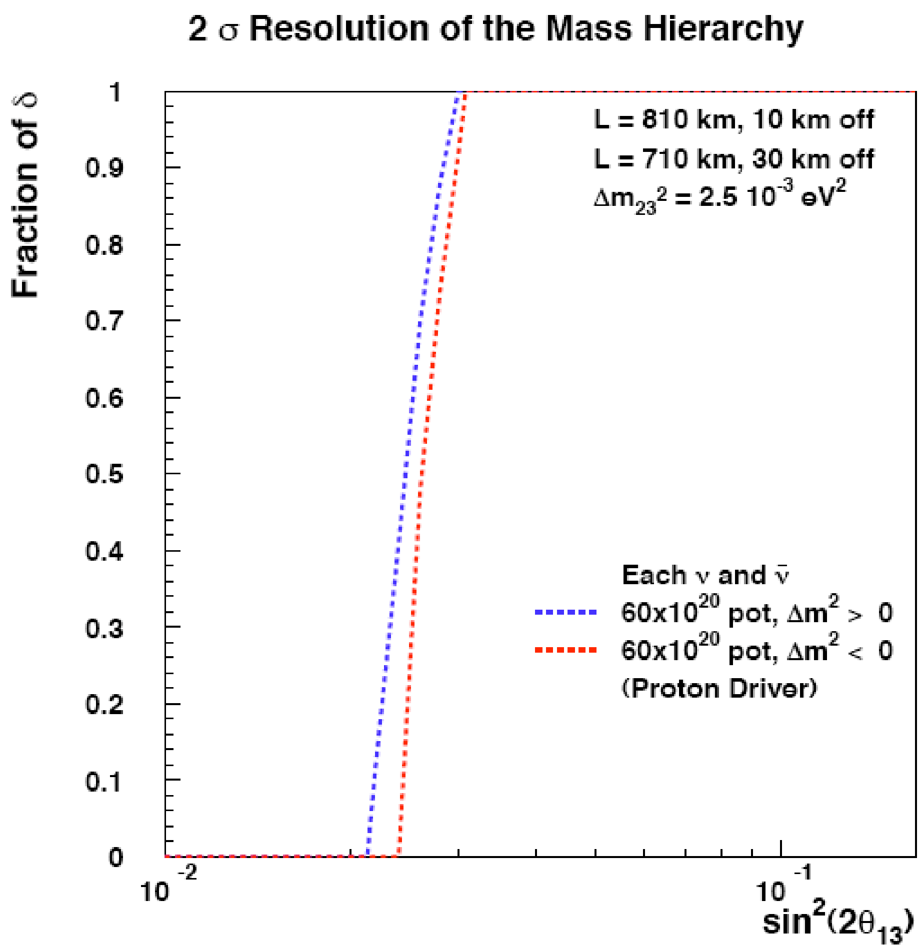
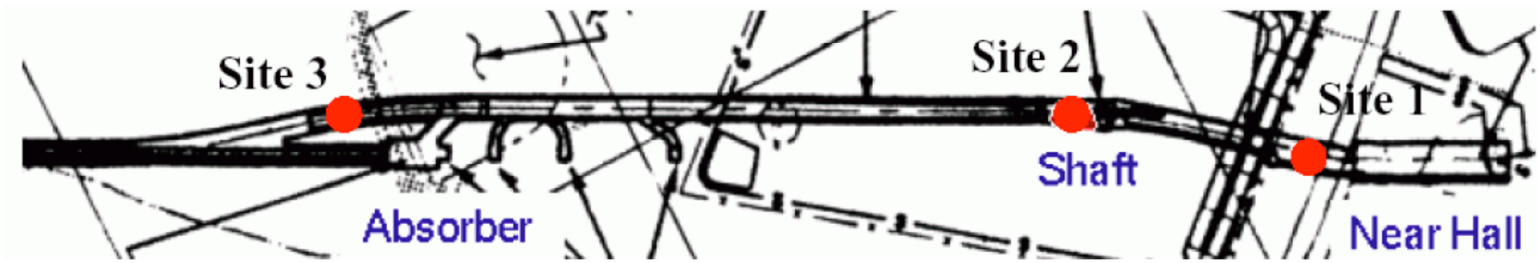
95% CL Resolution of the Mass Hierarchy with 2 Detectors



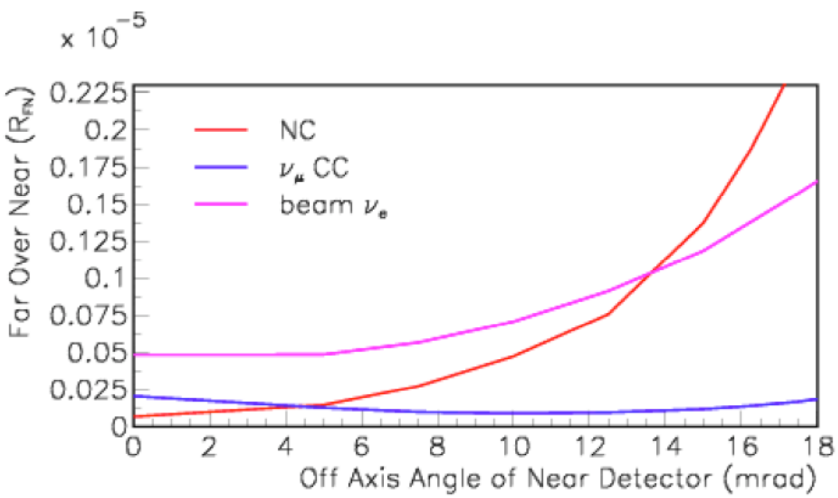
Near Detector (1)

- We propose a relatively small and simple off-axis near detector to reduce systematics through near-far comparisons.
- The site is the MINOS near detector hall access tunnel, probably between sites 1 and 2.



Near Detector (2)

- 120 tons, 3.7 m wide x 4.9 m high x 10 m long (44 planes with a total of 154 extrusions).
- Due to oscillations and the non-point source, backgrounds do not scale near to far. However, extrapolations of the measured CC cross section in the near detector should reduce the background error to the 5% level.



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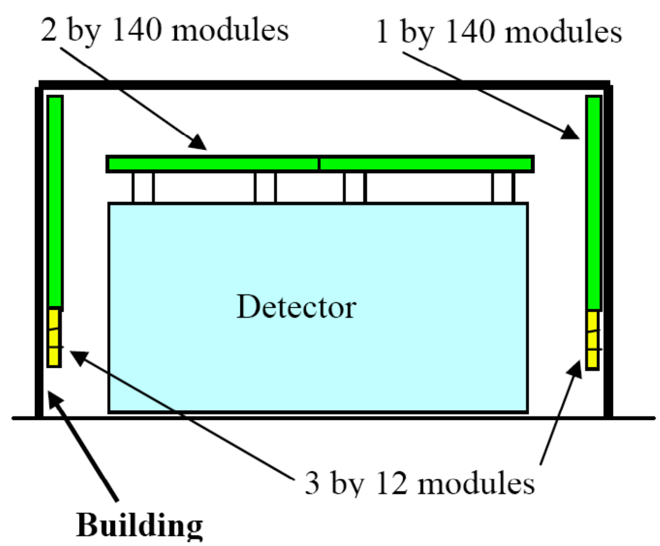
Active Shield

- In a sandwich detector, cosmic muons can enter along an absorber and cause a reaction in the interior of the detector. Although this is probably not a serious problem due to the short duty cycle, an active shield seems prudent.
- The design calls for a total of 632 extrusions.
- An active shield does not protect against neutrons. A test is needed to see if an overburden is necessary.



New Cost Estimate (1)

- A new cost estimate for the baseline design was made by a committee chaired by Gina Rameika. It used a conservative methodology and underwent a day-long internal review. Rather high contingencies were assigned for items that were in early design stages. The near detector and the active shield, left out of the estimate in the progress report were included.
- The new cost estimate, 147.3 M$, is substantially less than the 174.3 M$ estimate in the progress report.

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New Cost Estimate (2)

WBS	Description	Base plus Overhead	Contin-gency	Total
1.0	Near Detector	2.6	2.6	5.2
2.0	Far Detector	71.4	23.8	95.2
3.0	Building	22.0	14.9	36.9
4.0	Active Shield	2.0	2.0	4.0
5.0	Management	5.0	1.0	6.0
TPC	Total	103.0	44.3	147.3

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Technically Driven Schedule

	2004	2005	2006	2007	2008	2009	2010	2011	
Stage 1 Approval	◆								
Final Technology Decision	◆								
Final Approval		◆							
Start Construction			◆						
Start Data Collection					◆				
Finish Construction								◆	

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Requests

- Stage 1 Approval this June. We need a firm statement of Fermilab commitment to gain agency and collaborator support.
- R&D support for time critical activities.
  - NSF rejected our R&D proposal in spite of two “excellent” rating and one “very good” rating.
  - A vertical slice test of liquid scintillator is critical to a final technology decision in less than a year.
  - Cosmic ray test stand is critical to understanding whether an overburden is necessary.
- A Fermilab plan for obtaining 4 x 10^{20} pot/yr in the 2008-2010 time period.

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Final Thoughts (1)

- We see the exploration of the lepton masses and mixings as important or more important than the similar exploration in the hadronic sector.
- This program is also a national priority. The DoE's Office of Science Strategic Plan lists "Determine the pattern of neutrino masses and the details of neutrino mixing parameters" as a goal for 2011, roughly consistent with the schedule we have presented.

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Final Thoughts (2)

- With regard to the "pattern of neutrino masses," we note that the mass hierarchy can only be resolved through matter effects — ν_e's traveling long distances through the earth. NOνA is the leading long-baseline proposal as other regions are concentrating on shorter baselines: Japan 295 km and Europe 130 km.

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Final Thoughts (3)

- Unless Fermilab hosts the linear collider, we see the study of neutrino oscillations as the flagship accelerator program for Fermilab's future.
- We advocate a step-by-step program with NOνA as the second step, a proton driver as the third step, and possibly a new detector or beamline as the fourth step.
  - Each step provides guidance for the next.
  - Good utilization in Fermilab's investment in the NuMI beamline.
  - Only affordable approach at the present time.