Status of the MINOS Experiment

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Fermilab
(For the MINOS Collaboration)

21 June 2001
Les Houches

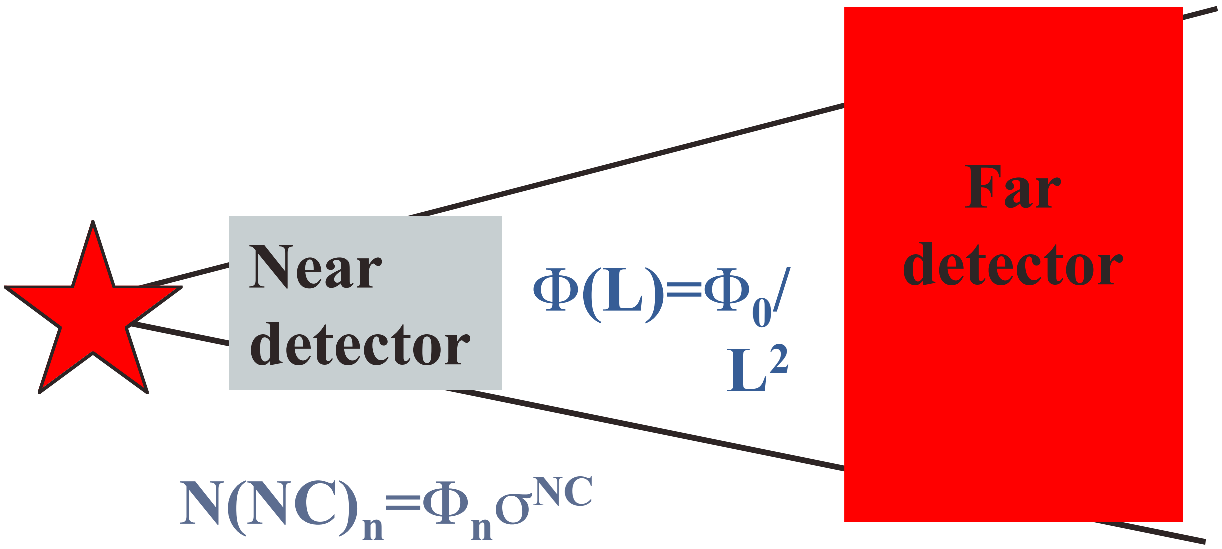
- The MINOS experiment
- The neutrino beam
- Civil construction status
- The detectors
- Physics measurements
- Summary

The MINOS Collaboration

Over 250 Physicists and Engineers

IHEP-Beijing | Athens | Dubna | ITEP-Moscow | Lebedev | Protvino | Oxford | Rutherford | Sussex | University College London | Argonne | Brookhaven | Caltech | Chicago | Elmhurst | Fermilab | James Madison | Harvard | Indiana | Livermore | Minnesota | Northwestern | Pittsburgh | South Carolina | Stanford | Texas-Austin | Texas A&M | Tufts | Western Washington | Wisconsin

Two detector experiment



$N(NC)_n=\Phi_n\sigma^{NC}$

$N(CC)_n=\Phi_n\sigma^{CC}$

$N(NC)_f=\Phi_f\sigma^{NC}$

$N(CC)_f=\Phi_f\sigma^{CC}$

- Make two detectors as identical as possible
  - same scintillator, same steel etc.
- Measure ν spectrum in the near detector
- Predict the ν spectrum in the far detector
- Near-far comparisons reduce the systematic errors

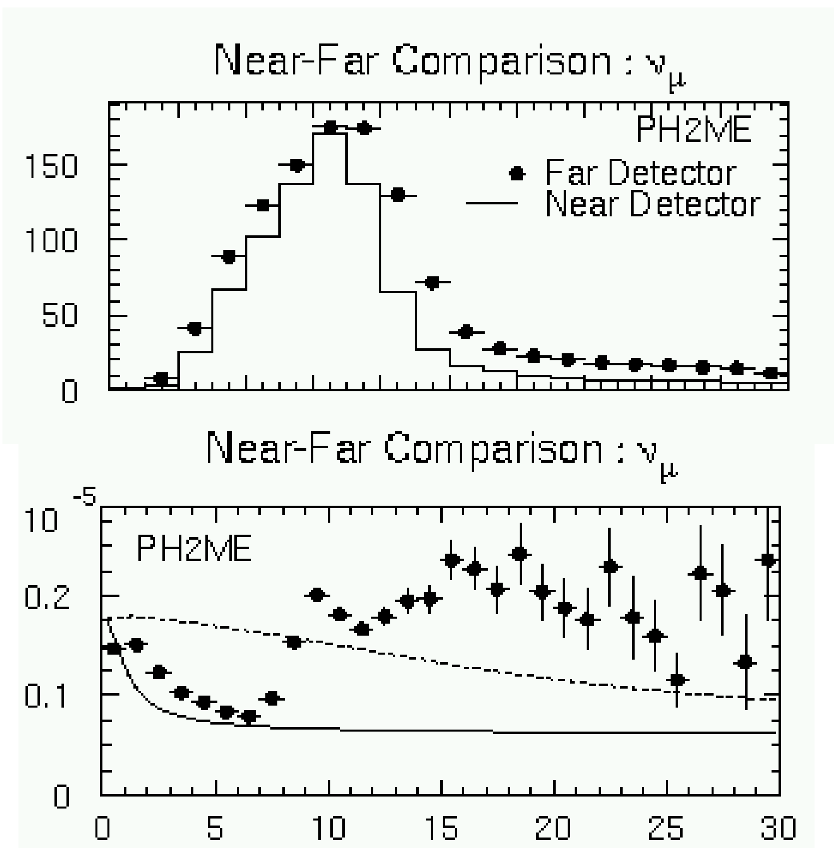
Goals for MINOS

- Obtain firm evidence for or against oscillations
  - Charge current (CC) interaction rate and energy distribution
  - NC/(CC+NC) ratio (T-test)
- Discriminate between oscillation and other models
- If it's oscillations: measure of parameters, Δm^2, $\sin^2 2\theta$ using CC energy distribution
- Determination of the oscillation mode(s)
  - ν_τ or ν_s from NC and CC energy distributions
  - $\nu_\mu \rightarrow \nu_e$ limits or observation by identification of electrons

The truth about the beamline…

The ratio of near/far flux is not $1/L^2$

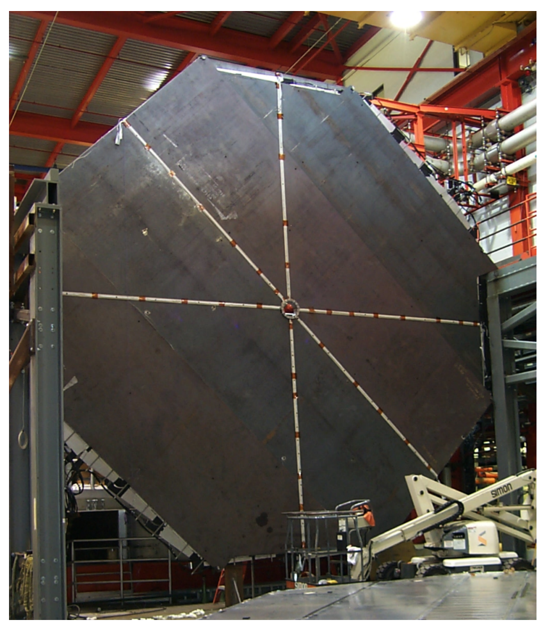
- 700m decay region, followed by 250m shielding, then near detector
  - High energy particles decay much closer on average to ND
  - Even at one energy neutrinos at ND aren't from a point source



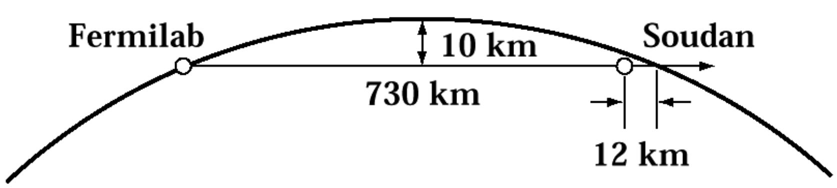
The truth about the detectors

The near and far detectors are not identical, nor can they be identical given where the ND is…

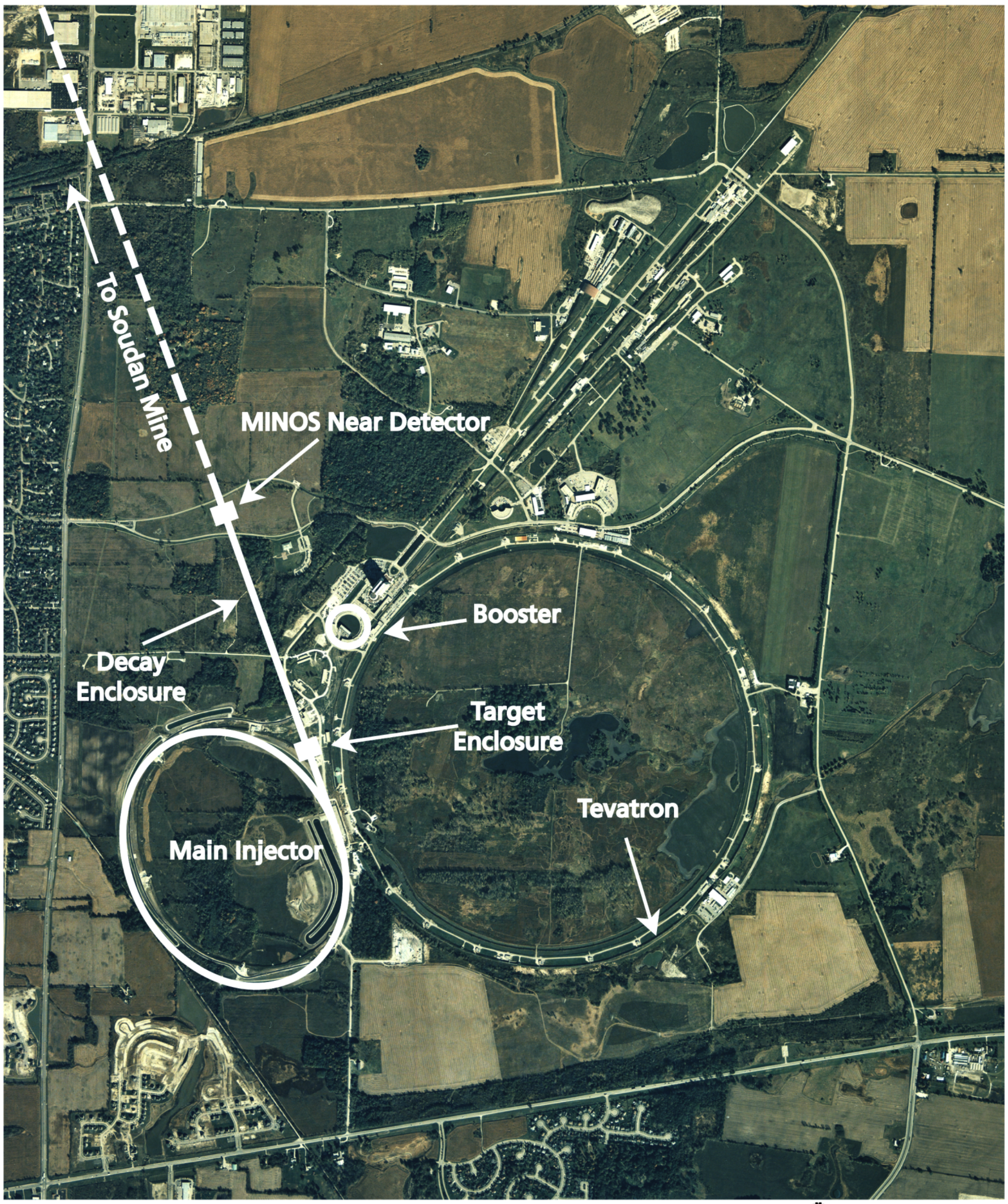
- Rate and accidentals much higher at near detector—will be using different electronics!
- Angle subtended by ND much larger than angle subtended by FD
- FD fully instrumented, ND not fully instrumented
- ND much smaller than FD, so light propagation in scintillator is different
- one-ended readout +mirror instead of two-ended readout



The MINOS Experiment

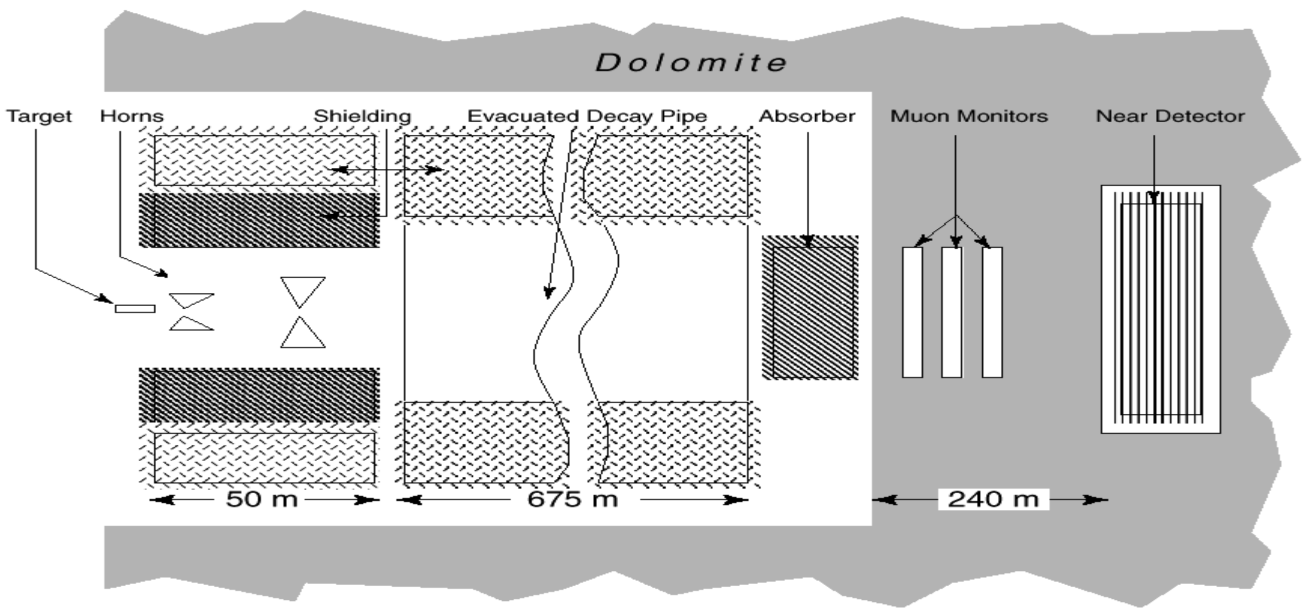


Beamline from above



FERMILAB #98-1348D

Neutrino Beam Line

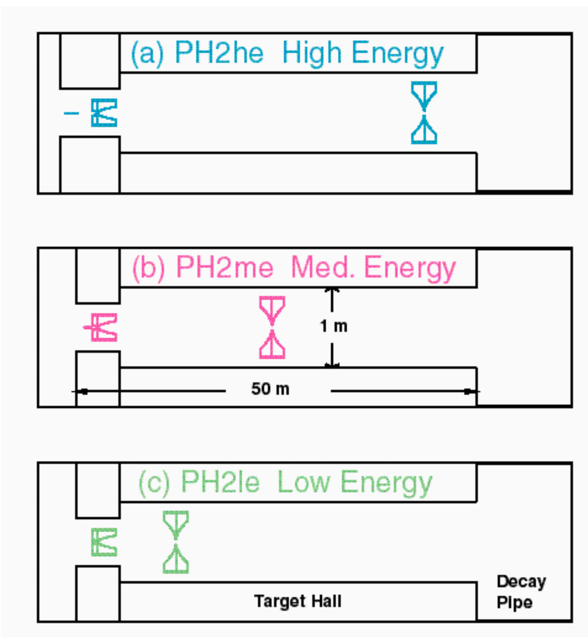


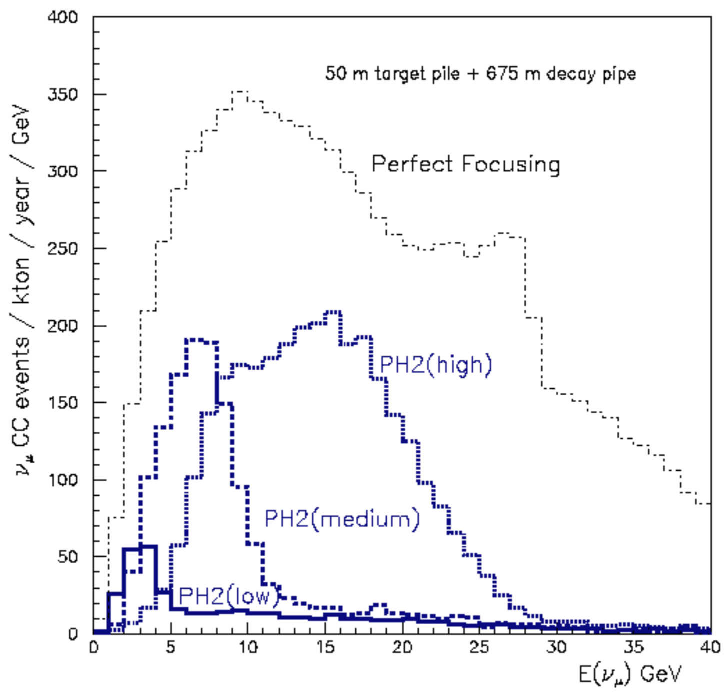
High Power Beam: 4e13 120GeV Protons on target
Every 1.9 seconds (0.4MWatt proton source!)

Everything must be very shielded to prevent groundwater contamination

2-horn focusing system

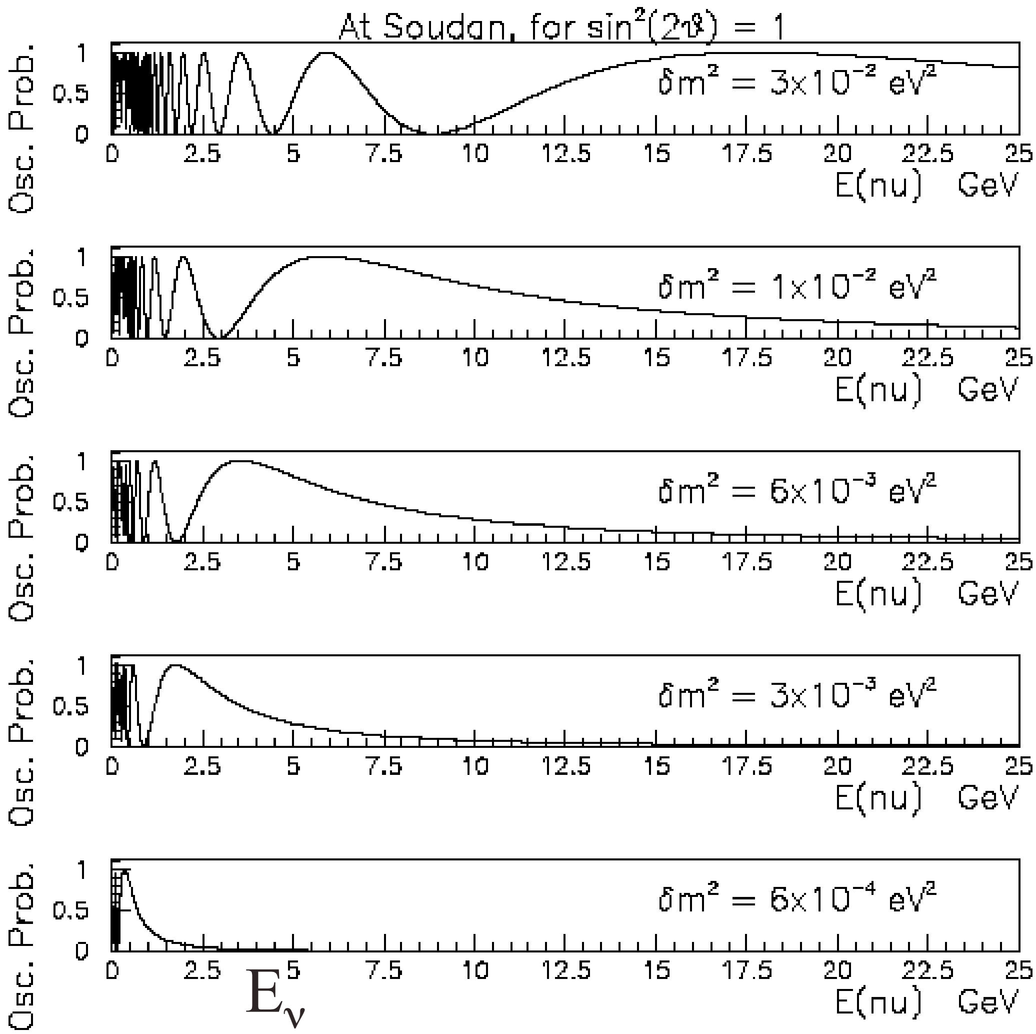
Beam Options





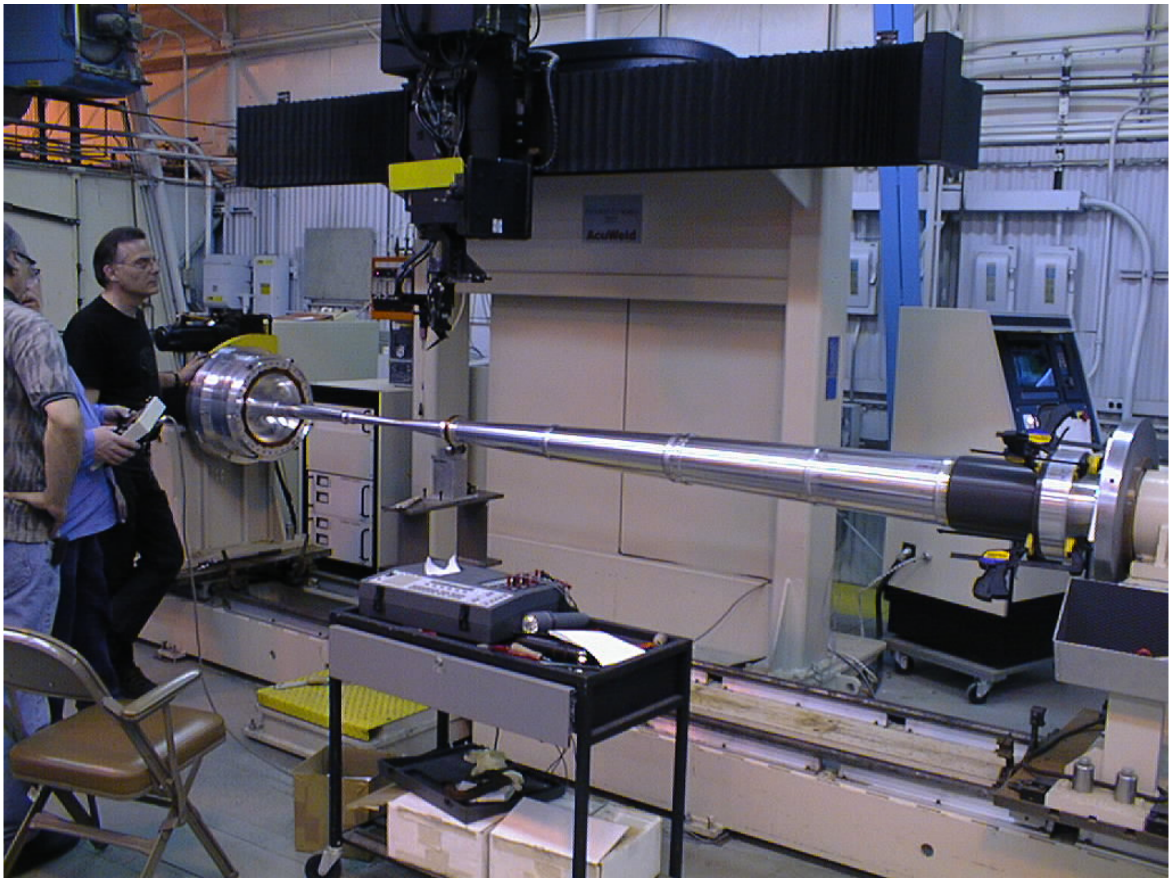
Target and second horn are moveable –
Used to change the beam energy
Given most recent SuperK results,
730km baseline, start with Low Energy Beam
--3039 events/10kton-yrs if no oscillation

What neutrino beam energy to use?



Want beam near 1st oscillation maximum for best δm^2 precision—will start with Low Energy Beam (3.5GeV at peak)

Magnetic Horns



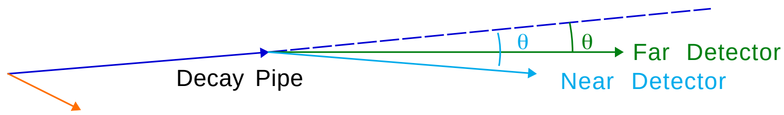
Inner conductor for the prototype of first horn

>2 million pulses at full current (.2MAmp!)
 - corresponds to about 1 month of running

Magnetic field measurements agree with very well with calculations

Hadronic Hose

Normal Running



$1/L^2$ distribution to Near Detector depends on:

- where hit decay pipe wall
- pion lifetime

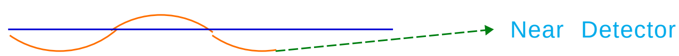
θ to Near Detector larger than θ to Far Detector hence E, Flux are different

$$E_\nu \;\alpha\; \frac{1}{1+\gamma^2\theta^2} \qquad \nu \text{ Flux } \;\alpha\; \frac{1}{L^2}\left(\frac{1}{1+\gamma^2\theta^2}\right)^2$$

*** *** HADRONIC HOSE CONCEPT *** ***

Continuous focusing reduces Far/Near difference

Wire in decay pipe
I= 0.5 to 1 kA



- dont let hadrons hit walls

(* but can't change pion lifetime)

Angular distribution to Far and Near now much more similar

e 2: How Hadronic Hose reduces differences in the energy spectrum seen
e near and far detectors.

Hadronic Hose

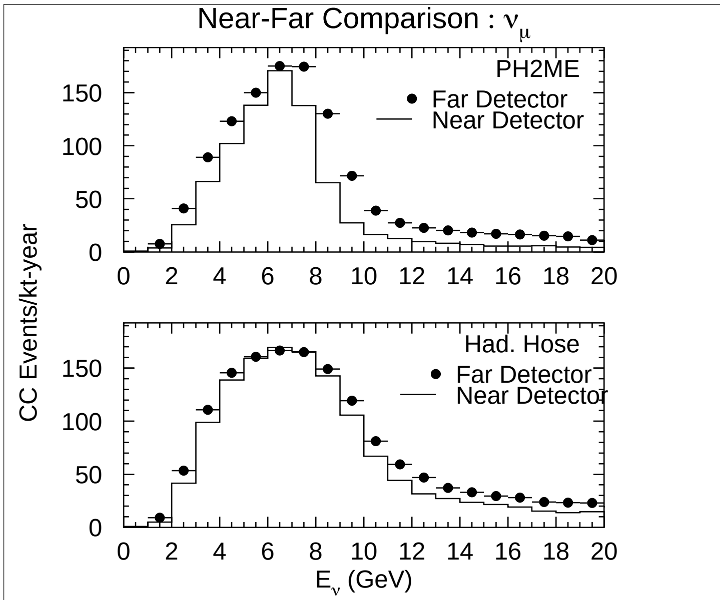


Figure 1: Top: Comparison of the ν_μ charged-current event spectrum for the baseline PH2ME beam in the Far Detector (dots) with the spectrum in the Near

Will be included if funding permits

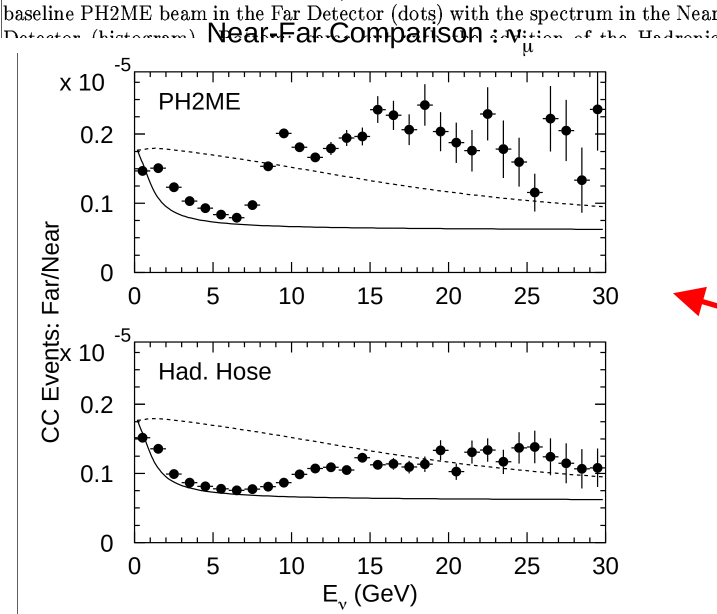
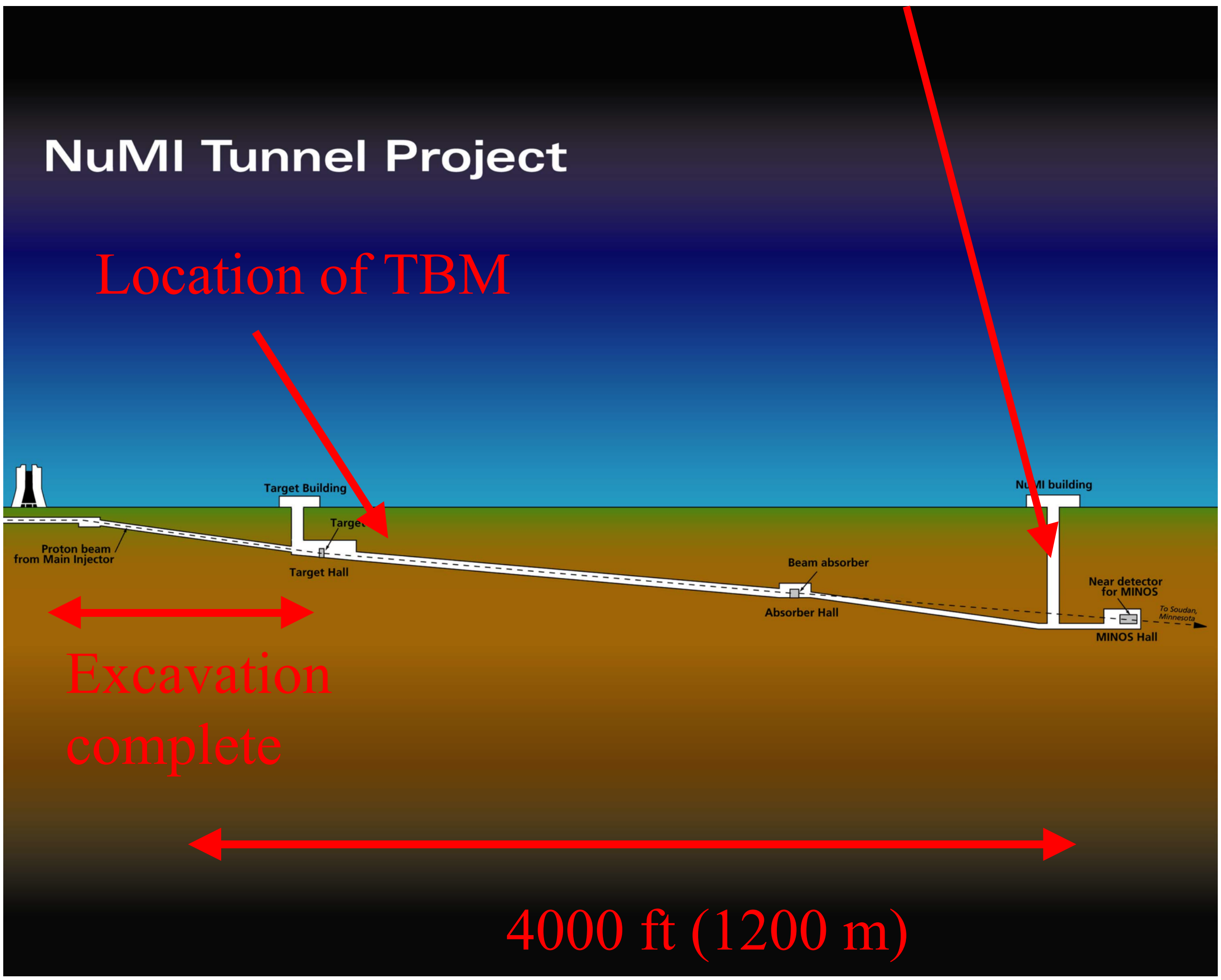


Figure 9: The ratio of the far to near spectrum for PH2ME (top) and for PH2ME with the addition of the Hadronic Hose (bottom). In each plot the solid curve is the expected ratio based on the pion lifetime and the dashed curve is the expected ratio based on the Kaon lifetime.

π lifetime

Beamline from side

Detector shaft
about 3/4
complete



Civil Construction at Fermilab

tunnel boring machine

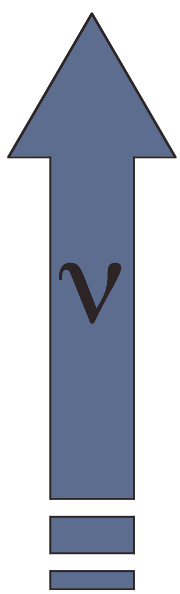
Tunneling started May 5, 50m so far

Civil Construction at Soudan

The MINOS cavern at Soudan

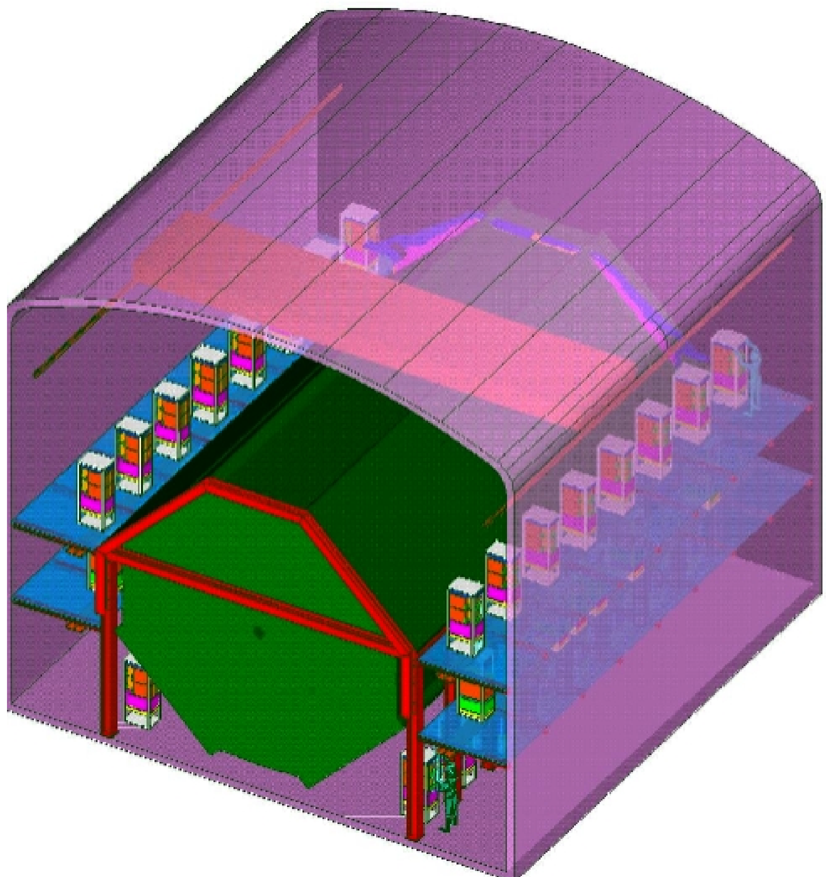
Excavation Complete!

Outfitting is on schedule



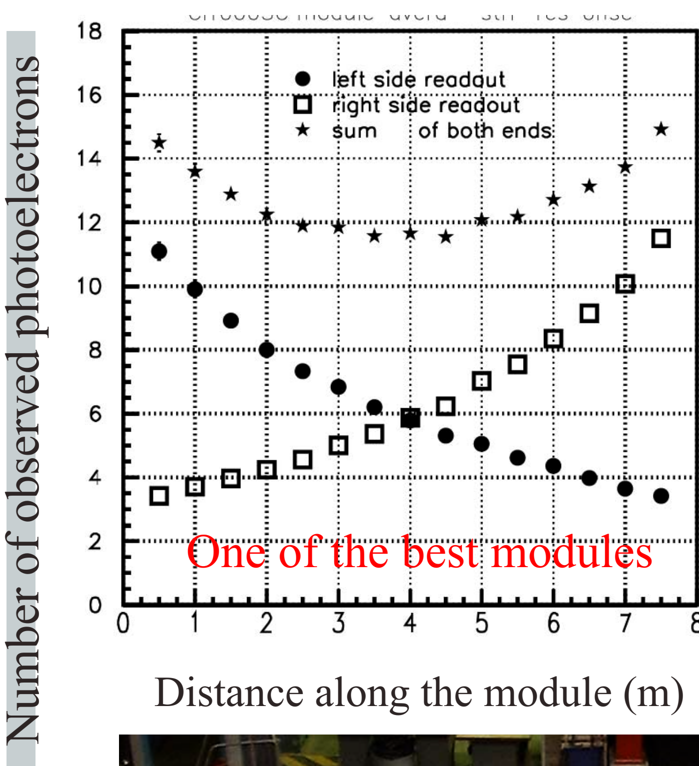
Beneficial occupancy July 2001- begin detector assembly in August 2001

MINOS Far Detector

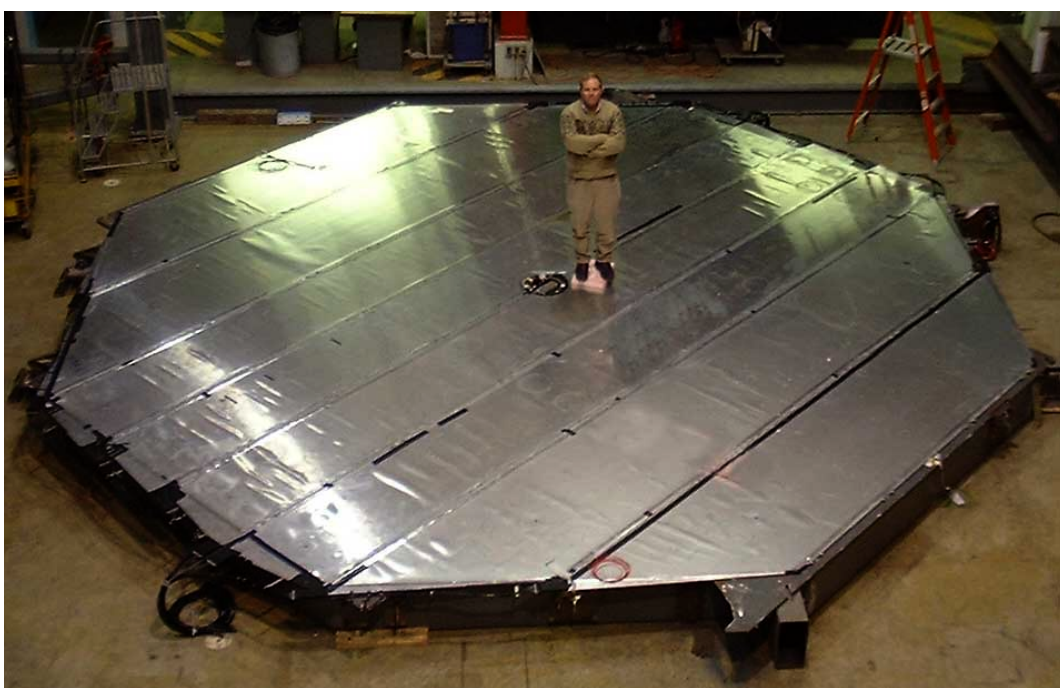


- 5.4kton 8m Octagonal Tracking Calorimeter
- 486 layers of 2.54cm Fe
- 2 sections, each 15m long
- 4.1cm wide solid scintillator strips, WLS fiber
- 25,800 m^2 active detector planes
- Magnet coil provides $\langle B \rangle \approx 1.3$T

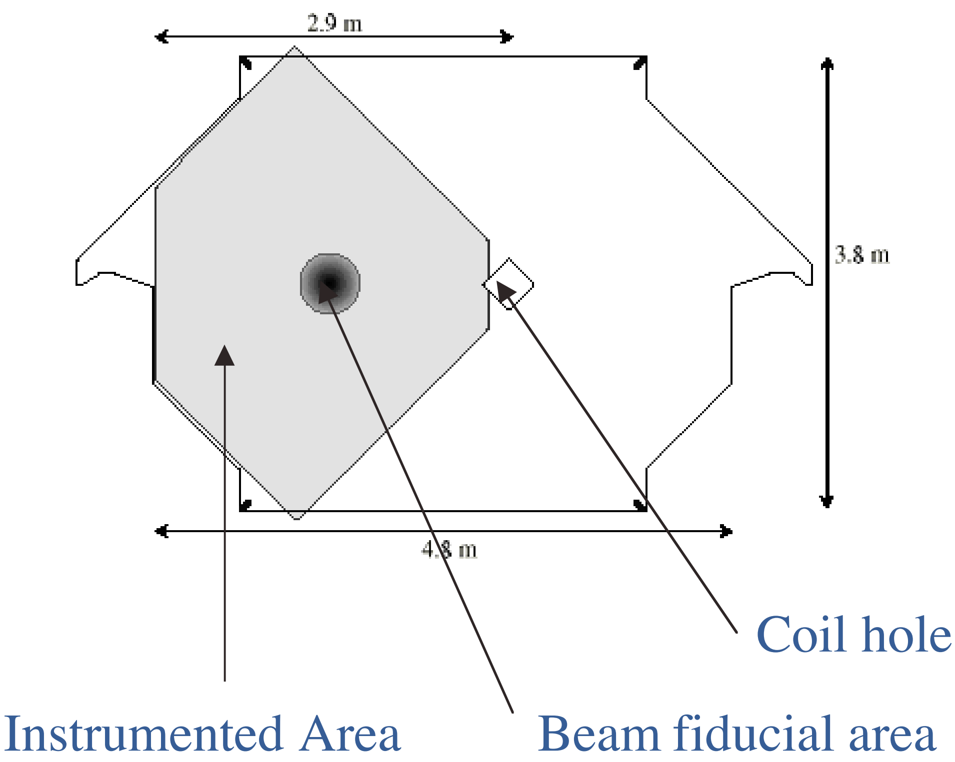
Light Output Measurements



light output measured
Using full MINOS readout chain (connectors, clear fibers, PMTs…).
Light to phototubes improving from initial design (2.2 to 4.7!)



MINOS Near Detector



16.6 m long, 980 tons, 282 “squashed octagon” planes

Forward section: 120 planes

4/5 partially instrumented, 1/5: full coverage

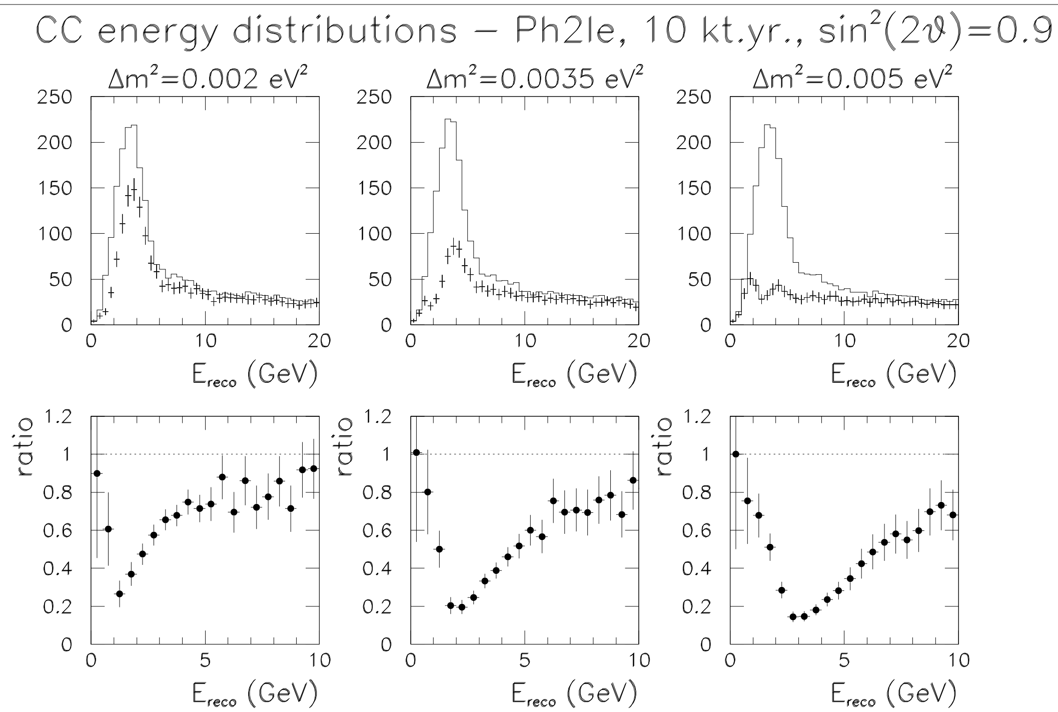
Spectrometer section:162 planes

4/5 not instrumented, 1/5: full coverage

Physics Measurements

- Obtain firm evidence for oscillations
  - Charge current (CC) interaction rate and energy distribution
  - NC/(CC+NC) ratio (T-test)
- Measurement of oscillation parameters, Δm^2, $\sin^2 2\theta$
  - CC energy distribution
- Discriminate between oscillation and other models
- Determination of the oscillation mode(s)
  - ν_τ or ν_s from NC and CC energy distributions
  - $\nu_\mu \rightarrow \nu_e$ limits or observation by identification of electrons

CC Energy Distributions

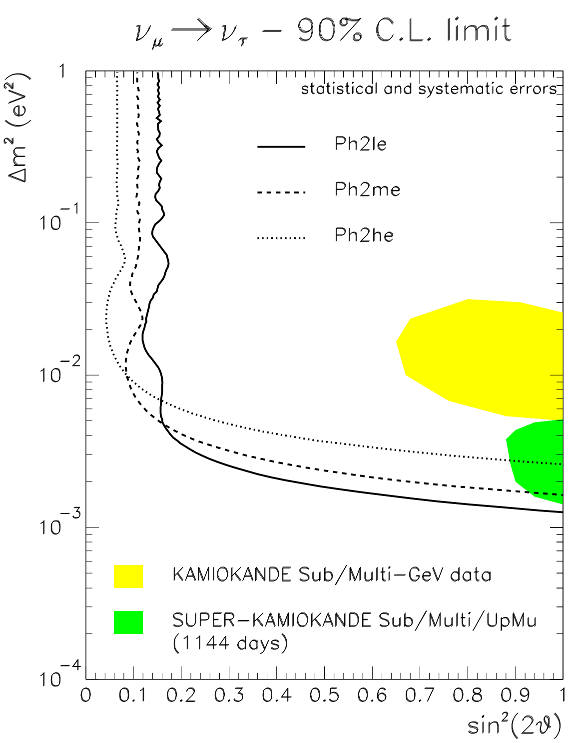


- Hadron Energy smearing: 55%/sqrt(E(GeV))
- Muon Energy smearing: 10%
- Neutral Current Background included
- Shown for $\sin^2 2\theta = 0.9$
- Uncertainties include δ(efficiency shape vs E)

Limit from the T-test

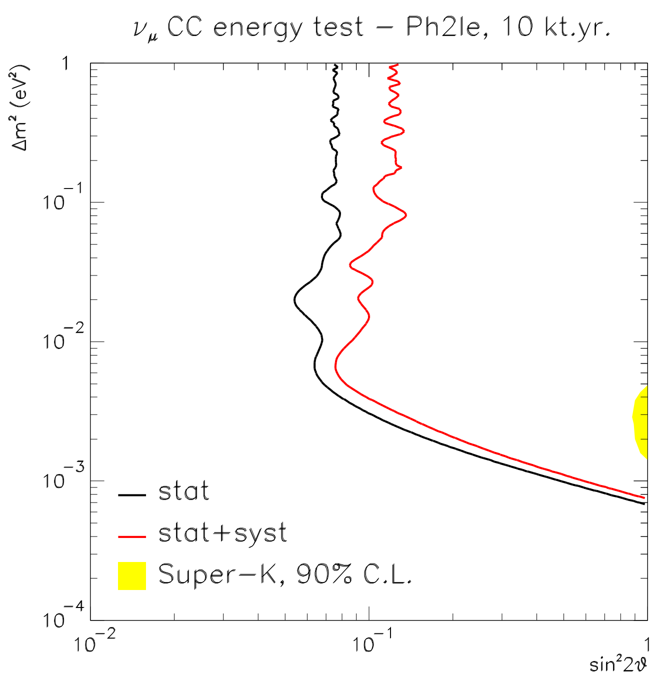
$$T = \frac{N_{CC-like}}{N_{CC-like} + N_{NC-like}}$$

$N_{CC\text{-}like}$ ≡ events with identified muon
$N_{NC\text{-}like}$ ≡ events with no muon



10 kton-yr exposure
2% overall δflux
2% δ(CC efficiency)
2% δ(NC trigger efficiency)

Limit from the CC Energy Spectrum



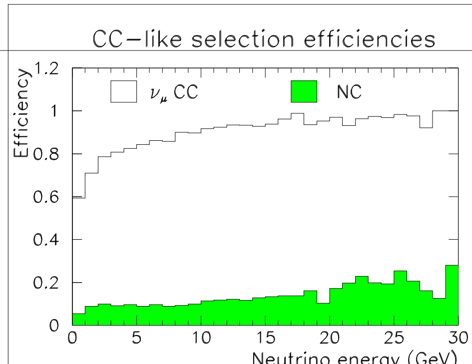
10 kton-yr exposure

2% δ(flux)

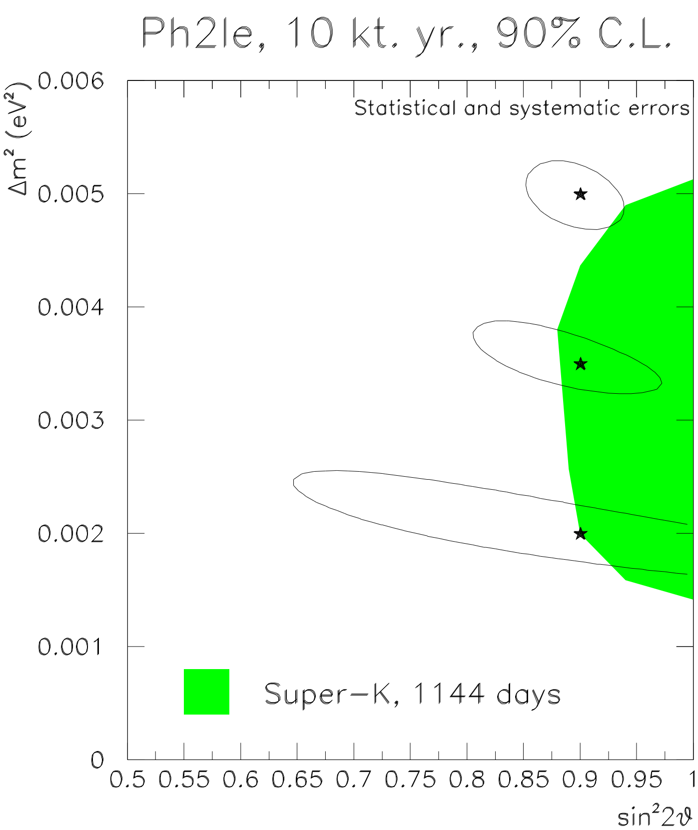
2% bin-to-bin δ(flux)

2%δ (CC efficiency) +

5% in shape…



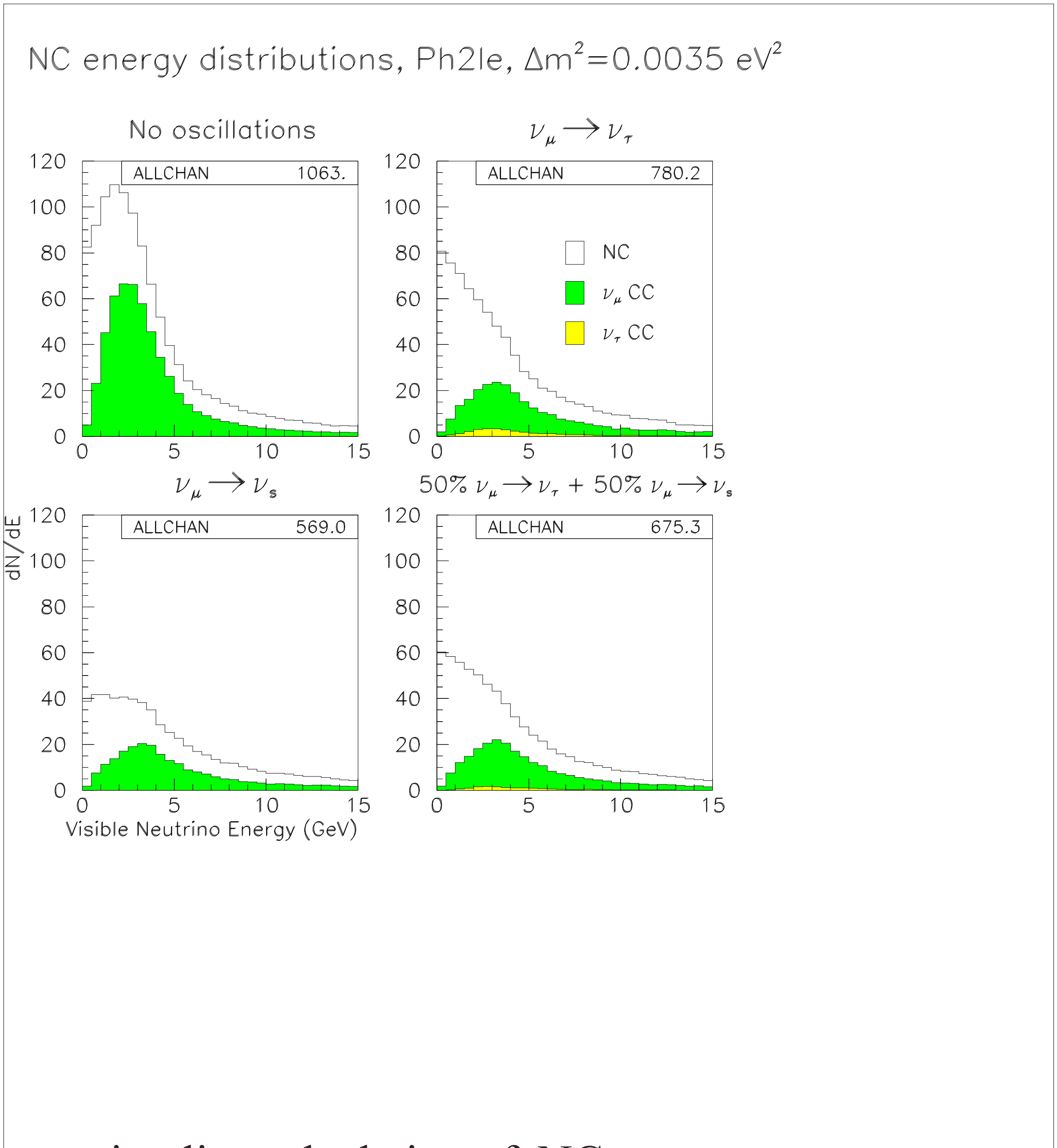
Δm^2, $\sin^2 2\theta$ Sensitivity



- 10 kton-yr exposure
- 2% δflux overall
- 2% bin-to-bin flux
- 2% δ(CC eff)+ ….

For $\Delta m^2 = 0.0035$ eV^2 should be able to achieve better than 10% error at 68% C.L on both Δm^2 and $\sin^2 2\theta$

$\nu_\mu \rightarrow \nu_s$ or $\nu_\mu \rightarrow \nu_\tau$

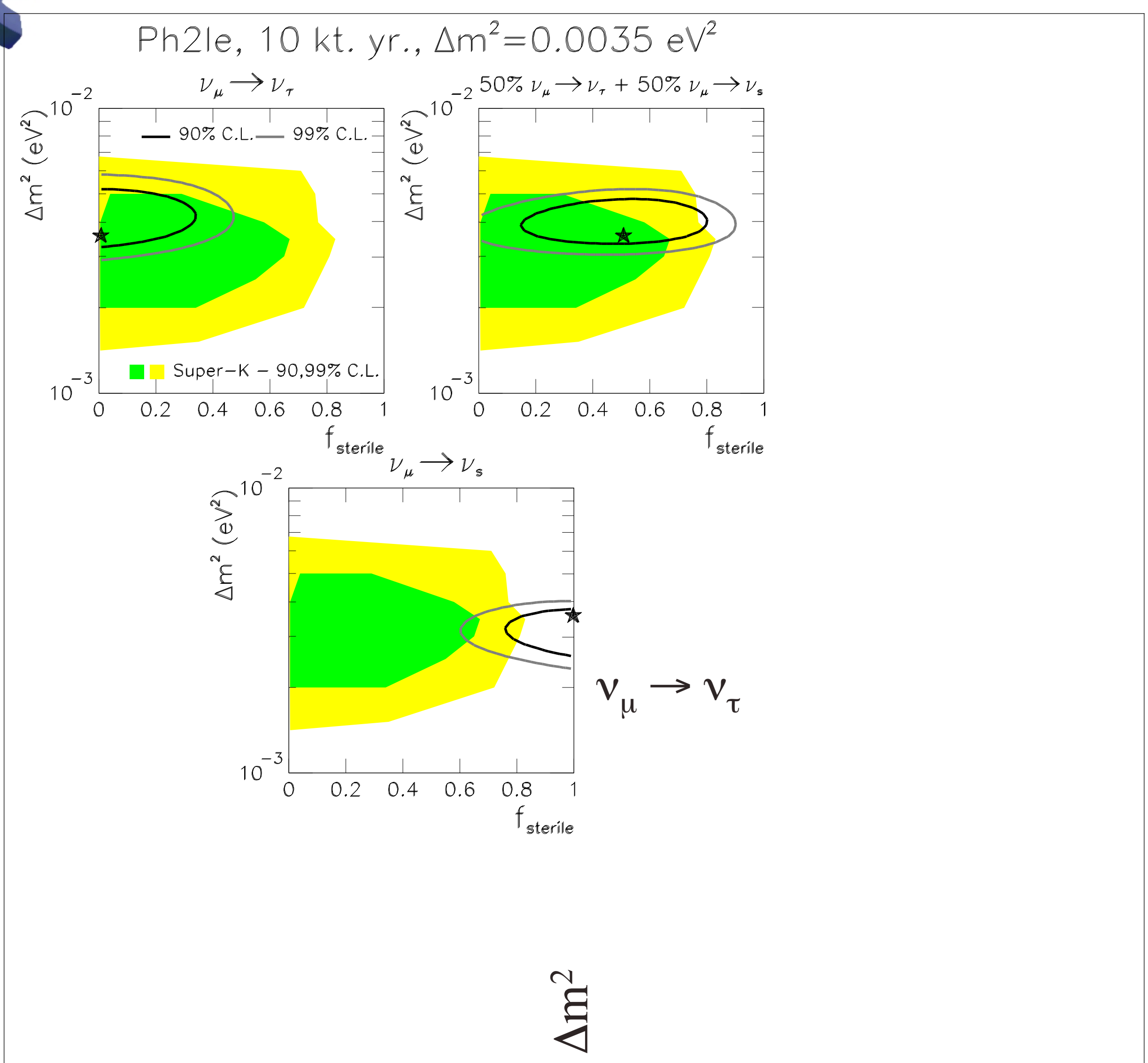


$\nu_\mu \rightarrow \nu_s$ implies a depletion of NC events

Compared to $\nu_\mu \rightarrow \nu_\tau$

Rate and shape of visible energy spectrum for NC-like events discriminates between $\nu_\mu \rightarrow \nu_s$ and $\nu_\mu \rightarrow \nu_\tau$

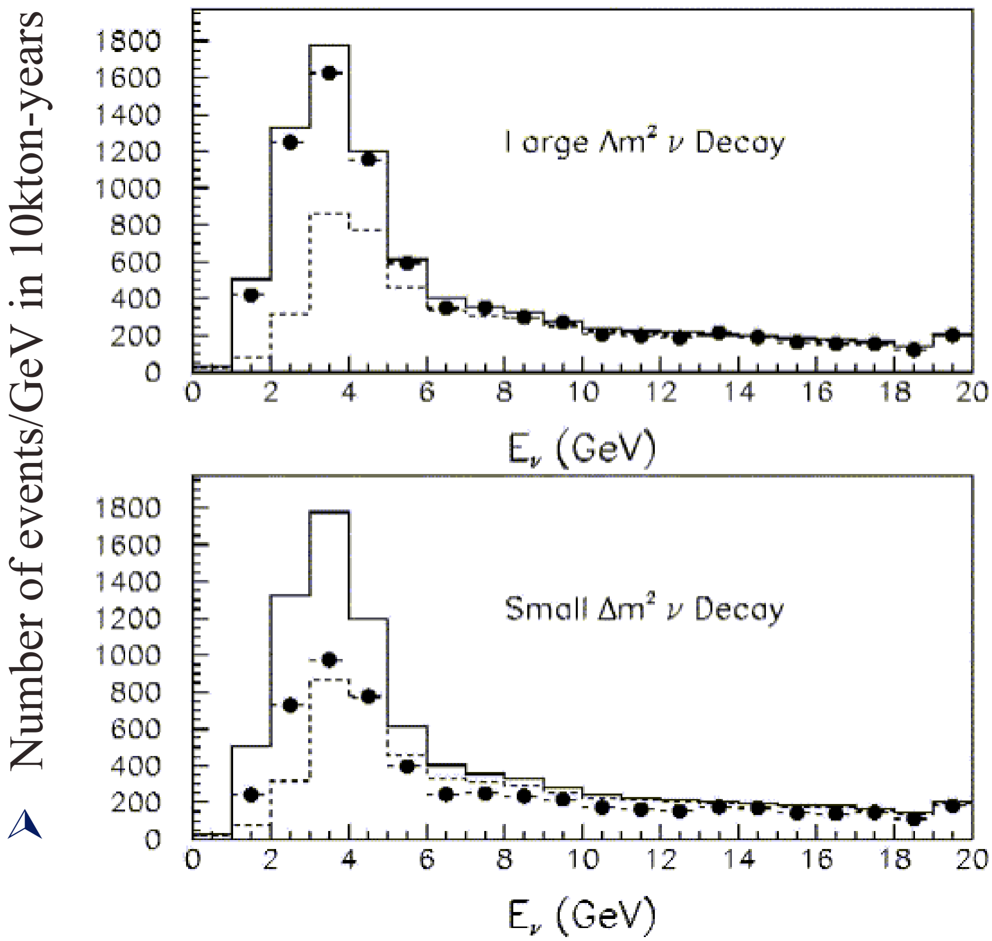
$\nu_\mu \rightarrow \nu_s$ or $\nu_\mu \rightarrow \nu_\tau$



SuperK allowed regions based on analysis of hep-ph/0009299 Fogli, Lisi & Marrone

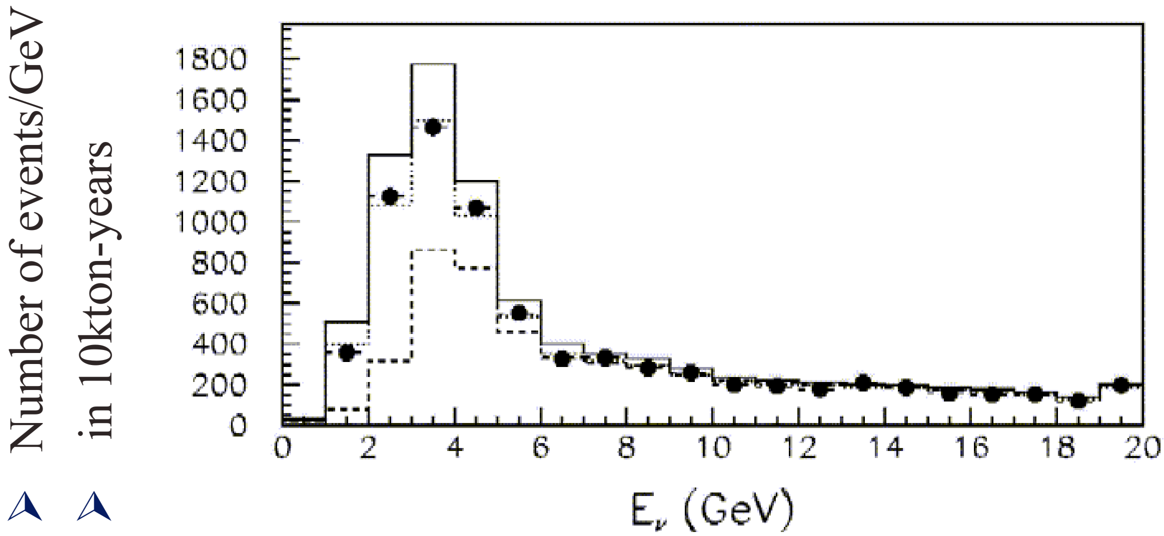
Have also done 4-flavor analysis

Decay or Oscillation?



- Solid-no oscillations
- Dashed – neutrino oscillations
  - $\delta m^2 = 3 \times 10^{-3} eV^2$, $\sin^2 2\theta = 1$
- Points: neutrino decay, two different lifetimes
  - Barger *et al*, *PRL* **82** (1999)
- Efficiency and energy smearing included

Extra Dimensions?



- Solid-no oscillations
- Dashed – neutrino oscillations
  - $\delta m^2 = 3x10^{-3} eV^2$, $\sin^2 2\theta = 1$
- Points:extra dimensions model that fits SuperK data
  - Barbieri, Creminelli, Strumia, hep-ph/002199
- Efficiency and energy smearing included

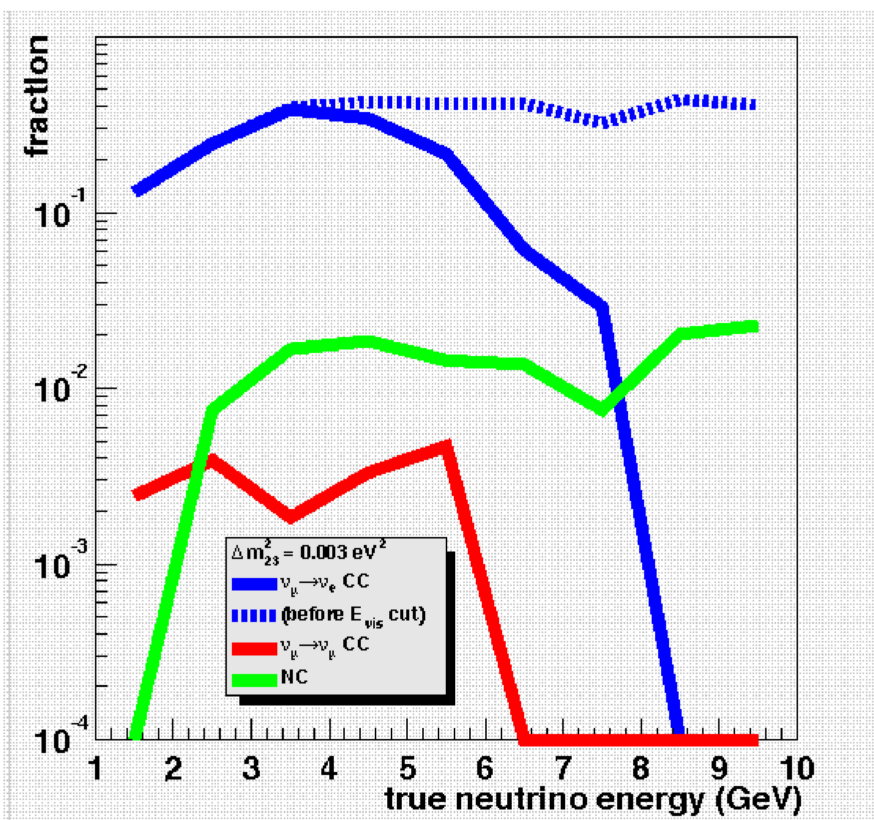
Searching for $\nu_\mu \rightarrow \nu_e$

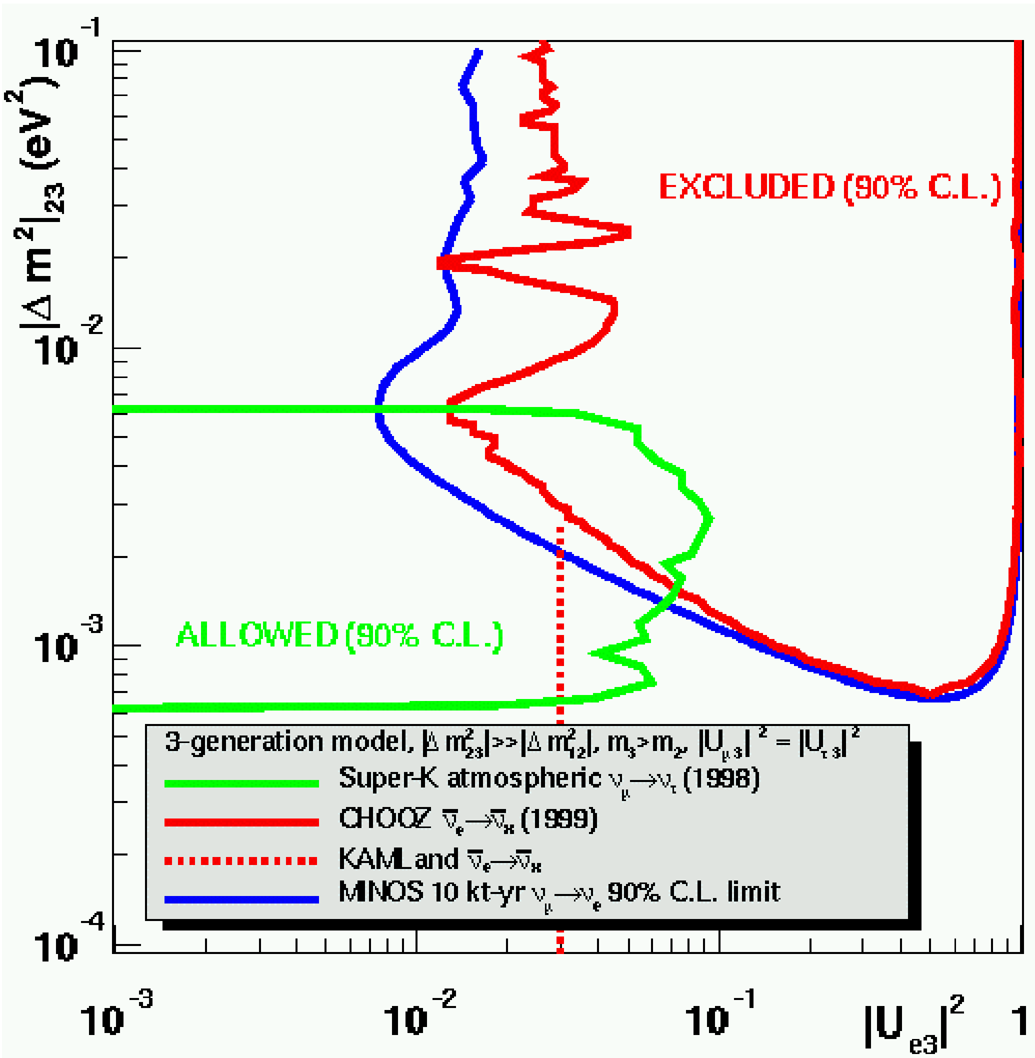
Before Any Cuts: (per 10 kt-yrs)

- 3906 $\nu_\mu \rightarrow \nu_\mu$ CC events
- 1802 NC events
- 70 Beam ν_e CC events
- 46 $\nu_\mu \rightarrow \nu_\tau$ CC events
- 30 $\nu_\mu \rightarrow \nu_e$ events IF
  $|Ue3|2=.01, \Delta m^2=.003 eV^2$

After cuts

- 3.9 $\nu_\mu \rightarrow \nu_\mu$
- 27.2 NC events
- 5.6 Beam ν_e events
- 3.0 $\nu_\mu \rightarrow \nu_\tau$ events
- 8.5 $\nu_\mu \rightarrow \nu_e$!!!



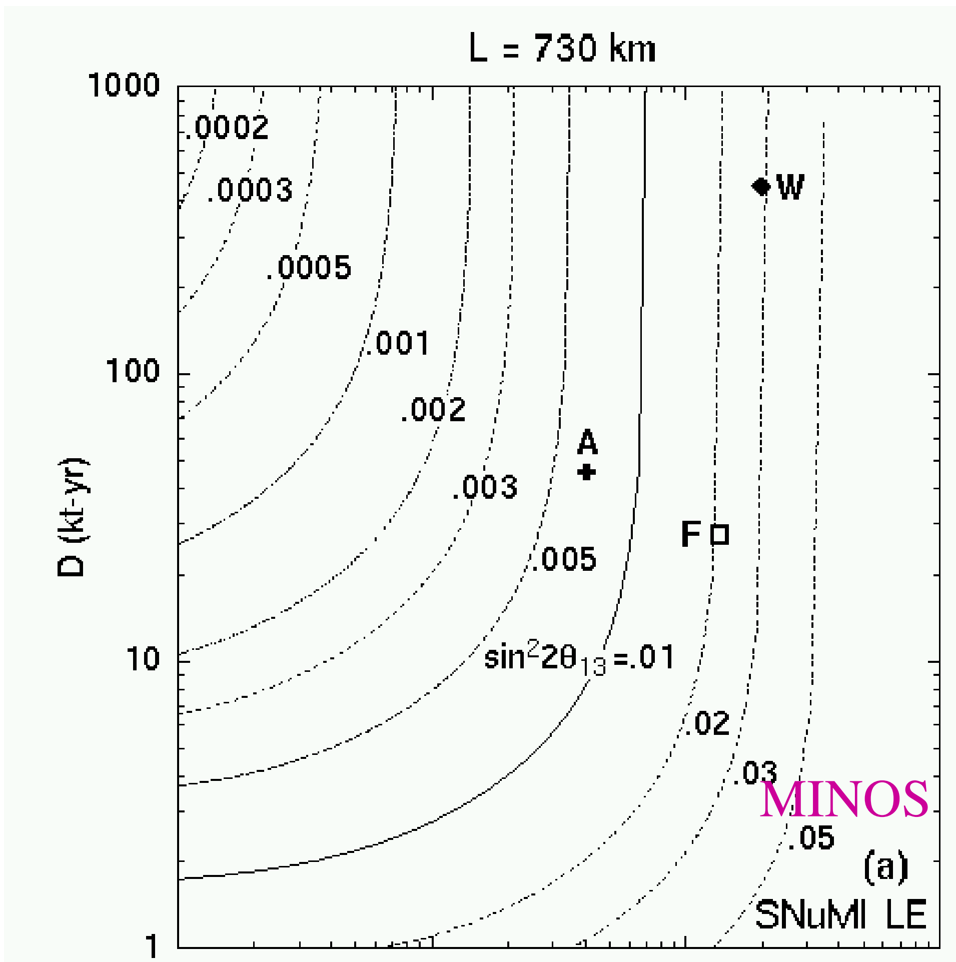


$U_{e3}^2 < 0.013$
@ $\Delta m^2 > 3 \times 10^{-3}$ eV^2
$\sin^2 2\theta_{13} < 0.05$
@ $\Delta m^2 > 3 \times 10^{-3}$ eV^2

Matter effects included
$\Delta m^2_{solar} = 3 \times 10^{-5}$ eV^2
$\theta_{12} = \theta_{23} = \pi/4$
10% systematic error on background

$\nu_\mu \rightarrow \nu_e$ with this Beamline?

Θ_{13} Sensitivity with 4xMINOS vs background fraction and exposure in kton-years Barger *et al*, *PRD* **63** (2001)



Matter effects included, assuming 10% δ(bkgd)

$\Delta m^2_{atm} = 3 \times 10^{-3}$ eV^2, $\theta_{12} = \theta_{23} = \pi/4$

To do much better, need lower backgrounds first, AND more beam (second)

Schedule (assuming full funding in 2002 and 2003)

- October, 2000 – Start of Scintillator Module Production
- December, 2000 – Soudan Cavern Excavation Complete
- August, 2001 - Start of Far Detector Installation
- May, 2002 –Beamline Excavation Complete
- September, 2002 – Completion of 1st MINOS SuperModule
- October, 2002 –Start of Installation of Beam Components and Near Detector
- June, 2003 – Start of System Commissioning
- August, 2003 – Completion of Detector Installation
- October 2004 – Start of Physics Data Taking

Summary

- Civil construction at Soudan almost complete - detector assembly starts August 2001
- Civil construction at Fermilab is proceeding - the target hall is dug and the TBM has started excavating the decay tunnel. The detector shaft is mostly dug
- Detector construction is on schedule
- Physics measurements using the low energy beam:
  - No-oscillation hypothesis - MINOS will cover the SuperK allowed region at 90% C.L
  - Oscillations hypothesis - MINOS will be able to confirm SuperK results and also observe the first oscillation maximum
  - For $\Delta m^2 = 0.0035$ eV^2 and $\sin^2 2\theta \sim 0.9$ should be able to determine the mixing parameters to better than 10% at 68% C.L.
  - Improve the limit on $\nu_\mu \rightarrow \nu_e$ by about factor of 2 with 10 kton-yr of data
  - Reduce the fraction of $\nu_\mu \rightarrow \nu_s$ allowed at 90% CL to ~ 30% - down from current 67% at SuperK
- Looking forward to beam at the end of 2004