

NUMI



MINOS

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# MINOS Status

WIN '03

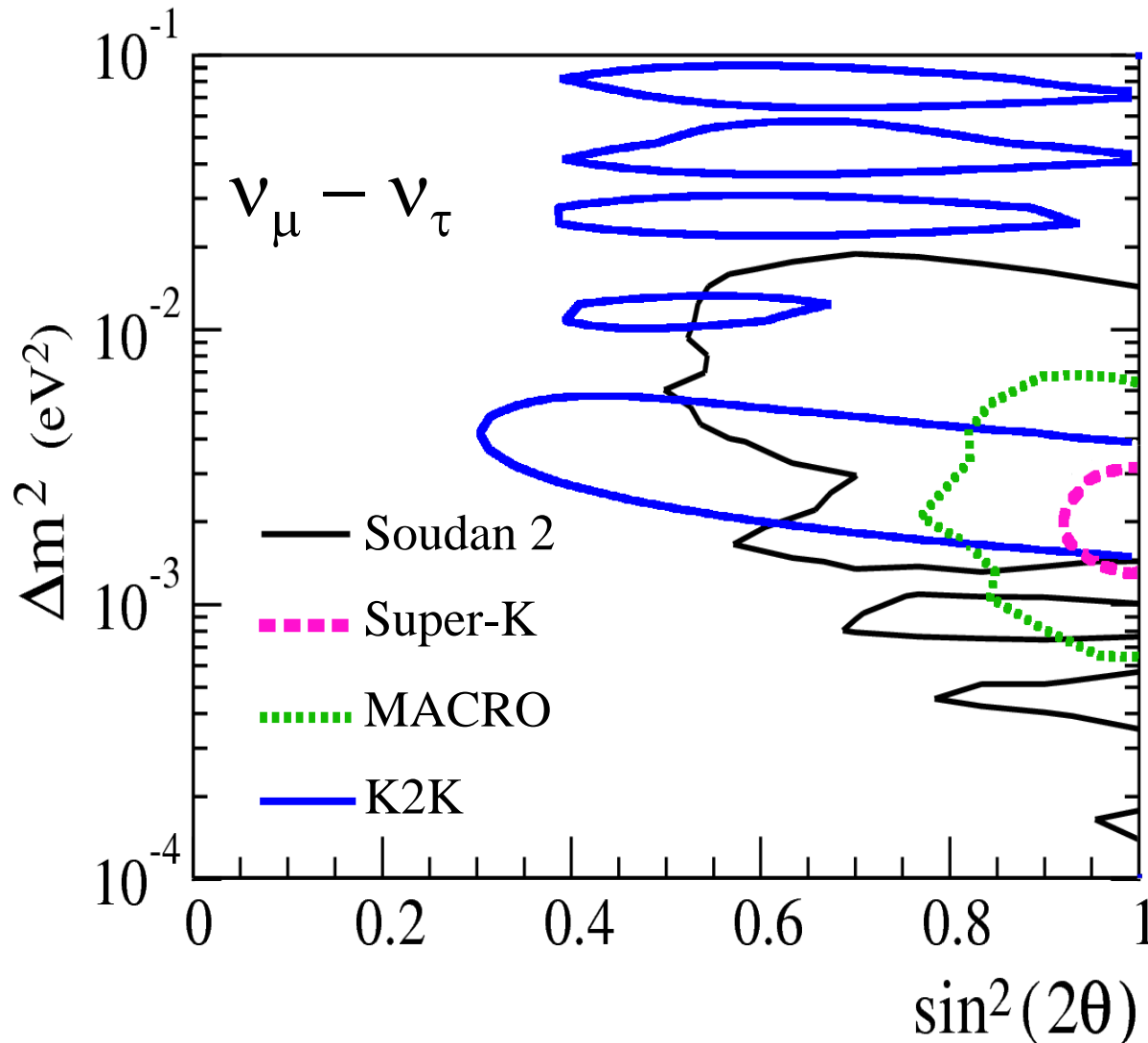
Jeff Nelson

Fermilab



- MINOS overview
- Status of...
  - > Far detector
  - > Beamline
  - > Near detector
  - > Calibration data
- Atmospheric neutrinos
  - > First data
- Oscillation measurements
- What you'll see ... what you won't

# Currently Allowed Oscillation Parameters



[hep-ex/0307069](http://hep-ex/0307069) (Soudan 2)  
[hep-ex/0212007](http://hep-ex/0212007) (K2K)  
[hep-ex/0106049](http://hep-ex/0106049) (MACRO)  
 Hayato, EPS 2003 (Super-K)

# MINOS Physics Goals

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- Demonstrate oscillatory behavior
  - > Precise measurement of CC energy distribution between near & far detectors (2-4% sys. uncertainty in  $E_\nu$  per GeV bin)
  - > "Standard" or non-standard oscillations?
- Precise measurement of oscillation parameters
  - >  $\Delta m^2_{23}$  at  $\sim 10\%$
  - > How close to 1.0 is  $\sin^2 2\theta_{23}$ ? (Can test to  $\sim 5\%$  level)
    - Are we looking at a new fundamental symmetry?
- Improved determination of flavor participation
  - > # of CC  $\nu_\mu$  events far/near (for  $\nu_\mu \rightarrow \nu_x$  at about  $\sim 2\%$ )
  - > # of CC  $\nu_e$  events far/near (for  $\nu_\mu \rightarrow \nu_e$  down to about 2%)
  - > # of NC events far/near (for  $\nu_\mu \rightarrow \nu_s$  down to about 10%)
- Direct measurement of atmospheric  $\nu$  vs  $\bar{\nu}$ 
  - > CPT Violation

# MINOS Collaboration



Argonne • Athens • Brookhaven • Caltech • Cambridge • Campinas • Fermilab  
College de France • Harvard • IIT • Indiana • ITEP-Moscow • Lebedev • Livermore Macalester •  
Minnesota-Twin Cities • Minnesota-Duluth • Oxford • Pittsburgh • Protvino Rutherford • Sao  
Paulo • South Carolina Stanford • Sussex • Texas A&M  
Texas-Austin • Tufts • UCL • Western Washington Wisconsin

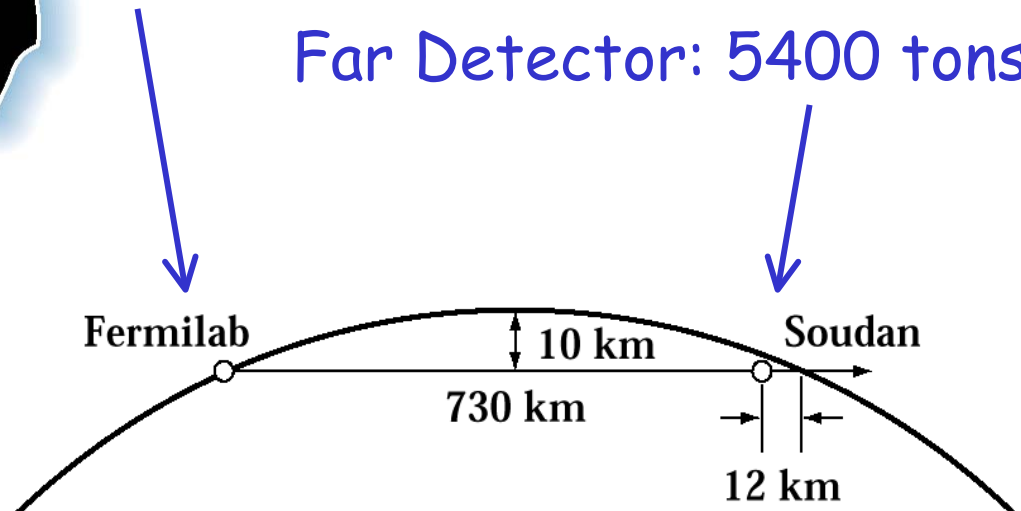
# MINOS Detectors & NuMI Beam



A 2-detector long-baseline neutrino oscillation experiment in a beam from Fermilab's Main Injector

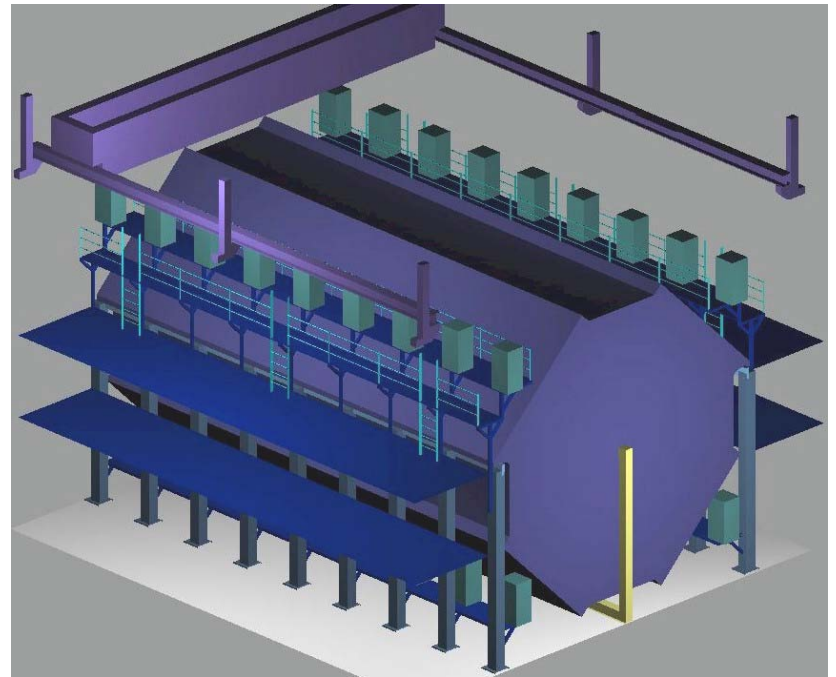
Near Detector: 980 tons

Far Detector: 5400 tons



# The MINOS Far Detector

- 8m Octagonal Tracking Calorimeter
- 2 sections, 15m each
- 486 planes of steel & scintillator
- 95,000 scintillator strips
  - Largest area by  $\sim 10X$
- 5.4 kT total mass



Half of the MINOS Far Detector







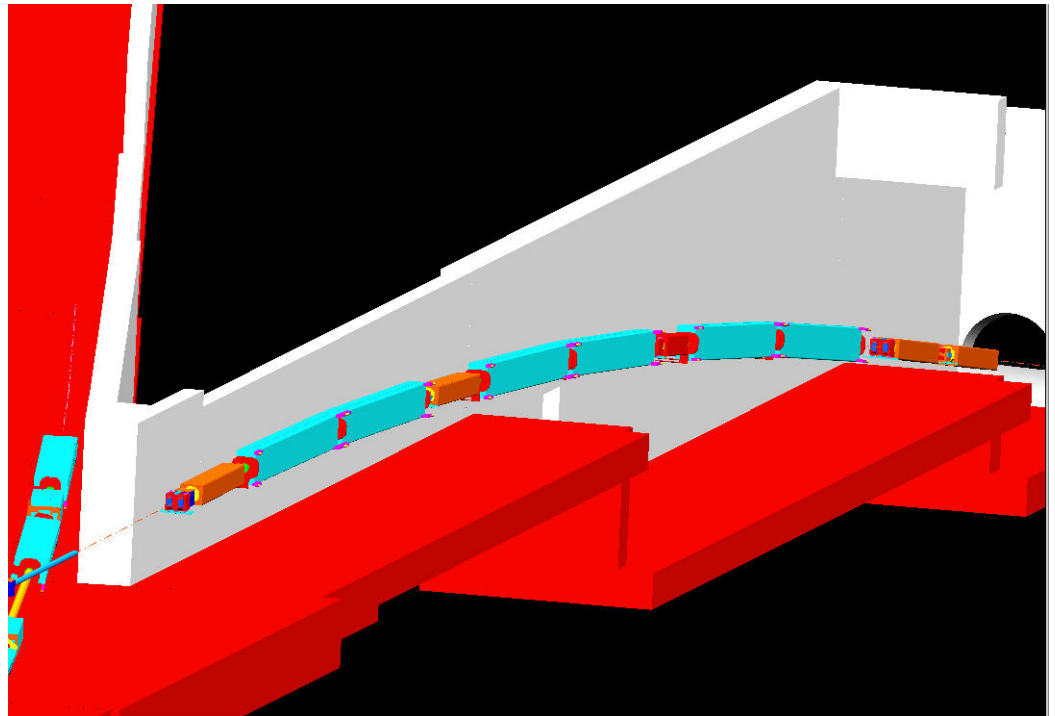
# On the Fermilab Site



# Out of the Main Injector Work Started During Shutdown



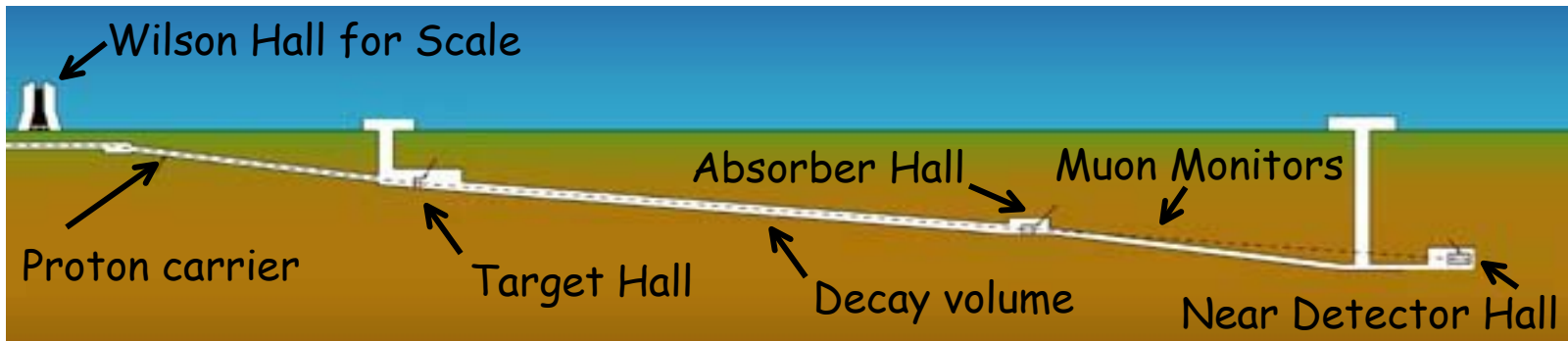
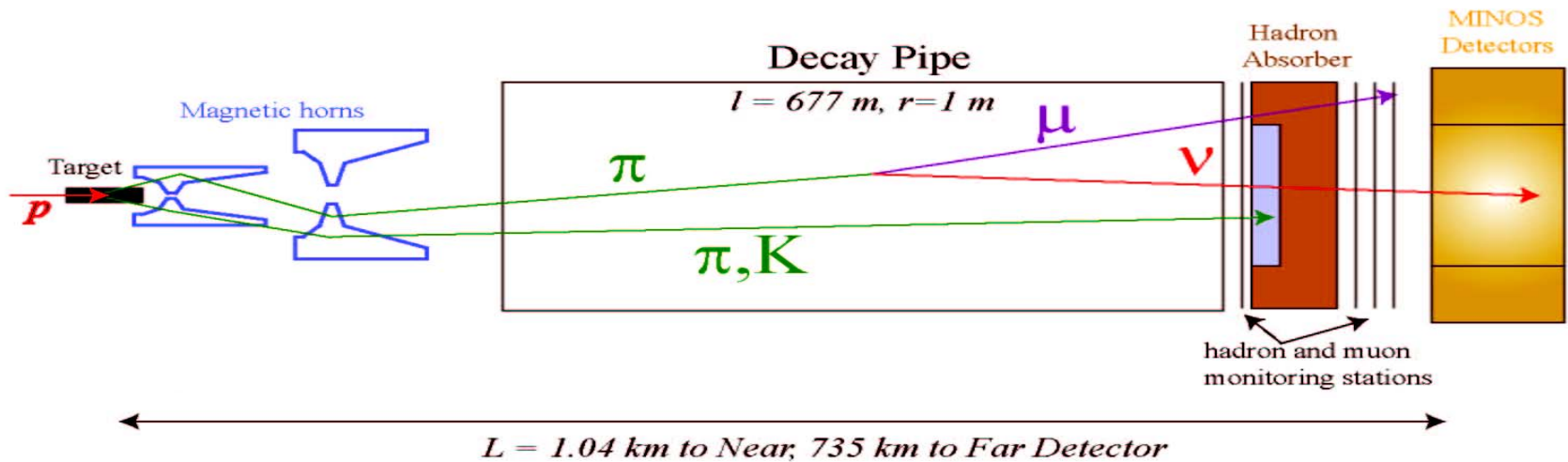
Drawing of the NuMI  
extraction line  
coming out of the MI  
below the Recycler



The main vertical  
bend to send the  
protons down into the  
NuMI tunnel

# The NuMI Beam

120 GeV/c protons strike graphite target  
 Magnetic horns focus charged mesons (pions and kaons)  
 Pions and kaons decay giving neutrinos



# NuMI Civil Construction (Virtual Tour)



# MINOS ND Hall



MINOS Access Tunnel (left) looking upstream  
MINOS Hall (right) looking upstream

# On the Surface

August



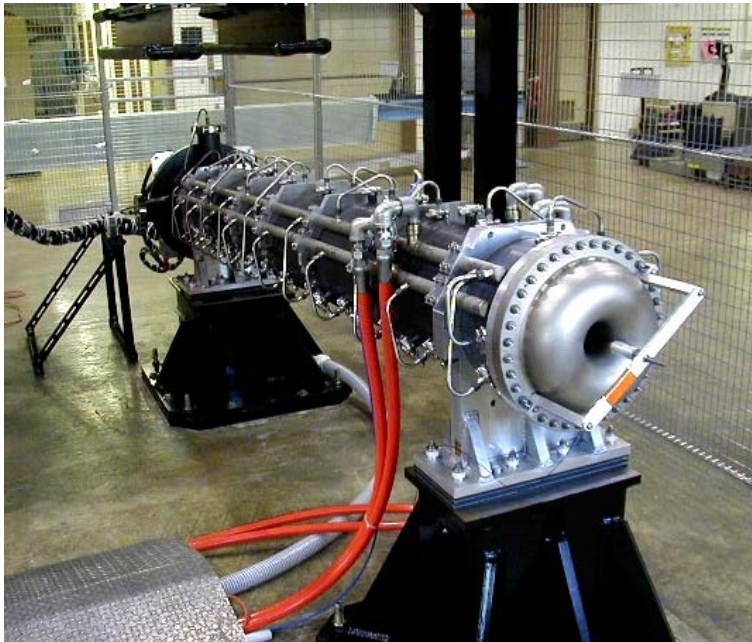
MINOS Surface Building

Target Surface Building

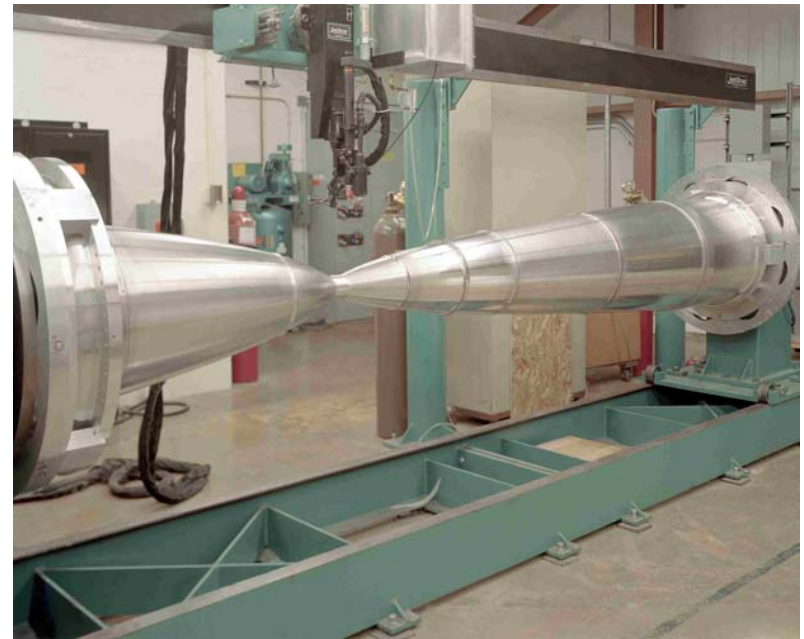
Sept



# NuMI Horns (Will See on Tour)



Horn 1 (spare) assembled  
for lifetime test

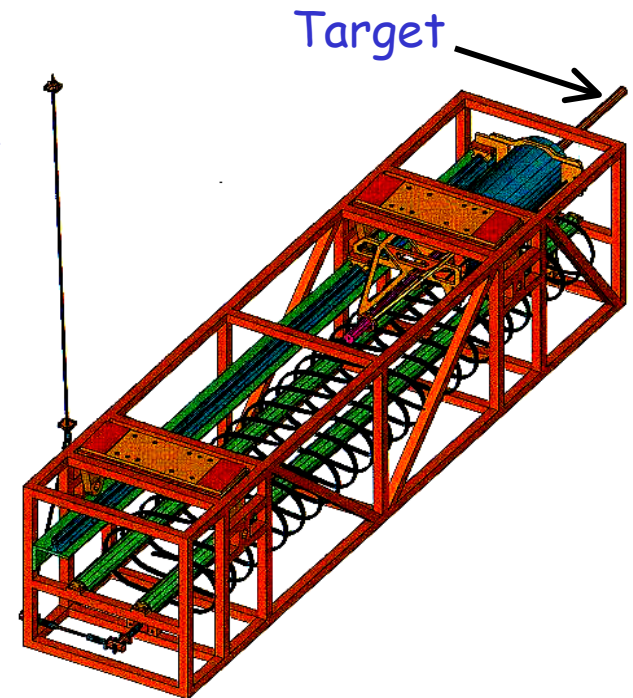
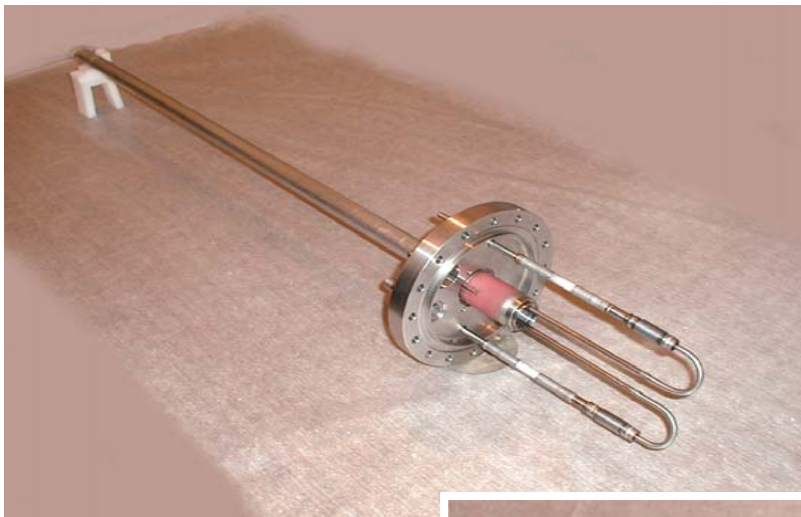


Horn 2 Inner Conductor

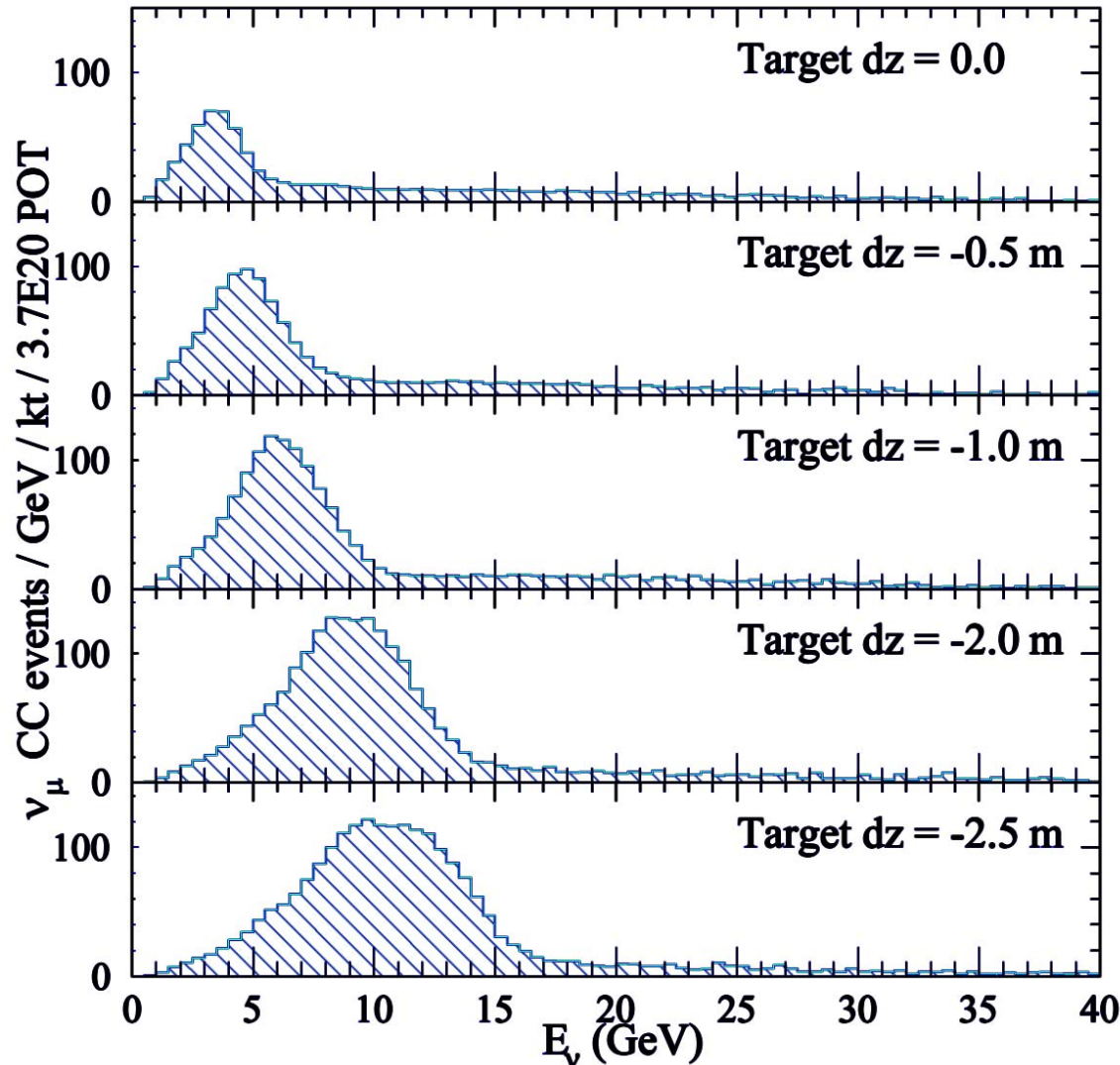


# Target & Carrier

- Carbon target can move up to 2.5m on beam axis along with water, vacuum & electric lines
- Provides variable neutrino beam energy with real time control



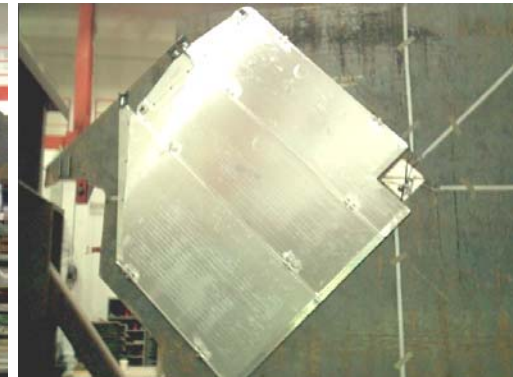
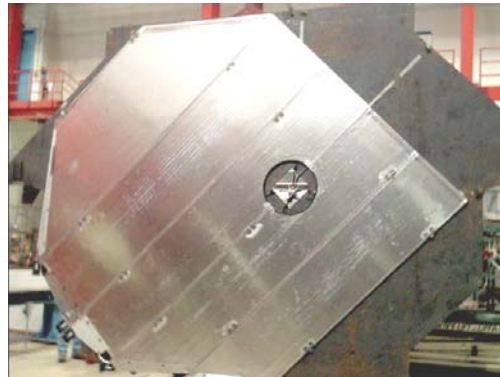
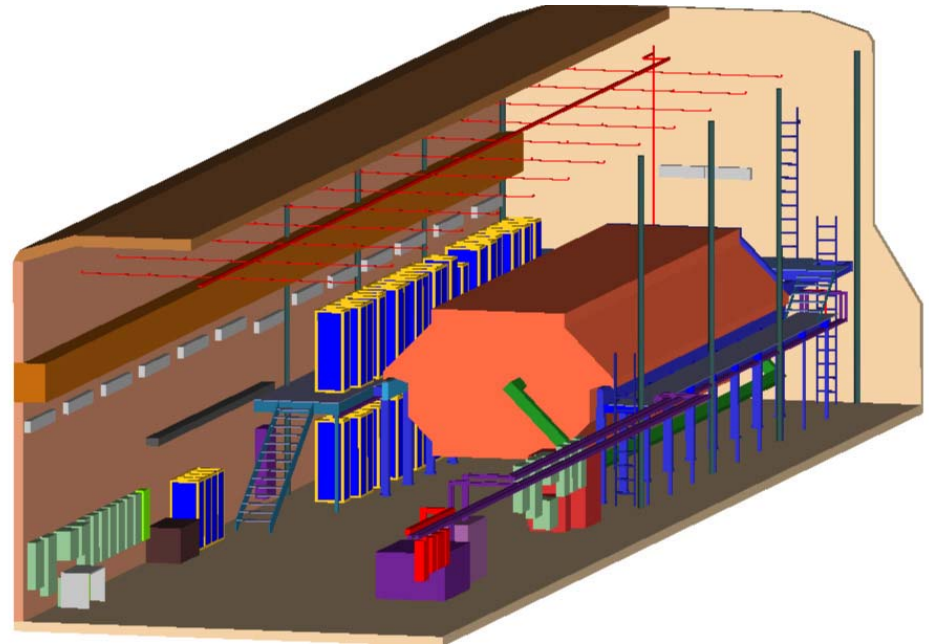
# NuMI Beam Spectra



- Different spectra can be obtained by
  - Moving the target or
  - Moving the 2<sup>nd</sup> horn

# Near Detector

- 3.8 x 4.8m "octagonal" steel & scintillator tracking calorimeter
- Same basic construction, sampling & response as the far detector
  - › Hamamatsu M64 PMT
  - › Faster Electronics (QIE)
- 282 planes of steel
- 153 planes of scintillator

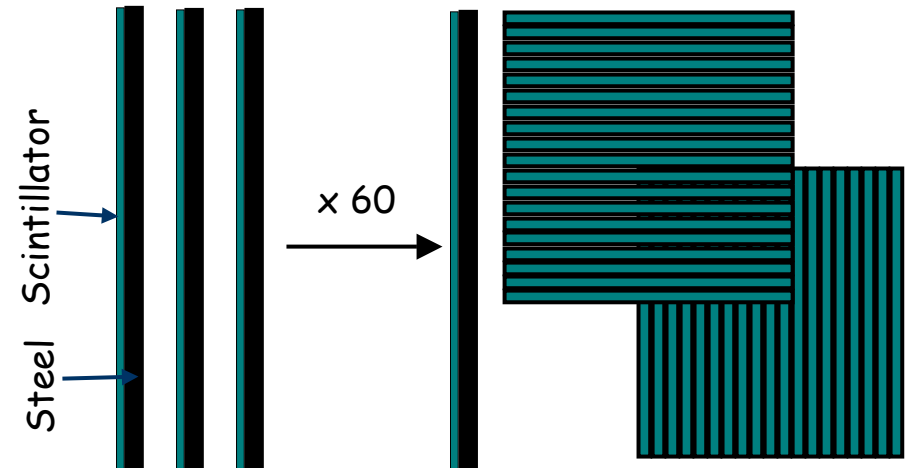
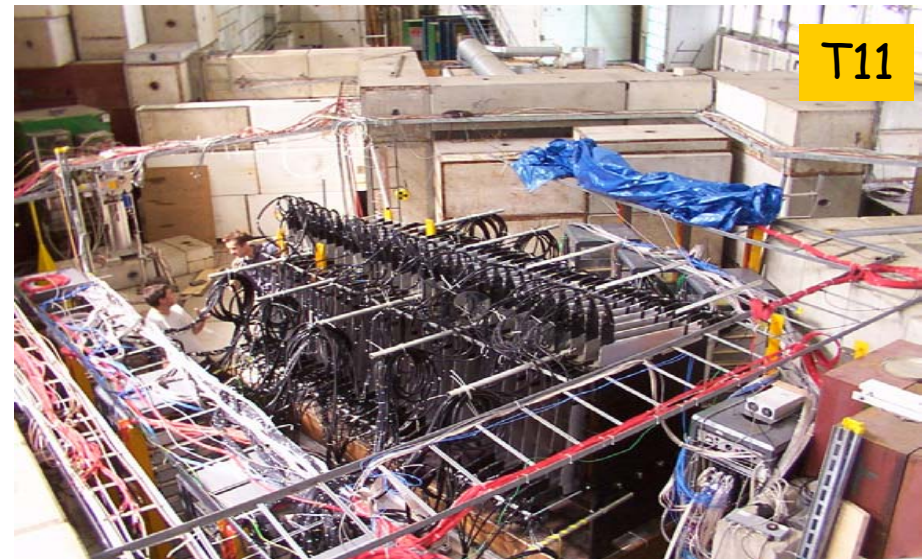


# New Muon Lab Staging Facility (Will See on Tour)

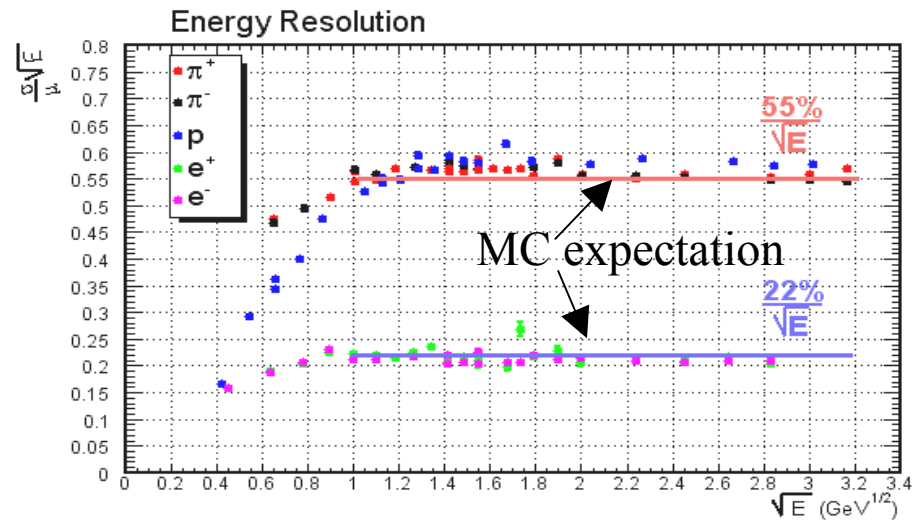
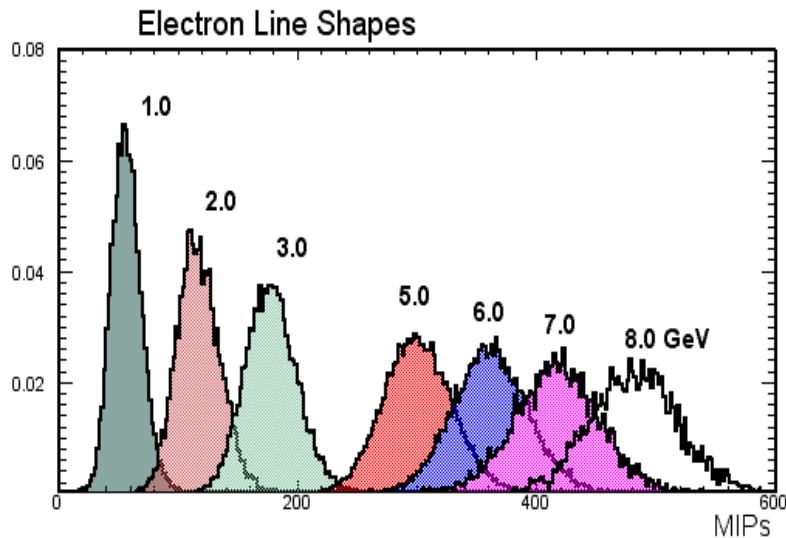
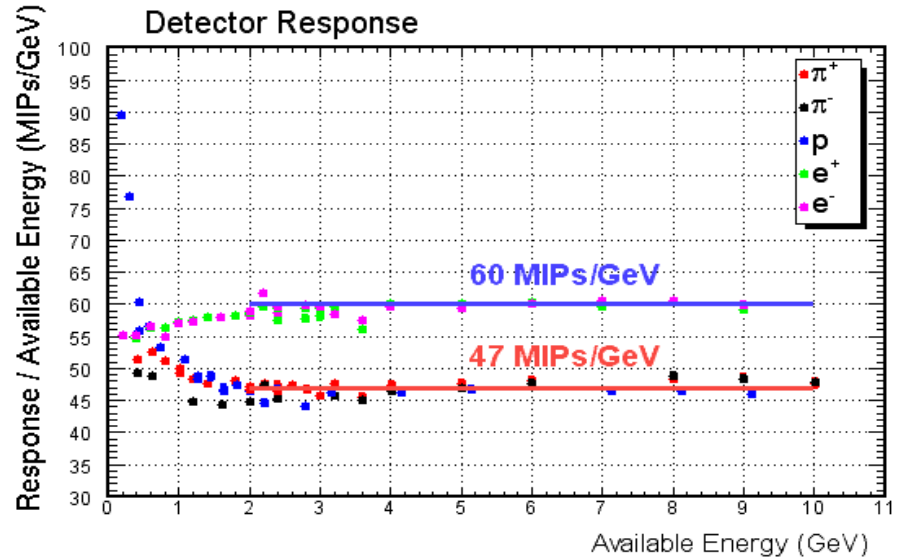
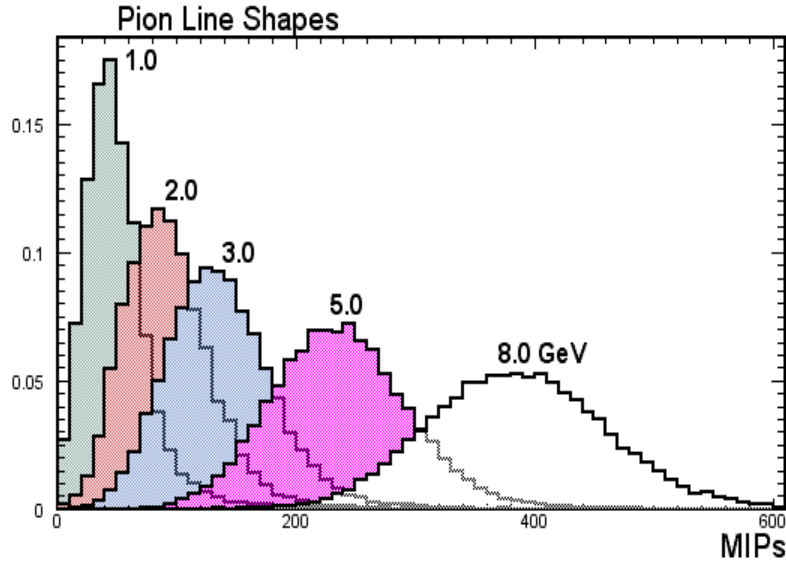


# The Calibration Detector

- A miniature version of MINOS detector
  - 1m x 1m x 3.7 m
  - 60 planes x 24 strips/plane
  - Readout technologies of both the near and far detectors
- Being exposed to electron, pion, proton and muon from 0.5 - 10 GeV/c momentum at the CERN PS
- Goals
  - EM & hadron energy response
  - EM & hadron event topology
  - Near/Far readout comparison



# Particle Responses (Preliminary)



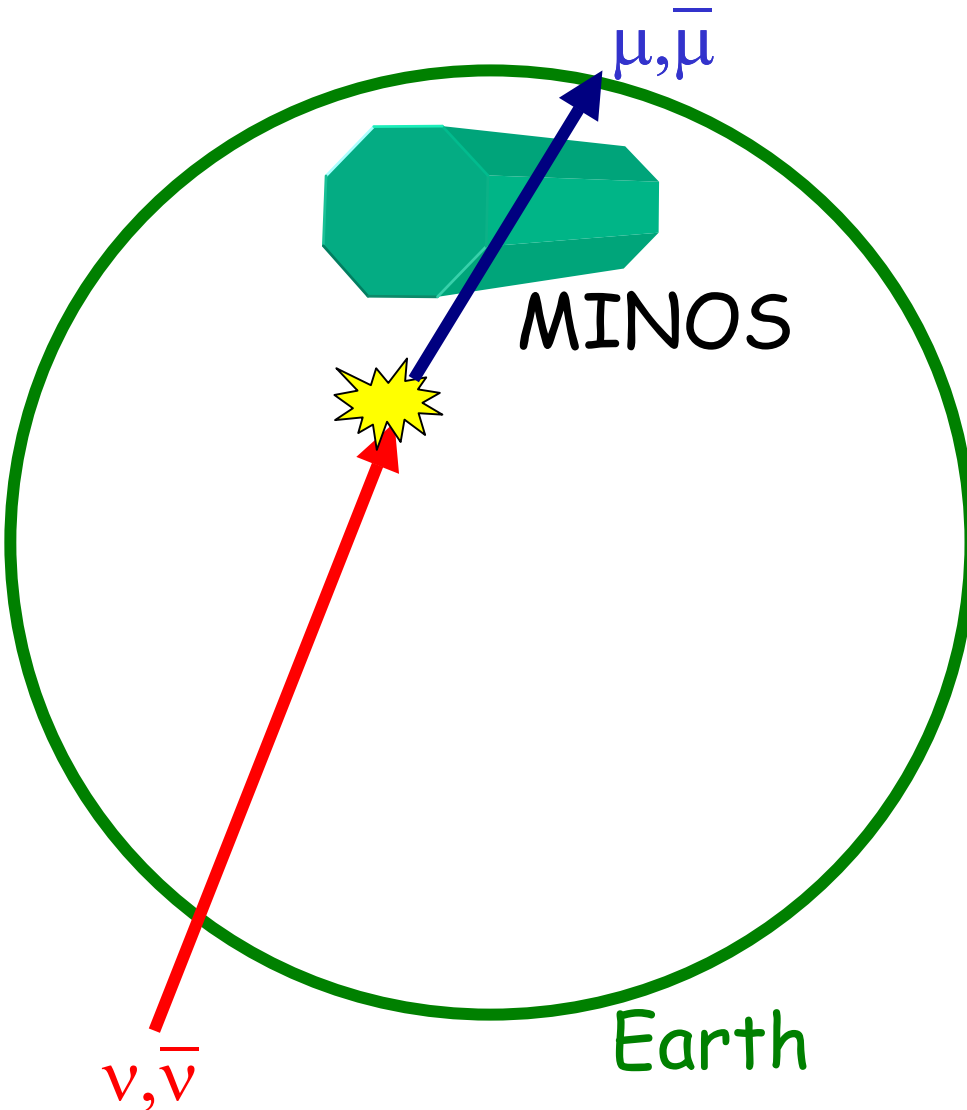
# Atmospheric Neutrinos in MINOS

- MINOS is the first large deep underground detector with a magnetic field
  - > Measures for Q & p of muons  $\sim 0.5 - 100 \text{ GeV}/c$
  - > Full L/E measurement even if  $\mu$  exits detector
- Obtain event direction from timing & topology
- Able to separate CC  $\nu_\mu$  and  $\bar{\nu}_\mu$  from NC &  $\nu_e$  events over a broad energy range (if  $p_\mu > \sim 1 \text{ GeV}/c$ )
- **We can directly test if atmospheric  $\nu_\mu$  and  $\bar{\nu}_\mu$  oscillate in the same way**

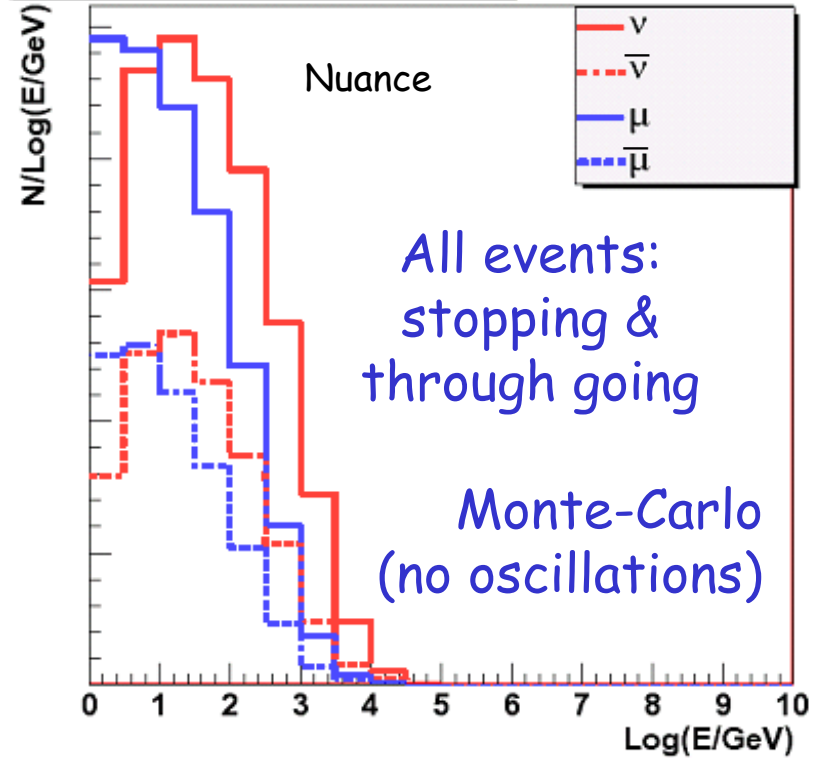
Events in 24 kT years for  $\Delta m^2 = 0.003 \text{ eV}^2$ ,  $\sin^2 2\theta = 1.0$

	Neutrino	Antineutrino
Reco'd contained vertex with muon	440	260
Reco'd upward going muon	280	120

# Upward-Going Muons



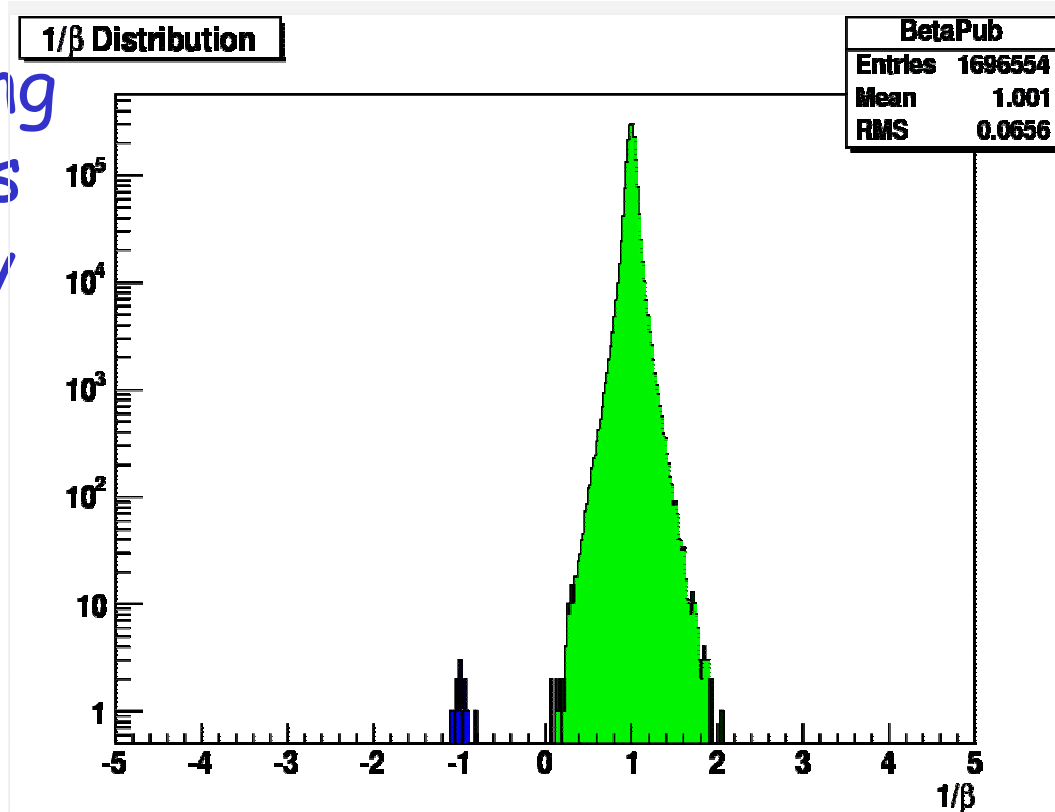
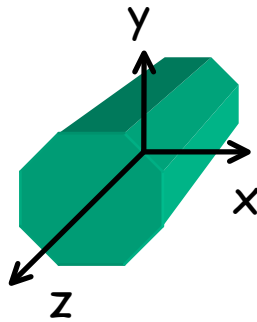
Energy distribution





# Direction Determination

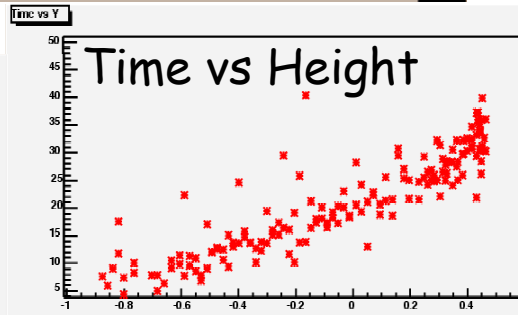
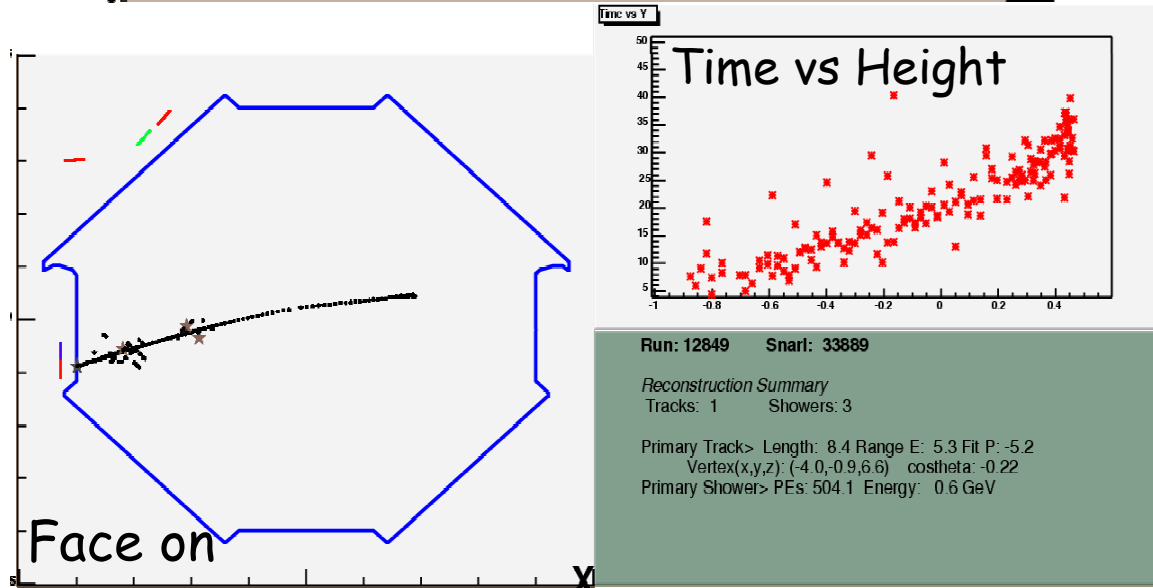
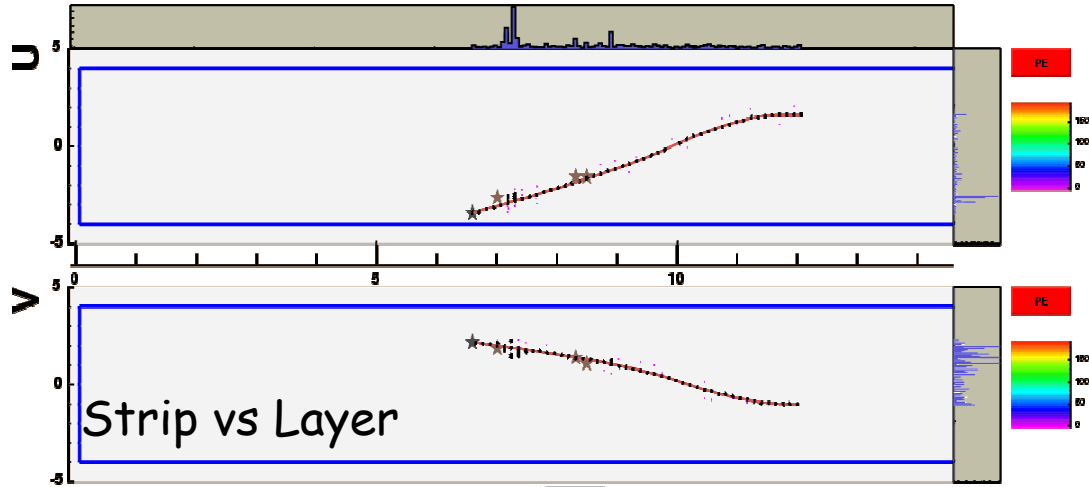
- Use  $y$  direction timing and direction cosines at vertex to identify upward-going muons



- Tight  $1/\beta$  ( $=c/v$ ) distribution indicates good timing
- Negative  $1/\beta$  values indicate upward-going muons

# Example Upward Muon

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



Run: 12849 Snarl: 33889

Reconstruction Summary  
Tracks: 1 Showers: 3

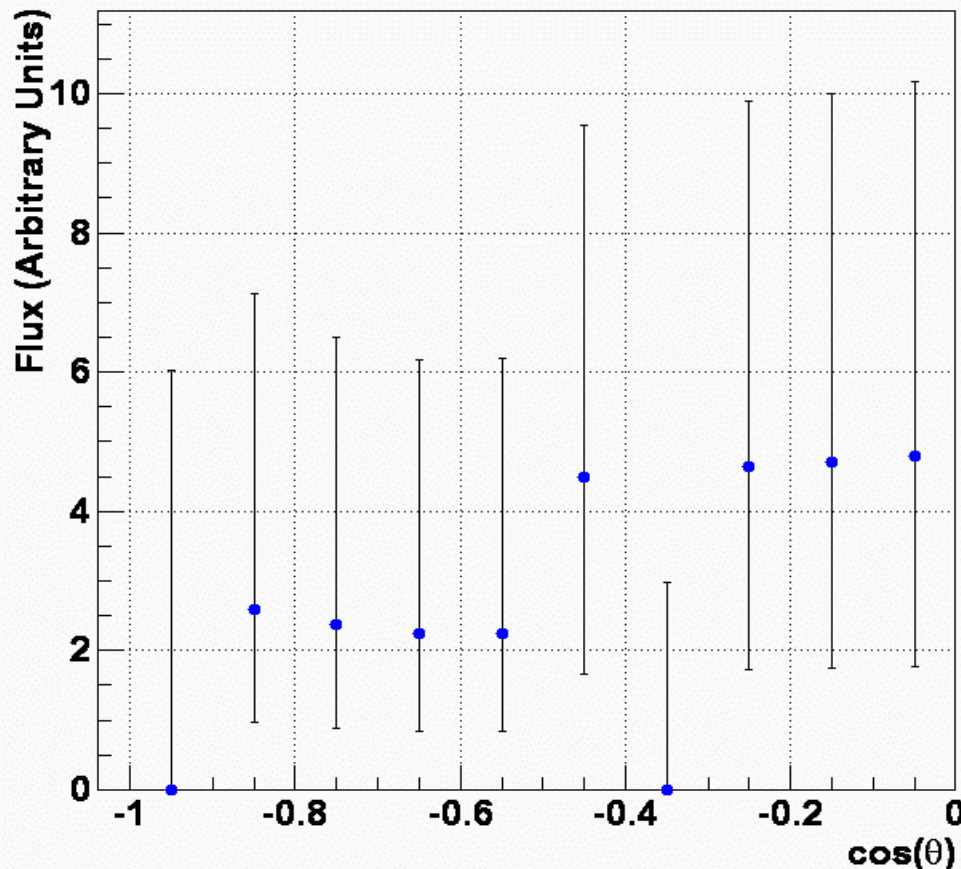
Primary Track> Length: 8.4 Range E: 5.3 Fit P: -5.2  
Vertex(x,y,z): (-4.0,-0.9,6.6) costheta: -0.22

Primary Shower> PEs: 504.1 Energy: 0.6 GeV

# Upward-Going Muon Flux

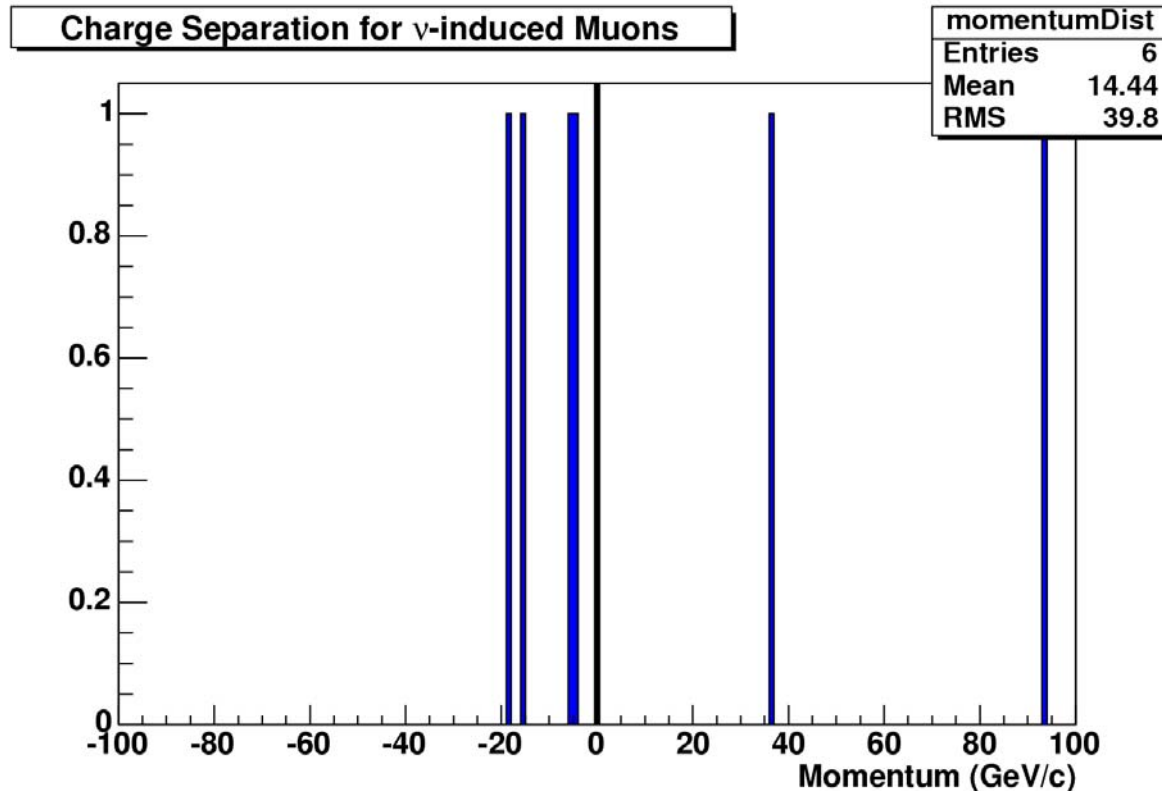
## Preliminary

**MINOS Summed Upward-Going Flux**



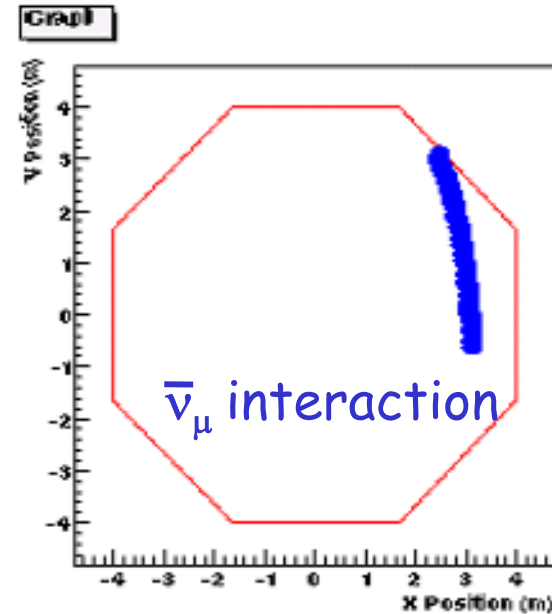
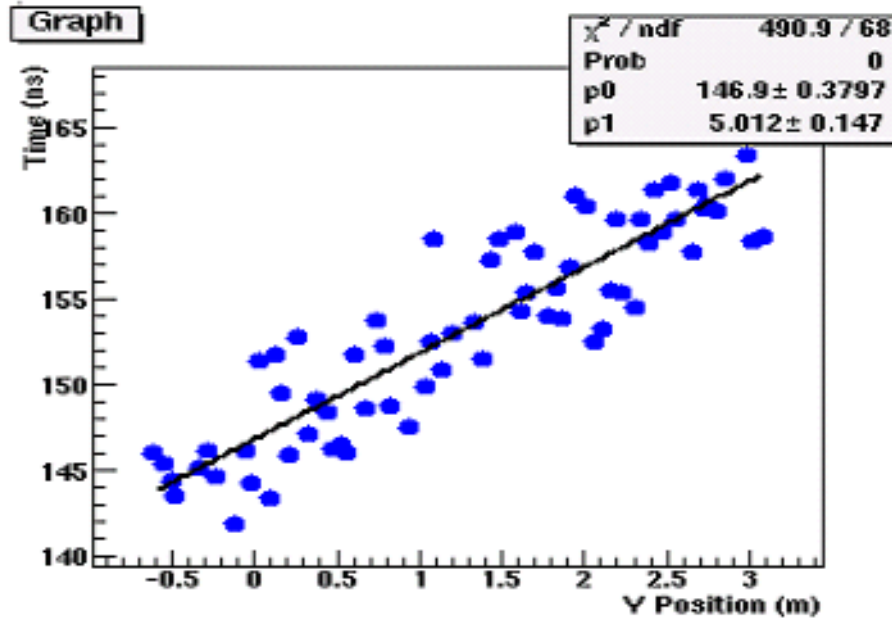
- Horizon at  $\cos\theta = 0$
- Nadir at  $\cos\theta = -1$
- There are 12 upward going events in the data sample
  - > 8/02 -> 12/02
  - > Half of the detector magnetized
  - > 45% live during construction

# Charge & Momentum of Upward Going Muons



- $< 70$  GeV, charge & momentum are generally well determined
- $> 100$  GeV, the charge & momentum are not very reliably determined (at this time)

# A Medium Energy Contained Vertex Event

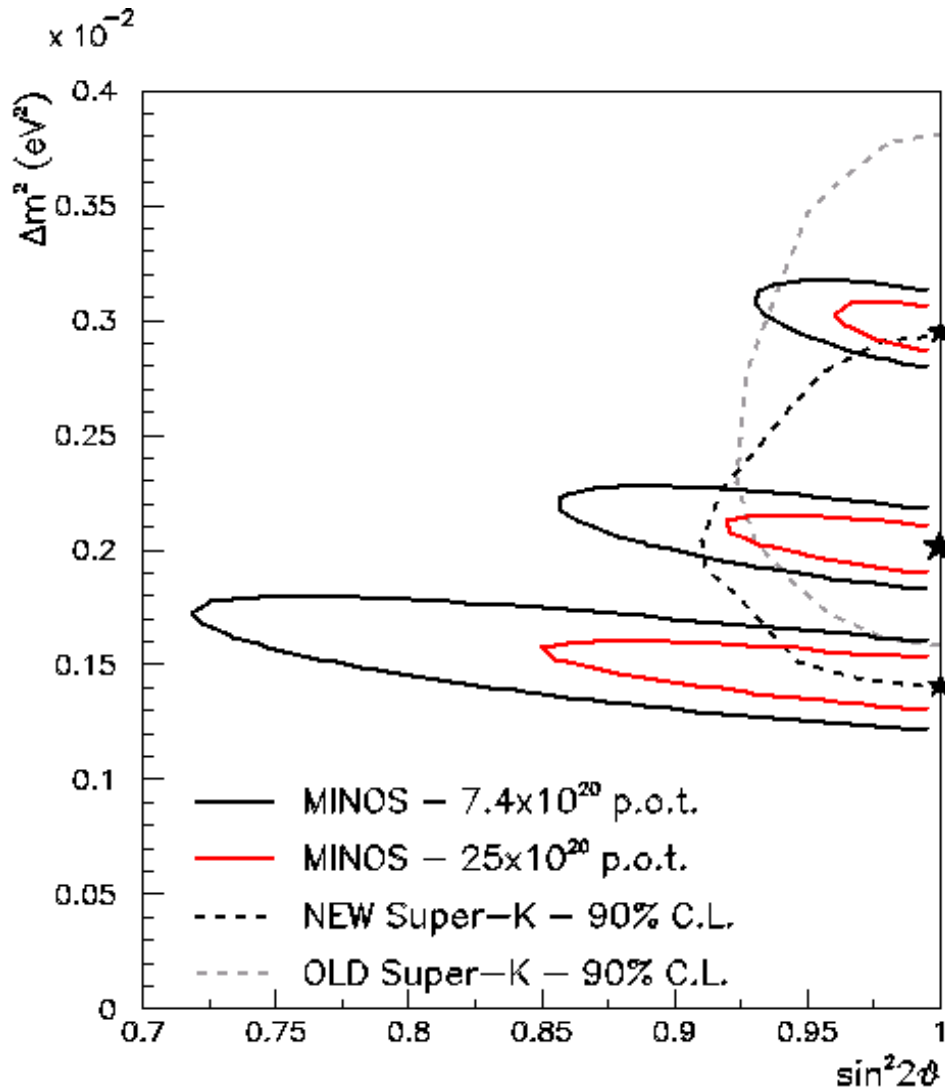


# Precision Measurements Require a Lot of Protons

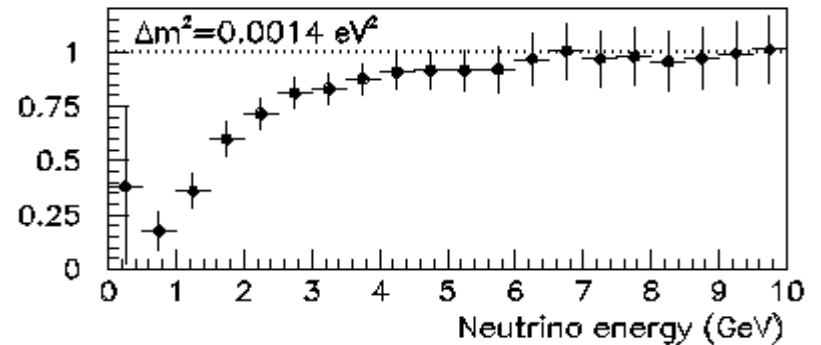
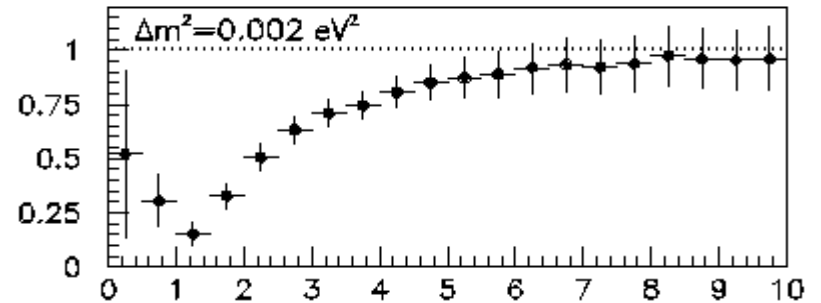
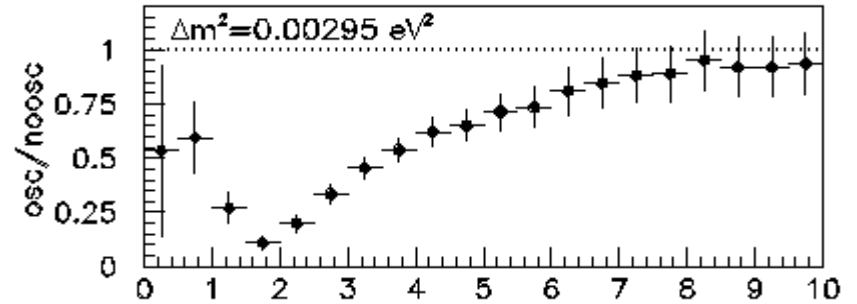
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- Draft Fermilab Long-Range Plan
  - › NuMI beam commissioning starting in December 2004
  - › 4 years of physics running for MINOS starting in April 2005
  - › Goal for protons on target in first year =  $2 - 2.5 \times 10^{20}$
  - › Plans are being developed for increased proton intensity
- New MINOS Run Request (May 2003)
  - › MINOS has submitted a request to Fermilab for **5 years** of running with a total of  **$25 \times 10^{20}$  protons on target**
  - › MINOS has provided updated physics sensitivity curves based on 7.4, 16 and  $25 \times 10^{20}$  total protons on target (PoT)
    - Original MINOS physics sensitivity was based on  $7.4 \times 10^{20}$  pot
  - › There are several options for providing this number of protons in a reasonable time scale

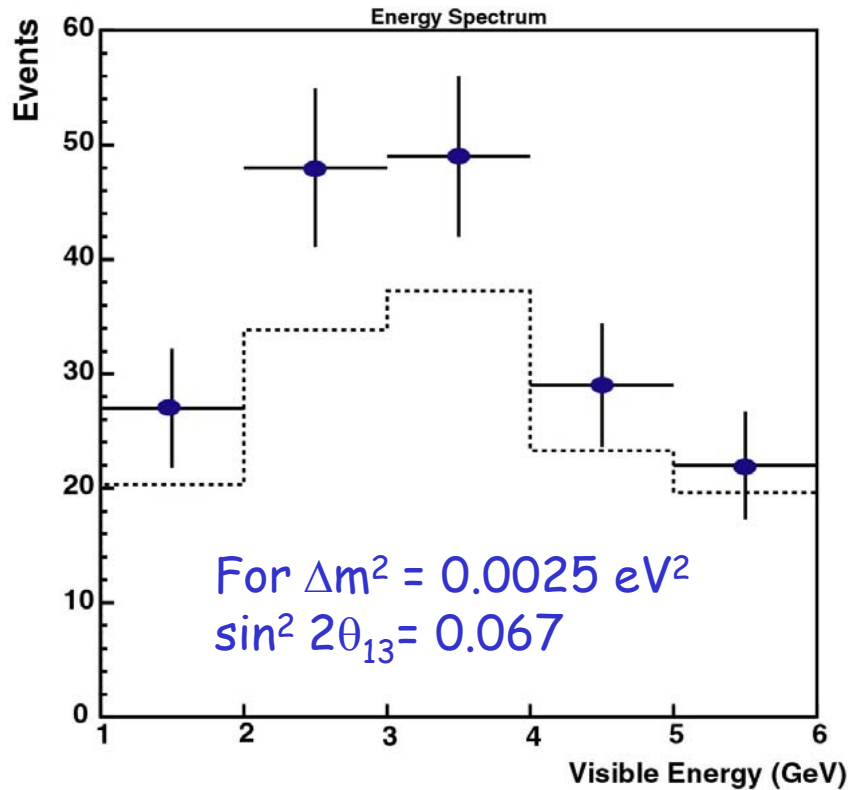
# Updated MINOS CC Sensitivity



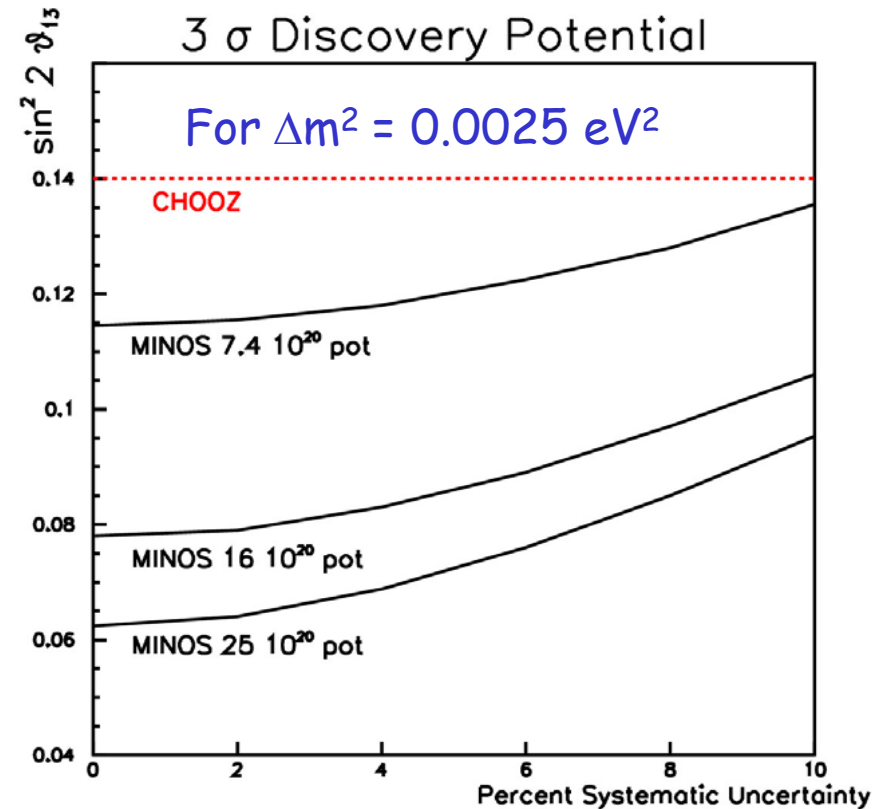
Spectrum ratios,  $7.4 \times 10^{20}$  p.o.t.



# Appearance of Electrons



Observed number of events identified as coming from  $\nu_e$  CC interactions with and without oscillations (25x10<sup>20</sup> protons on target)

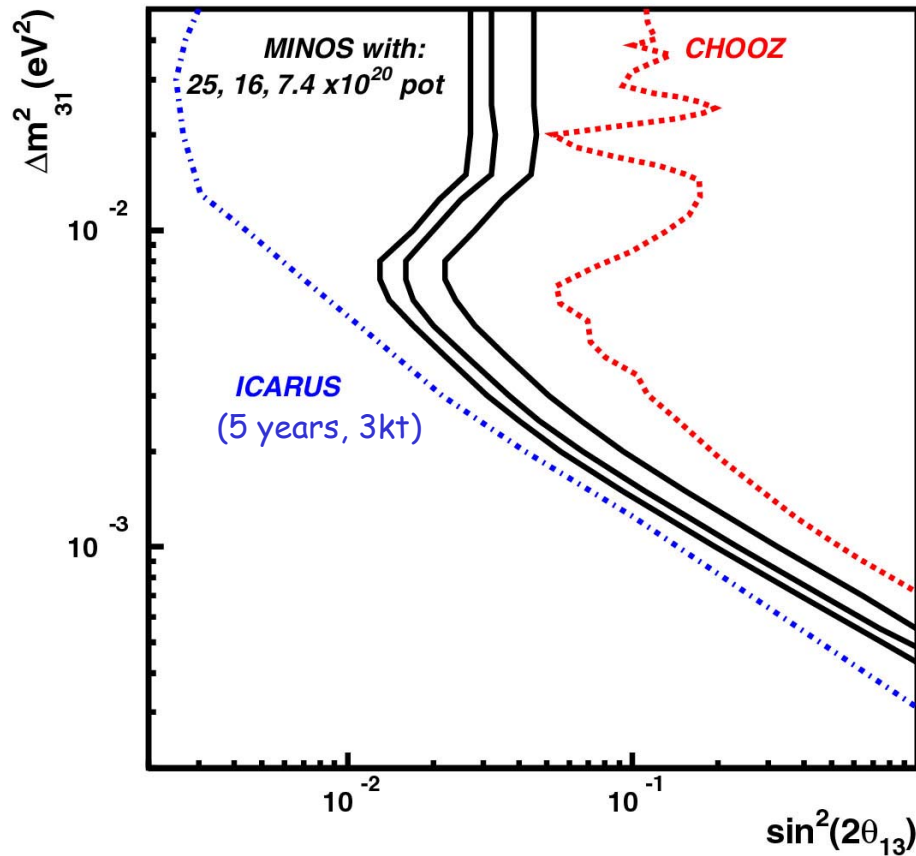


3  $\sigma$  discovery potential for three different levels of protons on target and versus systematic uncertainty on the background

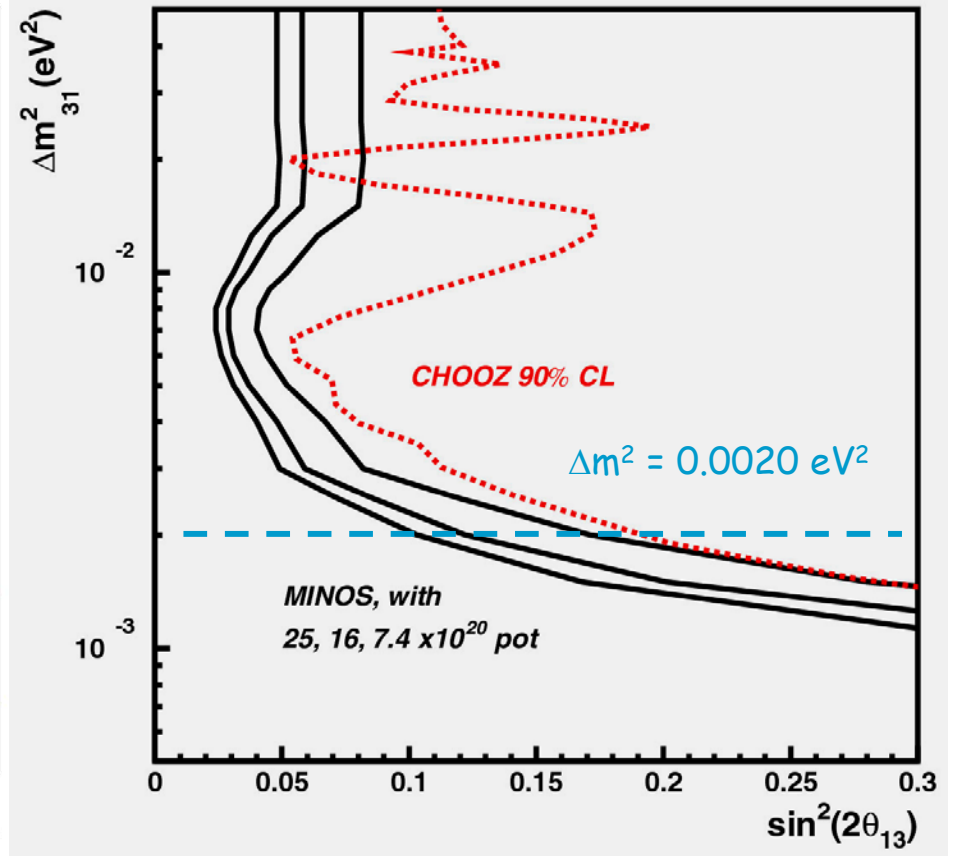


# Appearance of Electrons

90% CL Exclusion



3  $\sigma$  Contours



MINOS sensitivities for  
varying numbers of protons on target

# Status of NuMI/MINOS

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- Detectors
  - > Far Detector is finished (Aug. 03) & running well
    - Taking atmospheric neutrino data as we speak
  - > Near Detector surface assembly complete
  - > Calibration Detector run complete next month
- Fermilab site civil construction almost done
  - > Occupancy of target area this month
  - > Occupancy of downstream beginning of next year
- Beam installation started during current shutdown
  - > Will be complete next year
- Expect beam in Dec '04

# MINOS will...

- Will measure  $\nu_\mu$  &  $\bar{\nu}_\mu$  in atmospheric neutrinos
- Make first precision measurements of the atmospheric mass splitting
- Provide improvements to flavor participation including
  - > Improved  $U_{e3}$  sensitivity
  - > Improved sensitivity on sterile admixtures & nonstandard oscillation models