MINOS Status and Prospects

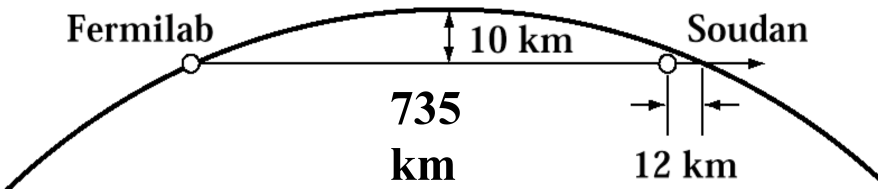
Argonne • Athens • Benedictine • Brookhaven • Caltech • Cambridge • Campinas • Fermilab
College de France • Harvard • IIT • Indiana • ITEP-Moscow • Lebedev • Livermore
Minnesota-Twin Cities • Minnesota-Duluth • Oxford • Pittsburgh • Protvino • Rutherford
Sao Paulo • South Carolina • Stanford • Sussex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

32 institutions
175 scientists

P. Shanahan, Fermilab
Fermilab PAC Meeting
October 20, 2006

MINOS: 2 Detectors with 735km baseline

- ν_μ disappearance
  - $P(\nu_\mu \rightarrow \nu_\mu) \approx 1 - \sin^2(2\theta_{23})\sin^2(1.27\Delta m^2_{23} L/E)$

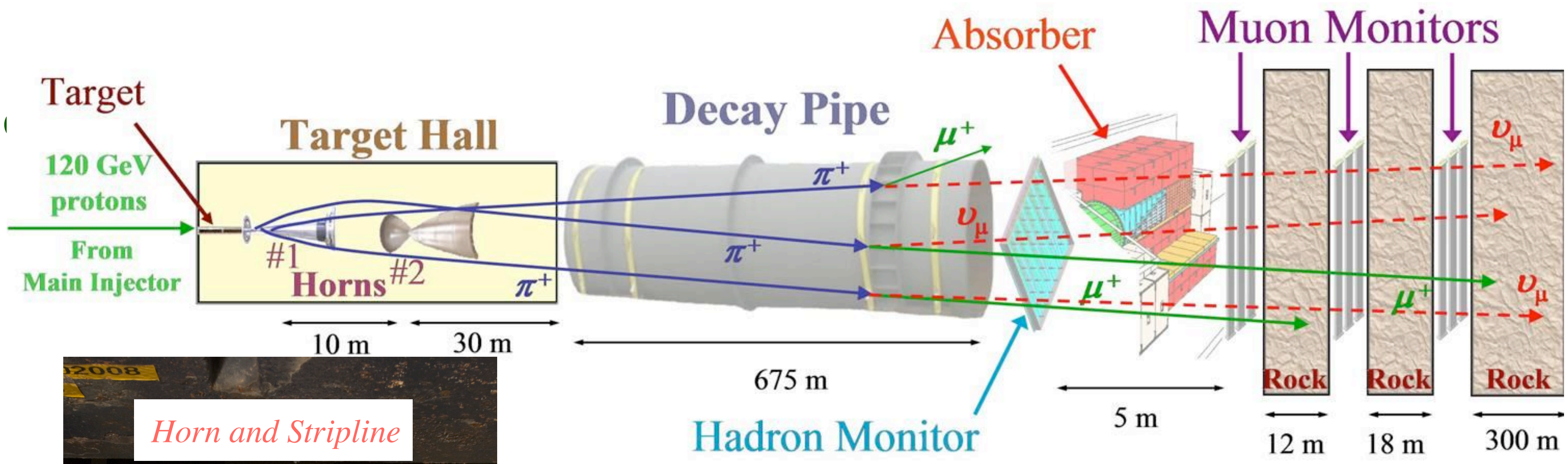


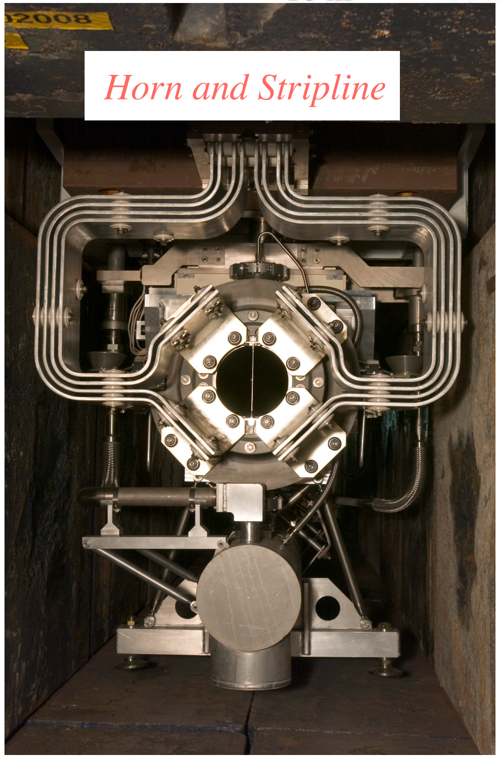
- ν_e appearance
  - $P(\nu_\mu \rightarrow \nu_e) \approx \sin^2(\theta_{23})\sin^2(2\theta_{13}) \frac{\Delta^2_{13}}{(\Delta_{13} \mp aL)^2} \sin^2(\Delta_{13} \mp aL)$ $\Delta_{13} \equiv 1.27\, \Delta m^2_{13}\; L/E$

  matter effects

- Other topics:
  - ν scattering topics: DIS Cross Sections, etc.
  - Exotic processes: sterile neutrinos, etc
  - Non-accelerator neutrinos: CPT conservation

NuMI Beamline

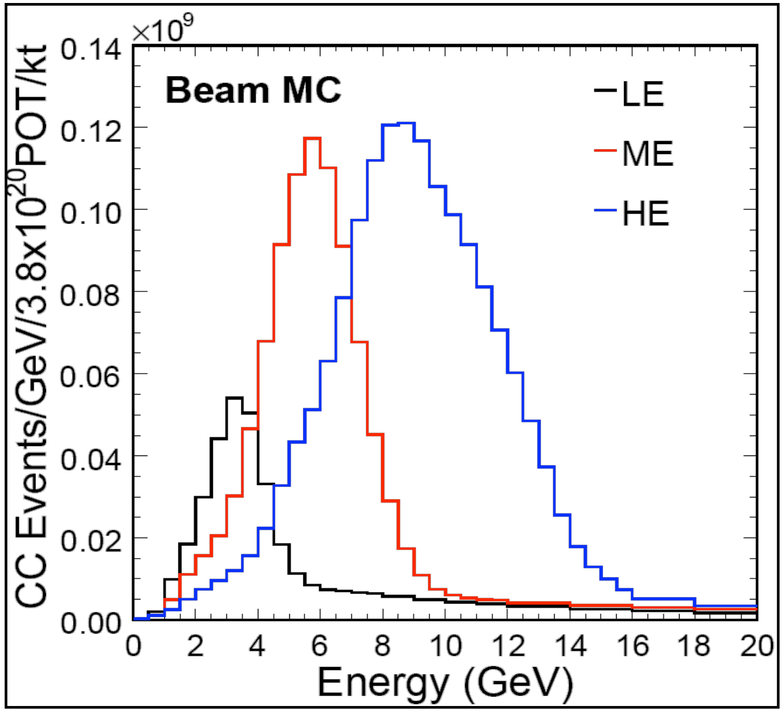




- 120 GeV protons strike the graphite target
- Charged hadrons focused by 2 Parabolic horns
- Nominal Intensity $2.4\text{x}10^{13}$ ppp with ~2 sec cycle time.
- Initial intensity ~2.5×10^{20} protons/year
- Ultimate intensity ~ 3.2×10^{20} protons/year (2008-9)

Beam Energy Spectrum

- Beam energy spectrum is adjustable via target position
  - LE-10 is best match for atmospheric Δm^2
  - Data taken in 5 other configurations for systematic studies



Expected number of Far Detector events without oscillations

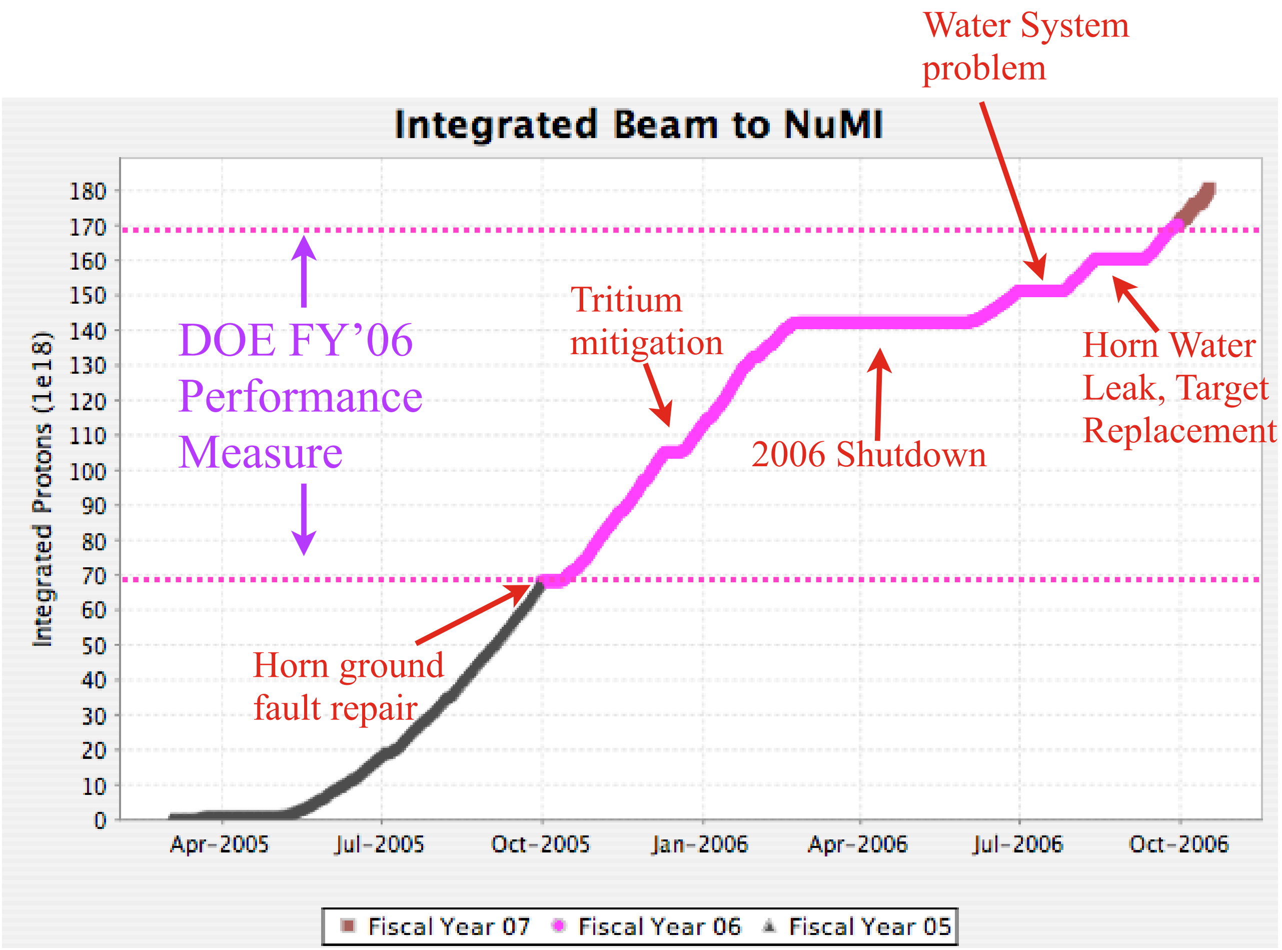
Beam	Target z position (cm)	FD Events per 1e20 pot*
LE-10	-10	390
pME	-100	970
pHE	-250	1340

NuMI Performance

FY'05: Excellent turn on
- 6.8×10^{19} Protons on Target (POT) total since March'05

FY'06:
- Unscheduled downtimes for Beam Components
- 1.0×10^{20} POT total

Oct. 19, 2006
- Record NuMI Daily POT (unfortunately on back of TeVatron downtime)



Beam Components

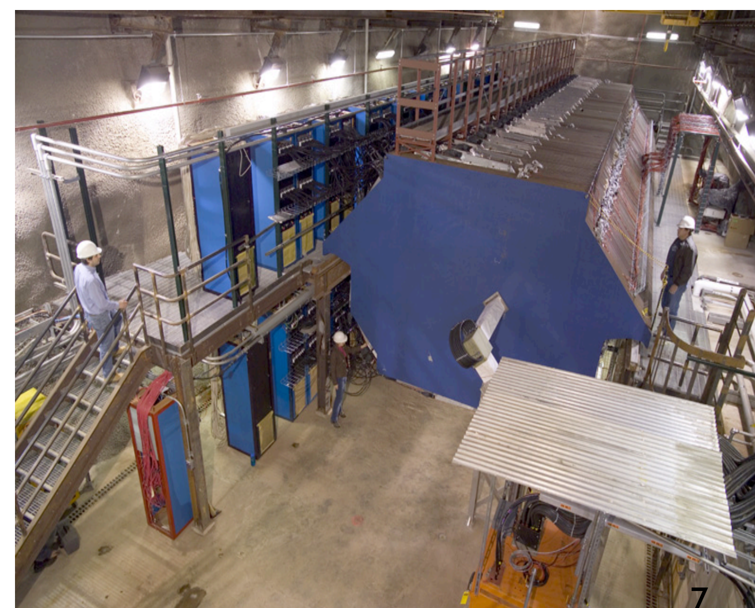
- NuMI downtimes covered in R. Dixon's talk this morning
- Improving system uptime
  - Cooperation among leadership of MINOS, Accelerator Division, and Mechanical Engineering for increased spares production
- Horn 1 spare almost ready for testing

MINOS Detectors: Tracking Calorimeters

Far:
5100 t total mass
485 planes divided into 2 supermodules
8x multiplexing

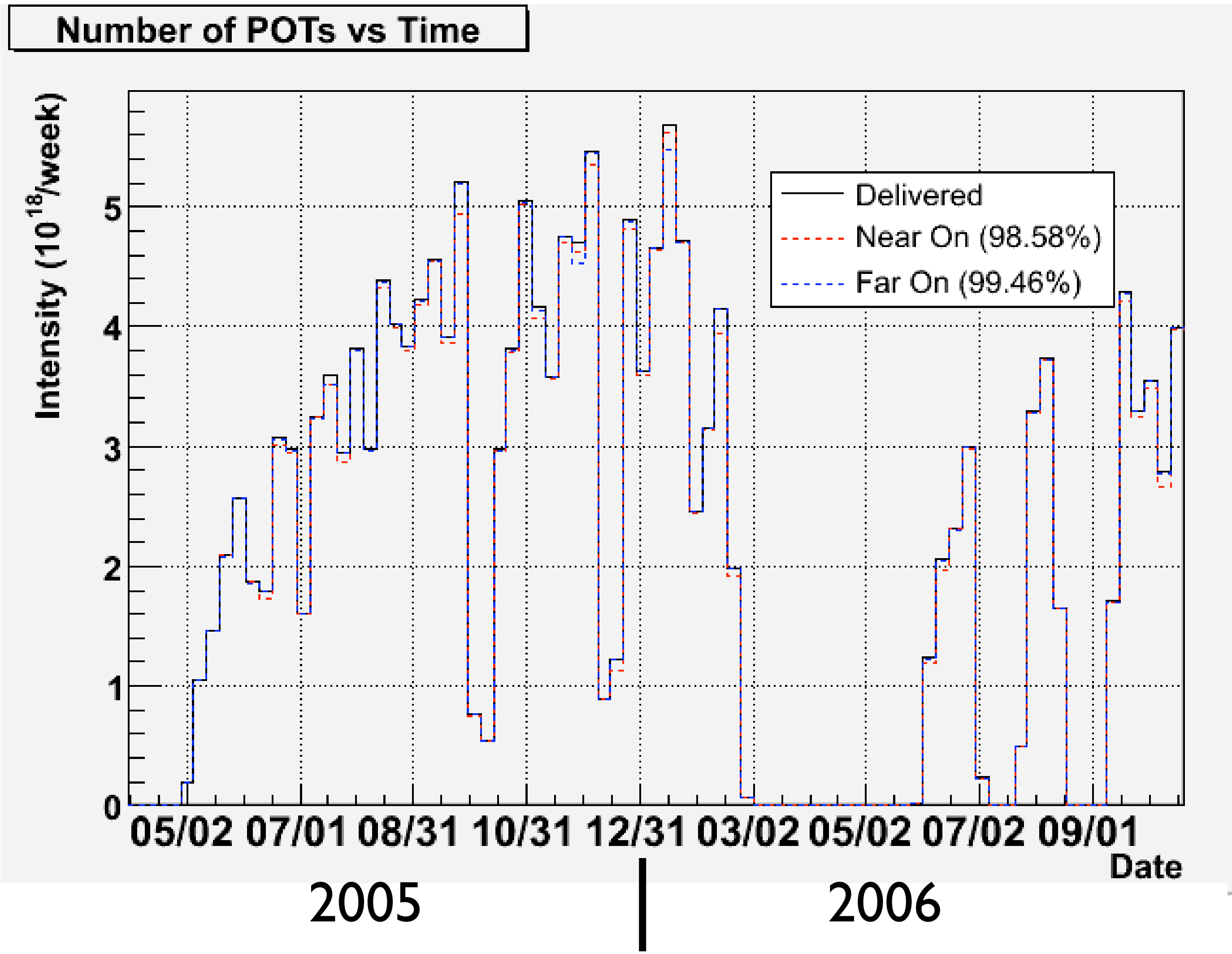
Near:
smaller - 980 t total mass, 50t fiducial
High Rate - energy from 10's of interactions per 10μs spill
Multiplexing only in downstream end (spectrometer)

Magnetized Iron plates:
2.5 cm thick, magnetized to ~1.3T
Scintillator:
1cm thick, 4.1cm transverse
Readout:
Wavelength Shifting Fiber to Multi-anode PMTs



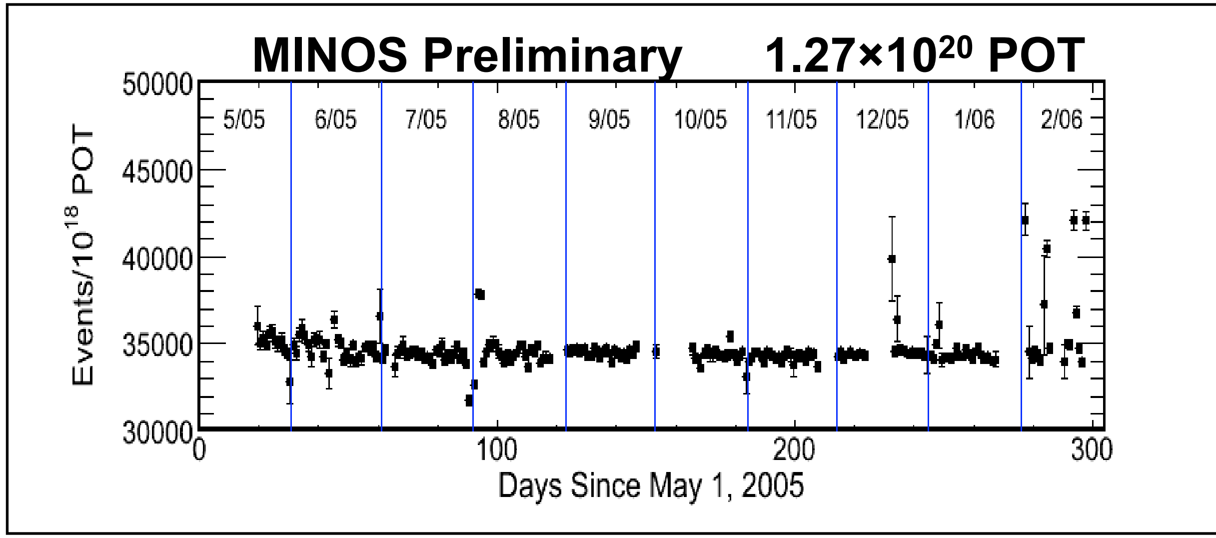
MINOS Detector Performance

- Very high data taking efficiency for both detectors
  - Most maintenance performed with beam off
  - NearDet has slightly more downtime due to electronics maintenance



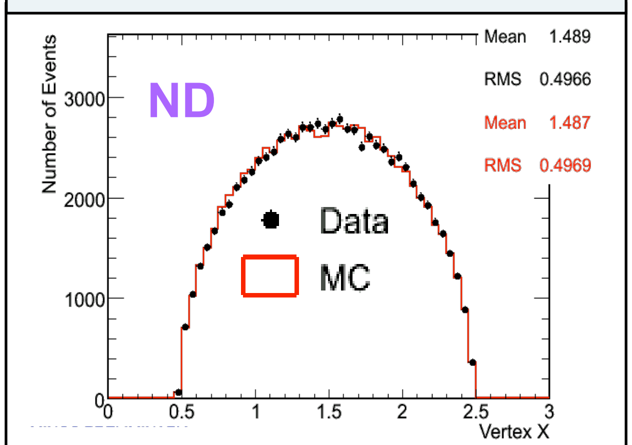
Near Detector Performance

Daily event Rate:

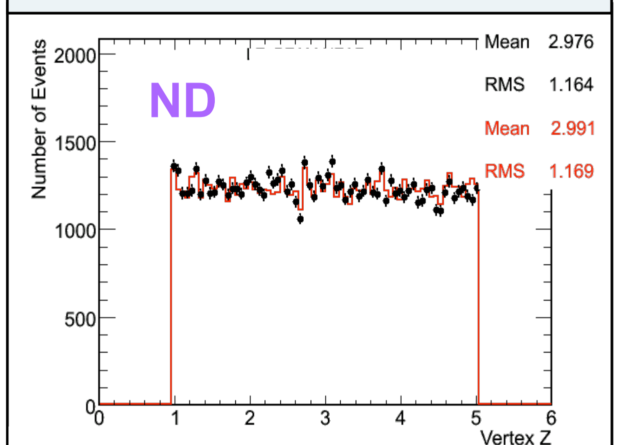


High Statistics Data/ MC comparisons

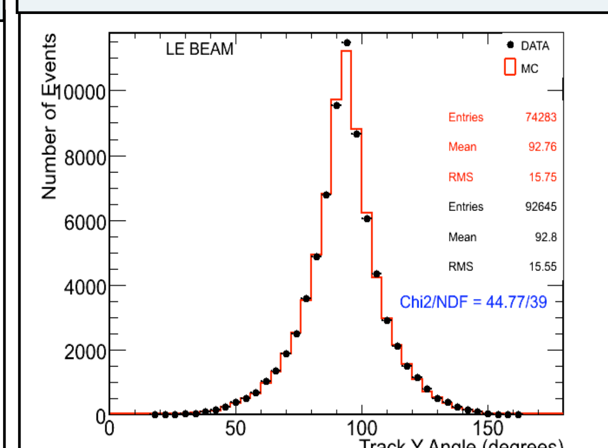
X Vertex



Z Vertex

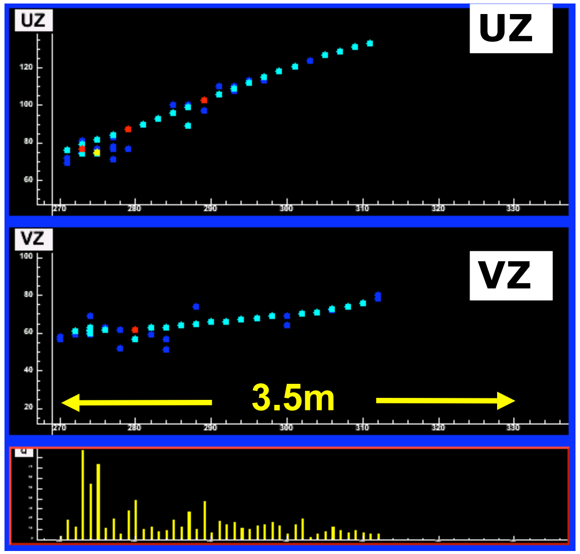


Track Angle (wrt vert.)



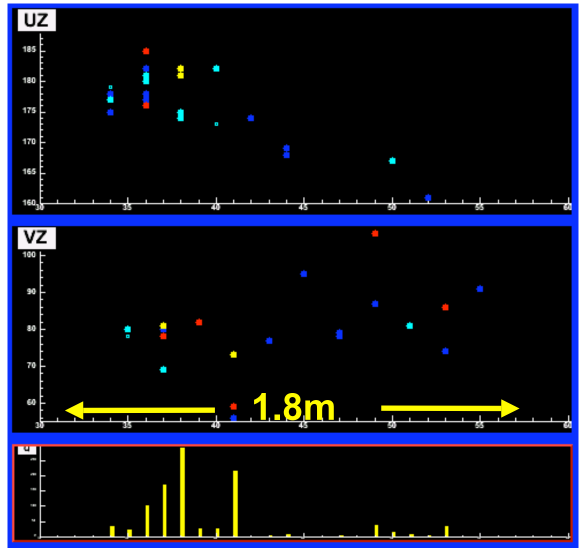
ν Interactions in MINOS

ν_μ CC Event



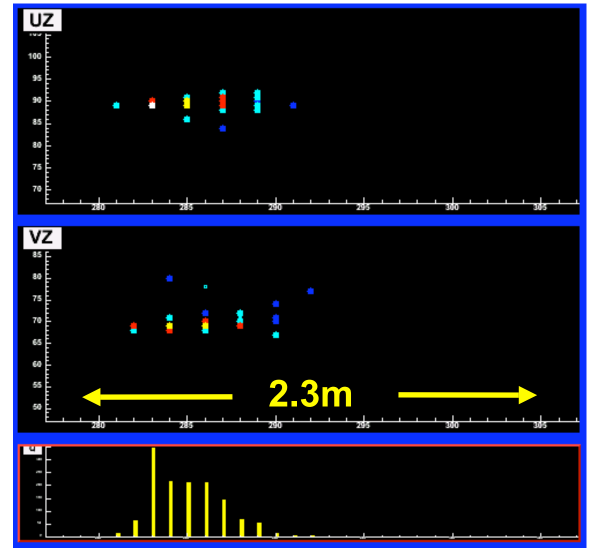
Long track + hadronic activity near vertex

NC Event



Shorter showering event, more diffuse

ν_e CC Event



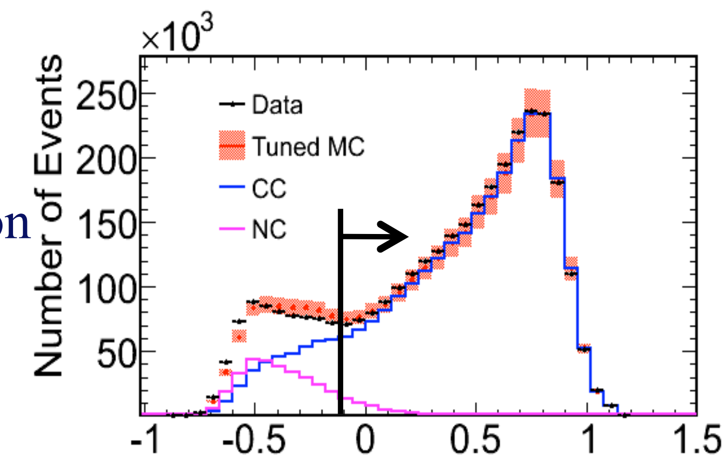
Short shower event with EM profile

$$E_\nu = E_{shower} + P_\mu$$

Shower energy resolution: 55%/√E

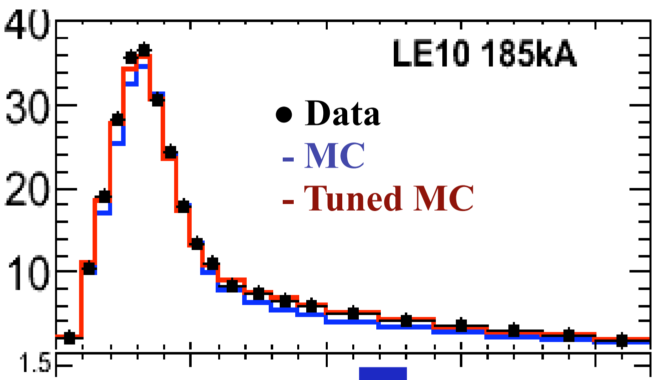
Muon momentum resolution: 6% range; 13% curvature

Event Classification parameter for selection of νμ CC events

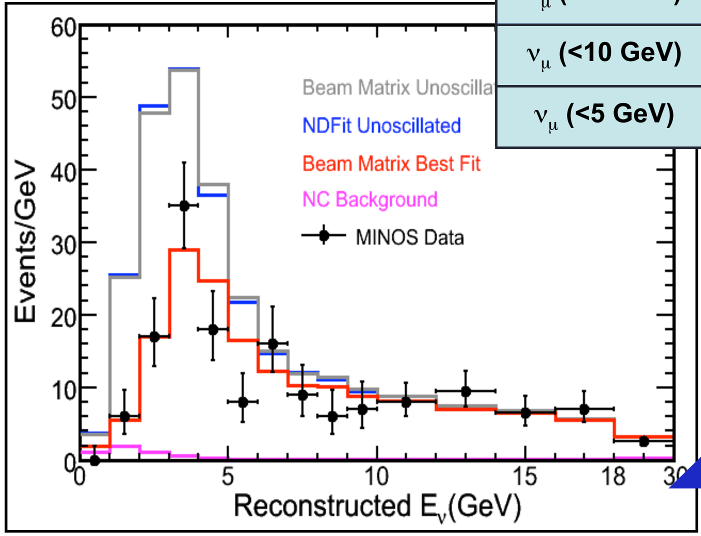


Predicting the Far Detector Spectrum

Near Detector E_ν Spectrum

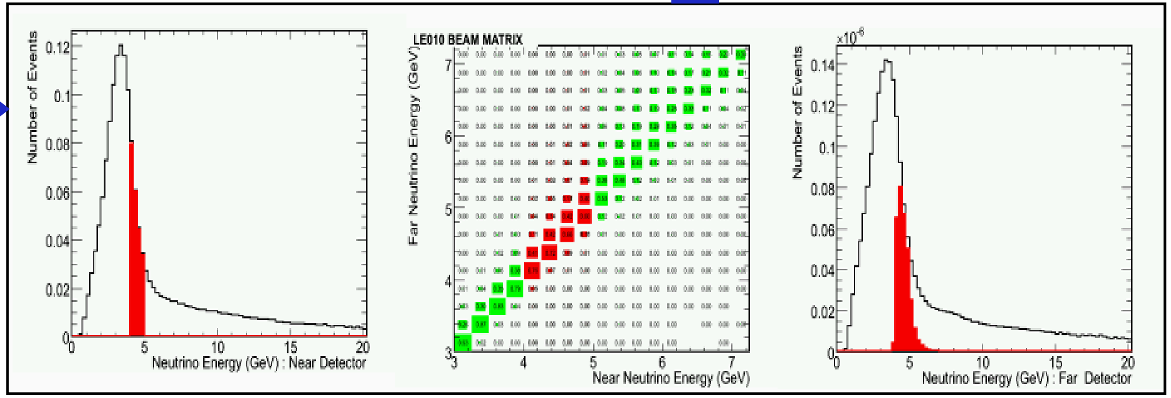


Far Detector E_ν Spectrum



Data Sample	FD Data	Expected (Matrix Method; Unoscillated)	Data/MC (Matrix Method)
ν_μ (<30 GeV)	215	336.0±14.4	0.64±0.05
ν_μ (<10 GeV)	122	238.7±10.7	0.51±0.05
ν_μ (<5 GeV)	76	168.4±8.8	0.45±0.06

Use near detector data, beam kinematics to predict far spectrum



Alternatives: bin-to-bin ratios, direct fitting to simulation
results are stable.

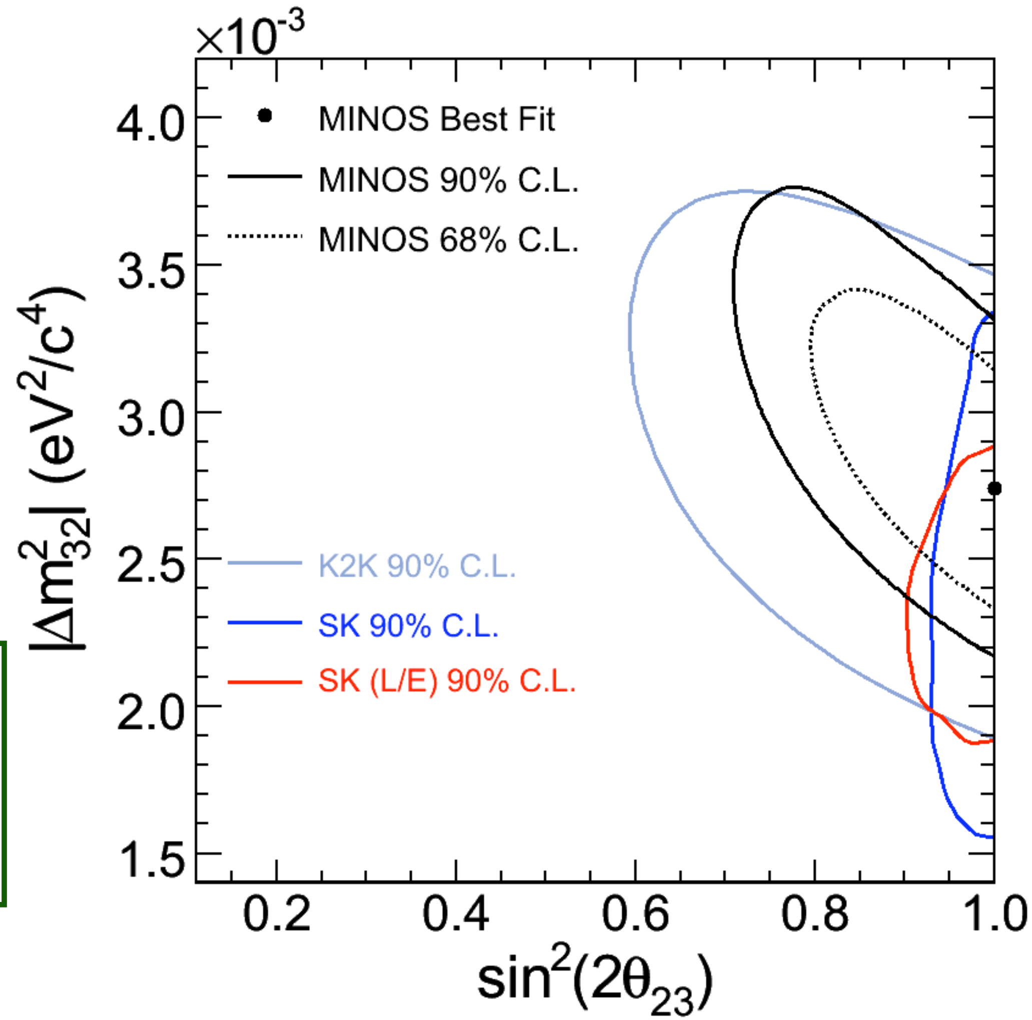
Oscillation Fit

- Fit includes penalty terms for three main systematic uncertainties
  - Near/Far Normalization
  - Hadronic E scale
  - NC contamination

- Fit is constrained to physical region: $\sin^2(2\theta_{23}) \leq 1$

$$|\Delta m^2_{32}| = 2.74^{+0.44}_{-0.26} \times 10^{-3}\ eV^2$$

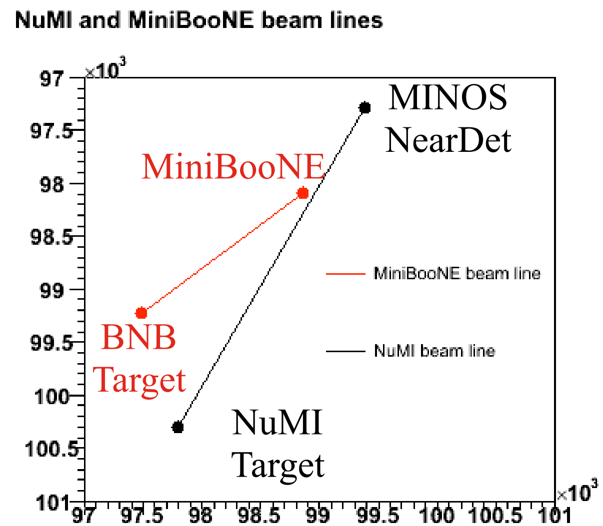
$$\sin^2(2\theta_{13}) = 1.00_{-0.13}$$



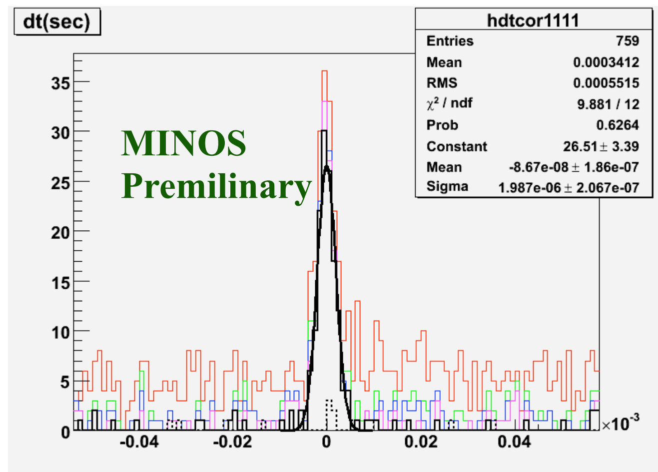
Work In Progress with Current Data

- Continuing analysis of ν_μ Disappearance
- ν_e Appearance Search
- Exotics: e.g. Sterile Search with Neutral Current Channel
- Non-accelerator: Far Detector
  - CPT Test in atmospheric ν Oscillations (published in PR**D** 73)
  - Cosmic ray charge ratio $\gtrsim$ 1 TeV
- Near Detector
  - Work in progress on general ν Cross Sections
  - specific channels (e.g., can we measure coherent pion production)
  - MiniBooNE ν's

MiniBooNE ν's in MINOS NearDet



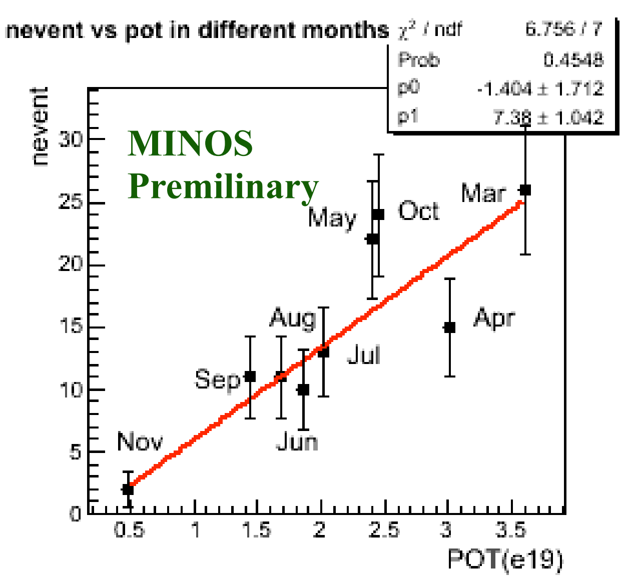
Time from Event to BNB Spill

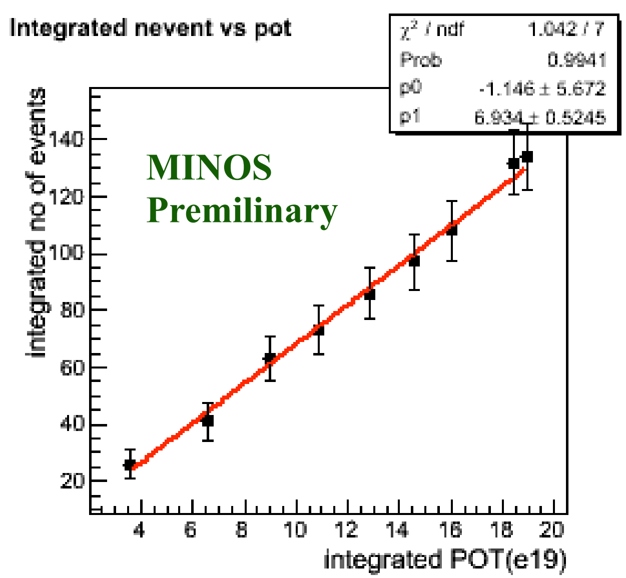


Signal:

- Identify with timing and angle
- Negligible background

> - **Fid. containment**
> - **cos(α)>0.6**
> - **Timing cut**
> - **end of track containment**
> - **track momentum < 4 GeV shower E < 4 GeV**
>
> **--- Reversed horn current**



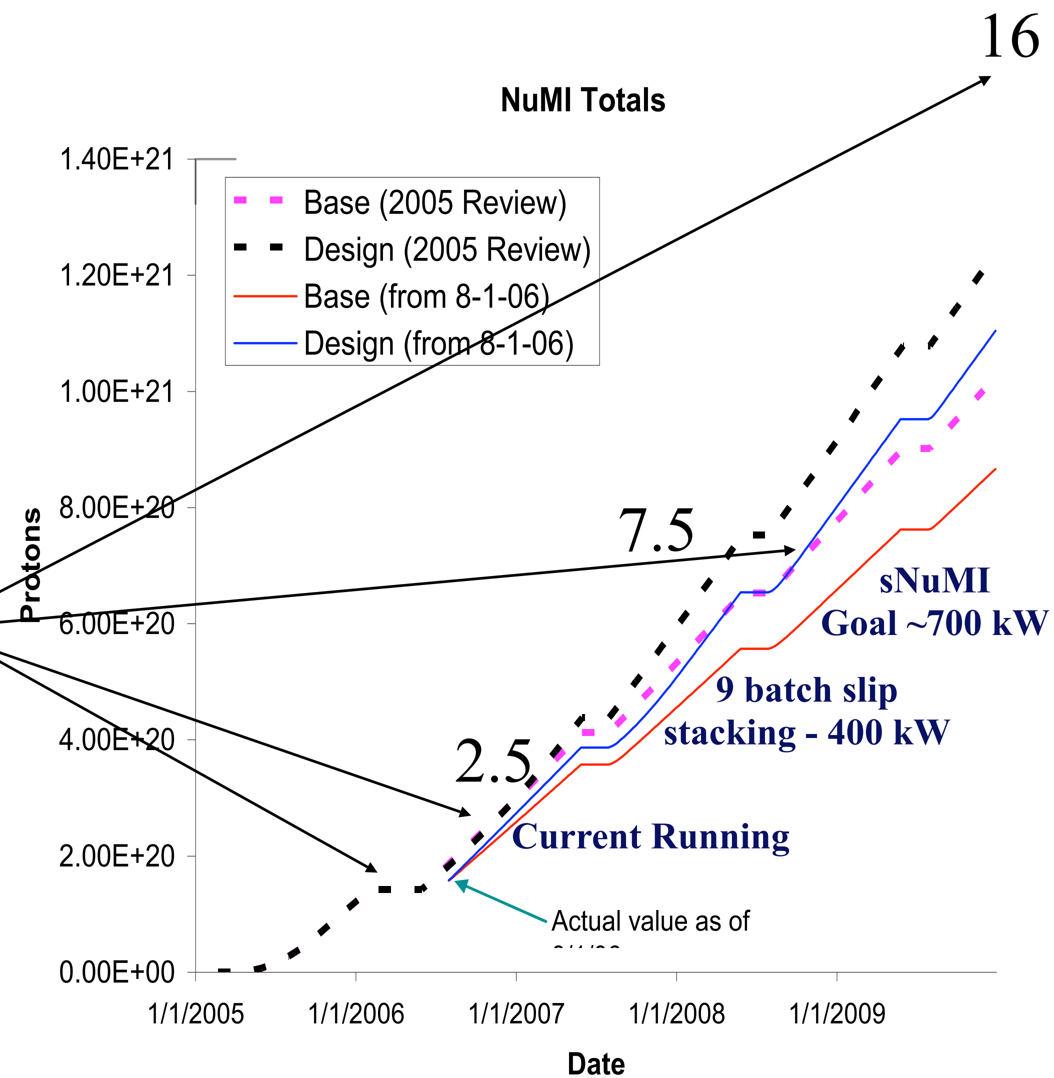


Work is at an advanced stage:

- comparisons to MiniBooNE K production model
- studies of MINOS detector response

Fermilab Proton Plan for NuMI

These values used by MINOS to compute sensitivities



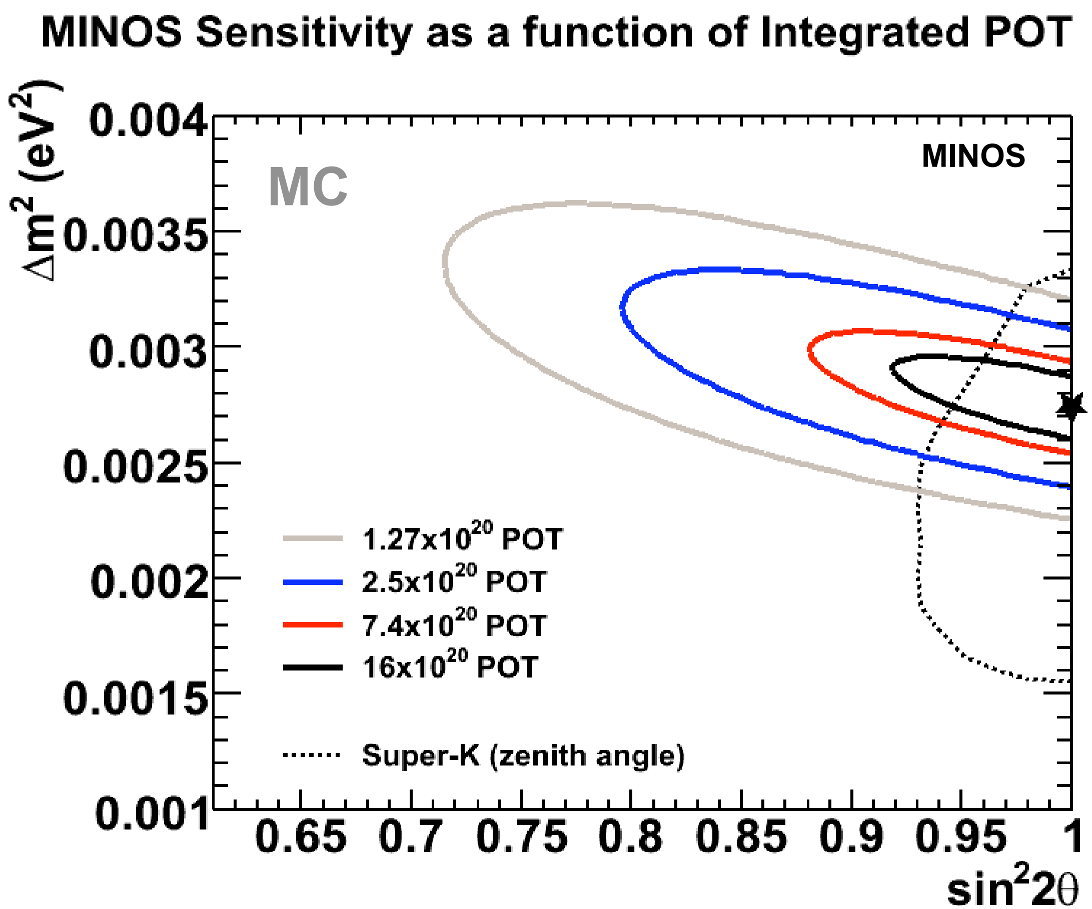
Projected MINOS ν_μ Sensitivity

- MINOS sensitivity for different POT
- Current best values used as input:

  $\Delta m^2_{32}=2.74\times10^{-3}eV^2$

  $\sin^2 2\theta_{23}=1.00$

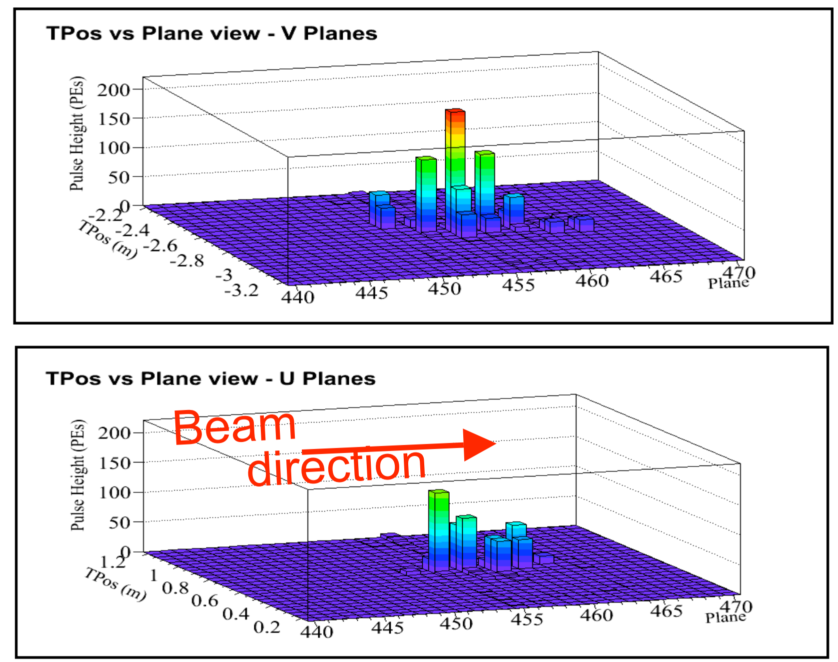
- Contours are 90% C.L. statistical errors only

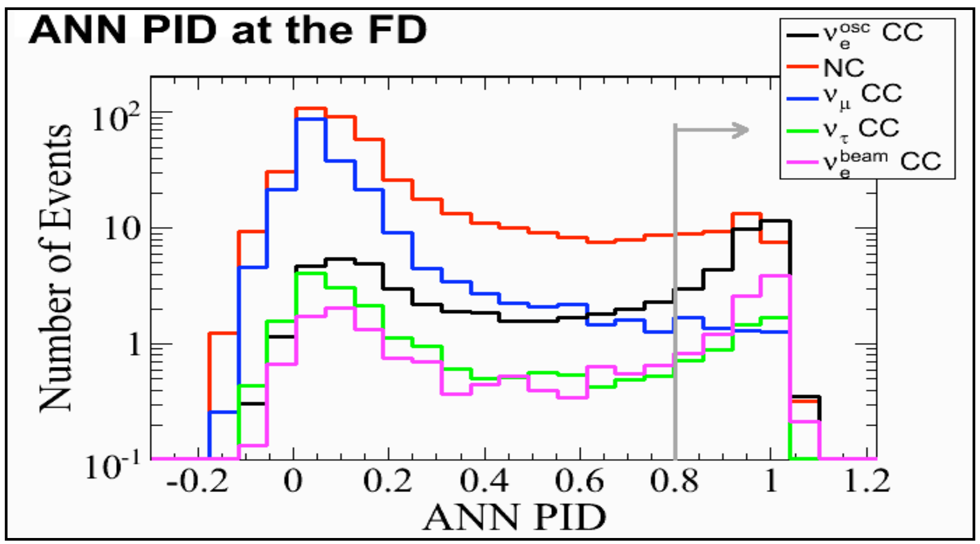


Sensitivity to ν_e Charge Current

- Challenge due to detector granularity
  - Typical electron shower is 8 planes x 4 strips
  - High backgrounds, esp. NC
  - Several algorithms under study

8.7 GeV electron candidate from data





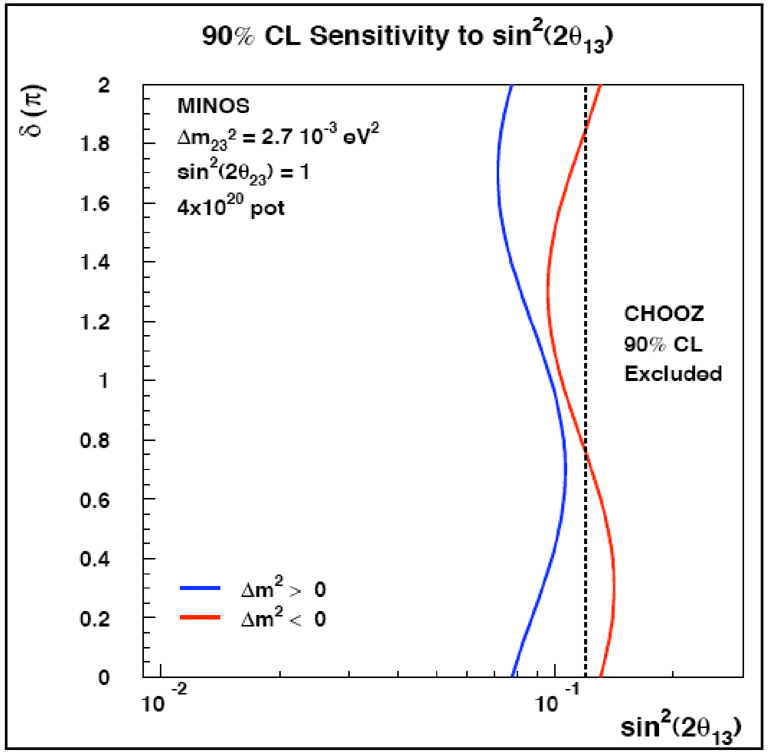
ν_μ CC	NC	ν_e^{beam}	ν_τ CC	Total	ν_e^{osc}
5.6	39.0	8.7	4.7	58.0	29.1

Background composition from MC
(16×10^{20} POT)

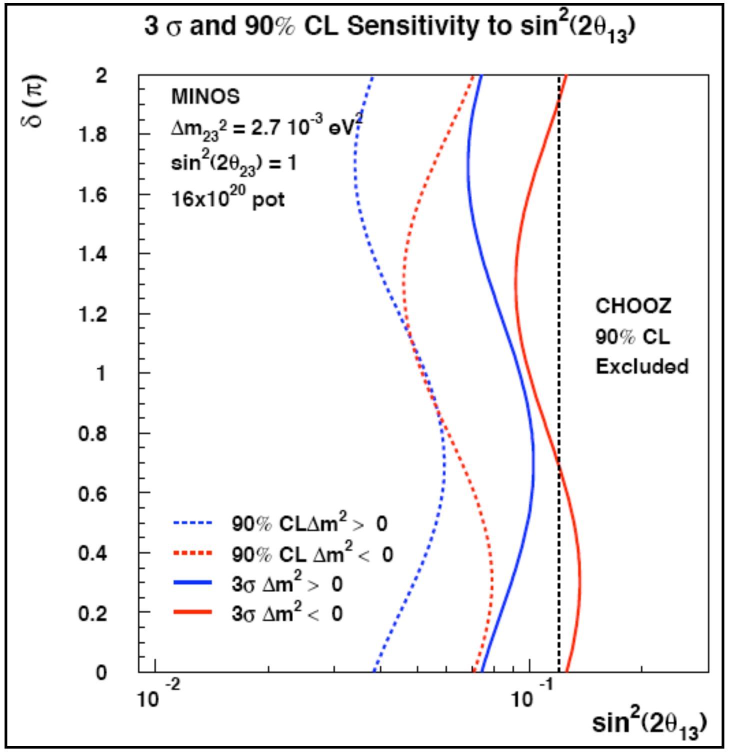
Input oscillation parameters:
$\sin^2(2\theta_{13})=0.1$
$|\Delta m_{32}|^2 = 2.7\times10^{-3}\mathrm{eV}^2$
$\sin^2(2\theta_{23}) = 1$

Projected θ_{13} Exclusion and Sensitivity Potential

- Reach depends on
  - Mass Hierarchy (via matter effects)
  - Leptonic CP violation



4 x 10^{20} POT



16 x 10^{20} POT

Conclusions and Expectations

- The MINOS experiment and NuMI beam have had a successful first running period.
  - Two publications accepted, atmospheric and beam oscillation papers
  - 3 more in pipeline.
- Operational difficulties with the NuMI beam have been repaired
  - Tritium mitigation, horn and target problems
  - Remarkable effort by Fermilab Accelerator Division
  - "Industrialization" effort for spares underway
- MINOS has active short and long-term physics program
  - Short term includes improved CC analysis, first ND physics, special topics.
- Fermilab proton plan provides a well-defined path forward in proton Intensity