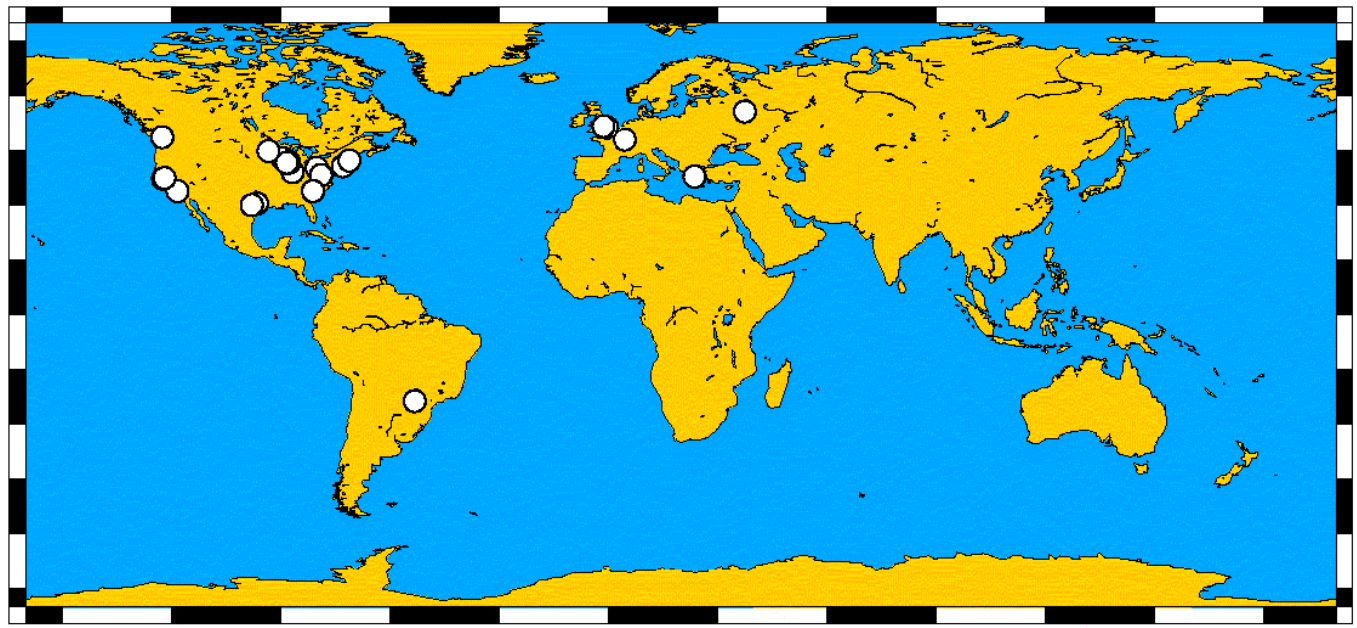
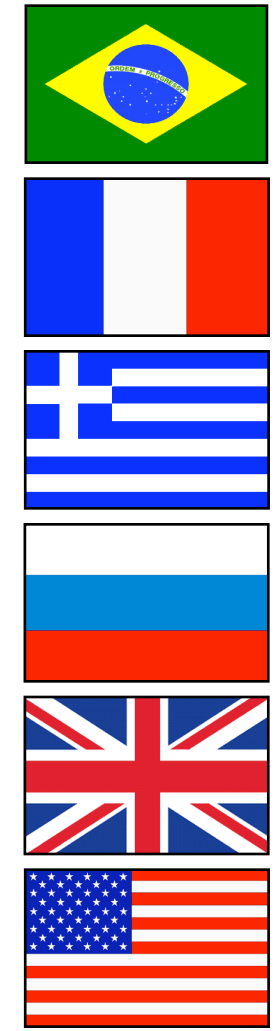
Recent Results from MINOS

Peter Shanahan - Fermilab
For the MINOS Collaboration
La Thuile, March 7, 2006





Argonne • Athens • Benedictine• Brookhaven • Caltech • Cambridge • Campinas • Dubna • Fermilab
College de France • Harvard • Illinois Inst. of Technology • Indiana • ITEP-Moscow • Lebedev
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Rutherford • Sao Paulo • South Carolina • Stanford • Sussex • Texas A&M • Texas-Austin • Tufts
• University College London • Western Washington • William&Mary • Wisconsin

First....

- We hope to have a preliminary beam ν oscillation result soon - *O*(1 month)

MINOS Experiment

- Main Injector Neutrino Oscillation Search
  - Improve Δm^2 and $\sin^2(2\theta)$ measurement in ν_μ disappearance
  - Improve limit on $\nu_\mu \rightarrow \nu_e$

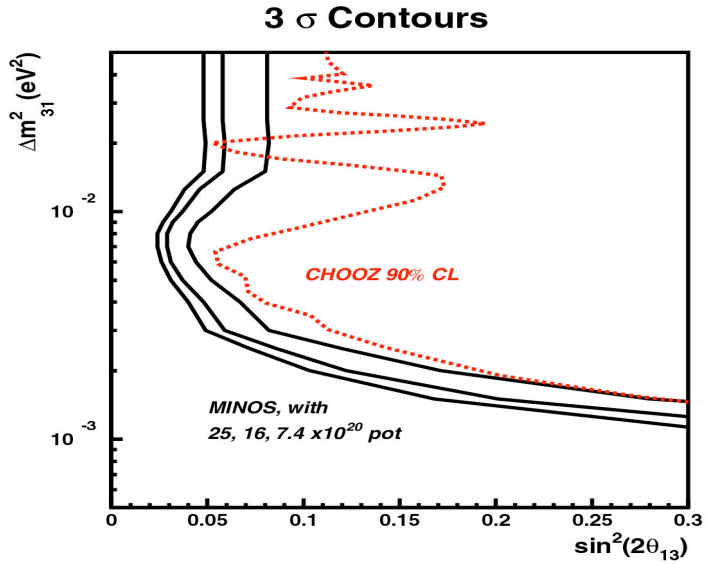
$$P(\nu_\mu \rightarrow \nu_\mu) = 1 - \sin^2(2\theta)\sin^2(1.27\Delta m^2 L/E)$$

- Long baseline: 735 km
  - Neutrino beam from Fermilab
  - 2 Detectors: Near at FNAL, Far in Soudan, Minnesota
- Atmospheric ν's in Far Detector
  - Magnetic field allows differentiation of μ^- and μ^+
  - Compare disappearance of ν_μ and $\overline{\nu}_\mu$ ➞ CPT test

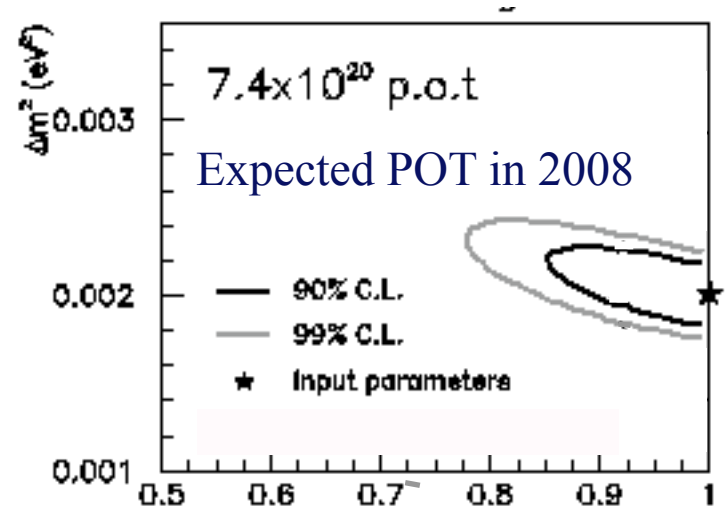
hep-ex/0512036 - to appear in Phys. Rev. D

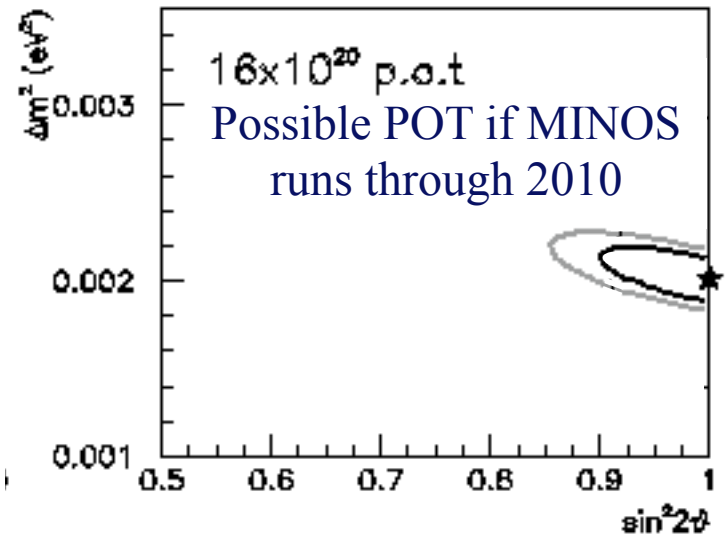
Expected MINOS Reach

- Monte Carlo sensitivities for different total Protons-on-Target (POT)
  - Total nominal run is 12×10^{20} by 2009
  - ν_μ disappearance: Significant step in precision on Δm^2
  - ν_e appearance (θ_{13}): Improvement over CHOOZ limit vs. POT



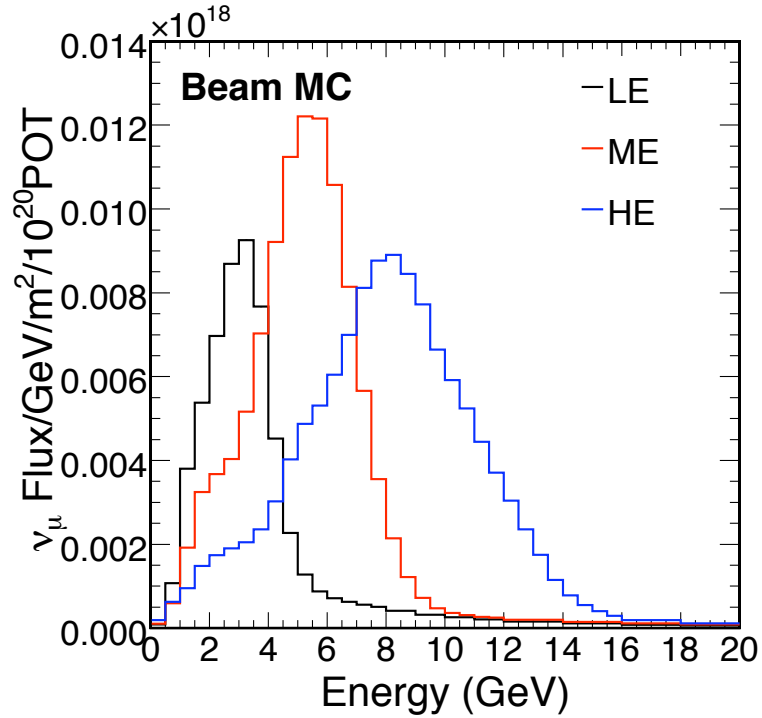
For $\Delta m^2 = 2.0 \times 10^{-3}$ eV^2

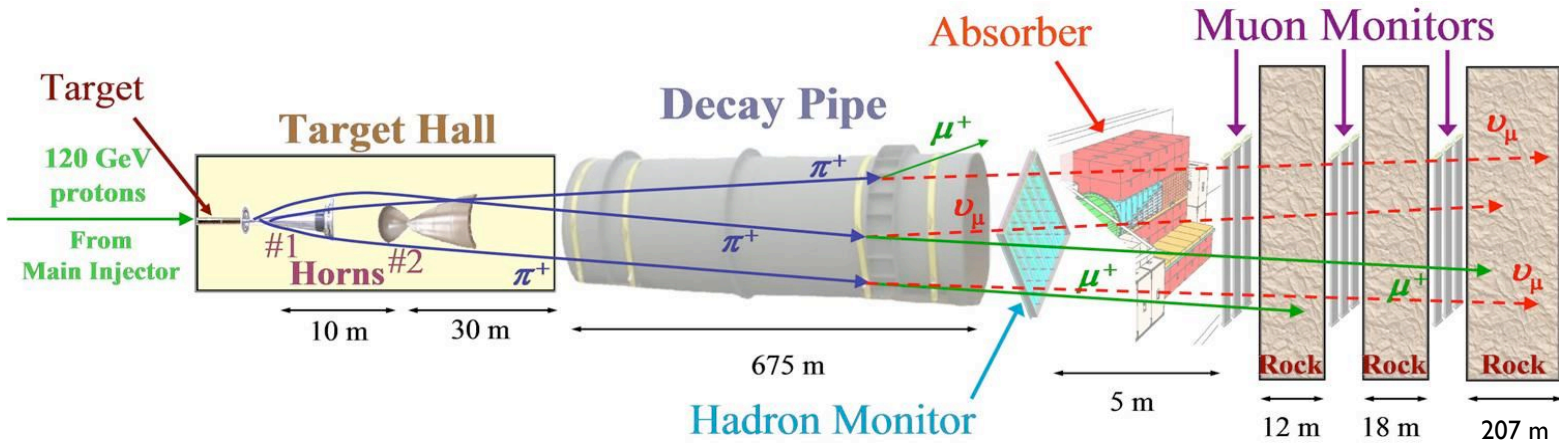




NuMI Beam

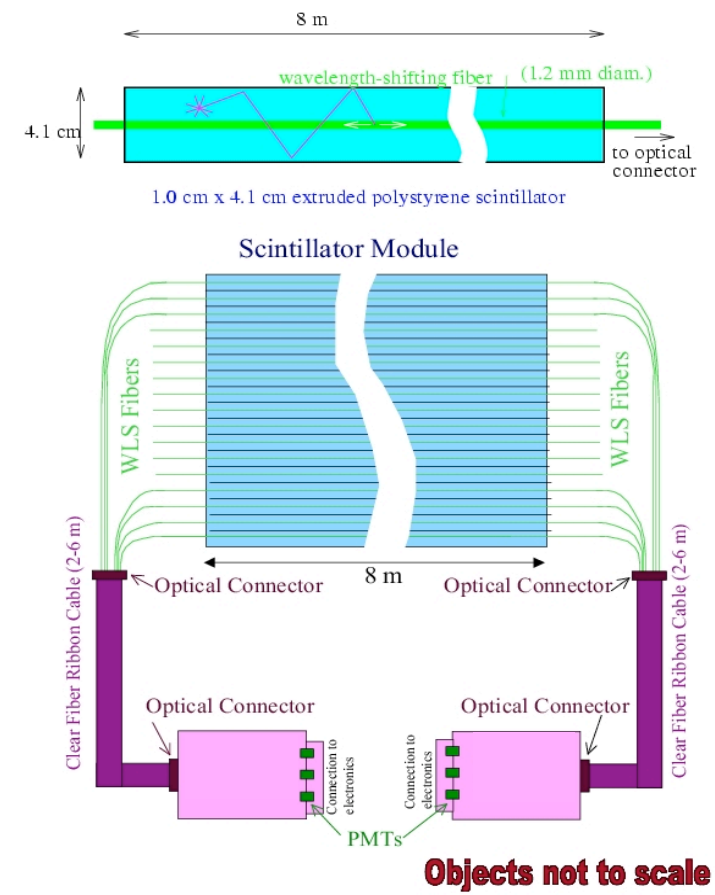
- Neutrinos at the Main Injector
  - Parabolic magnetic horns focus hadrons
  - Energy spectrum tunable by changing target position
  - Up to 10μs neutrino spill every 1.9s





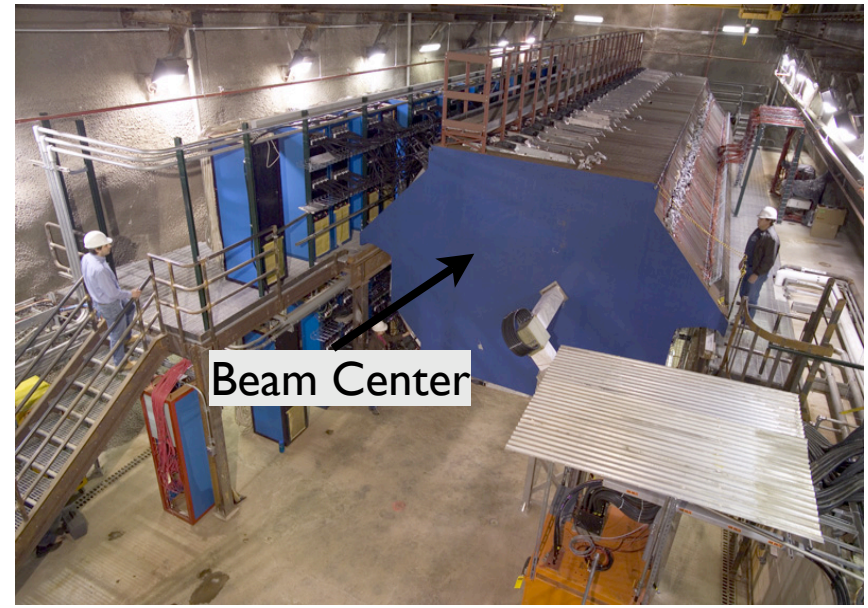
MINOS Detectors

- Planes of Scintillator and Magnetized Iron
  - 2.54 cm thick Fe (~1.5 T)
  - 1 cm thick scintillator
  - 4.1 cm transverse segmentation
- Read out via Wavelength Shifting Fibers into Multi-Anode PMTs



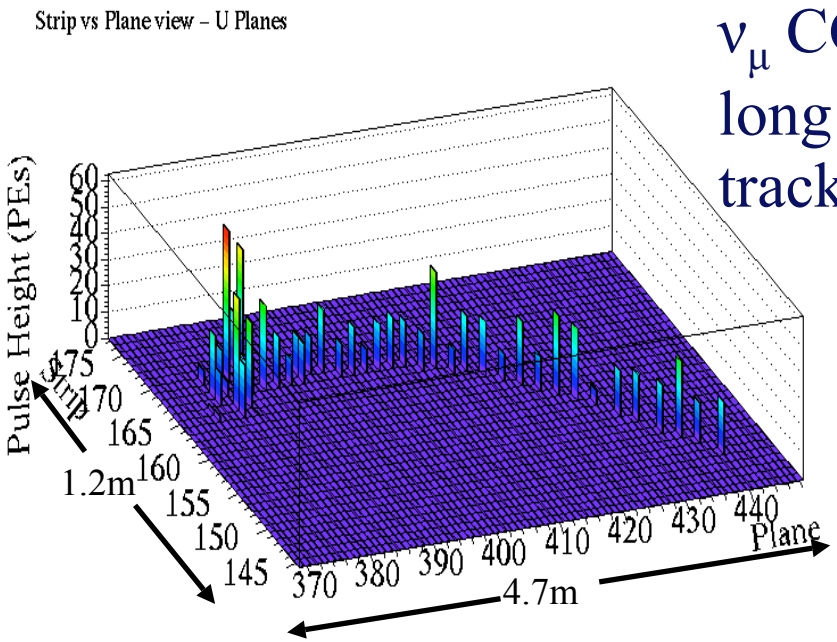
MINOS Detectors

- Near Detector:
  - 980t, 100m underground
  - Partially Instrumented
  - High-rate electronics
  - Strips read out at one end

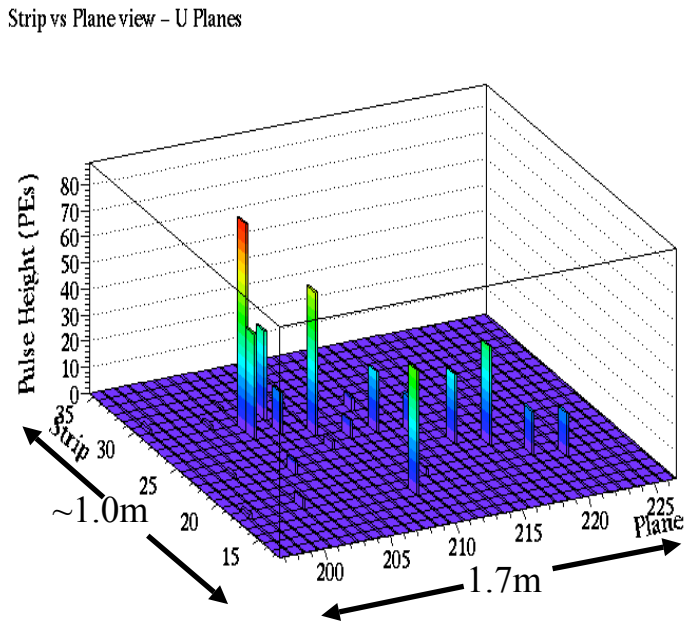


- Far Detector:
  - 5400 t, 710 m underground
  - Fully Instrumented
  - Veto Shield for Atmospheric ν studies
  - Strips read out at both ends

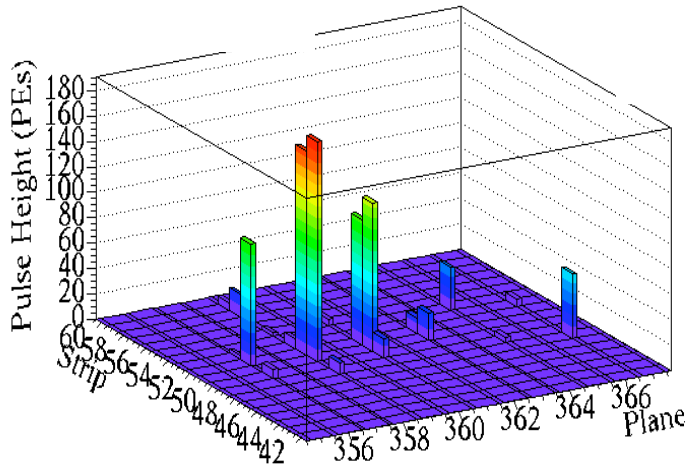
ν Signatures in MINOS



ν_μ CC: long muon track



NC: diffuse shower

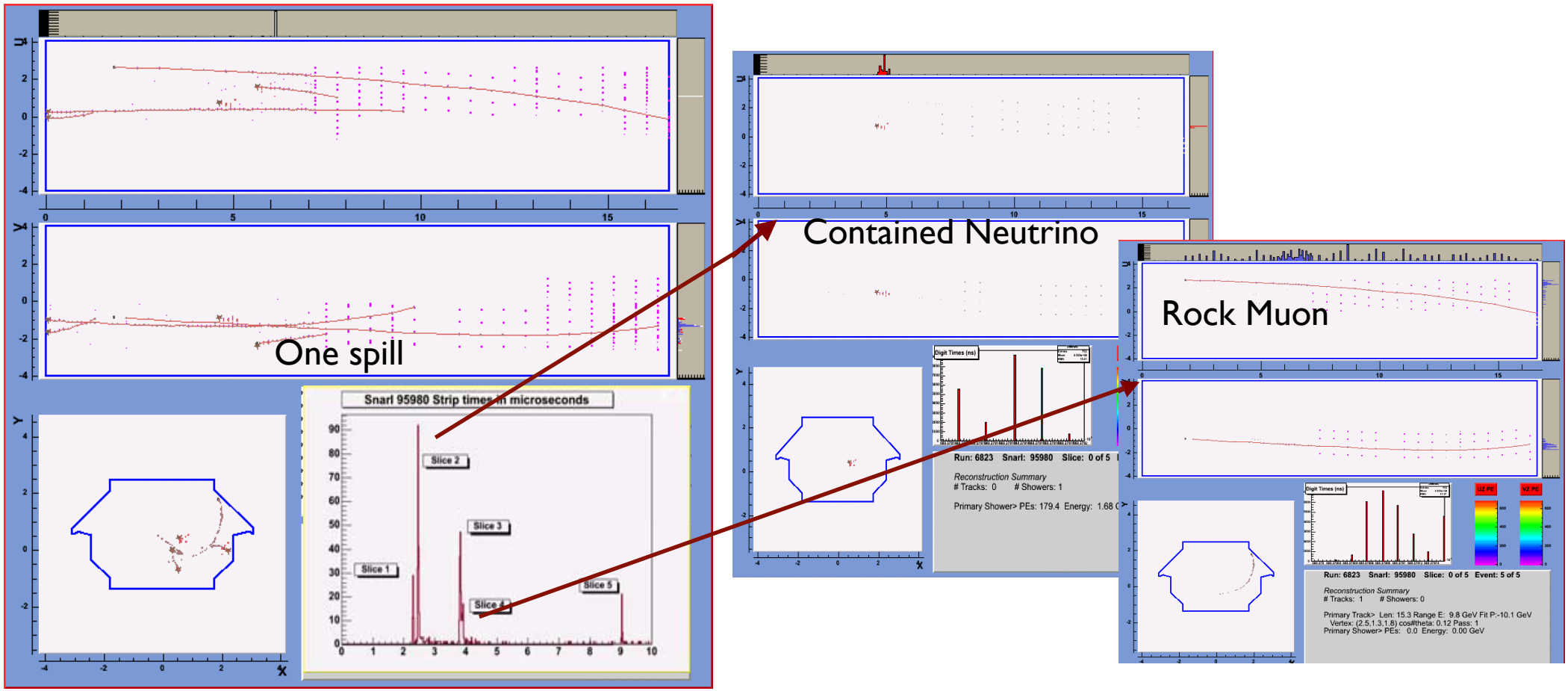


Example Monte Carlo events Pulse height vs. Strip & plane 4-5 GeV neutrinos

ν_e CC: Shorter shower, with higher pulse heights

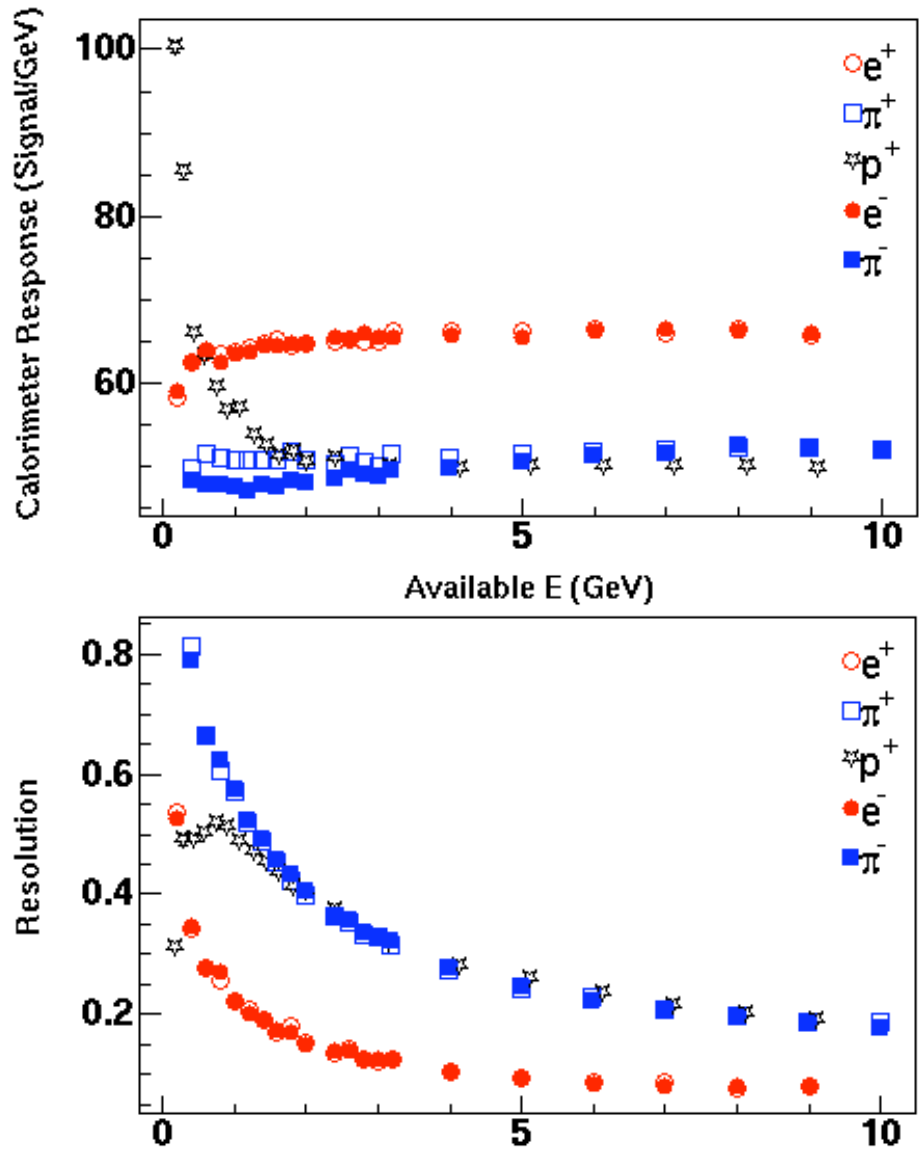
Near Detector Slicing

- Near Detector has multiple events per 10μs spill
  - Spill data are sliced in time and space before reconstruction



Calibration

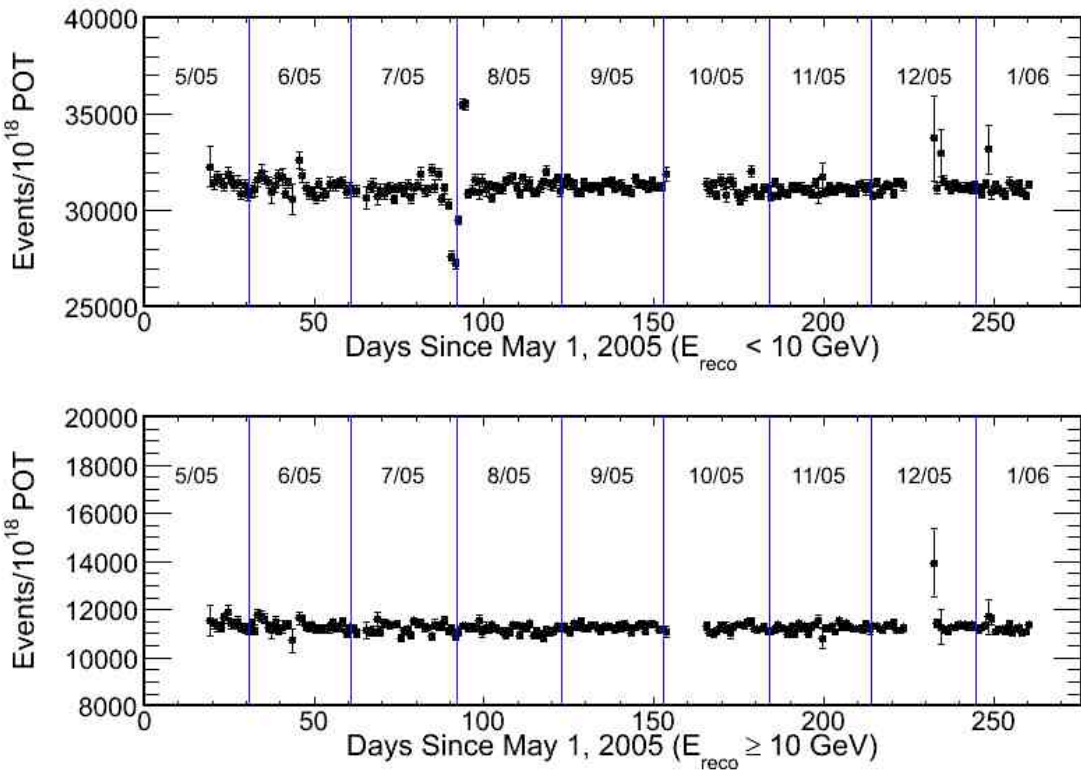
- Near/Far and Intra-detector calibration
  - Use cosmic muon response
- Absolute calibration
  - Calibration Detector at CERN
    - 60 planes, 1m x 1m
  - p, $\pi^{\pm}$, kaons, e, $\mu^{\pm}$
  - Compare response in Data & MC



Beam ν Data Taking

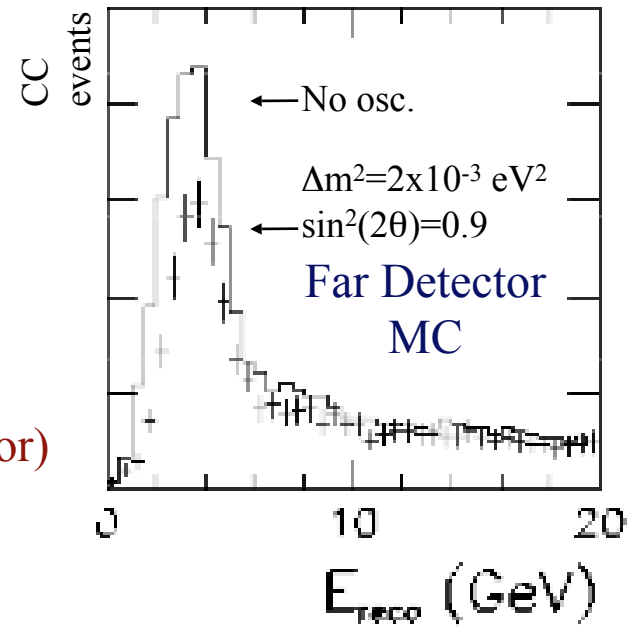
- 1st Neutrinos in January 2005
- 1st run: March 2005 - February 2006
  - 1.4×10^{20} Protons-on-Target
- Low Energy Spectrum:
  - Best overlap with Atmospheric Disappearance scale at 735 km baseline
- "1e20" Data set
  - First beam ν oscillation analysis underway with 0.95×10^{20} protons on target
  - May - December, 2005

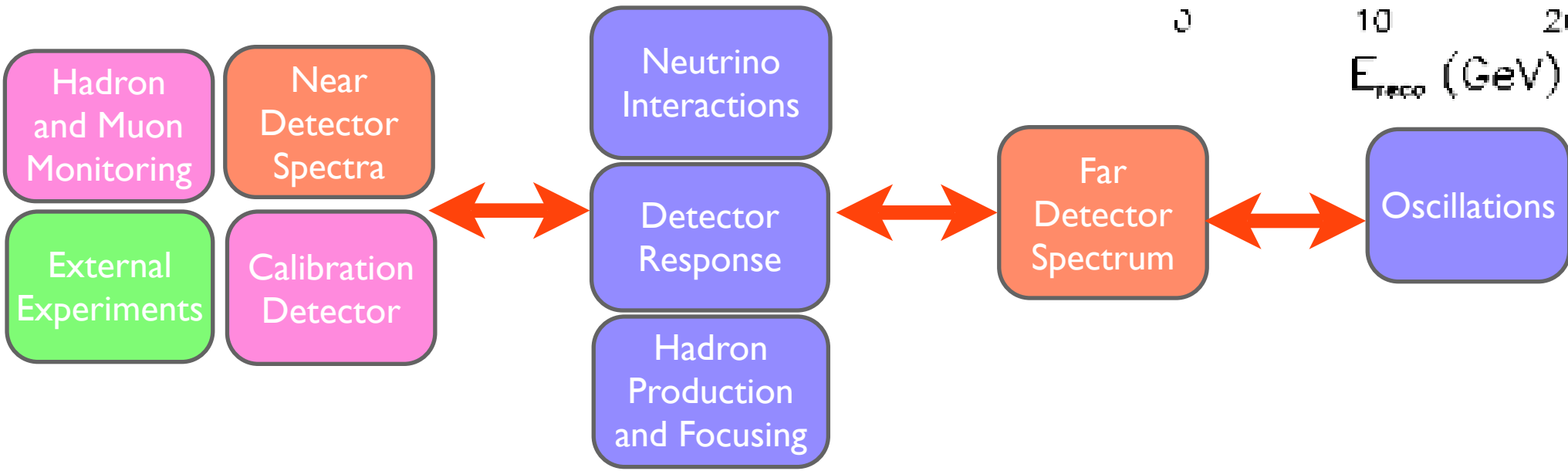
Near Detector neutrino daily event rate/10^{18} protons-on-target
Less than 10 GeV (*top*), 10 GeV and above (*bottom*)



Analysis Sketch

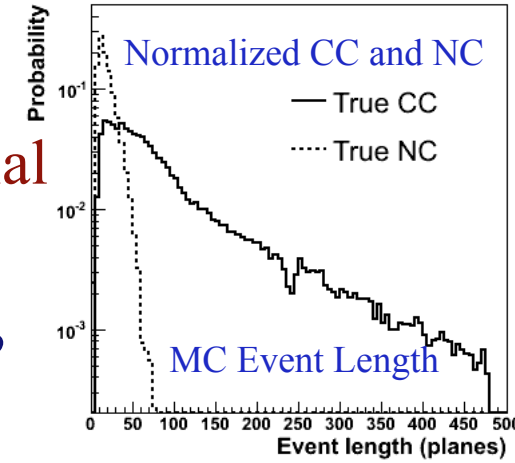
- Compare Far Detector ν_μ CC spectrum to expectation
  - Fit for Oscillation Parameters
  - Constrain uncertainties on expectation with External Information, Near Detector and Beam Instrumentation
  - Near Detector constraints can be explicit (fit parameters or adjustments to MC), or implicit (direct extrapolation to Far Detector)





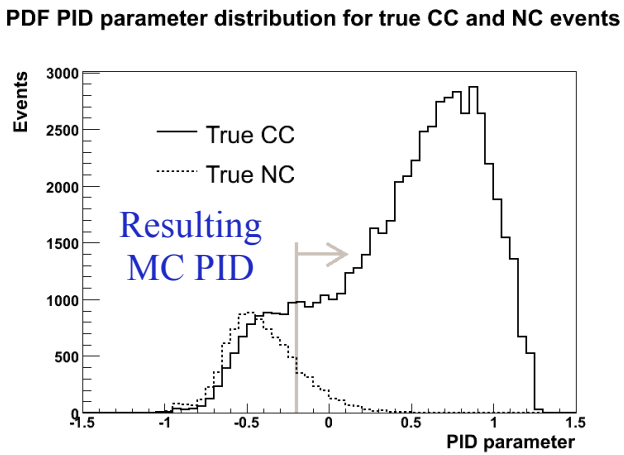
CC Event Selection

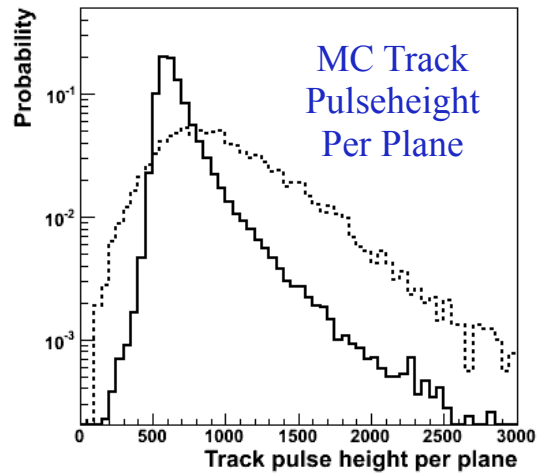
- Charge Current Pre-selection:
  - Events with tracks (*CC Muon*), Vertex within fiducial volume, event timing consistent with Beam Spill.

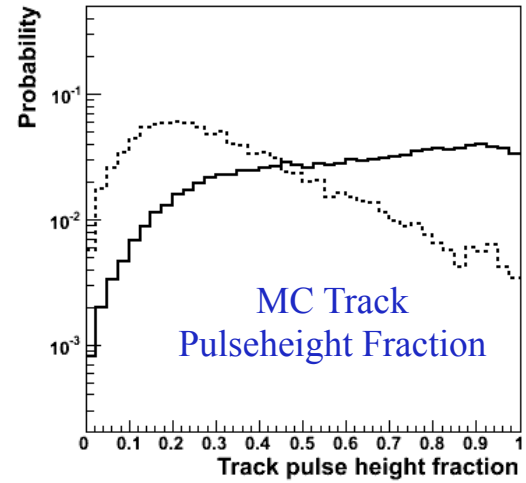


- CC/NC Separation: Likelihood-like "PID"

  Based on PDFs of 3 basic reconstruction quantities







13 parameter Artificial Neural Net gives consistent results

Blind Analysis

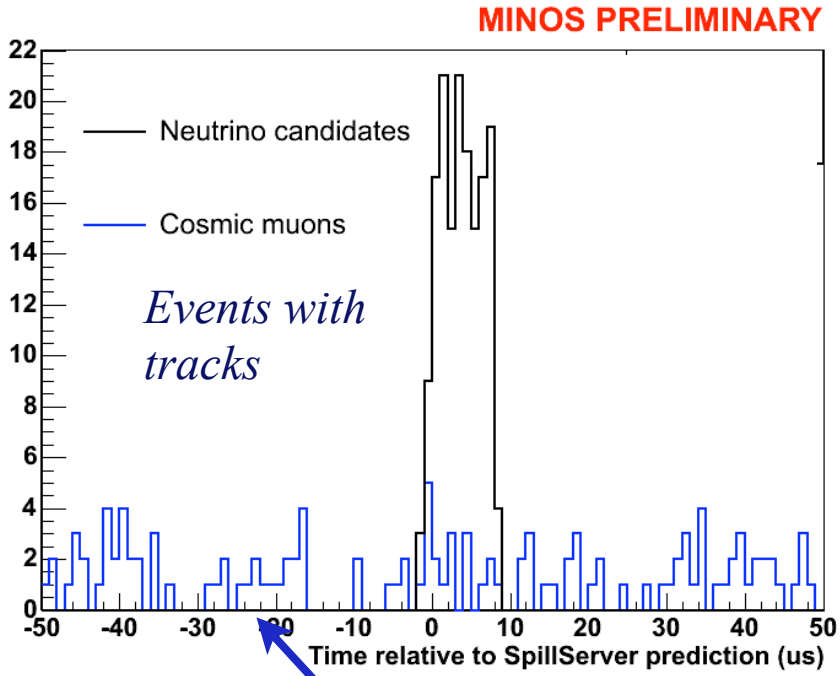
- The MINOS collaboration has instituted a Blind Analysis Policy
- Near Detector Data set is fully open (no blinding)
- Far Detector Data set is partially blinded:
  - Most events are excluded from direct study, according to an unknown function of basic energy-related reconstruction parameters
  - Permits meaningful Far Detector Data/MC comparisons for quantities that correlate weakly with neutrino energy.
  - Total sample will be opened once we are satisfied with studies

Far Detector ν Timing

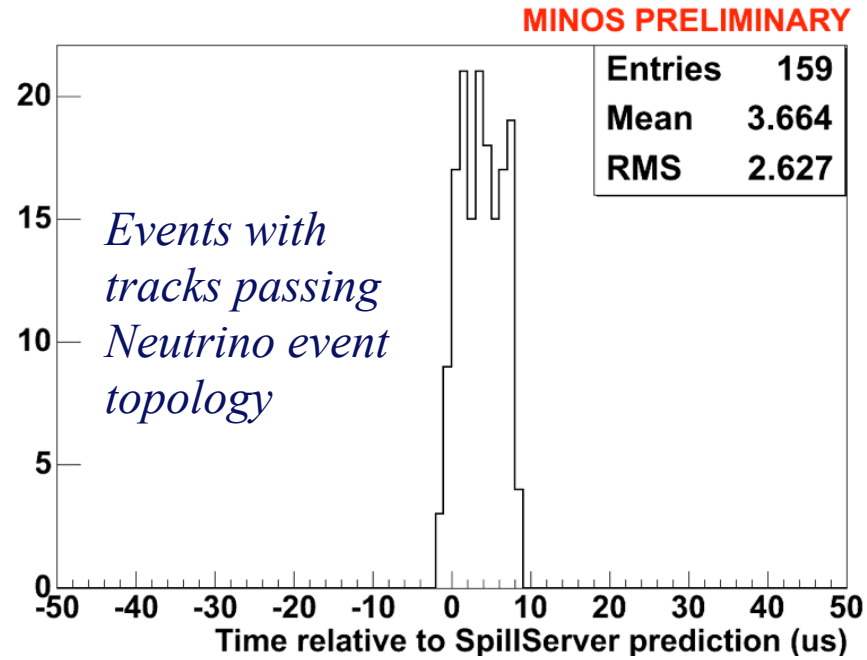
Timing of Cosmic Ray and Neutrino Candidates

Selected using event topology only, within 100μs window of beam

Far Detector Data: subjected to blinding



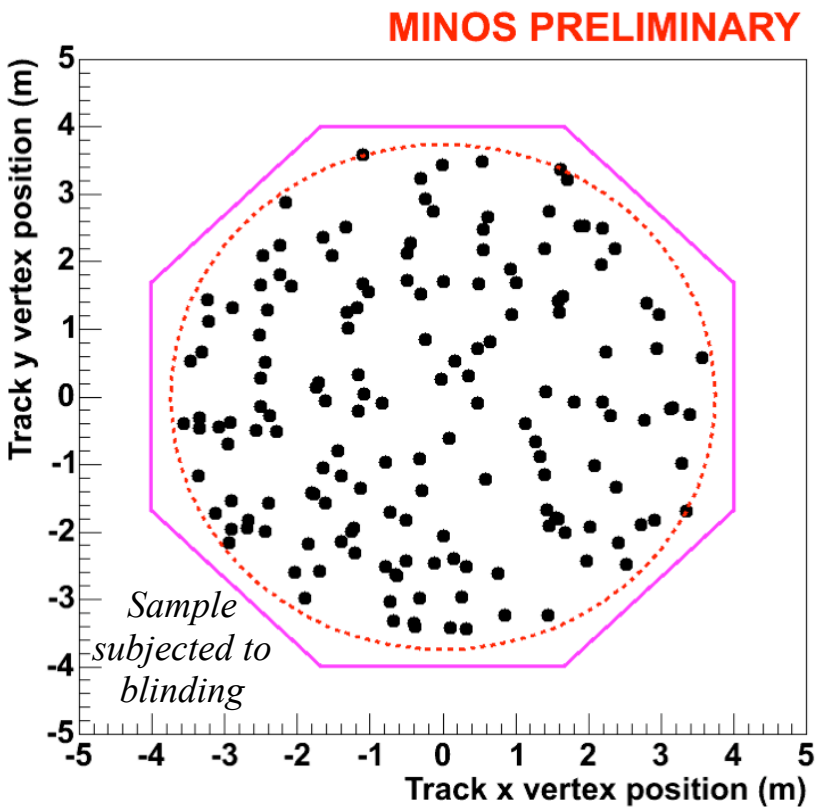
Cosmics identified by topology alone



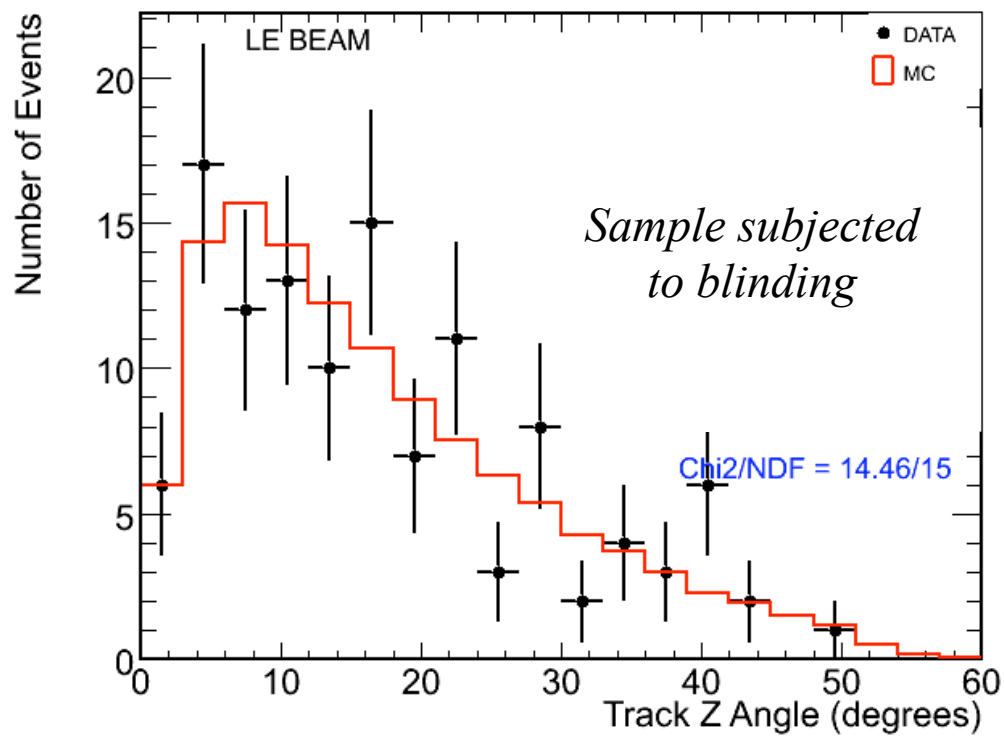
No detectable cosmic background after topology cuts

Far Detector ν Candidates

Transverse Vertex Position

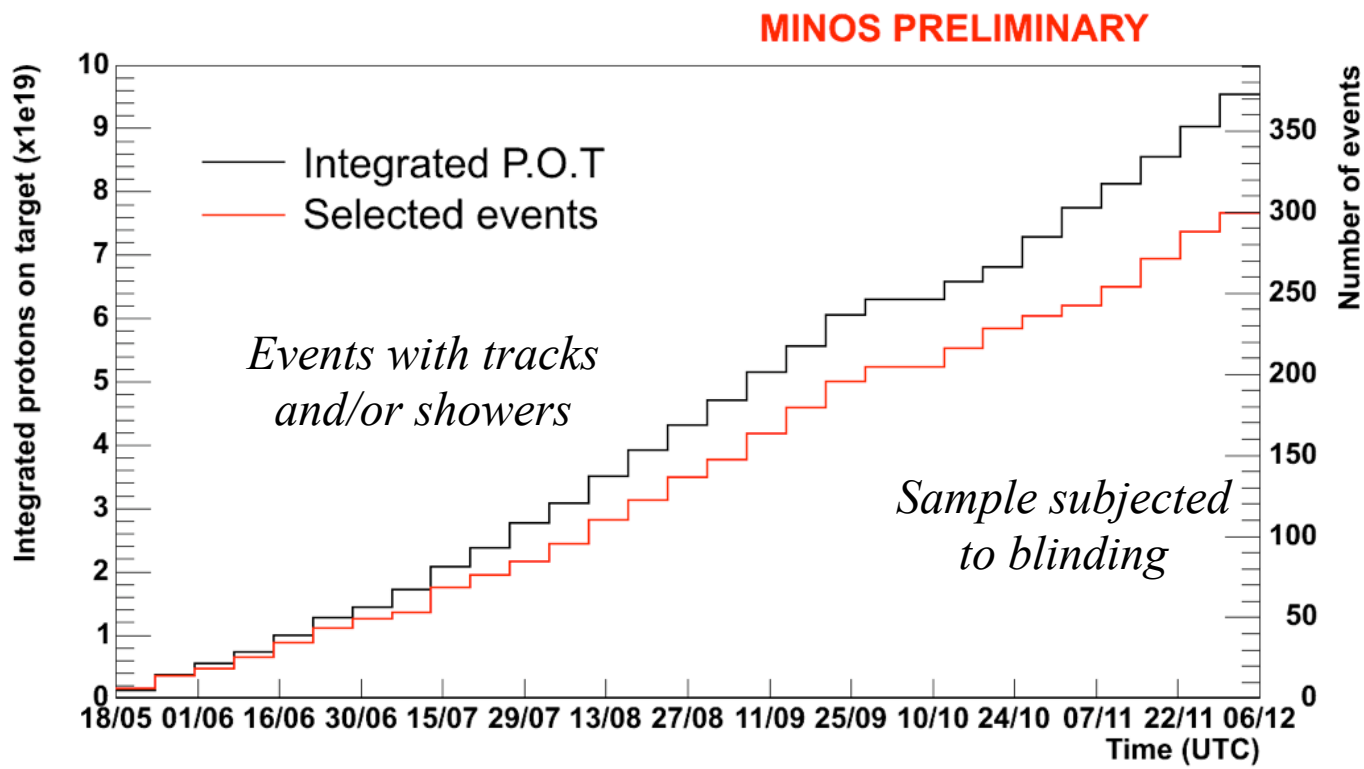


Track angle with respect to detector axis: Pointing to Fermilab



Far Detector Events vs. Time

- Far Detector neutrino rate tracks well with Protons on Target



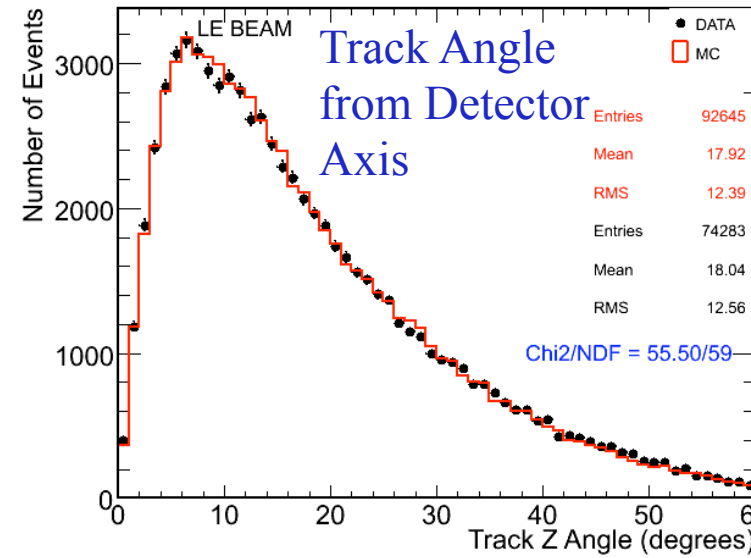
Systematic Effects

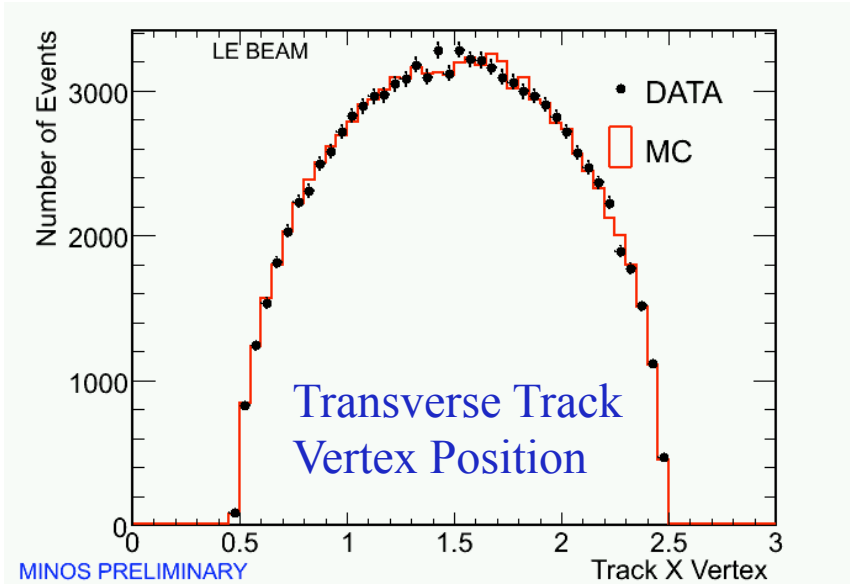
- Neutrino interactions
  - Neutrino cross sections, nuclear effects
- Detector response
  - Calibrations, detector simulation, reconstruction, event selection
- Beam modeling - flux extrapolation
  - Far Detector sees point source, Near Detector sees extended source
  - Hadron production and focusing

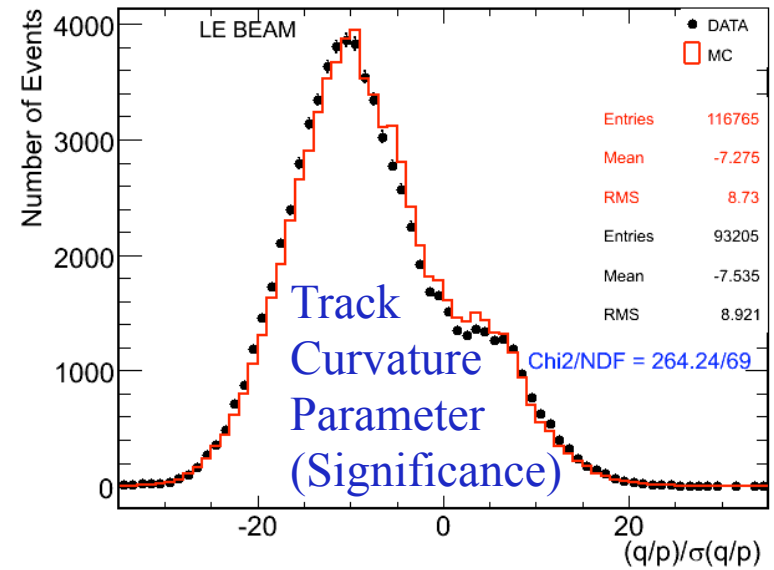
Detailed Studies of Each Are in Progress

Detector Modeling

- Near Detector: 10s of thousands ν events/day in ~17 t fiducial volume. Detailed studies of:
  - Detector Response
  - Interaction Physics
  - Beam Modeling





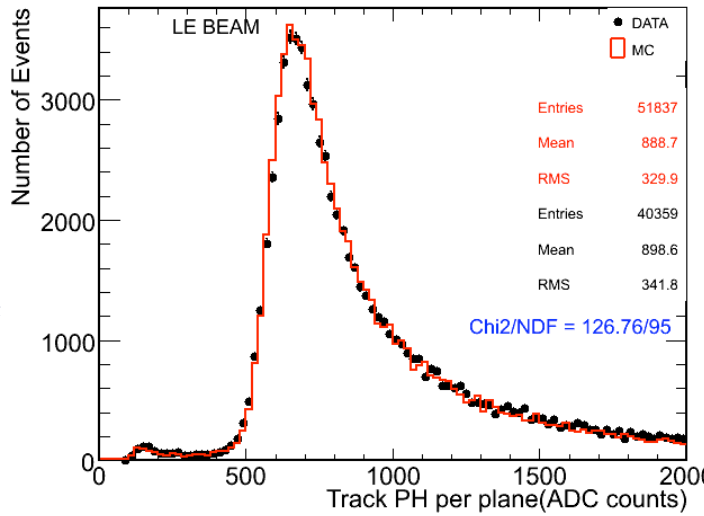


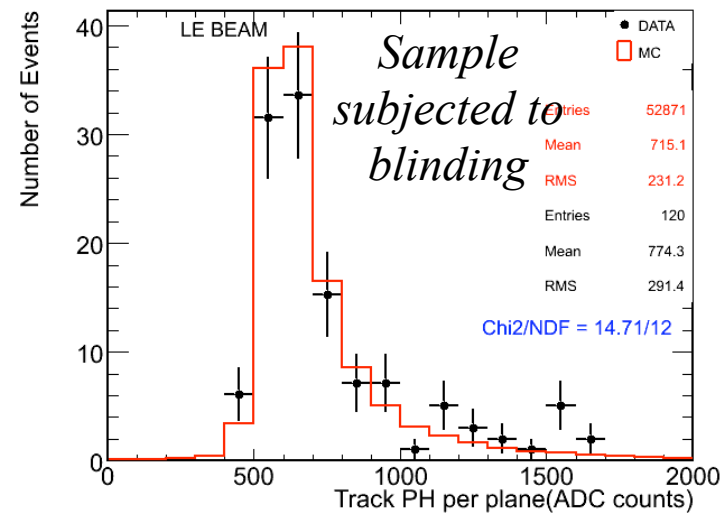
Near/Far Comparisons

Near Detector

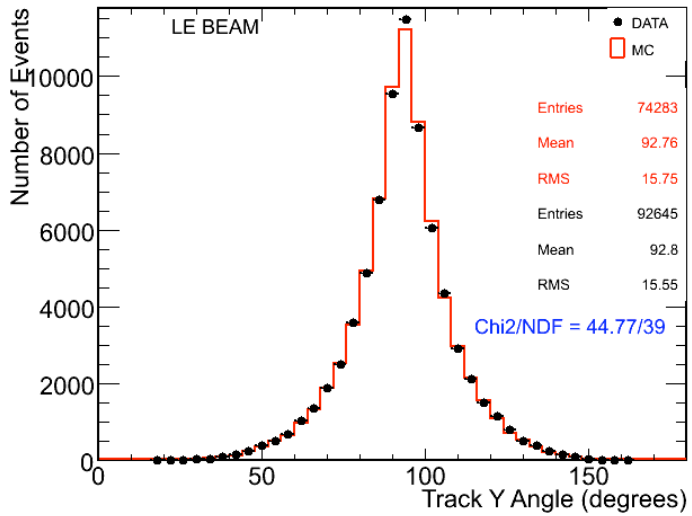
Far Detector

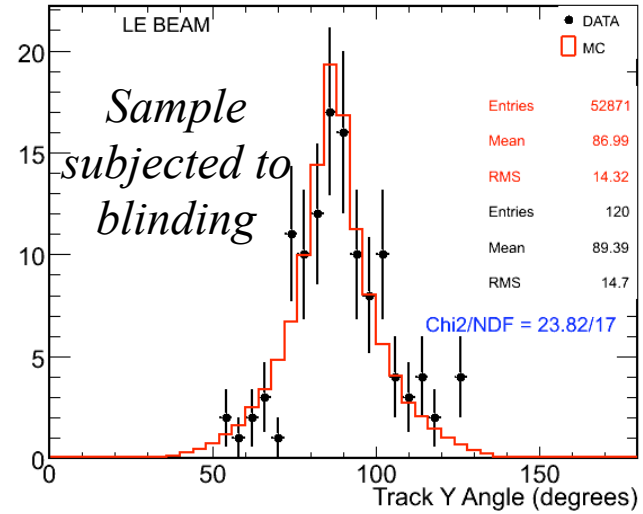
Track Pulse Height per Plane





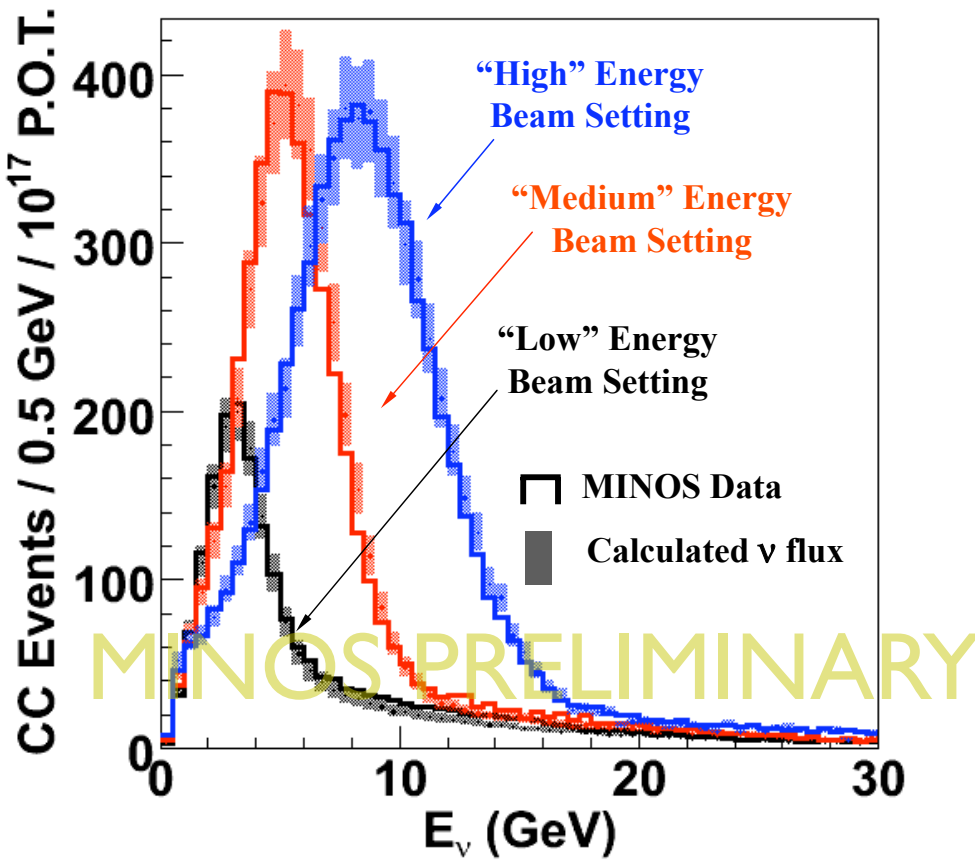
Track Vertical Angle





Beam Modeling

- Hadron Production: Fluka'05
- Hadron tracking and non-target interactions: GEANT3
- Constraints
  - External experiments, beam component modeling, hadron and muon monitors, Near Detector
  - Coming Soon: Results from MIPP - MI hadron production experiment

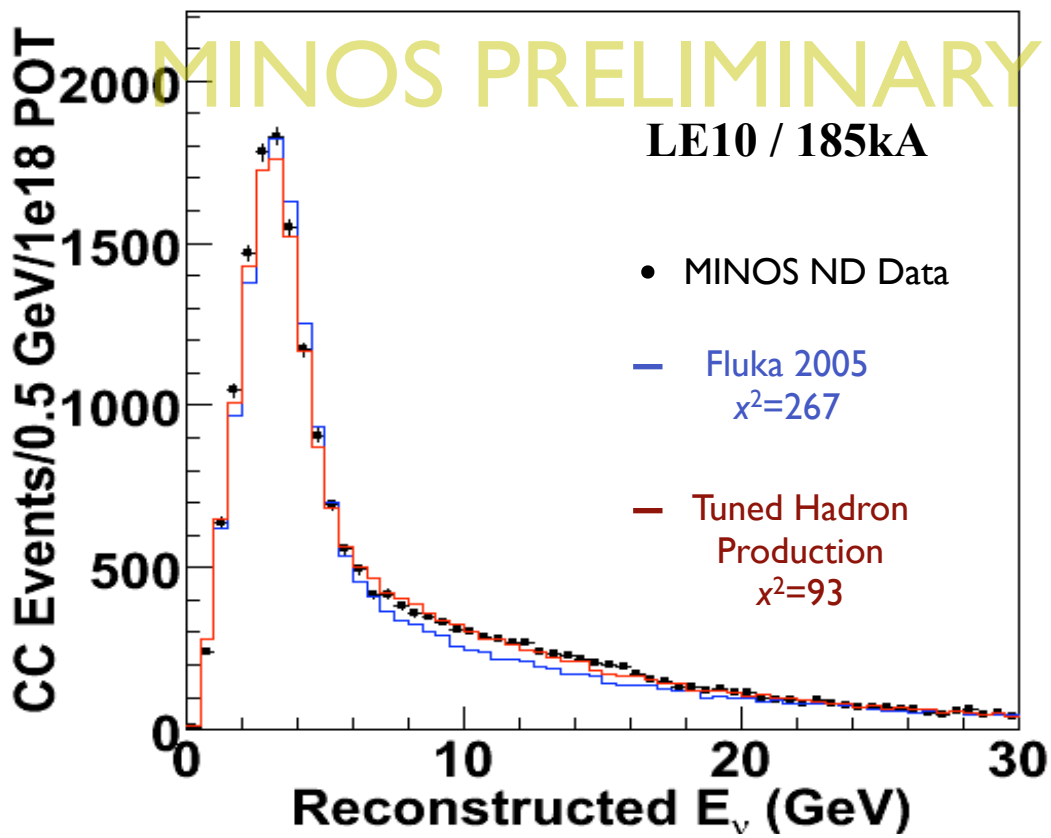


Beam Tuning

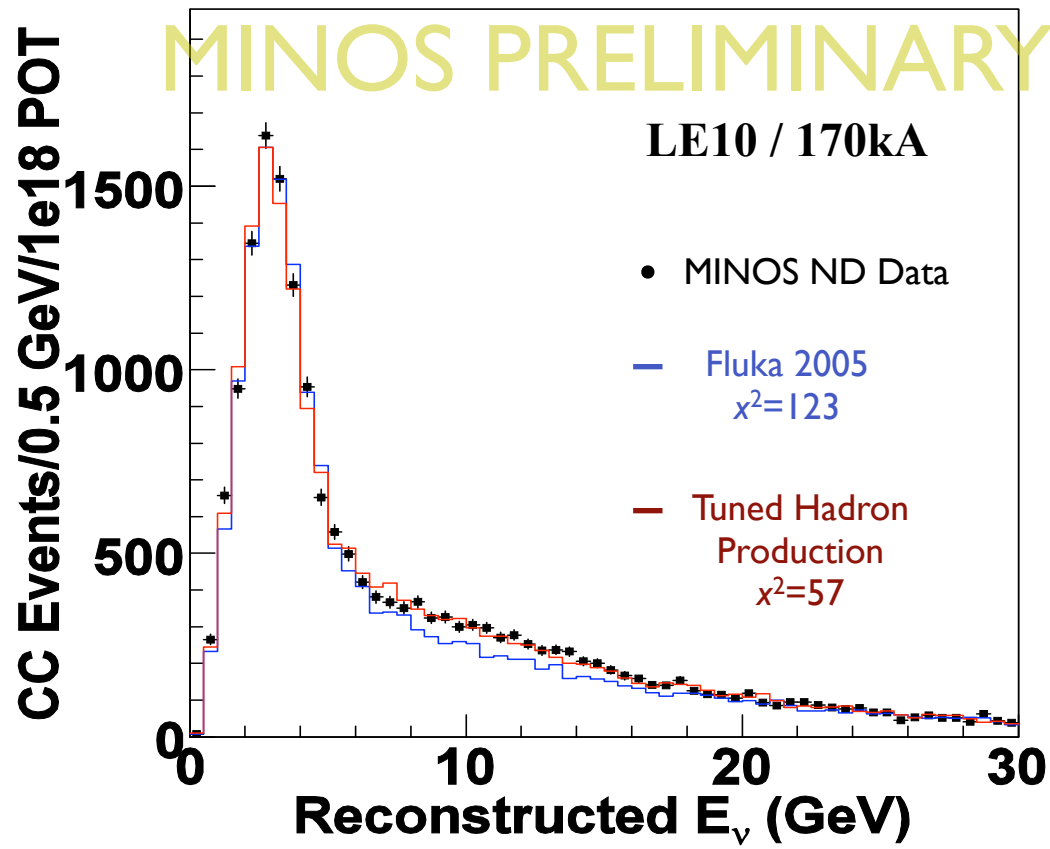
Tuning to Near Detector:

- Parameterize Fluka2005 in x_F, P_T
- Range of parent hadron (x_F, P_T) and mapping to E_ν changes with beam configuration:
- Vary parameterization simultaneously in different beam configurations to maximize agreement of MC and Data
- **Substantial Improvement In All Configurations**

Nominal Beam Configuration: Low Energy



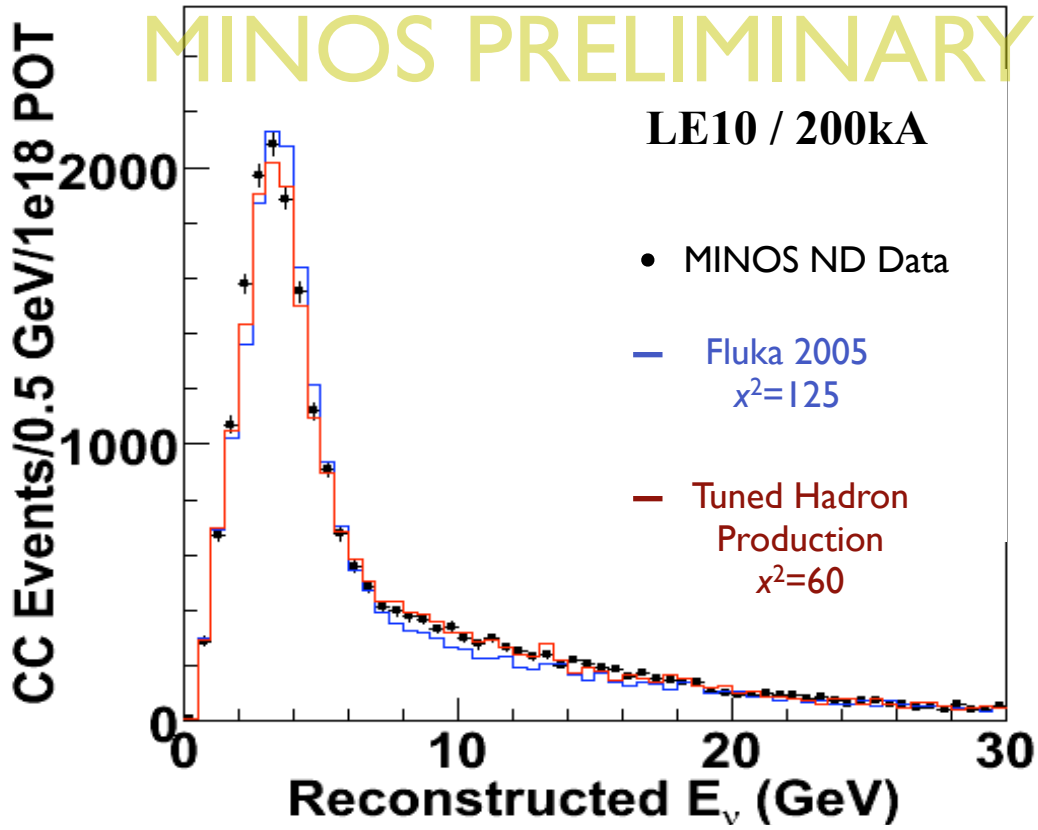
Beam Tuning



Low Energy
Target Position/
Low Horn Current

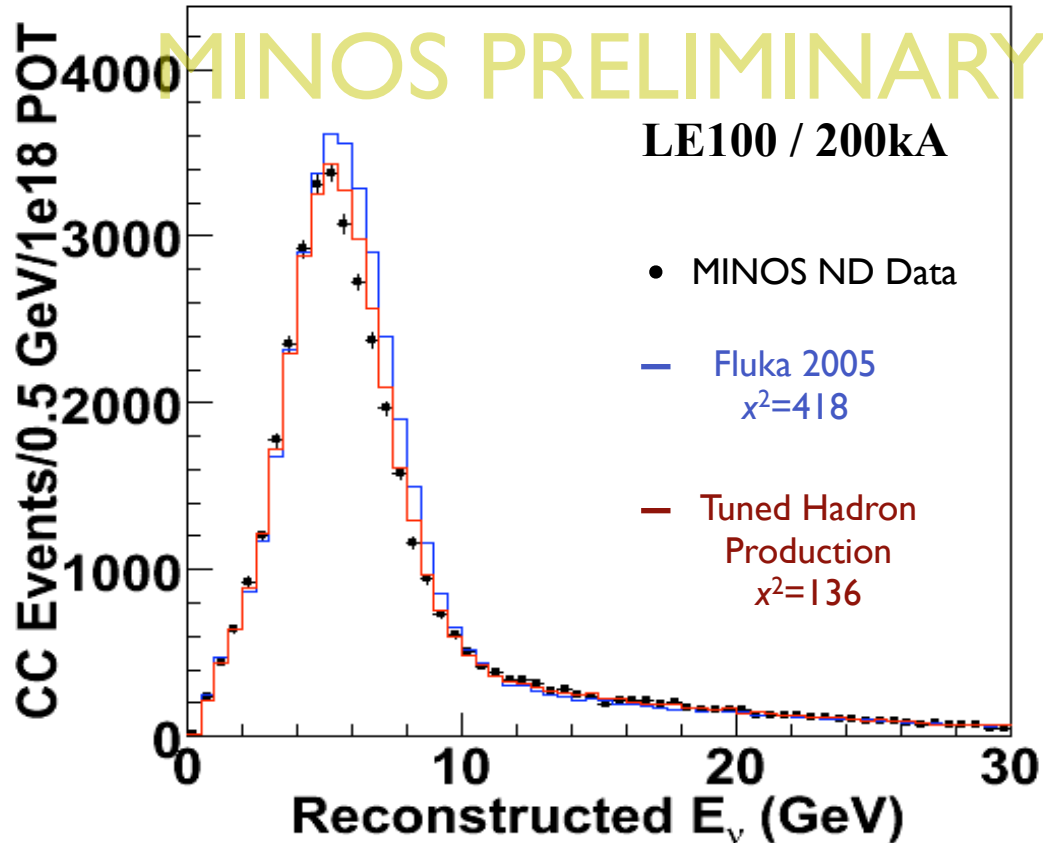
Beam Tuning

Low Energy Target Position/ High Horn Current



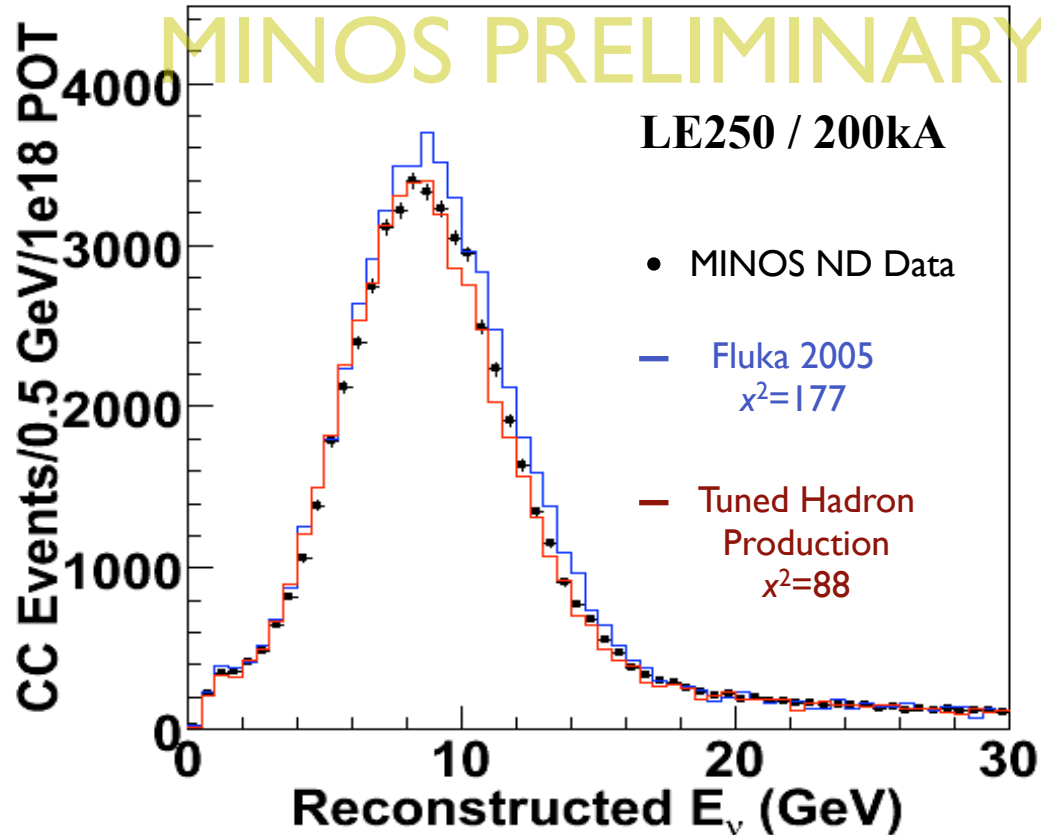
Beam Tuning

Medium Energy Target Position



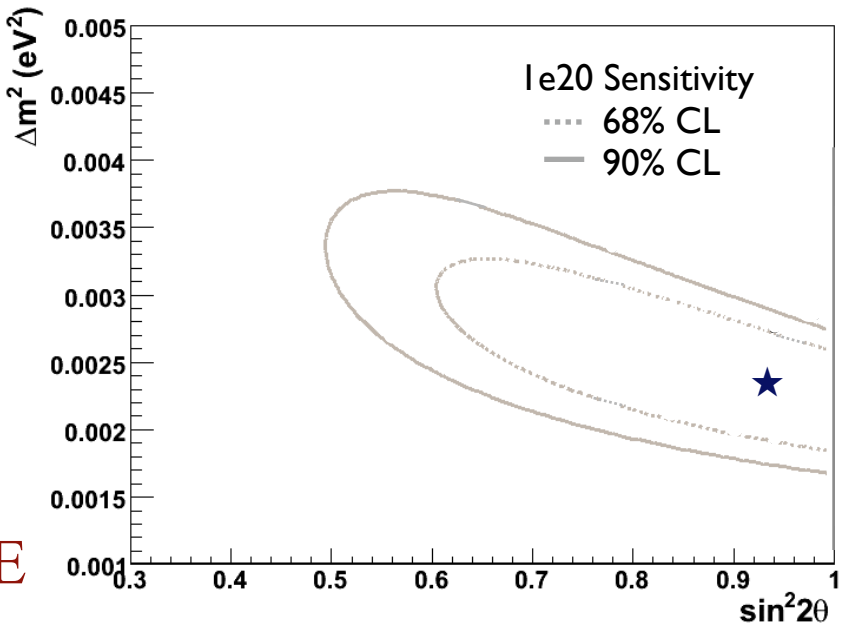
Beam Tuning

High Energy Target Position



MINOS Status

- Current Analysis - Results soon!
  - 0.95×10^{20} Protons-on-Target (data through Dec. 5, '05)
- 1st Run Through Feb. 26, '06
  - Start of Fermilab Shutdown
  - 1.35×10^{20} Protons-on-Target in nominal LE beam, 6×10^{18} in other configurations
  - We hope for a full analysis by summer 2006
- Restart beam data taking in June '06
  - Hopefully with somewhat higher intensity



1E20: MC Statistical Uncertainty For $\Delta m^2 = 2.38 \times 10^{-3}$ eV^2 $\sin^2(2\theta) = 0.931$

Conclusions

- The MINOS experiment has been taking beam neutrino data for the past year.
- Our analysis of our first 1×10^{20} Protons-on-target data set is well underway, with much recent progress.
- We look forward to a significant preliminary measurement of Δm^2_{23} soon.
- Analyses of ν_μ disappearance, and many other topics, continue