Status of the MINOS Experiment

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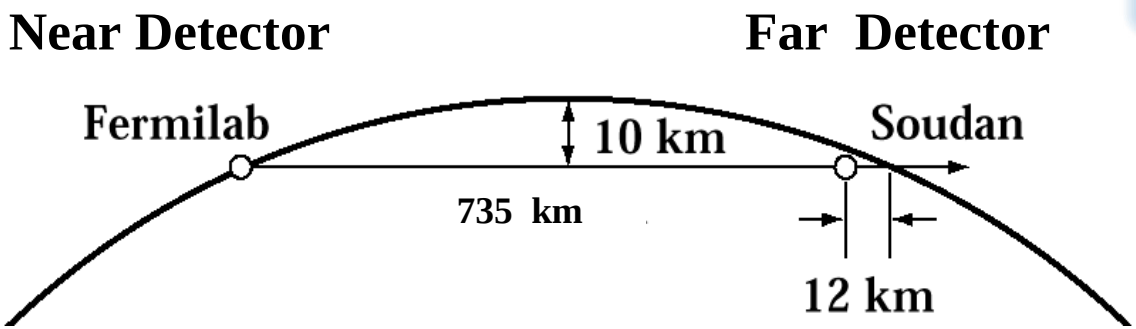
Outline

- Introduction
- Experiment Overview
- Neutrino Beam & MINOS Detectors
- Atmospheric neutrinos
- Beam Neutrino Data in :
  - Near Detector
  - Far Detector
- Physics Potential (Near & longer term)
- Summary

MINOS Experiment

- **MINOS (Main Injector Neutrino Oscillation Search) is a two detector long baseline neutrino oscillation experiment.**
- ***Its goal is to study the region of parameter space indicated by atmospheric neutrino experiments and make precise measurement of the oscillation parameters Δm^2 & $\sin^2(2\theta)$***



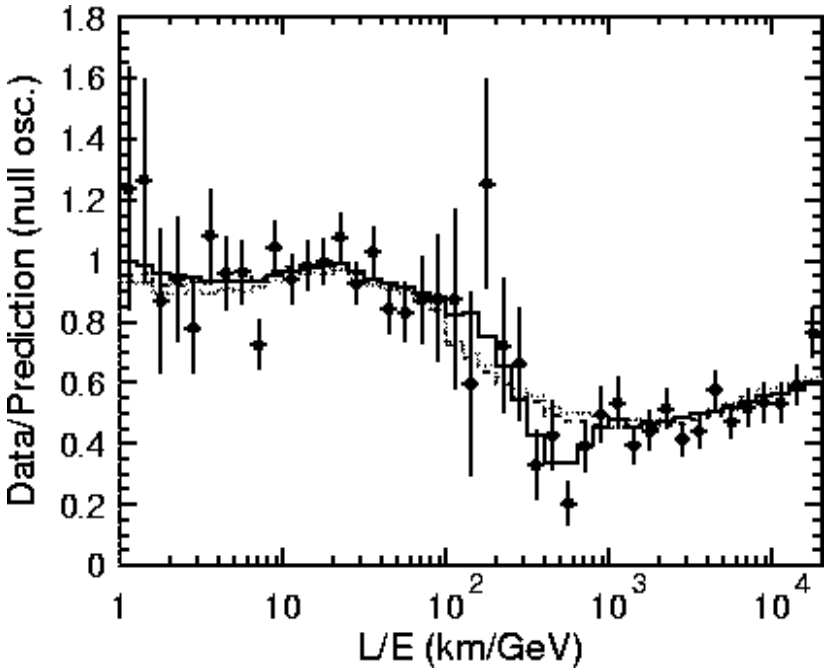
Comparison between Near/Far measurements will establish the oscillation signal and characteristics

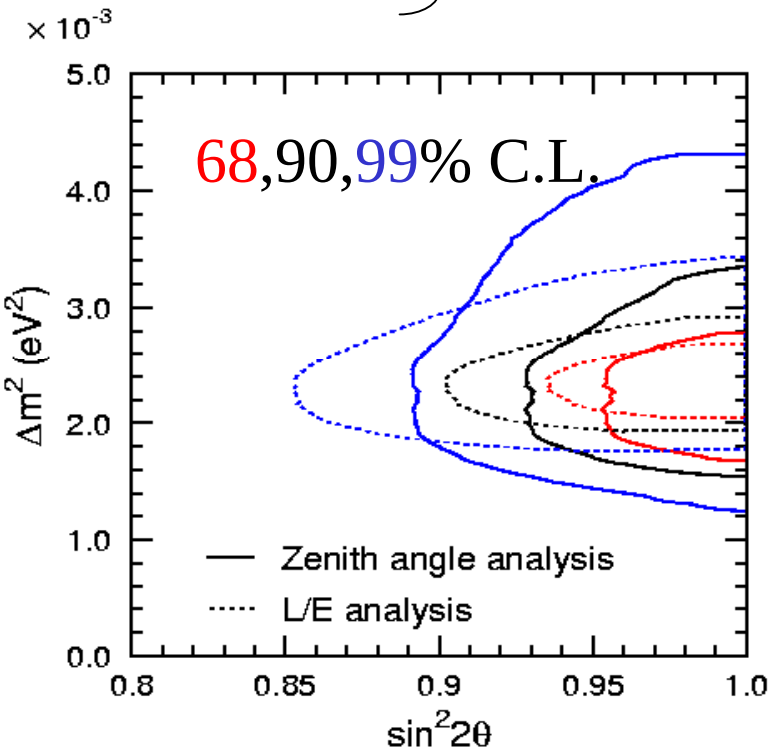
SuperK , Atmospheric neutrinos

- **Study muon and electron neutrinos produced in the upper atmosphere.**
- **Observation : fewer muon neutrinos than expected**
  : as many electron neutrinos as expected
  : as many NC interactions as expected

$\nu_\mu -> \nu_\tau$

Observed / Expected $\nu_\mu CC$ interactions



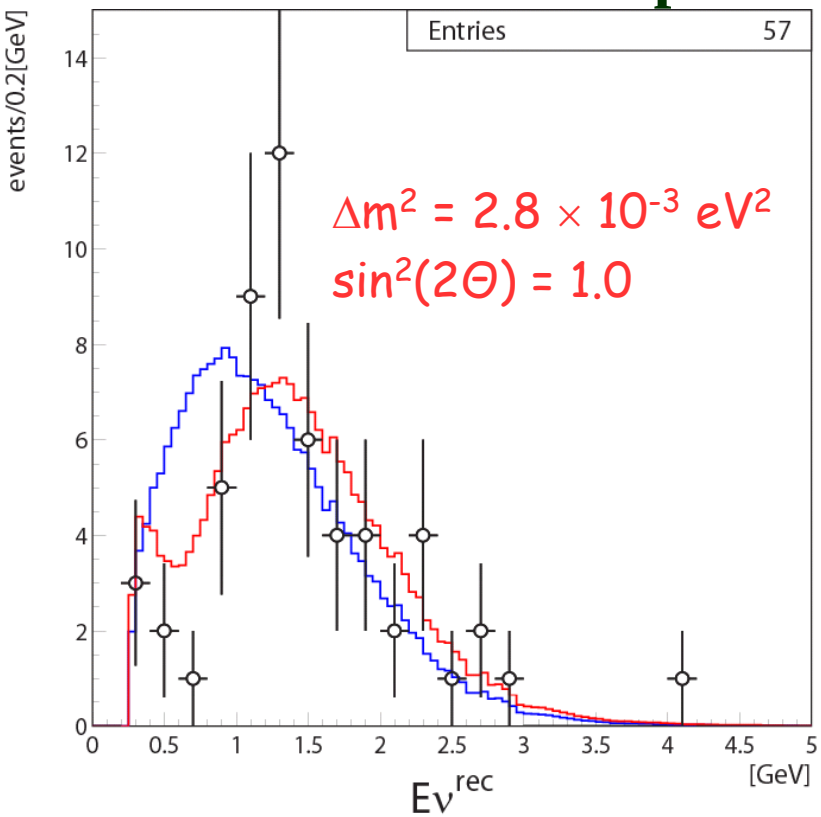


90% C.L. $\sin^2(2\theta_{23})>0.92$ & $0.0015<\Delta m^2_{23}<0.0035$

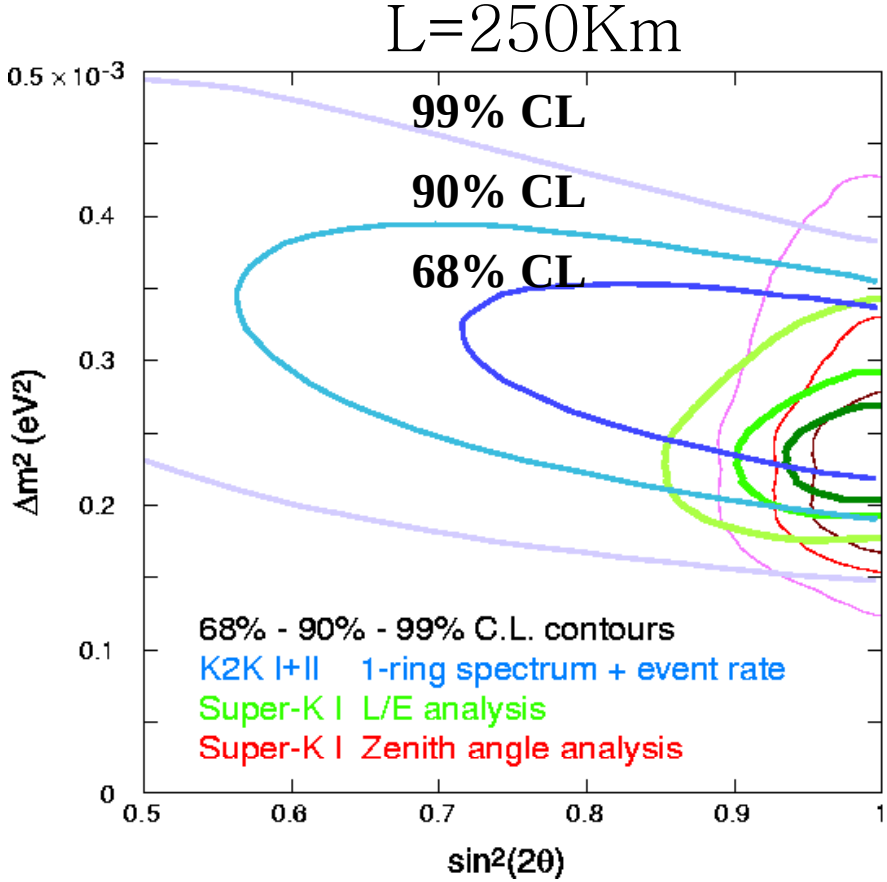
K2K – the 1st Long-Baseline Accelerator-based Experiment

- **Goal was to confirm SK result with accelerator muon neutrinos**

107 Observed / 149.7 Expected



0.89 x 10^{20} p.o.t.



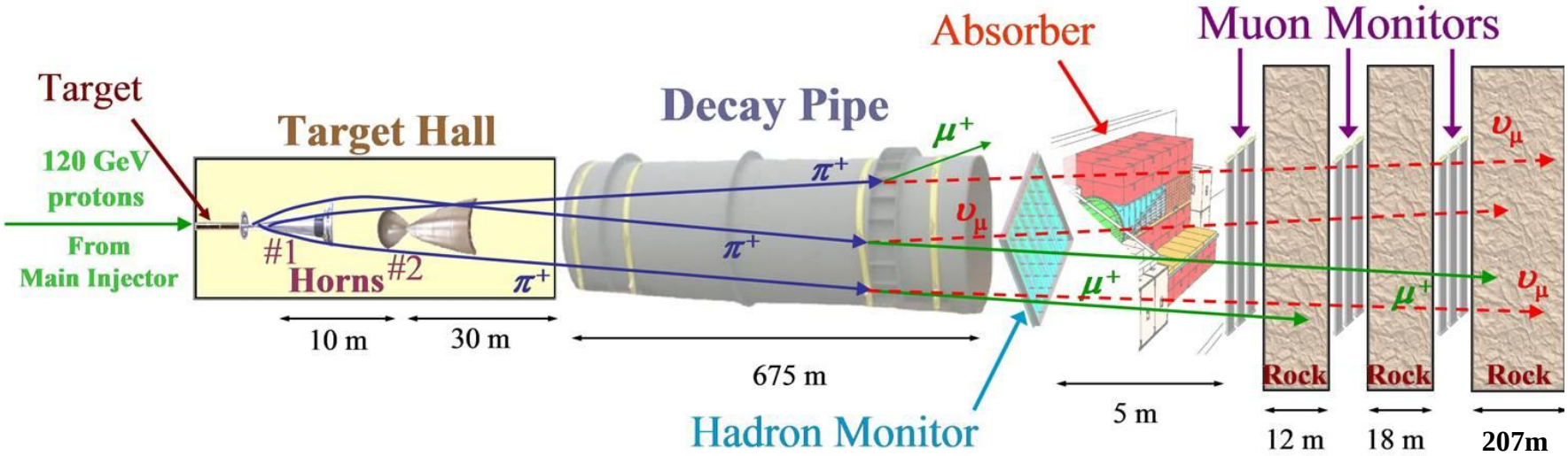
Plots courtesy C. Walter

MINOS Collaboration

32 institutions
175 physicists

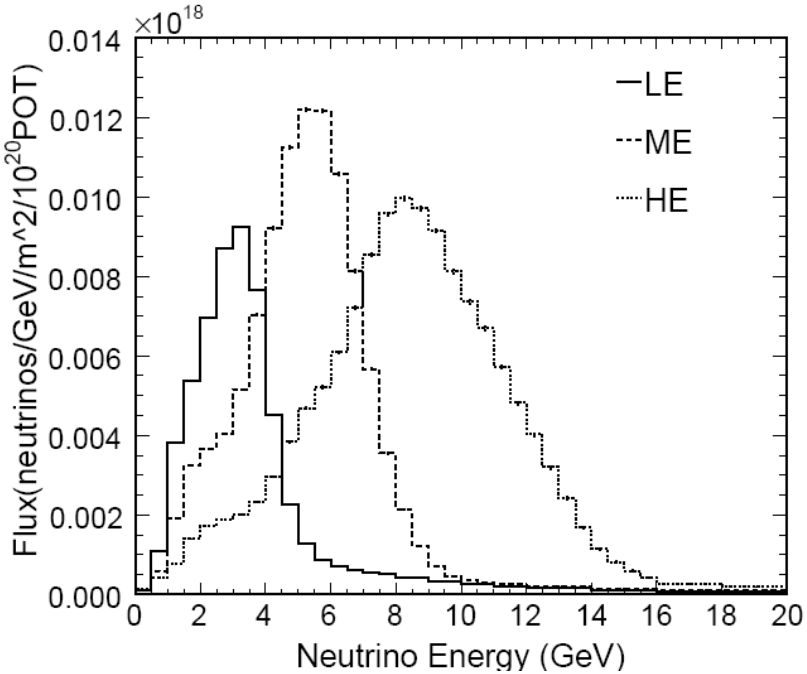
Argonne • Athens • Benedictine • Brookhaven • Caltech • Cambridge • Campinas • Fermilab
College de France • Harvard • IIT • Indiana • ITEP-Moscow • Lebedev • Livermore
Minnesota-Twin Cities • Minnesota-Duluth • Oxford • Pittsburgh • Protvino • Rutherford
Sao Paulo • South Carolina • Stanford • Sussex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

NuMI Neutrino Beam



- 120 GeV protons strike the graphite target
- Initial intensity 1.5×10^{13} ppp every 2-4 sec
- Current intensity 2.5×10^{13} ppp every 2.2 sec
- Goal for 2006 is to run stably at ~ 2.5×10^{13} ppp every 2 sec.
- (2008-9) expected rate ~ 3.4×10^{20} protons/year

NuMI Neutrino Beam configurations



Running in the LE configuration we expected 1300 ν_μ CC events for 2.5×10^{20}/year in the 5.4kt FAR detector (in the absence of oscillations).

•One can obtain different neutrino spectra by moving the target (fast, have taken data already for three different energy configurations).

• LE, ME and HE data used to perform systematic studies in the Near Detector and tune our Monte Carlos (more about this later).

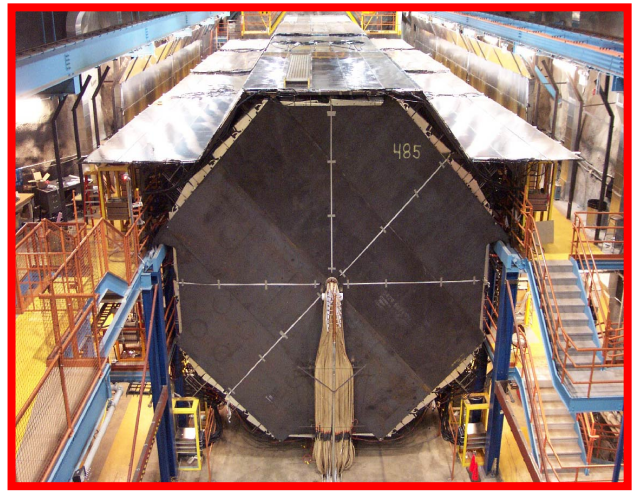
The MINOS Detectors

NEAR

0.98 kt

FAR

5.4kt

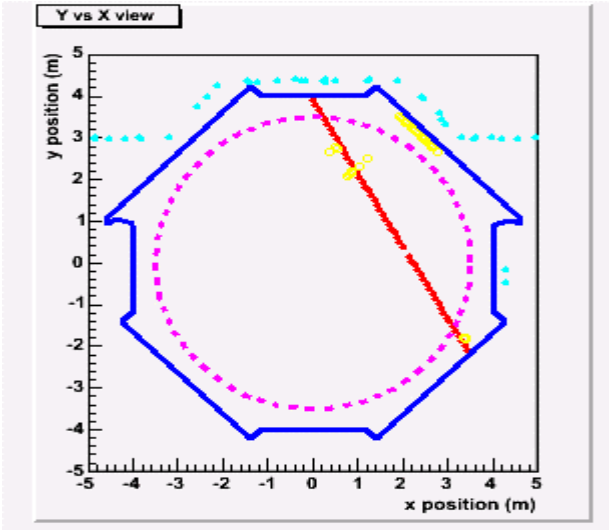


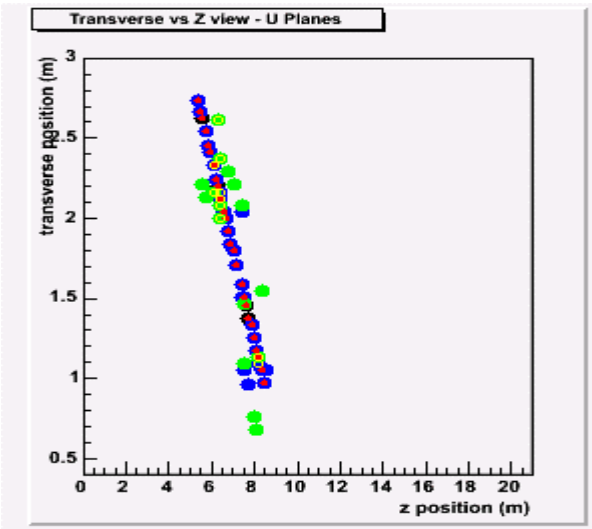
- **Basic Idea : Two detectors "identical" in all their important features.**

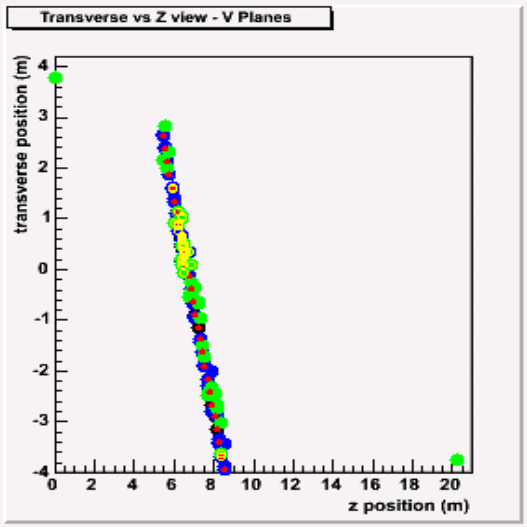
- Both detectors are tracking calorimeters composed of interleaved planes of steel and scintillator

  - 2.54 cm thick steel planes
  - 1 cm thick & 4.1 cm wide scintillator strips
  - 1.5 T toroidal magnetic field.
  - Multi-Anode Hamamatsu PMTs (M16 Far & M64 Near)
  - Energy resolution: 55%/√E for hadrons, 23%/√E for electrons (measured with Calibration detector at CERN)
  - Muon momentum resolution ~ 6 % from range (~ 12 % from curvature)

Far Detector Non Beam data
Typical events







- **In the Far detector we record events that satisfy either of the following trigger conditions:**

4/5 consecutive planes

OR

Sum of ADC >1500 or 6 hits in any 4 consecutive plane window

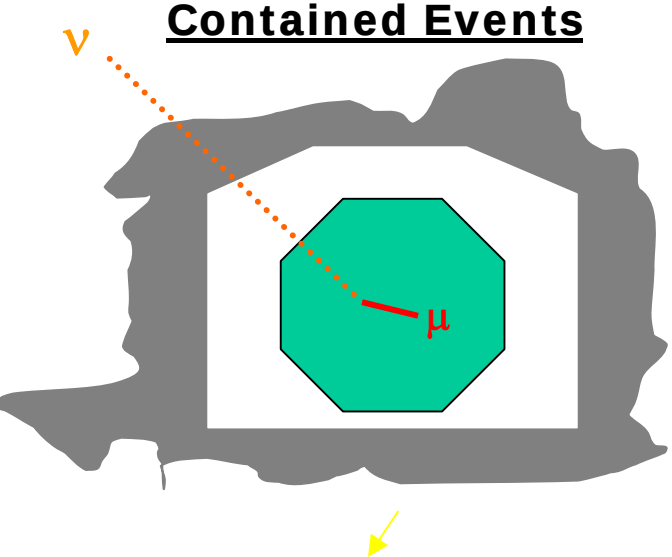
0R

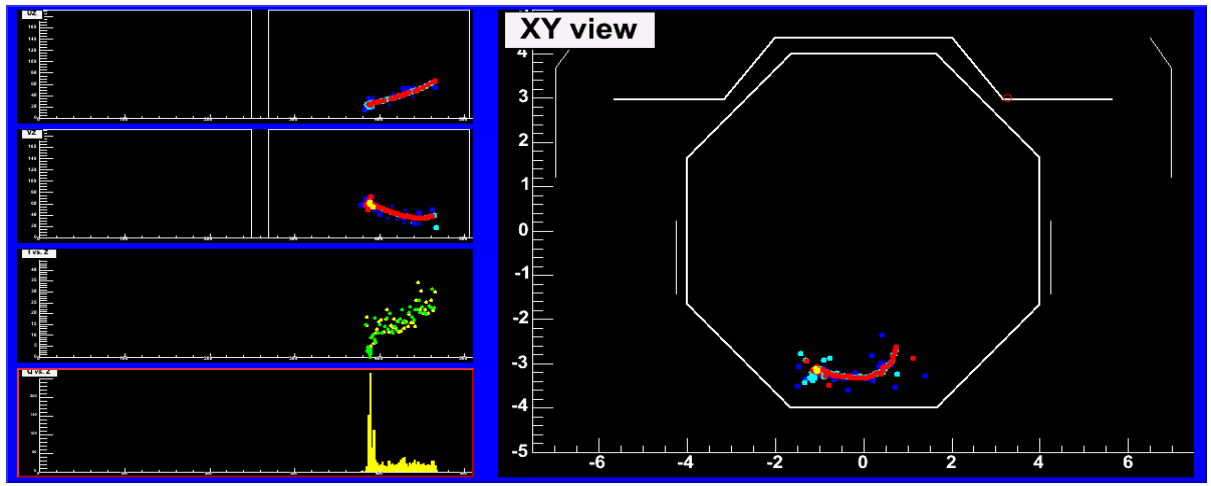
Events within +/-50 usec from a beam spill (beam data)

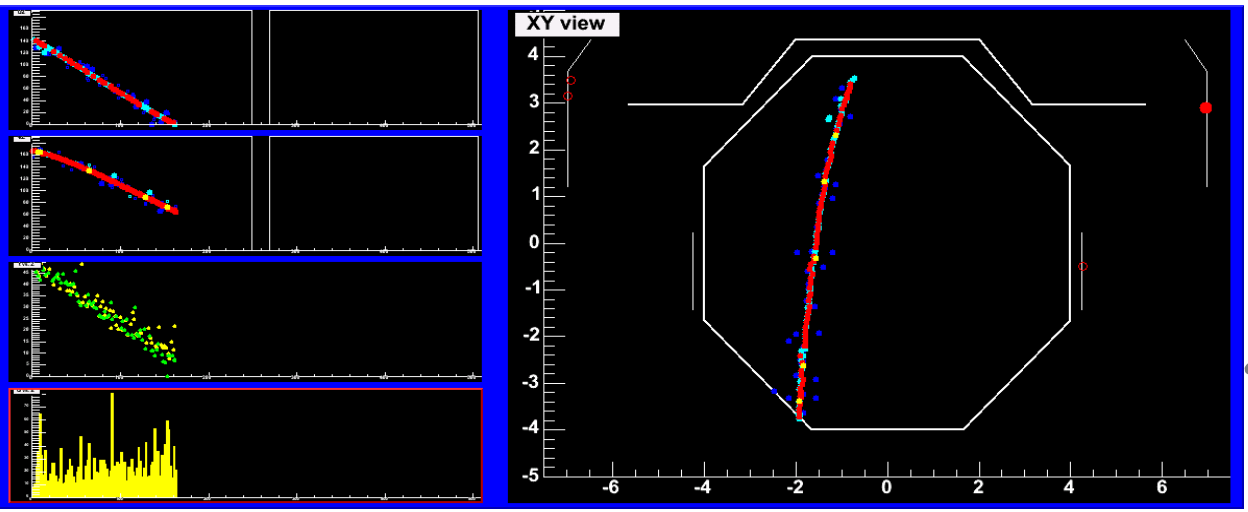
- **Mostly we record cosmic ray muons @ a rate of 0.5 Hz**

Far Detector Non Beam data
Atmospheric events

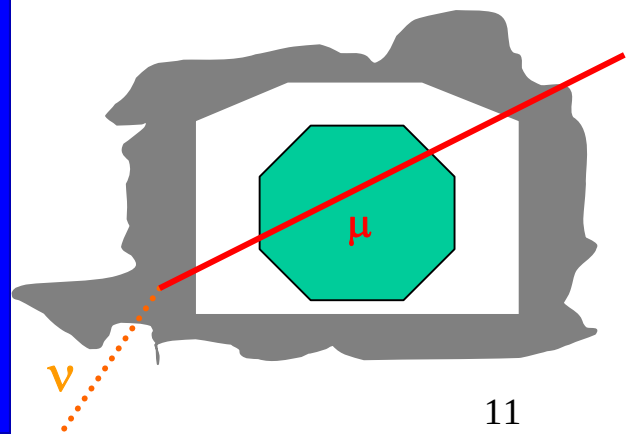
Contained Events







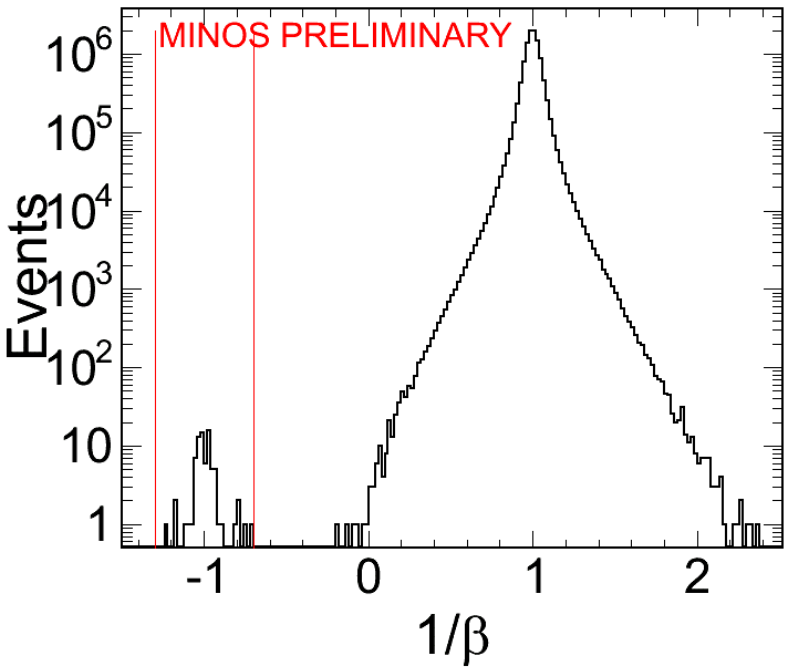
Upward-going muons

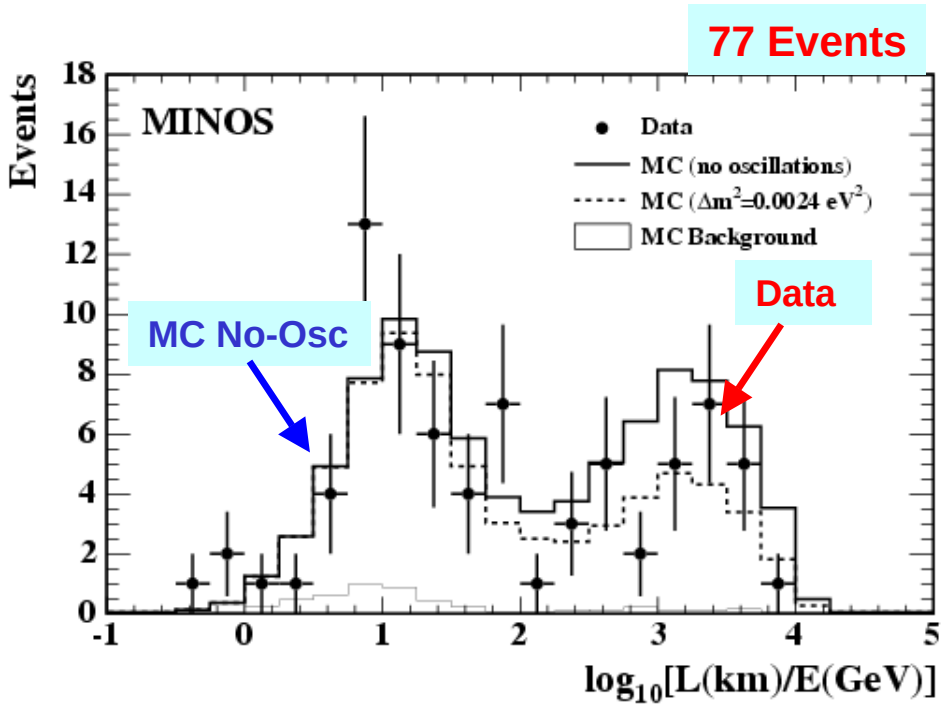


Far Detector Non Beam data

Atmospheric Events

c dt / ds = 1 / β (*signed by dy/dt*)



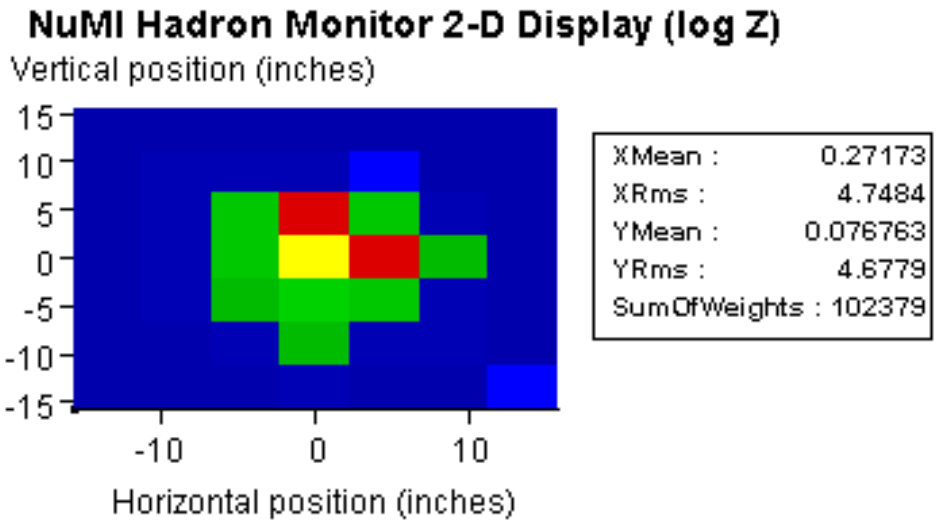


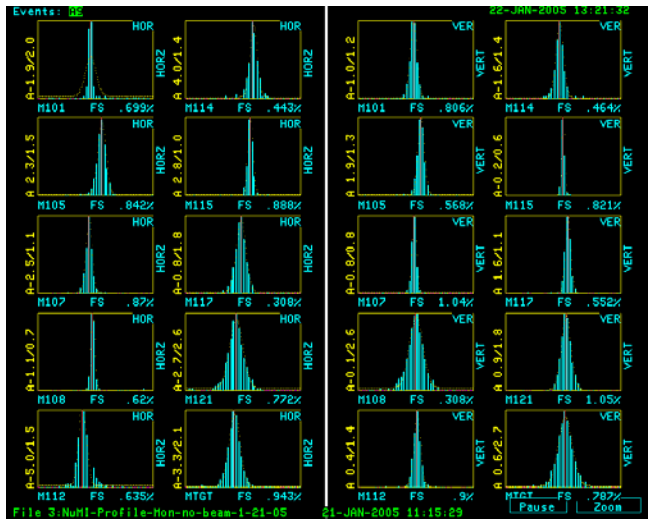
For ~418 live days we have 91 Upward-going (atmospheric neutrino induced) muons and 107 Contained atmospheric neutrino events.

Note: 2.4 ns single hit timing resolution !!

NuMI Starts.

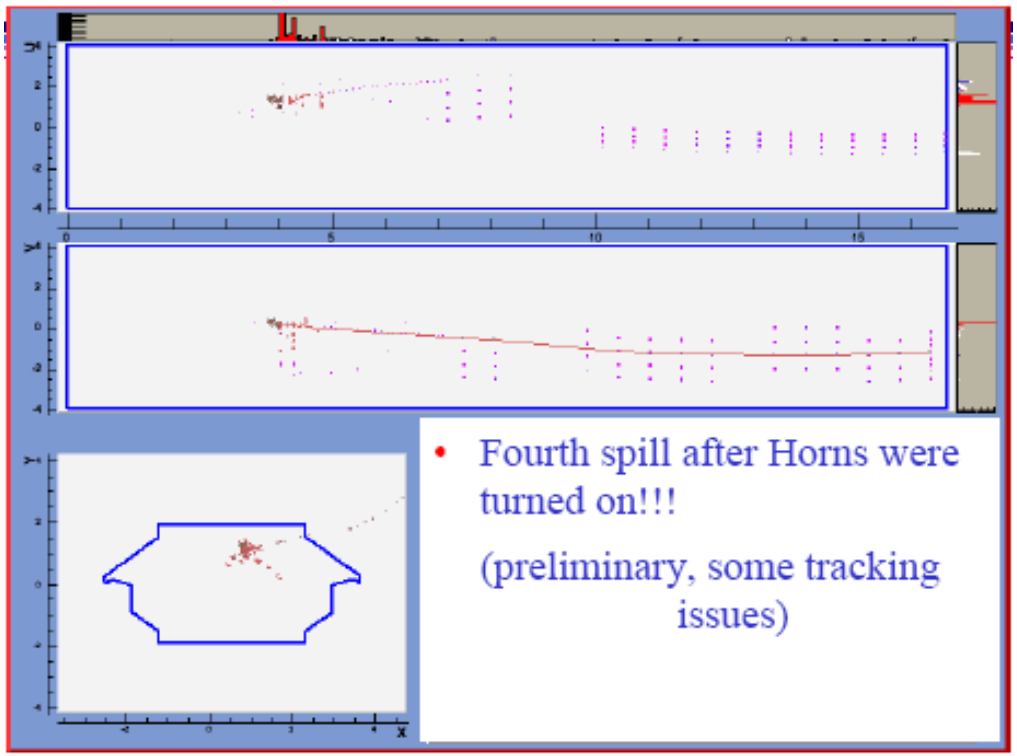
- **December 3 - 4, 2004**
  - **Beam transported through the target hall & onto hadron absorber**
    - **Target out & decay pipe evacuated , no neutrinos expected (or seen)**
  - **Saw beautiful signal on profile monitors all the way down the beam line to the absorber and the hadron monitors on the 10th pulse!**



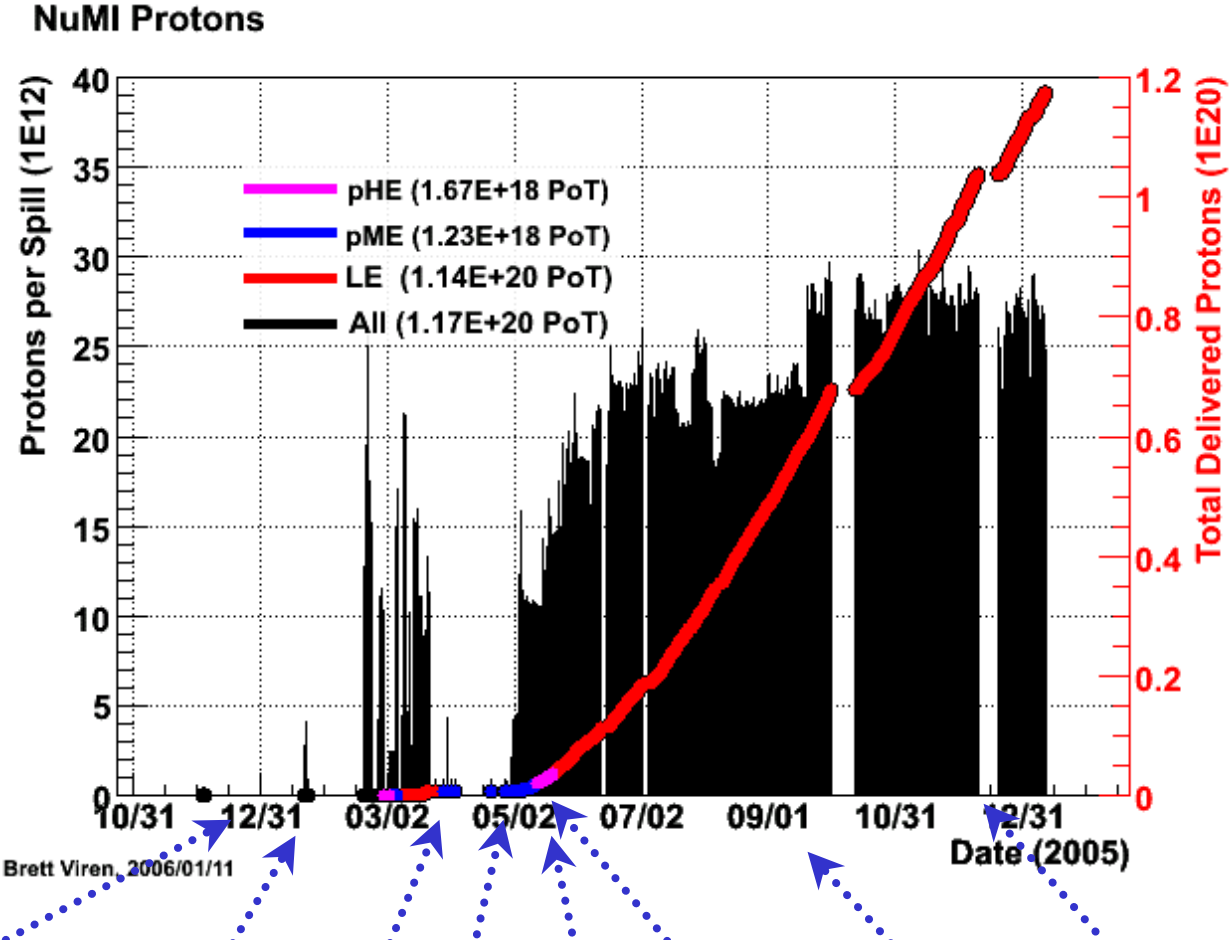


MINOS Starts.

- **January 21 - 22, 2005**
  - **First beam on target, Horns on, ME beam**
  - **On 4th!! horn pulse saw the first neutrino in the Near Detector ! (since then we have been seeing many many more!)**



& Continues...



First neutrino beam

First ND neutrino events

First FD neutrino events!

Target Leak, down for a month

Back up ME running

HE running

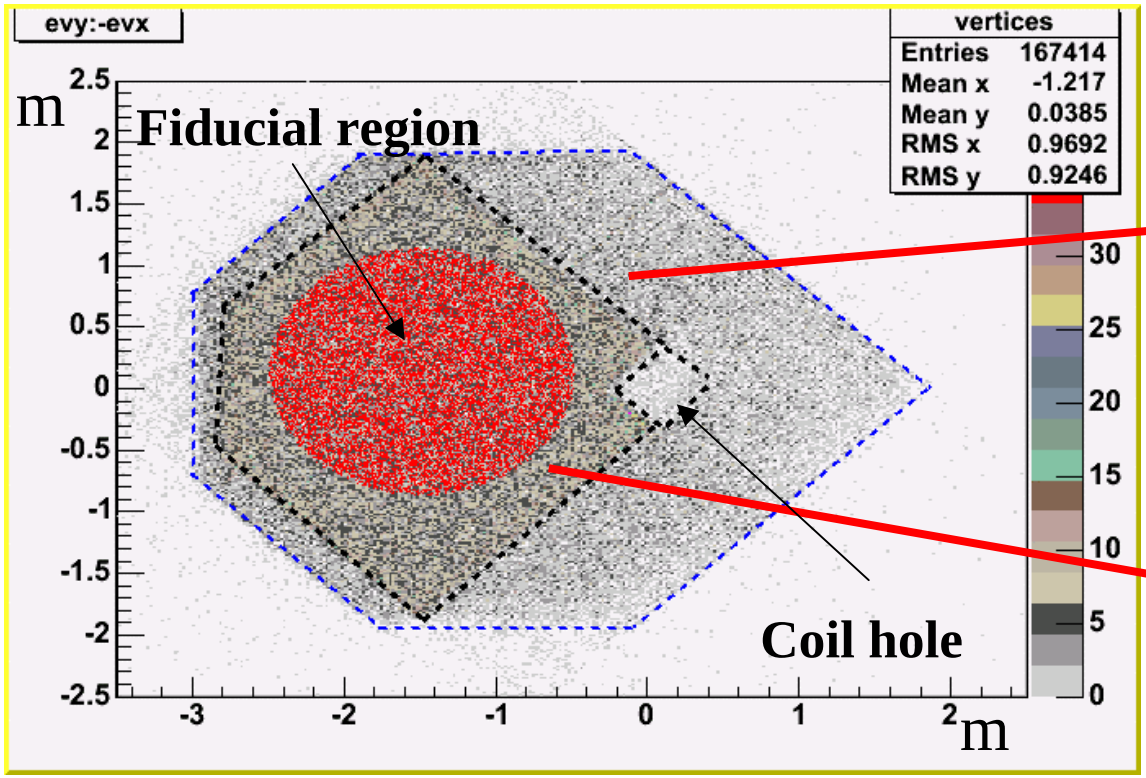
LE running

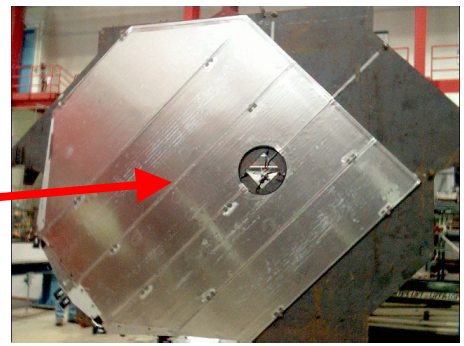
1E20 P.O.T.s!!

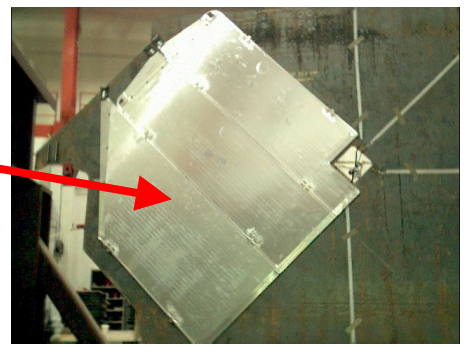
Event Vertices & Fiducial Region

- Unlike "older" neutrino experiments, statistics in our Near Detector are very high (1,000,000 ν's in the fiducial for 1E20 P.O.T.s)

- We can clearly "see" detector details from the reconstructed vertices of our neutrino events!



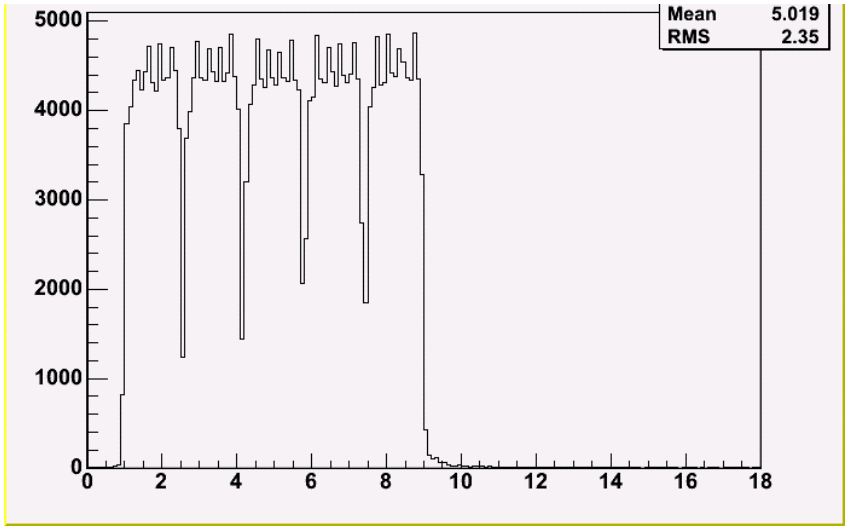




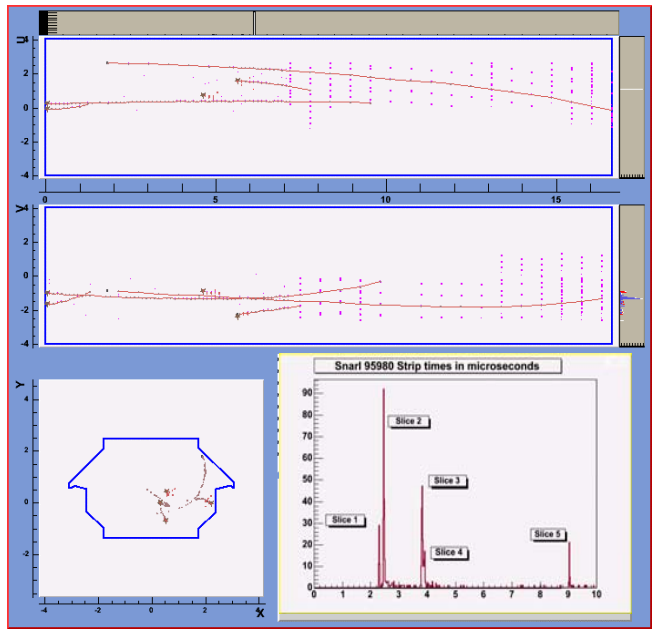
Near Detector Timing

Detector activity

Starting time of Events with respect to the Spill Gate



One Spill

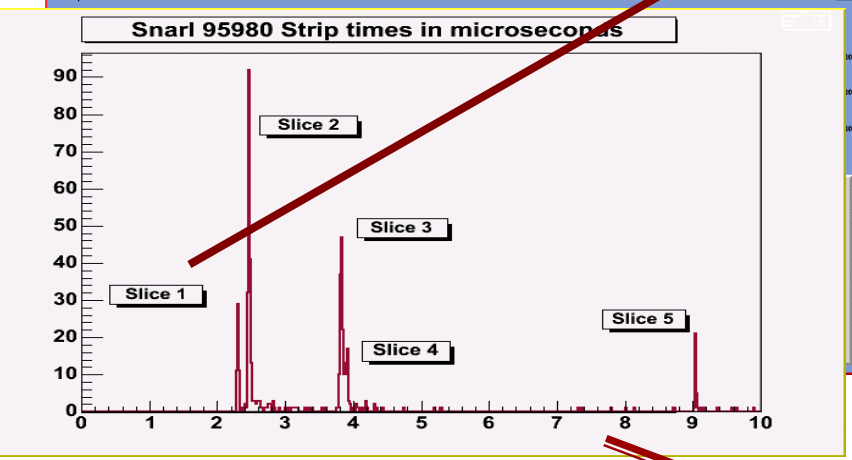


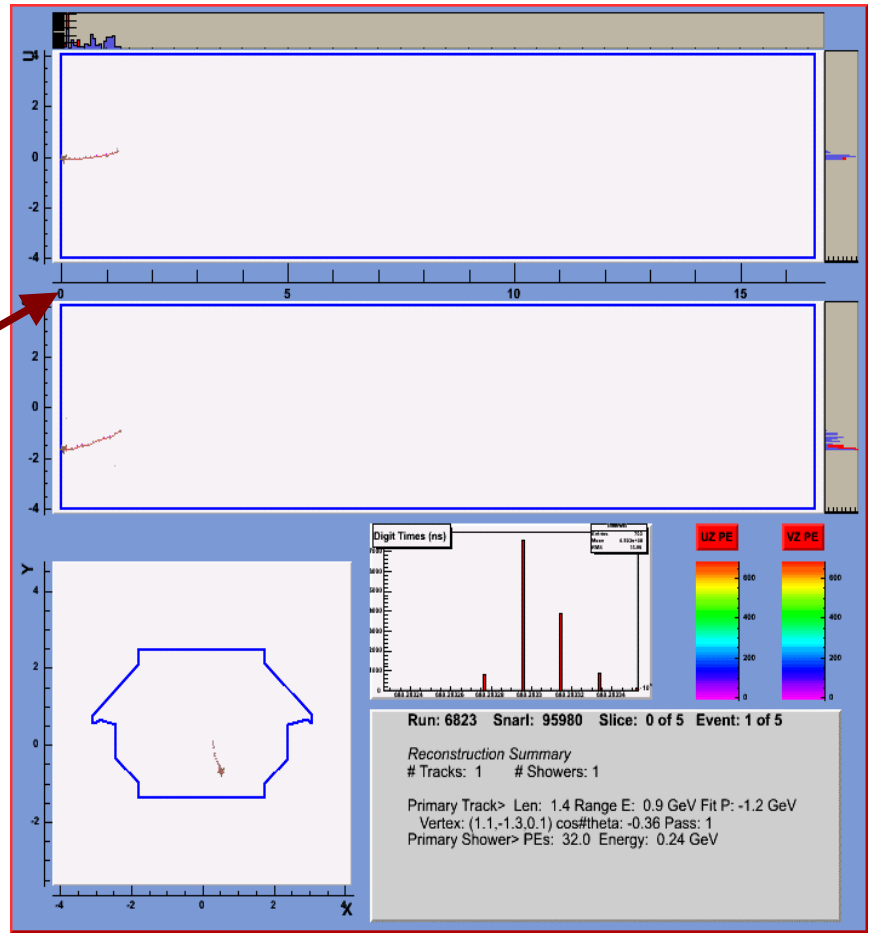
- **8 –10 usec spill of 5-6 "batches" each of ~ 1.6 usec length.**
- **Events recorded within a 18 micro sec window.**
- **Many neutrino interactions per spill , time and space used to "slice" = separate individual events (timing resolution : 18.9 nsec)**

Event Timing

One Spill

"Rock muon"

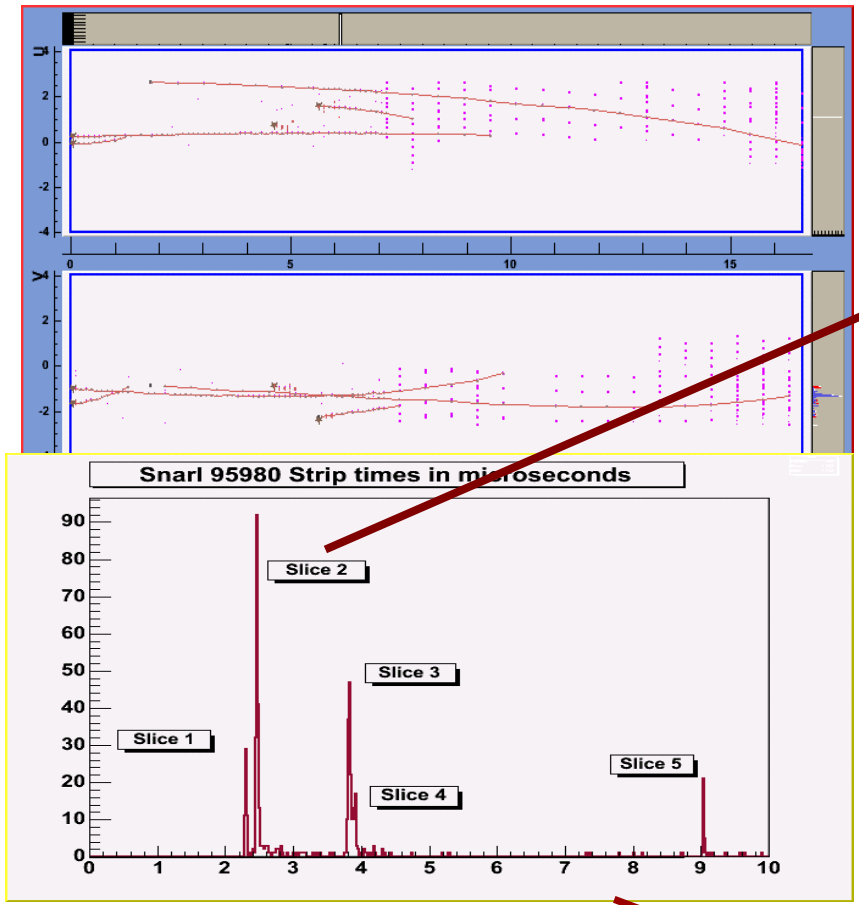




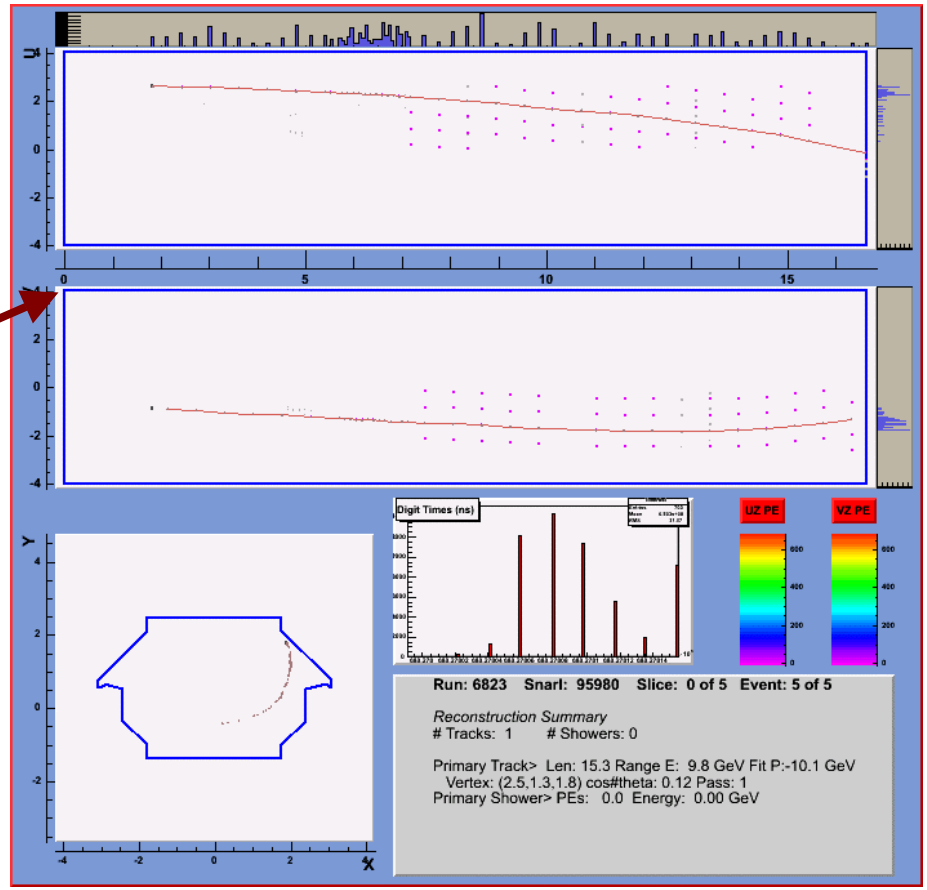
5 time slices -> 5 events

Event Timing

One Spill



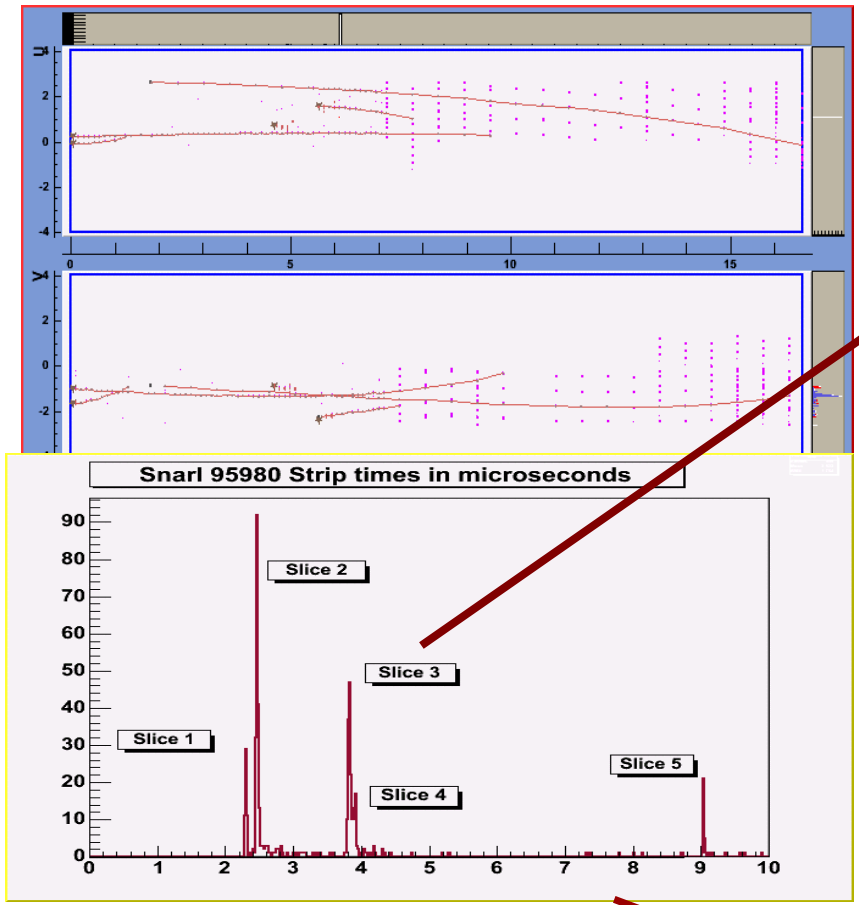
Rock Muon



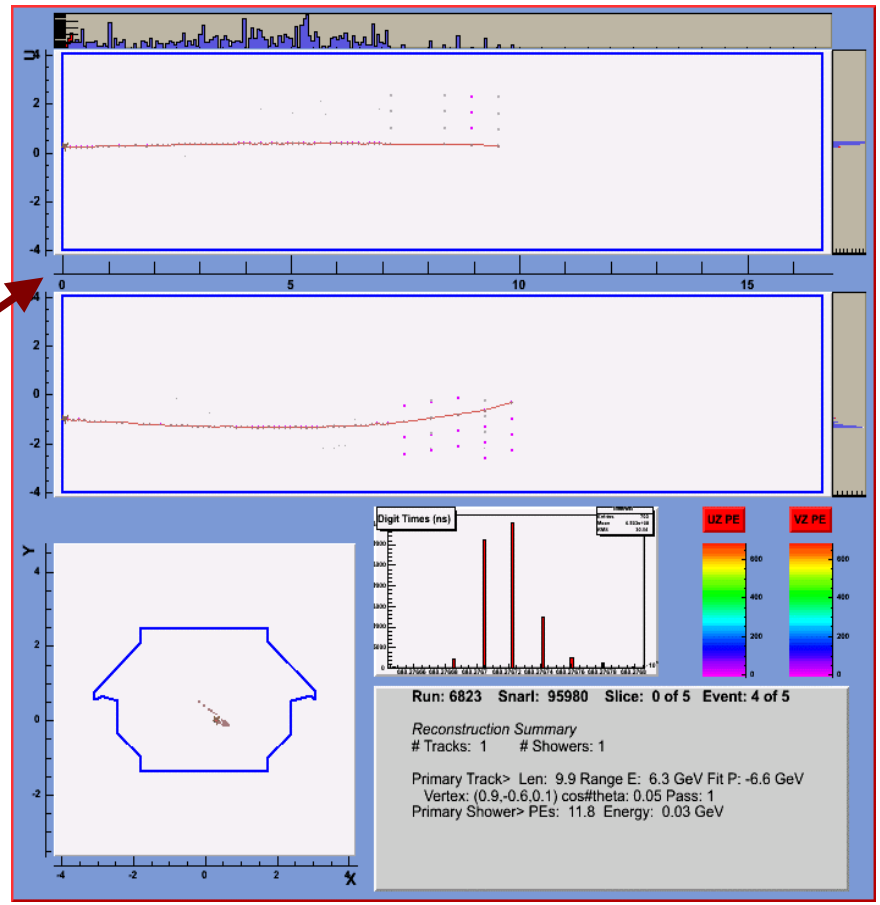
5 time slices -> 5 events

Event Timing

One Spill



Rock Muon

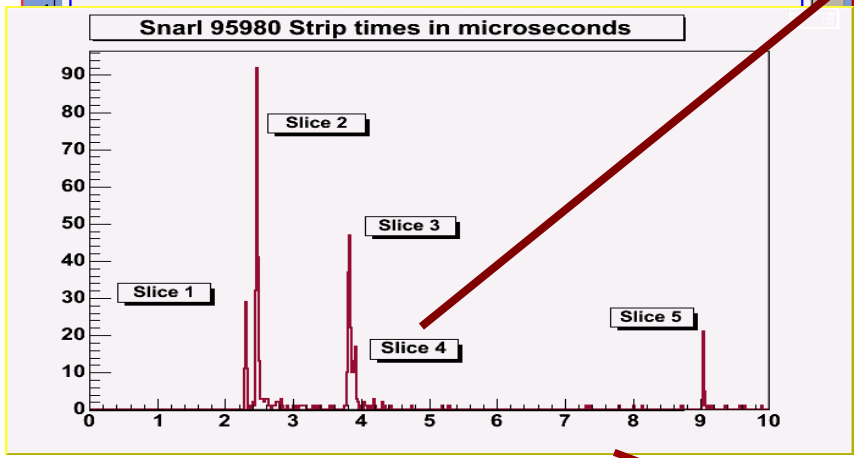


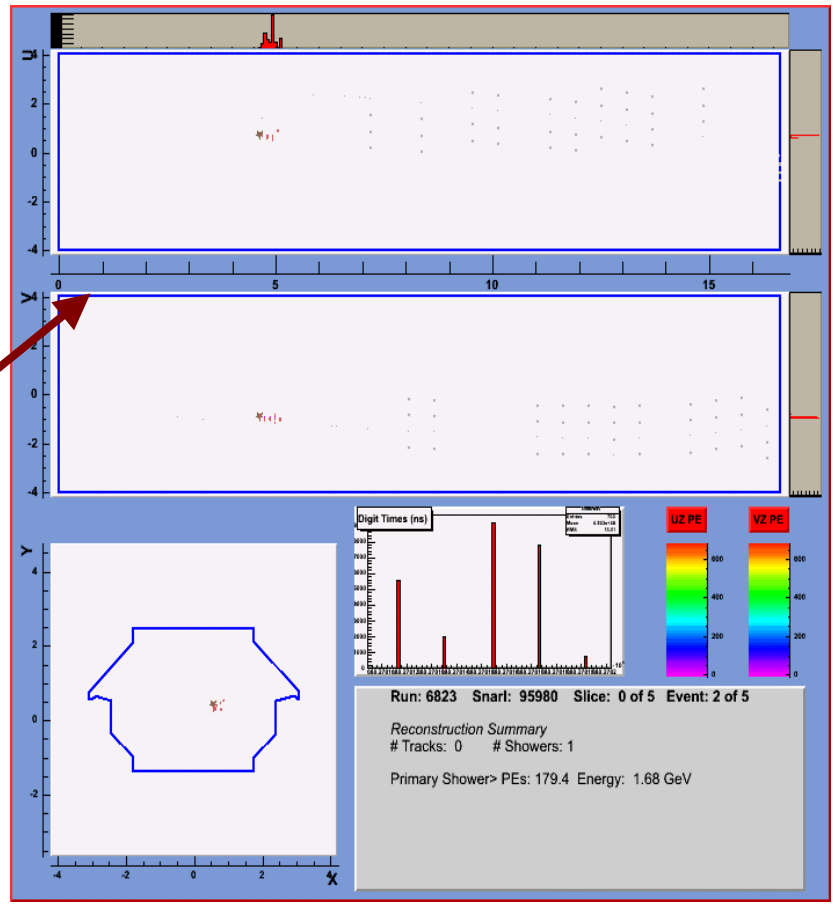
5 time slices -> 5 events

Event Timing

One Spill

Contained event

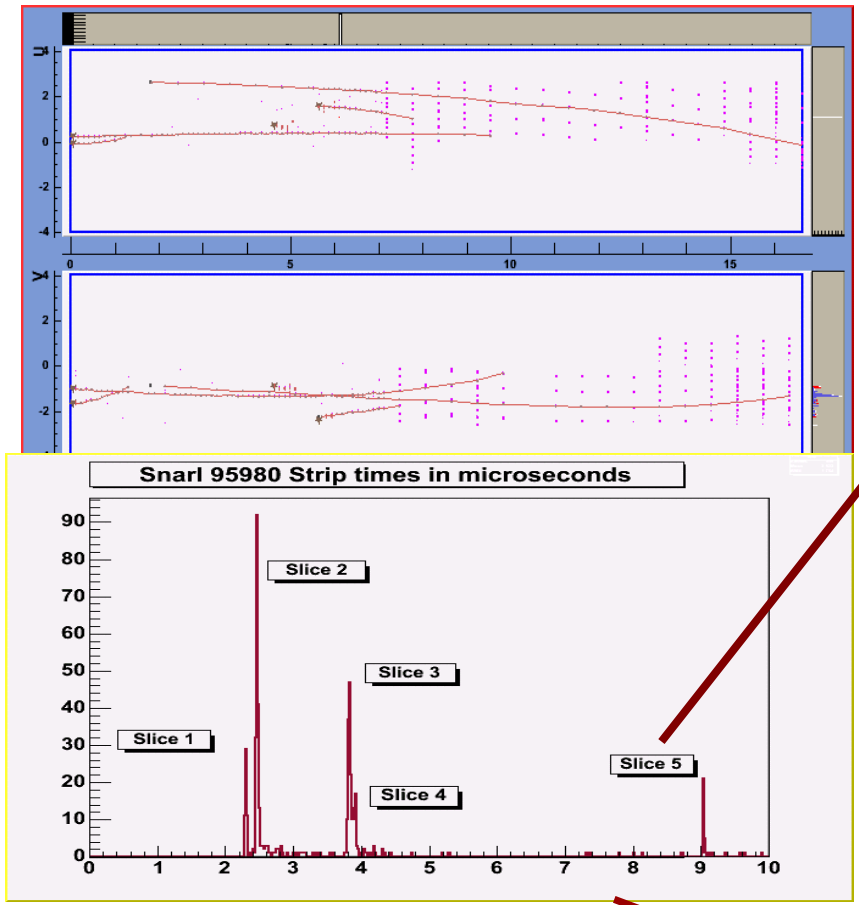




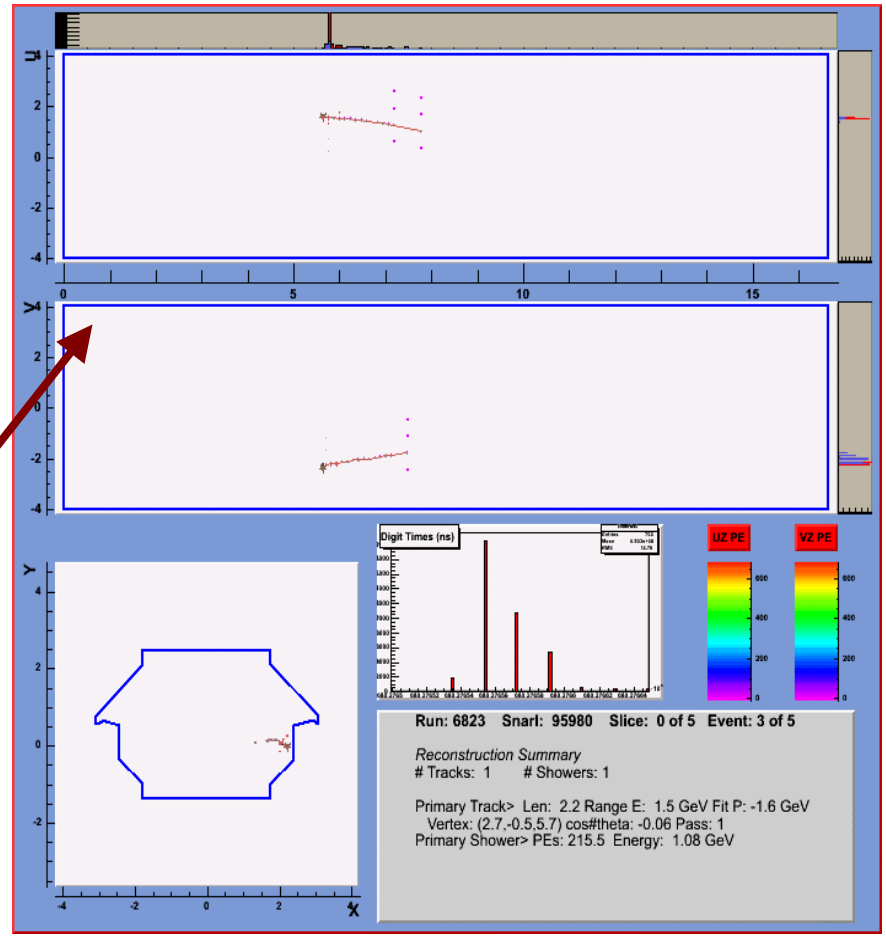
5 time slices -> 5 events

Event Timing

One Spill



Contained event

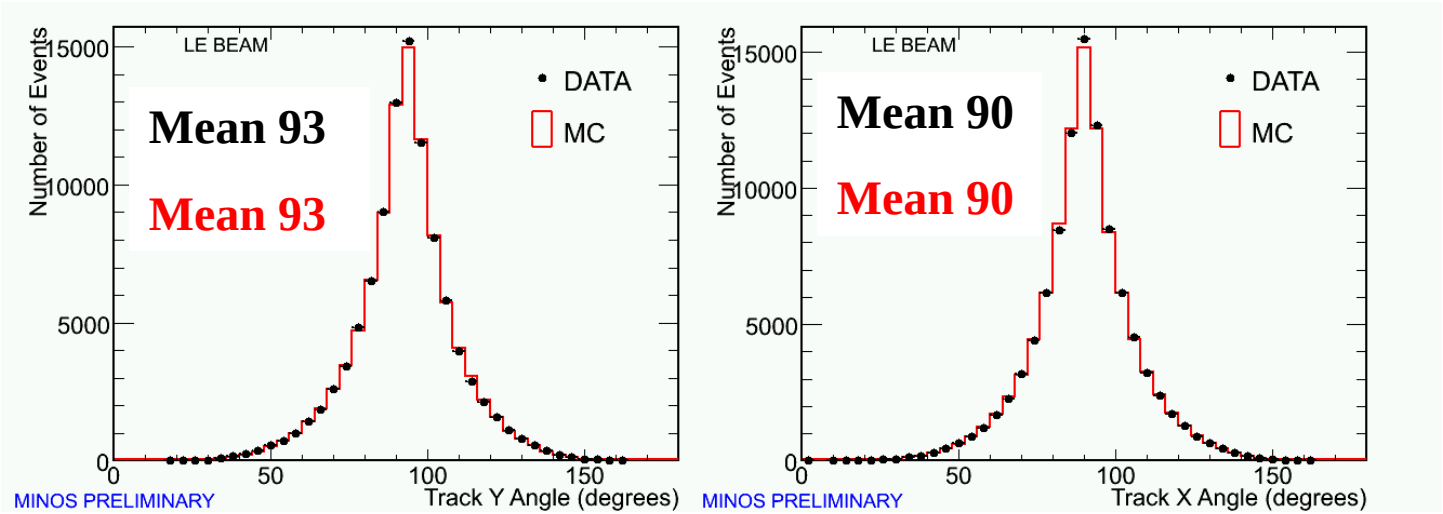


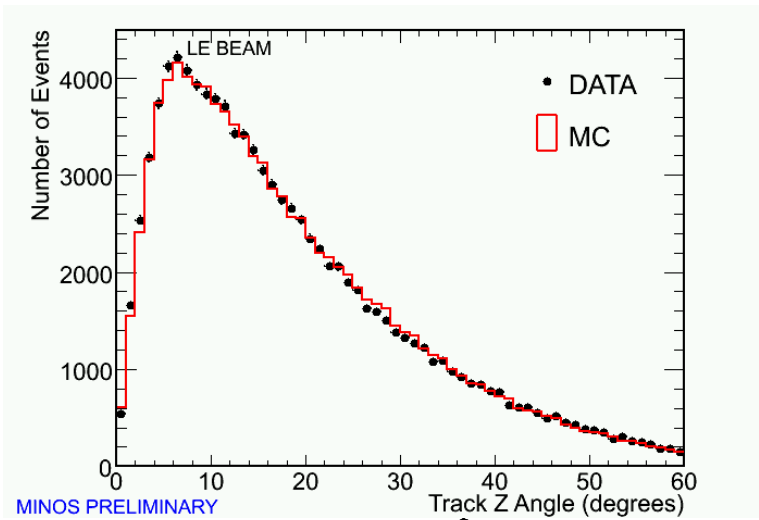
5 time slices -> 5 events

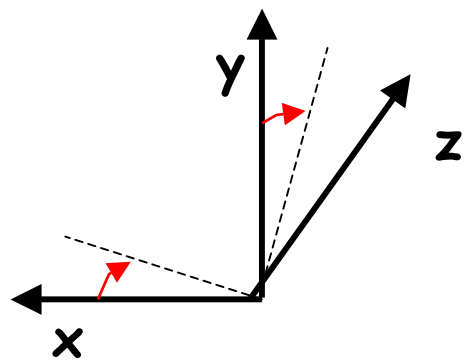
Near Detector Track Angles : Data/MC

- **Neutrino beam in the Near Detector is pointing 3 degrees down in Y.**
- **Agreement between Data/MC very good.**

Plots normalized to area

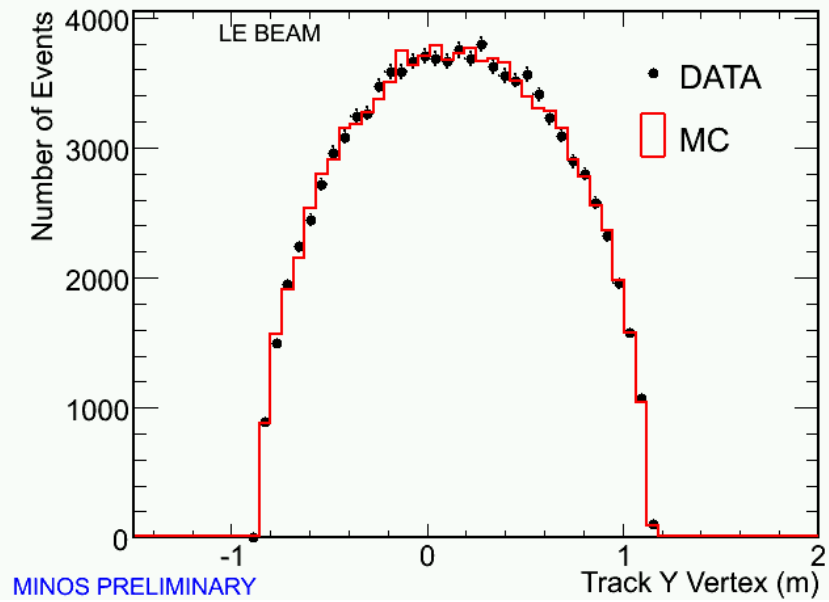


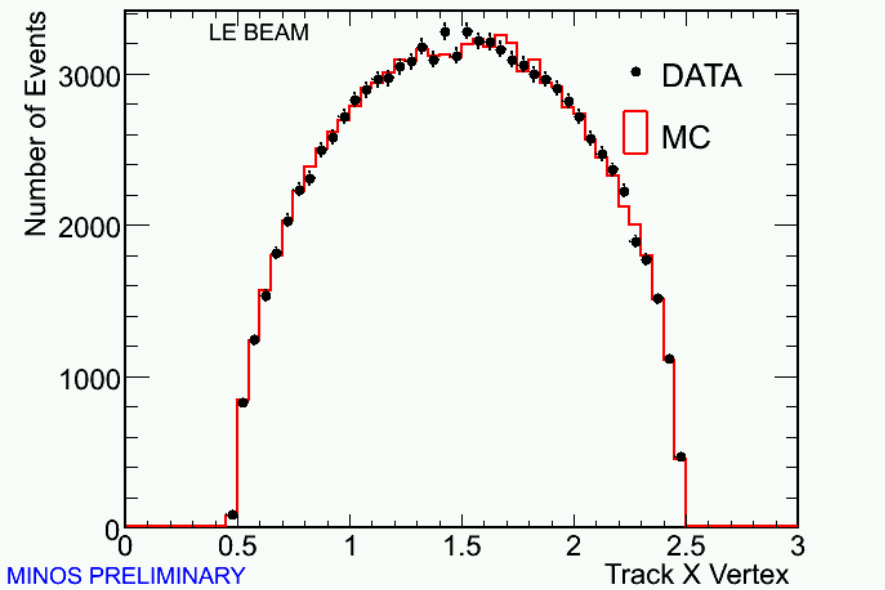




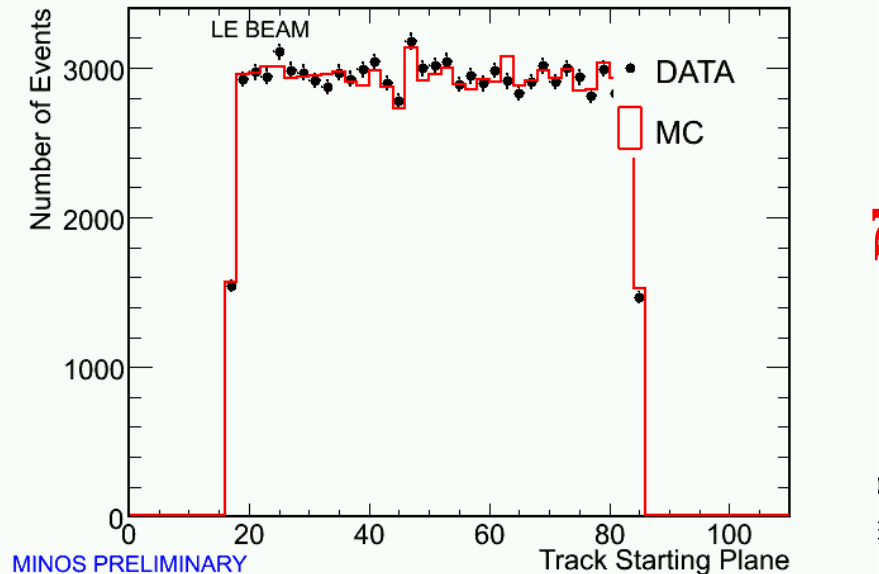
Near Detector : Data/MC

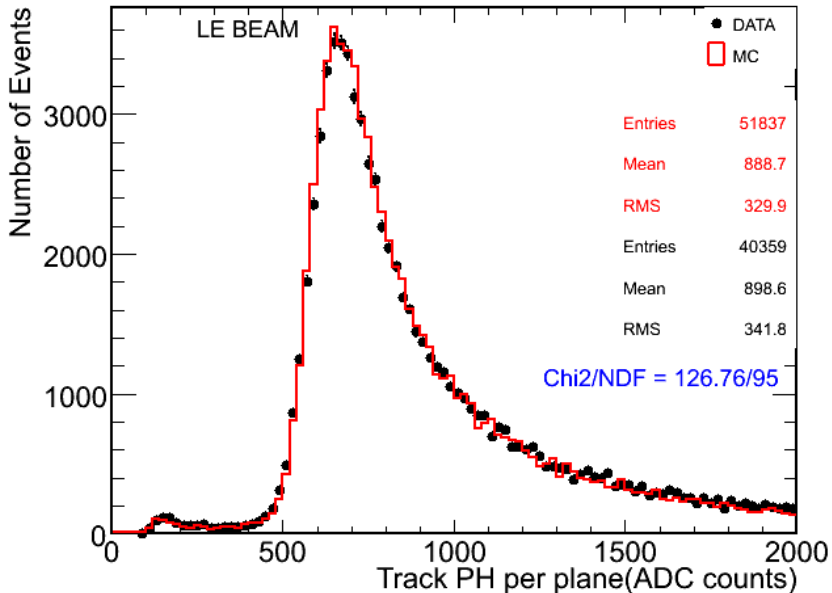
Agreement between Data and MC very good.





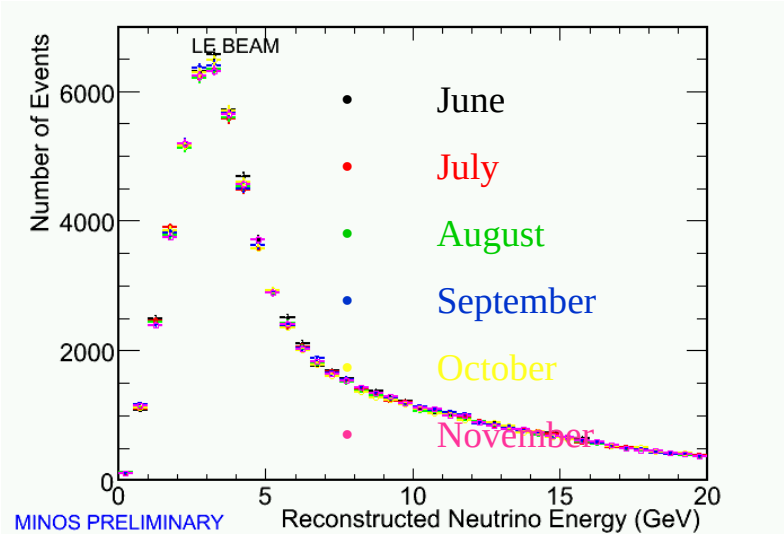
Plots normalized to area

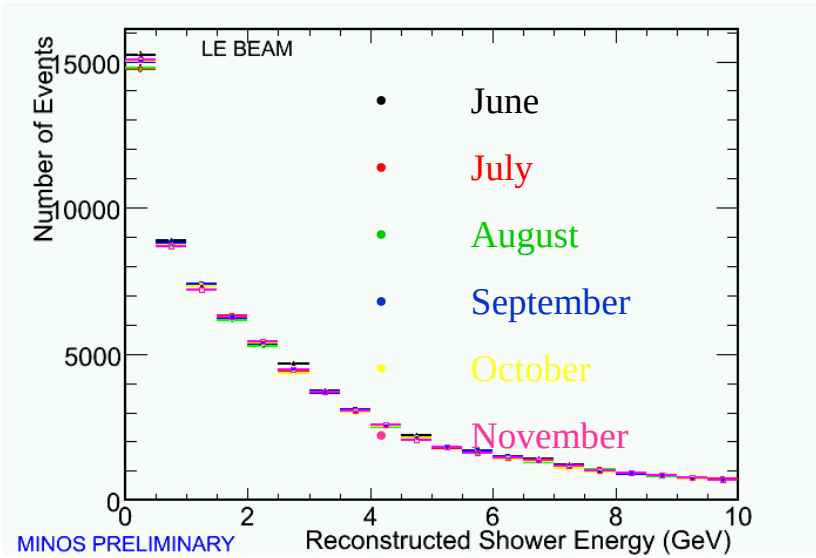




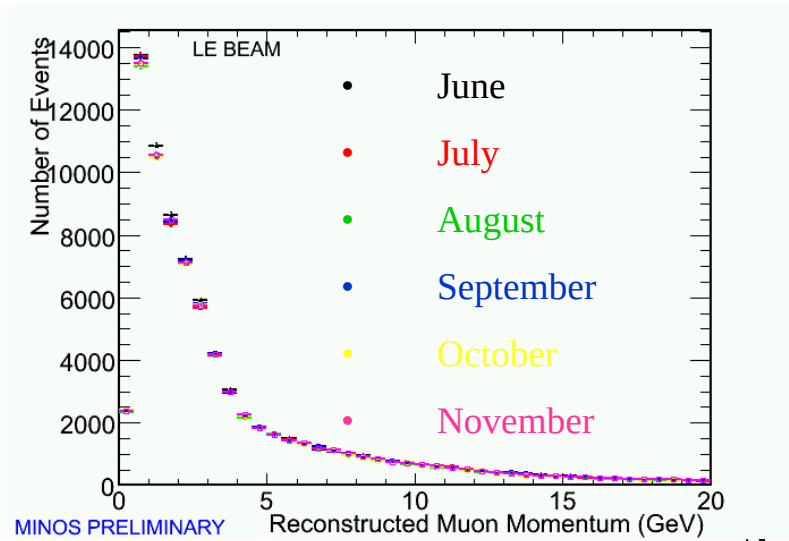
Near Detector : Data Stability

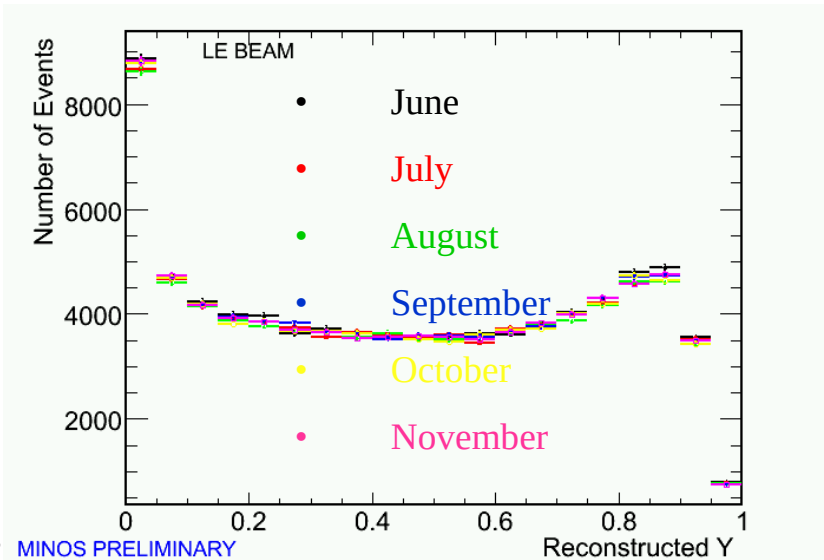
Beam, Detector Performance and Event Reconstruction very stable.



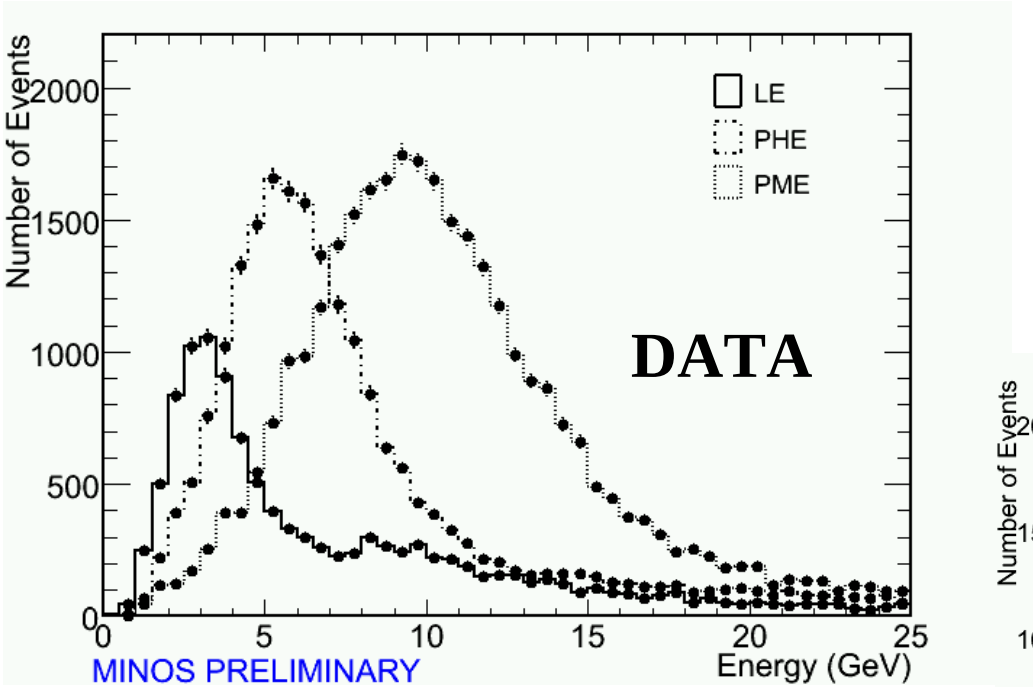


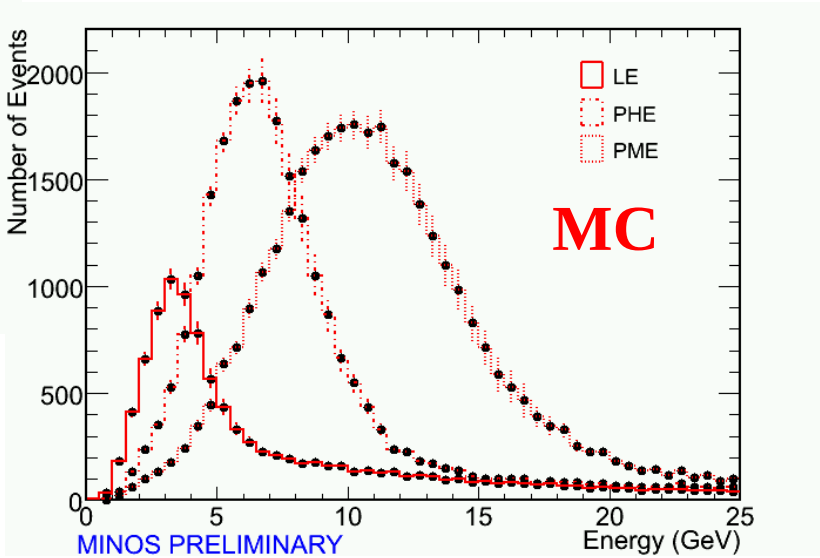
Plots normalized to P.O.Ts





Near Detector Data : Finalizing Beam Tuning





Plots normalized to P.O.Ts

Using "Energy Scan" data (Low, Medium and High energy configurations along with different horn current running) we are working towards a final tuning of our Beam Monte Carlo (work in progress).

Far Detector Beam Data : Blind Analysis

ΘΕΜΙΔΑ

Justice is Blind

- **Since May 20th 2005 running in the Low Energy configuration**

- **Collaboration decided to perform Blind Analysis:**

  (Blinding procedure hides unknown fraction of our events based on their length and total energy deposition. That way the open spectrum is distorted and the total number of neutrino events is unknown)

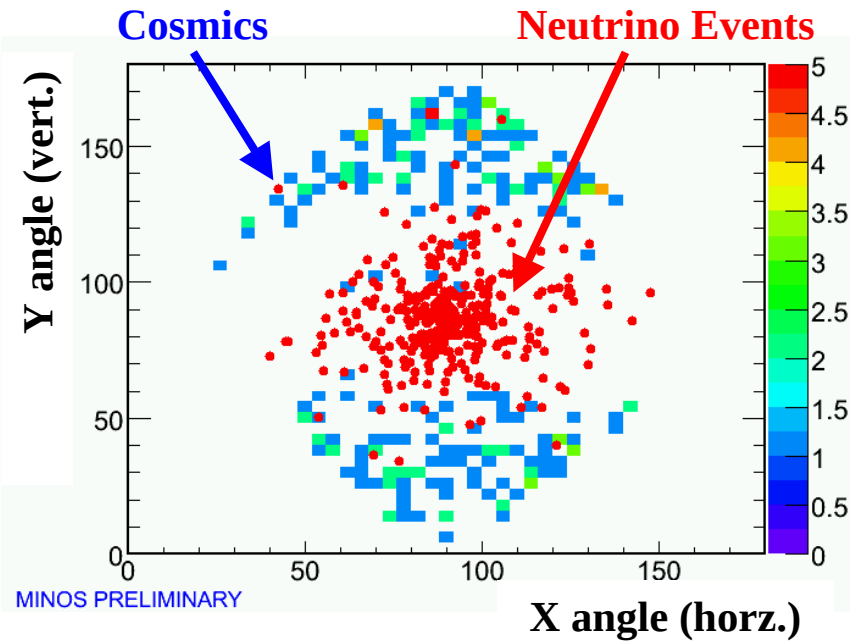
  - **Unknown fraction of our Far Detector Data are "open" and we use them to perform data quality checks.**

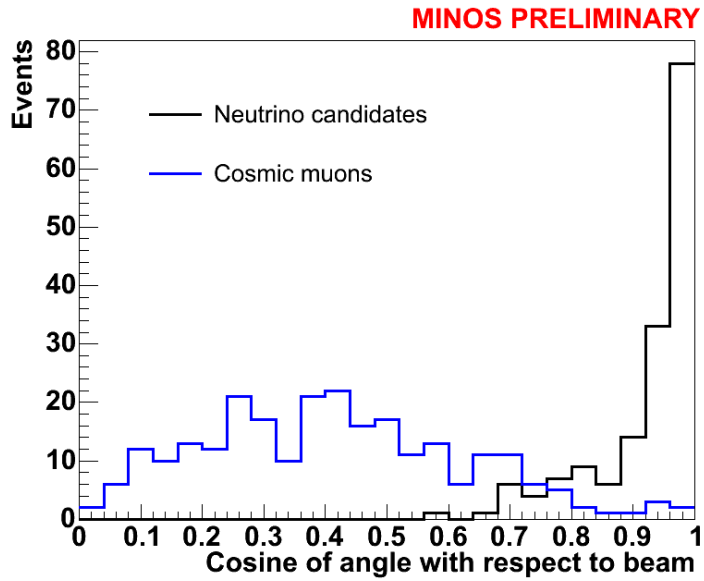
  - **Remaining fraction of our Far Detector Data are "hidden" and final analyses will be performed on total sample once Box is opened.**

- **Results presented in subsequent slides are from our "open" sample.**

Far Detector Beam Data

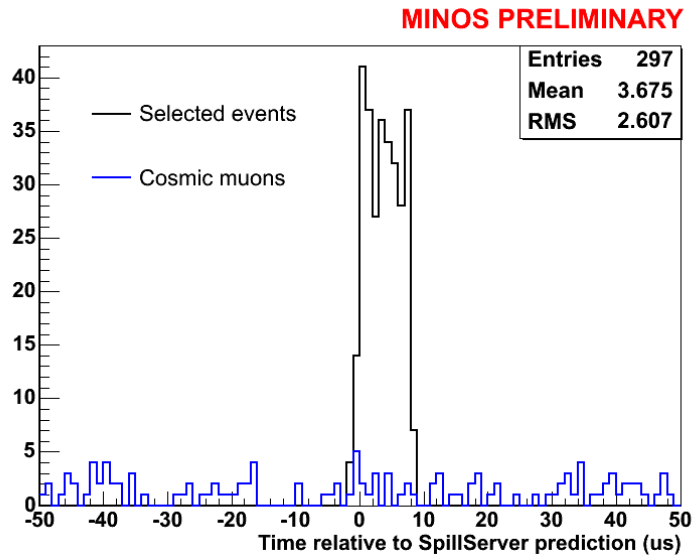
Neutrino candidates have quite distinct topology



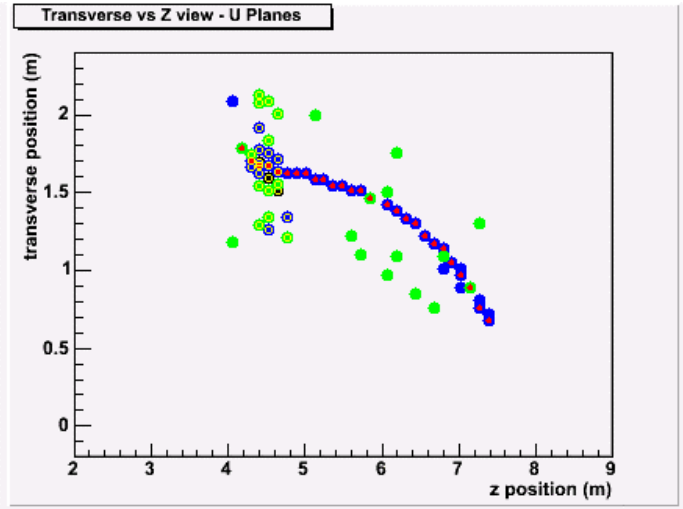


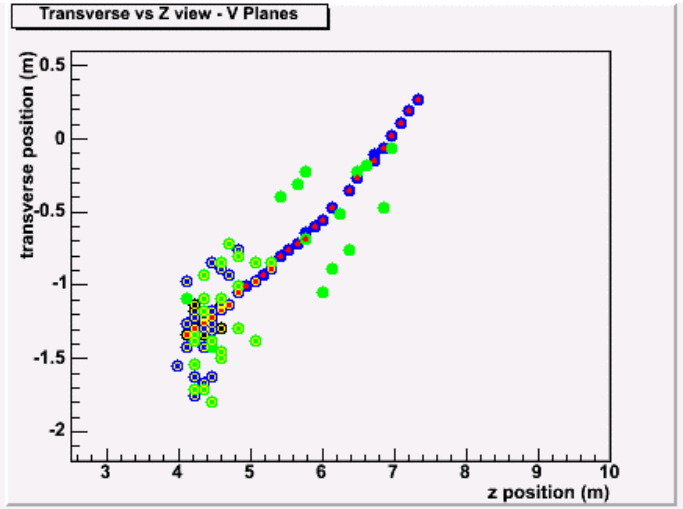
Time difference (in sec) between neutrino candidates and far spill signal in the +/-50 usec window.

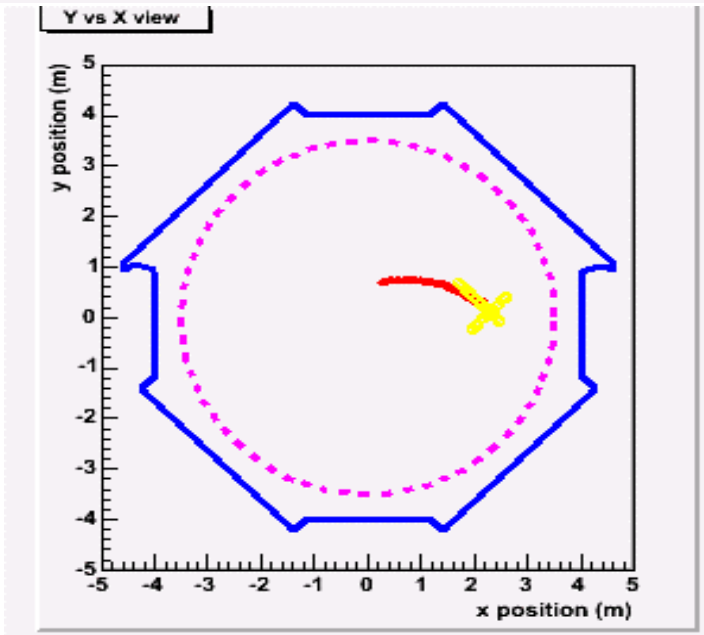
Beam neutrino candidates are within a 10 usec time interval, as expected for the 10usec width of NuMI beam.



Far Detector Neutrino Events



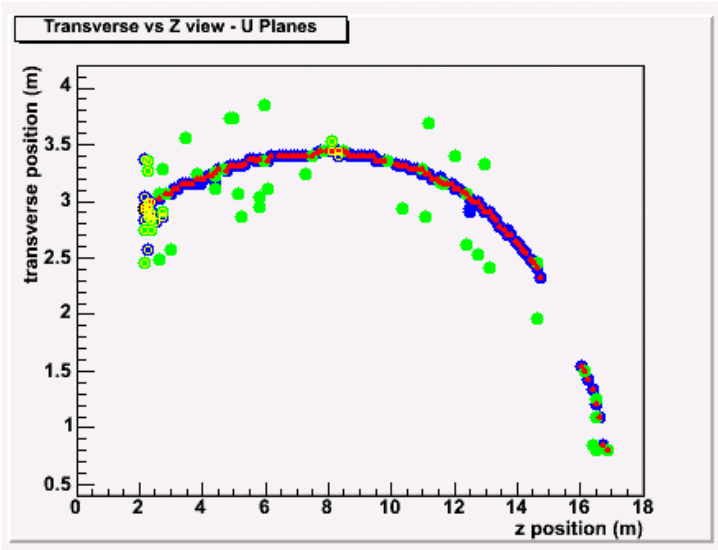


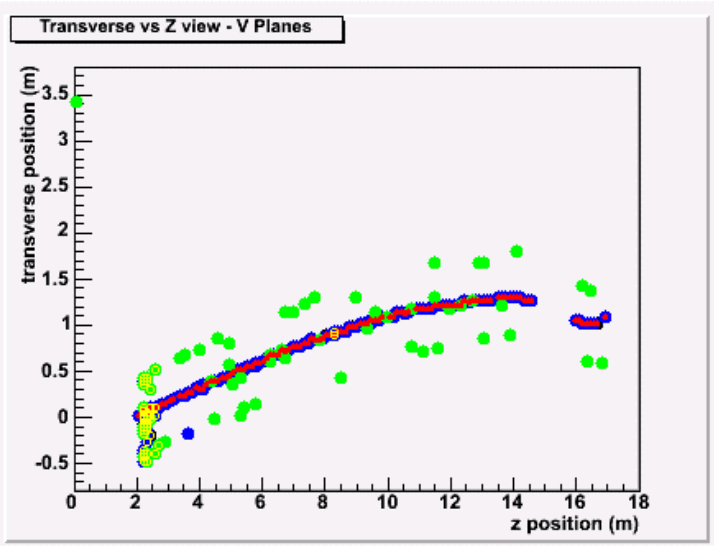


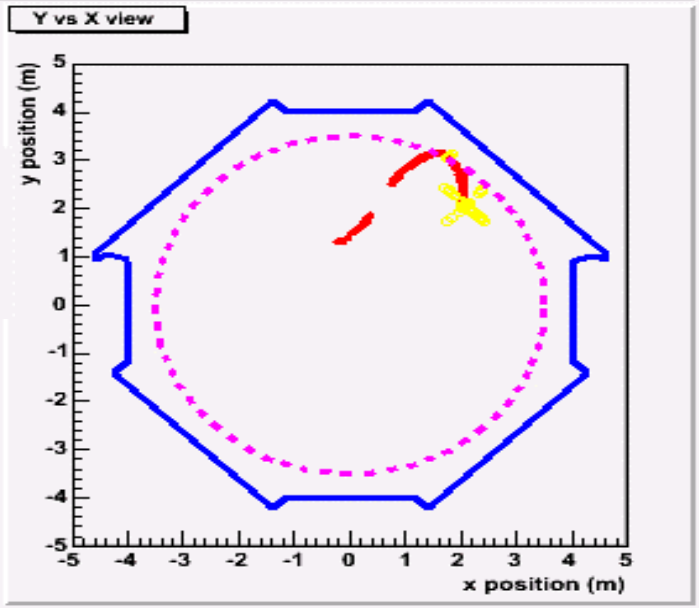
TrkRangeEnergy: 2.481 RecoShwEnergy: 4.754

Vtx: 2.18, 0.29, 4.11

Far Detector Neutrino Events



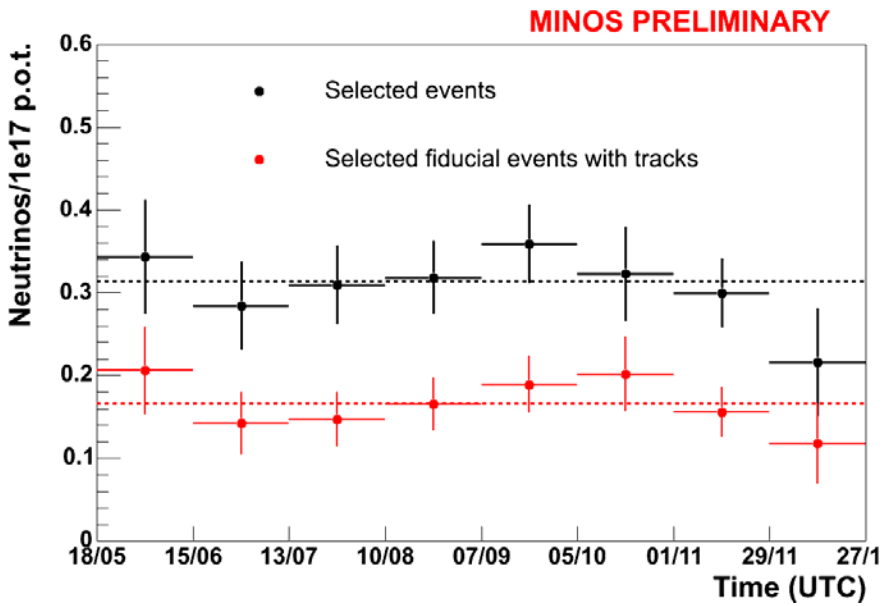


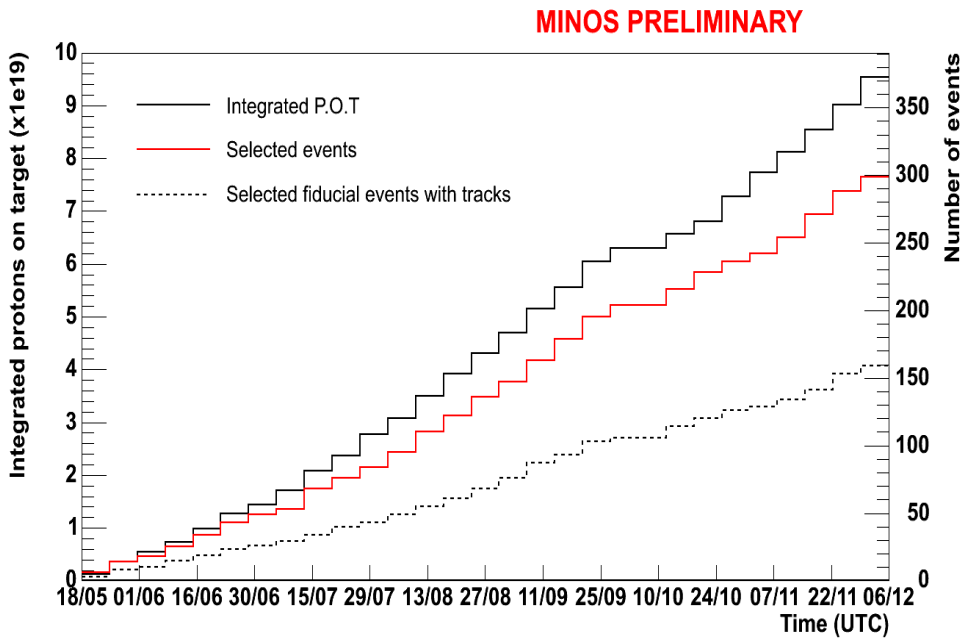


TrkRangeEnergy: 9.596 RecoShwEnergy: 5.108

Vtx: 2.07, 2.11, 2.09

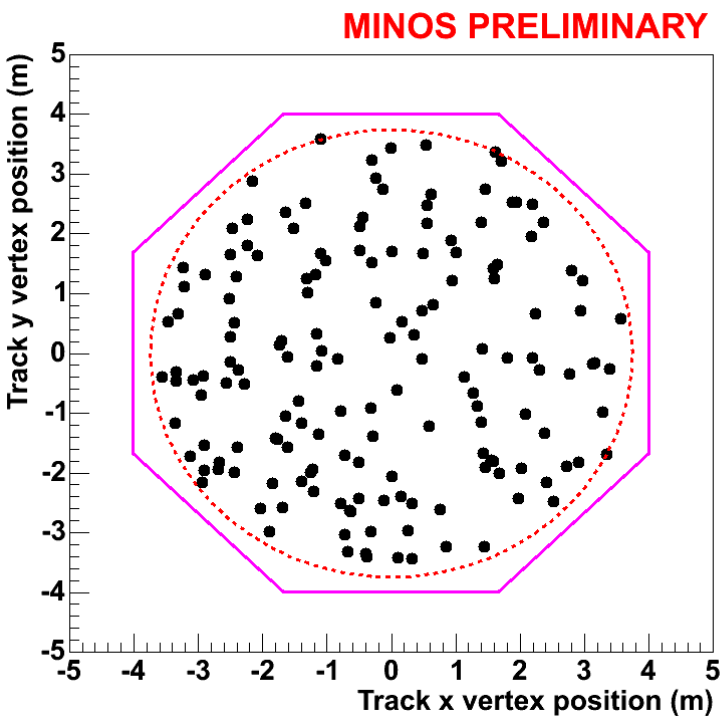
Far Detector Beam Data vs Time & P.O.Ts

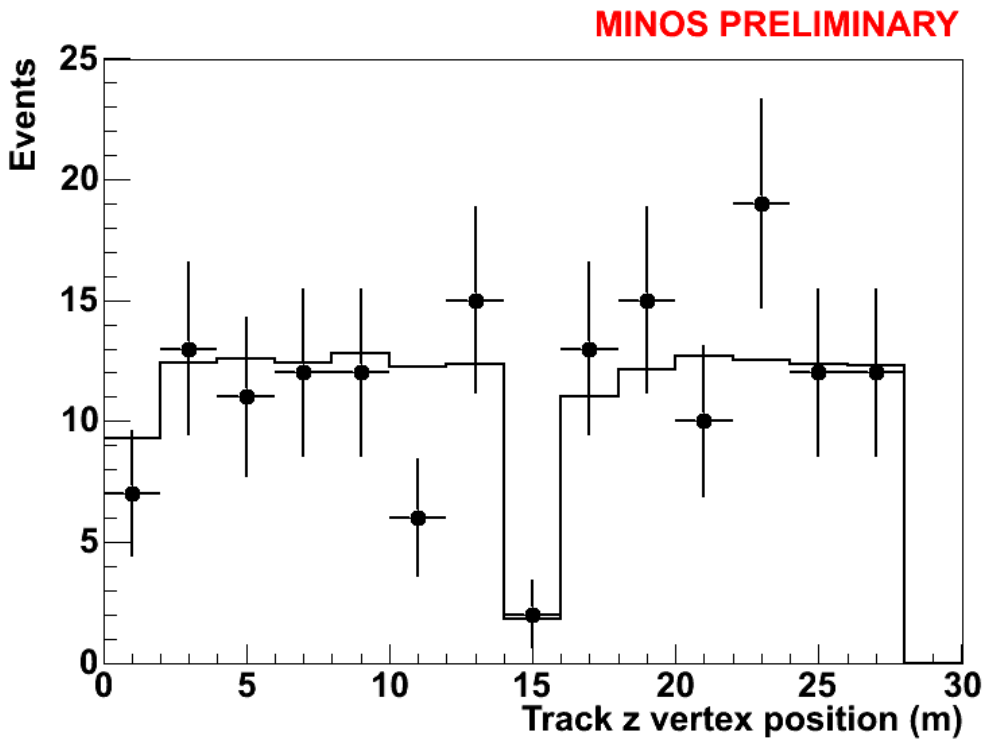




- **Neutrino events per P.O.T are flat as a function of time.**
- **Neutrino events follow integrated P.O.Ts nicely.**

Far Detector Beam Data : Vertices

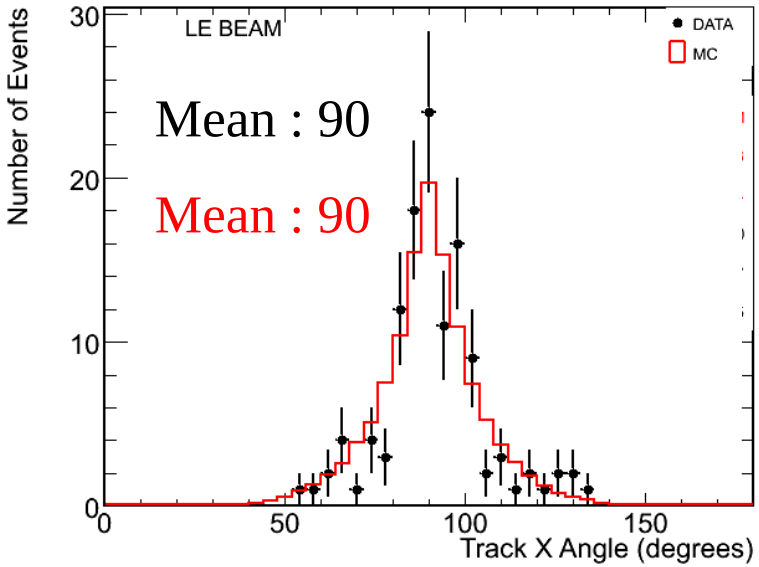


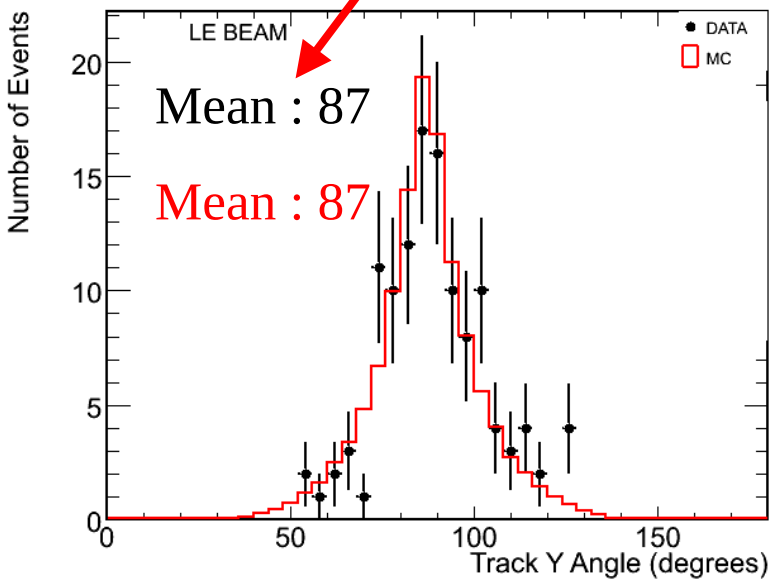


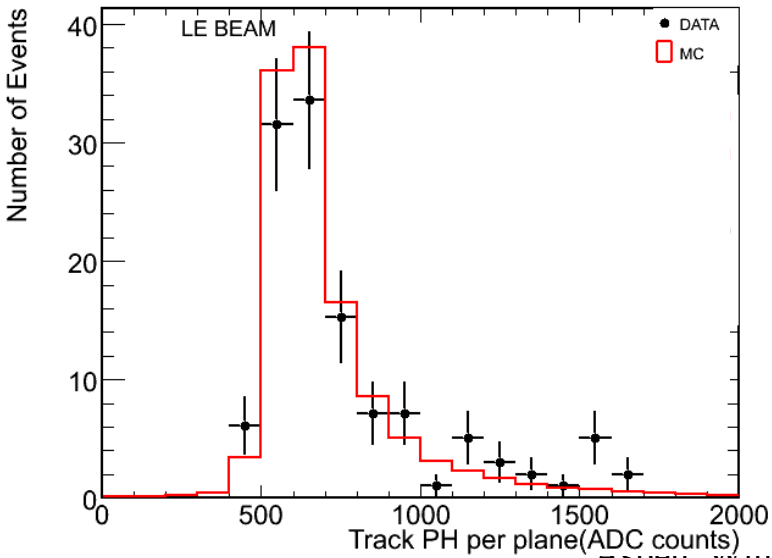
• Timing and topological characteristics of beam neutrino event candidates in agreement with expectations.

Far Detector Beam Data : Track characteristics

Neutrino events in the MINOS FAR detector are pointing 3 degrees up in Y !

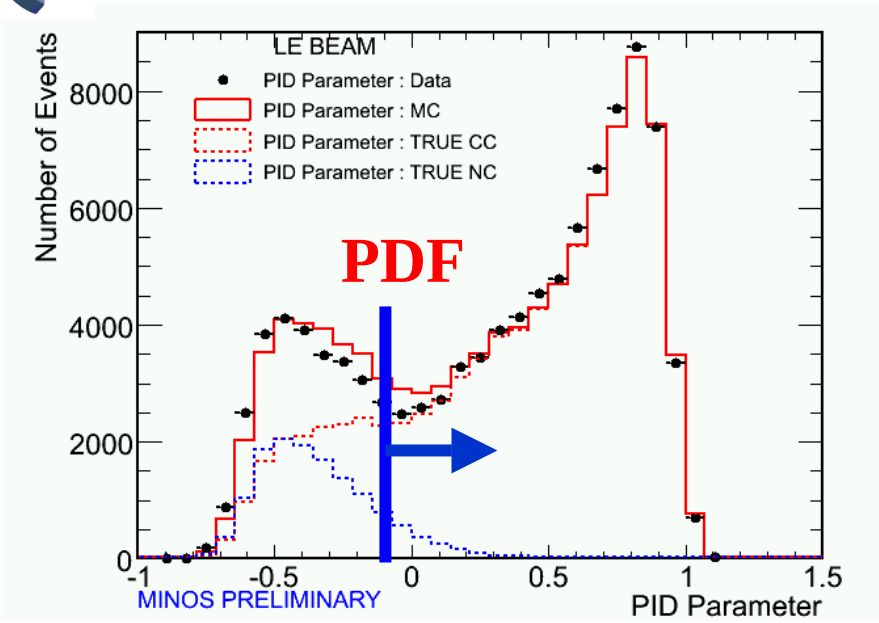


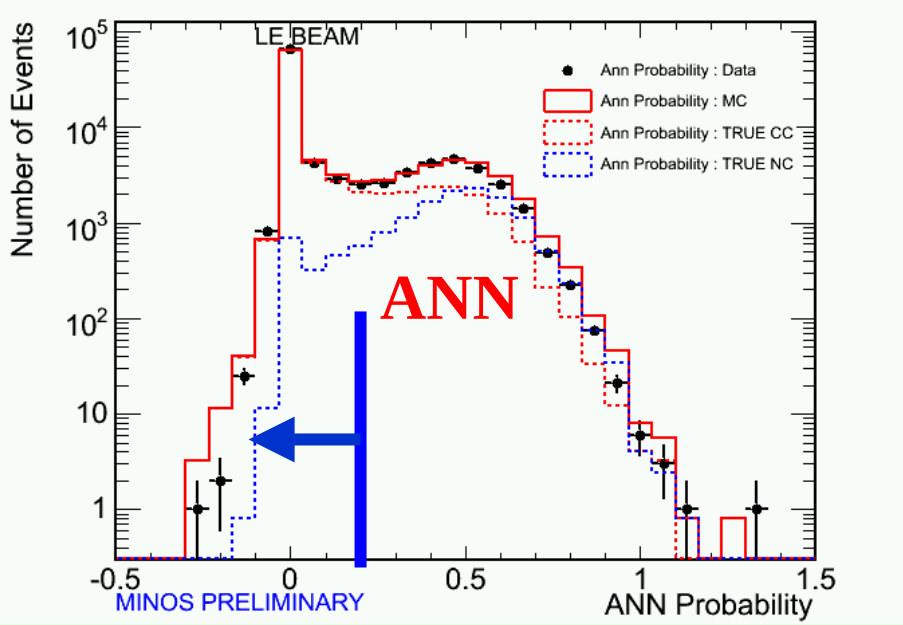




Agreement between Data and MC very good.

Beam Data : CC – like Selection



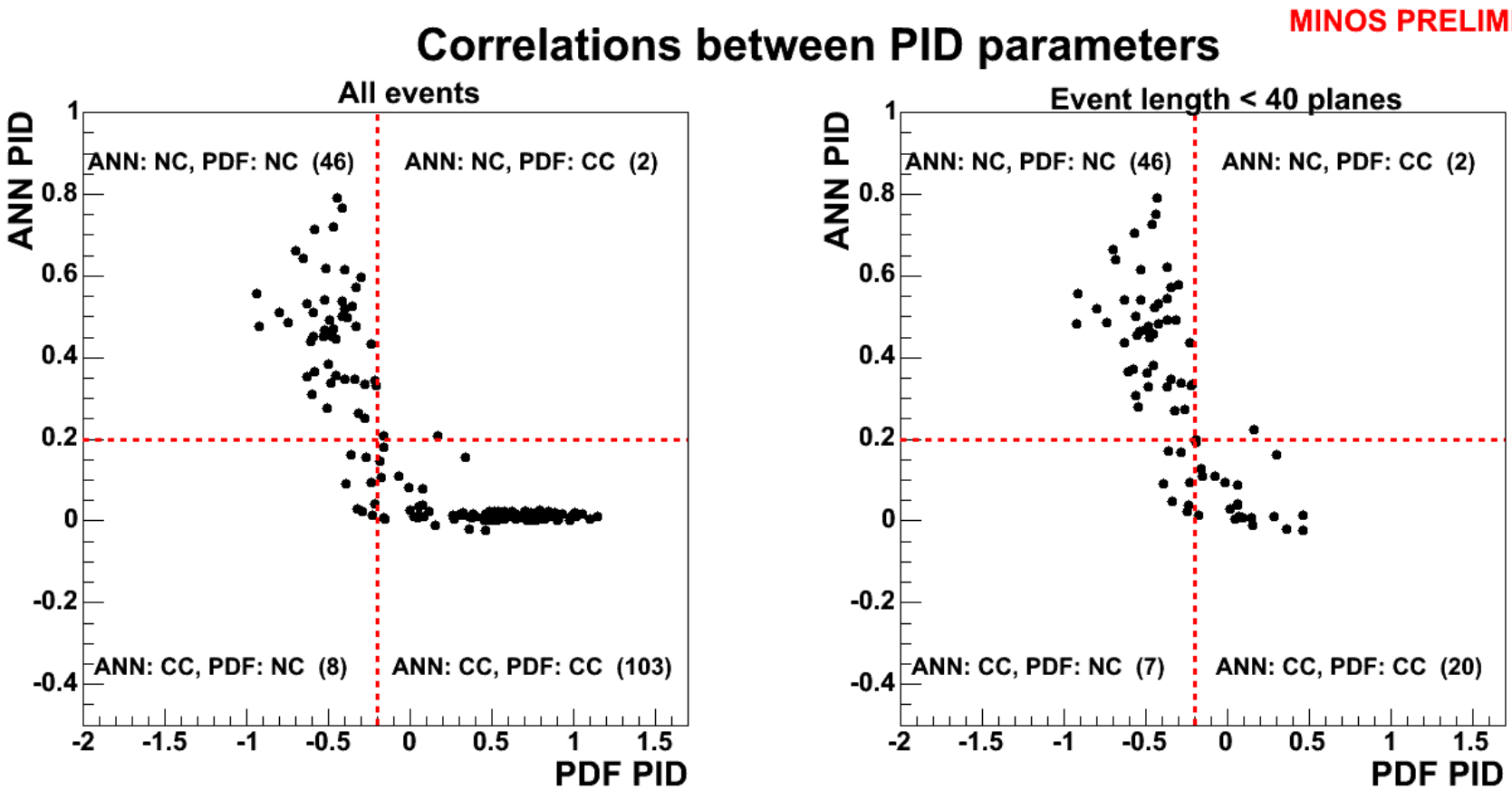


- **In order to select CC-like candidates we have :**
  - Simple method based on existence or not of a track (quite robust but with limited sensitivity).
  - PDF based method.
  - ANN based method.

- **PDF and ANN selection methods tested on high statistics neutrino sample from our Near Detector and performance is quite good.**

Far Detector Beam Data : CC – like Selection

MINOS PRELIMINARY



PDF and ANN selection methods give very consistent results on Far Detector Beam neutrino events.

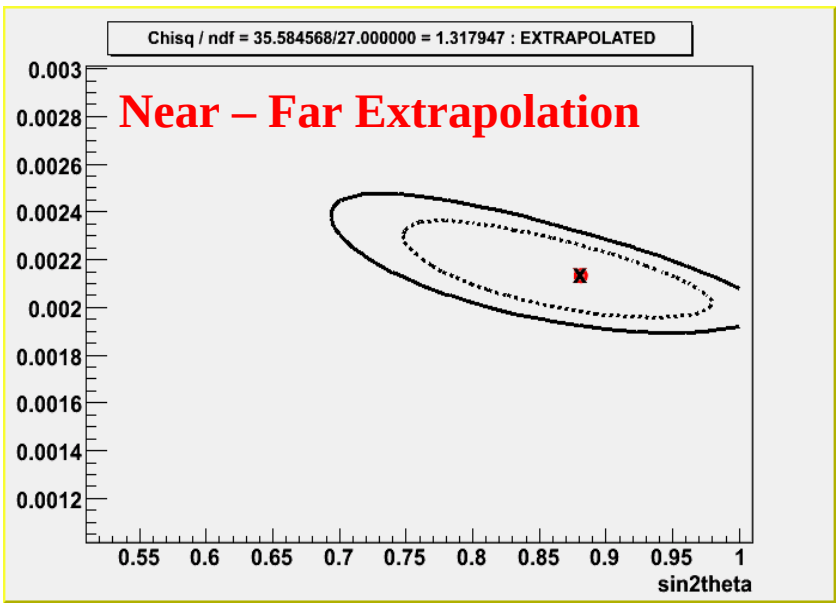
Oscillation Analysis Techniques

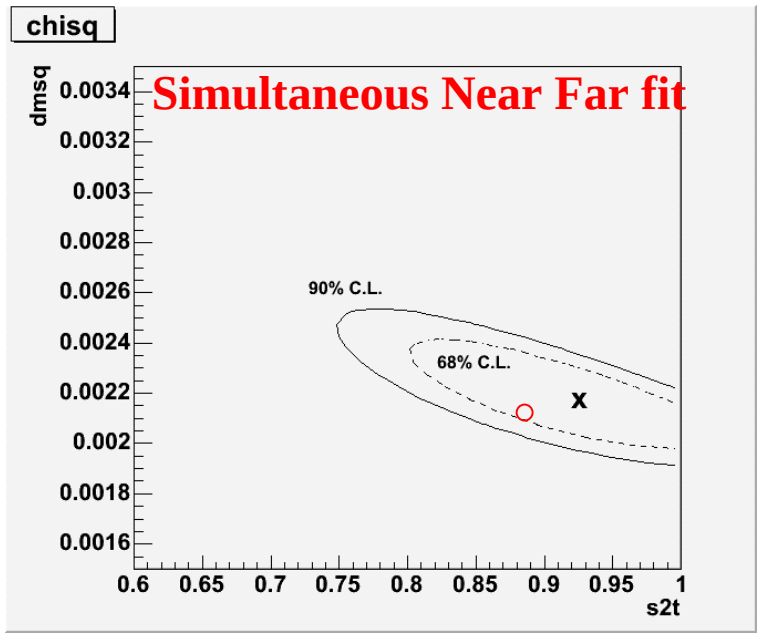
- There are two main oscillation analysis techniques:

  - **Simultaneous Near Far fit** : Goal is to use Near Detector Data in order to constrain systematic parameters (beam modeling, cross sections e.t.c) and obtain a predicted Far Detector spectrum.

  - **Near – Far Extrapolation :** Use of the Near Detector Data and beam Monte Carlo to “extrapolate” and obtain the Far Detector spectrum.

Performance on Mock Data Challenge Set

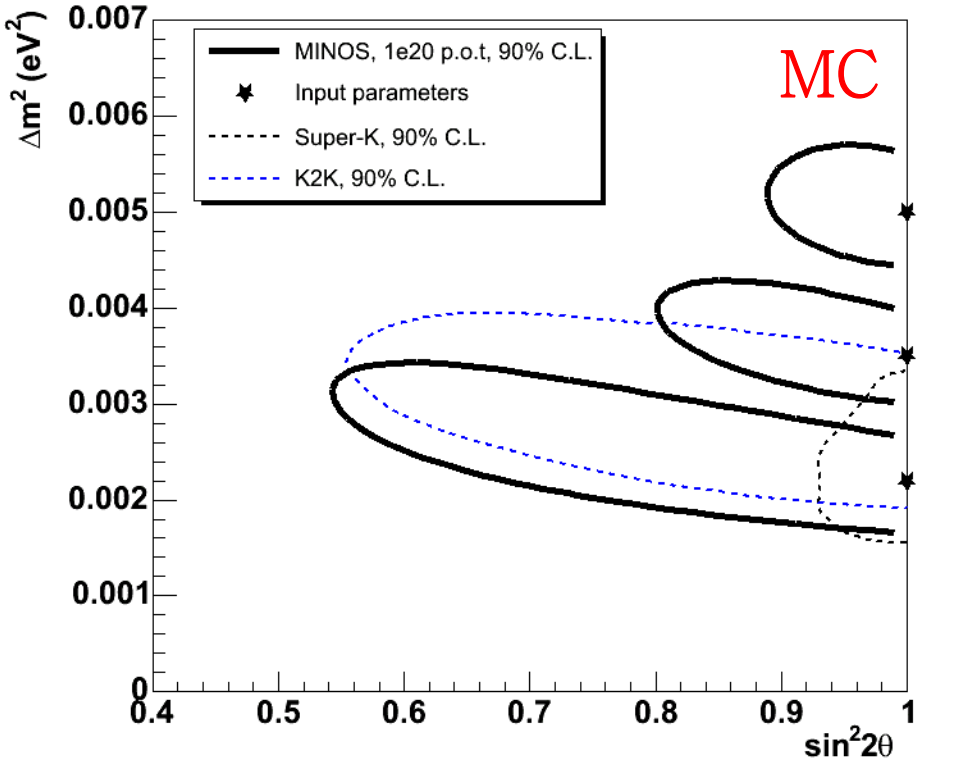




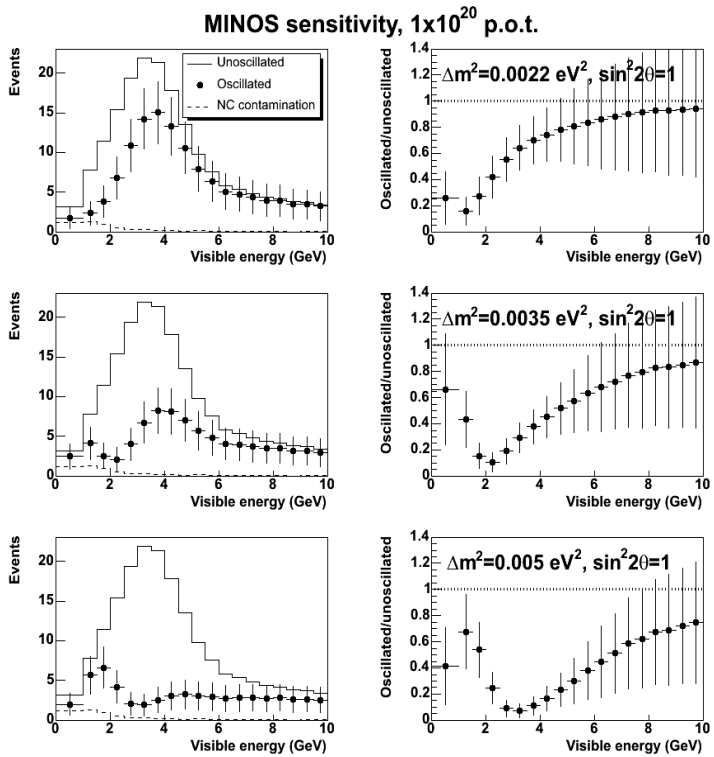
MINOS Sensitivity for 1E20 P.O.T.

•We already have accumulated 1E20 P.O.T.s.

• We are working towards our initial oscillation analysis, which with this exposure should yield a sensitivity comparable to, or even better than K2K.



$\nu_\mu \not\rightarrow \nu_\mu$



MINOS Long Term Physics Goals

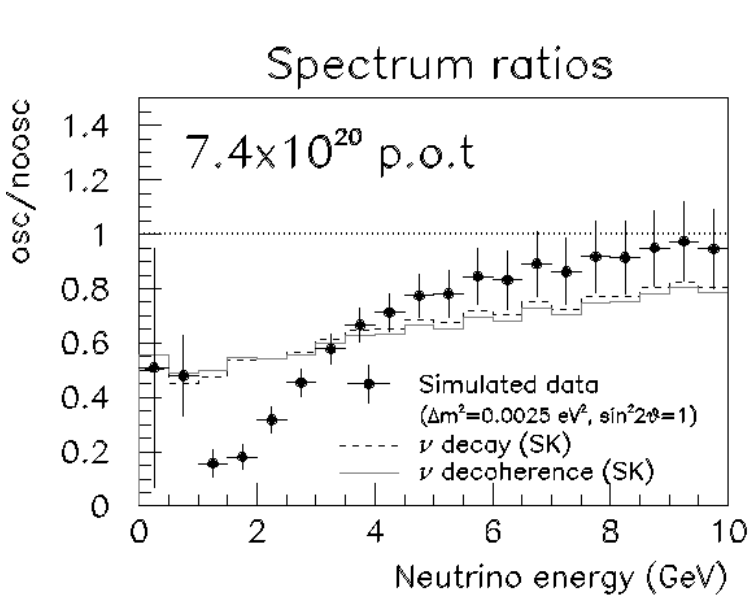
- **The study and comparison of ν_μ CC interactions between the NEAR and FAR detector will allow us to:**

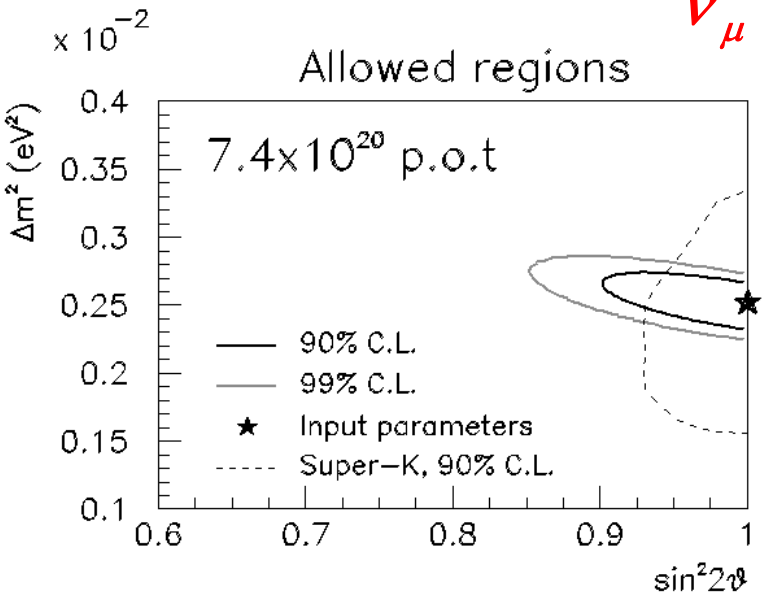
  -Confirm oscillation hypothesis with accelerator muon neutrinos (ν_μ disappearing from the beam)

  - Obtain precise measurements of the oscillation parameters, (Δm_{23} <10%) and $\sin^2 2\Theta_{23}$

$$\Delta m^2 = 0.0025 eV^2, \sin^2 2\theta = 1.0$$

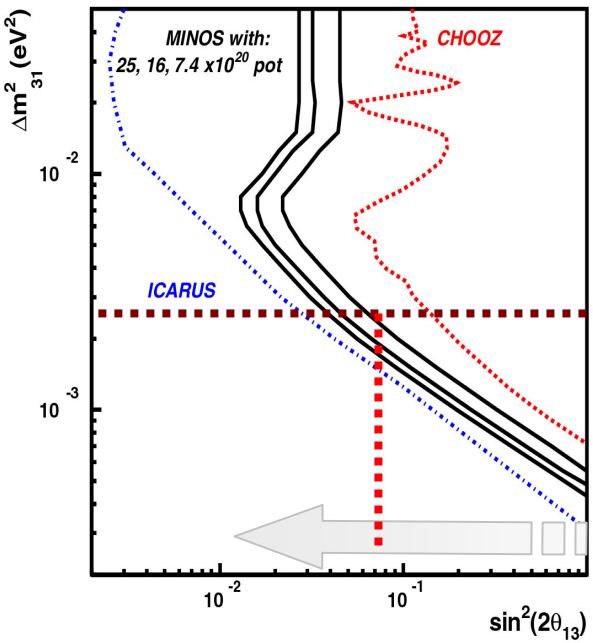
$$\nu_\mu \rightarrow \nu_\mu$$





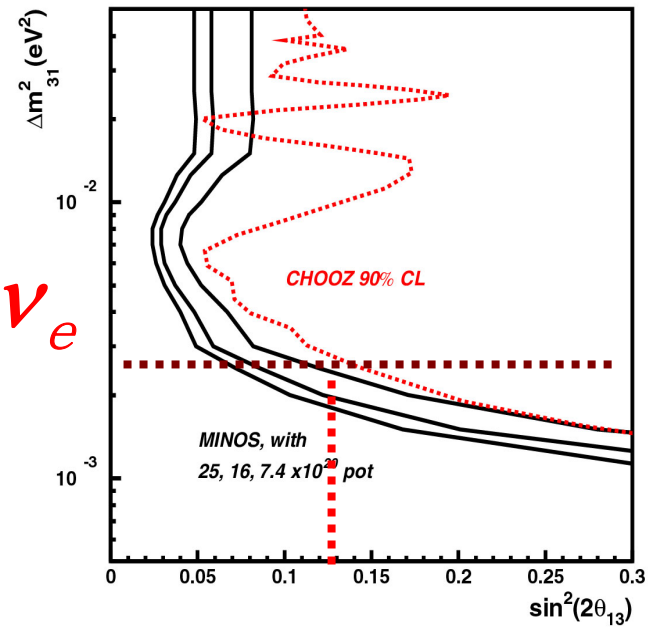
MINOS Long Term Physics Goals

90 % CL exclusion plot



$\nu_\mu \rightarrow \nu_e$

3σ sensitivity plot



- **Measuring θ_{13} is currently one of the most "hot" issues in neutrino physics.**
- **Trying to do so with the MINOS detector and the current LE beam is very challenging but we will try!**
- **If θ_{13} is close to the CHOOZ limit, we will see a >3 σ effect in ~3 years of running.**
- **Otherwise we will be able to improve the current limit by a factor of 2 or 3.**

Summary & Conclusions

- **Performance of the MINOS Near and Far detectors is very good.**
- **Data collection, event reconstruction and event selection in both MINOS detectors are well understood and in good agreement with expectations.**
- **Using the plethora of neutrino data in the MINOS Near Detector final beam tuning is underway!**
- **Tools in place to perform first MINOS oscillation analysis for 1E20 P.O.T. s when we decide to open the "Box"!**
- **Stay tuned!!!**