Status of MINOS after one Year of Running

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Batavia, IL, USA

NO-VE

III International Workshop on:

"NEUTRINO OSCILLATIONS IN VENICE“

7 February, 2006

My talk is dedicated to my friend and devoted colleague, Doug Michael

Doug sadly passed away on Christmas Day, 2005, from complications of lymphoma.

He was a source of inspiration to everyone who knew him.

Italy was special to Doug.

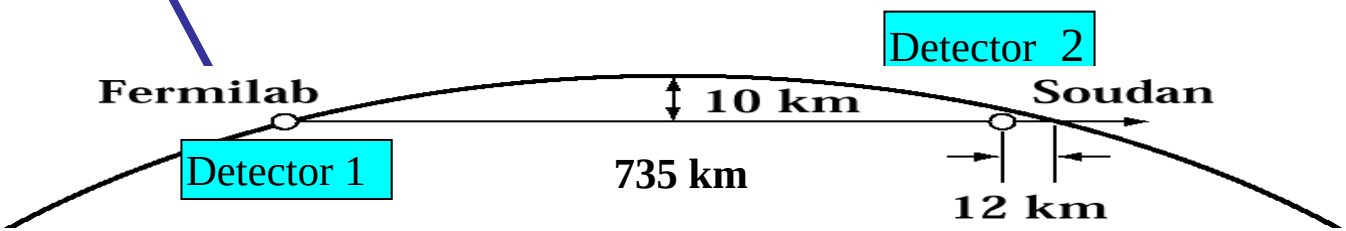
We all miss him terribly, his voice, his energy, even his anger.

MINOS Long-Baseline Experiment

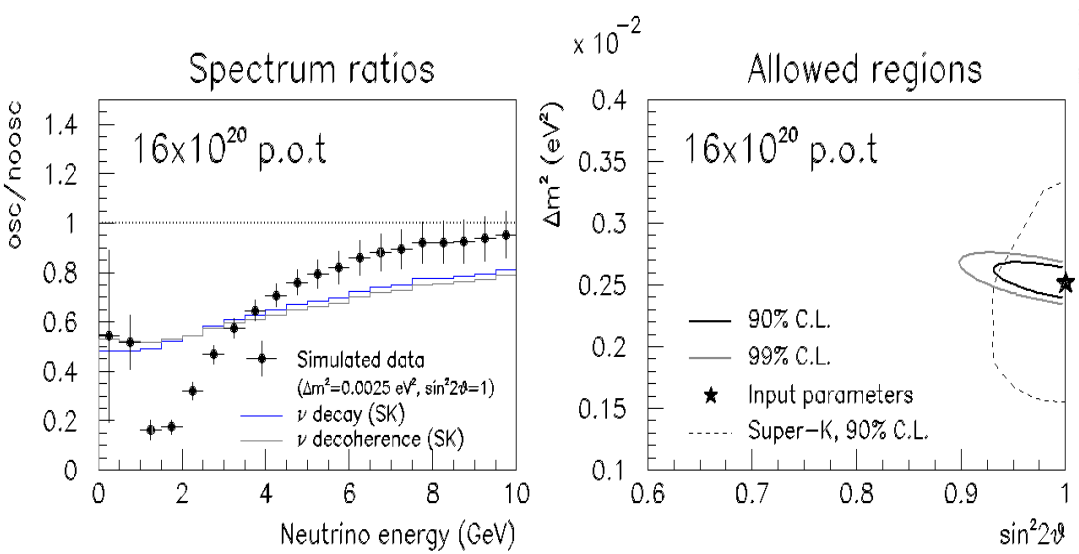
Fermilab to Soudan, Minnesota

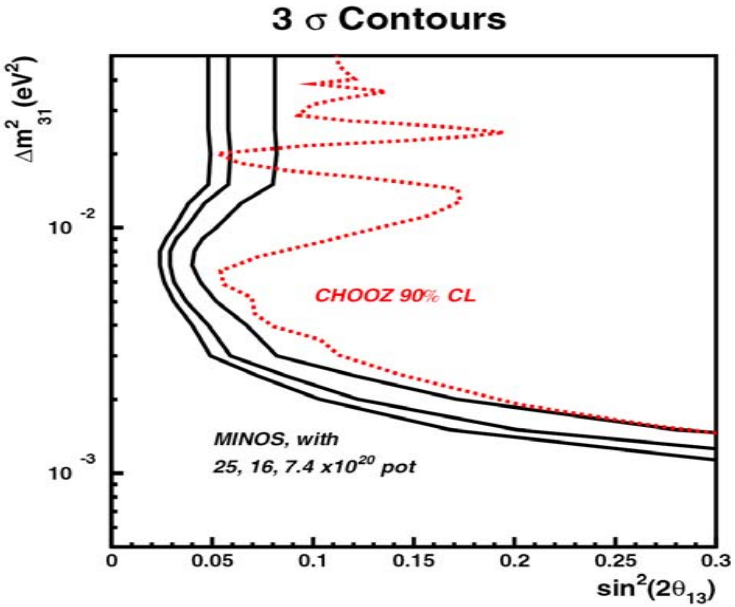
Far Detector: 5400 tons

Near Detector: 980 tons



Expected MINOS Sensitivities





ν_e *appearance =>non-zero* θ_{13}

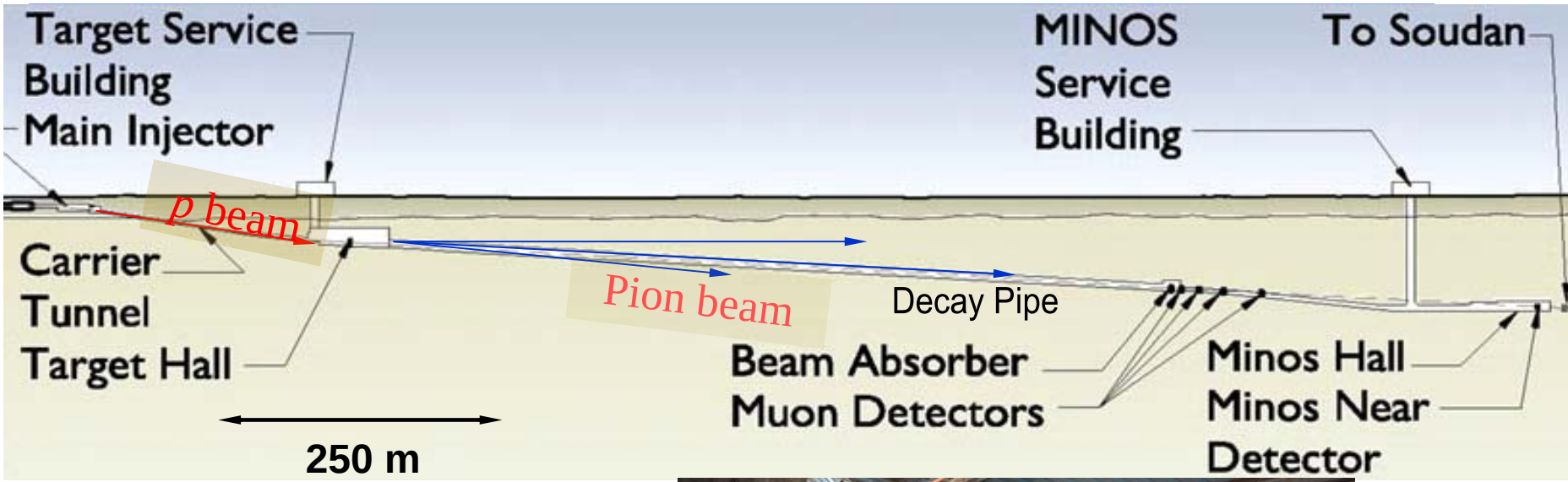
Δm^2 and $\sin^2 2\theta_{23}$

Greatly improve existing measurement;
excellent test against alternative hypotheses

Can improve CHOOZ limit by ~2 with adequate protons

MINOS measurements improve with more protons

NuMI Tunnels and Facility



NuMI Components in Main Injector

NuMI Pretarget Area

NuMI Neutrino Beam

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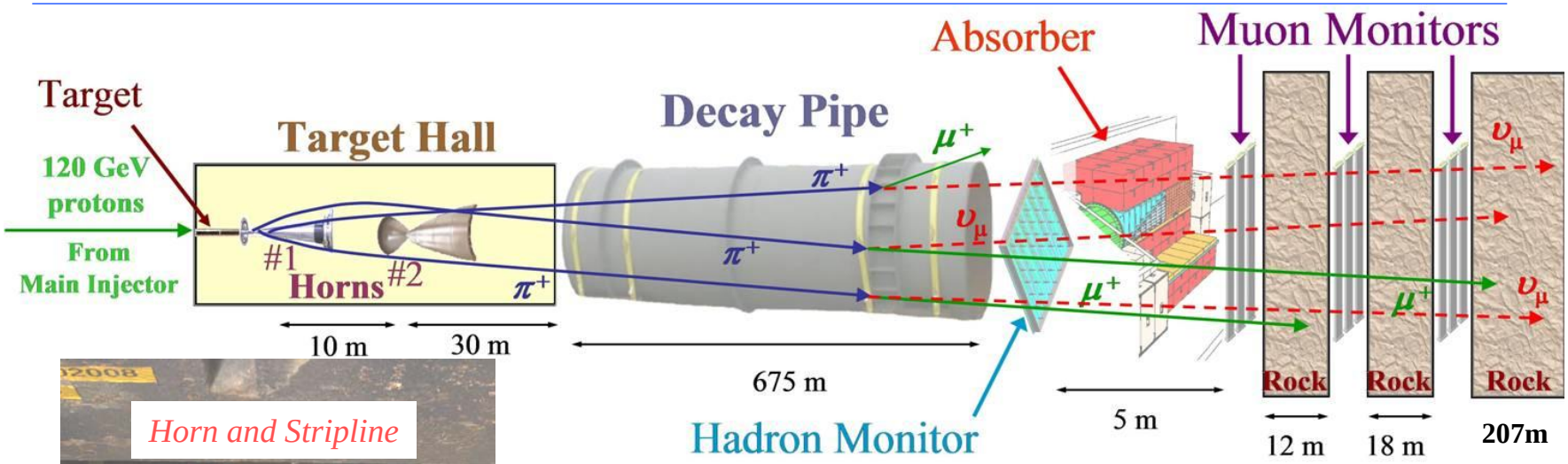
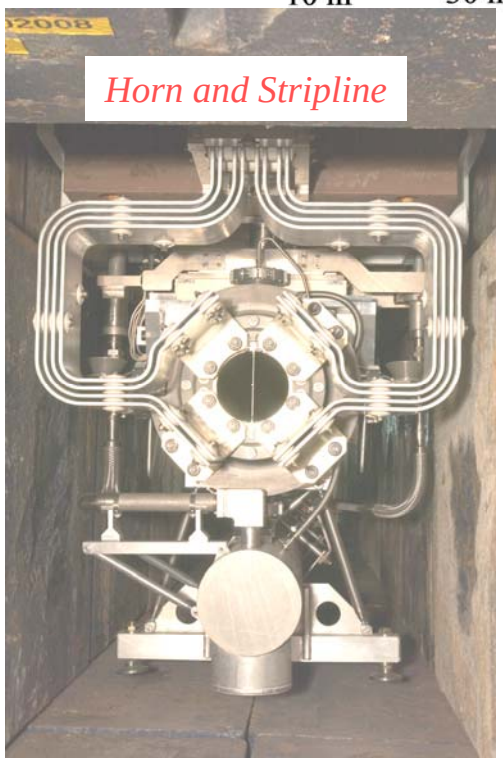
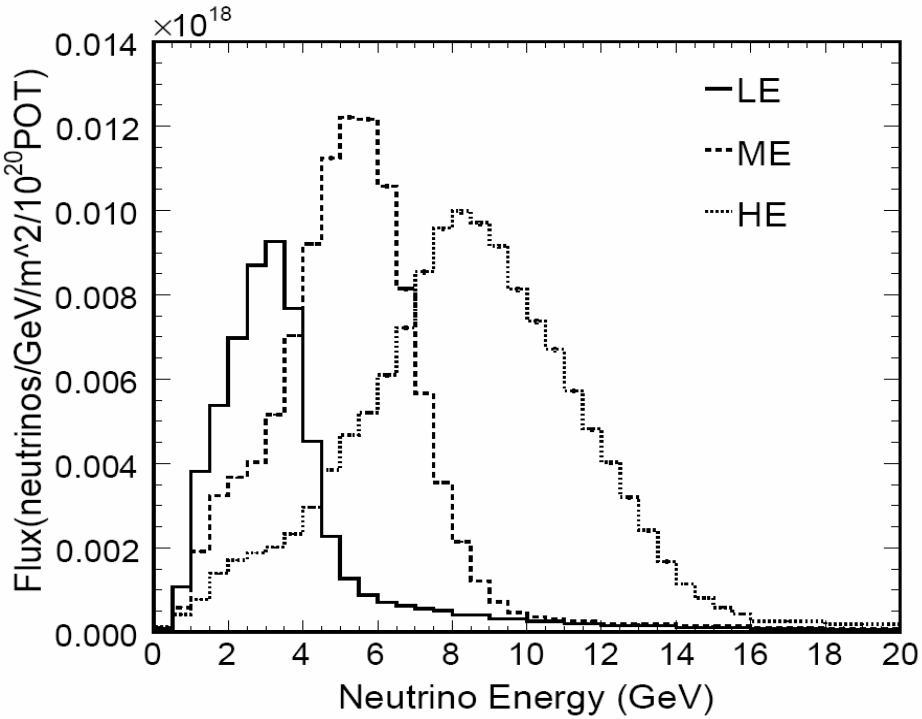




- **120 GeV protons strike the graphite target**
- **Nominal Intensity 2.4x10^{13} ppp with ~2 sec cycle time.**
- **Initial intensity ~2.5 x 10^{20} protons/year**
- **Ultimate intensity ~ 3.4 x 10^{20} protons/year (2008-9)**

Beam Energy Variability



Example spectra from varying horn positions

Start with low energy beam to accommodate $\Delta m^2 \sim 0.002\ eV^2$

ν_μ CC Events in MINOS 5kt detector (2.5 x 10^{20} POT/yr)

Low	~ 1600/yr
Medium	~ 4300/yr
High	~ 9250/yr

Hadron and Muon Monitor Performance - Vertical Scan

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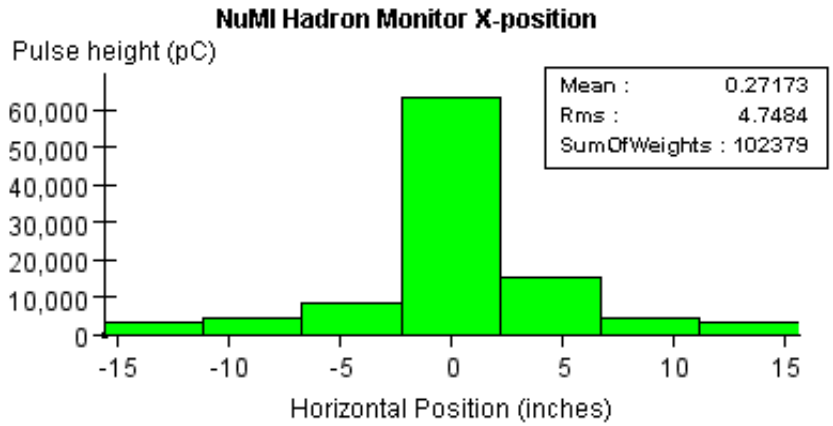
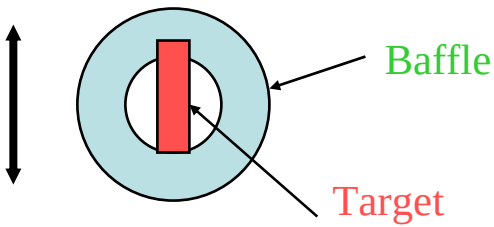
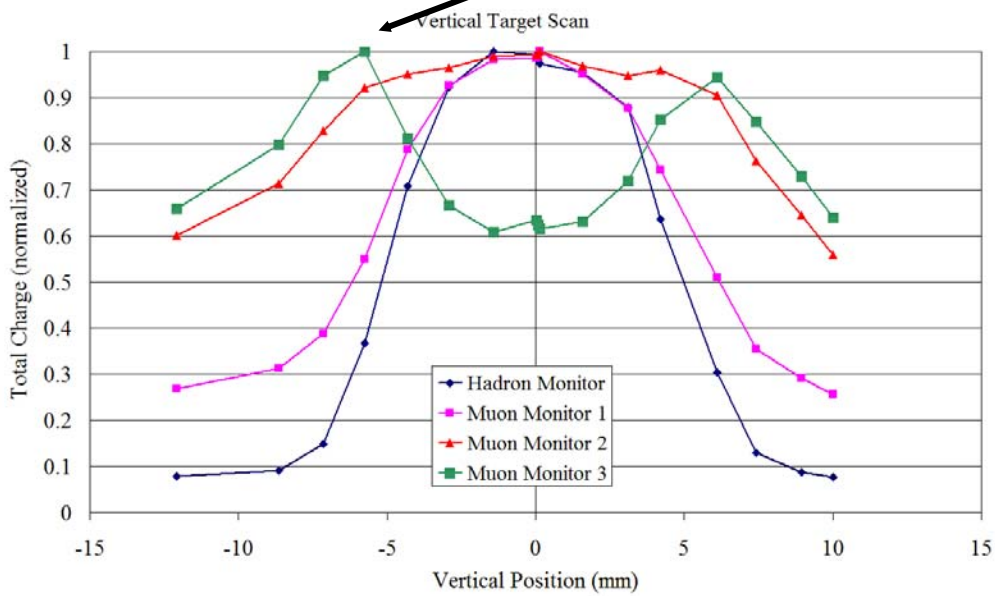


Beam scans with target
Hadron and muon monitors

Increased focusing energy due to beam hitting upstream baffle.





Recent Performance of Main Injector for NuMI

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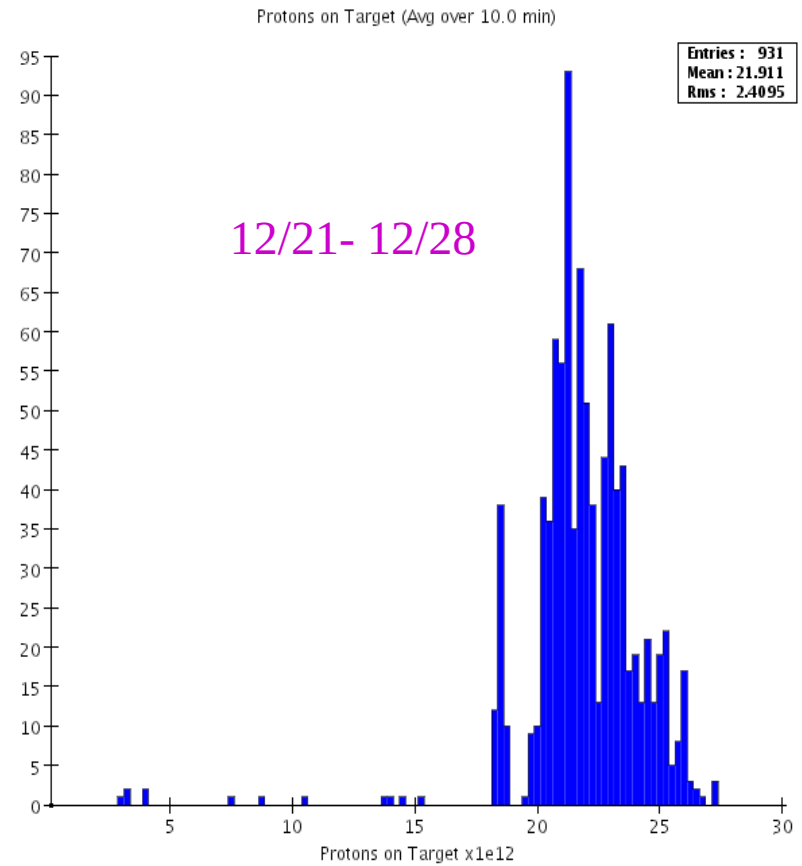
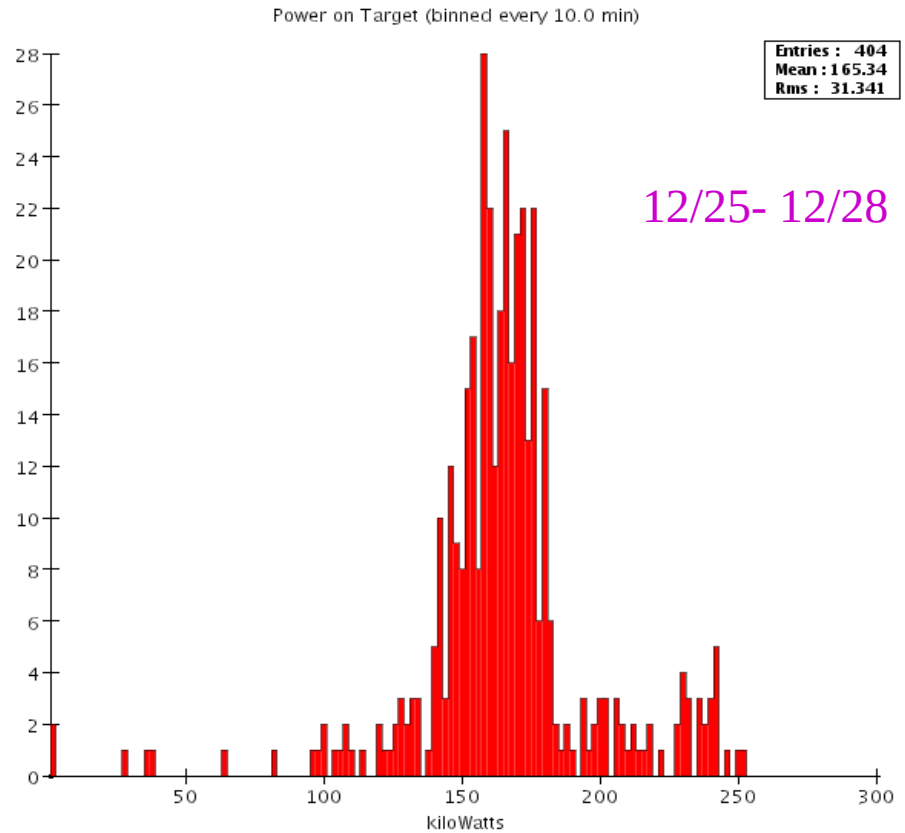
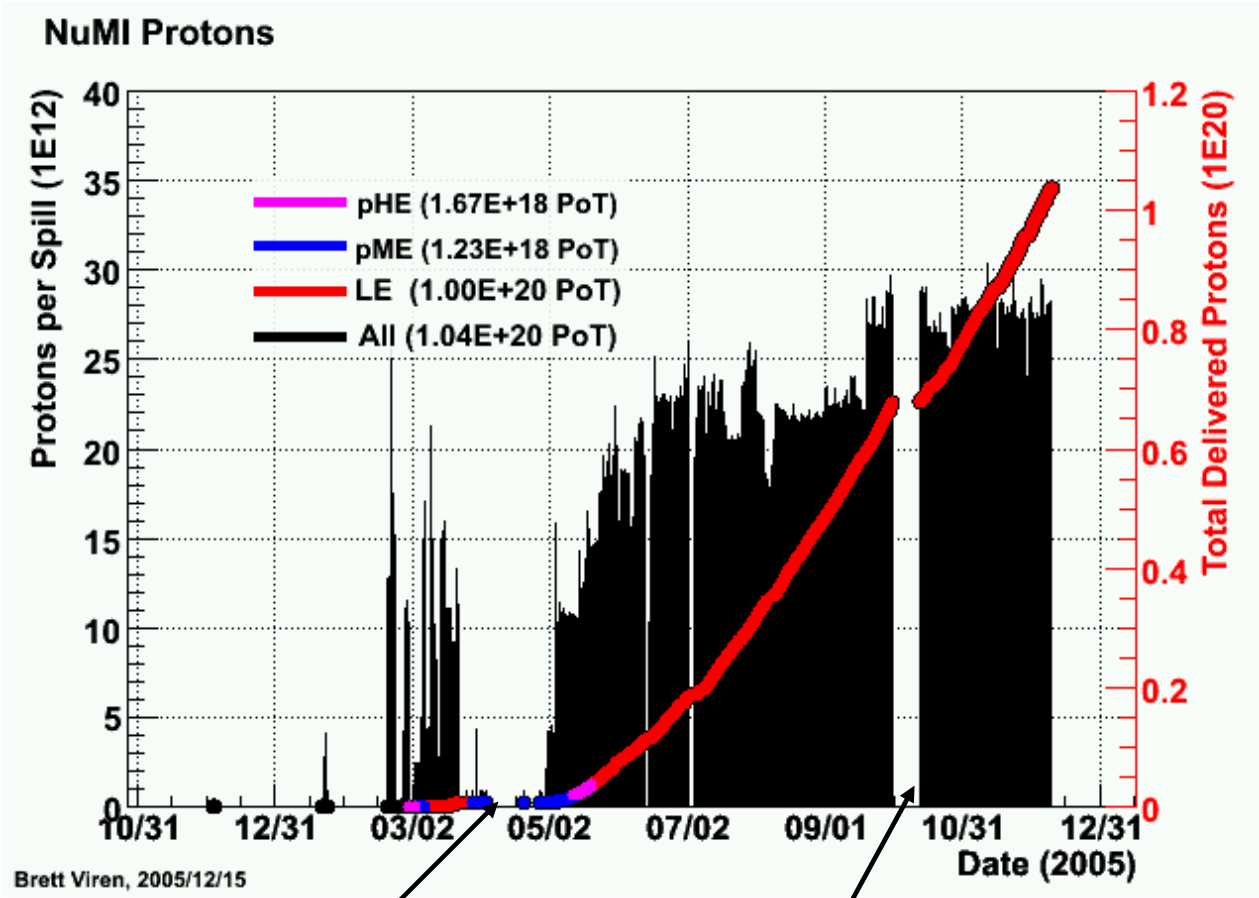




Protons on Target and Uptimes



The MINOS Detectors

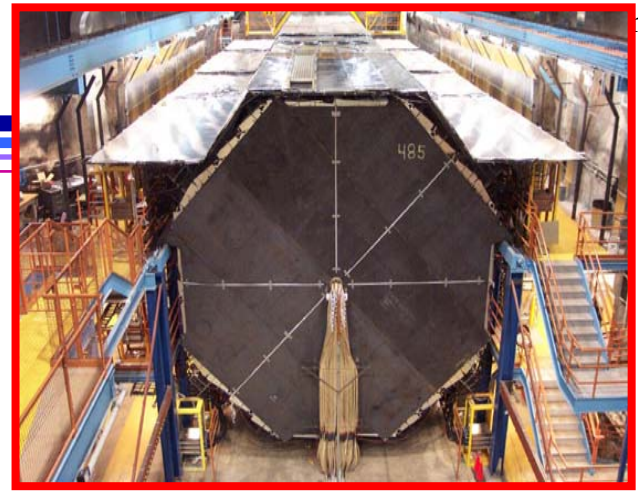
NEAR

0.98 Kton

MINOS Detector Hall, Fermilab

FAR

5.4 Kton



Soudan Underground Lab, Minnesota

Both detectors are tracking calorimeters composed of interleaved planes of steel and scintillator – uptimes routinely exceed 95-97%.

- 2.54 cm thick steel planes
- 4.1 cm wide scintillator strips
- 1.5 T toroidal magnetic field.
- Multi-Anode Hamamatsu PMTs (M16 Far & M64 Near)
- Near electronics optimized for high occupancy (~20) during 10 μs spill
- Energy resolution: 55%/√E for hadrons, 23%/√E for electrons
- Muon momentum resolution ~ 6 % from range (~ 12 % from curvature)

Near Detector neutrino events

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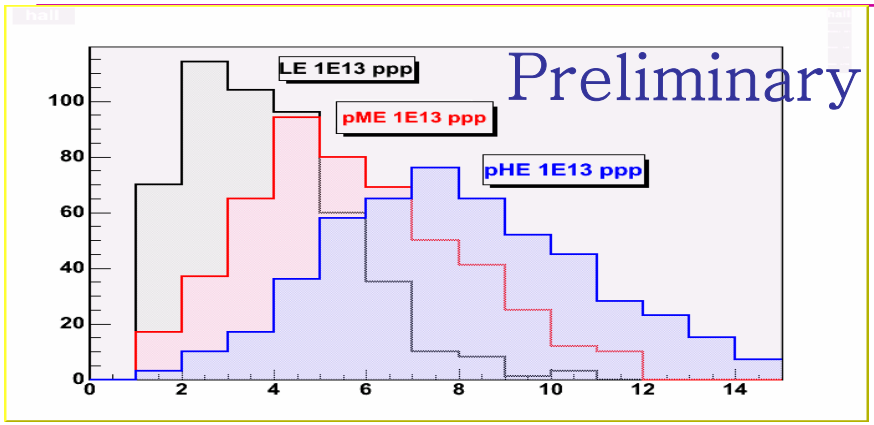
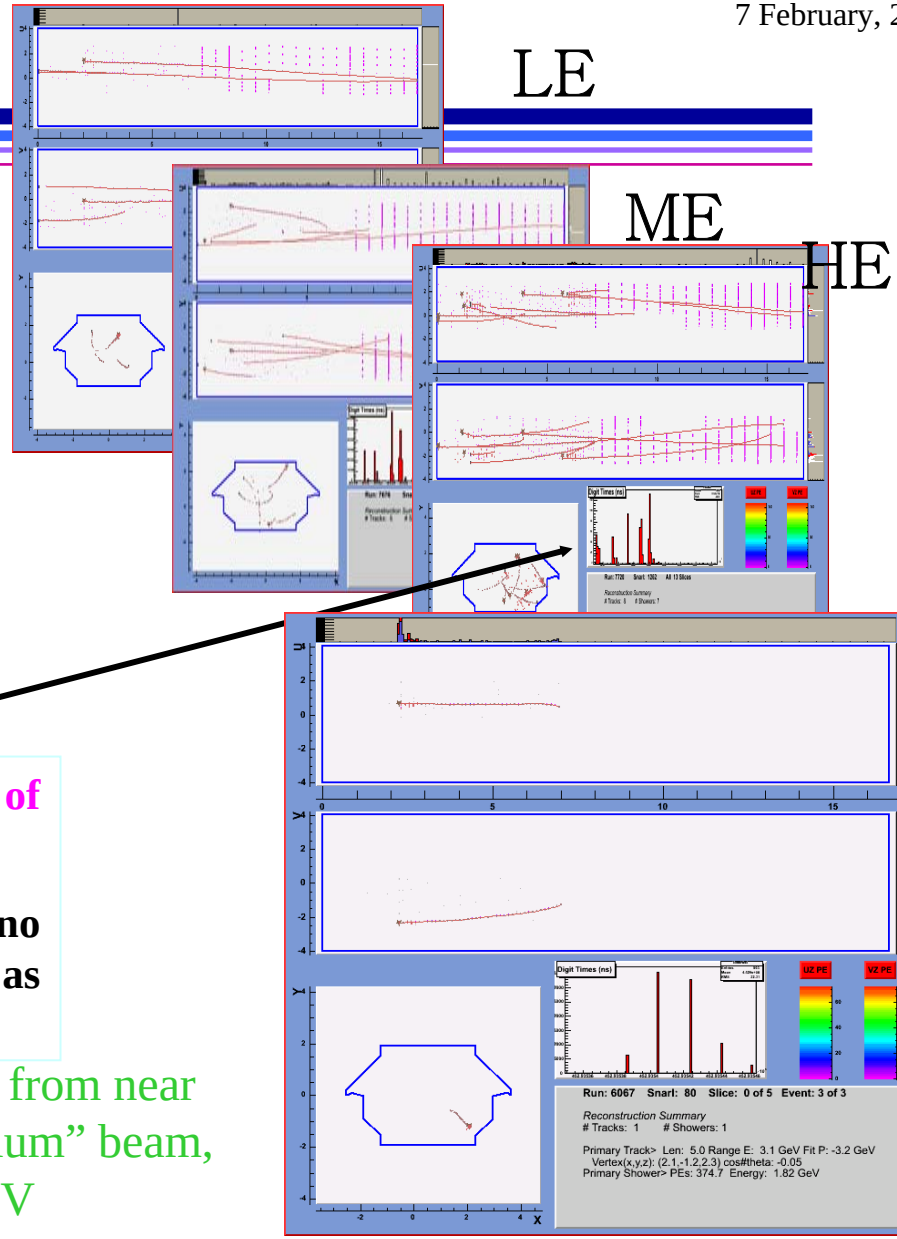




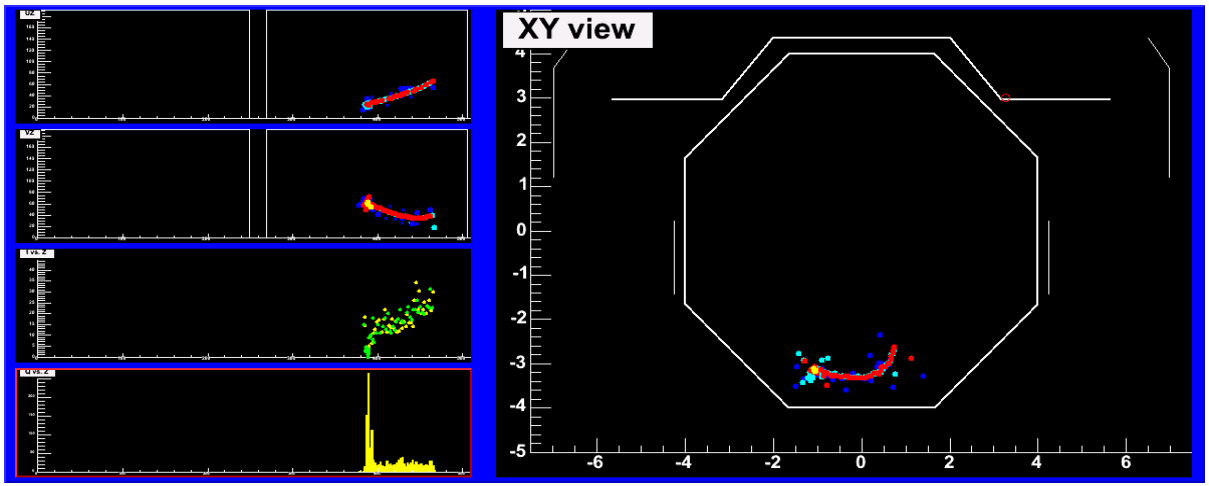
Event/spill distribution for various beam configurations

Events are separated for analysis on the basis of timing.

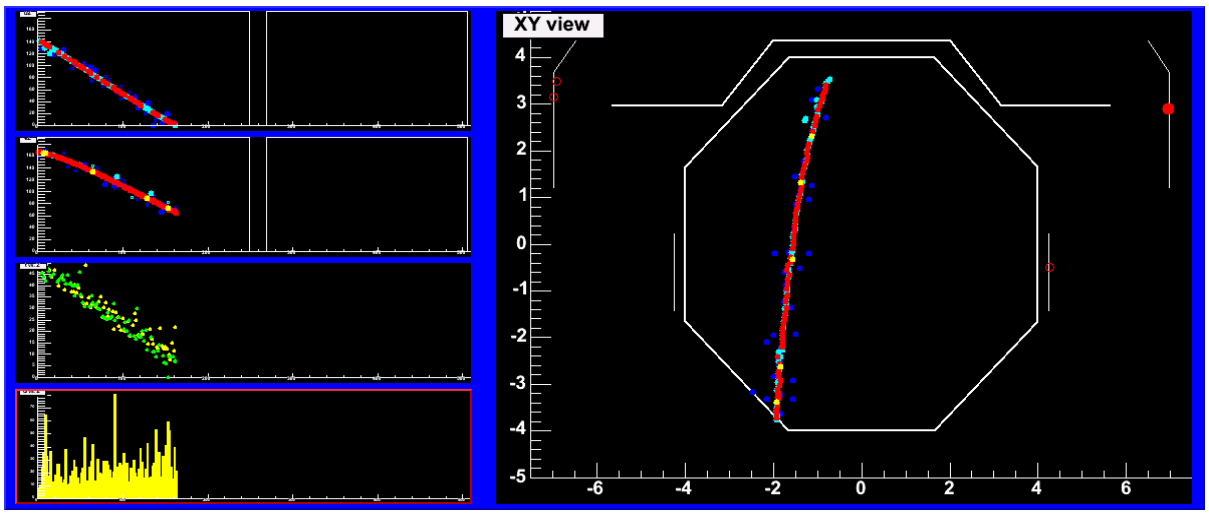
For constant intensity the number of neutrino events scales with neutrino energy (scaling factor as expected from MC).

Medium energy track from near peak in “pseudo-medium” beam, track energy ~ 3.1 GeV

Minos Far Detector Events



Contained CC event
Expected rate ~3/day

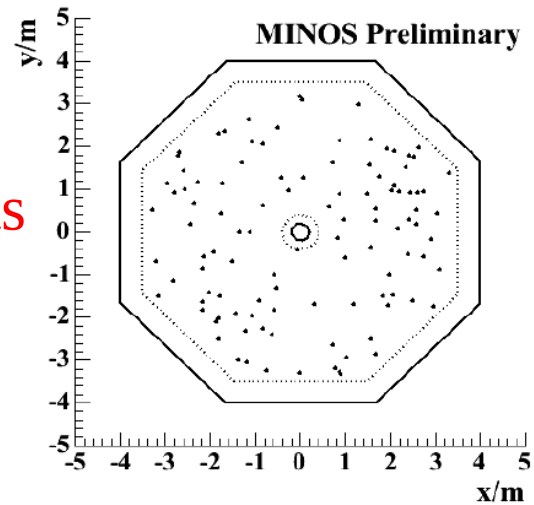


Up-going muon
Rate ~0.2/day

Minos Atmospheric Neutrinos

- Modest mass detector but magnetized – can investigate ν vs. anti-ν oscillations.
- 6.18 kT years exposure, of which 4.5 are fiducial
- Trigger on 4/5 contiguous planes.
- Divide data into fully contained (FC) + downgoing PC, and upgoing PC events. Different background rejection algorithms in these two samples.
- Resulting candidate sample 107 in all categories
- "Good timing" sample divides into 49 down-going, 28 upgoing.
- Up-going muons subject of another analysis.

Vertex Distribution for 107 selected events



Atmospheric Neutrino Results

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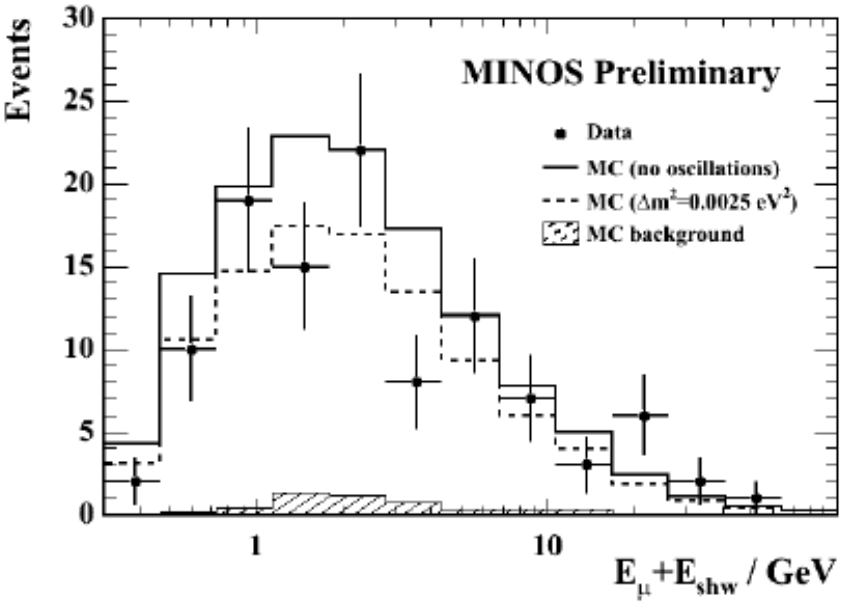
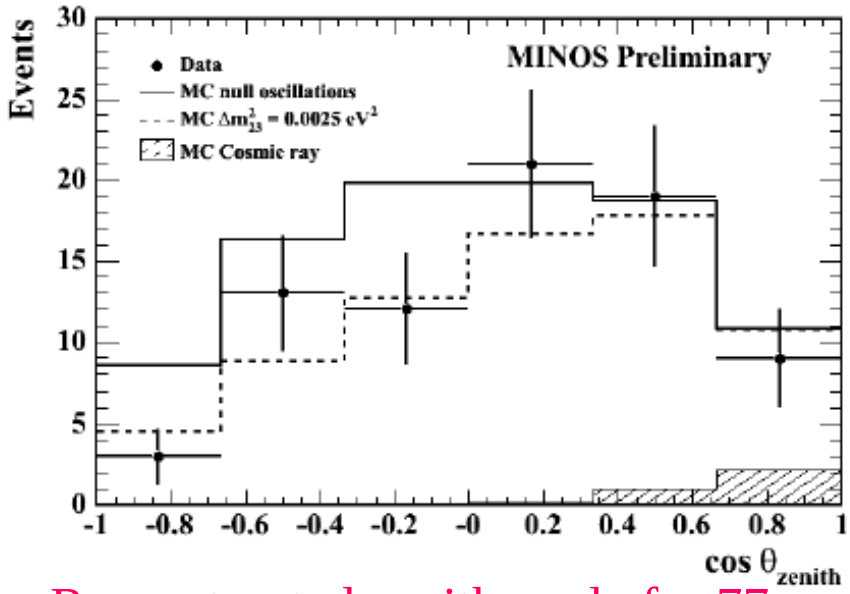


Reconstructed E(ν) for 107 events



Reconstructed zenith angle for 77 events

$R(up/down)^{data}/R(up/down)^{MC} = 0.62 \pm 0.14 \pm 0.02$

Using a high-resolution sample, exclude no-osc. hypothesis at 98%

From 52 events with well-measured charge:

$f(anti\text{-}\nu)^{data}/f(anti\text{-}\nu)^{MC} = 0.98 \pm 0.19 \pm 0.06$

Assuming oscillations for ν and anti-ν at $\Delta m^2 = .0024$ eV^2

MINOS Beam Event Characteristics

- Simple event selections for both detectors.
- Far Detector
  - 50 μs window around beam spill
  - Reconstructed track within fiducial volume (70% for CC)
  - Track angle along beam direction.
  - Data and beam quality cuts (96%)
- Only an unknown fraction of the far detector data is used for checks and testing (and presentations).
- Near Detector
  - Fiducial cuts using track or event vertex for candidate neutral currents
  - Track quality cuts for events with tracks
  - Beam quality cuts

Vertex and Timing Distribution of Far Detector Events

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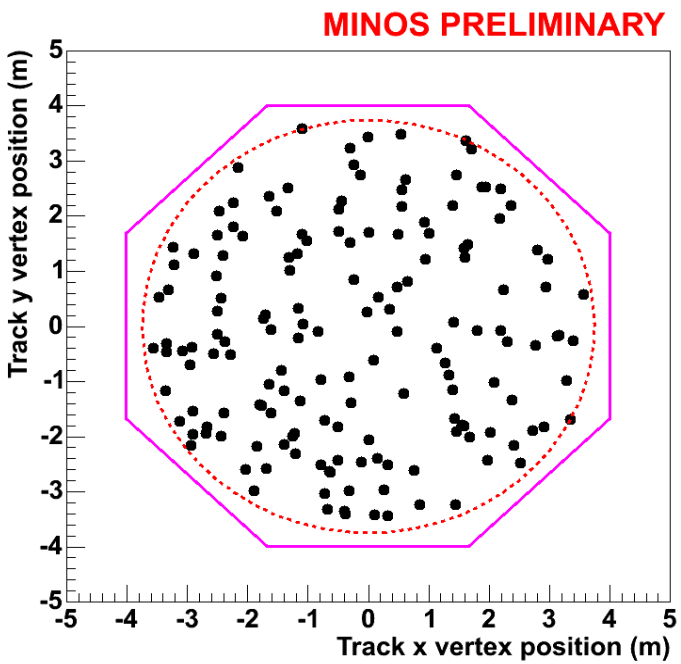
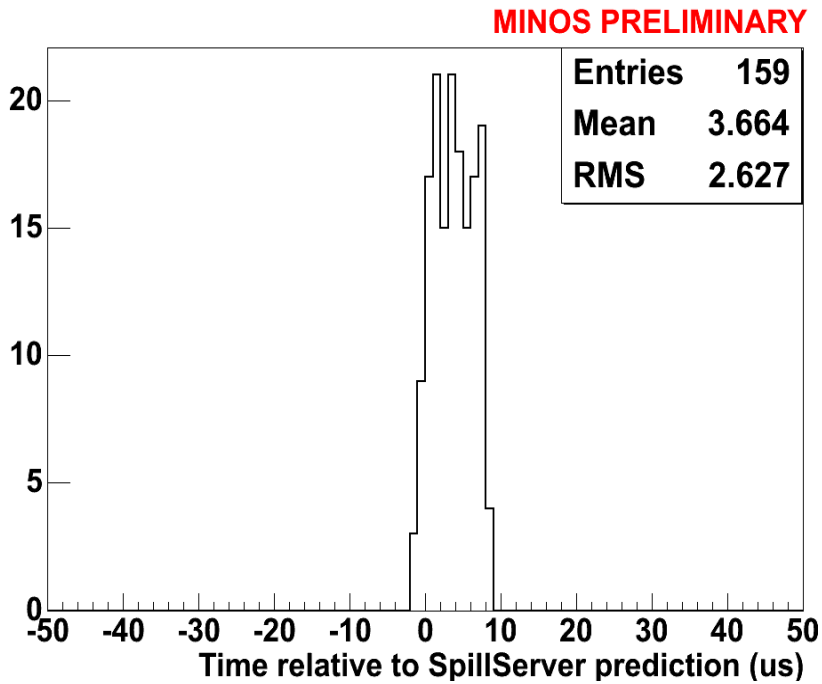
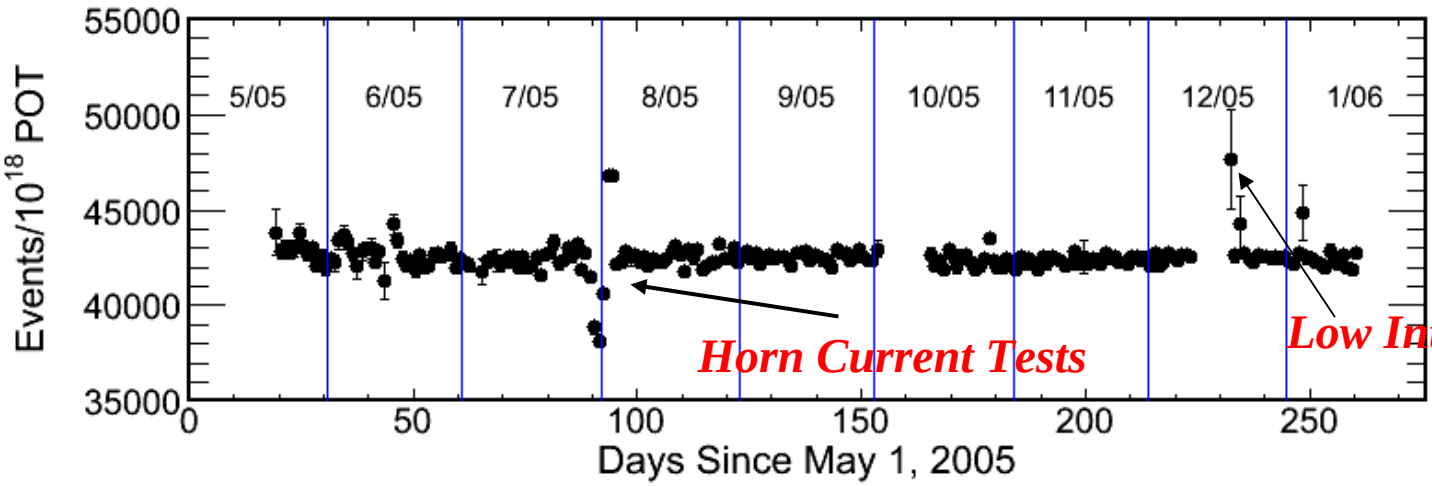


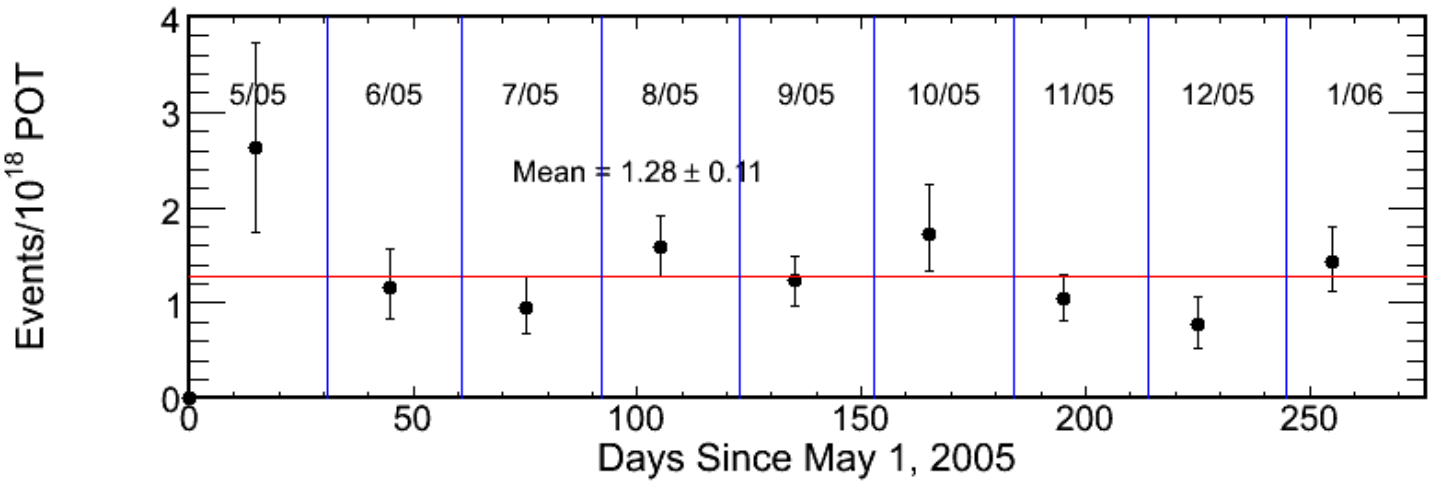


The cuts described result in 159 neutrino events.
Protons used for this work 9.3×10^{19}
Caution: This is MINOS open sample only!

Stability of Datataking



Near Detector



Far Detector
"open sample"

Angular Comparisons – Reconstructed Track Angle

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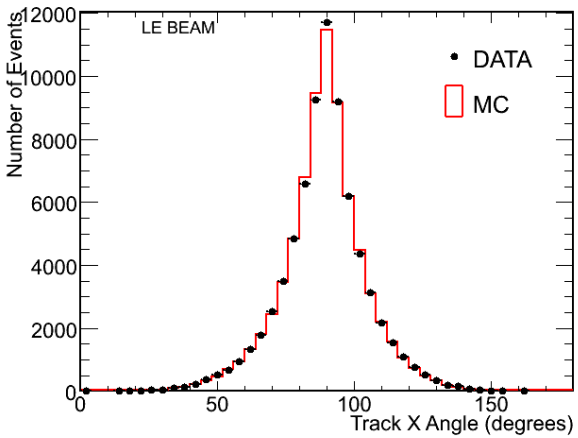
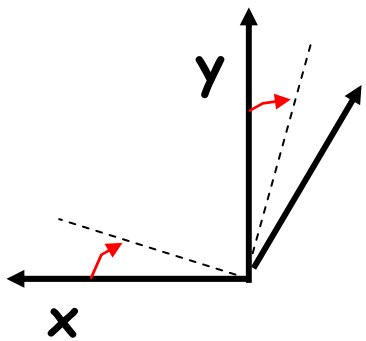
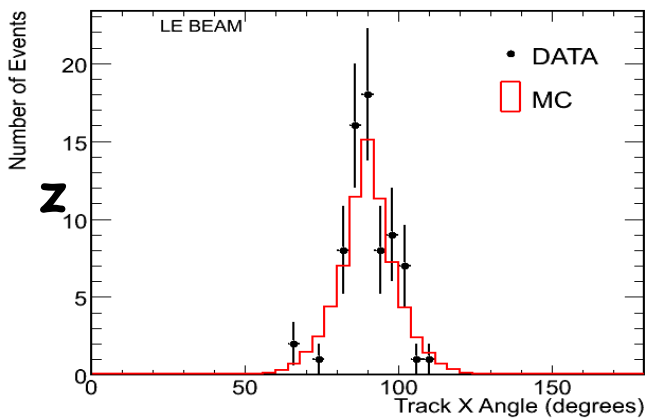
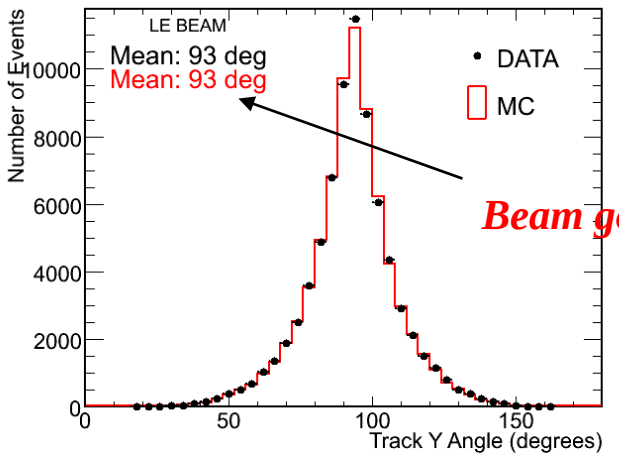
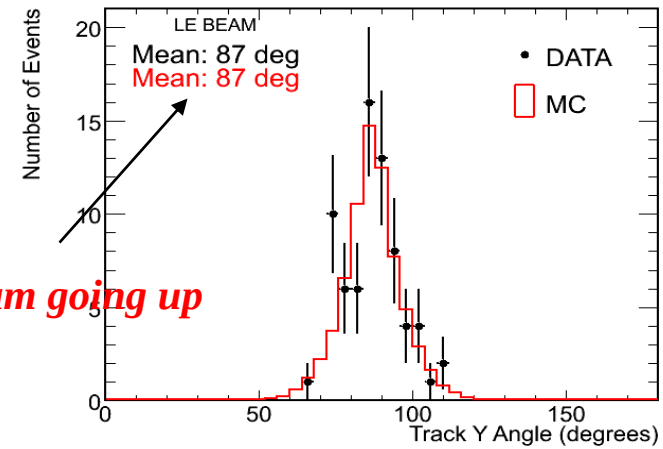








Beam going down



Beam going up

Near Detector

Far Detector, using longer events to get best angular resolution.

Range and Curvature Momentum Comparison

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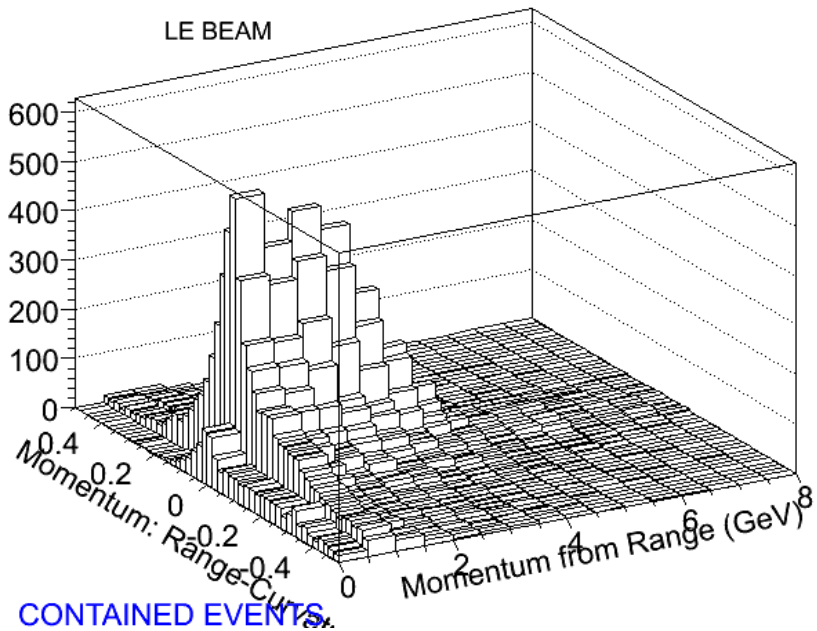
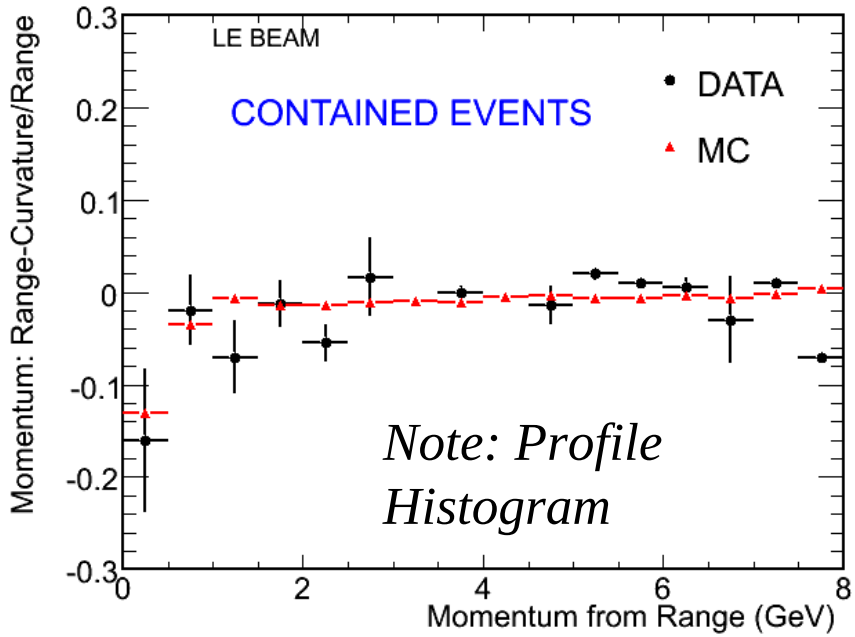


Near Detector



Far Detector

Comparison in momentum regime where events are contained. Builds confidence in magnetic field map and calibration.

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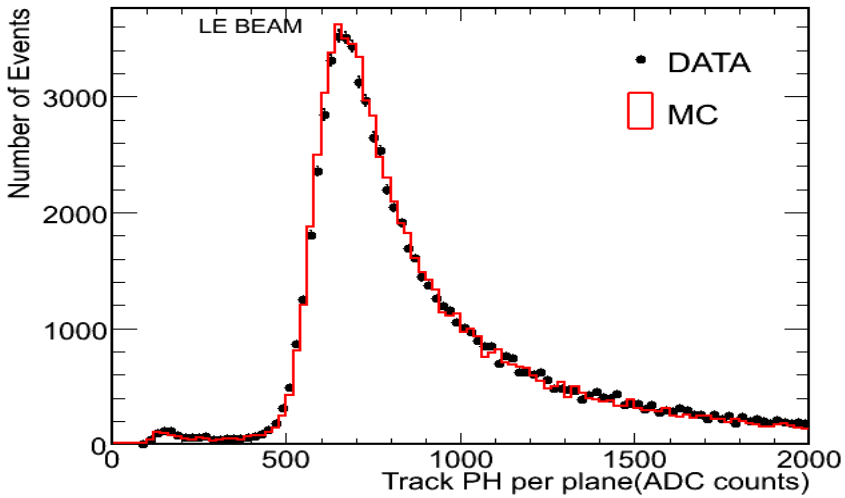
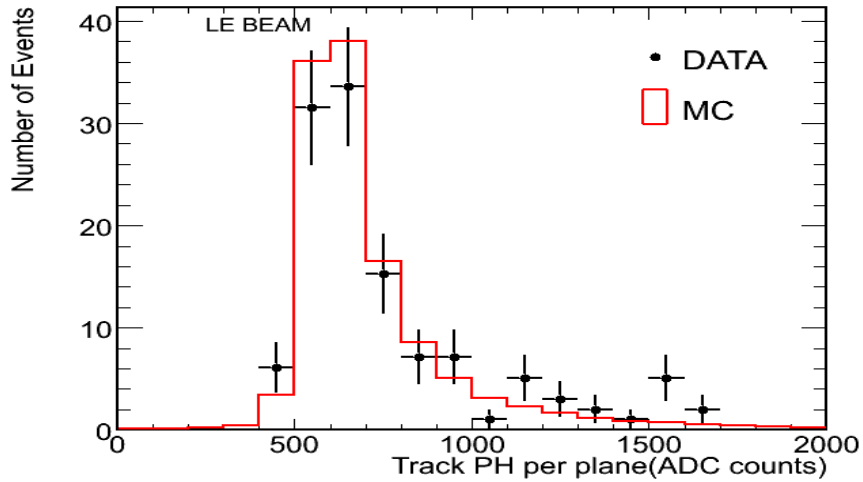
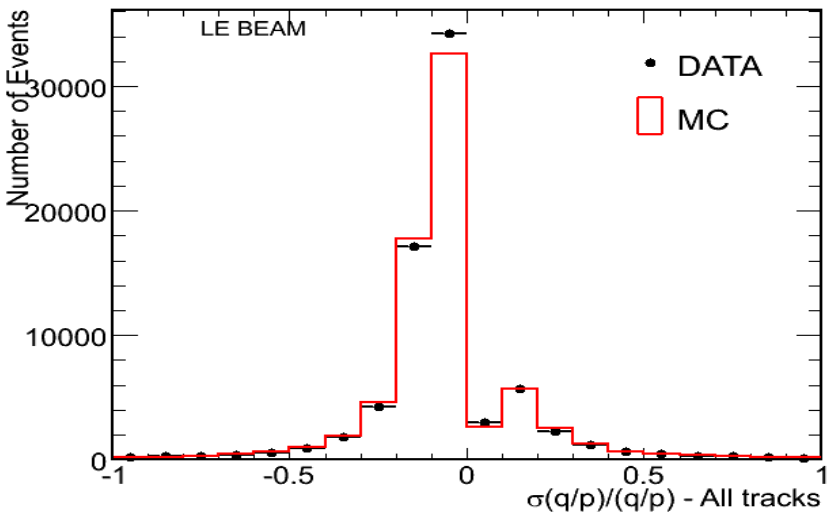
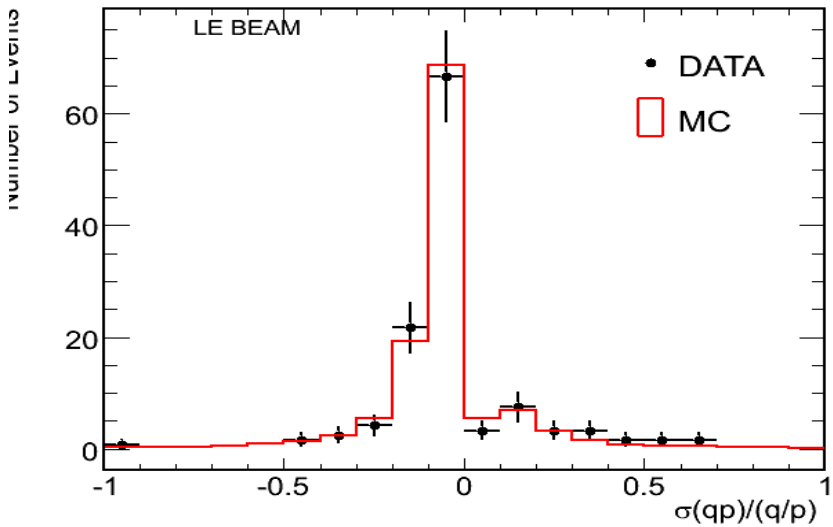
Tracking Performance









Near Detector Spectrum showing stability and beam uncertainty.

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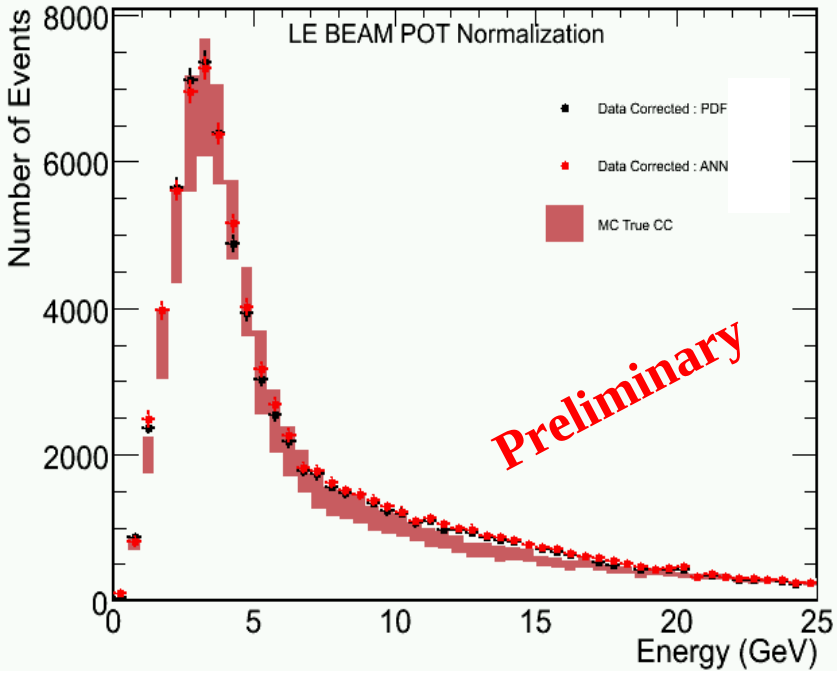
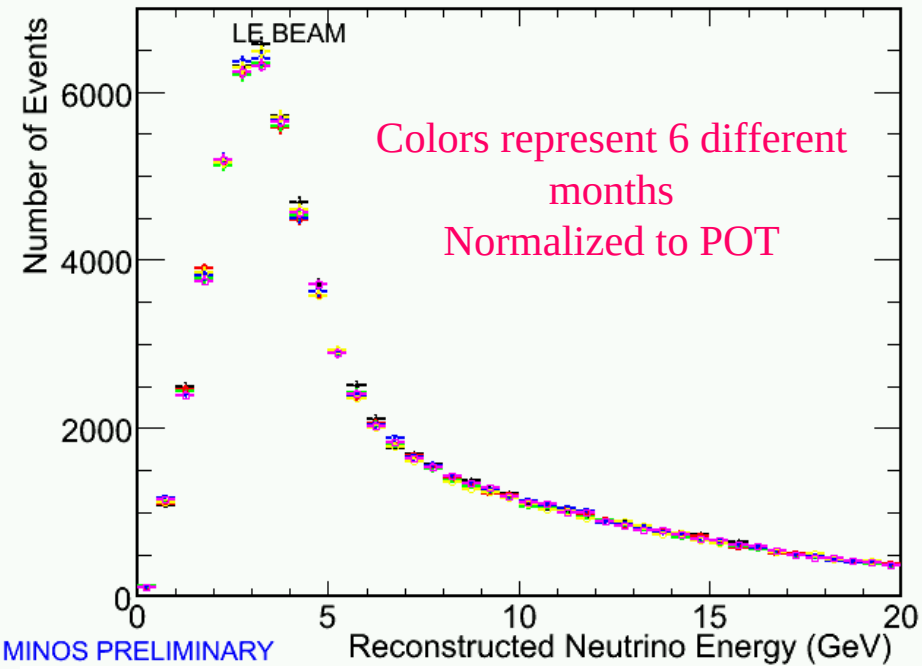




Using ND data to study variations and parametrizations of hadron production

Work in progress.

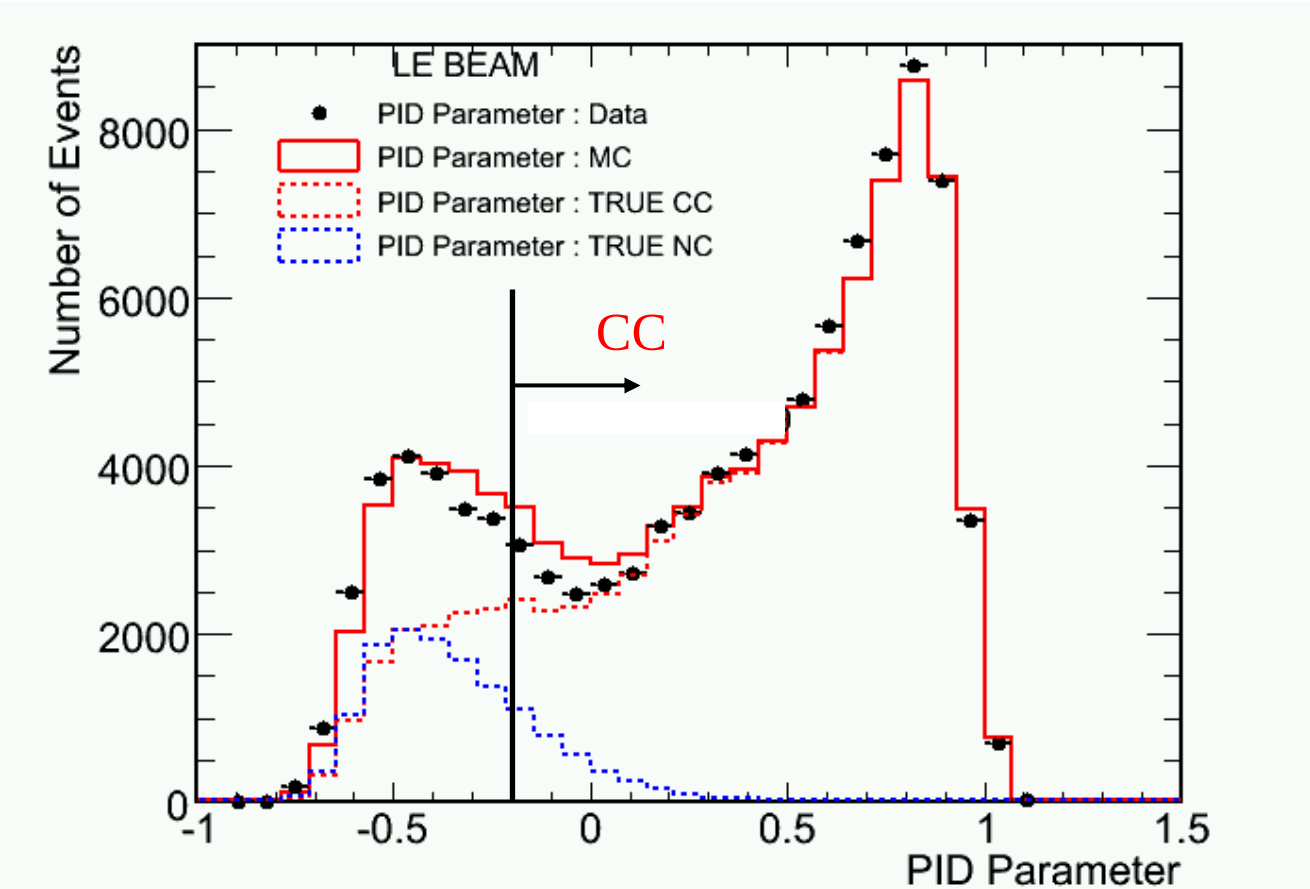
Towards a CC Disappearance Analysis

- Blind analysis - only <50% of data in open sample for comparisons.
  - Remainder modified by “blinding function”.
- Steps in analysis
  - Select neutrino events
  - Classify as CC events
    - Likelihood-based procedure using pulse height, event length
    - Check with neural net based procedure - good agreement. Also controlled scanning checks.
  - Simultaneous fit to near and far CC spectra to extract oscillation parameters.

Notes: NuMI/MINOS MC used to extrapolate far/near

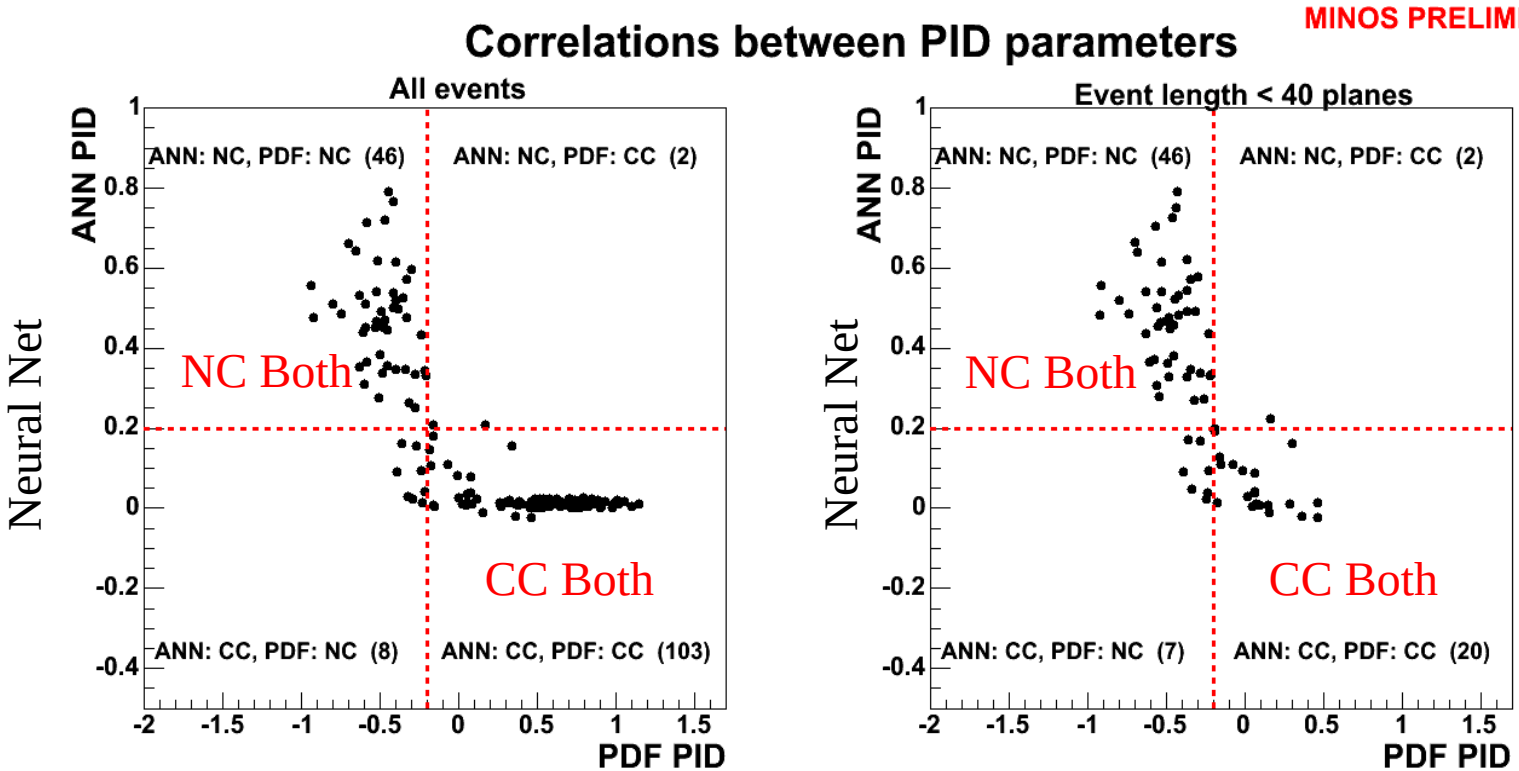
Fit χ^2 will include systematic errors.

Performance of PID Charged Current Selection Algorithm



With cut at -0.2, MC estimate of efficiency is 87%, with purity 98%

Stability of CC Selection Algorithms



Excellent overlap between algorithms for charged-current selection.

Results of Mock Data Challenge (simulated 7.4 x 10^{20} protons)

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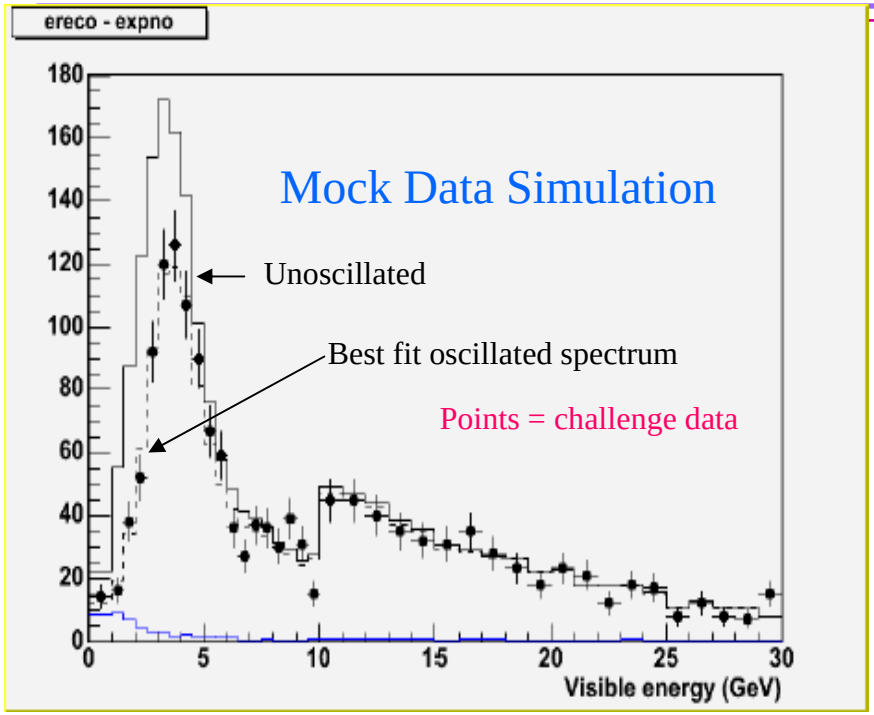
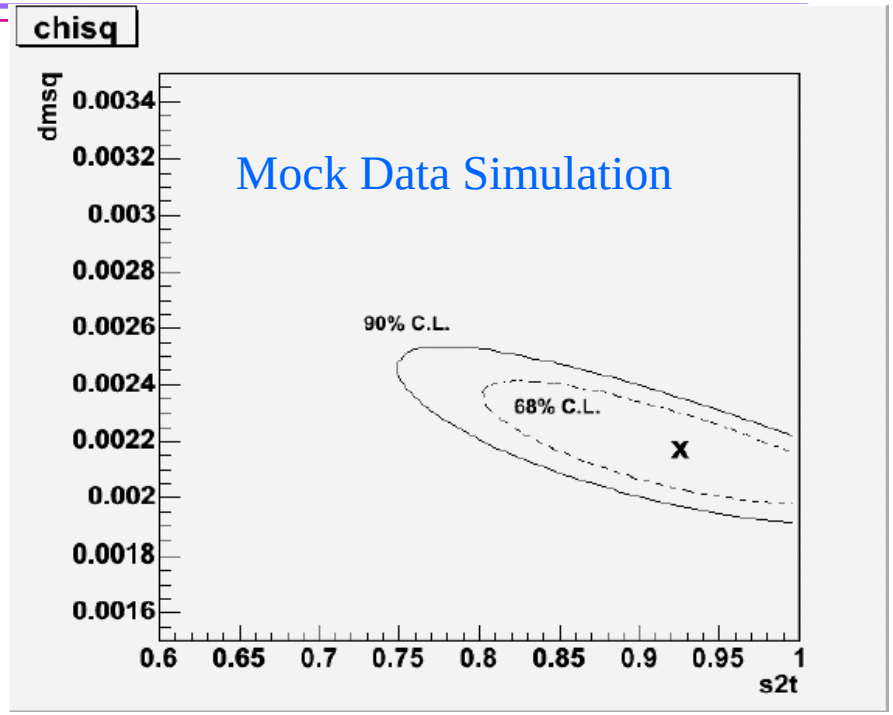


Fit to reconstructed far energy spectrum



Best fit results for oscillation parameters

	Challenge Value	Fitted Value
Δm^2	2.1×10^{-3}	2.2×10^{-3}
$\sin^2(2\theta_{23})$	0.88	0.93

Status of CC Analysis

- Data samples and event selections defined.
- Fitting procedures well-advanced.
- Currently concentrating on understanding beam systematics on measurement.
  - Take advantage of huge Near Detector dataset.
- Continue cross-checking before opening blinded box.
- Anticipate results for conferences soon.

Summary and Conclusions

- A very successful commissioning year!
  - All MINOS measurements improve with more beam.
- Atmospheric results submitted for publication.
  - Approximately 100 each of up-going muons and contained events.
- CC analysis well towards completion.
- Will certainly be able to use first 10^{20} protons data to verify choice of low-energy (LE) beam as operating point.