

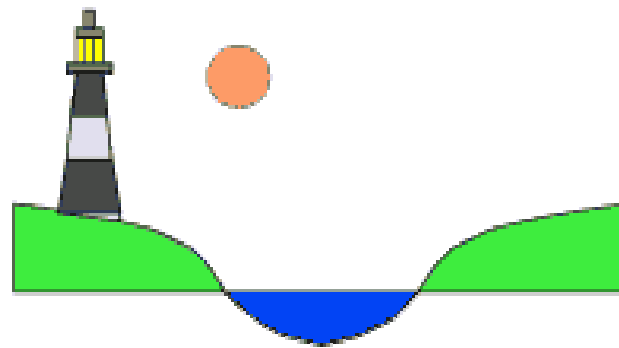


MINOS



Physics Program and Construction Status

Karol Lang
The University of Texas at Austin



**YITP: Neutrinos and Implications for Physics Beyond
The Standard Model, Stony Brook, Oct. 11-13, 2002**



MINOS



Main Injector Neutrino Oscillation Study

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Outline:

- **Physics Goals**
 - NuMI beam ν 's
 - CR atmospheric ν 's
- **Construction Progress**
- **Beginning of data collection**
 - CalDet
 - Cosmics



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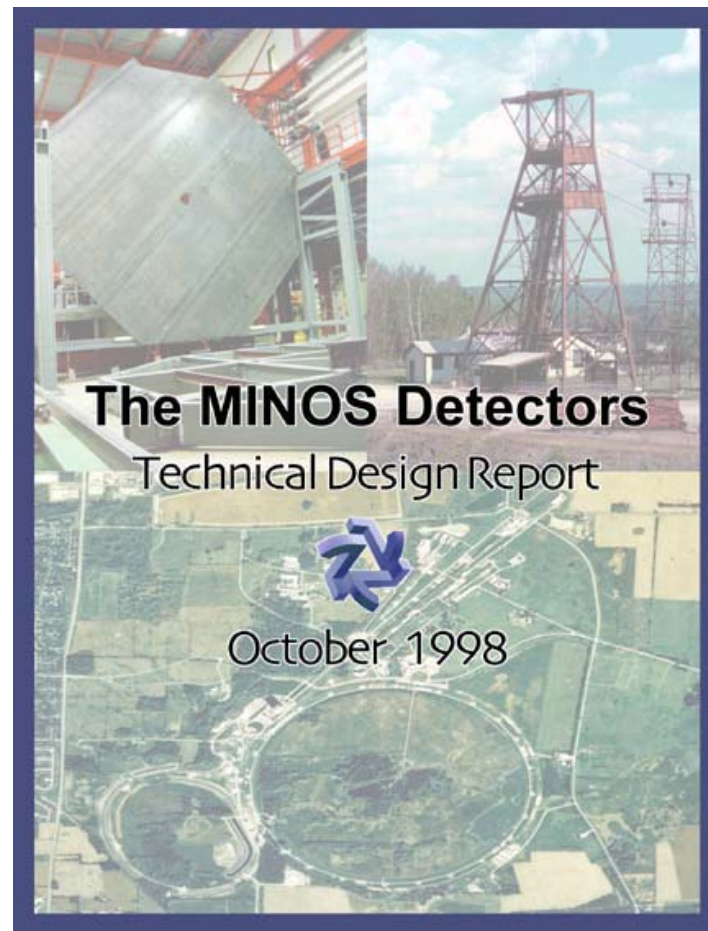
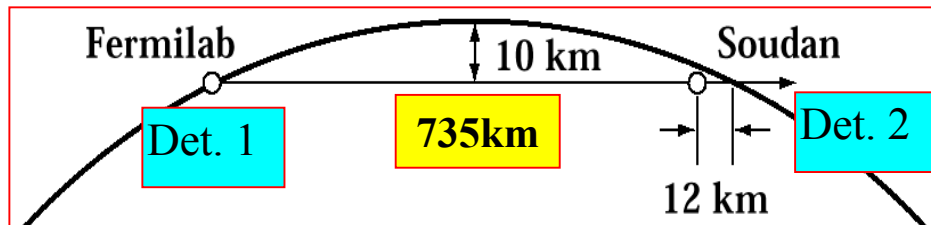


Strategy



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- **Two-detector** measurement
 - high mass w/ low price / kg
 - reliable and robust technology
 - underground (shielding)
- Use **high intensity** 120 GeV MI
 - 4×10^{13} protons/pulse
 - 0.4 MW
 - Single turn extraction ($8.4 \mu\text{s}$)
 - 4×10^{20} protons/year
- Flexible **well-controlled** beam
- (Hadronic hose)



Now: Start data collection in early 2005



MINOS Collaboration

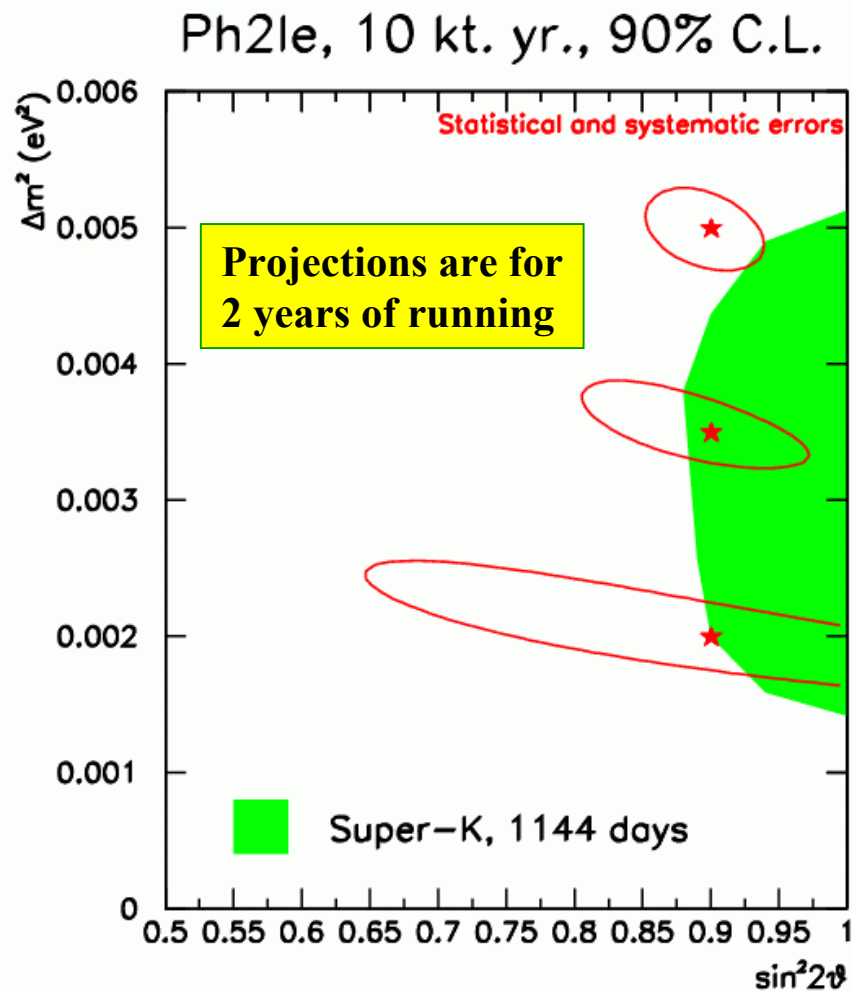
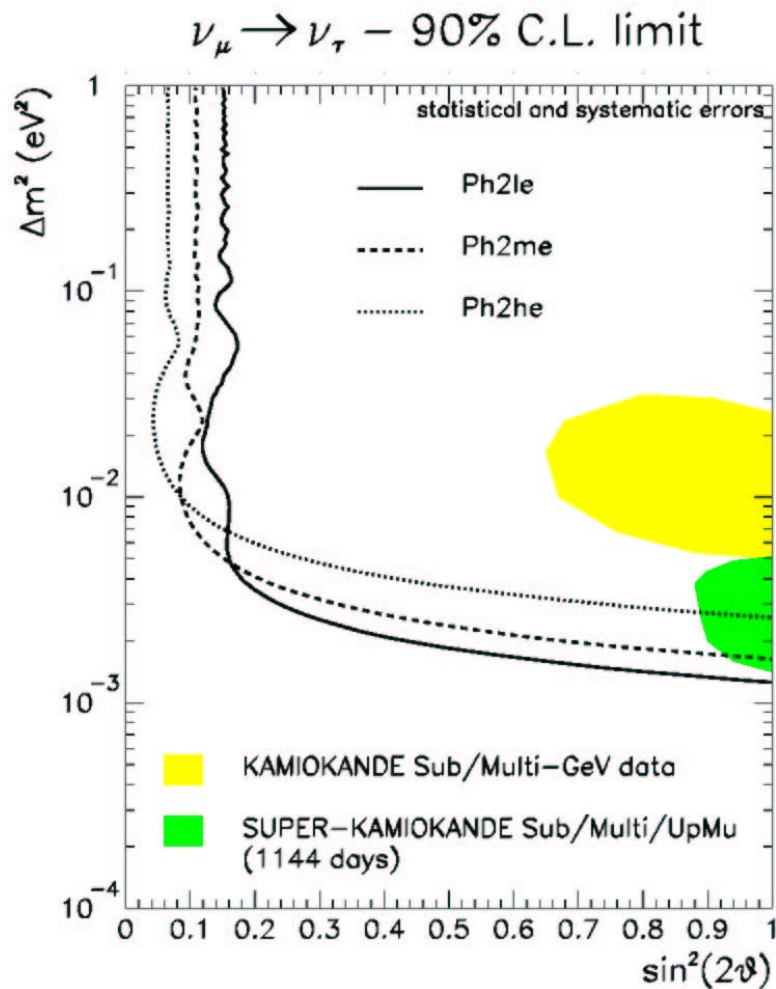
**32 institutions
175 physicists**



MINOS sensitivity to Oscillations



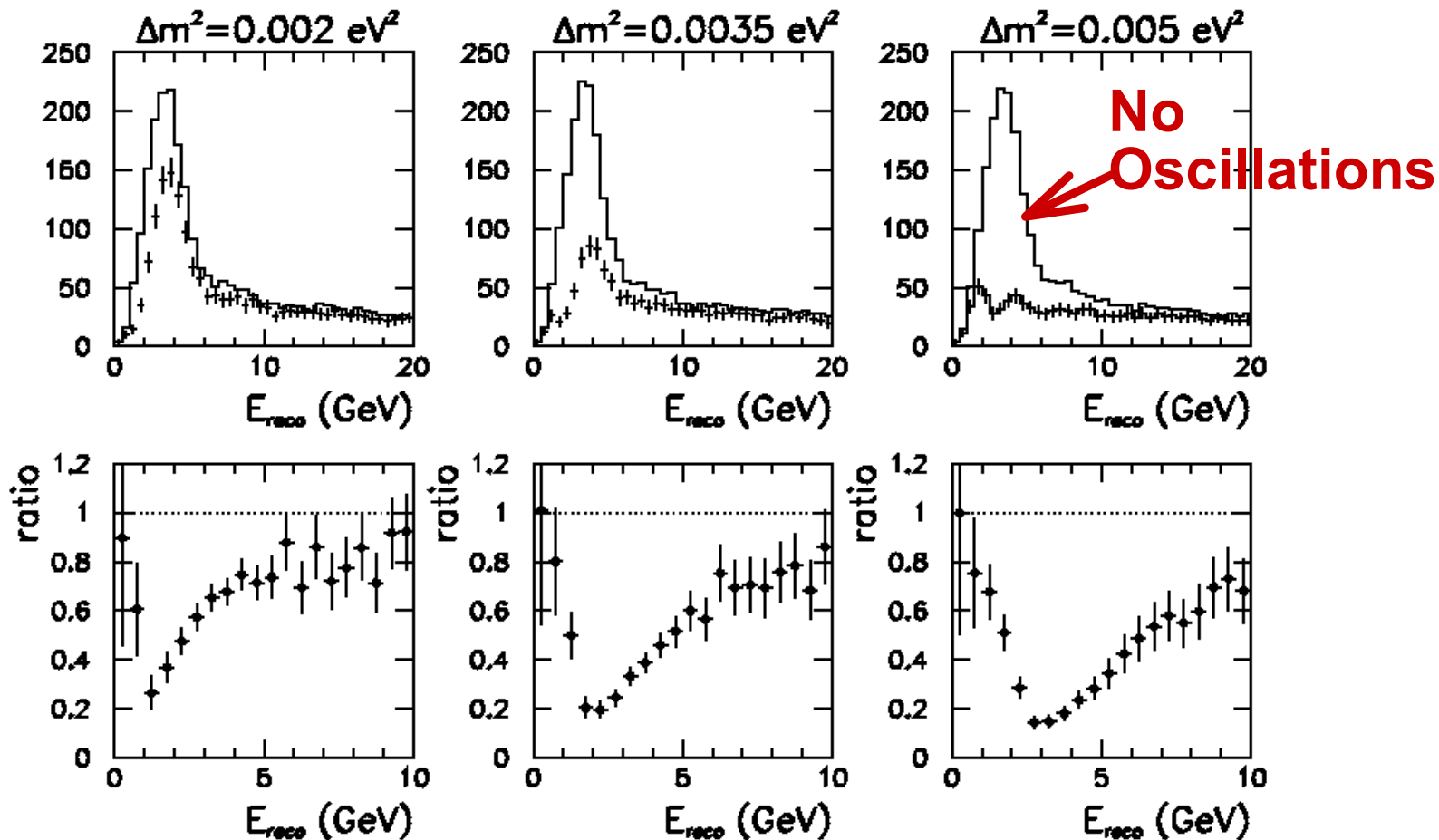
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Near to Far projections

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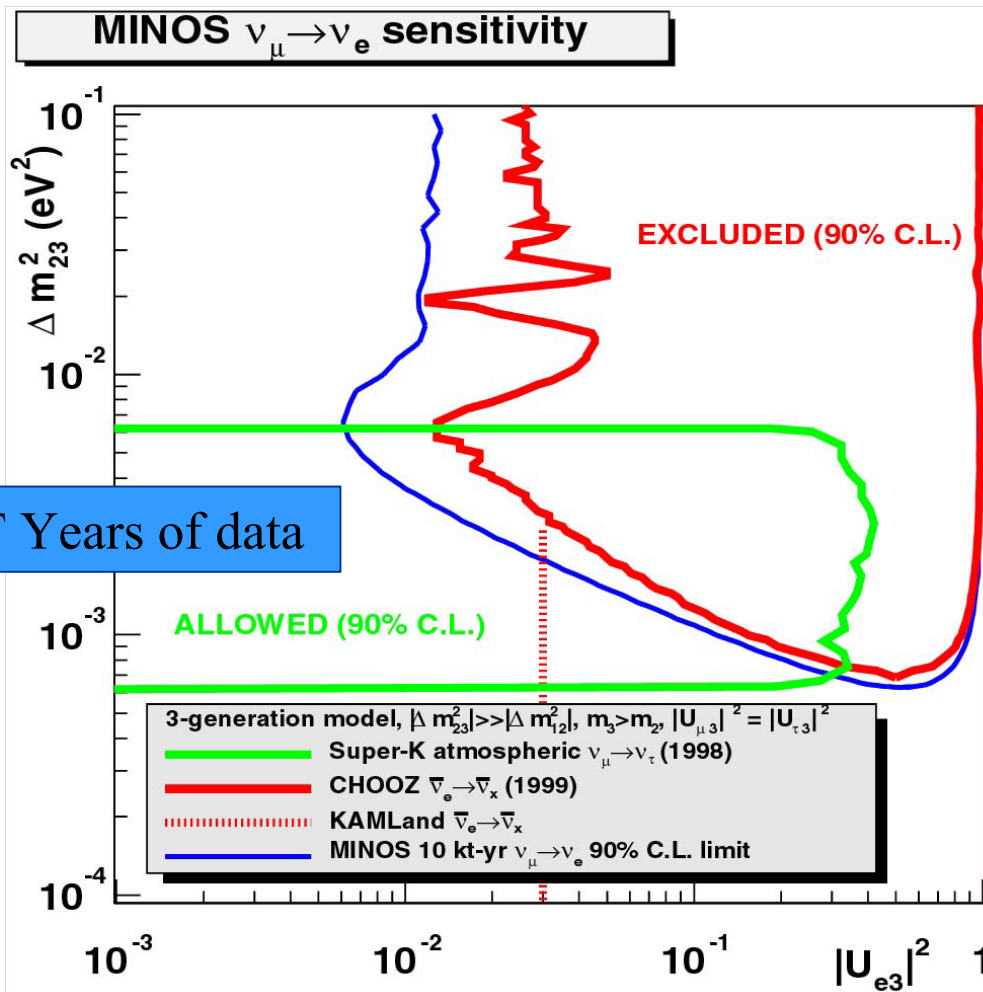


2 yrs of running



Electron appearance (U_{e3}^2)

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- Sensitivity is determined by statistical fluctuation of the NC π^0 BG in the far detector.
- Limit on U_{e3}^2 will scale like $1/\sqrt{N}$ and is not limited by systematics for any realistic exposure.
- Limit can be further improved by removing high-energy tail from the NuMI beam and increased proton flux in later years.
- Ultimate MINOS limits $\sim 1/3$ as shown here assuming extended running.

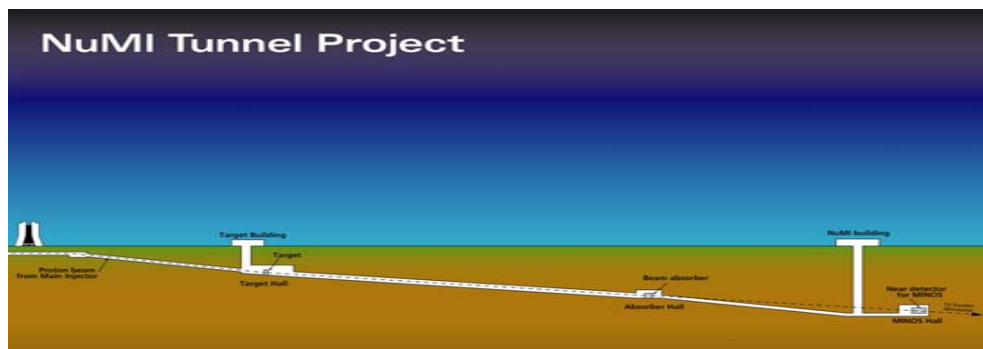
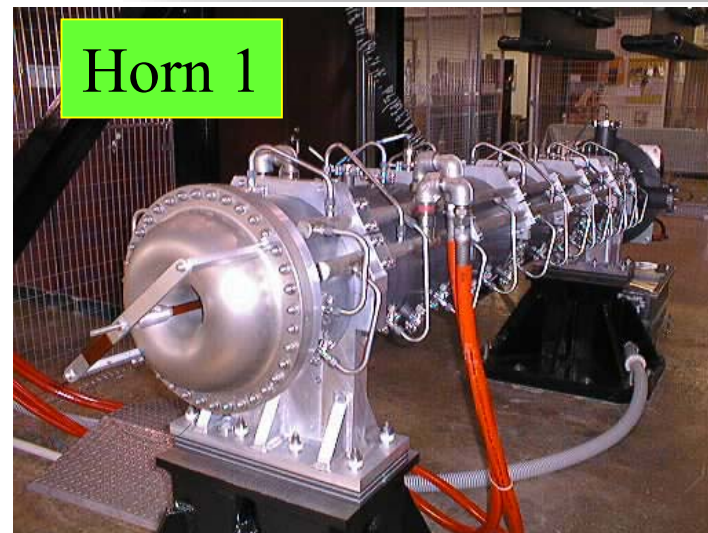
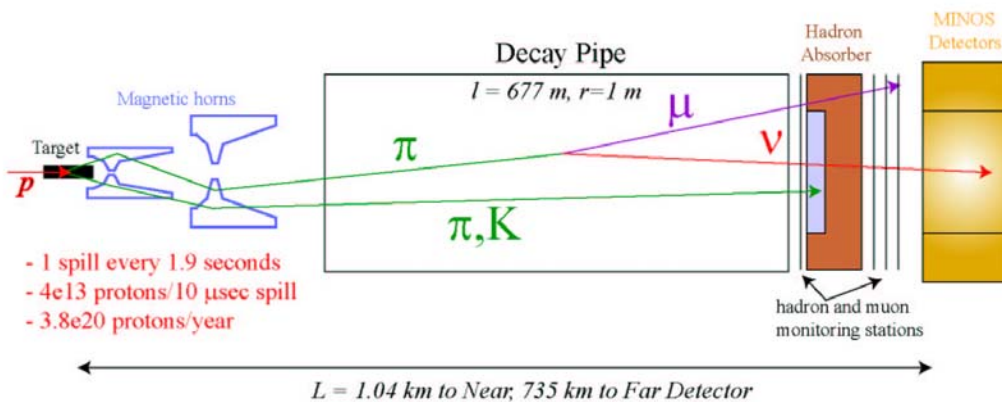


NuMI beams



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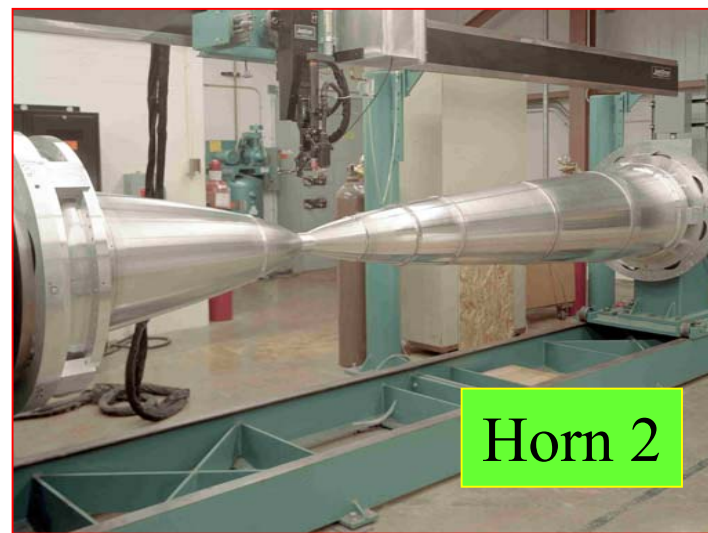
120 GeV/c protons strike graphite target
 Magnetic horns focus charged mesons (pions and kaons)
 Pions and kaons decay giving neutrinos



▲ Target

677 m decay pipe

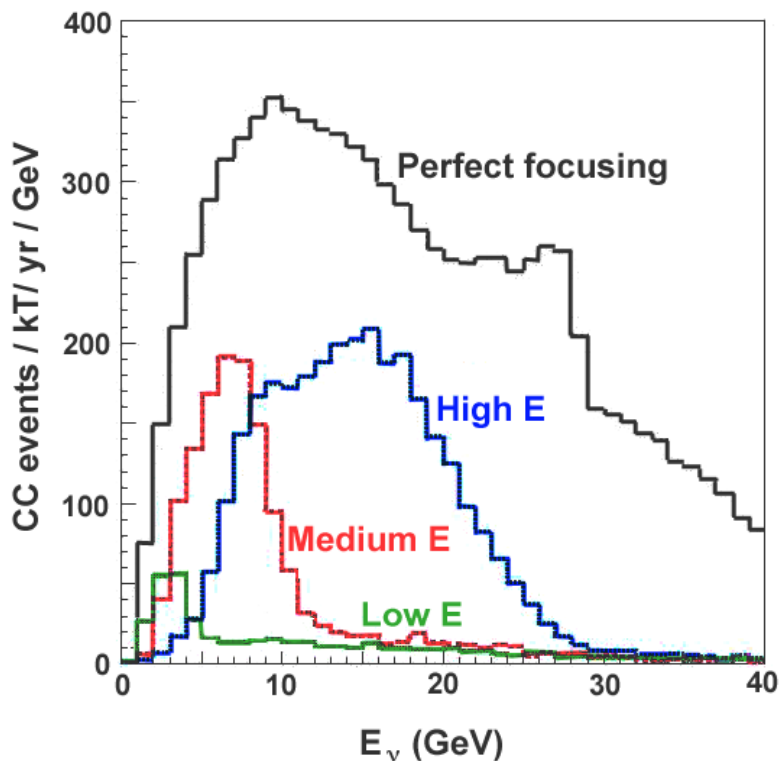
→ Near Detector





NuMI neutrino beams

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horns and target can be moved to tune to a different energy spectrum

In a later stage (> 2007 ?) running with Antineutrinos is foreseen

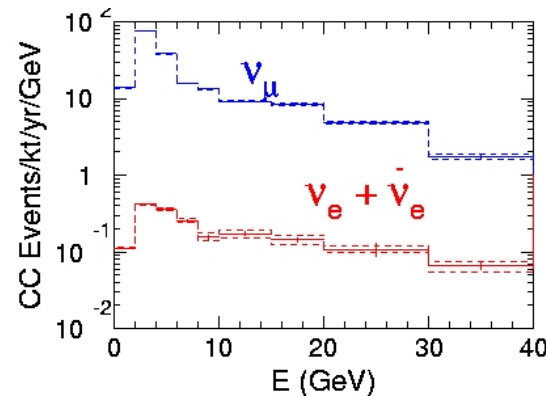
ν_μ CC Events/kt/year

Low	Medium	High
470	1,270	2,740

ν_μ CC Events/MINOS/2 year

Low	Medium	High
5,080	13,800	29,600

4×10^{20} protons on target/year
 4×10^{13} protons/1.9 seconds



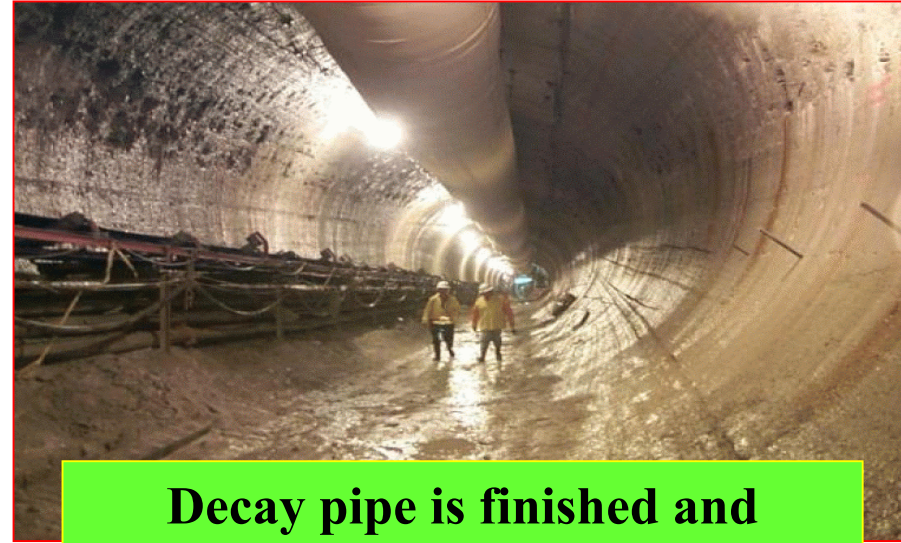


Modern tools of experimental particle physics: TBM – Tunneling Boring Machine



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TBM - front



Decay pipe is finished and



Tunneling: a nightmare...but it's over



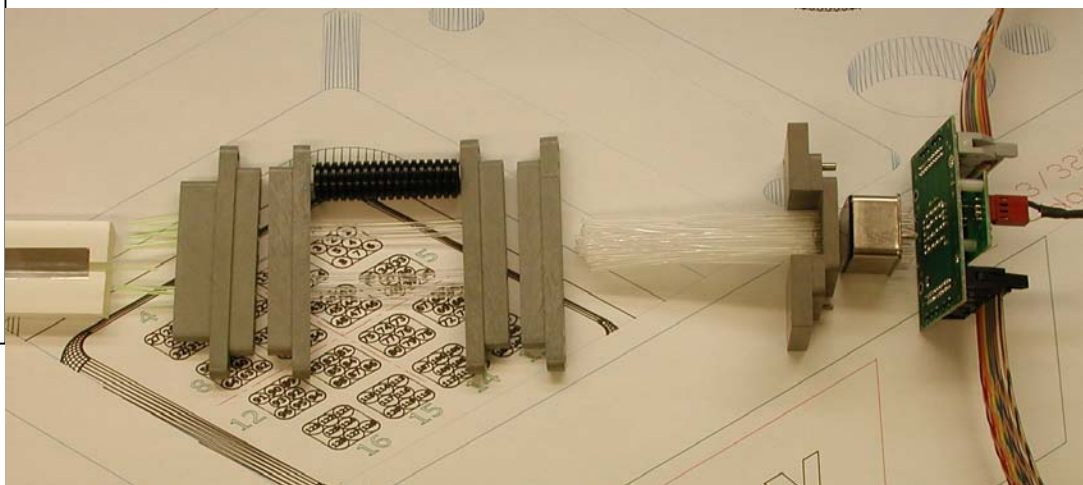
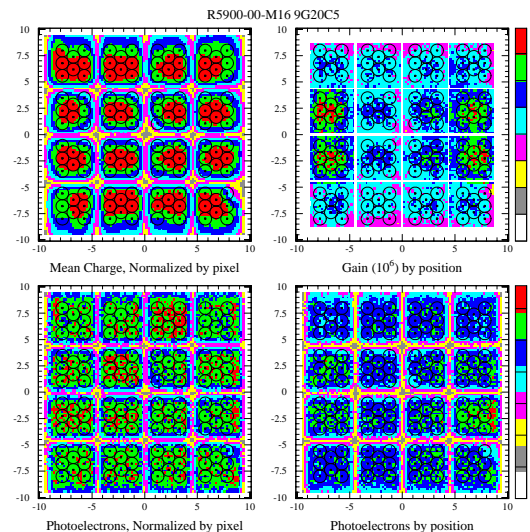
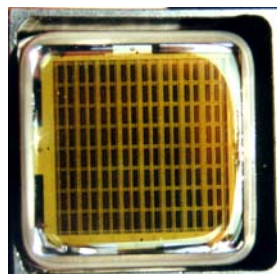
Detector technology



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MAIN FEATURES:

- **Extruded scintillator strips**
 - Far in 8 modules
- **Wavelength-shifting** + clear fibers
- **8m octagonal 1 in thick Fe plates**
 - Far in 8 pieces
- **Multi-anode PMT readout**
 - **M16** in Far
 - **M64** in Near
- **8-fold optical multiplexing** in Far
- **Front-ends**
 - **VA(IDE)** for M16
 - **QIE** for M64
- **Software trigger**

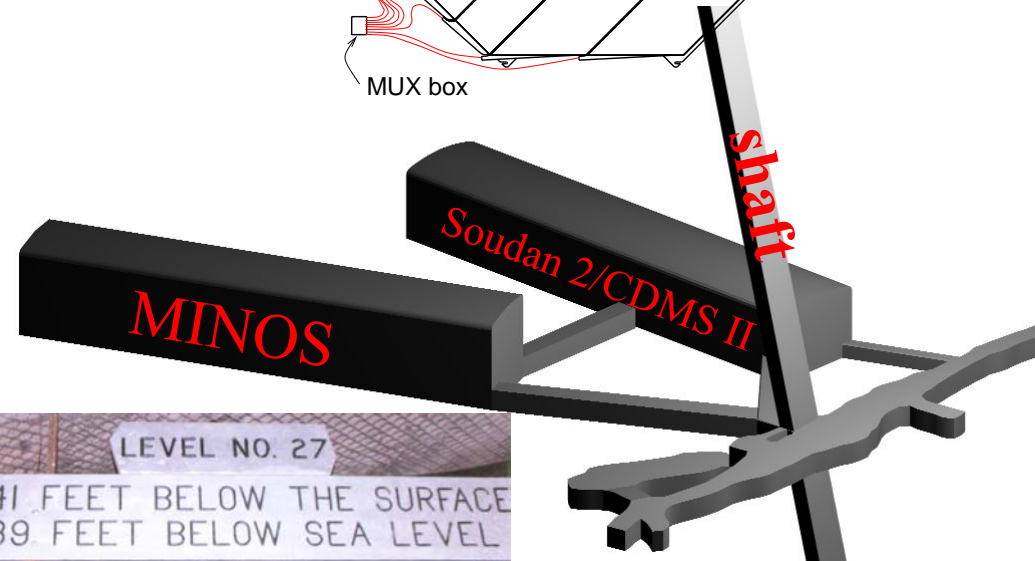
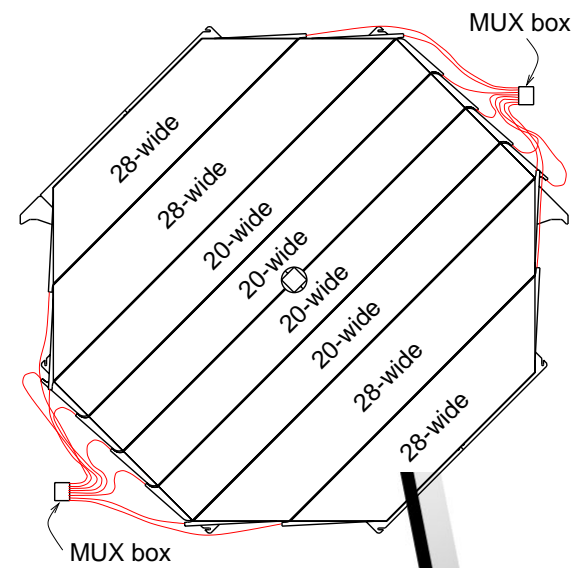
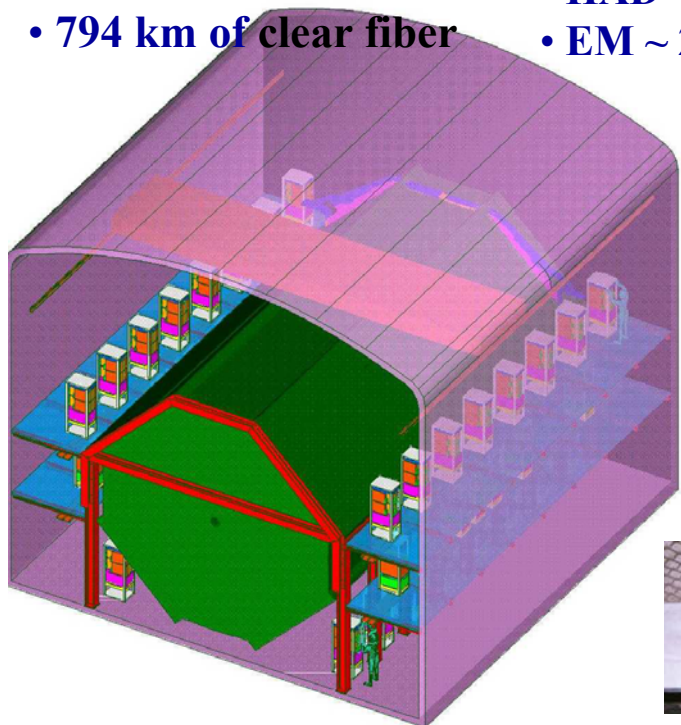




Far – 735.3 km away

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- 2 Supermodules
 - 5.4 kT
 - 484 scint. planes
 - 92,928 strips (4.1 x 1.0 cm)
 - 8-fold MUXed 2-ended readout
 - 1452 M16s
 - 722 km of WLS fiber
 - 794 km of clear fiber
- $B \sim 1.5T$ ($R=2m$)
 - $HAD \sim 55\%$ / $E^{1/2}$
 - $EM \sim 23\%$ / $E^{1/2}$





Plane assembly



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Steel Welded and modules placed.

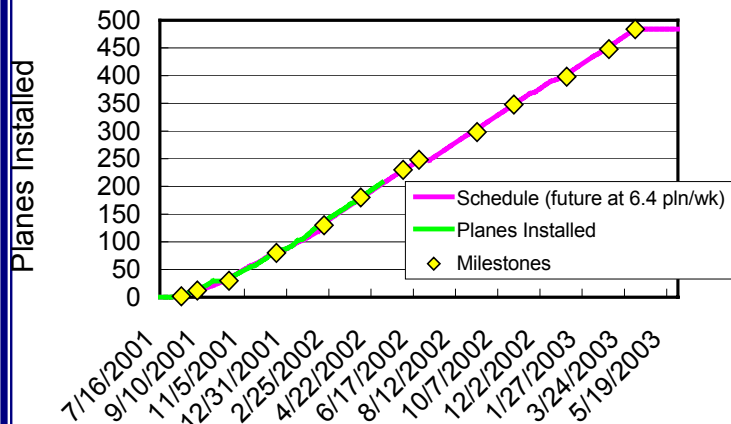


Plane lifted to vertical

Crane carries plane down the hall for installation



FarDet Installation by Week



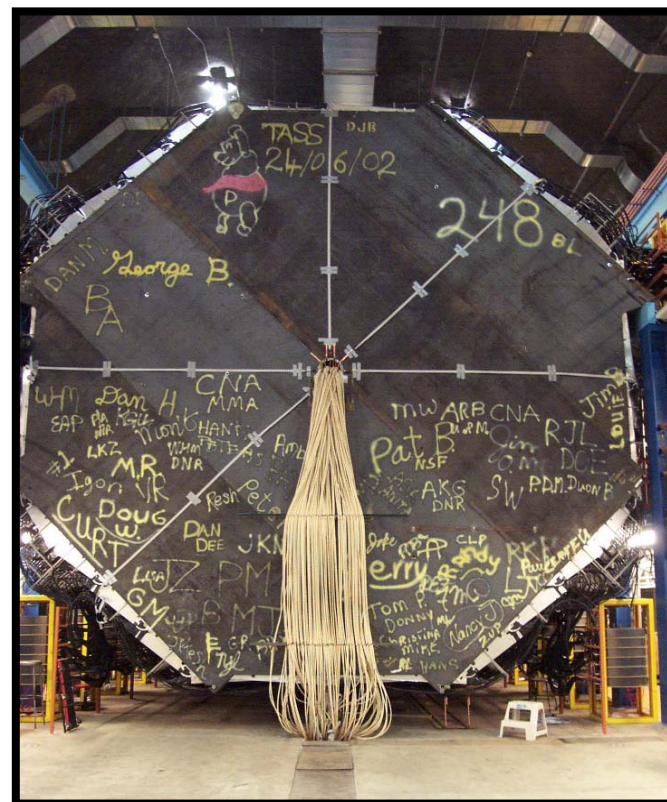
6-8 Planes per week



FarDet: Second Super-module underway



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Status as of October 2, 2002 (week #63):

- SM 1 completed (248 planes)
- SM 1 Bfield is on
- SM 2 25% completed
- 309/312 read out

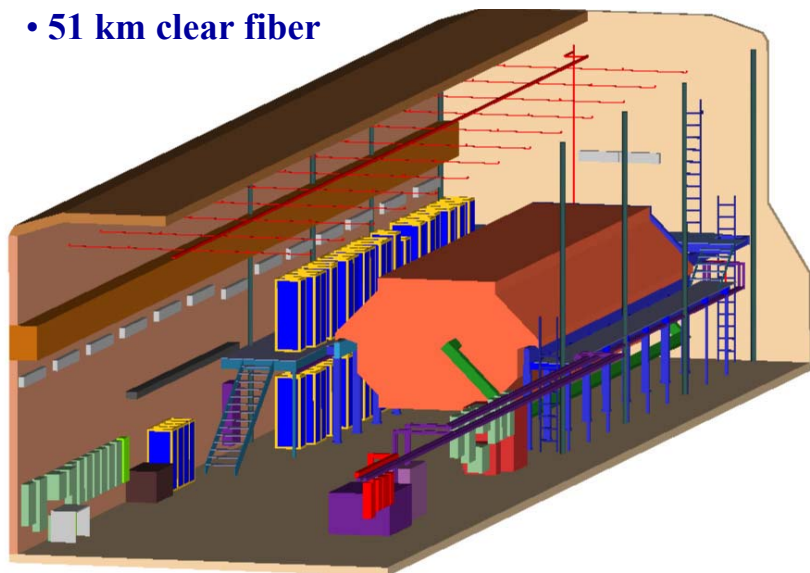




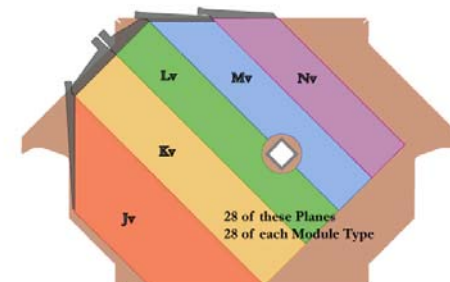
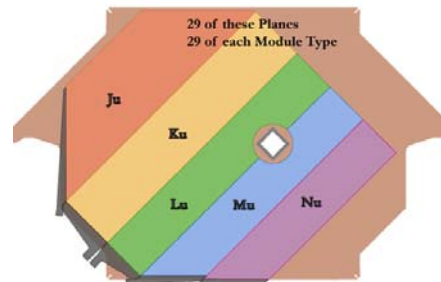
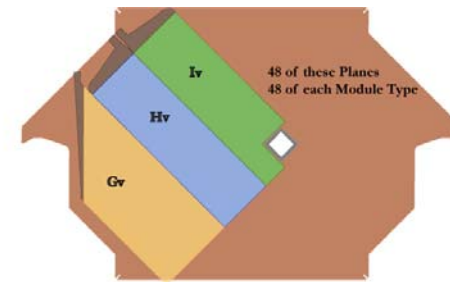
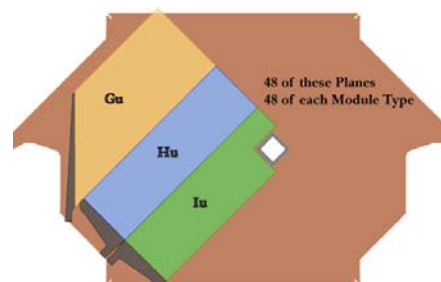
Near – 1040 m away

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- veto - target - shower - μ spectrometer
- 1 kT
- 3.8 x 4.8 “squeezed” octagon
- 12,300 scint.strips
- 1-end readout
- no-multiplexing
- 220 M64s
- QIE-based front-end
- 282 steel planes
- 153 scintillator planes
- 65 km WLS fiber
- 51 km clear fiber



ν target region



μ spectrometer region

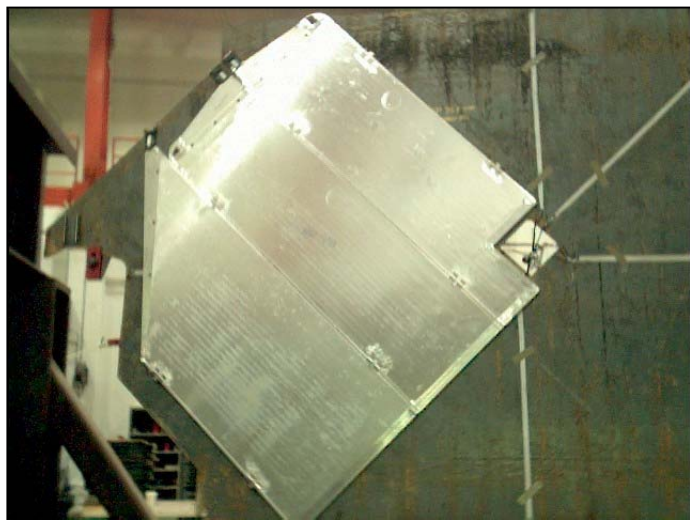
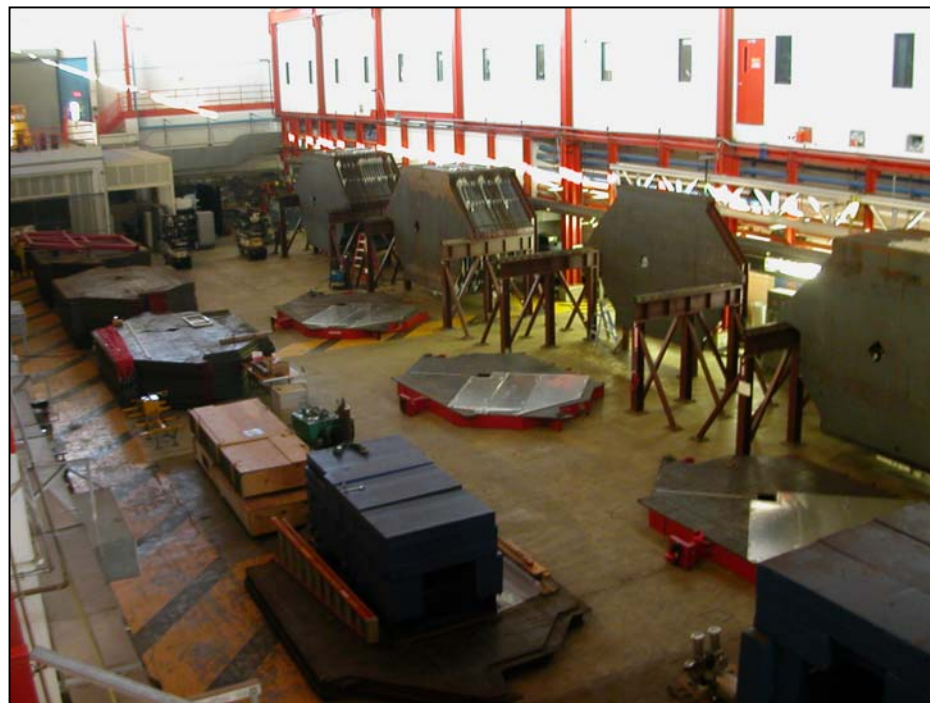
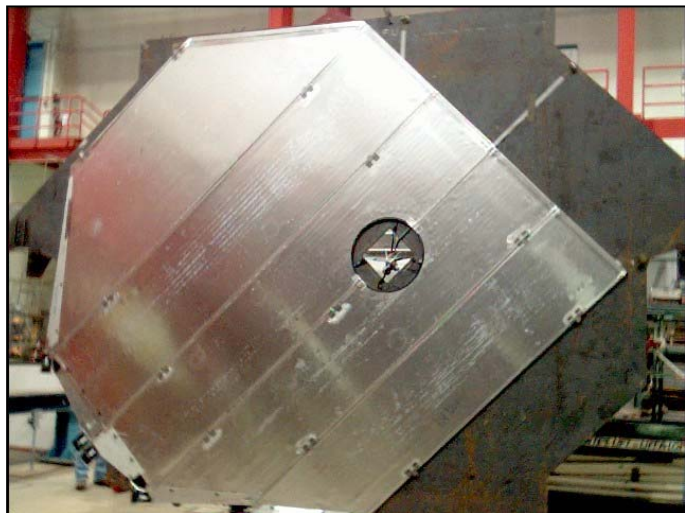
Near detector will provide high event statistics for “mundane” neutrino physics



NearDet construction



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Status as of October 2, 2002

- 70% (108/153) planes assembled and “shelved”
- Beneficial occupancy of the Near Hall in Dec’03
- Near detector will be ready 8 months later (Oct’04)



The **third** detector - CalDet



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- **MINOS calibration challenge:**

- Near/Far relative calibration to 2%
- absolute calibration of 5%

- **Main ingredients:**

- **cosmic ray muons**

- energy scale calibration
- strip-to-strip response
- muon energy unit (MEU)

- **light injection system**

- PMT gain drifts
- PMT/electronics linearity

- **calibration detector (CalDet)**

- define MEU
- topology and pattern recognition



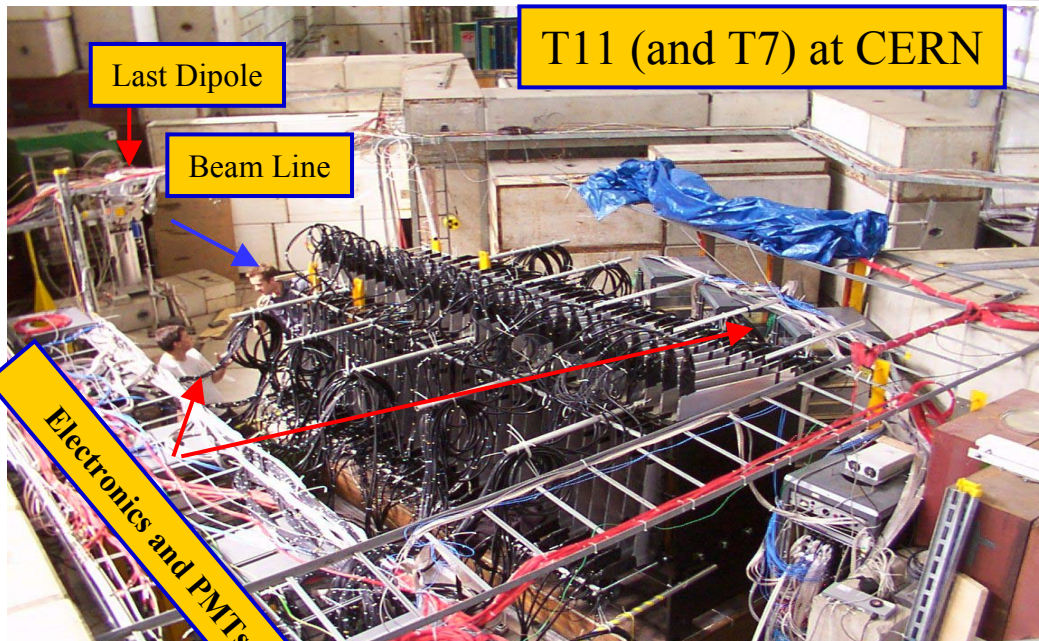
2 CalDet modules being staged in T7



CalDet – it's an experiment...



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- 5 tons
- 1 m x 1 m x 3.7 m
- 60 MINOS planes
- 5 modules (for moving)
- 24 strips/plane (a total of 1440 strips)
- Consecutive scintillator planes rotated 90°
- FarDet and/or NearDet readout
- Clear and green (to simulate size of far detector) ribbon cable transports light to PMTs
- **No B field**

- ~3,200 front-end channels
- **T11** (0.5-3.5 GeV/c) & **T7** (1-10 GeV/c)
- full MINOS calibration scheme
- “paved the road” for commissioning of FarDet
- data in 2001, 2002, 2003
- taking data now analysis



CalDet: light injection and muons

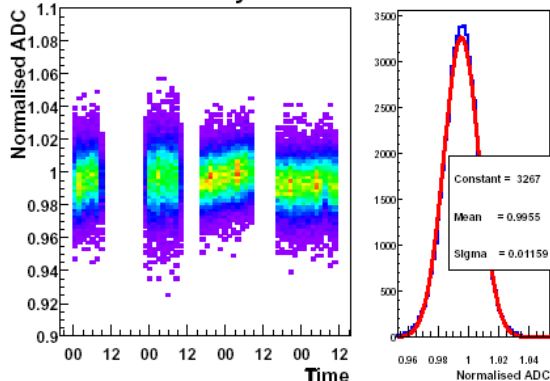


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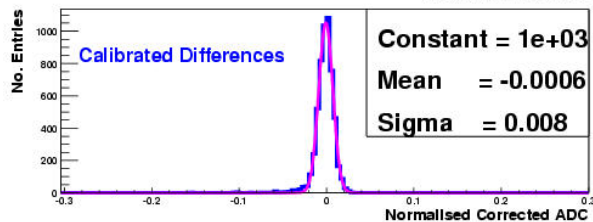
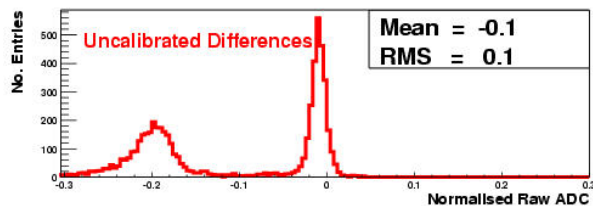
Light Injection

System stable to 2% over 4 days

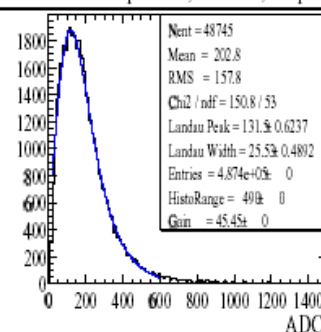
Gain drift over 4 days



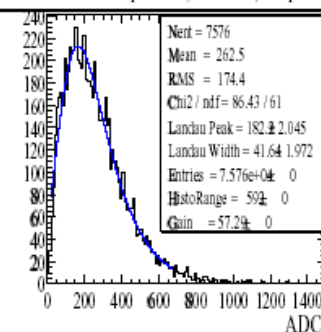
Calibration good to ~1%



CalDet Beam Spectrum; Plane 20, Strip 12

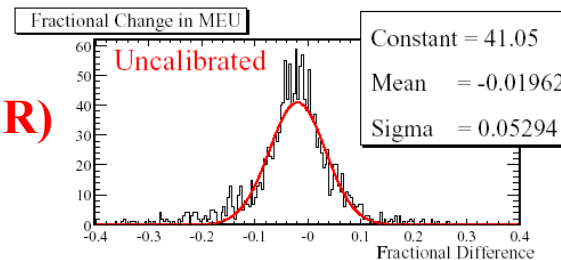


CalDet Cosmic Spectrum; Plane 20, Strip 12

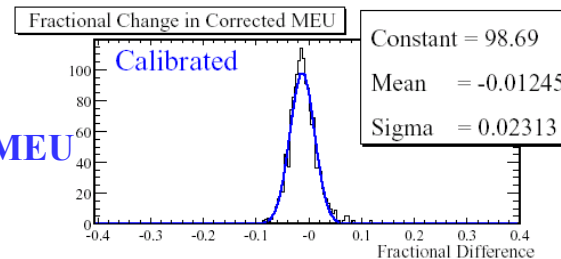


$$L \otimes P \approx N \sum_{\lambda,s} L(\lambda,s, \mu, \sigma) \cdot P(n, \lambda,s)$$

muons
(beam and CR)



Gain corrected MEU



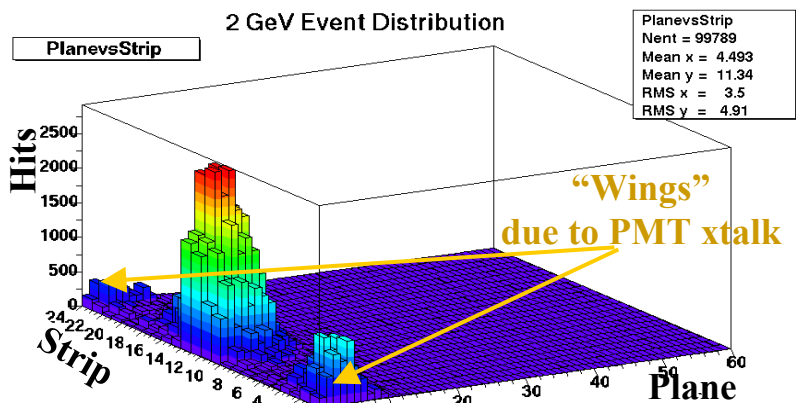


CalDet: electrons

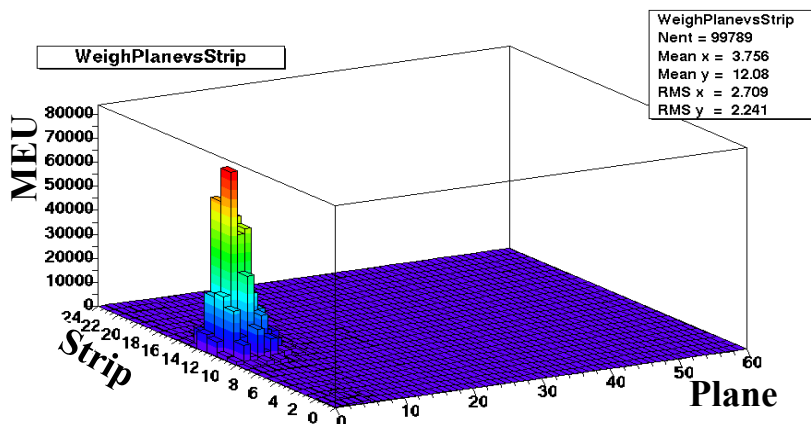


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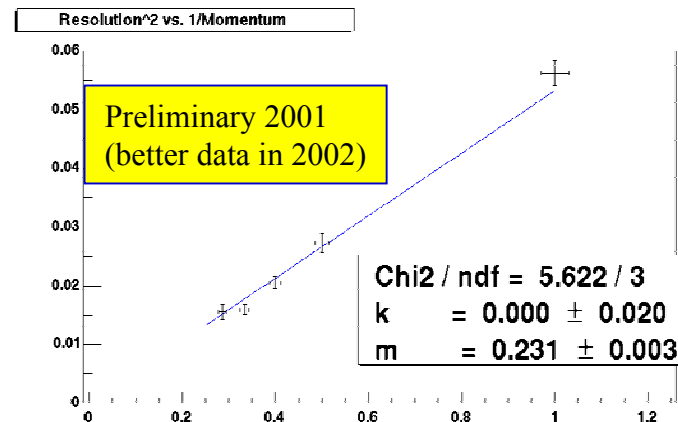
- MEU: Muon Energy Unit, mean pulse height due to a through-going muon measured in a strip end



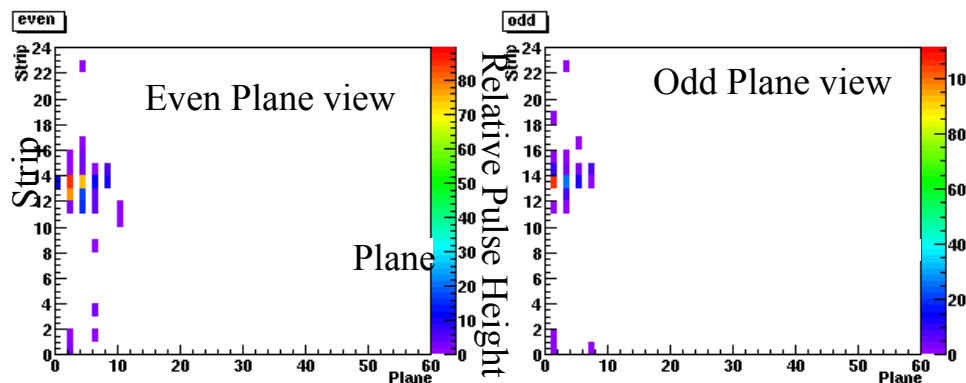
Strip vs. Plane profile, weighted by number of hits



Strip vs. Plane profile, weighted by MEU deposited



Sample Event (2GeV e⁺)



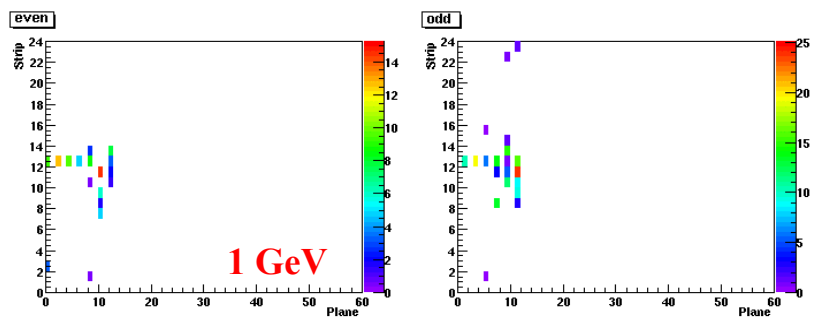
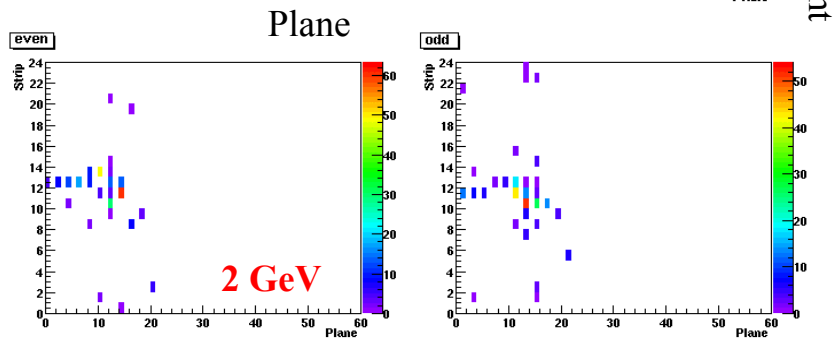
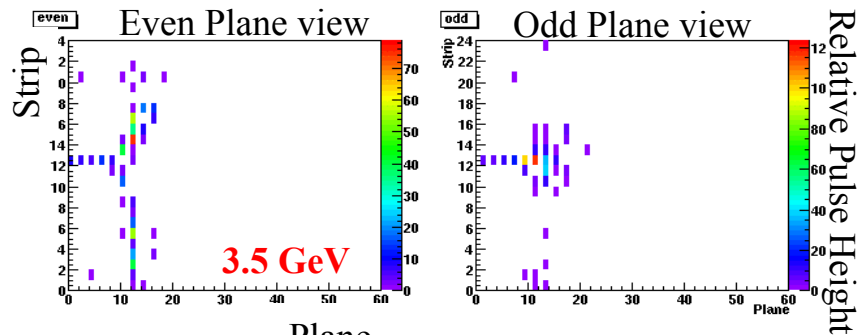


CalDet: pions and protons

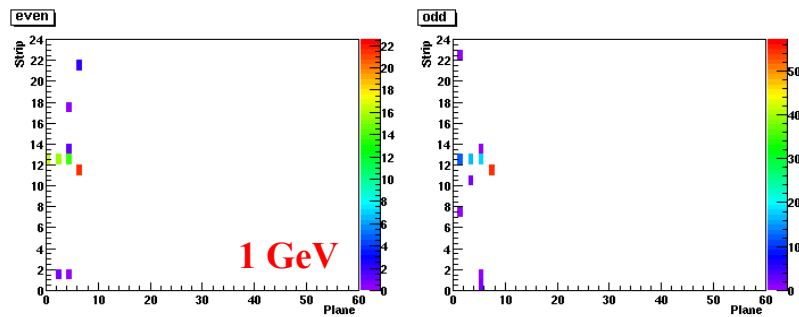
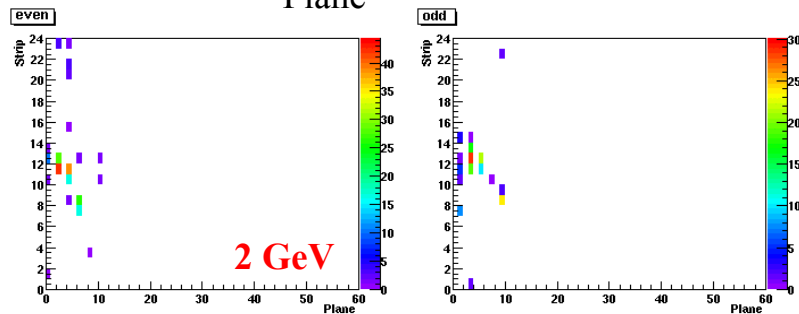
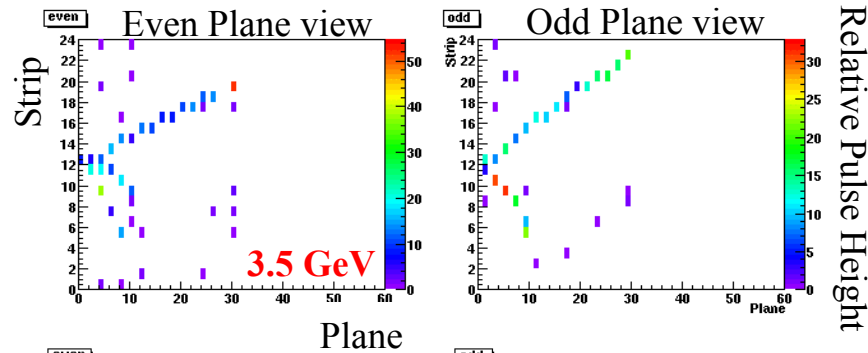


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Sample Pion Events



Sample Proton Events





Front-end electronics comparison: NearDet vs FarDet in CalDet



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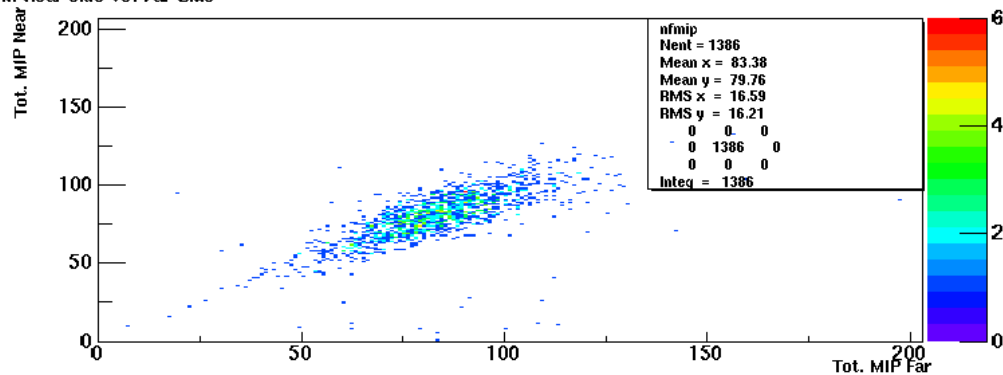
- In order to have NearDet and FarDet respond similarly they have to be ... different.

- This is due to scales of the detectors and event rates difference by $\sim 10^5$

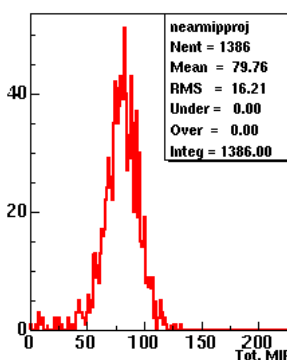
- VA + M16 (8x multiplexed)

- QIE + M64 (not multiplexed)

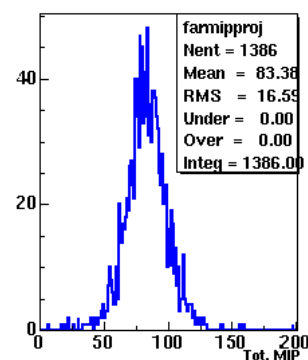
MIP in Near side vs. Far Side



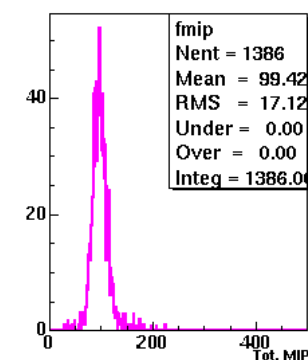
Total MIP Near



Total MIP Far



MIP in Far Side, whole detector



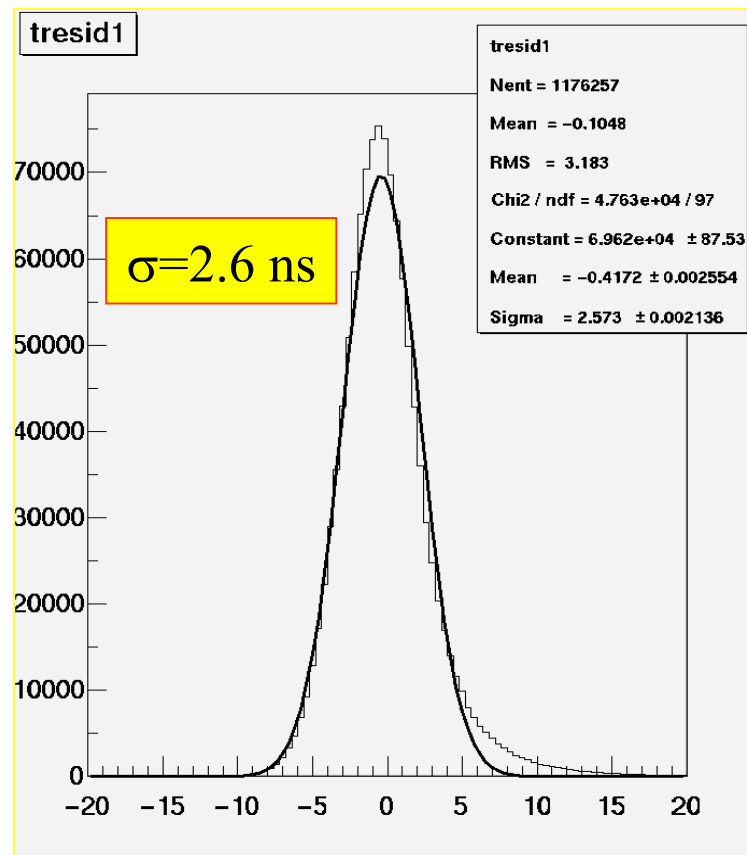


MINOS Observatory: Atmospheric Neutrinos and Muons



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- **B field makes MINOS a unique underground observatory**
 - measure **charge** and **momentum** of muons from ~ 0.5 -70 GeV/c.
 - distinguish neutrinos from anti-neutrinos (for $p_\mu > \sim 1$ GeV/c)
 - measure E_ν (even w/ exiting muon):
→ determines **L/E**
- Use **timing** and **topology** for event direction
- MINOS will **directly** compare atmospheric ν_μ and $\bar{\nu}_\mu$ oscillations
- Measure contained events and upward going muons
- Start data-taking before NuMI beam
- Opportunities for young researchers



Number of events in 24 kT years	Neutrino	Antineutrino
Reconstructed contained vertex with muon	620	400
Reconstructed upgoing muon	280	120



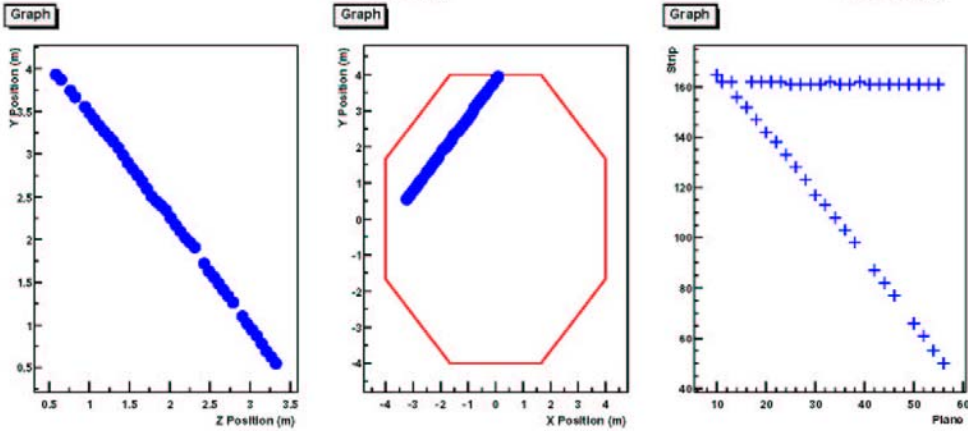
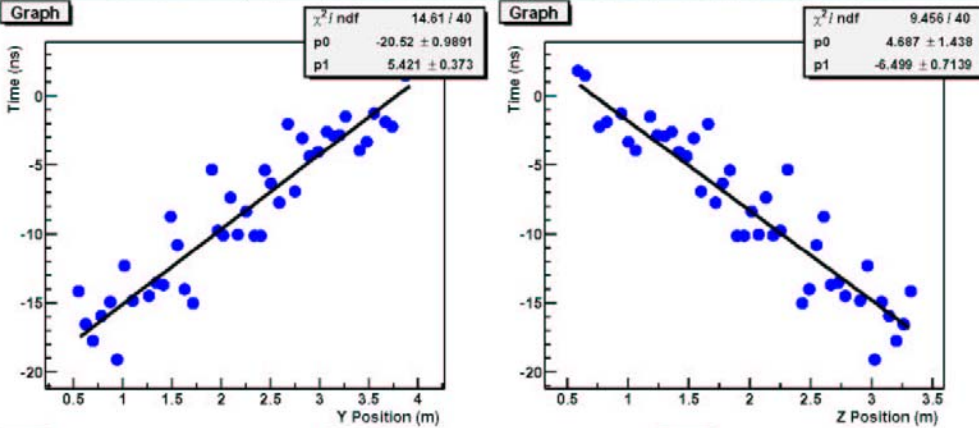
MINOS Observatory: CR muons



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Run 4436, Snarl 424.

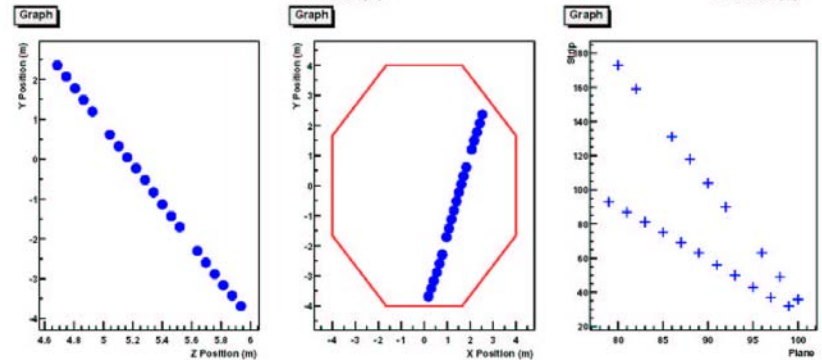
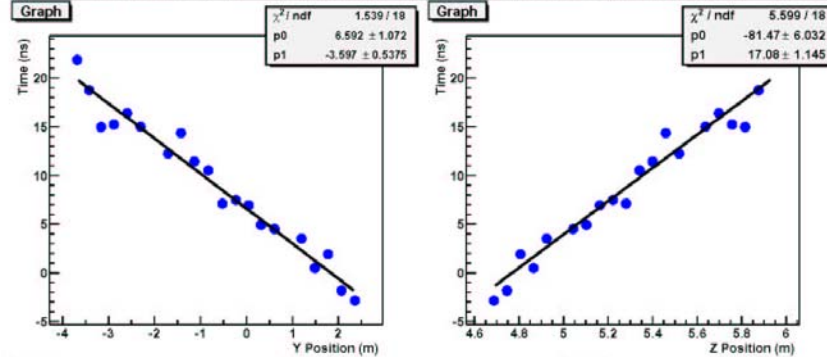
$\beta^{-1} = -1.072889$, $\phi = 140.578065$, $\chi^2 = 0.001683$, Planes Hit = 47



Upward candidate

Run 4436, Snarl 89.

$\beta^{-1} = 1.000265$, $\phi = 152.045888$, $\chi^2 = 0.346579$, Planes Hit = 23

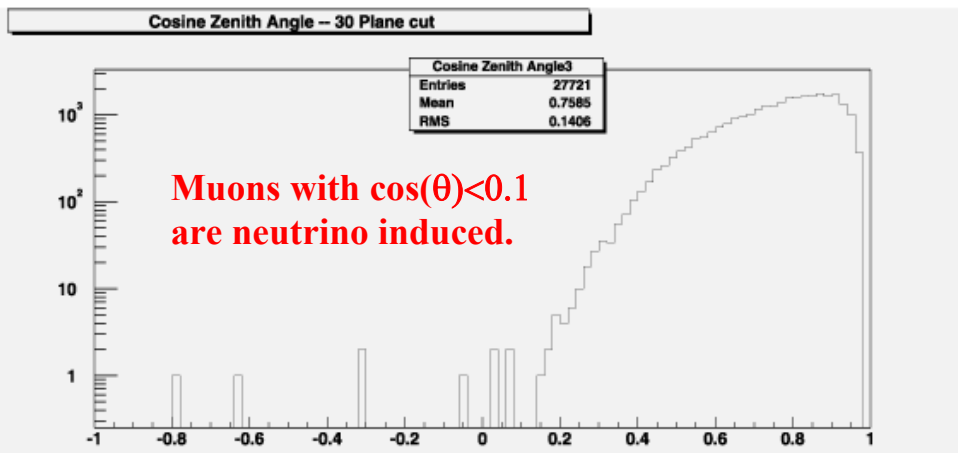
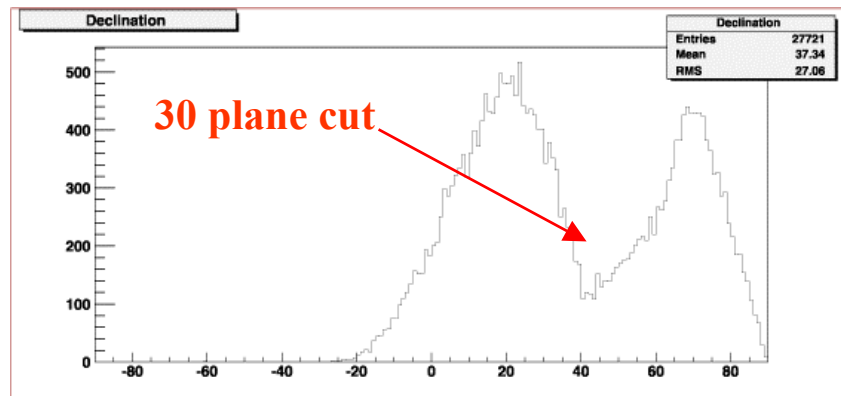
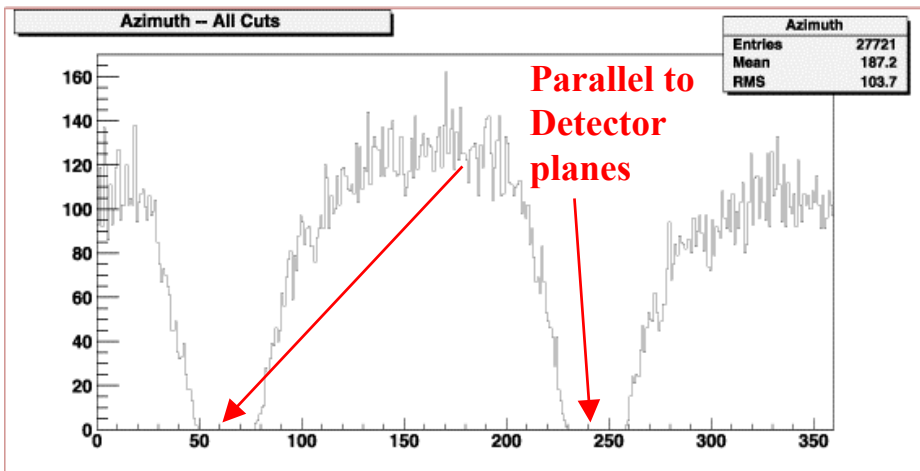


Downward candidate

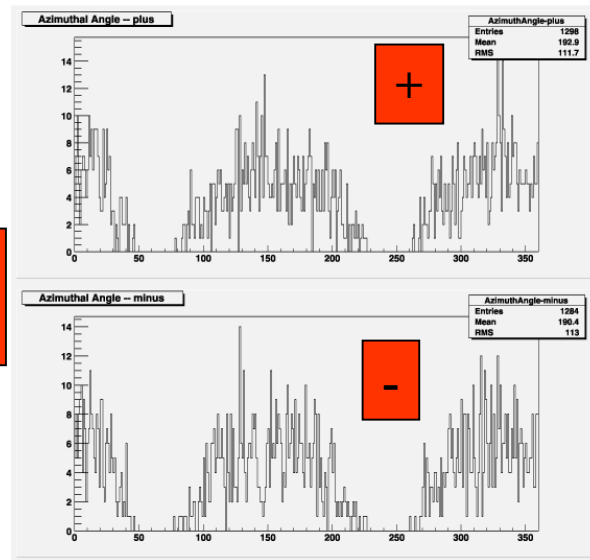


FarDet CR Muons

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Charge Selection!





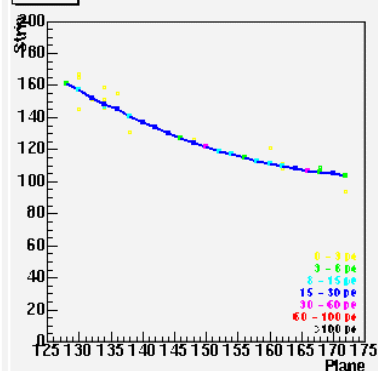
MINOS Observatory News: bending muons!



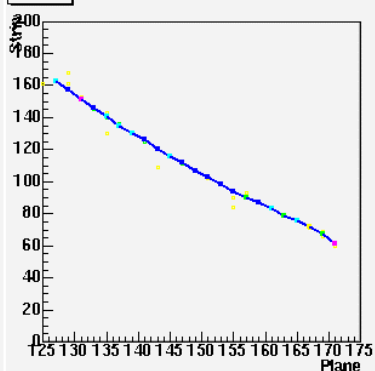
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Bending Muon in BField
Run 6645, Snarl 2400

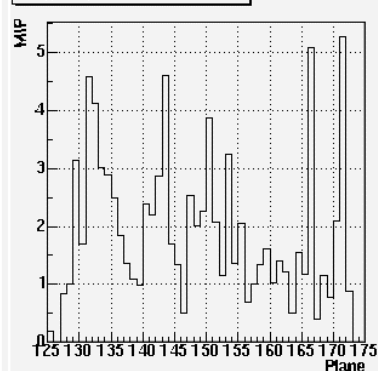
u-view



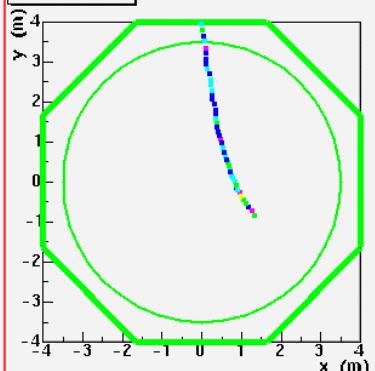
v-view



Energy Weighted Plane Distribution



Face On View



Stopping muon

$$P_{\text{range}} = 3.86 \text{ GeV}/c$$

$$P_{\text{curvature}} = 4.03 \text{ GeV}/c$$



MINOS Observatory News: Upward muon candidate



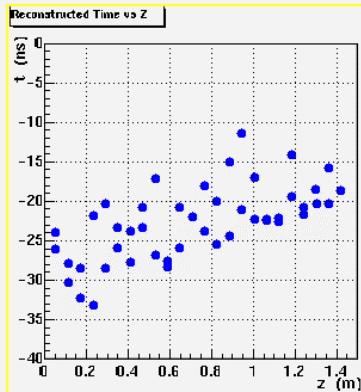
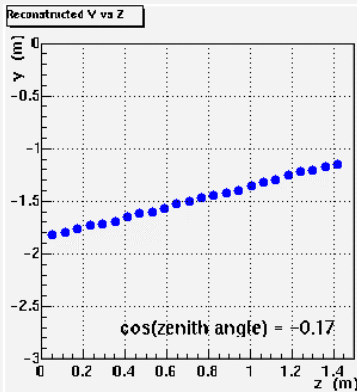
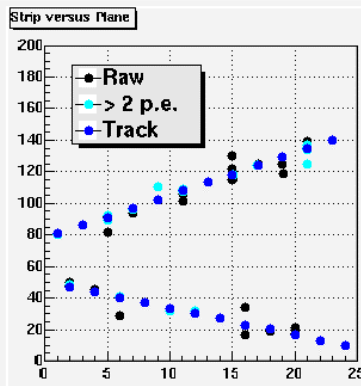
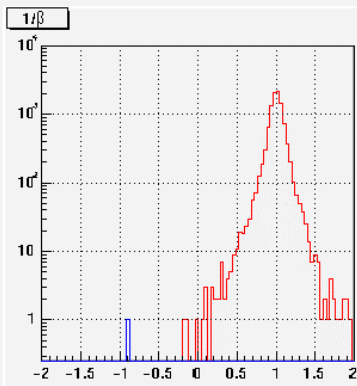
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Run 3281, Snarl 2621

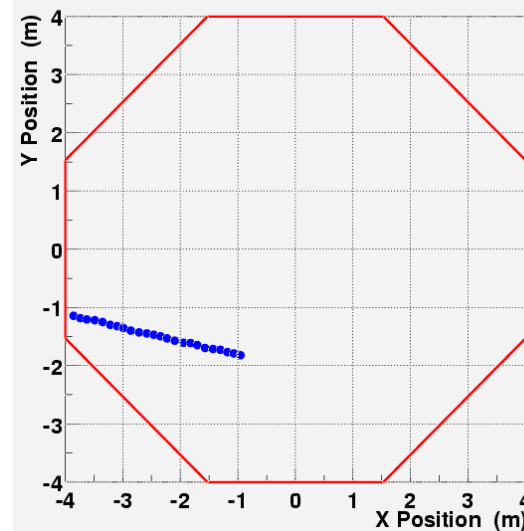
First Observed Upward Going Muon in MINOS

128 Planes, 3.5 days data

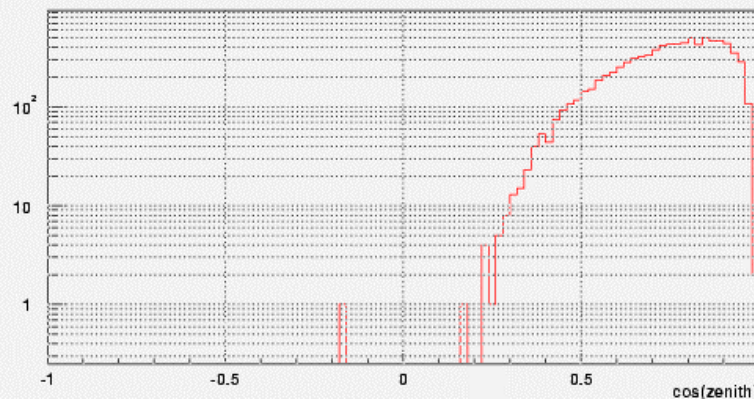
Number of Track Planes > 20, Hough $\chi^2 < 100$, Good Vertex and Exit Positions



Y vs X Position



cos(zenith) Distribution, |1/b|>0.5

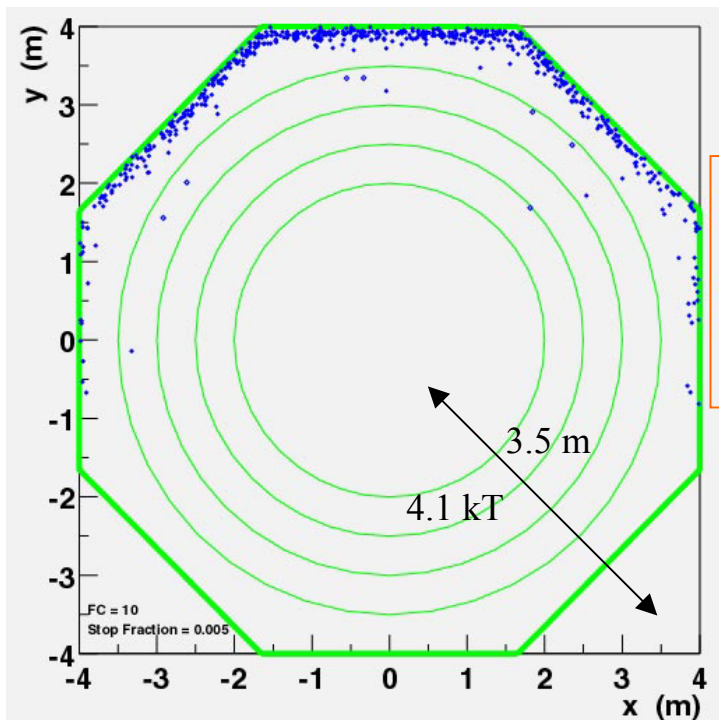




MINOS Observatory Challenge: Finding a ν -dile in a stack of steel...

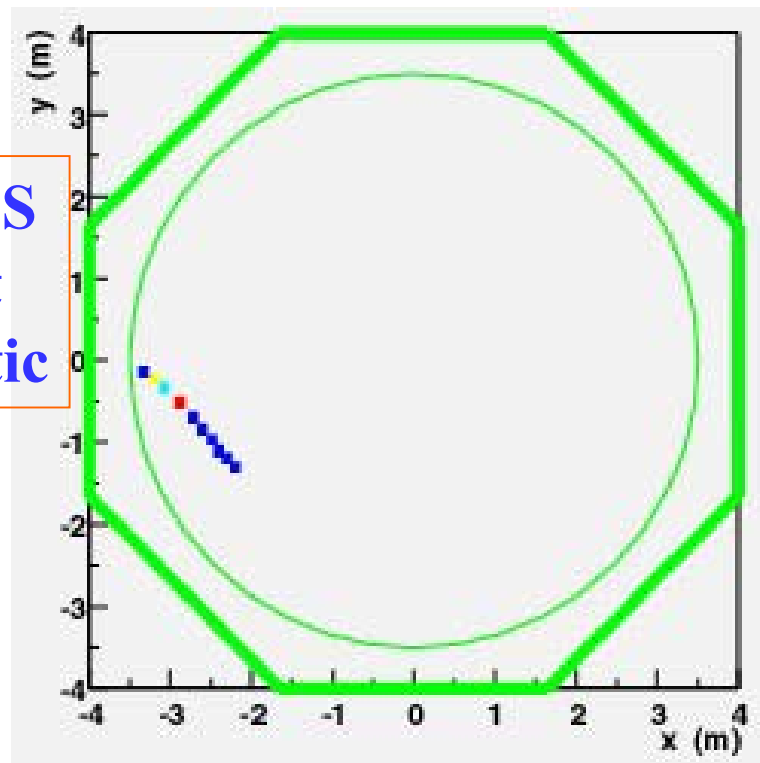


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MINOS
is not
hermetic

Reconstructed “vertices” for cosmic ray events which have a track that ends inside the detector. Most are clearly downgoing stopping muons. A few mis-reconstruct for known reasons (hardware and software commissioning) which will be fixed soon.



Example of one downgoing stopping muon which appears to have a vertex just inside the nominal fiducial volume of the detector. This was due to tracking software which is not yet completely commissioned.

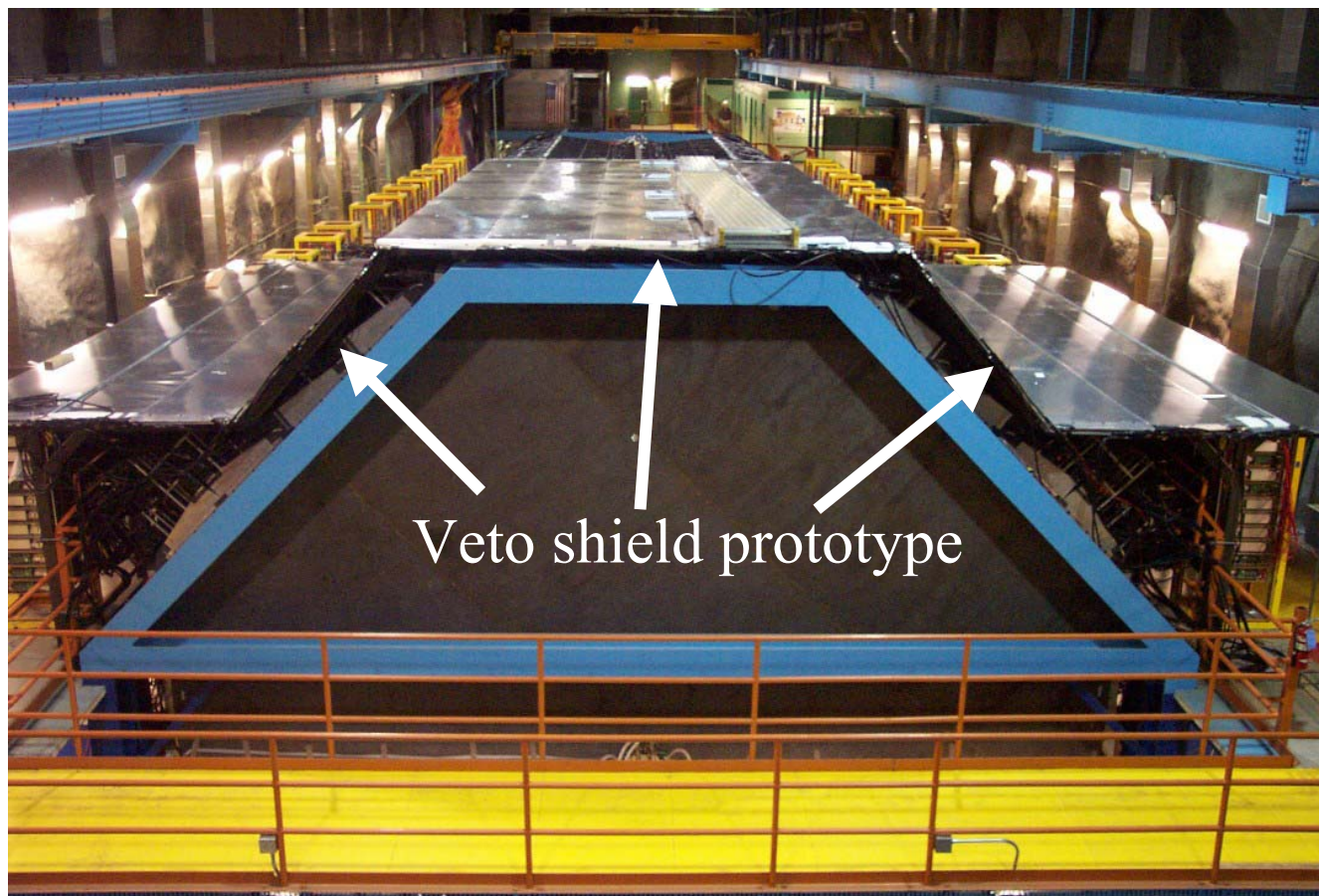


MINOS Observatory: Muon veto shield



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Conclusion: need a veto shield





MINOS Observatory News: Contained event candidate



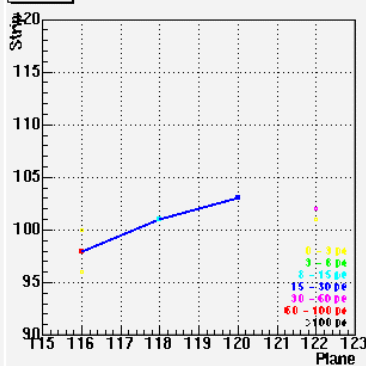
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Run 7465, Snarl 412

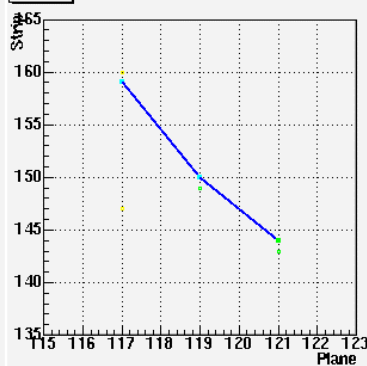
Vertex: $(x,y,z) = (-1.9, 2.1, 6.9)$

$\cos(\text{zenith}) = 0.42$, $d\cos z = 0.34$

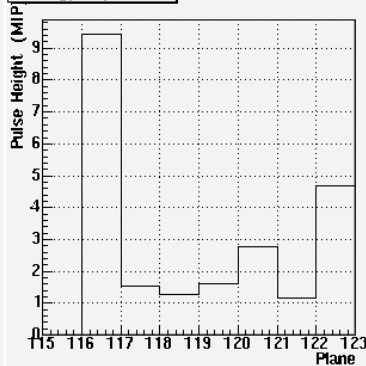
u-view



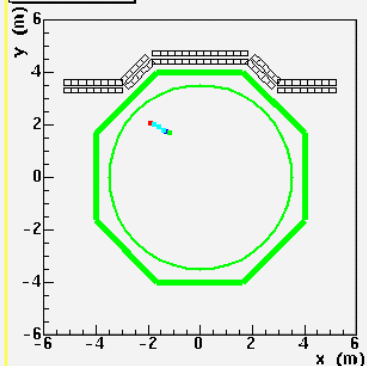
v-view



Energy Deposition



Face On View





Summary



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- **MINOS and NuMI construction progressing very well**
 - FarDet: 65%**
 - NearDet: 70% (but not underground)**
 - CalDet: taking data / analysis underway**
- **MINOS observatory in operation**
 - SM 1 B field is on**
 - Collect CR data**
 - calibration, commissioning**
 - physics**
- **Full FarDet complete in June 2003**
- **NearDet well underway**

- **Will be well prepared for the beam in Dec'04**





How to assemble a MINOS sandwich in 100 seconds



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