Status of the MINOS Experiment

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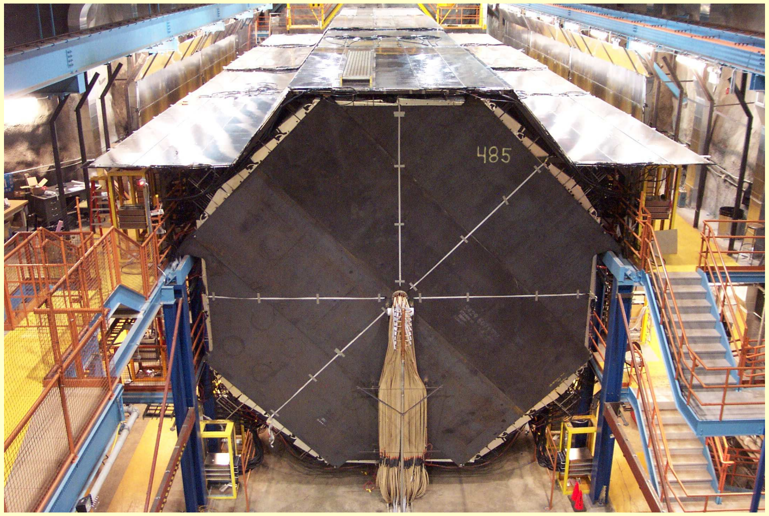
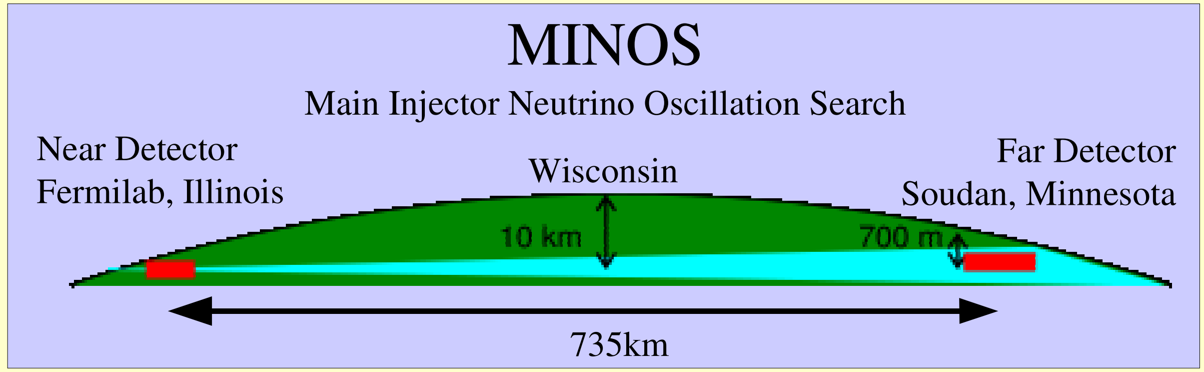
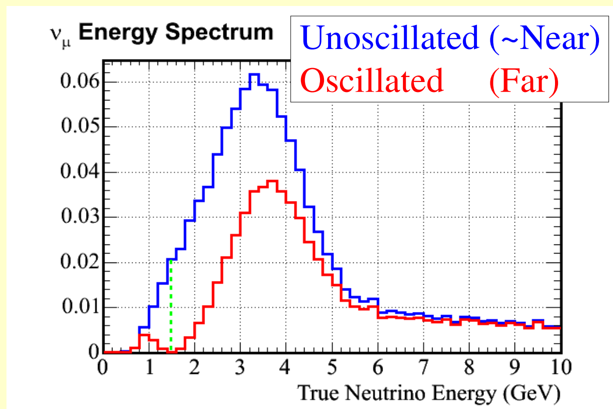
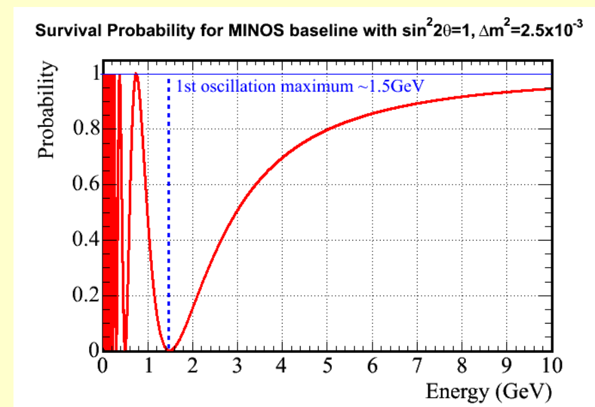


Introduction

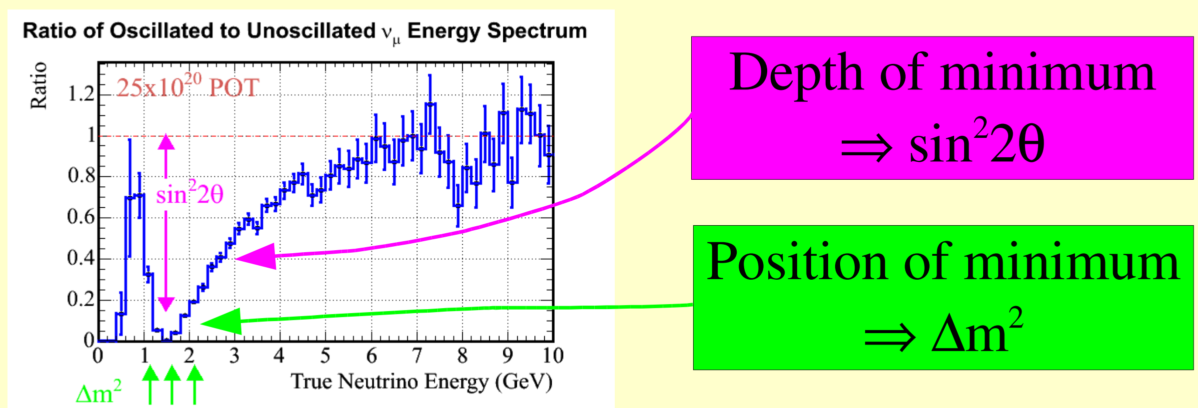
- MINOS is a long baseline neutrino oscillation experiment
- Measure ratio of neutrino energy spectrum in Far detector to that in Near detector
- Partial cancellation of systematic errors







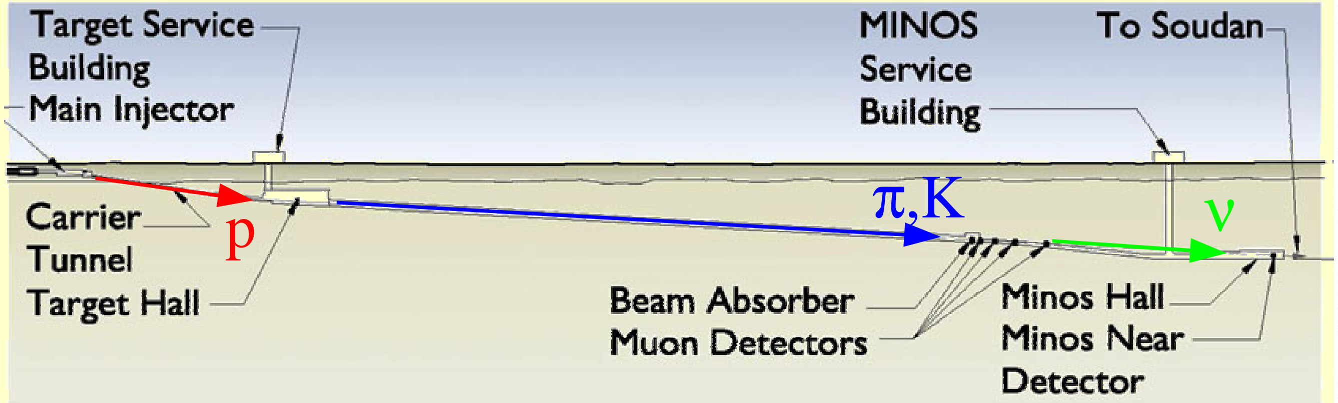
$$P(\nu_\mu \to \nu_\tau) \approx \sin^2 2\theta_{23} \sin^2(1.27 \Delta m_{23}^2 \, L/E)$$



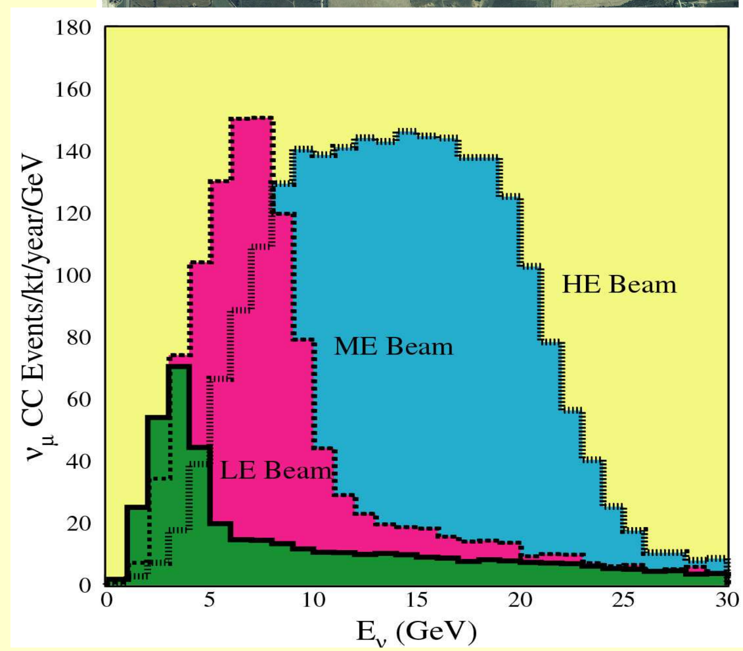
Physics Goals

- Measure ν_μ disappearance probability as a function of E_ν
  - Confirm flavour oscillations describe data
  - Discriminate against other models
    - Decoherence, ν decay, extra dimensions
- Measure oscillation parameters Δm_{23}^2, $\sin^2 2\theta_{23}$
  - Global 3 neutrino mixing fits give 3σ limits on Δm^2 at $\sin^2 2\theta=1$:
    - $1.4 - 3.3\text{x}10^{-3}\,\text{eV}^2$ with best fit $2.3\text{x}10^{-3}\,\text{eV}^2$ (J. Valle, NuFact04)
  - MINOS limits with $7.4\text{x}10^{20}$ POT at best fit: factor of ~3 smaller
- Search for sub-dominant $\nu_\mu \rightarrow \nu_e$ oscillations
  - Sensitivity is factor 2-3 better than previous experiments
  - Possibility of first indication of non-zero θ_{13}
- First measurements of ν vs $\bar{\nu}$ oscillations
  - MINOS detectors are magnetized
    - Far detector can distinguish $\mu^\pm$ in atmospheric neutrino interactions

NuMI Beamline



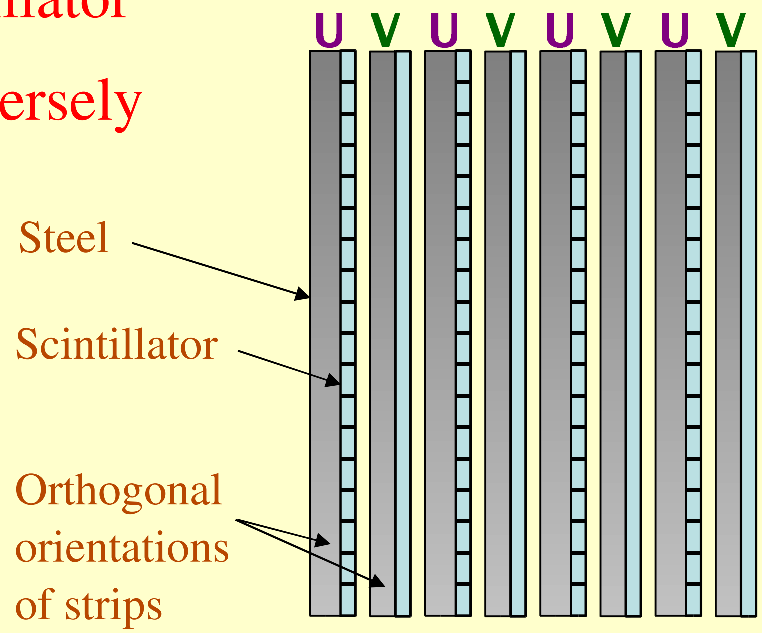
- 120 GeV protons from Main Injector incident on carbon target
  - 8.7µs extraction every MI cycle (1.9s)
  - Design: 4.0×10^{13} protons/pulse => 0.4MW
  - Initial Intensity: 2.5×10^{20} protons/year
- Secondaries from target focused by two parabolic magnetic horns
  - Relative positions of horns and target can be varied to tune beam energy
- π, K decay in 675m pipe (evacuated to 1 Torr) to produce a high purity ν_μ beam

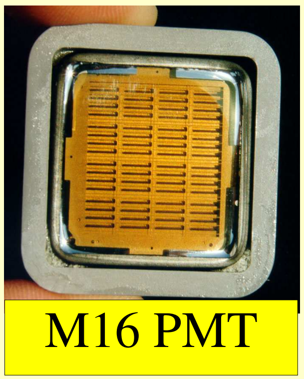


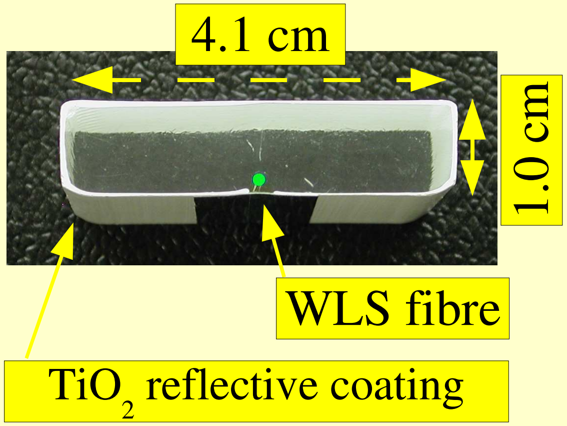
MINOS will start with LE beam for best sensitivity to $\Delta m^2 \sim 2.5 \times 10^{-3}$

MINOS Detectors

- Detectors are steel-scintillator sampling calorimeters
  - Each plane is 2.54cm steel + 1cm scintillator
  - Scintillator layers are segmented transversely into 4.1cm wide strips
  - Alternate planes have orthogonal strip orientations (U and V)
  - Energy resolution (E in GeV):
    - 55%/√E for hadrons
    - 23%/√E for electrons
- Scintillation light collected by wavelength shifting (WLS) fibres glued into groove
- Signals readout by Hamamatsu M16, M64 multi-pixel PMTs





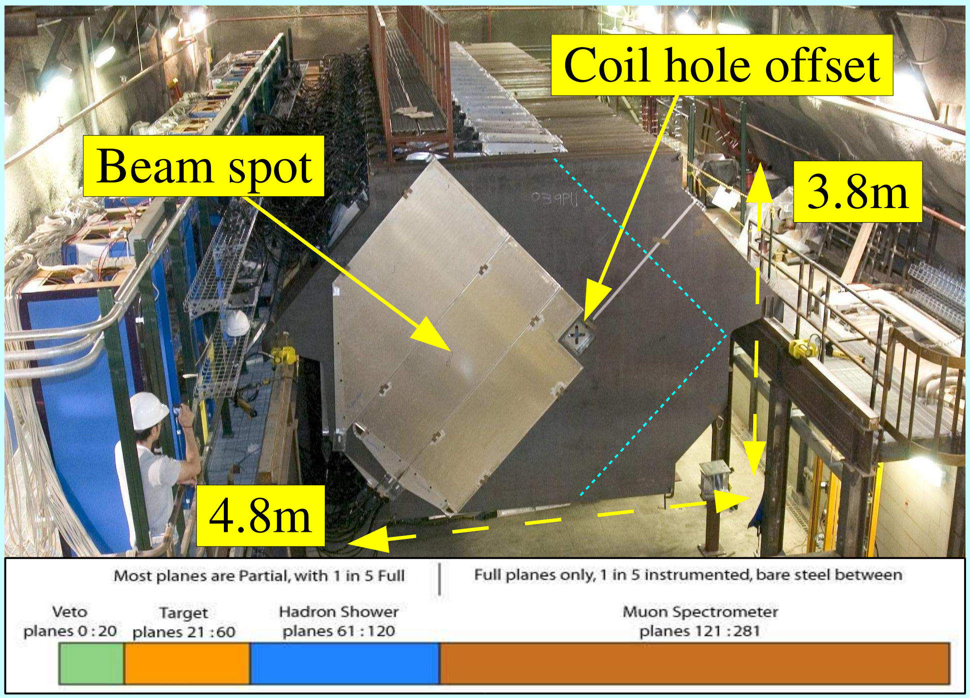


“NearDet & FarDet”

Detectors have same basic design: steel, scintillator, ~1.5T B field in steel

However some differences due to differing event rates and beam size

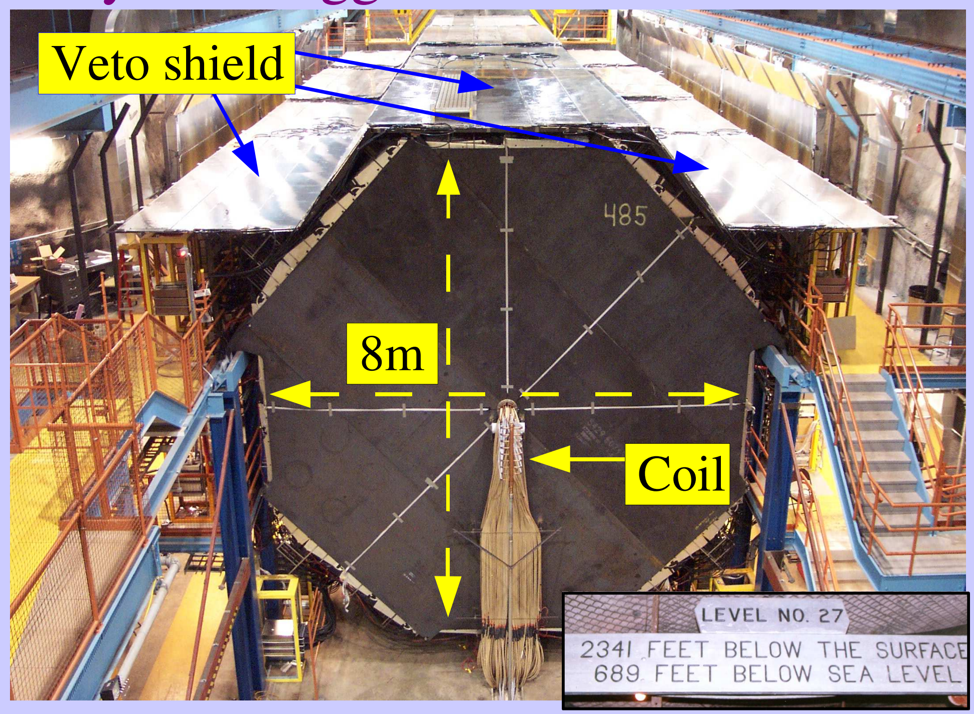
- Located ~1km downstream of target
- 1 kT, 4 sections, 282 planes
- Only partially instrumented
- Fast “deadtime-less” QIE electronics



NearDet installation finished Aug '04

– **Commisioning planes with CR μ**

- 735km away in Soudan mine, MN
- 5.4 kT, 2 supermodules, 485 planes
- Veto shield (scintillator modules)
- Dynode triggered VA electronics

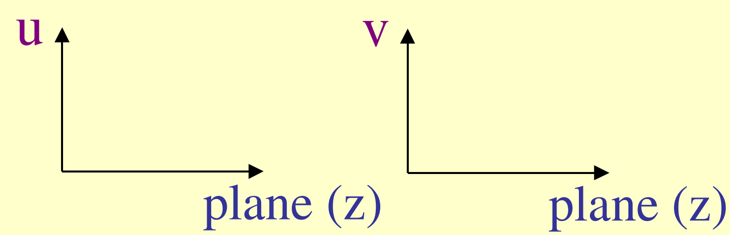


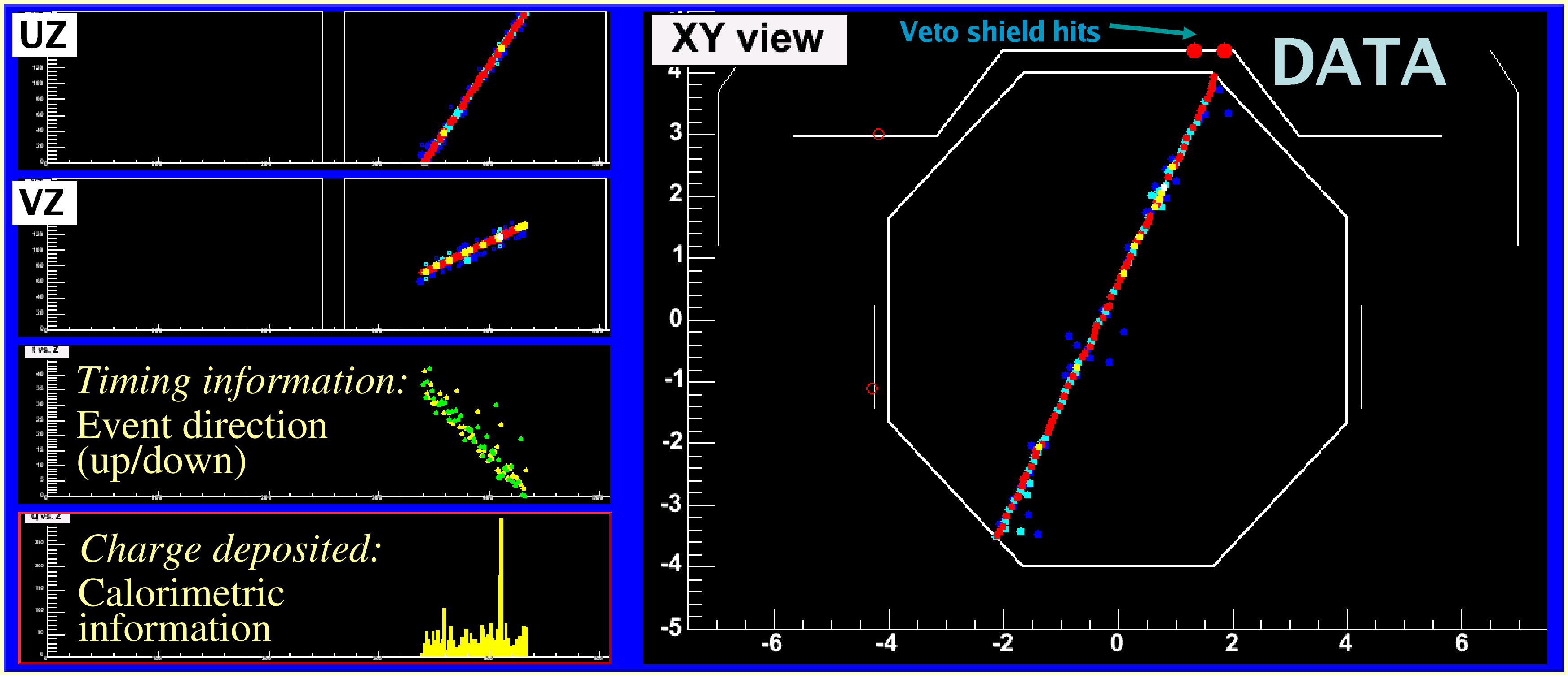
FarDet contruction finished Jul '03

– **Taking CR μ and atmos ν data**

Events in the MINOS Detectors

- Example cosmic ray muon from FarDet
  - Detector gives two views of event
    - Use software to reconstruct 3D event





- As well as calorimetric information, can also determine muon momentum from curvature or range (for stopping muons)
  - Gives resolution ~15% from curvature, ~6% from range

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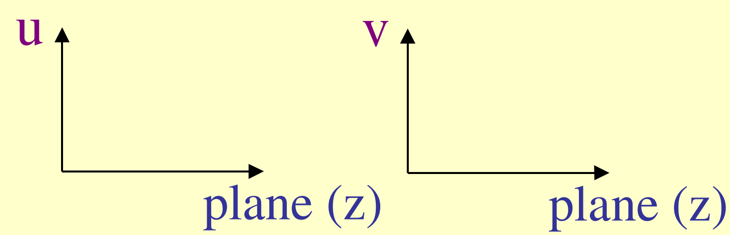

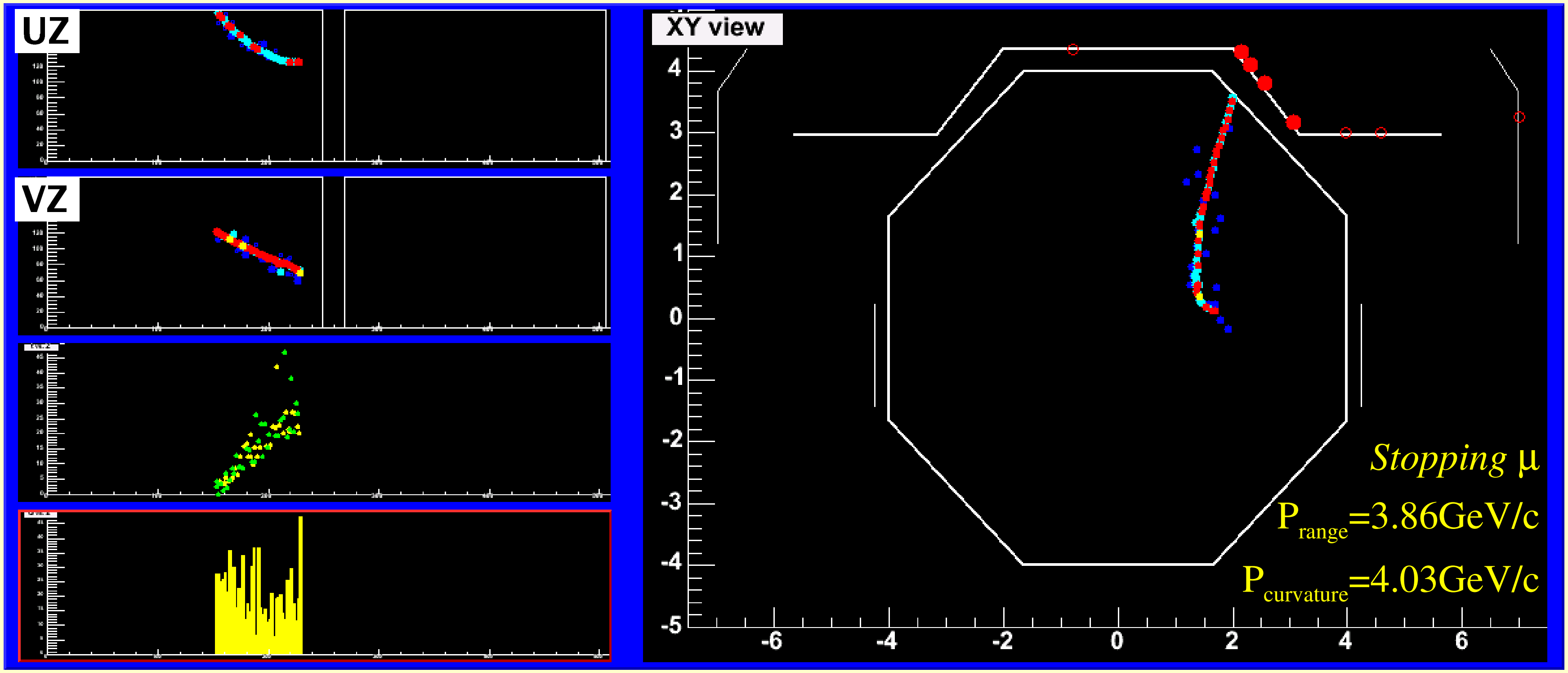

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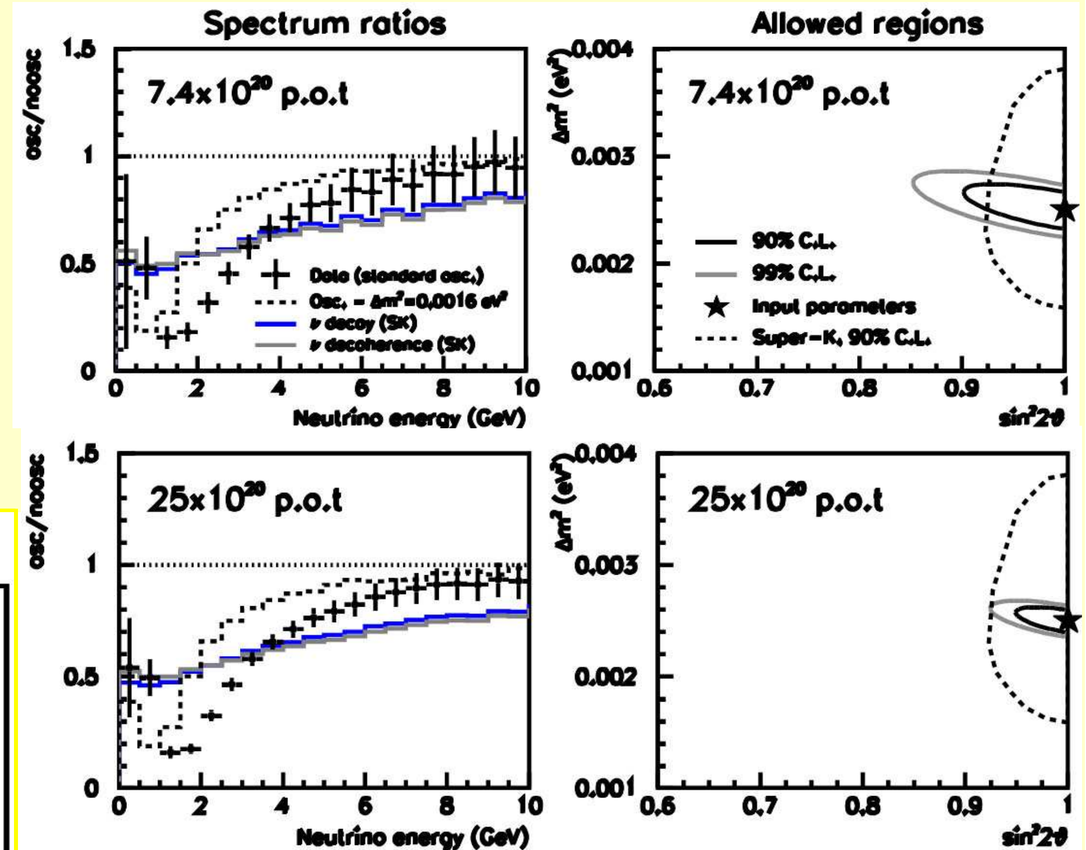
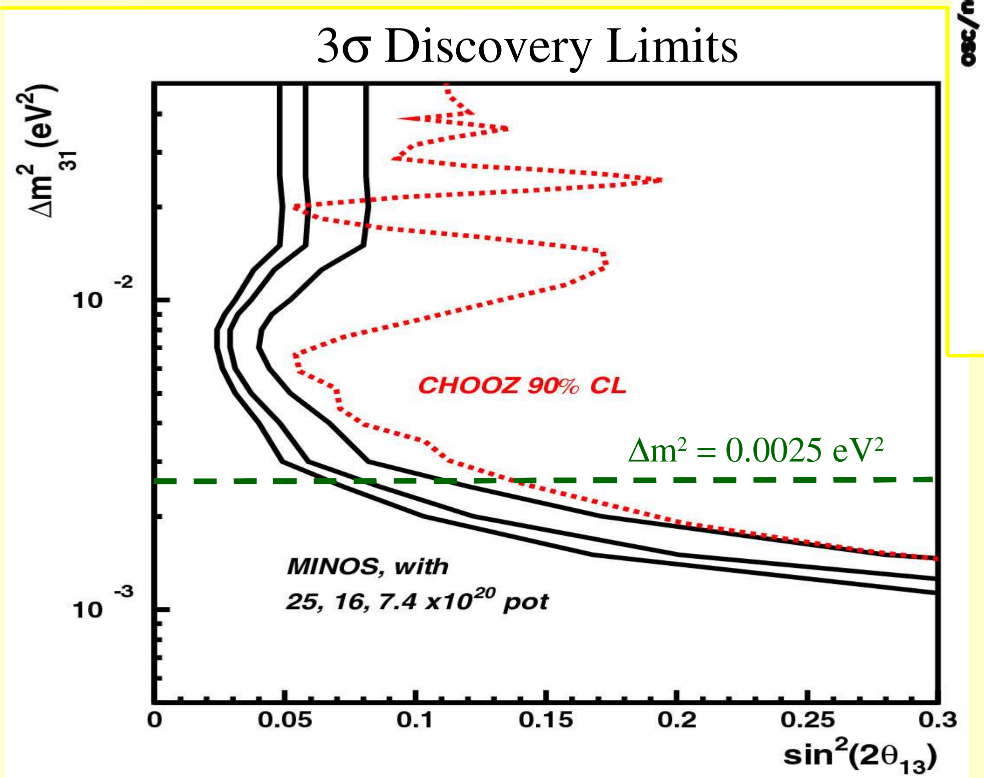
MINOS Physics Reach

- ν_μ disappearance signal
  $\Delta m^2 = 2.5\times10^{-3} eV^2$, $\sin^2 2\theta = 1.0$ shown
- Large improvement in precision
- Ultimate sensitivity depends on protons on target (pot)

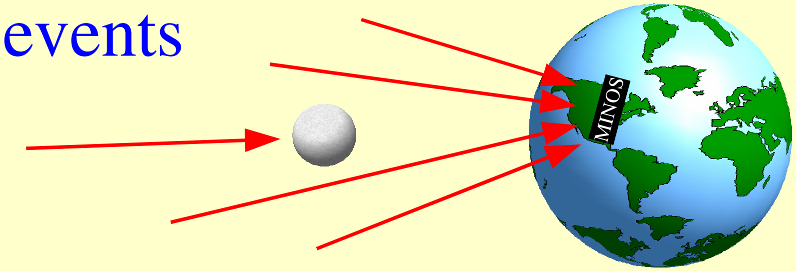




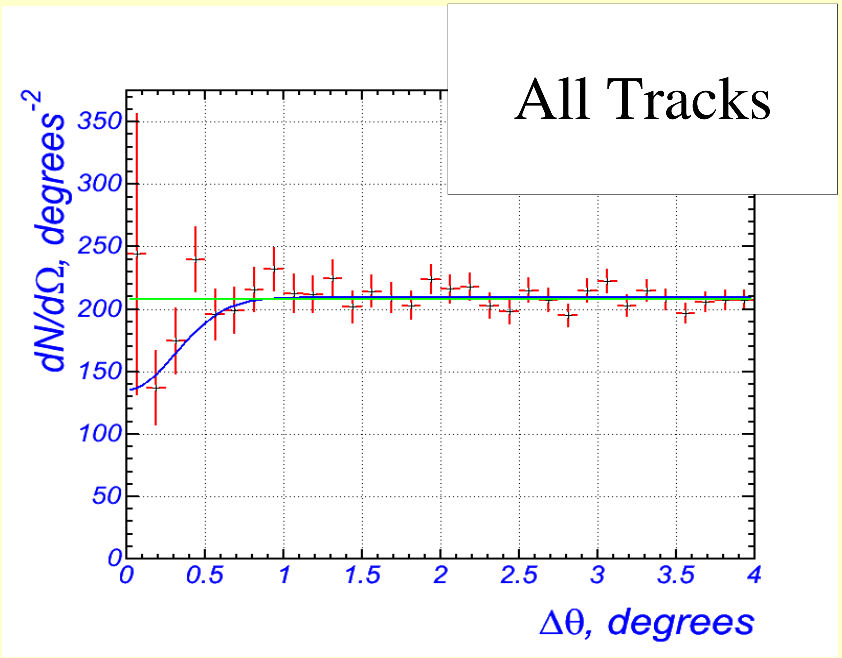
- Possibility of ν_e appearance signal
  - Would give first indication of θ_{13}
- Reach depends on pot!
  - At $0.0025 eV^2$ with 16×10^{20} p.o.t. reasonable chance of signal?

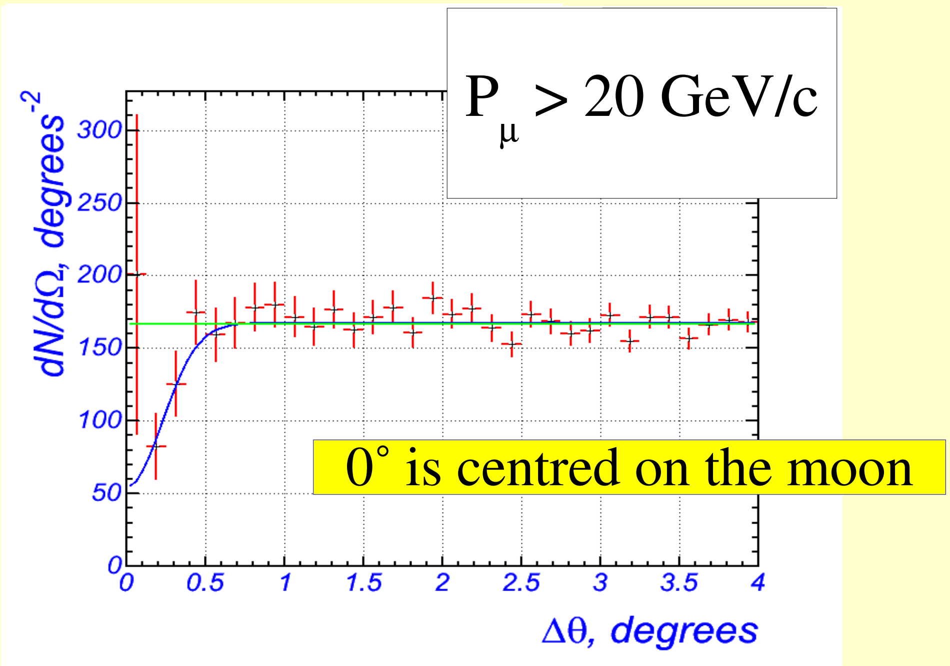
First Results: Moon Shadow

- MINOS has been taking cosmic ray muon data for more than a year and has recorded $>10^6$ events
- These can be used to observe the shadow of the moon



  - Angular resolution is improved by selecting high momenta muons
    - less multiple scattering

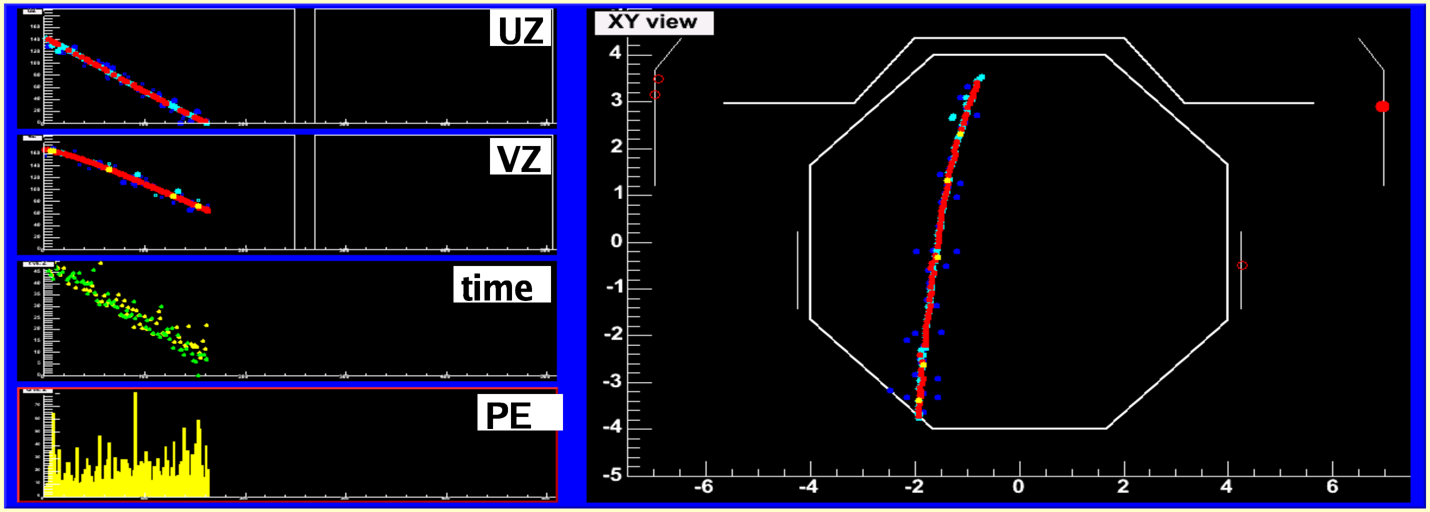




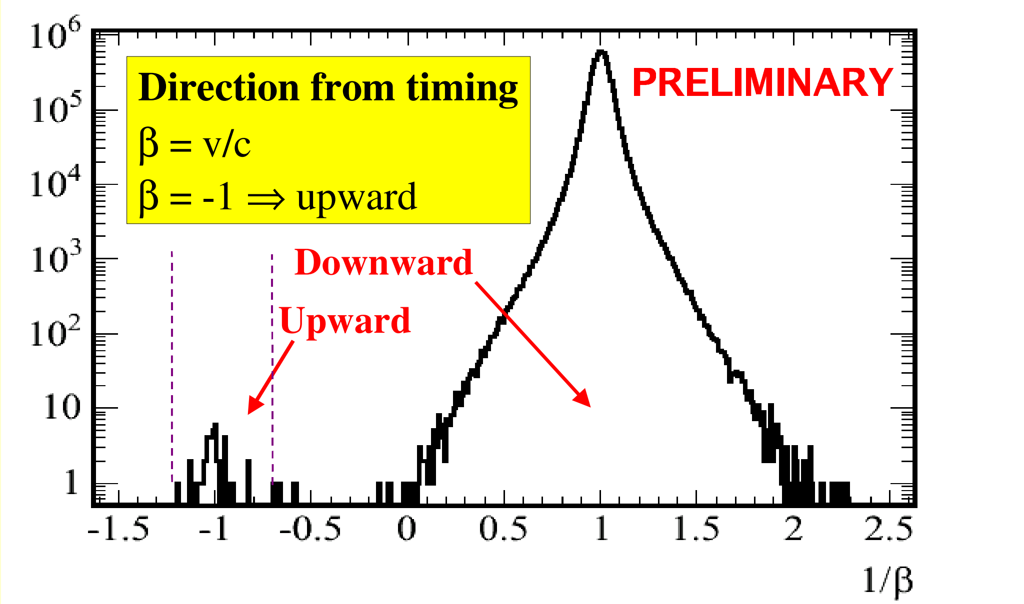
- Event reconstruction in Far detector performing well

First Results: Upward-Going Muons

- Neutrino interacting in rock can produce upward going μ in MINOS
- Timing indicates muon is upward going

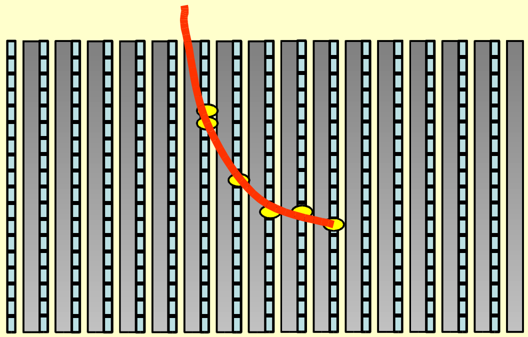


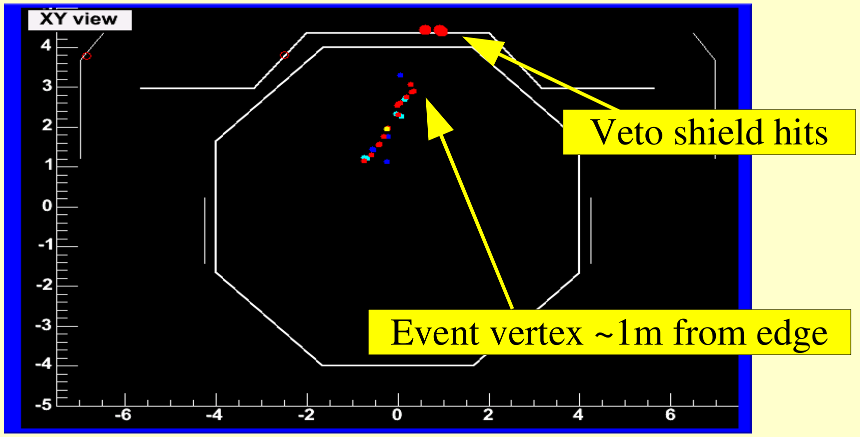
- Place track length cuts to ensure good up/down determination:
  - > 2.0m
  - > 20 plane crossings
- Clear separation of up/down μ
  - 48 upward events!
- Too early to interpret data in terms of oscillations
- Work in progress to understand systematics in analysis



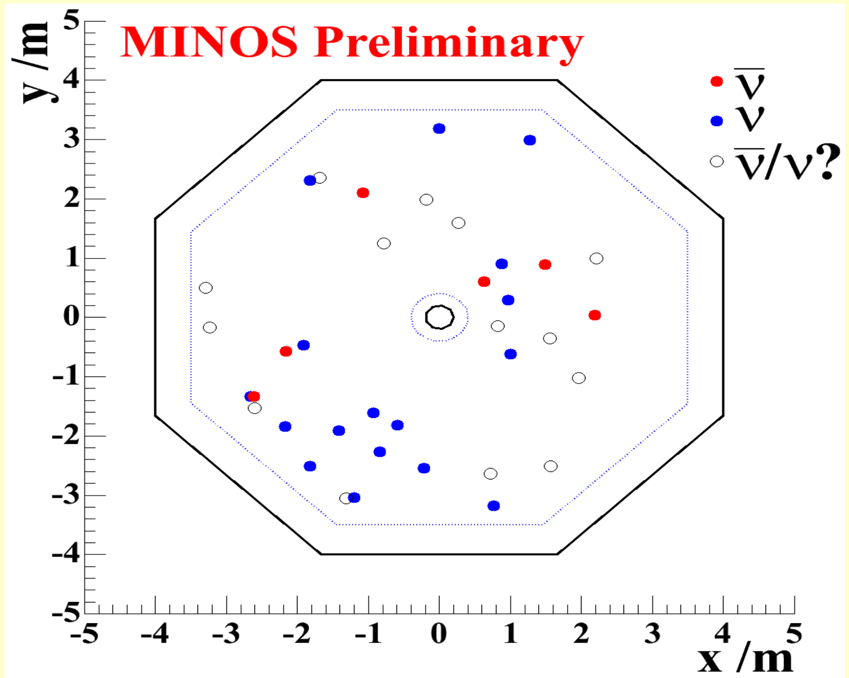
First Results: Contained Events

- Contained events in MINOS result from ν's interacting within detector
  - Cosmic ray muons entering detector in air gap between planes are major background to atmospheric neutrino contained event analysis
  - However veto shield is present with ~97% efficiency
    - Helps with background rejection





- Currently have 37 candidate events
- Using fitted muon curvature q/p can do charge ID
  - Based on $(q/p)/\sigma_{q/p}$: 6 $\bar{\nu}$, 17 ν, 14 ?
  - $N(\bar{\nu})/N(\nu) = 0.35 \pm 0.17$ (printed as "+/-")
    - Expect 0.51 if $\bar{\nu}$,ν oscillate the same
- Analysis underway, need more data!



Summary

- NuMI beam installation progressing well
  - Expect first protons on target December 2004
  - See talk tomorrow for more details
    - Session IV: Andrew Godley "The NuMI Beamline", 3:51pm
- Near Detector currently being commisioned at FNAL
- Far Detector taking physics data since July 2003
- Atmospheric neutrinos observed in Far Detector
  - Analyses of upward-going muon, contained and partially contained events underway
    - More details available from presentations at Neutrino 2004
- First direct observation of ν and $\bar{\nu}$ separated atmospheric neutrino events
- First beam data early 2005!