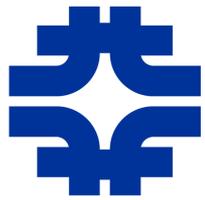




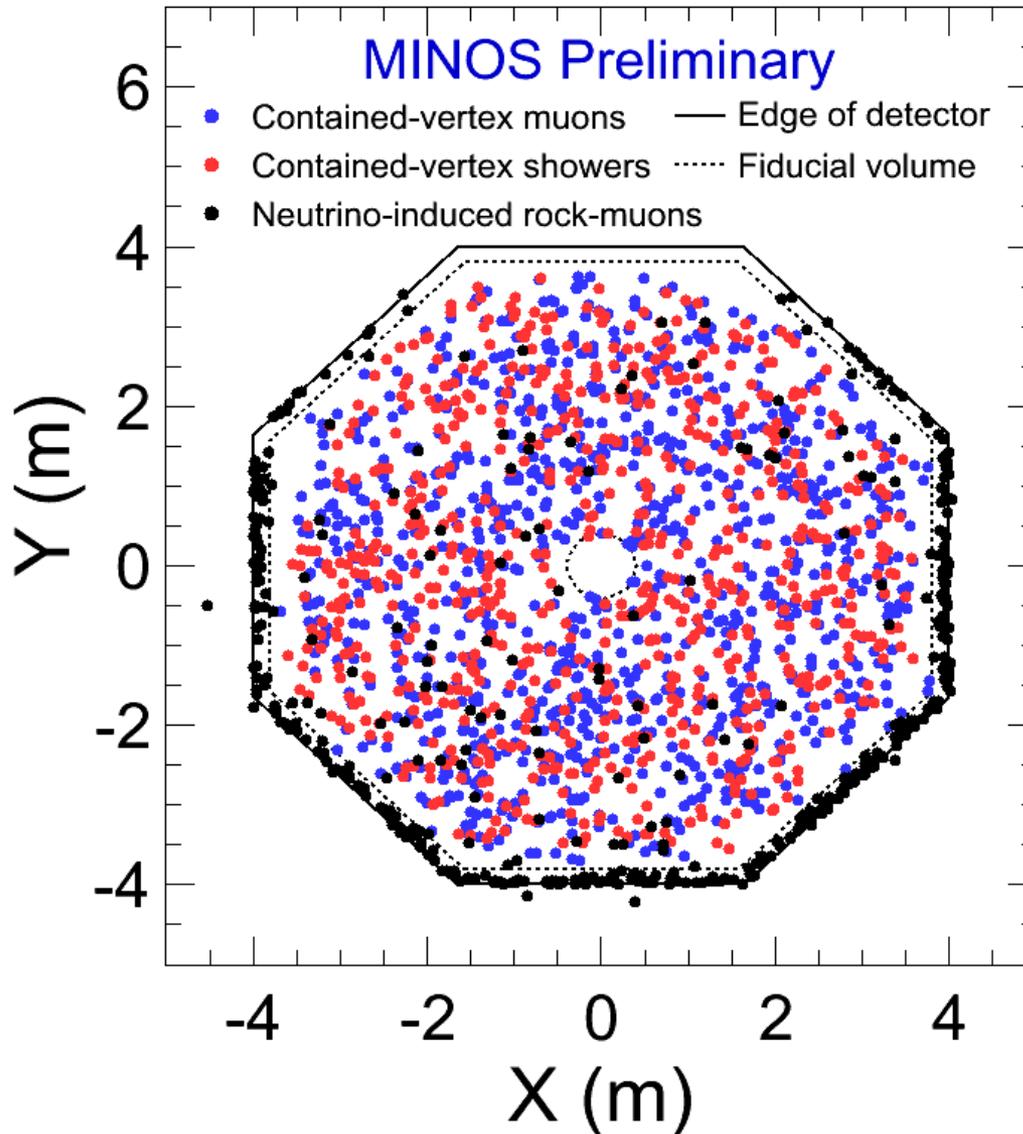
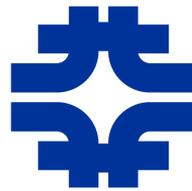
MINOS Results on Atmospheric Neutrinos and Antineutrinos



- ❑ **The MINOS experiment studies atmospheric neutrinos using its 5.4 kton Far Detector, located 705m underground (2070 mwe) at the Soudan mine.**
- ❑ **Far Detector is magnetised, enabling atmospheric ν_μ and anti- ν_μ to be separated using the curvature of the muons produced by charged-current neutrino interactions.**
- ❑ **The MINOS results on atmospheric neutrinos and antineutrinos are based on 2553 live-days (37.9 kt-yrs) of Far Detector data.**
- ❑ **We observe 2072 events:**
 - ◇ 905 contained-vertex muons and 466 neutrino-induced rock-muons.
 - These samples are composed of CC muon neutrino interactions.
 - ◇ 701 contained-vertex showers.
 - Composed mainly of CC electron neutrino and NC interactions.



Identifying Atmospheric Neutrinos in the MINOS Far Detector



□ Two techniques to identify atmospheric neutrinos:

(1) Contained vertex events:

- ◇ Apply several containment requirements to reduce the cosmic-ray muon background.
- ◇ Detector has scintillator veto shield which tags cosmic-ray muons with 97% efficiency.

(2) Upward and horizontal muons:

- ◇ Timing resolution is 2.5 ns.
- ◇ Apply selection requirements on timing variables to select neutrino-induced muons.
- ◇ Soudan mine has a uniform rock overburden, enabling events to be identified above the horizon ($\cos\theta_z < 0.05$).



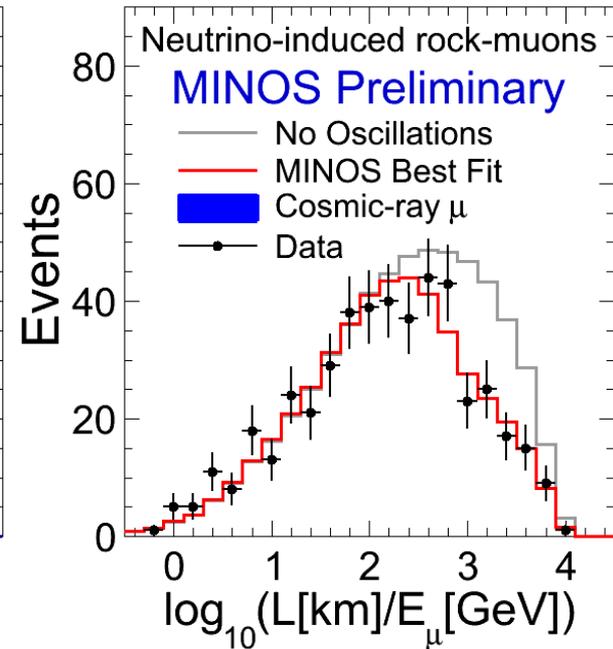
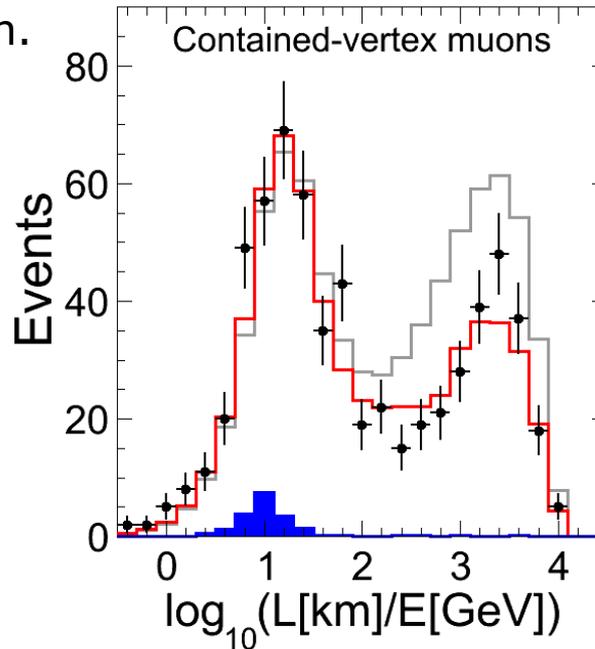
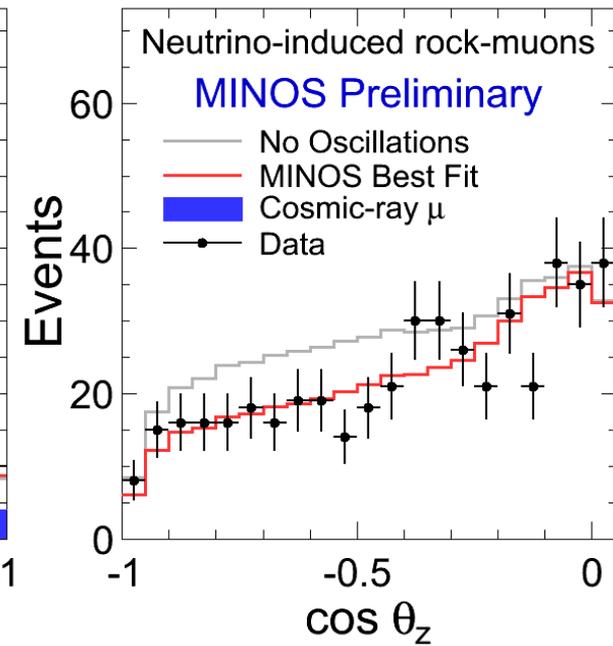
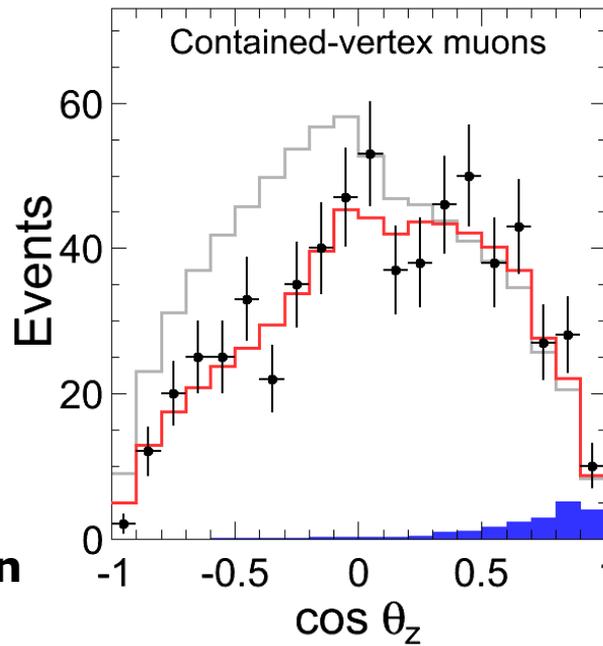
Neutrino Oscillations

□ **Select a sample of events with well-measured muon propagation direction.**

- ◇ Based on timing information.
- ◇ Select 631 well-measured contained-vertex muons and all neutrino-induced rock-muons.

□ **Plots on the right show observed zenith angle and L/E distributions for selected events.**

□ **We see clear evidence of neutrino oscillations.**





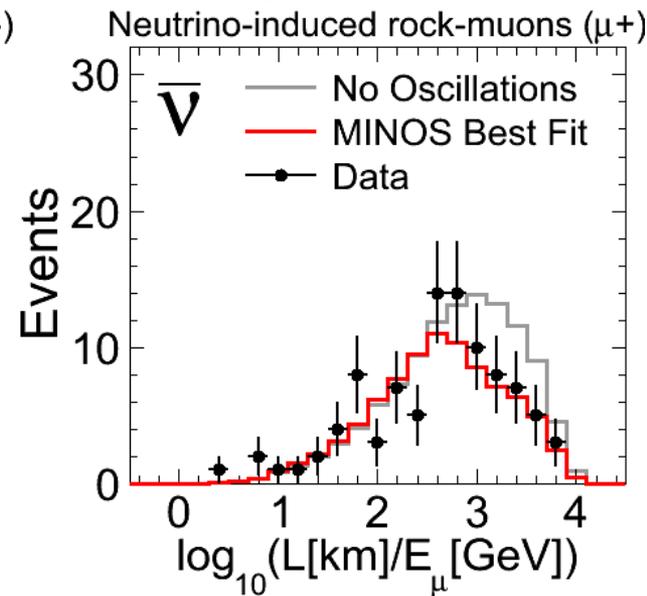
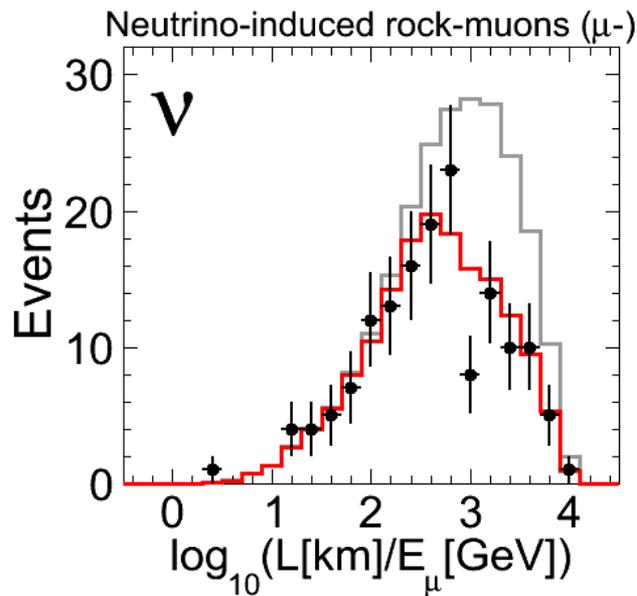
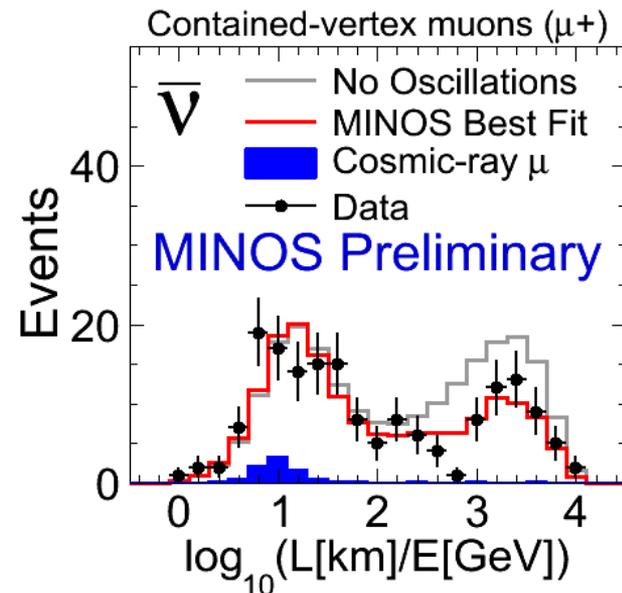
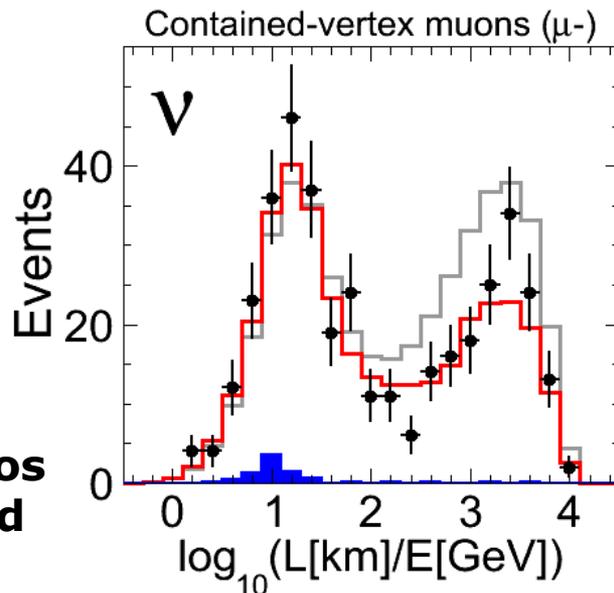
Neutrinos and Antineutrinos

□ **Separate muon neutrinos and antineutrinos based on muon charge sign.**

- ◇ Apply selection criteria that identify muons with unambiguous curvature.
- ◇ Identify 531 neutrinos and 268 antineutrinos.
- ◇ Obtain purity of 98%.

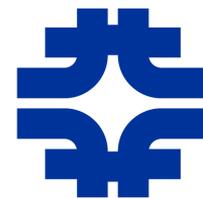
□ **Compare observed ratio of neutrinos to antineutrinos with the Monte Carlo prediction:**

$$R_{\bar{\nu}/\nu}^{\text{data}} / R_{\bar{\nu}/\nu}^{\text{MC}} = 1.03 \pm 0.08(\text{stat}) \pm 0.08(\text{syst})$$





MINOS Atmospheric Neutrino Oscillation Results



□ **Oscillation fit is based on the observed L/E distributions.**

◇ For improved sensitivity, a Bayesian technique is used to calculate an event-by-event L/E resolution and events are binned by resolution.

□ **The fit returns the following 90% confidence limits:**

$$|\Delta m^2| = 1.9^{+0.4}_{-0.4} \times 10^{-3} \text{ eV}^2 \quad \sin^2 2\theta > 0.86$$

□ **The fit is extended to allow different oscillation parameters for neutrinos and anti-neutrinos, giving the following 90% CL:**

$$|\Delta m^2| - |\Delta \bar{m}^2| = 0.6^{+2.4}_{-0.8} \times 10^{-3} \text{ eV}^2$$

◇ Consistent with equal oscillations for neutrinos and anti-neutrinos.

