The MINOS experiment and BNL

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Neutrinos

- It is well-established that neutrinos mix and have mass.
- This is the only experimental evidence for effects beyond the Standard Model in particle physics.

» Does neutrino mixing provide a mechanism for CP violation?

» Why is the neutrino massive and why is the mass so small?

What do we know about the neutrino mixing matrix and how do we know it?

$$U = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix}$$

$$= \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{23} & \sin\theta_{23} \\ 0 & -\sin\theta_{23} & \cos\theta_{23} \end{pmatrix} \times \begin{pmatrix} \cos\theta_{13} & 0 & e^{-i\delta_{CP}}\sin\theta_{13} \\ 0 & 1 & 0 \\ -e^{i\delta_{CP}}\sin\theta_{13} & 0 & \cos\theta_{13} \end{pmatrix} \times \begin{pmatrix} \cos\theta_{12} & \sin\theta_{12} & 0 \\ -\sin\theta_{12} & \cos\theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \times \begin{pmatrix} 1 & 0 & 0 \\ 0 & e^{i\alpha/2} & 0 \\ 0 & 0 & e^{i\alpha/2+i\beta} \end{pmatrix}$$

atmospheric, MINOS, K2K $\theta_{23} = \sim 45°$	reactor and accelerator Daya Bay and MINOS $\theta_{13} < 12^o$	SNO, solar SK, KamLAND $\theta_{12} \sim 32°$	$0\nu\beta\beta$

CP violation $\propto \sin 2\theta_{12} \sin 2\theta_{23} \cos^2\theta_{13} \sin 2\theta_{13} \sin\delta_{CP}$

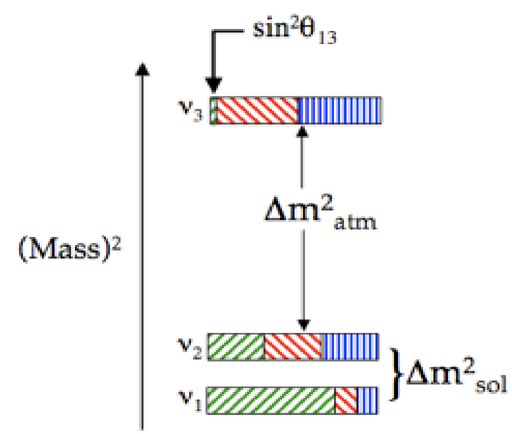
ν_μ Disappearance (2 flavors):

$P(\nu_\mu \to \nu_\mu) = 1 - \sin^2 2\theta_{23} \sin^2(1.27\Delta m^2_{32} L/E)$

ν_e Appearance:

$P(\nu_\mu \to \nu_e) \approx \sin^2\theta_{23} \sin^2 2\theta_{\mathbf{13}} \sin^2(1.27\Delta m^2_{31} L/E)$

Where L(km), E(GeV) are experimentally optimized and θ_{23}, θ_{13}, Δm^2_{32} (eV^2) are to be determined

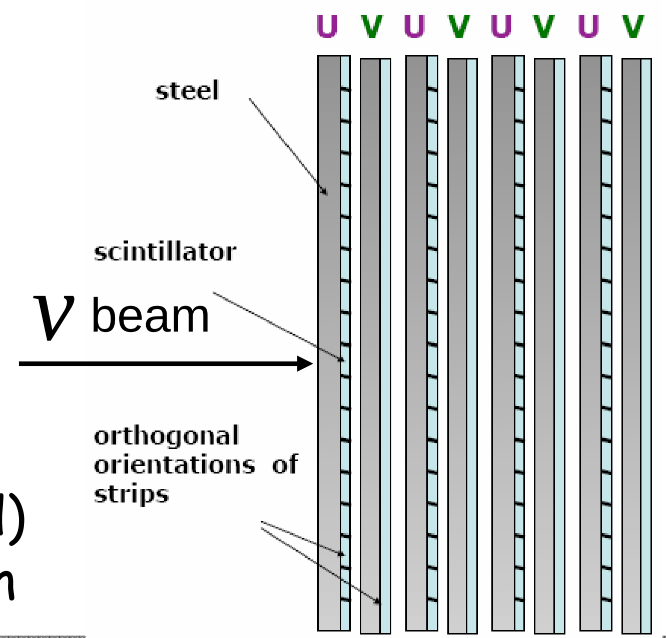


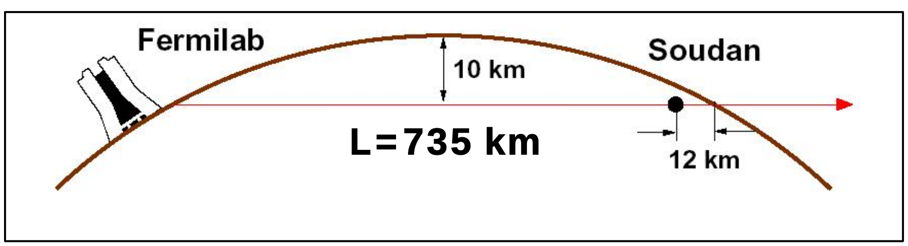
Main Injector Neutrino Oscillation Search

High power ν_μ beam produced by 120 GeV protons from the Main Injector at FNAL

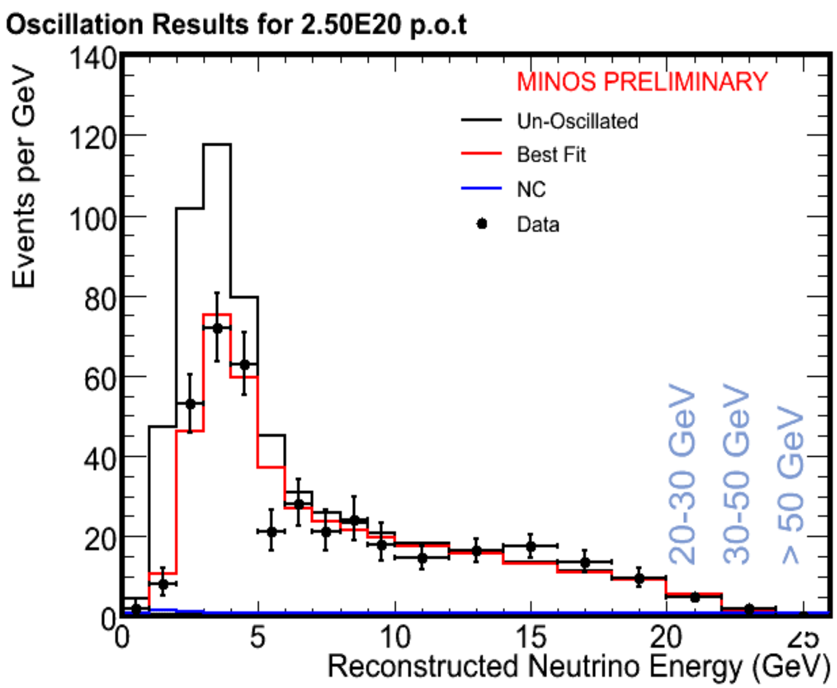
Two functionally identical magnetized iron/scintillator detectors:

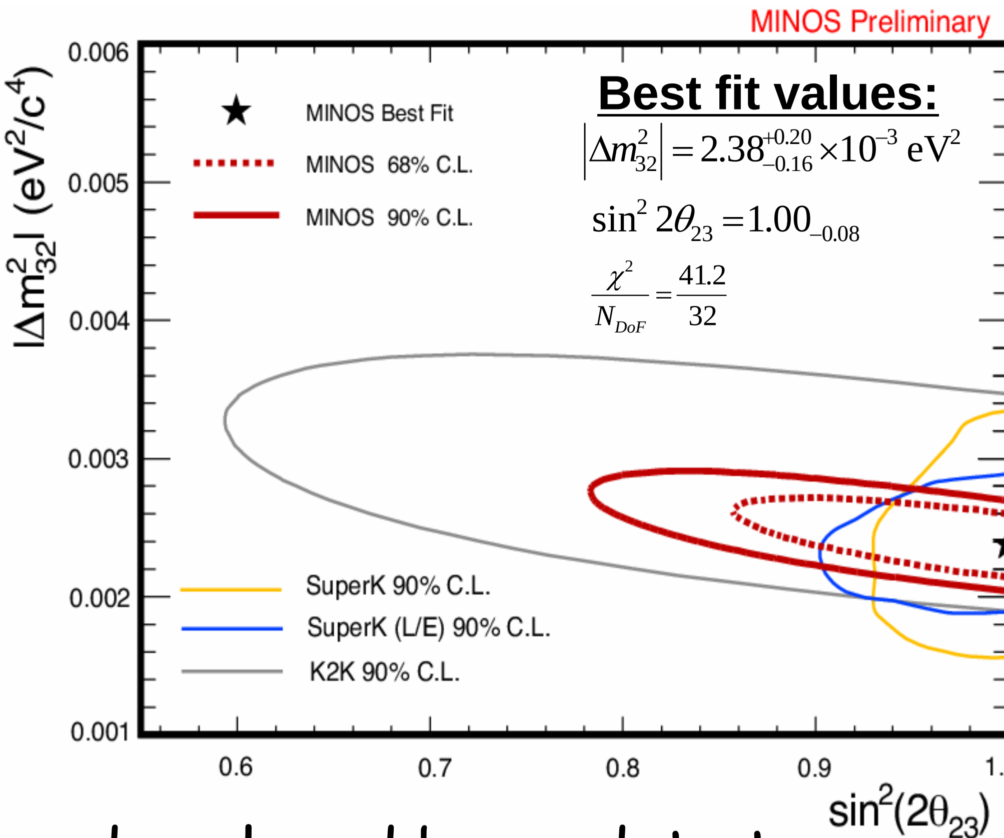
- Near detector(~1kton,~5 ν interactions/second) at Fermilab to measure the beam composition and energy spectrum
- Far detector (~5kton, ~3 ν interactions/day), 735km away, in the Soudan Mine, Minnesota to search for evidence of oscillations





Muon neutrino disappearance results



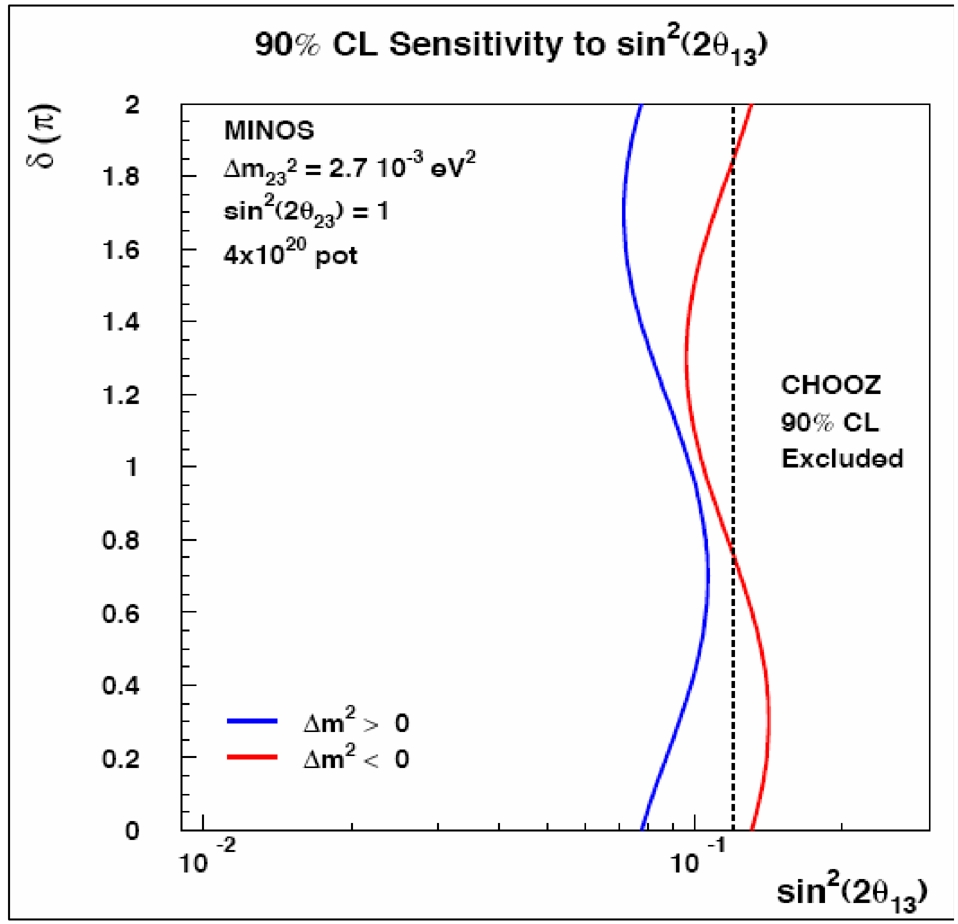


BNL contributions: Collected and analyzed beam data to ensure beam quality and count protons-on-target. Enabled spill-by-spill analysis & established the normalization uncertainty. Essential for all oscillation analyses requiring normalization.

Projected sensitivity of electron neutrino appearance

Background-dominated measurement:

BNL focus has been on establishing multiple data-driven methods to estimate main components of background and their uncertainty.



Summary

- BNL continues to provide MINOS beamline monitoring & analysis to ensure data quality for normalization
- Importance of beam analysis will increase with beam power
- BNL has a lead role in the electron neutrino appearance analysis --- results expected in 2008