Detecting Long Baseline Neutrinos in the NOvA Experiment

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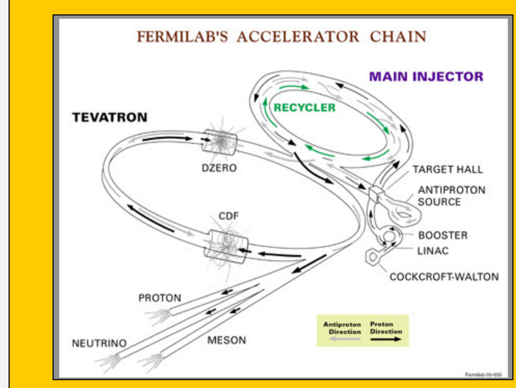
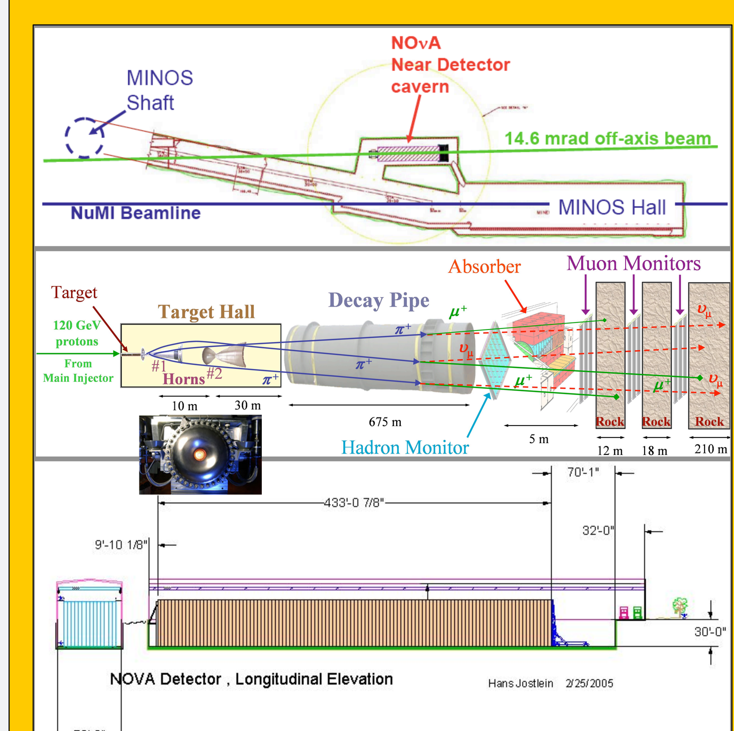
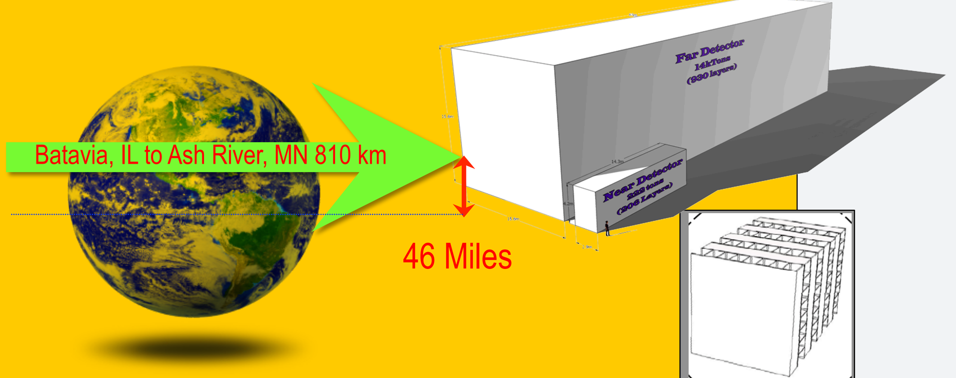
Introduction

ABSTRACT: The NOvA Collaboration is building a massive tracking liquid-scintillator calorimeter at a location in Northeastern Minnesota, which is 14 mrad off-axis of a high power muon neutrino beam (NuMI) originating 810 km away at the Fermi National Accelerator Laboratory (near Chicago), for the purpose of recording the appearance of electron neutrino events. The principle goals are in comparing neutrino events in a near and far detectors to establish electron neutrino appearance and a non-zero neutrino mixing angle theta_13, thus observing CP violation in neutrinos and resolving the neutrino mass hierarchy. Other important oscillation parameters will be recorded to improve knowledge of this phenomena. This calorimeter will be sensitive to supernova neutrinos. Building such a detector is not without challenges. In this talk we discuss the physics goals, describe the detecting components, and provide a status report on its installation and operation.

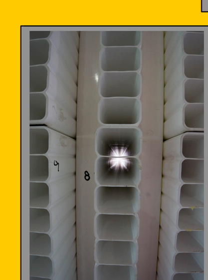


The **N**uMI **O**ff-axis ν_e (electron neutrino) **A**ppearance experiment operates in the Intensity Frontier when proton-graphite collisions produce charged pions which are magnetically lensed down a decay pipe to produce the most intense beam of muon-type neutrinos in the world. Neutrino interactions recorded in a 200 ton near-detector and in a 15 kiloton far detector will be used to make high precision measurements of mixing angle which contribute to understanding mass hierarchy, and CP phase, if non-zero may explain why matter dominates over anti-matter.



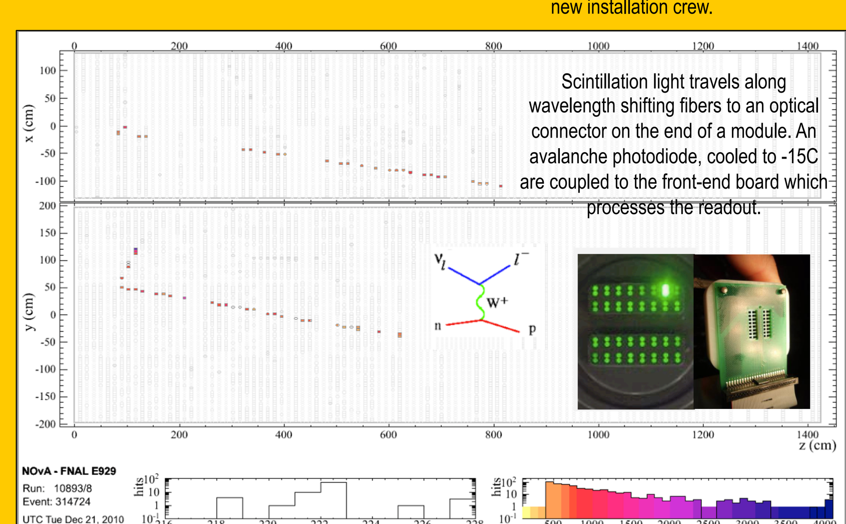


Module lifter alongside 28 NOvA modules at the Ash River site being used as exercise dummies to train a new installation crew.



A portion of a 32 cell module displayed here.

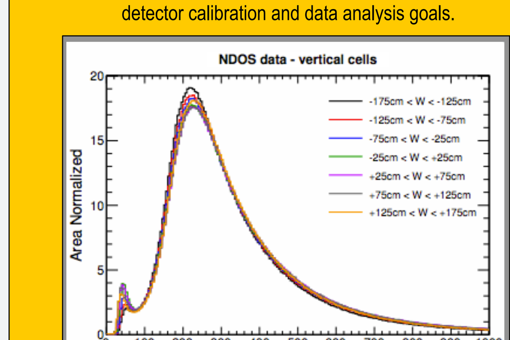
Near Detector on Surface (NDOS) which is currently running has been an important pilot exercise allowing understanding of calibration, beam composition, cosmic ray background sensitivity, response to electron neutrinos, and a provided a measurement of quasi-elastic neutrino interactions.



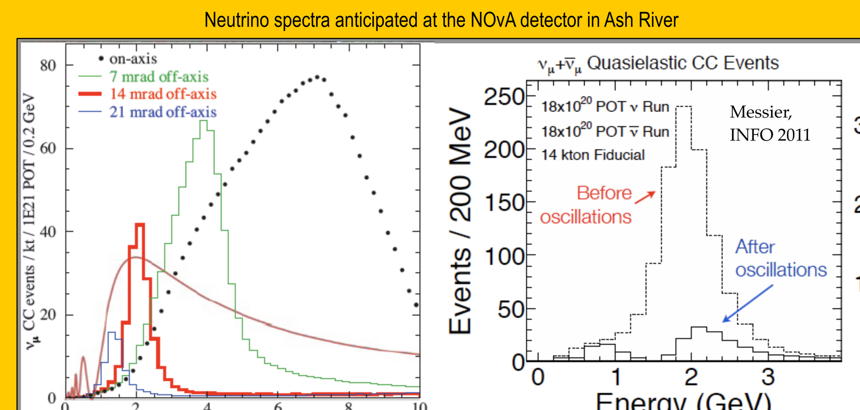
The NOvA detectors are designed to measure the oscillation of muon neutrinos to electron neutrinos, with a primary goal to resolve event topologies of electron neutrino charged current interactions such as the one displayed above. Distinguishing long muon tracks from muon neutrino charged current interactions is as important.

Front-end electronics house the APD, heat sink, thermal cooling control, and readout. All data is transmitted over standard Ethernet cabling.

NDOS detector ADC calibration using cosmic muons after attenuation corrections for varying track-length events. Accurate charged particle tracking is an integral part of detector calibration and data analysis goals.



Neutrino spectra anticipated at the NOvA detector in Ash River



Theory

The phenomena of neutrino flavor oscillations, attributable to B. Pontecorvo in 1957, is modeled for three generations of leptons participating in the weak interaction is detected in mass eigenstate1,2,3 with a probability given as proportional to U^2.

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = U \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

NOvA will measure θ_{13} and δ with unprecedented precision.

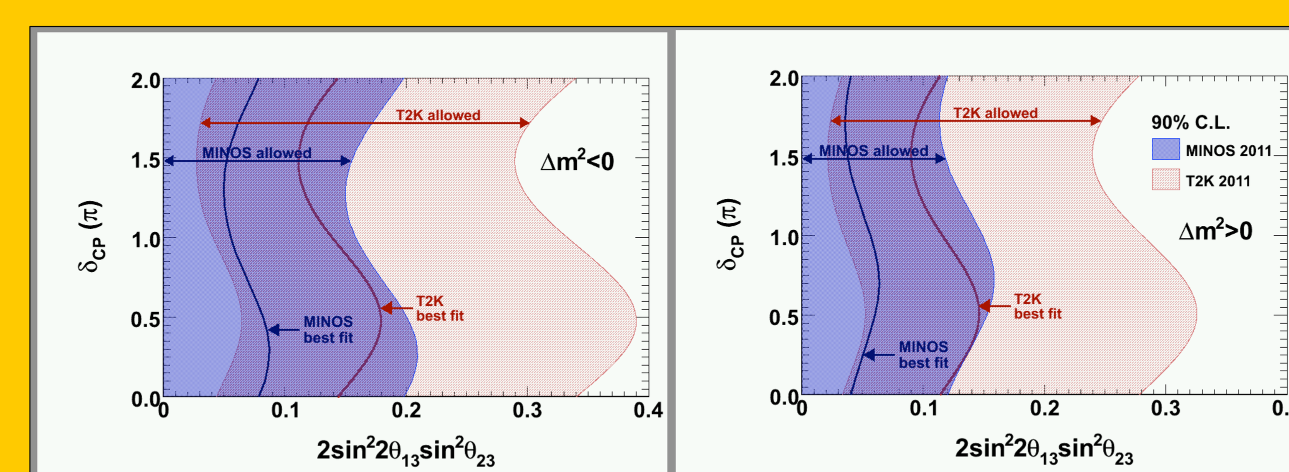
$$U = \underbrace{\begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{23} & \sin\theta_{23} \\ 0 & -\sin\theta_{23} & \cos\theta_{23} \end{pmatrix}}_{\text{Atmospheric and Accelerator parameters}} \boxed{\begin{pmatrix} \cos\theta_{13} & 0 & \sin\theta_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -\sin\theta_{13}e^{-i\delta} & 0 & \cos\theta_{13} \end{pmatrix}} \underbrace{\begin{pmatrix} \cos\theta_{12} & \sin\theta_{12} & 0 \\ -\sin\theta_{12} & \cos\theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}}_{\text{Reactor and solar neutrinos parameters}}$$

$$P(\nu_\mu \to \nu_e) = \left| \sum_j U_{\mu j} e^{-\frac{i m_j^2 t}{2E}} U_{je}^* \right|^2$$

$$\approx P_{\text{atm}} + P_{\text{sol}} + \sqrt{P_{\text{atm}} P_{\text{sol}}} (\cos\Delta_{32}\cos\delta \mp \sin\Delta_{32}\sin\delta)$$

$$P_{\text{atm}} = \sin^2(\theta_{23})\sin^2(2\theta_{13})\sin^2(\Delta_{31})$$

$$P_{\text{sol}} = \cos^2(\theta_{23})\cos^2(\theta_{13})\sin^2(2\theta_{12})\sin^2(\Delta_{21})$$

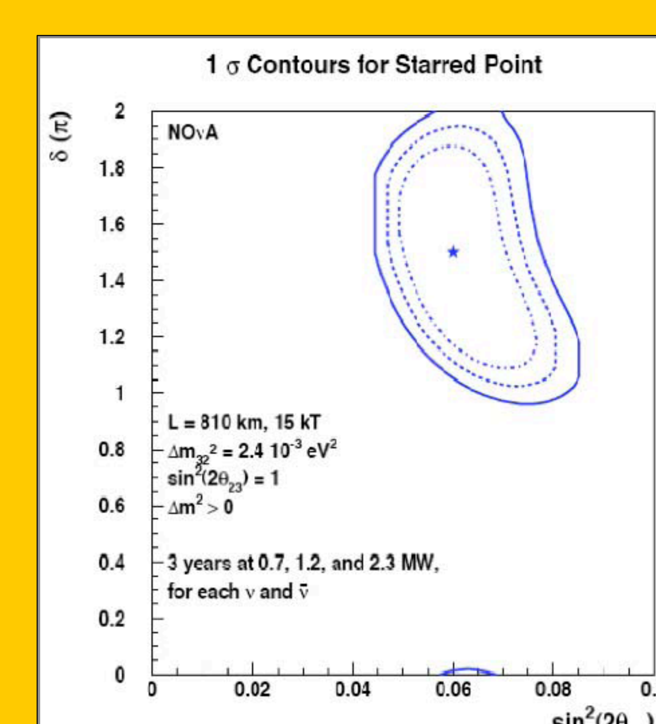


Minos and T2K results suggest θ_{13} is nonzero. arXiv: 1108.0015 1106.2822
Global fit yields $\sin^2(2\theta_{13})$ = 0.098+-0.028 and $\theta_{13} \sim 9^o$. arXiv: 1106.6028

Electron appearance is directly related to $\sin^2\theta_{13}$ and an an aim of NOvA is to improve this measurement by an order of magnitude beyond the current limit.

Pursuing a goal of resolving the mass hierarchy by running a beam of neutrinos and anti-neutrinos.

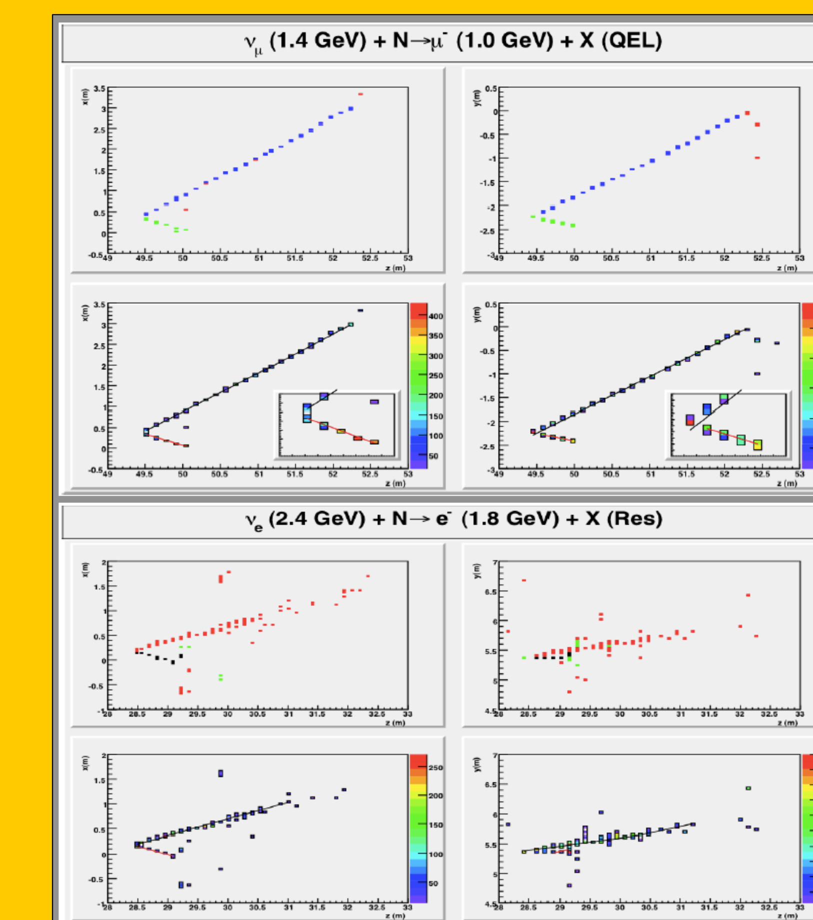
A goal to evidence CP violation via a measurement of muon neutrino disappearance and $\sin^2 2\theta_{13}$



Data

Neutrino Interacting Inside the NOvA Detector

Neutrino events as simulated by Monte-Carlo in the NOvA Detector where in both cases, the short track of the recoil proton is observed, as is the long track of the lepton. An electron shower is distinguished as a fragmented profile.

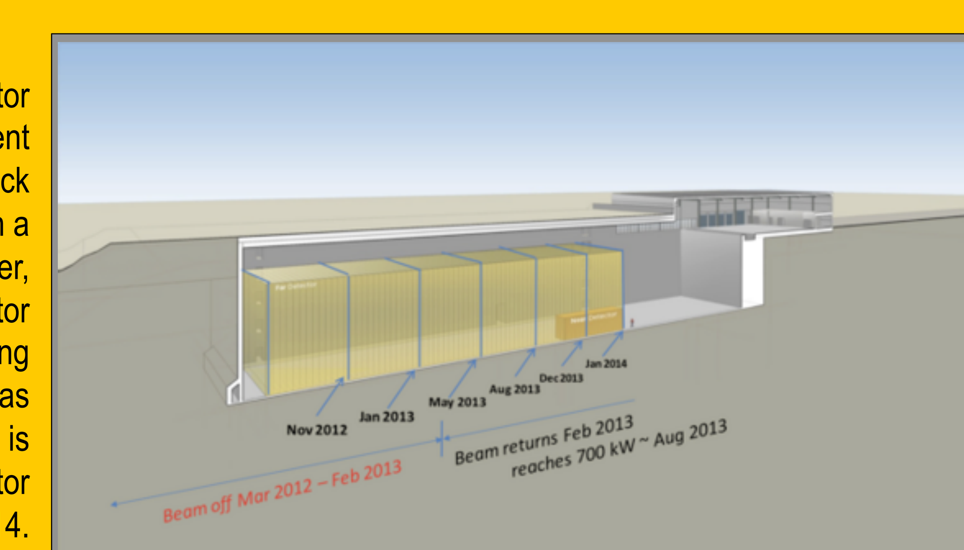


Cosmic Ray Capabilities of the NOvA Detector

Supernova ν, Upward going atmospheric ν, multiple muons, single and multiple hadrons in EAS and their correlations, Horizontal μ from ν interactions deep in the atmosphere, Fluctuations in air shower components, Coincidences with an air shower array.

Online computing is managed by the Fermilab Computing Division which will collect and buffer time-continuous data from over 350,000 readout channels, correlating beam spill events from the NuMI beam facility with those at the far detector at Ash River. Real-time analysis is accomplished in 5 ms time slices by more than 180 multicore commodity buffering nodes using standard gigabit ethernet switching, sustaining a data input rate of 2GB/s with and ability to buffer in excess of 20 seconds worth of data.

The installation of the NOvA detector is now underway with the placement of the first 384 module block scheduled for August 2012, with a second block following in September, forming di-block 1, when scintillator filling and electronics outfitting following. Installation will continue as the upgraded Fermilab beam is powered on, with a 30-block detector being completed in the Fall of 2014.



Credits: L. Corwin, M. Muether, N. Raddatz, A. Norman, M. Goodman

The universe is abundantly filled with these tiny-massed neutral neutrinos which rarely interact, making detection a challenge, but when they do interact, offer insight into the blueprint of nature.

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For more information: www-nova.fnal.gov

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