

# Search for active-sterile antineutrino mixing using neutral-current interactions with the NOvA experiment

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# Introduction

- NOvA Experiment
- Neutrino Oscillation Background
- Detector Background
- Filtering/Data Selection
- Results
- Conclusion



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## Research Motivation

- Research in oscillations from atmospheric, accelerators, the sun, and nuclear reactors provide substantial evidence of oscillation between the electron, muon, and tau neutrinos/antineutrinos
- Most projects do not test for the existence of hypothetical sterile neutrinos/antineutrinos
- A number of long-baseline accelerator and reactor neutrino experiments have not shown evidence of oscillations outside of the standard 3 flavor framework, such as the work done in *MINER $\nu$ A* and MINOS
- If a Sterile Antineutrino were to exist, it would help explain some unexpected experimental results, such as the work done at The Liquid Scintillator Neutrino Detector (LSND), that measured more electron neutrinos than expected through oscillation.

# The NOvA Experiment

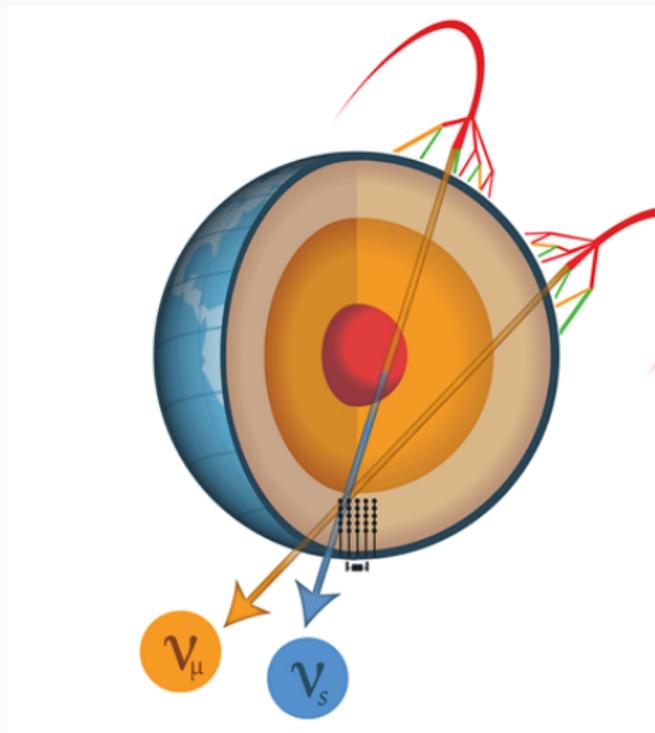
- Can search for evidence of active to sterile oscillations through Neutral Current (NC) interactions in the Near (ND) and Far Detector (FD)
- If an antineutrino were to oscillate to a sterile flavor, there would be a measurable reduction in the number of NC interactions from the near detector and the far detector
- This analysis of the NOvA experiment works with Antineutrinos, the first one to do so



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# Sterile Neutrinos

1. Hypothetical, no proof that they exist
2. Interact gravitationally, the weakest force, since they do not have electric charge, hyper-charge, or color charge
3. If a neutrino were to oscillate into a sterile flavor state, it can not oscillate back into an active flavor state, since it does not interact through the weak force, and is thought to have less mass than the active flavors



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# Sterile Antineutrino Oscillation

- The simplest extension of the 3-flavor model is the 3+1 flavor model with a new mass  $\bar{\nu}_4$  and a new sterile flavor state

$$\sum_{i=1}^4 U_{si}^* |\bar{\nu}_i\rangle$$

- Where U is the unitary 4x4 extended PMNS Matrix
- Since there has been no measurement outside of the standard 3 model framework yet, there are constraints on the allowed parameters of this model

# Sterile Antineutrino Oscillation

- A reduction in the number of NC interaction:

$$1 - P(\bar{\nu}_\mu \rightarrow \bar{\nu}_s) \approx 1 - c_{14}^4 c_{34}^2 \sin^2 2\theta_{24} \sin^2 \Delta_{41} - A \sin^2 \Delta_{31} \pm B \sin 2\Delta_{31}$$

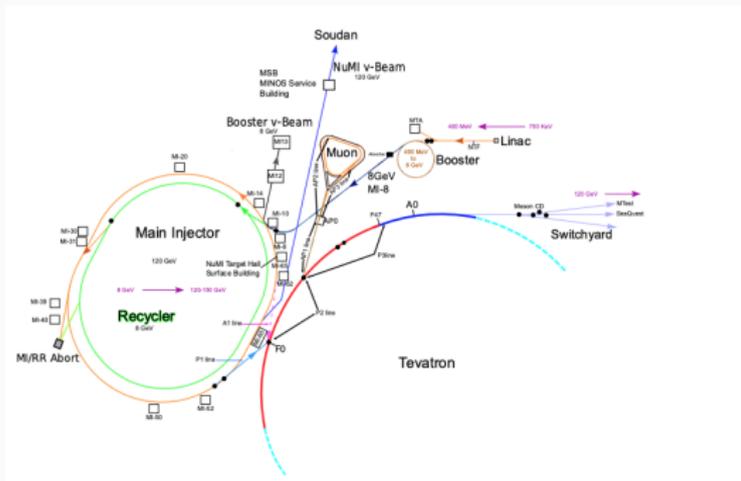
$$- A = \sin^2 \theta_{34} \sin^2 2\theta_{23}, B = \frac{1}{2} \sin \delta_{24} \sin \theta_{24} \sin 2\theta_{34} \sin 2\theta_{23}, \Delta_{ij} = \frac{\Delta m_{ij}^2 L}{4E}$$

- The probability to oscillate from a flavor  $\alpha$  to  $\beta$  goes as

$$P_{\nu_\alpha \rightarrow \nu_\beta} = \sin^2 2\theta \sin^2 \left( \frac{1.27 \Delta m^2 L}{E} \right)$$

- for oscillations to be significant,  $\Delta m^2 L \gtrsim E$
- In a 3+1 model these slower oscillations are driven by mass splittings in the range  $0.05 \text{eV}^2 \leq \Delta m_{41}^2 \leq 0.5 \text{eV}^2$

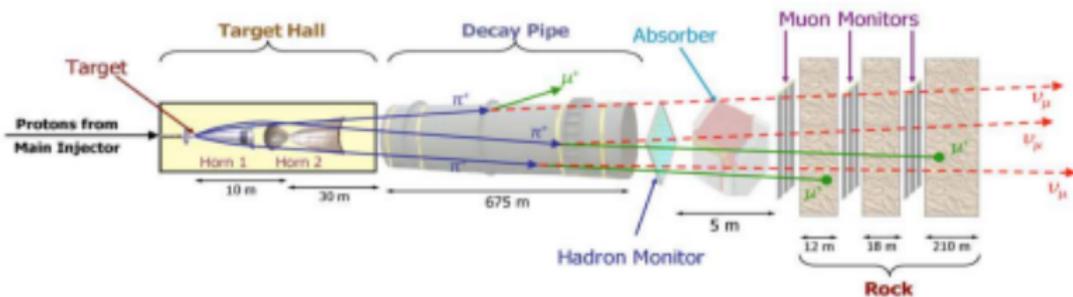
# The NuMI Beam



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- The antineutrino beam is generated by a proton carbon interaction producing a negative hadron

# The NuMI Beam Cont.



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- To get an antineutrino, the NuMI beam would focus  $\pi$  into the decay pipe since it has the following decay modes:

$$\pi^- \rightarrow \mu^- + \bar{\nu}_\mu$$

$$\pi \rightarrow \nu + \bar{\nu}$$

- Since this decay is mediated by the  $Z^0$  boson, it is a "neutral" current interaction

# Near and Far detector

- Near detector is located in Batavia with Fermilab
- Far detector is located in Ash River, Minnesota, about 810km away from the Near Detector
- Constructed with PVC cells with planes alternating horizontal and vertically to track three dimensions
- Each cell is filled with mineral oil based liquid scintillator
- Work in tandem with one another



# Background Filtering

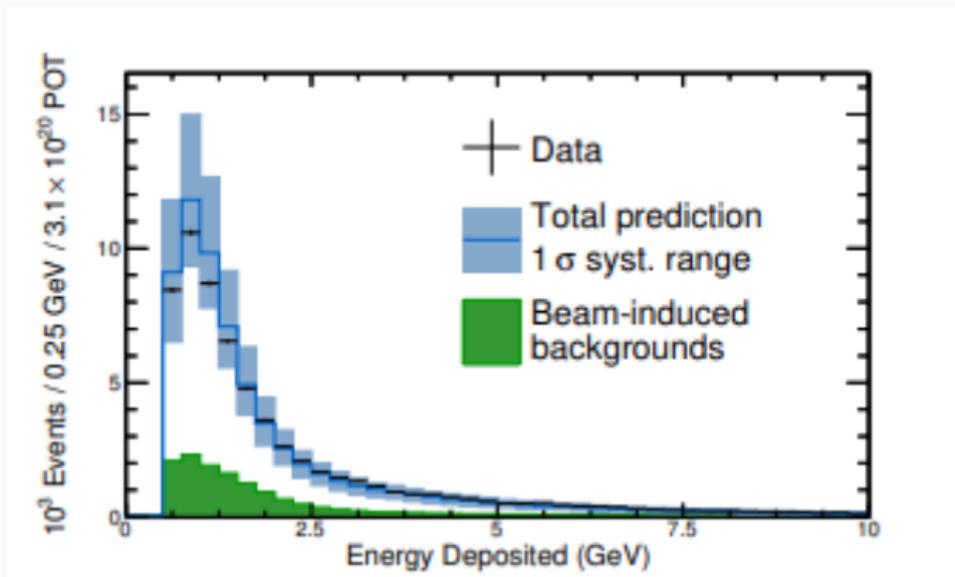
- The backgrounds for this experiment are CC events and cosmic neutrinos
- A full simulation of the beam was used to predict the flux at the NOvA detectors using GEANT4
- Event vertices are created from "hits" in the detector, and are then back projected to a starting point.
- To avoid backgrounds, these vertices must be:
  1. For the ND, greater than 25cm from all sides
  2. For the FD, greater than 100 cm from the top, 10cm from the bottom, and 50cm from the sides.
  3. Between 150-1000cm from the upstream face of the detector

# Data Selection Process

- NC events are characterized by the lack of a differently charged lepton in the results than from the original hadron
- Interactions are identified by requiring a certain level of activity and rejecting CC events
- The detectors have enough resolution to have a good distinction between  $\pi$  mesons and positrons
- This allows for a distinction of NC and CC events

## Results Near Detector

- The measured candidates of neutrinos in the near detector
- The ND data is used to constrain the selected simulated events before propagating the resulting distribution to the FD



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## Predicted Results Far Detector

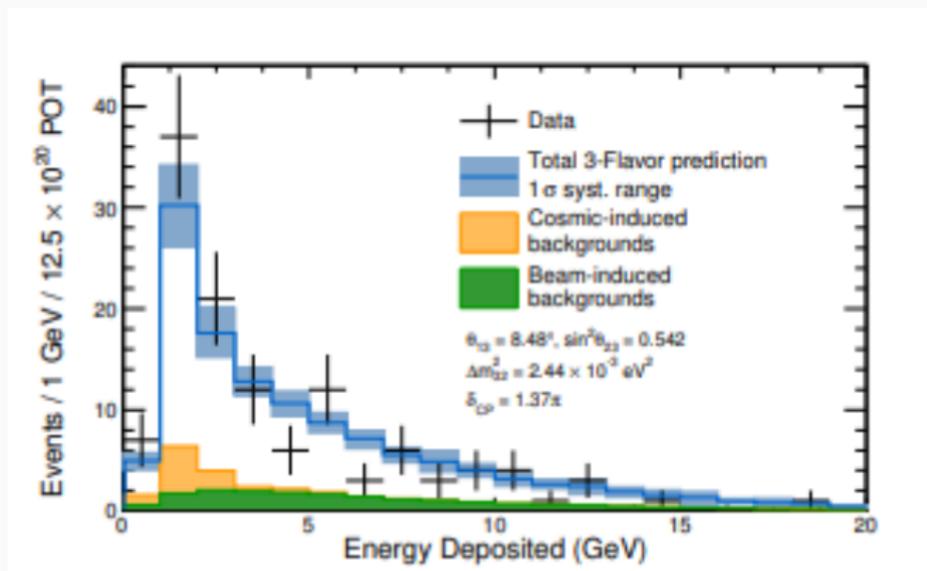
- The Predicted measured values of the Far detector using only a 3 flavor oscillation model

NC signal	$95.5 \pm 14.6$
$\nu_\mu$ CC background	$12.2 \pm 2.0$
$\nu_e$ CC background	$3.6 \pm 0.6$
$\nu_\tau$ CC background	$2.2 \pm 0.4$
Cosmic background	$8.7 \pm 0.4$
Total	$122.2 \pm 14.8$

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## Measured Results Far Detector

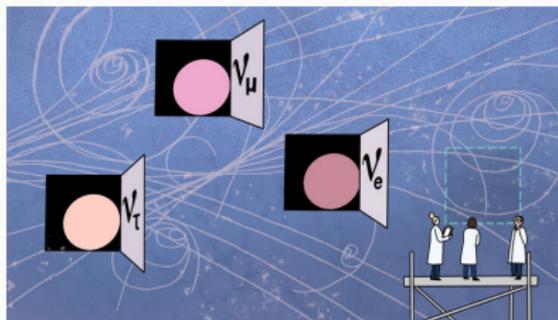
- The measured spectrum of events in the far detector



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- The total amount of events measure is 121

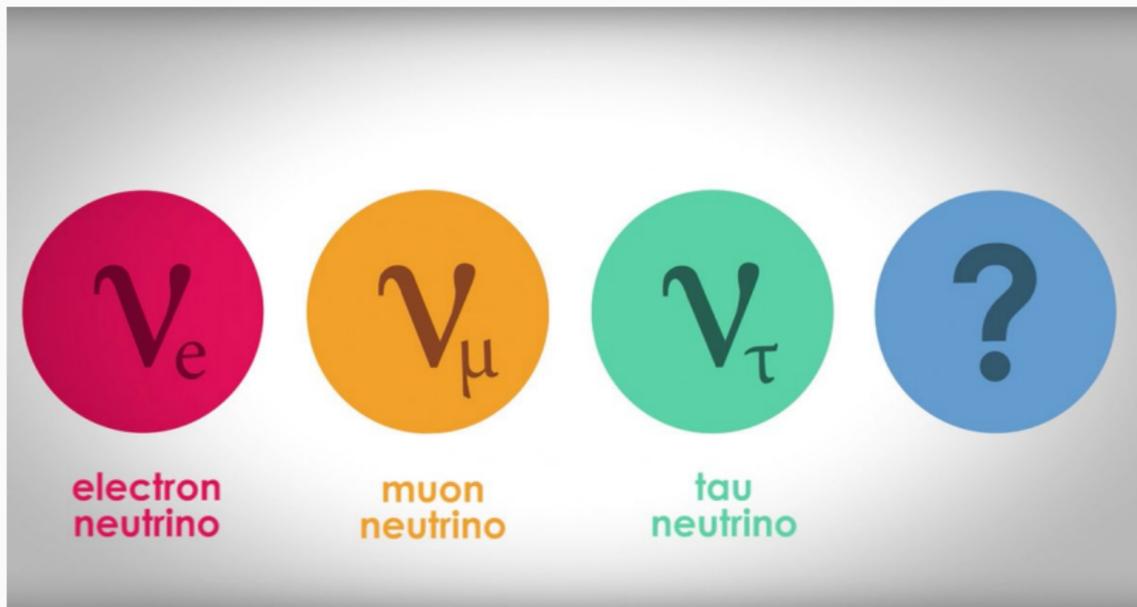
- Measured results are within statistical and systematic error of 3 flavor model
- Since no degradation on flavor oscillation, the sterile antineutrino still evades us



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## Conclusion/Future Work

- No proof of the Sterile antineutrino yet
- Want to increase the amount of antineutrino by 2.5 times
- Plans to take data for NOvA until at least 2025



# References

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Questions?