

NOvA in 10 Minutes

David Dueñas

University of Cincinnati

New Perspectives, Jun 26, 2023

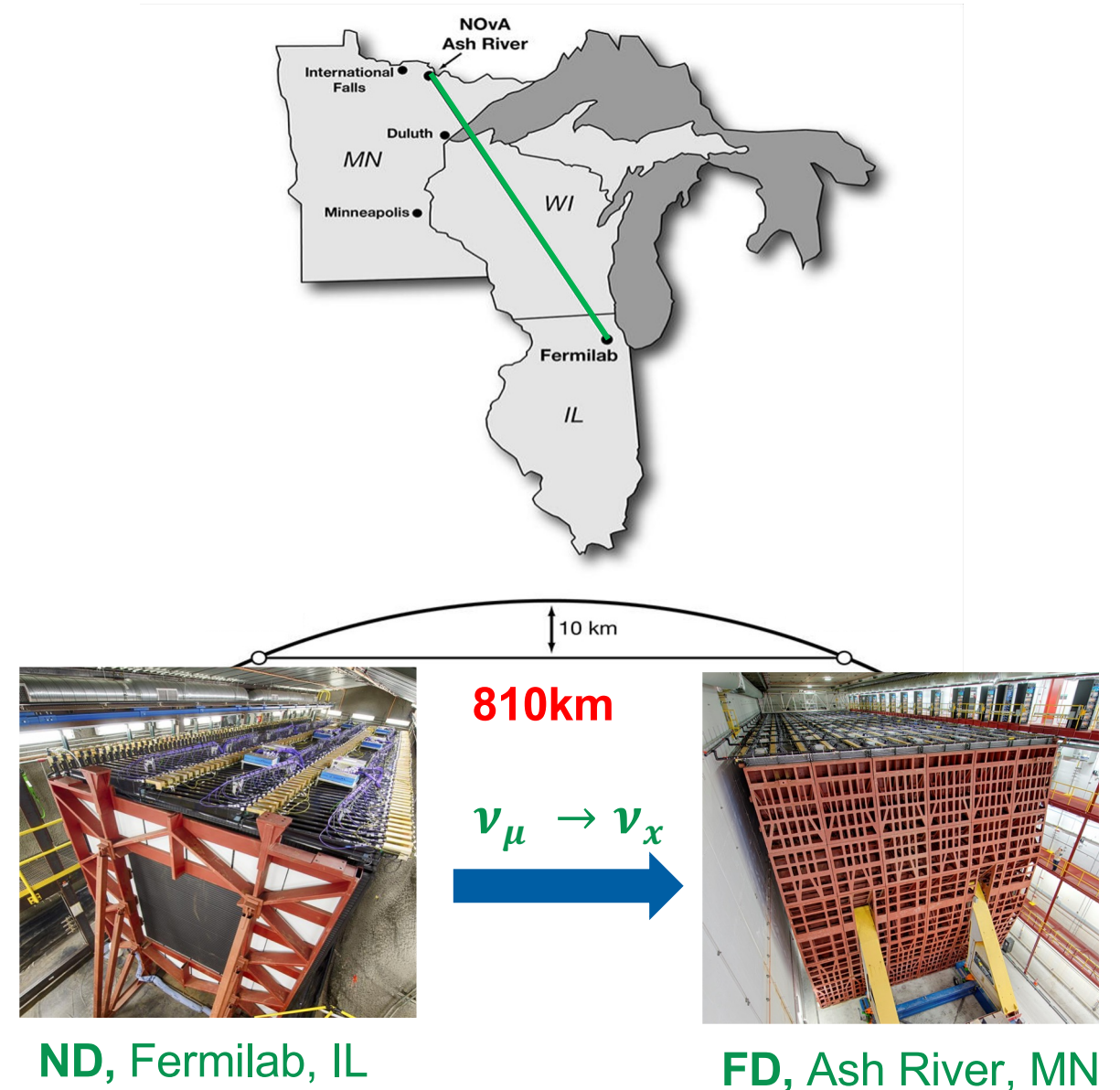
On behalf of the NOvA collaboration

FERMILAB-SLIDES-23-138-V.

The NOvA Experiment

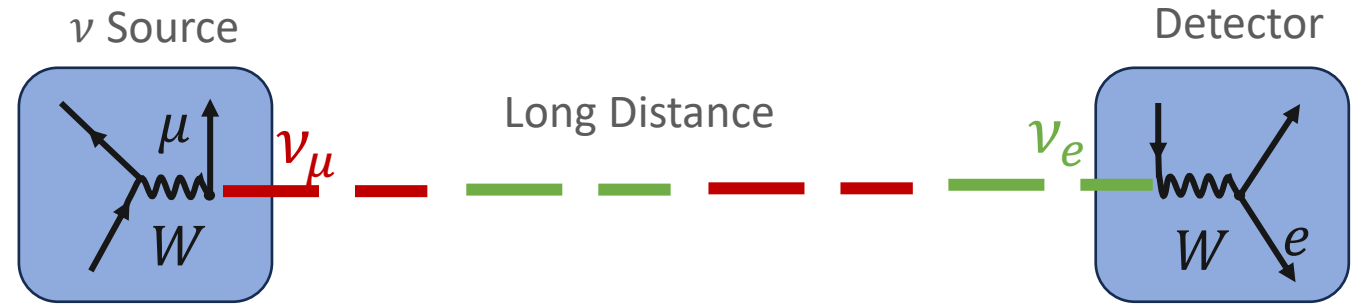
NOvA(NuMI Off-Axis ν_e Appearance)

- Long-baseline neutrino oscillation experiment
- NuMI Beam at Fermilab
- 14.6 mrad off-axis
- Neutrinos detected after 1km by the Near Detector (ND)
- And 810km after at the Far Detector (FD)



Neutrino Oscillations

- Neutrinos change their flavor as they propagate over long distances
- Oscillations are governed by the unitary matrix $U(\text{PMNS})$
- $U(3 \times 3)$ is parametrized in terms of the mixing angles $\theta_{23}, \theta_{13}, \theta_{12}$ and the CP-violating phase δ_{CP}
- The mass differences, Δm_{21}^2 and Δm_{32}^2 , control the oscillation frequency



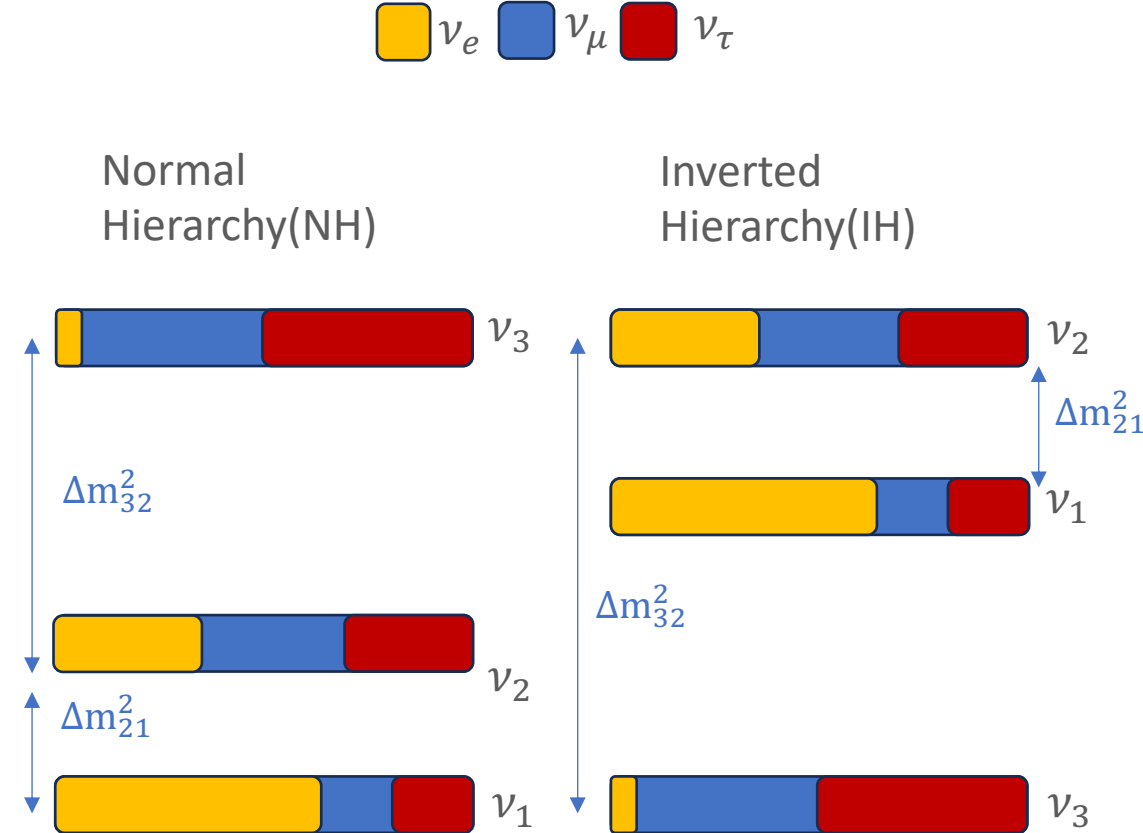
$$|\nu_\alpha\rangle = \sum_i U_{\alpha i}^* |\nu_i\rangle$$

Flavor states
 $\alpha = e, \mu, \tau$
 Mass states
 $i = 1, 2, 3$

$$U(\theta_{23}, \theta_{13}, \delta_{CP}, \theta_{12})$$

NOvA Physics Goals

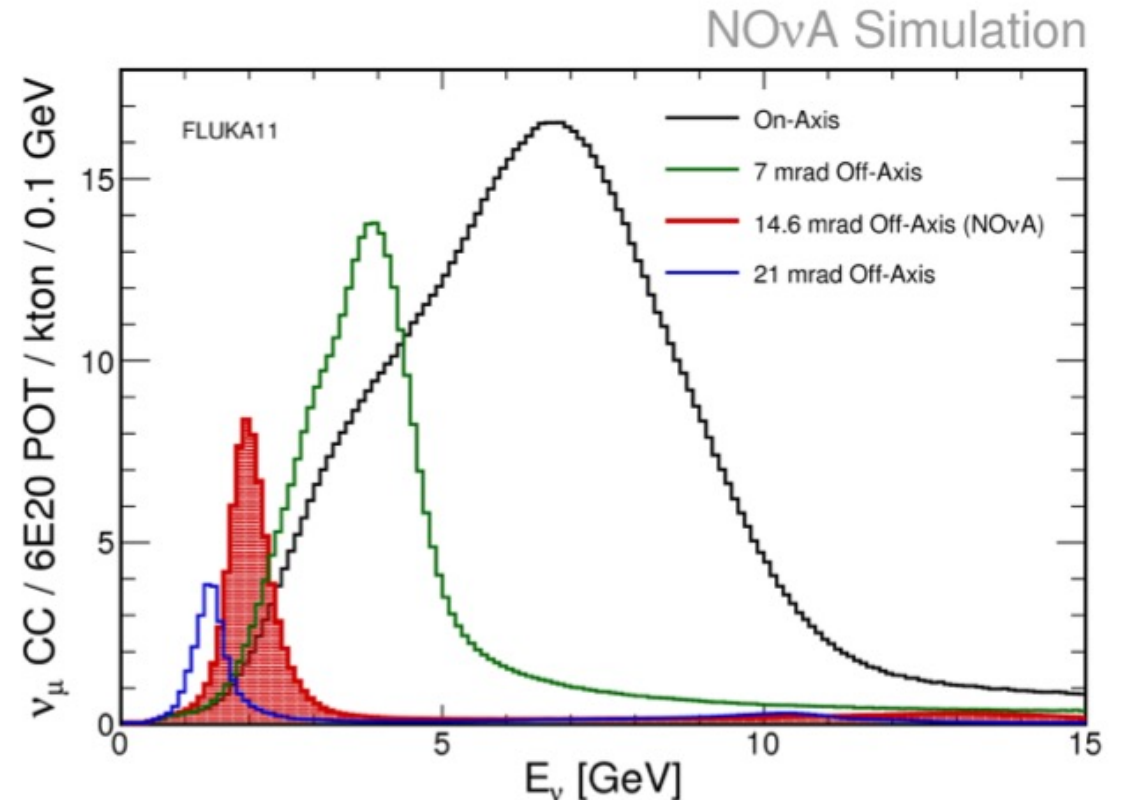
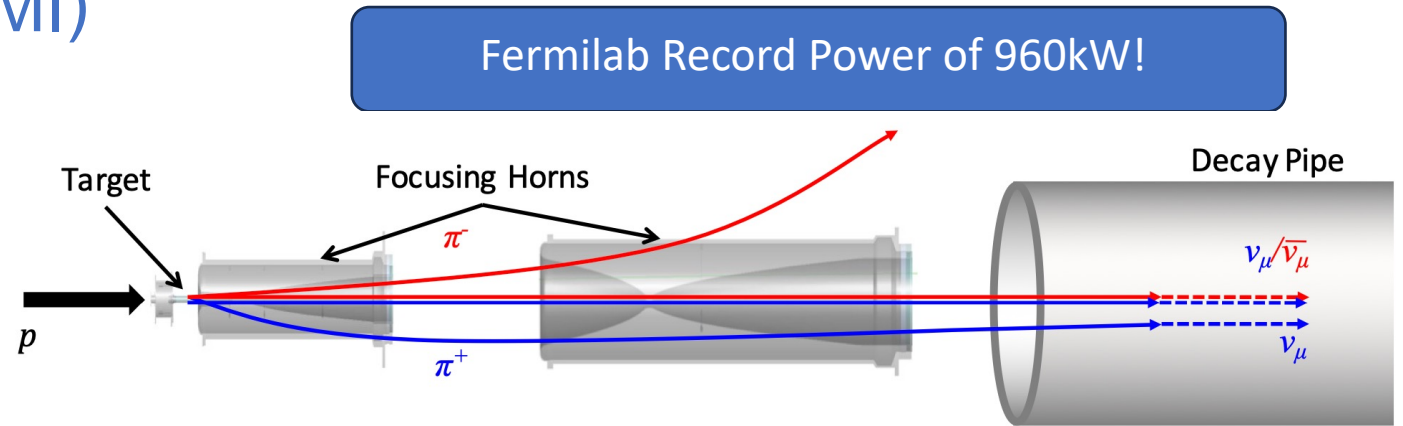
- Determine neutrino mass hierarchy
 - Normal or inverted ?
- θ_{23} mixing angle
 - Is $\theta_{23} = 45^\circ$ (maximal-mixing)?
 - If not, what is its octant?
 - $\theta_{23} < 45^\circ$ Lower Octant(LO)
 - $\theta_{23} > 45^\circ$ Upper Octant(UO)
- Search for evidence of CP violation
 - What is the value for δ_{CP} ?
 - Important for matter/antimatter asymmetry
 - It can be investigated using $\nu / \bar{\nu}$ data



More analyses: Neutrino cross-sections, supernovae, exotics, Test Beam and more...

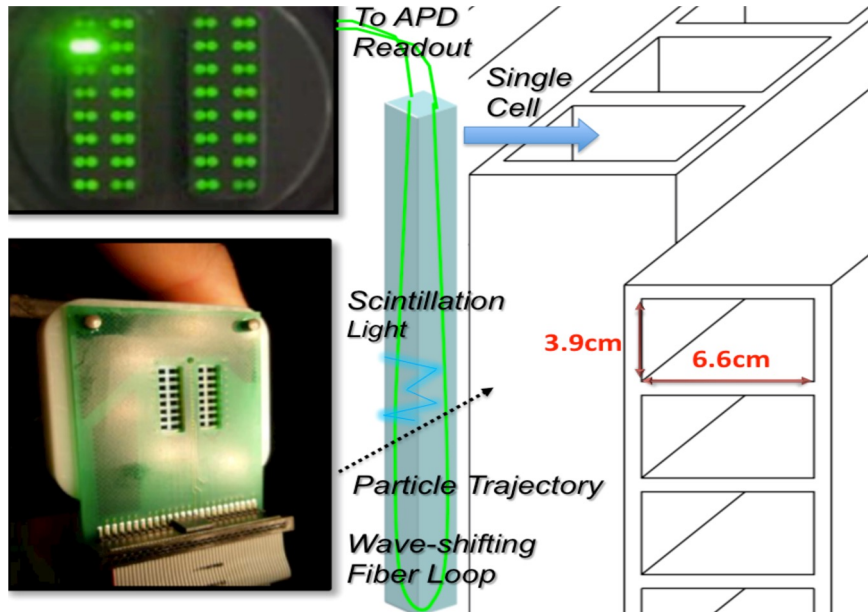
Neutrinos in the Main Injector(NuMI)

- Two running configurations
 - Neutrino
 - Antineutrino
- High energy protons interact on a carbon target
 - Creates a massive number of hadrons(π , K)
 - Pions are charged-selected by magnetic horns
 - Pions decay into neutrinos
- 14.6 mrad off-axis mitigates high energy background
- $\sim 2\text{GeV}$ energy peak



NOvA Detector Technology

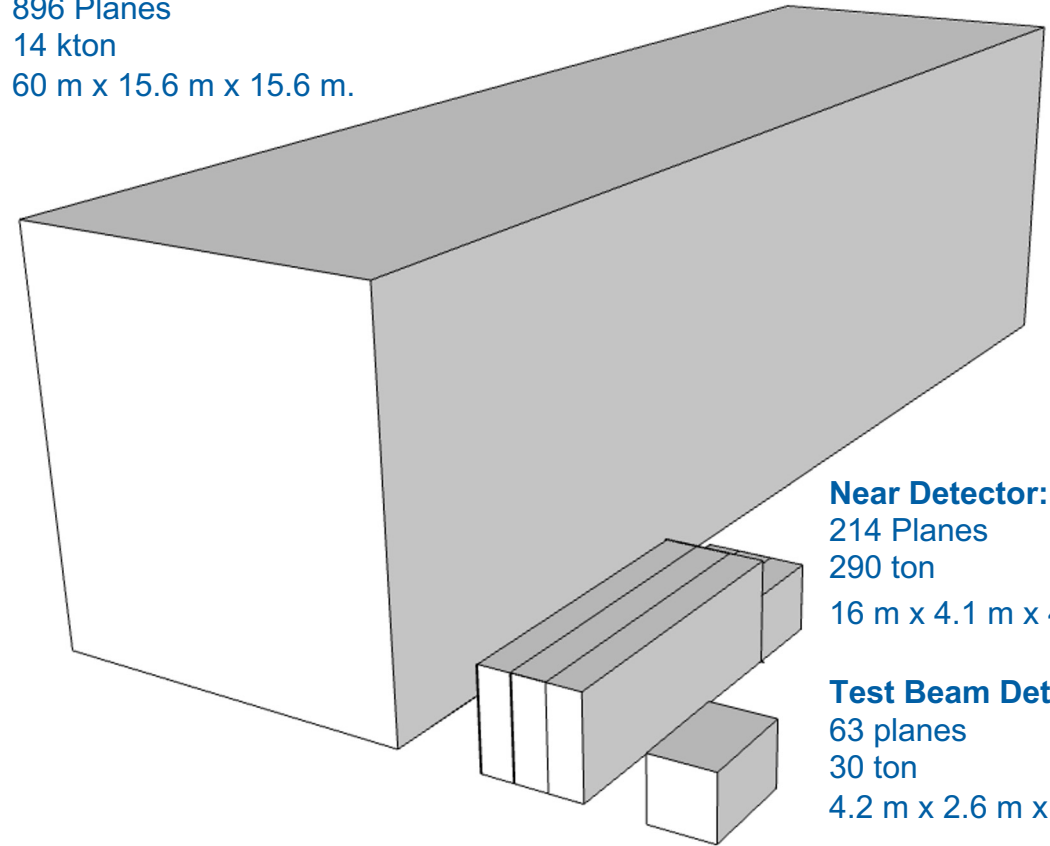
- Composed of vertical and horizontal planes to enable three-dimensional reconstruction
- Filled with liquid scintillator and instrumented with wavelength shifting fibers
- Scintillation light is collected by the fibers and read out by APDs



Avalanche Photodiode (APD).

Far Detector:

896 Planes
14 kton
60 m x 15.6 m x 15.6 m.



Near Detector:

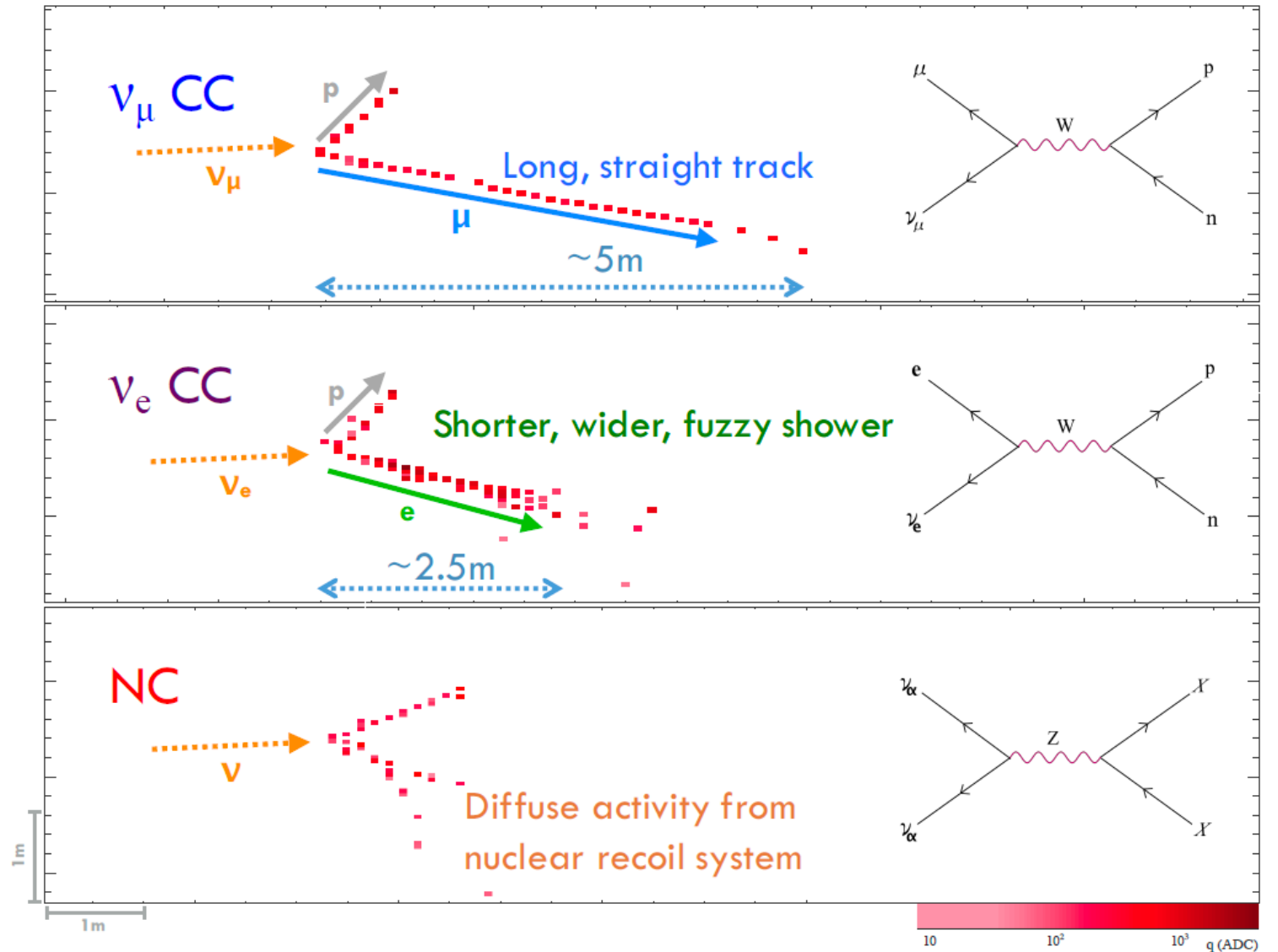
214 Planes
290 ton
16 m x 4.1 m x 4.1 m.

Test Beam Detector:

63 planes
30 ton
4.2 m x 2.6 m x 2.6 m.

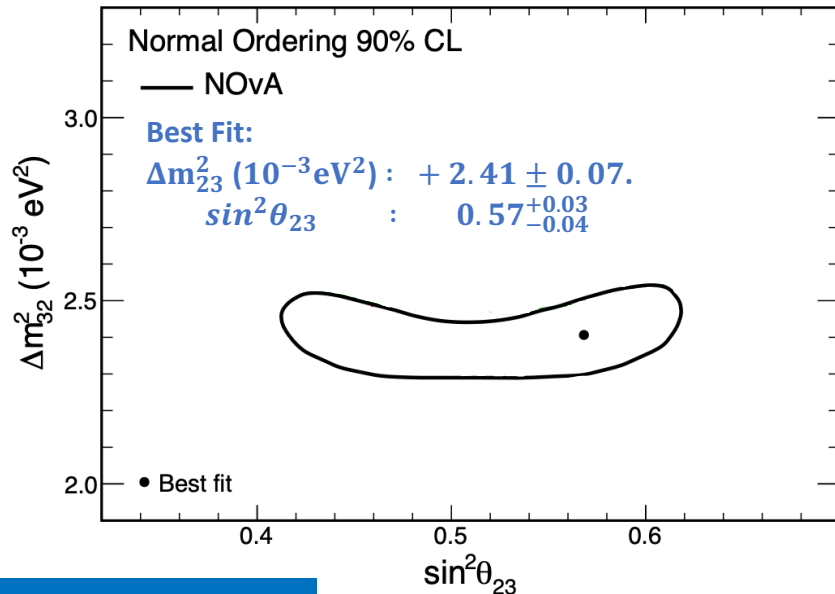
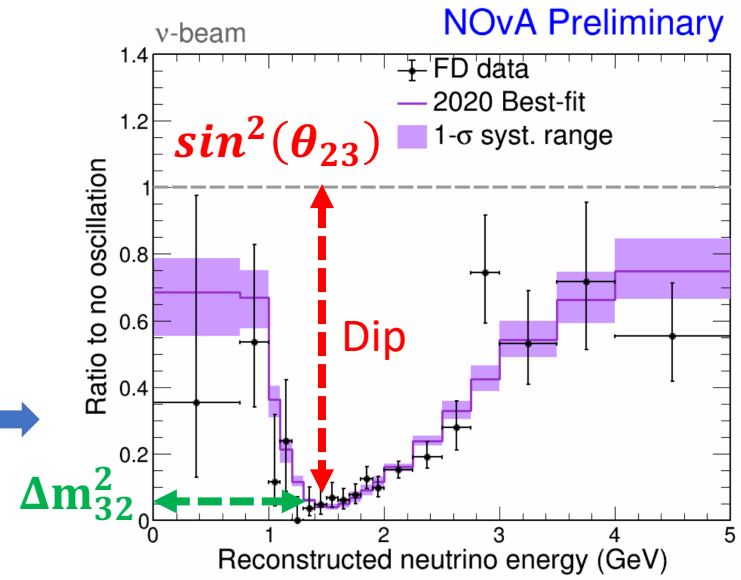
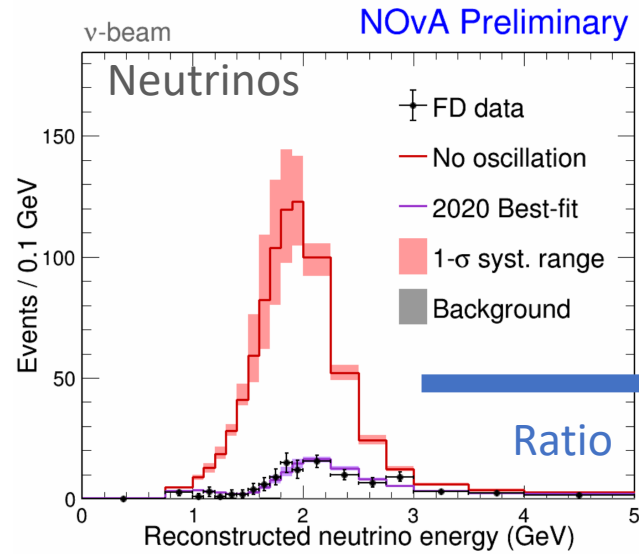
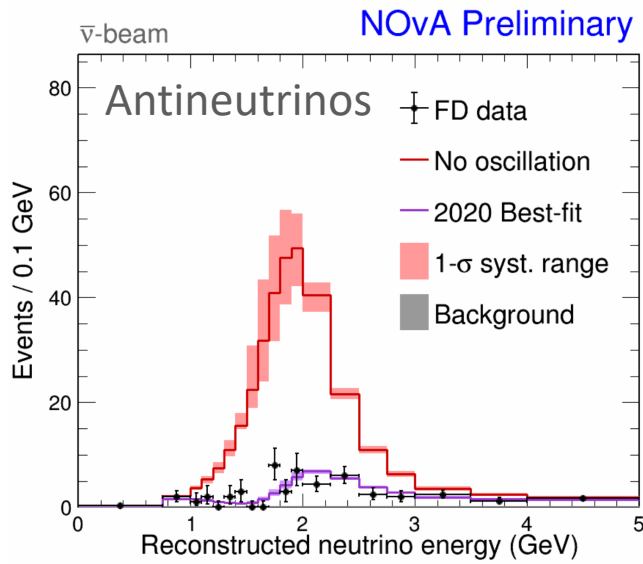
Event Classification

- Utilizes Convolutional neural networks(CNN), which is a deep learning technique to classify events
- Identifies ν_e CC , ν_μ CC , ν_τ CC and NC interactions
- A Boosted decision tree is implemented to classify cosmic ray events



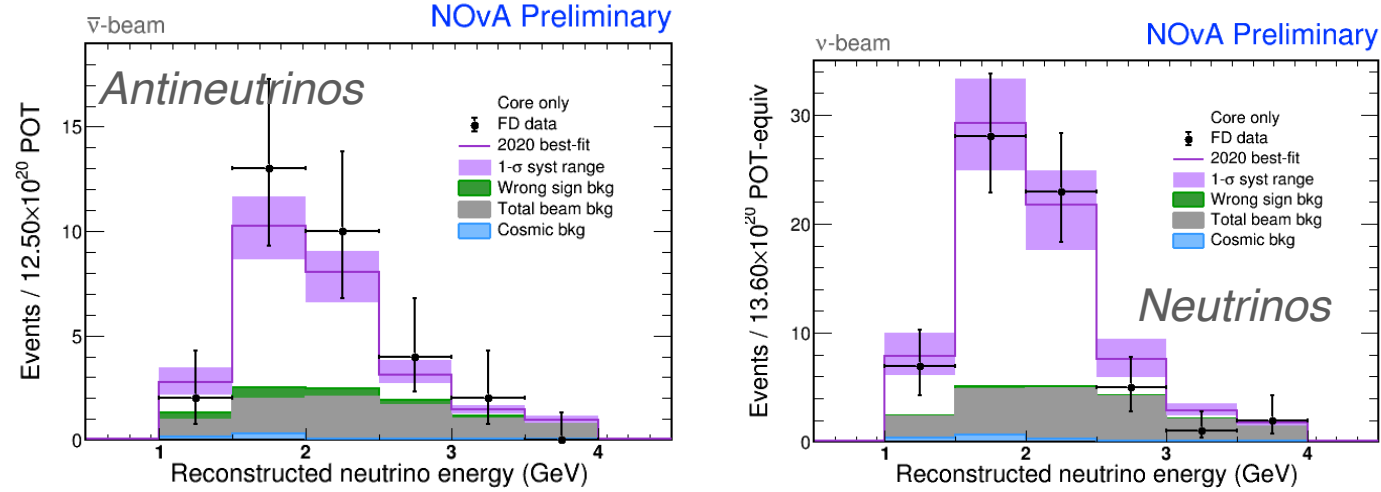
Selected NOvA Results

$\nu_\mu/\bar{\nu}_\mu$ Far Detector Spectra and Δm_{32}^2 vs $\sin^2\theta_{23}$ Fit Contour

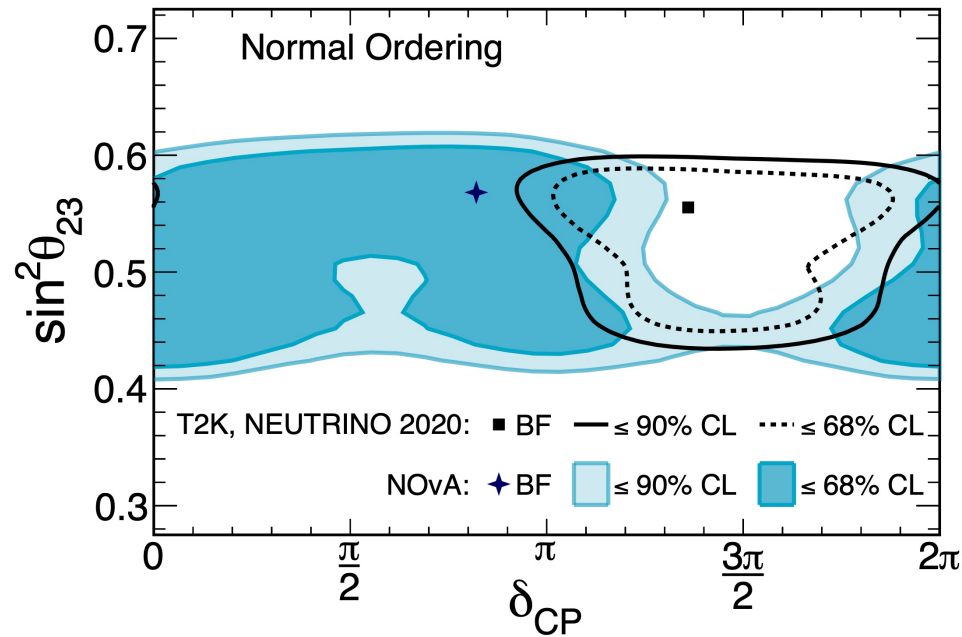


- Precision measurements of Δm_{32}^2 (3%) and $\sin^2\theta_{23}$ (5%)
- Preference for Normal Hierarchy and Upper Octant at 1σ and 1.2σ respectively

$\nu_e/\bar{\nu}_e$ Far Detector Spectra and $\sin^2\theta_{23}$ vs δ_{CP} Fit Contour



- Results are consistent with ν_e appearance
- NOvA disfavors $\nu_e / \bar{\nu}_e$ asymmetry
- T2K prefers $\nu_e / \bar{\nu}_e$ asymmetry

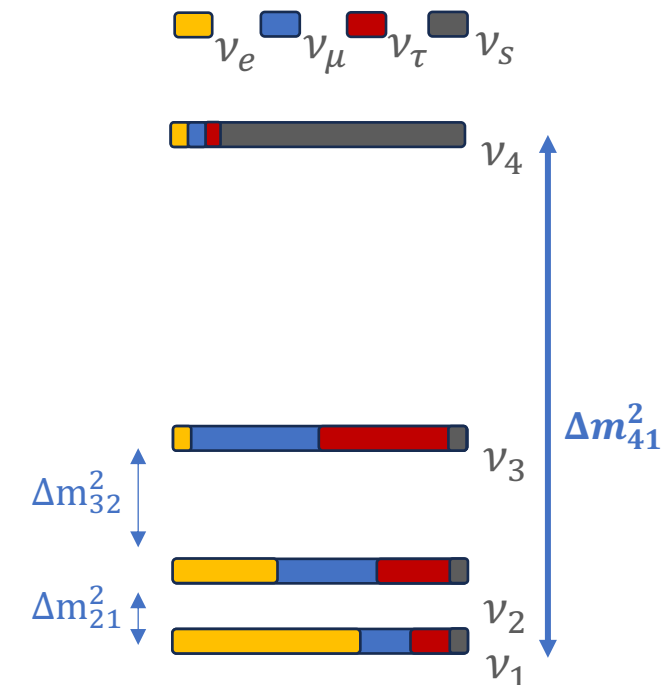
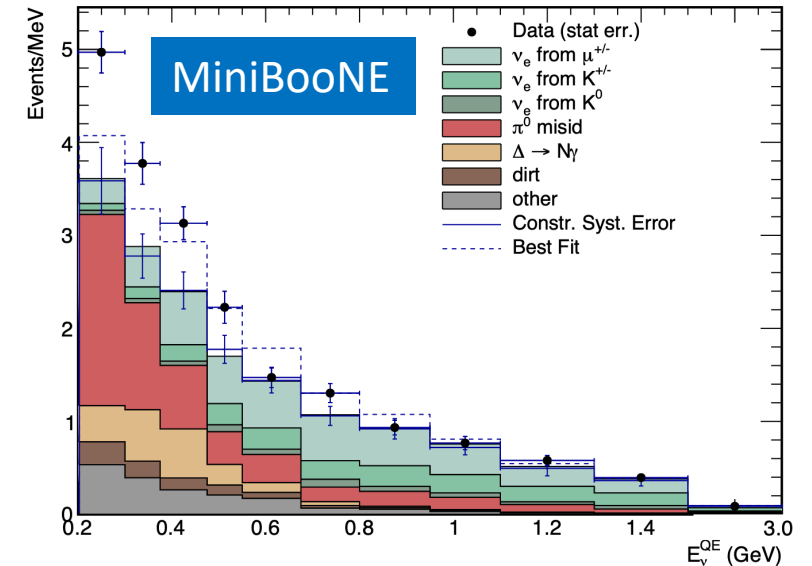


Are there more than 3 neutrino flavors?

> 3-flavor mixing?

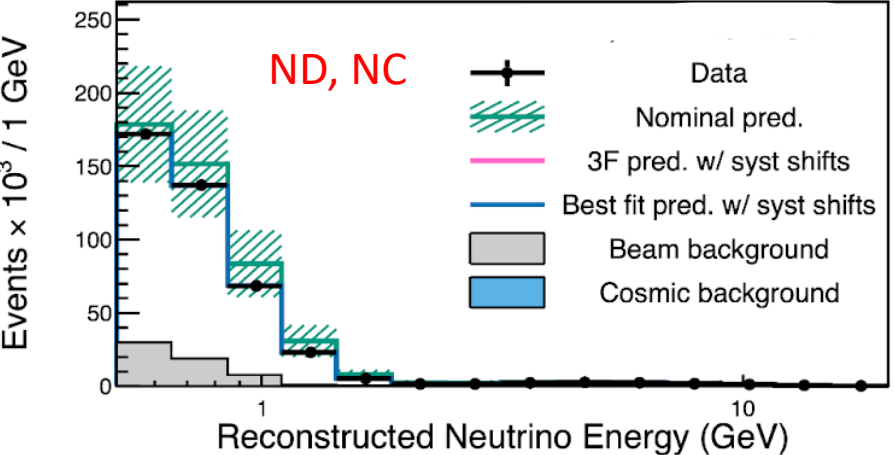
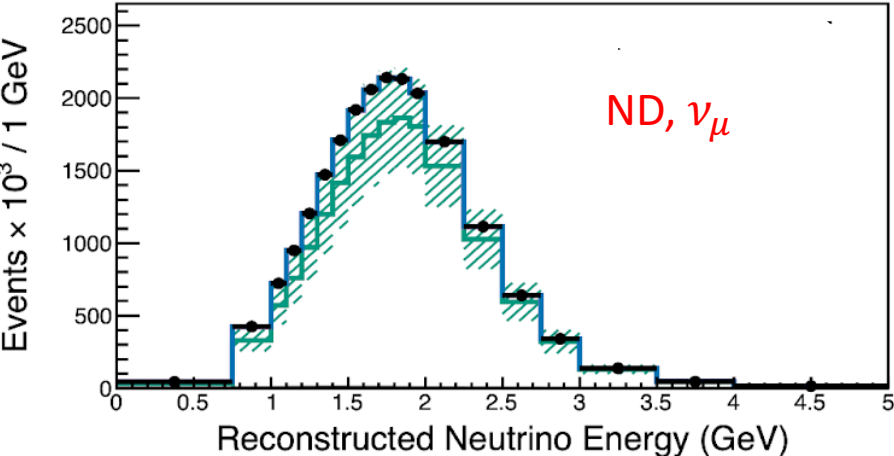
- Anomalies have been observed that are not expected in the 3-flavor model
 - They can be explained by adding a new $\Delta m^2 \sim 1eV^2$
 - Requires a new type of neutrino in the 3+1 model
 - This neutrino is called sterile since does not take part in the weak interaction
 - Can participate in oscillations with ν_e , ν_μ and ν_τ
- the extended model to 3+1 gives us access to
 - θ_{24} , θ_{34} , δ_{24} and Δm_{41}^2
- NOvA searches for sterile neutrinos in the ND and FD
- NC and ν_μ samples are used for the analysis

Phys. Rev. Lett. 121, 221801 (2018)

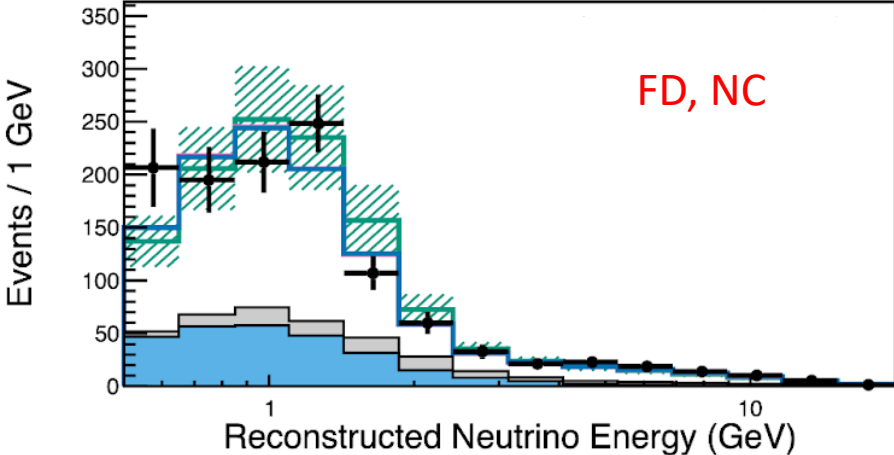
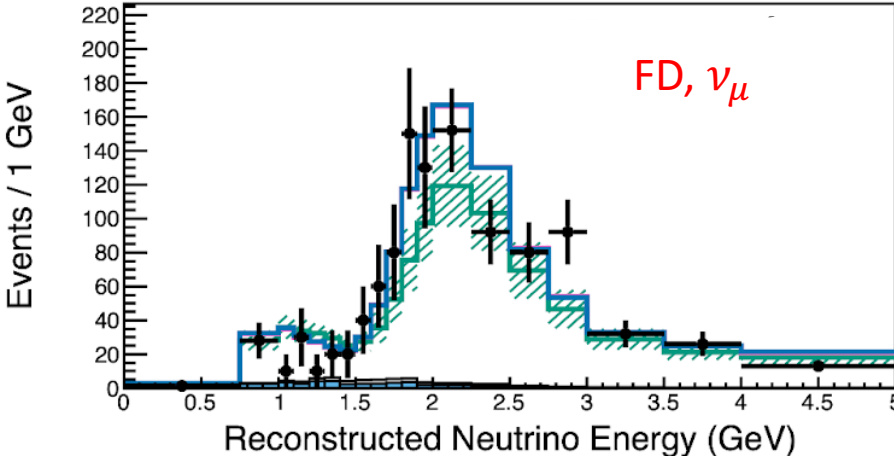


Searching for sterile neutrinos at NOvA

Neutrino Beam



NOvA Preliminary

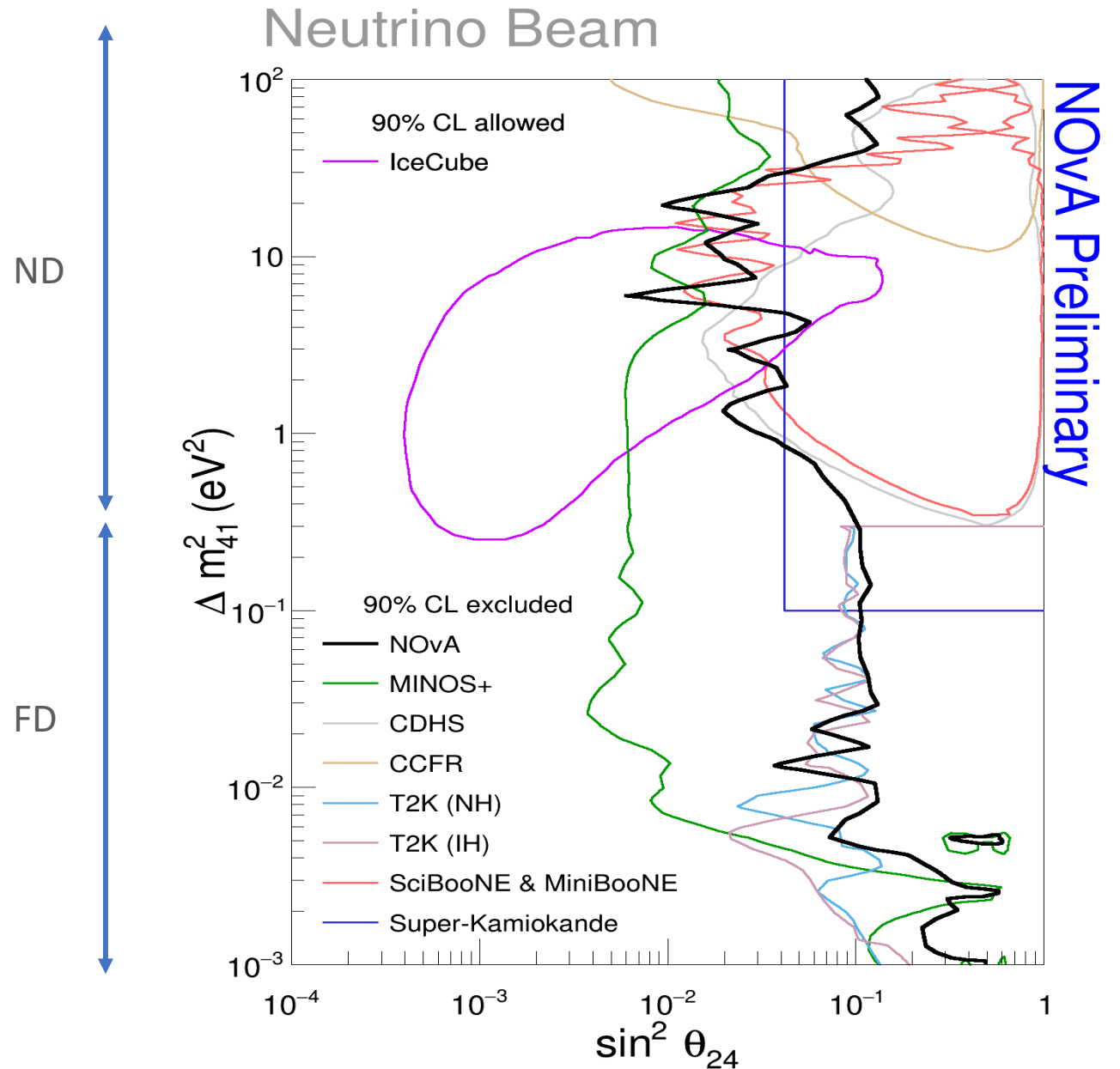


- The 4-flavor fit spectra aligns with the 3-flavor one
- Data is within the systematic error band
- Consistent with 3 flavor-oscillations

Δm_{41}^2 vs $\sin^2(\theta_{24})$ Fit Contour

- NOvA found no evidence of sterile neutrino oscillations
- Near Detector region is systematically limited
- Competitive values for $\Delta m_{41}^2 \sim 10 eV^2$

Fermilab WC Seminar:
<https://indico.fnal.gov/event/56765/>



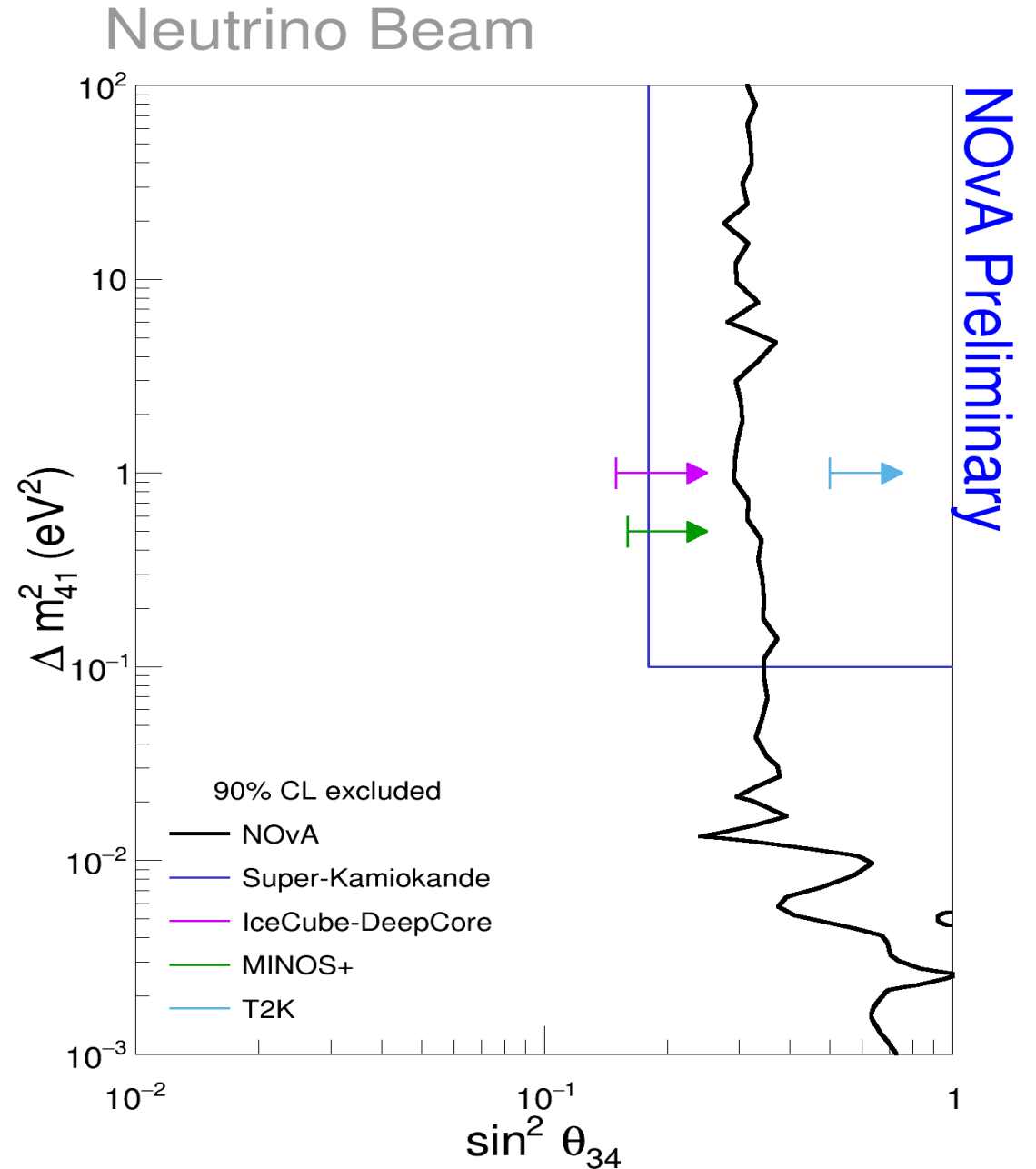
Δm_{41}^2 vs $\sin^2(\theta_{34})$ Fit Contour

- NOvA found no evidence of sterile neutrino oscillations
- Near Detector region is systematically limited
- **World-Leading results for θ_{34} as a function of Δm_{41}^2**

Fermilab WC Seminar:
<https://indico.fnal.gov/event/56765/>

ND

FD



NOvA into the Future

- NOvA is expected to run until 2026 increasing the amount of data!
- With the full data set and beam upgrades, NOvA can reach the 3σ mass hierarchy determination for 30% to 50% of δ_{CP} values
- NOvA, T2K joint fit!
- NOvA Test Beam program is dedicated to reduce some of the biggest systematic uncertainties in the NOvA analyses





<http://novaexperiment.fnal.gov>

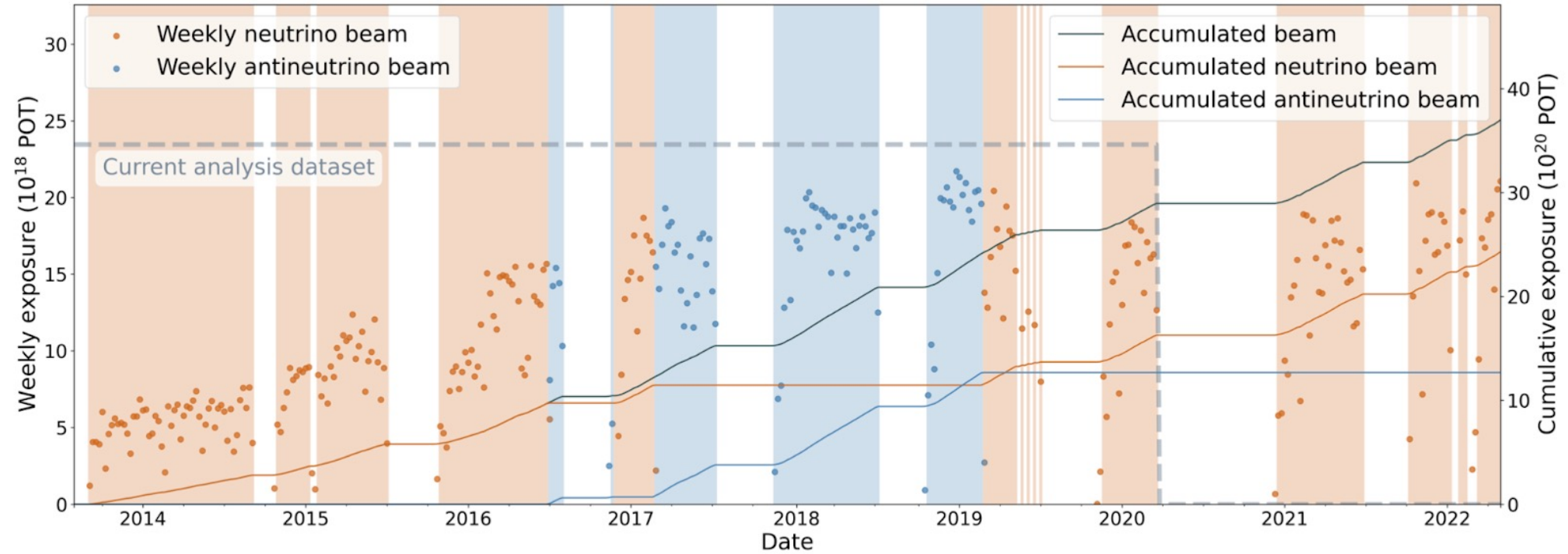


Thank you!

David Dueñas – New Perspectives Conference. 17

Additional slides

NuMI beam exposure



- Current analyses :
 - 13.6×10^{20} POT neutrino-beam data
 - 12.5×10^{20} POT antineutrino-beam data

