NOvA in 10 Minutes

New Perspectives Meeting 2019

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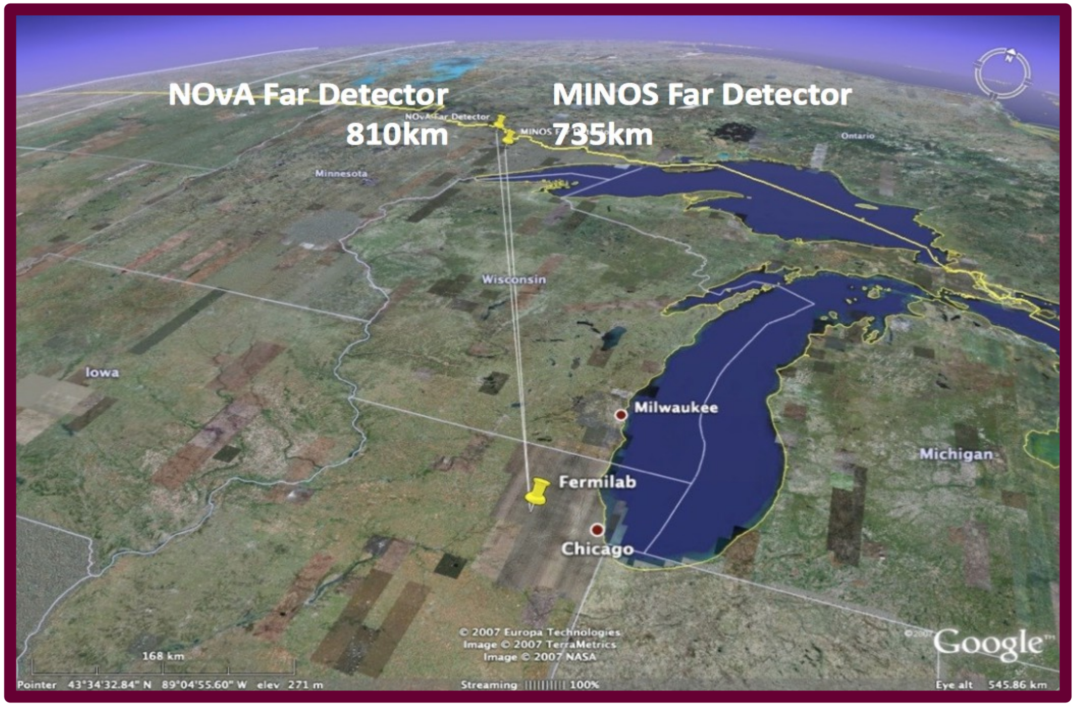
The NOvA Experiment

NOvA is a long-baseline neutrino oscillation experiment.

The experiment is comprised of two detectors both a near positioned at Fermilab and and far in Minnesota.

The NOvA detectors observe the disappearance of $\nu_\mu / \bar{\nu}_\mu$ and the appearance of $\nu_e / \bar{\nu}_e$

These oscillations depend upon many parameters including:
Δm^2_{21}, Δm^2_{32} , θ_{12}, θ_{23}, θ_{13}, and δ_{CP}



$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} \text{PMNS} \\ \text{matrix} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

NOvA's Physics Goals

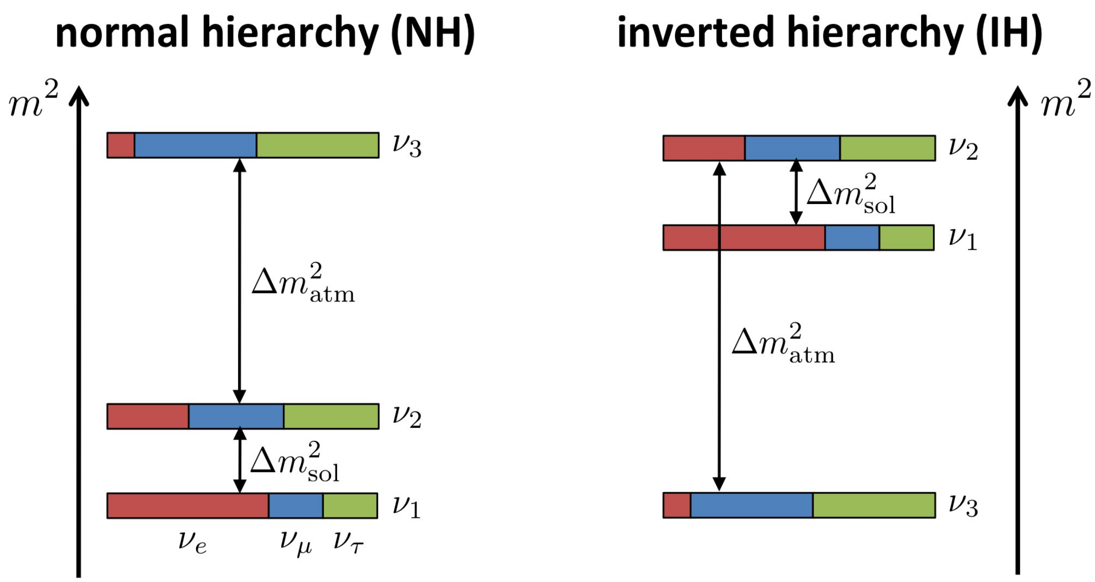
$\nu_\mu \to \nu_e$ $\bar{\nu}_\mu \to \bar{\nu}_e$
$\nu_\mu \to \nu_\mu$ $\bar{\nu}_\mu \to \bar{\nu}_\mu$

NOvA uses the neutrino oscillation measurements to obtain **three primary physics goals**

1. Probe the neutrino mass hierarchy.

2. Determine the octant of θ_{23}.

3. Find evidence of CP violation to determine if the symmetry between neutrinos and anti-neutrinos is broken.



More research goals include:

- Searches for sterile neutrinos
- Cross section measurements
- Supernova neutrinos
- Cosmic ray physics

The NOvA Detectors

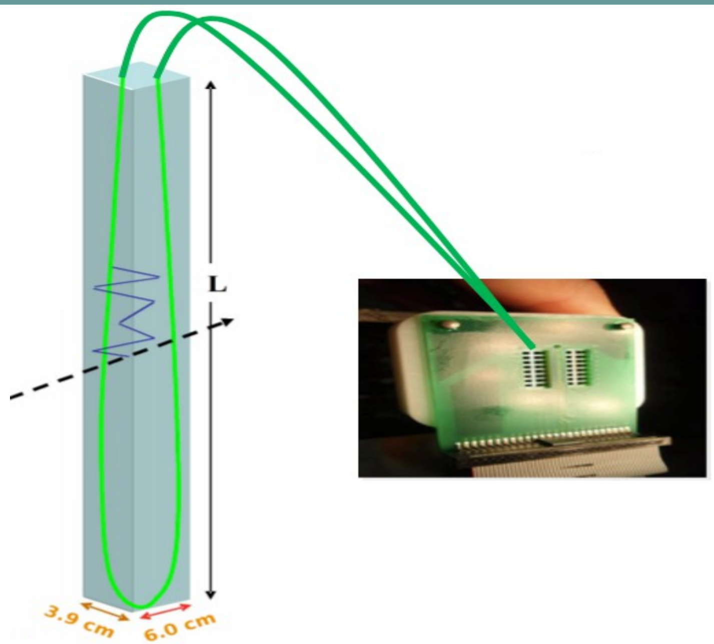
Functionally Identical Detectors

Made of PVC planes with alternating orientations.

Filled with liquid scintillator that is
~95% mineral oil
~ 5% Pseudocumene and PPO

Light is collected by Avalanche PhotoDiodes

Stationed 14 mrad off-axis.



Near Detector

Sits 105 m underground in front of the NuMI beam.

Has approximately 20,000 cells.

Far Detector

Positioned on the surface 810 km away in Ash River, MN.

Has approximately 344,000 cells.

65% active detector mass.

The NuMI Beam

How it works

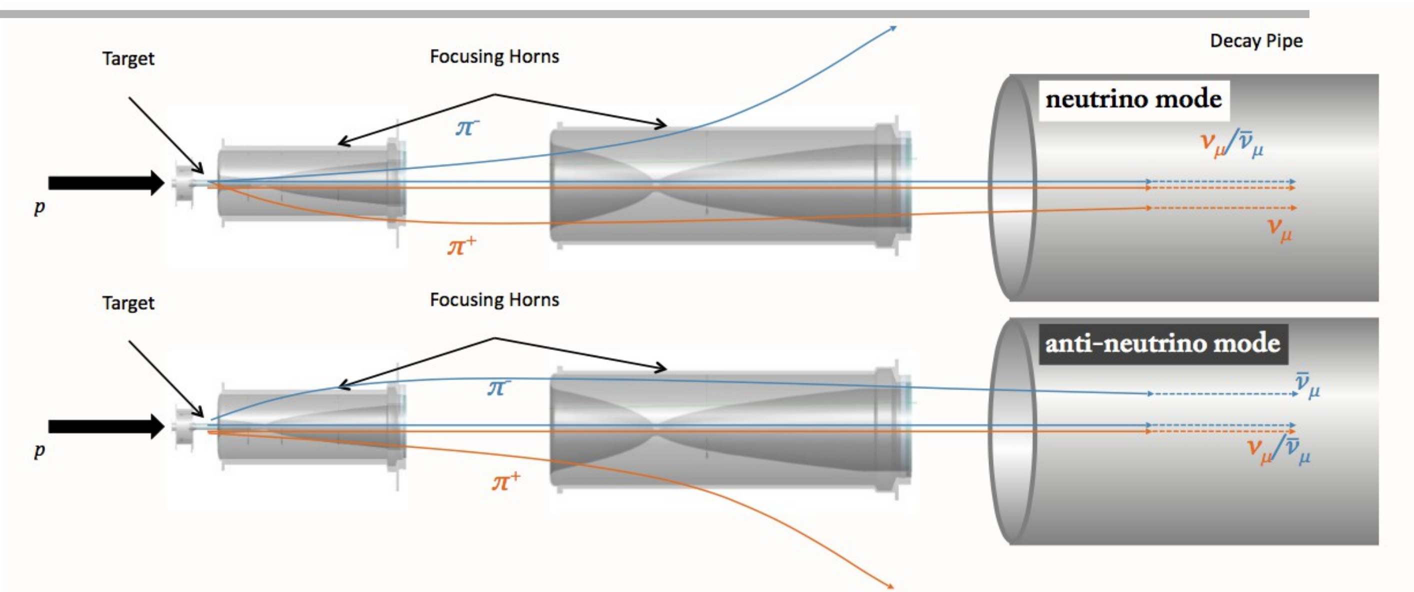
Create a beam of 120 GeV protons.

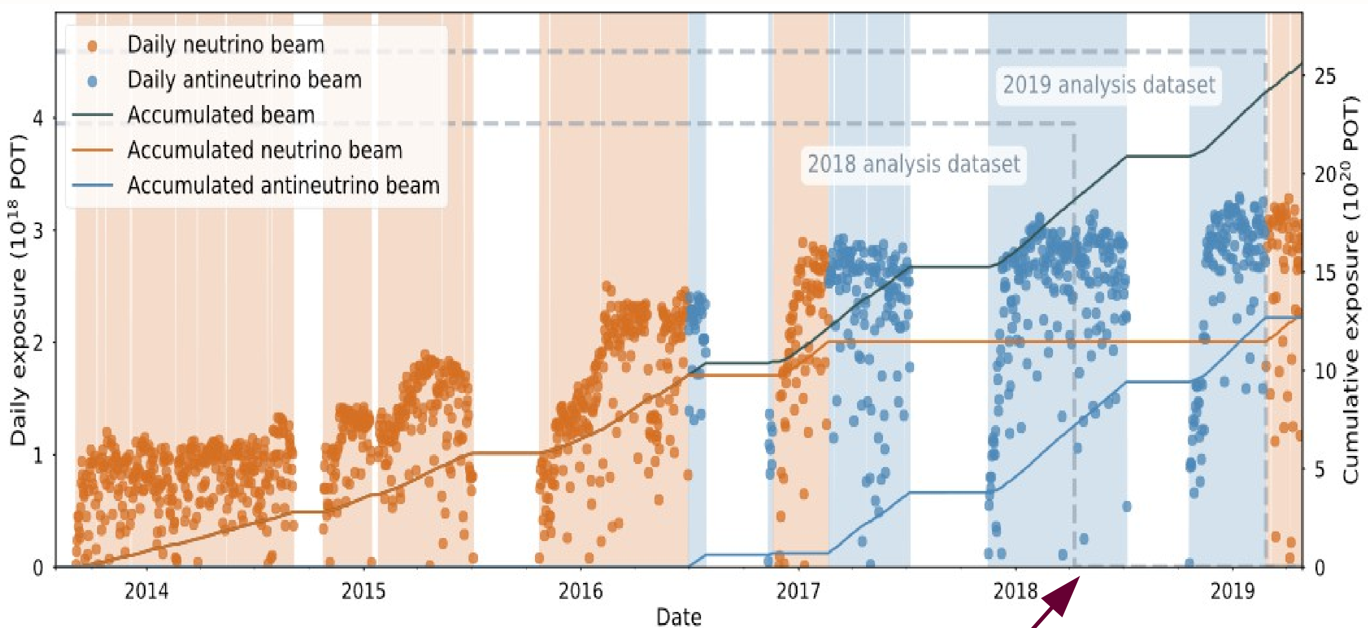
Hits a graphite target producing a shower of mesons.

Directed by magnetic focusing horns into a decay pipe.

Magnet sign selects mesons for a neutrino mode and an anti-neutrino mode.

NuMI beam operating at over 700 kW.



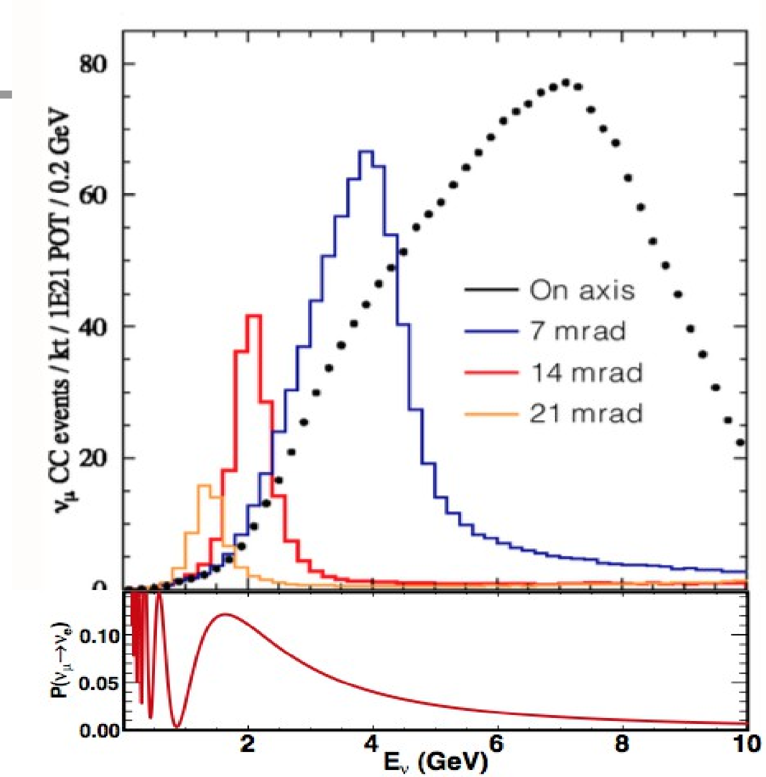


*New 2019 NOvA Results Thursday at the User's Meeting! *

This talk is on the 2018 analysis

The NuMI Beam

Kinematics of pion decay allows for a selection of energy ranges

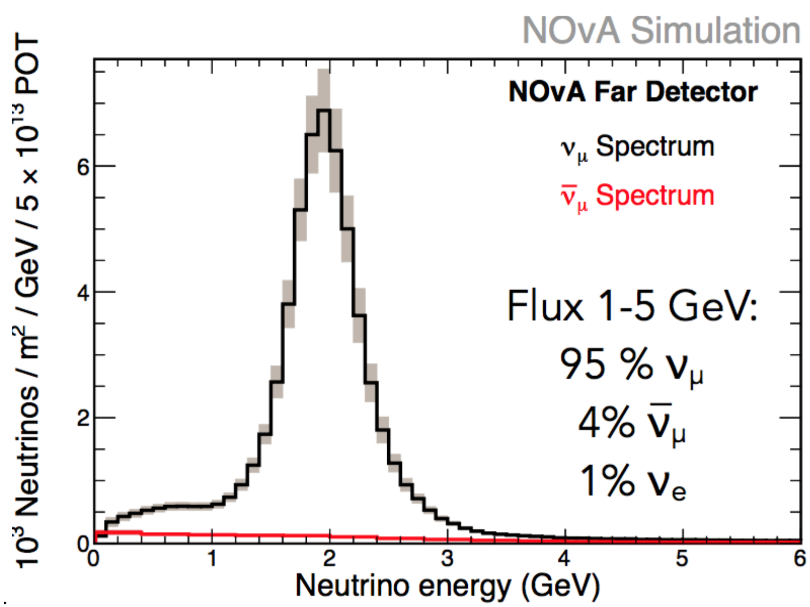


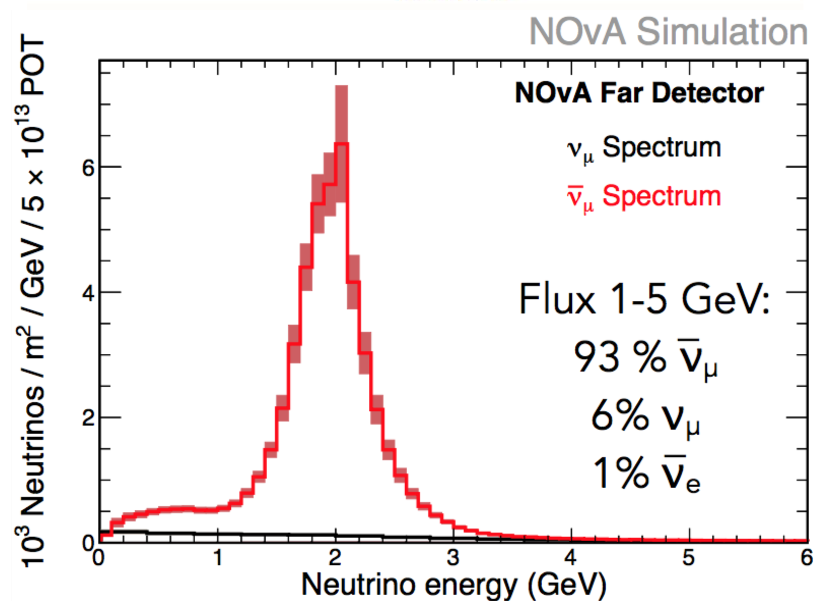
NuMI Beam Off-Axis Advantages

Neutrino beam is narrowly peaked near the oscillation maximum

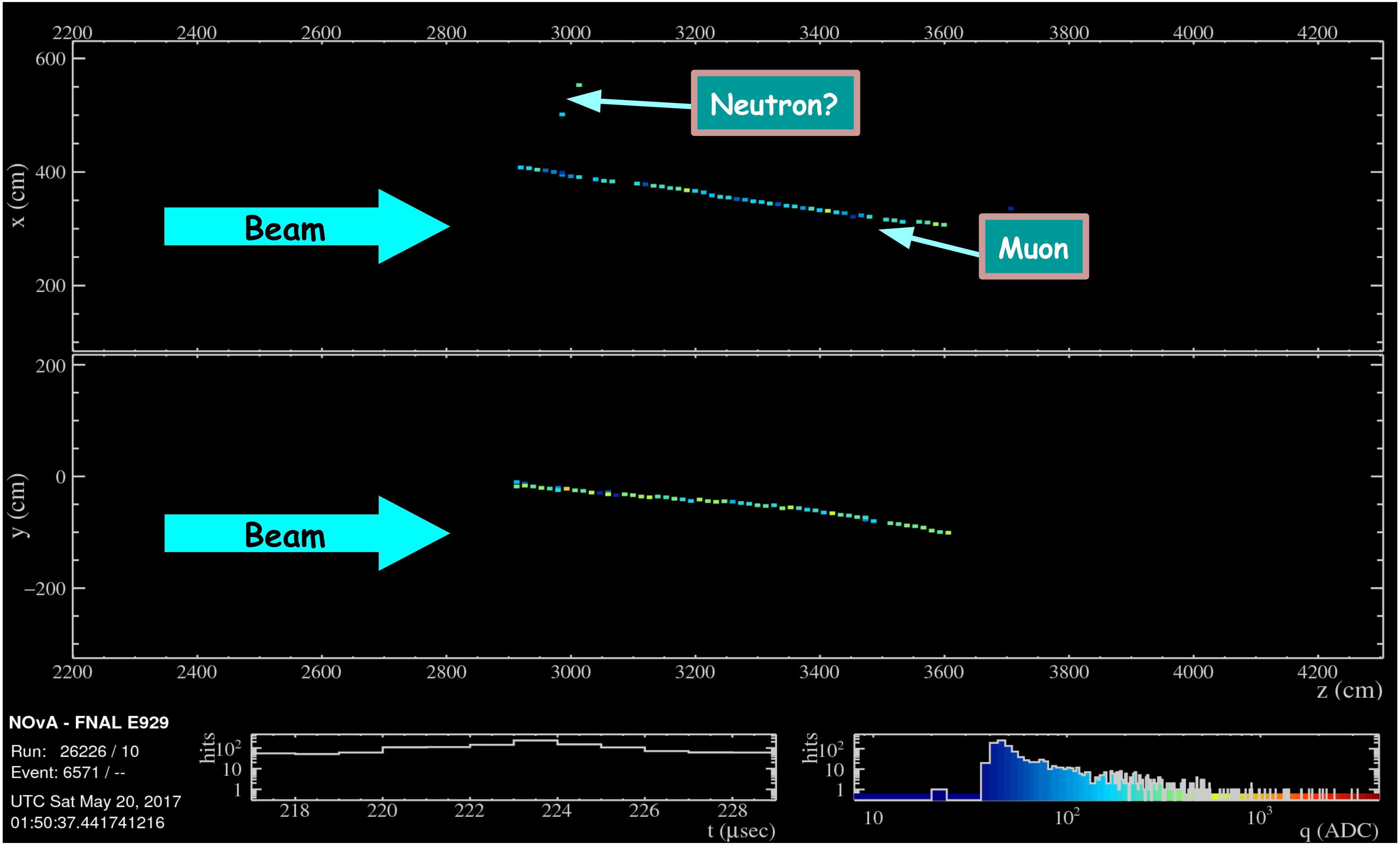
Reduced backgrounds

Reduced wrong sign contamination



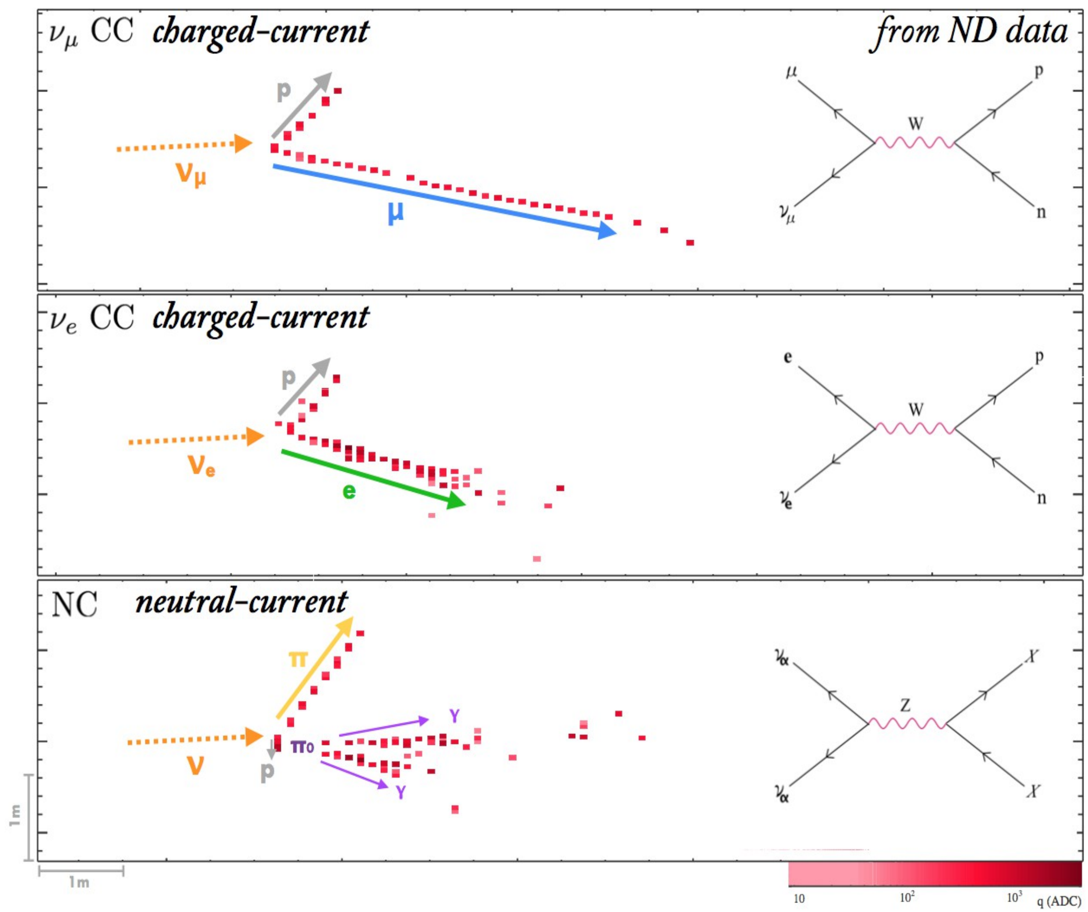


NOvA Anti-Neutrino Interaction Candidate



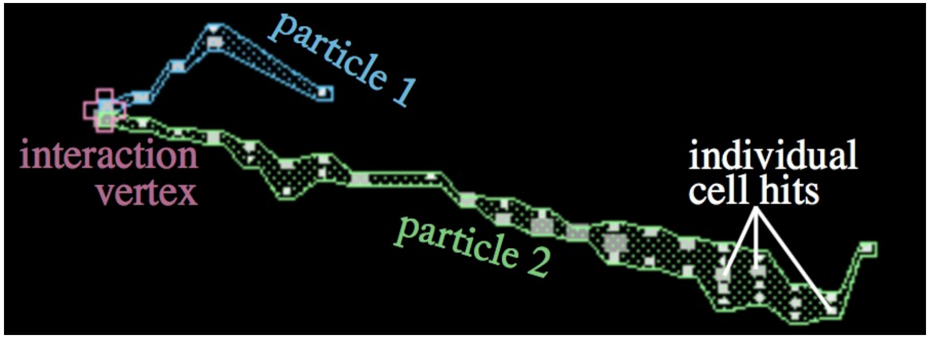
NOvA Neutrino Event Topologies and Reconstruction

Event Topologies



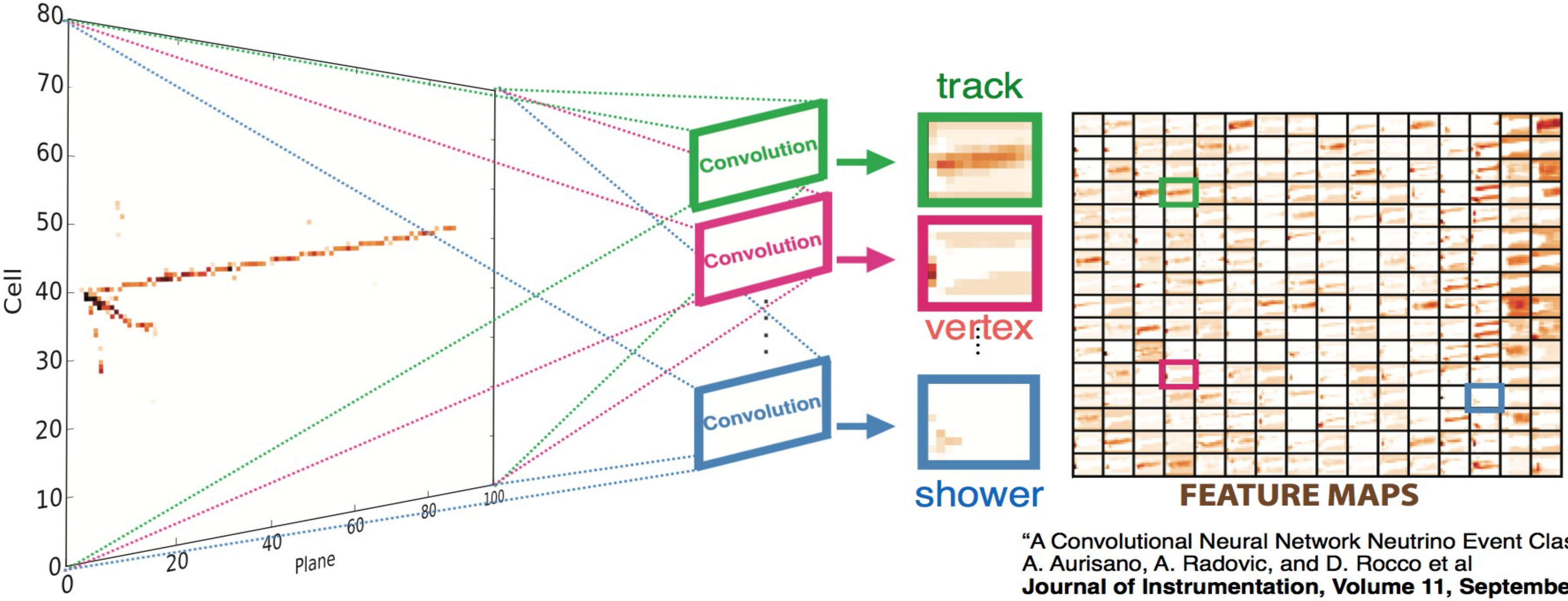
Event Reconstruction

- Group together hits that are close in space and time
- Use these to find tracks and make clusters of those hits close together
- Identify the muon track and vertex
- Sum up the leptonic and hadronic energies to reconstruct the neutrino energy



Classification of Neutrino Interactions

- NOvA pioneered the use of Convolutional Neural Networks in neutrino physics
- Each interaction is treated as a picture and features such as showers, the vertex, etc are extracted from the data
- Classifies the type of event and uses this as context to identify particles as well!



"A Convolutional Neural Network Neutrino Event Classifier"
A. Aurisano, A. Radovic, and D. Rocco et al
Journal of Instrumentation, Volume 11, September 2016

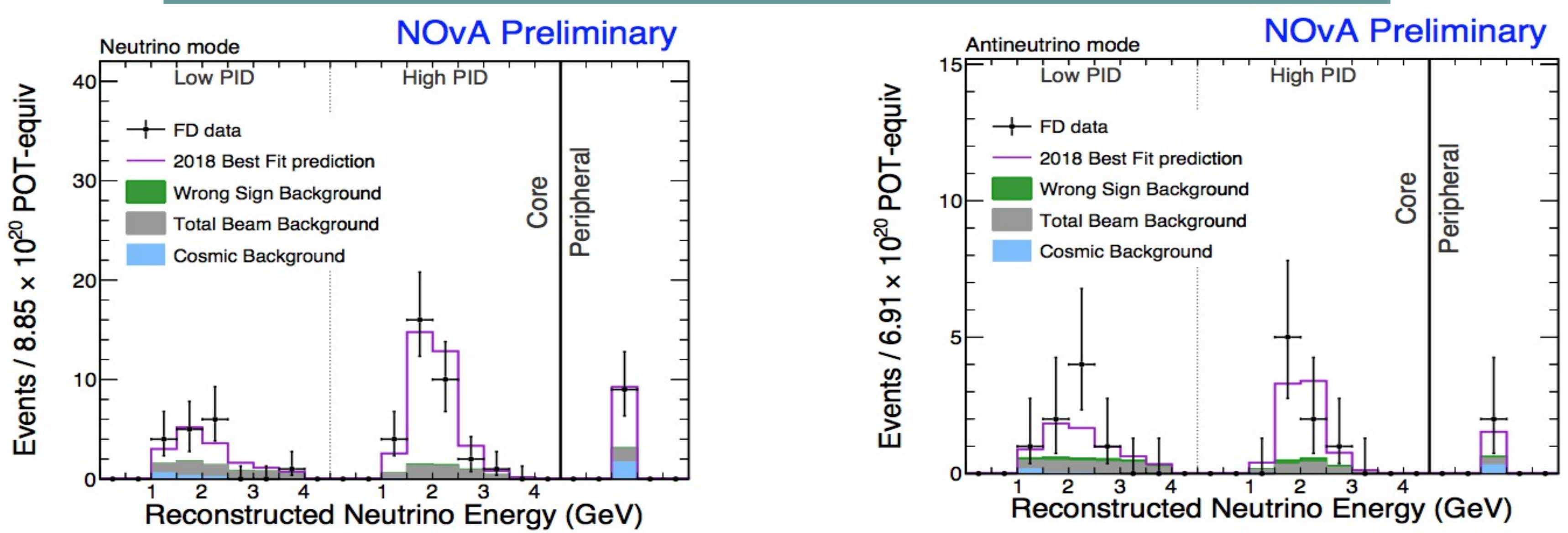
Recent NOvA Results
Electron Neutrino Candidate Counts

Neutrino Mode

- Observed 58 events with 15 expected to be background
  - 11 beam, 3 cosmic, and 1 wrong sign

Anti-neutrino Mode

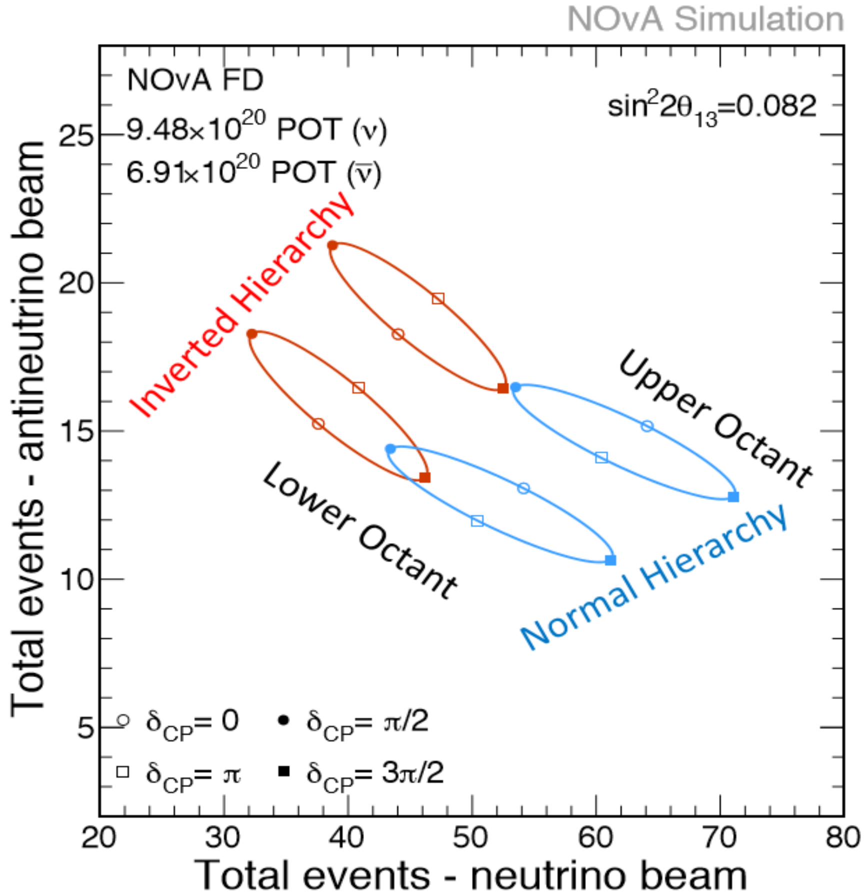
- Observed 18 events and expect 5.3 as background
  - 3.5 beam, 1 cosmic, and 1 wrong sign



Used this to produce first oscillation results using both neutrino and anti-neutrino data!

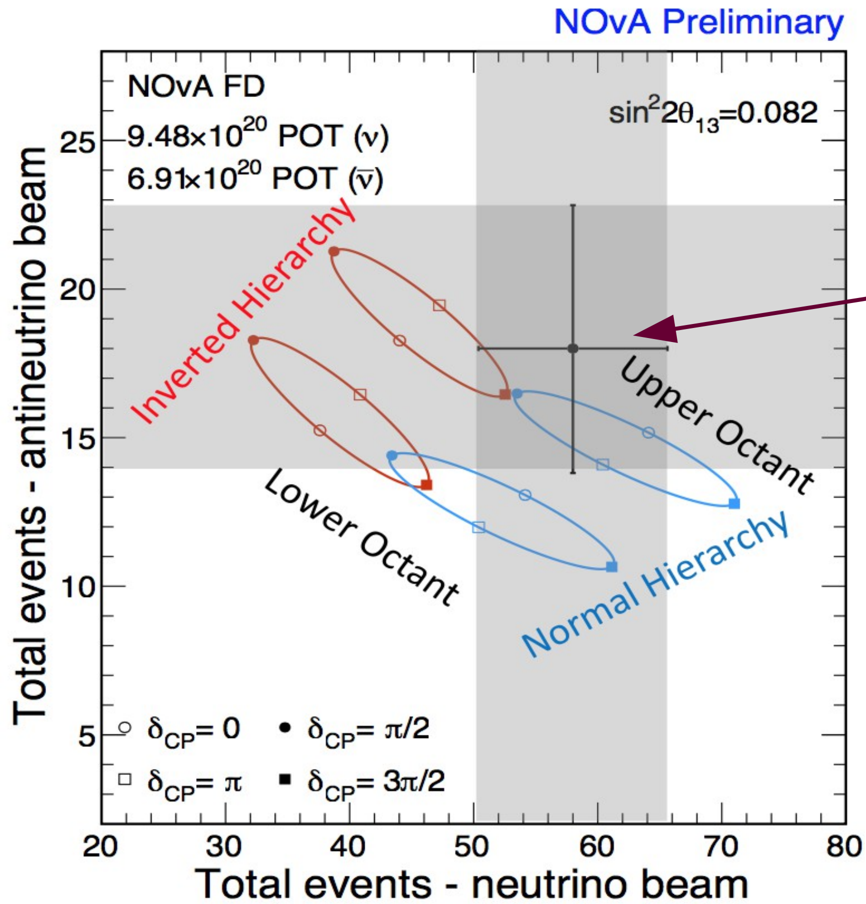
Recent NOvA Results Hierarchy and Octant

Ellipses correspond to how the CP violating phase changes with the number of observed neutrino and anti-neutrino events given a selection on the hierarchy and the octant of θ_{23}



Recent NOvA Results Hierarchy and Octant

NOvA 2018 results favor the normal hierarchy and the upper octant

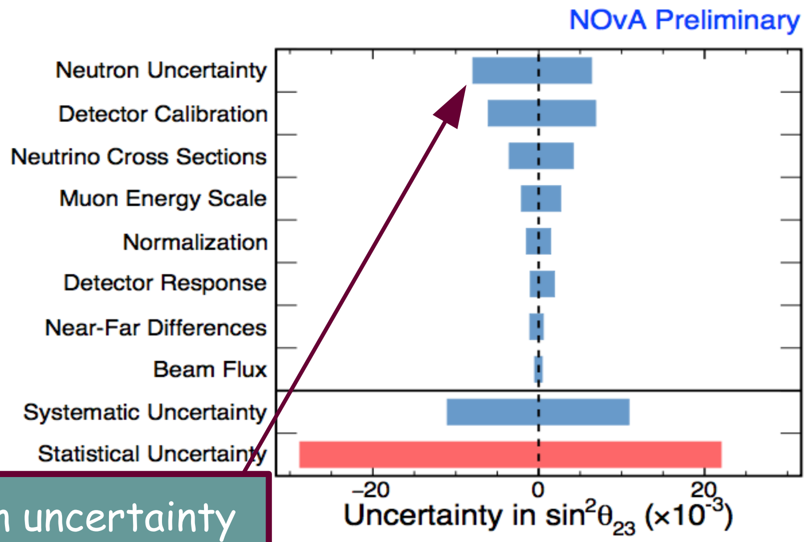


NOvA's 58 neutrino and 18 anti-neutrino observed events

The Future at NOvA

Given favorable parameters the expectations are to have:

- 3σ sensitivity to hierarchy by 2020
- 2σ sensitivity to CP-violating phase in 30-50% of the parameter space by 2024



Neutron uncertainty is important for anti-neutrino data!

NOvA test beam is taking data this year!

More NOvA This Week...

New Perspectives

NOvA Talks:

- NuMI Beam Muon Monitor Simulation for Neutrino Beam Quality Improvement....................Yiding Yu
- Neutrino Event Classification with Deep Learning in NOvA..Grand Nikseresht
- NOvA's Far Detector Predictions and Understanding Key Systematic Uncertainties.......Ashley Back
- NOvA's Approaches on Estimation of Wrong Sign Contamination ....Abilash Dombara
- Cross Section Model Tuning and Multiplicity Studies in NOvA..........................Maria Martinez-Casales
- The NOvA Test Beam Program..Teresa Lackey

User's Meeting

NOvA Talks-

- **New NOvA Results (Last Session Thursday ....Jeremy Wolcott**

NOvA Posters-

- Test beam ....Dung Phan
- Steriles..Anne Norrick
- Numu CC Cross Section Measurement Update...Shih-Kai Lin
- Nue CC Cross Section Analysis Status..Matthew Judah
- 3 Flavor Oscillations in NOvA...Thomas Warburton
- Numu CC Pion Production..Steven Calvez

The NOvA Collaboration

The NOvA collaboration is made up of more than **240 scientists and engineers** from **50 institutions** in **7 countries!**

http://novaexperiment.fnal.gov

Backup Slides

Why Study Neutrinos?

First postulated in 1930 in order for beta decay follow conservation laws.

Took **more than 20 years** to detect at **Savannah River, South Carolina**. A feat that was awarded the **1995 Nobel Prize** in Physics.

The **solar neutrino problem** proved our understanding was not complete. Was solved by the **discovery of neutrino oscillations**.

Illustration: © Johan Jarnestad/The Royal Swedish Academy of Sciences

Since then more questions have been asked.

- Are there only 3 flavors of neutrinos?
- What is the mass of the neutrino? Which hierarchy is correct?
- Do neutrinos hold answers to CP violation?

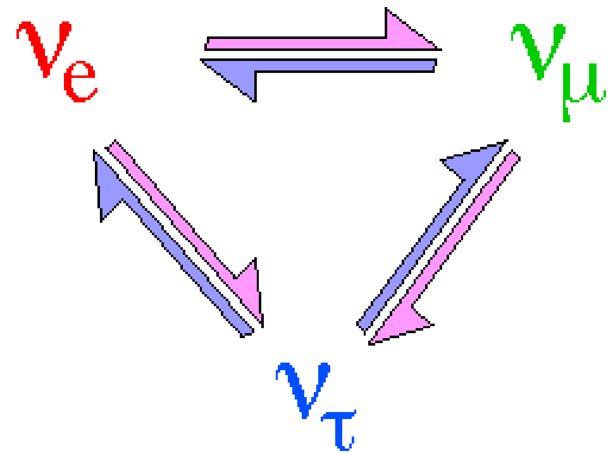
Neutrino Oscillations

Neutrinos start as one "flavor" but can be detected as another (In NOvA we see $\mu \rightarrow e$)

These oscillations depend upon many parameters including:

Δm^2_{21}, Δm^2_{32}, θ_{12}, θ_{23}, θ_{13}, and δ_{CP}

We can get a handle on the values of these parameters from the relationship between the mass and flavor eigenstates



Get this from the probability of ν_e appearance

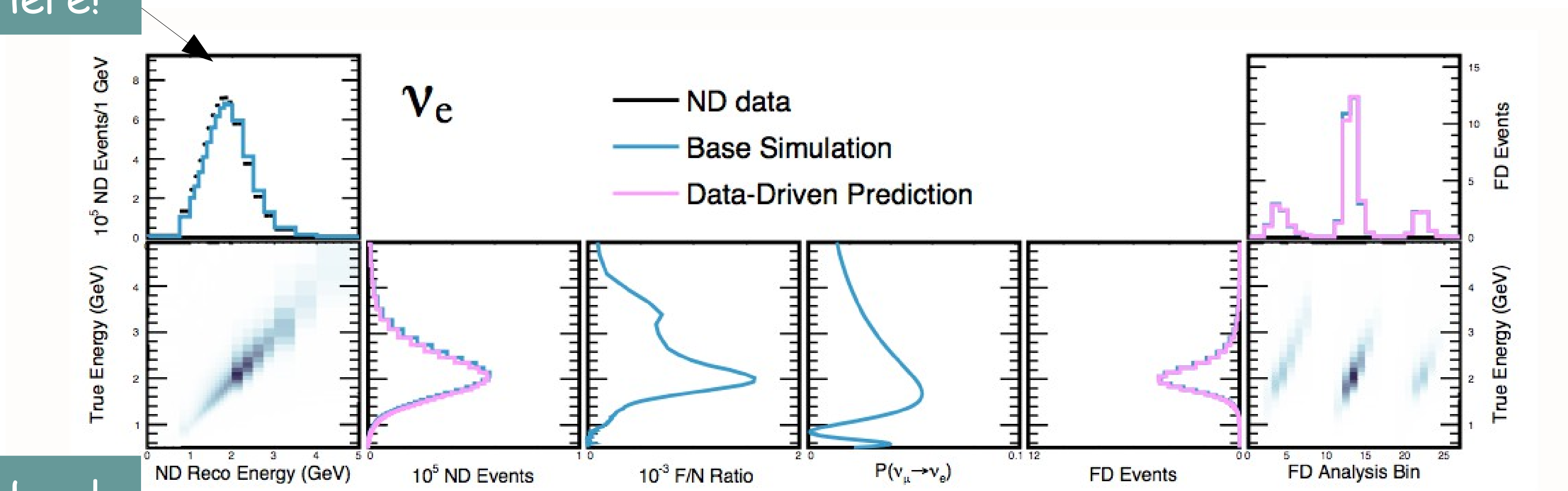
$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} \text{PMNS} \\ \text{matrix} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

Disappearance Probability

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

Extrapolation

Start Here!



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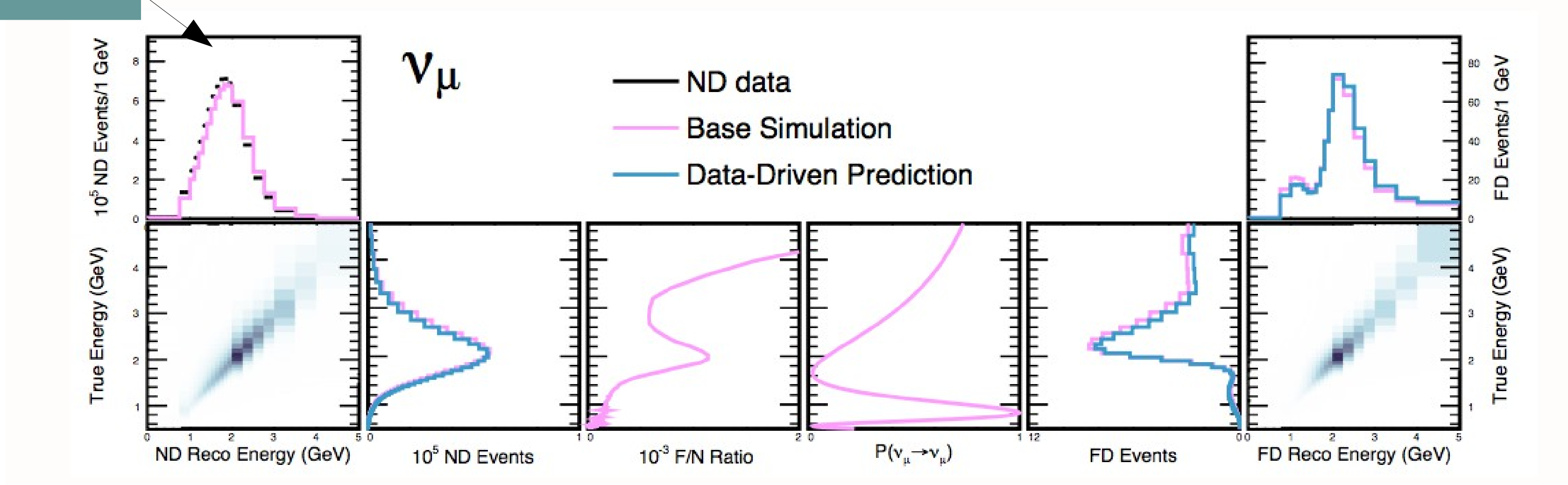
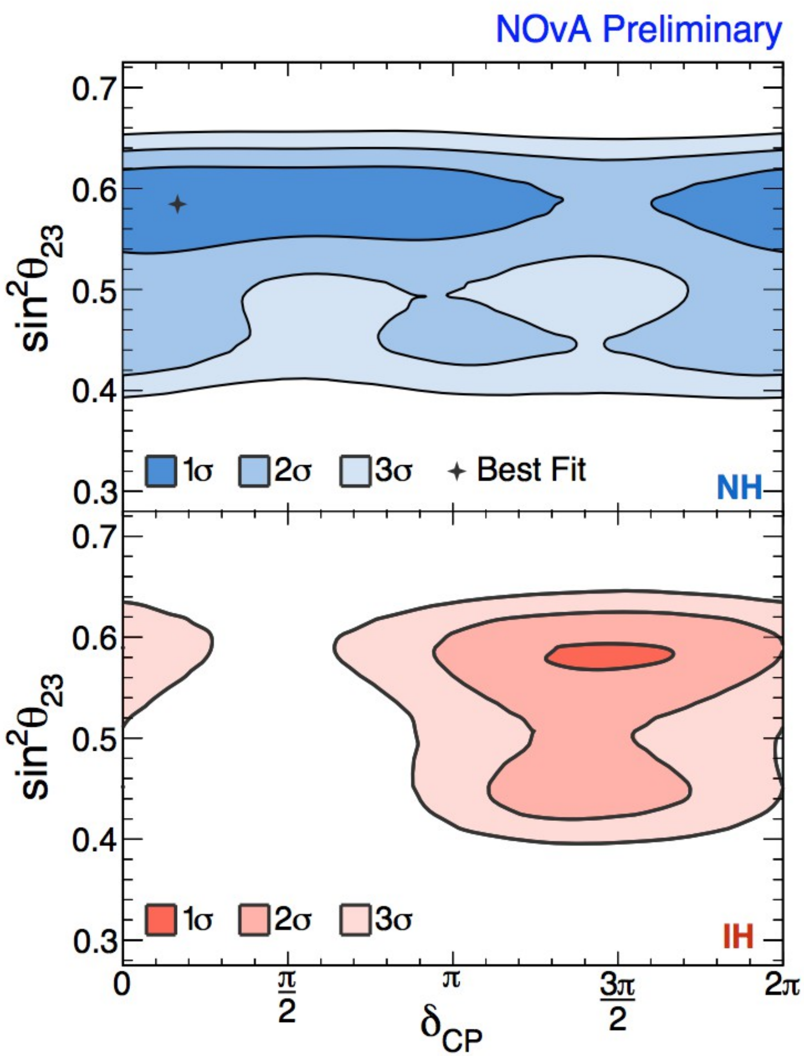
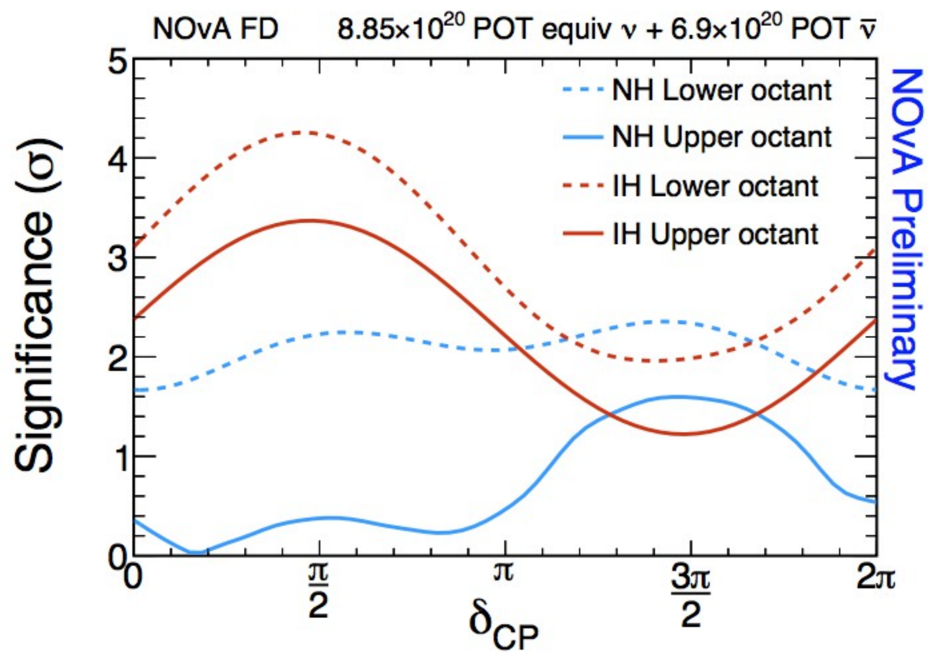


Recent NOνA Results – Oscillation Parameters





Best fit:

- $\delta_{CP} = 0.17\pi$
- $Sin^2\theta_{23} = 0.58 \pm 0.03$
  Upper Octant
- $\Delta m^2_{32} = (2.51^{+0.12}_{-0.08}) * 10^{-3} eV^2$

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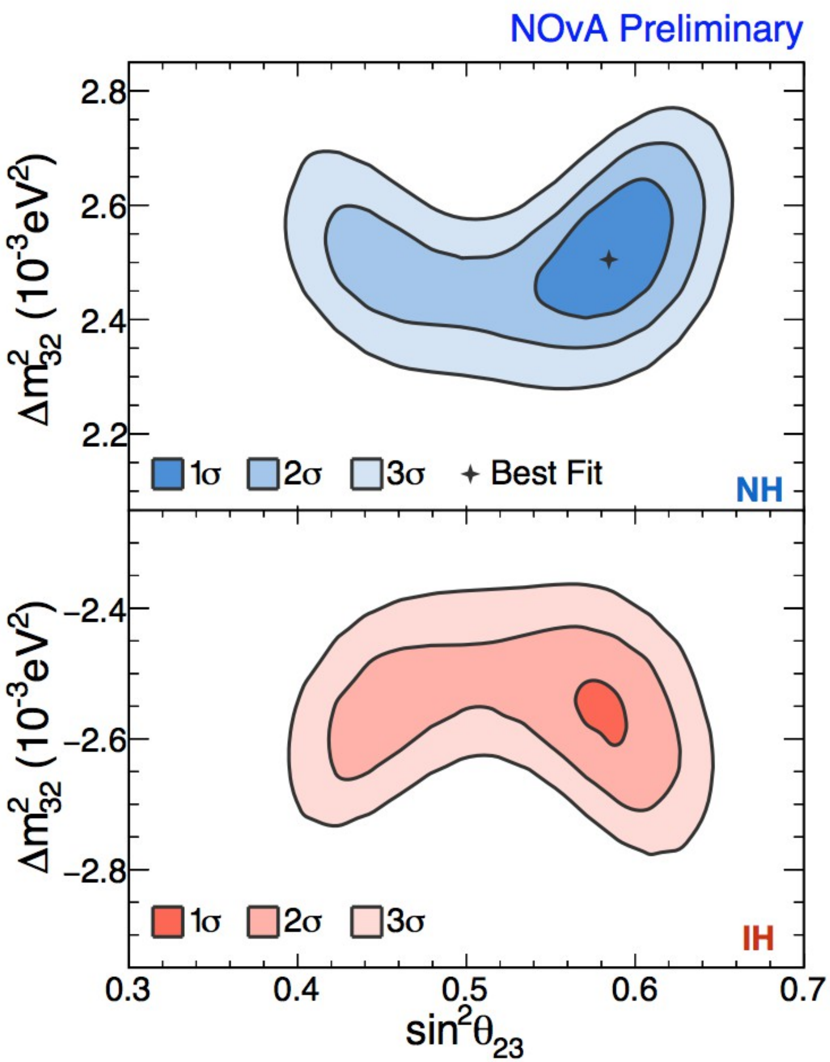

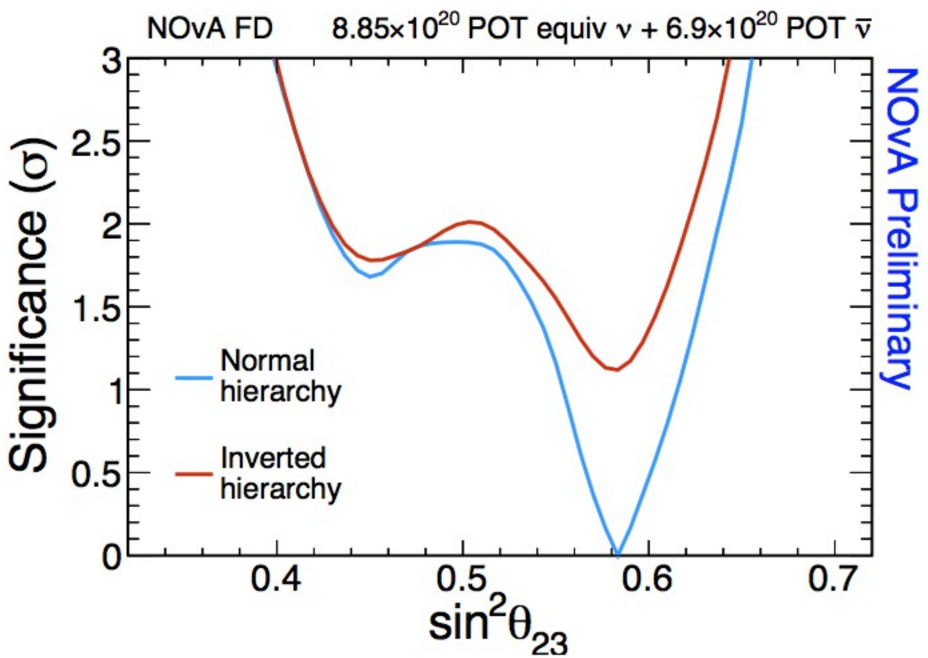

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Recent NOvA Results - Joint Appearance and Disappearance