Recent oscillation results from NOvA

Lake Louise Winter Institute
February 2018

Gregory Pawloski

University of Minnesota

What is NOvA

Long baseline neutrino experiment

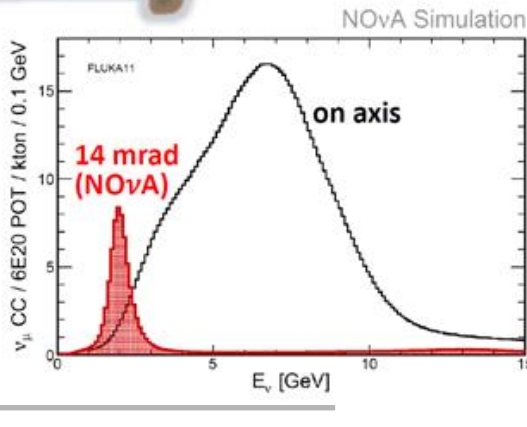
- E ≈ 2 GeV (off-axis narrow band beam)
- L = 810 km
- Oscillations governed by Δm^2_{32} (Δm^2_{31})

NuMI beam produced at Fermilab

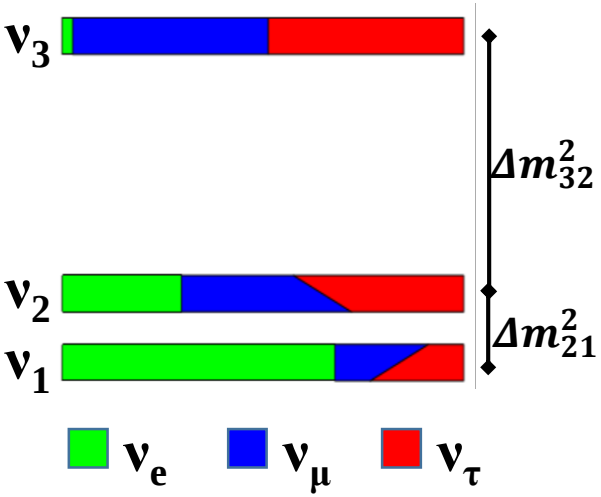
- ν_μ and $\overline{\nu}_\mu$ beam modes
  - Analyzed 8.85e20 POT with ν_μ mode *(this talk)*
  - Should have comparable POT of $\overline{\nu}_\mu$ by this summer
- $(\overline{\nu}_\mu) \rightarrow (\overline{\nu}_x)$ oscillations

Two detector experiment

- Near detector (Fermilab, IL)
  - Measure beam before oscillation
- Far Detector (Ash River, MN)
  - Measure oscillated beam



Physics Goals



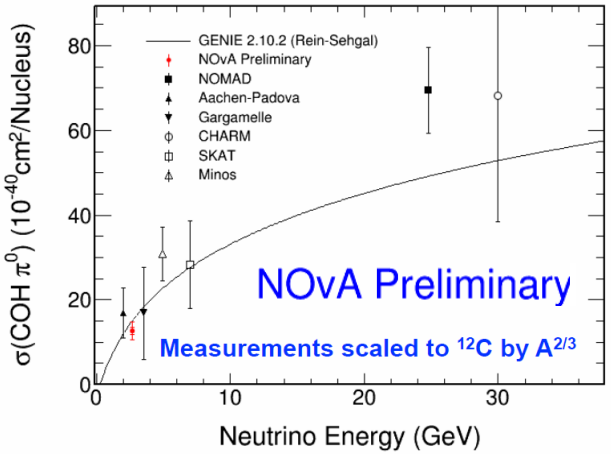
Long baseline neutrino oscillation measurements

- **ν_μ CC disappearance**
- **ν_e CC appearance** (long baseline $\pm$30% matter effect)
  - Sensitive to: θ_{23}, δ_{CP}, Δm^2_{32} (*Mass Hierarchy*)
- **NC disappearance**
  - Sensitive to Sterile Neutrinos: θ_{24}, θ_{34}, Δm^2_{41}

Non-oscillation Measurements

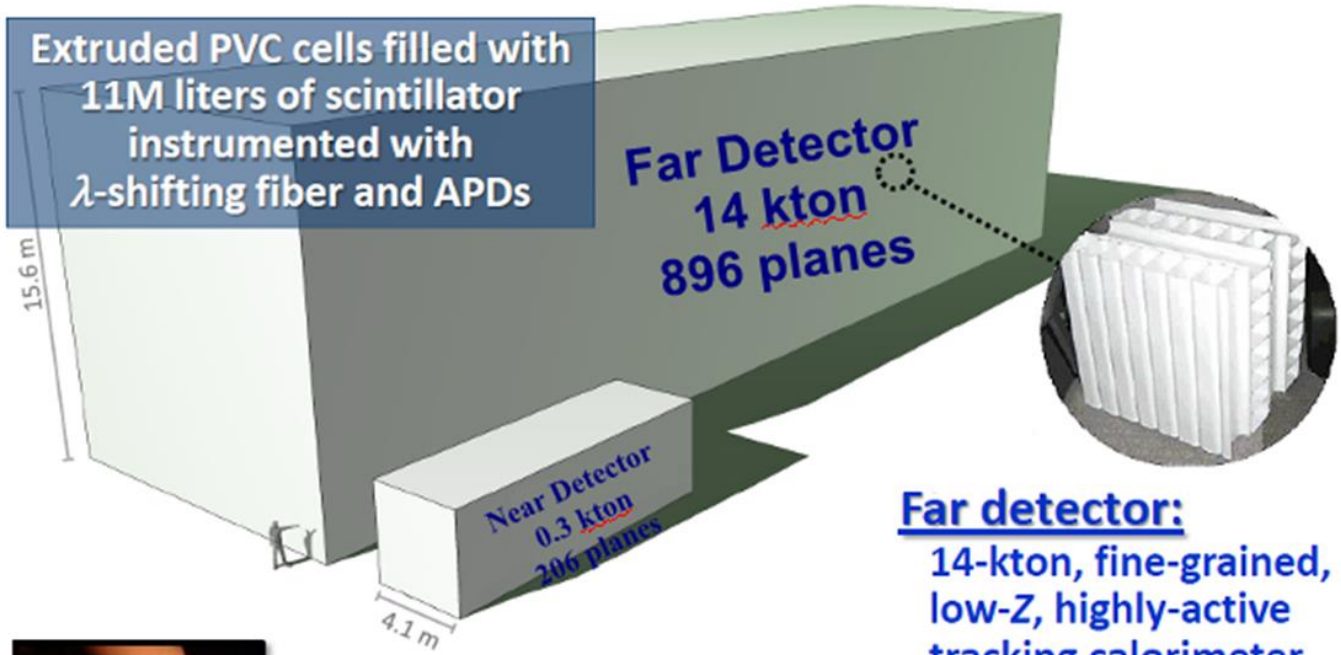
- **Near Detector cross sections measurements**
- **Supernova detection**
- **Exotic phenomena**
  - Monopoles, neutrino magnetic moment, etc

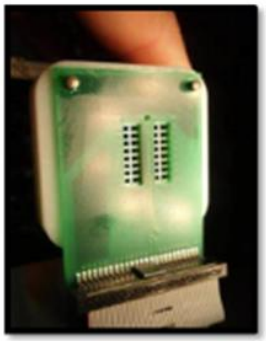
NC Coherent Pion Production Measurement



$\sigma = 14.0 \pm 0.9(stat.) \pm 2.1(syst.) \times 10^{-40}$cm^2/nucleus

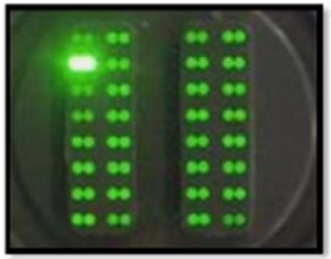
Two Detector Experiment





32-pixel APD

Fiber pairs from 32 cells



Far detector:

14-kton, fine-grained, low-Z, highly-active tracking calorimeter

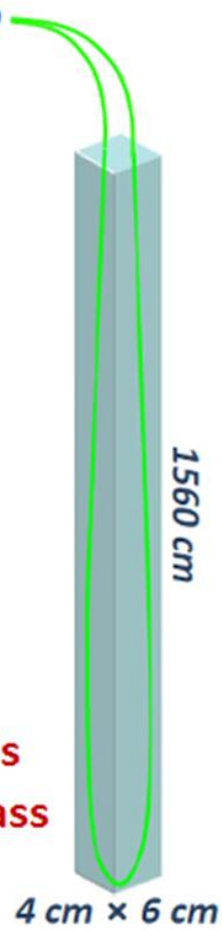
340, 000 channels

77% active by mass

Near detector:

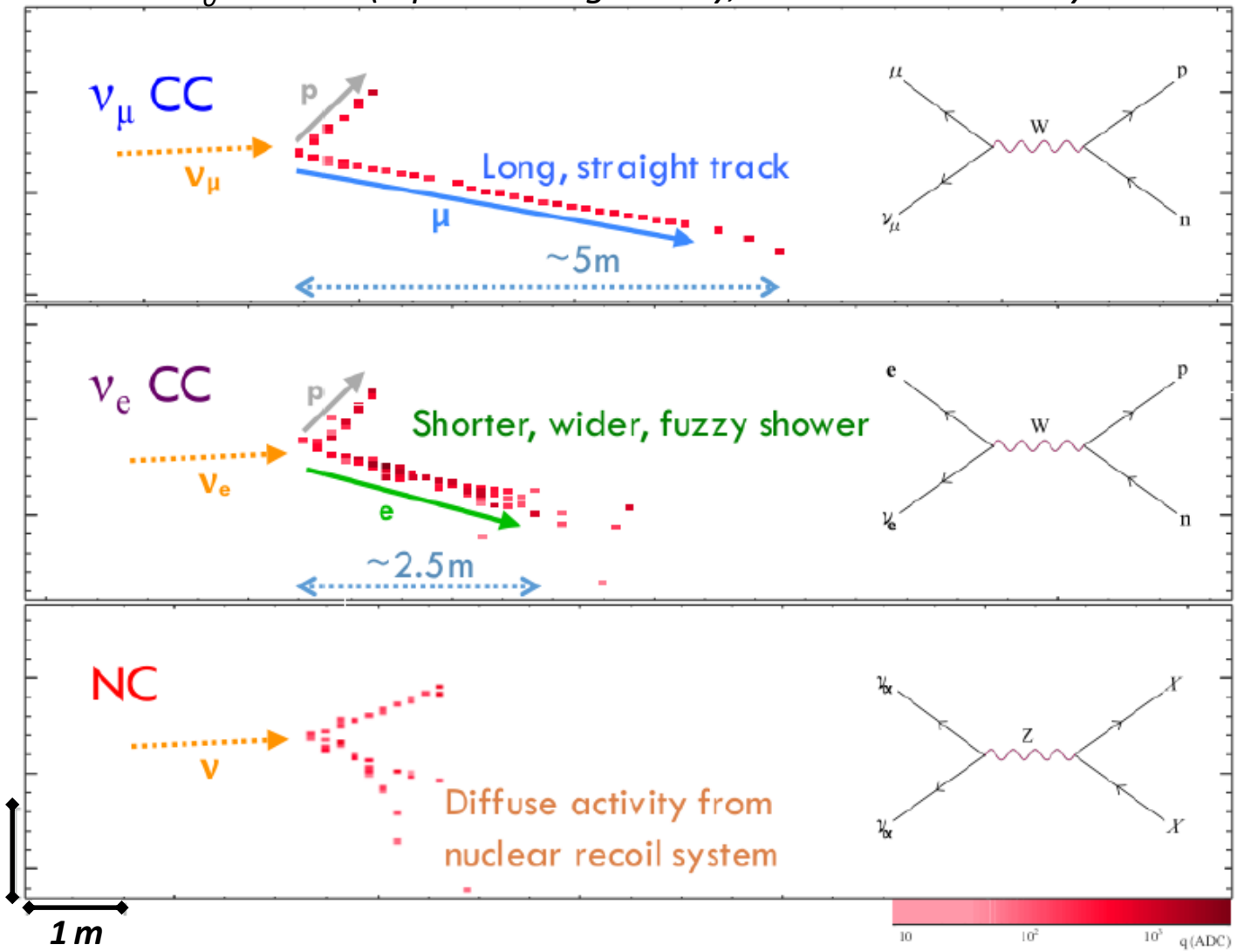
0.3-kton version of the same

18, 000 channels



Event Topologies

X_0 = 38 cm (6 planes longitudally, 10 cells transversely



Event Selection

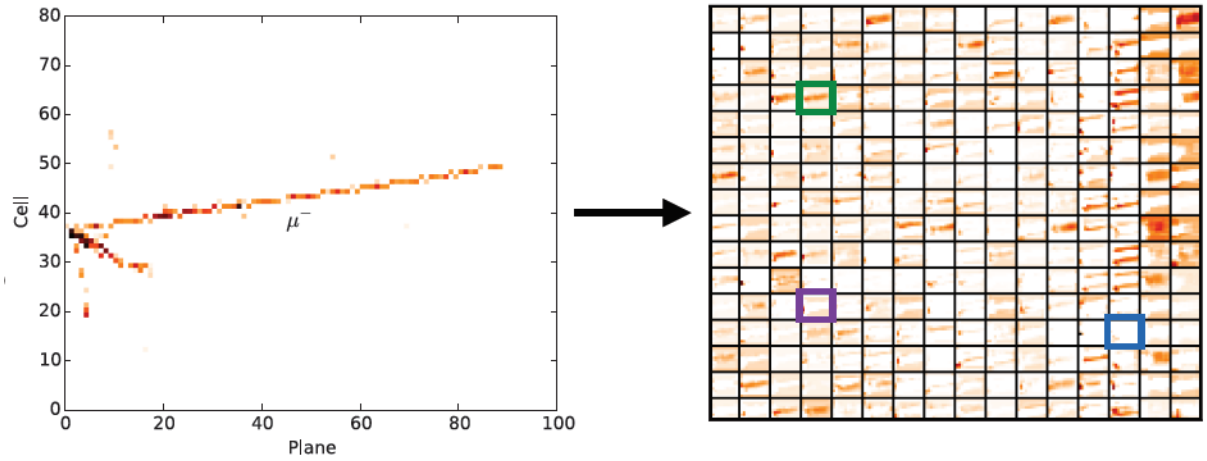
Events classified with Convolutional Visual Network (CVN)

A deep learning algorithm similar to image recognition software

Cells are like pixels and the energy depositions are like colors

Filters pick out event features

JINST 11 (2016) P09001



One algorithm classifies: **1) ν_μ CC** **2) ν_e CC** **3) NC** **4) Cosmic**

More selection criteria

Data Quality, preselection, containment, and cosmic rejection

- e.g. min number hits, directionality cuts, distance from detector edges, etc
- Reduces cosmic background from $\sim 10^6$ events to less than 10 events (CVN does a lot too)
- Analysis specific

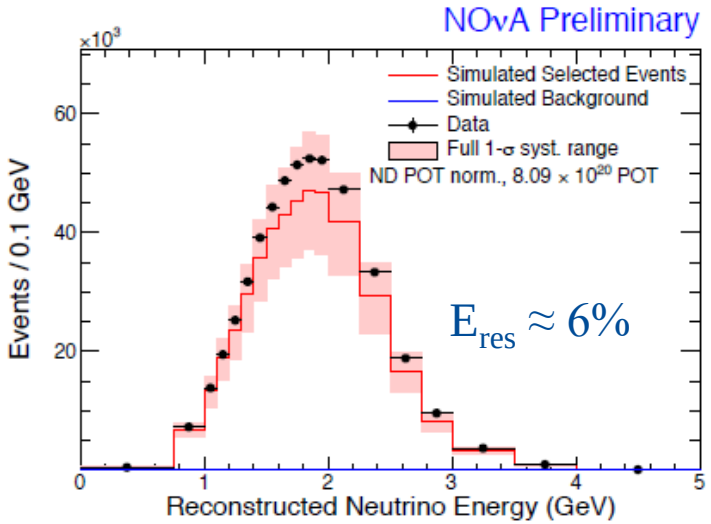
ν_μ disappearance analysis

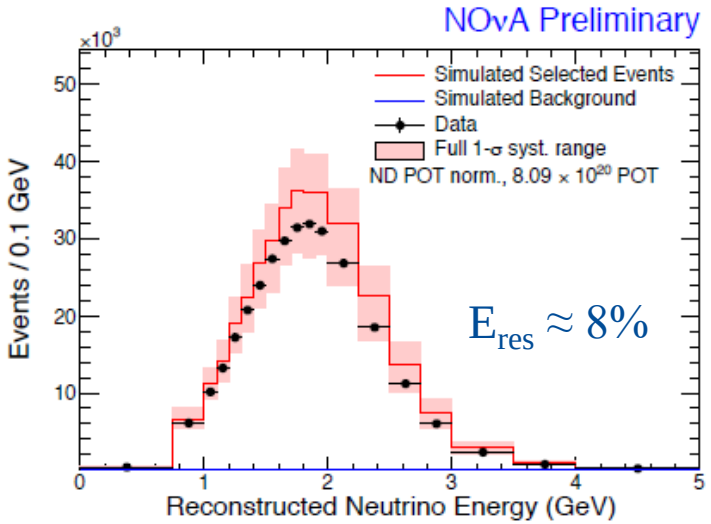
- Additional muon track ID based on kNN (track length, dE/dx, scattering, quality)
- Events separated into 4 subsamples by hadronic energy fraction
  - Lower had E fraction $\rightarrow$ fraction has better energy resolution and purity

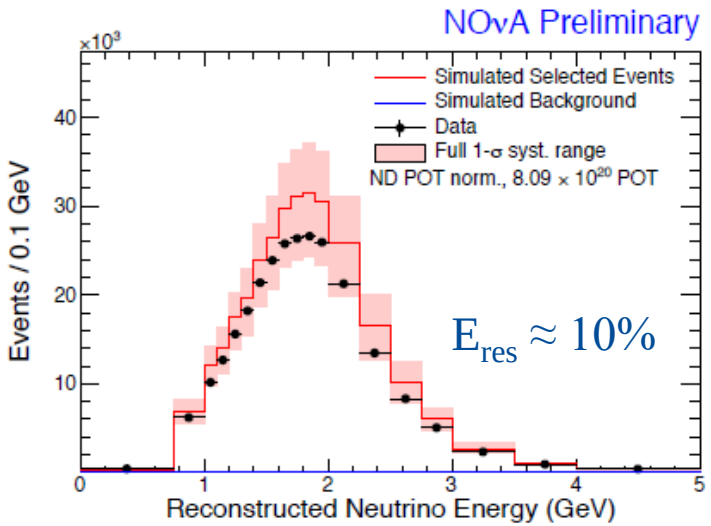
ν_e appearance analysis

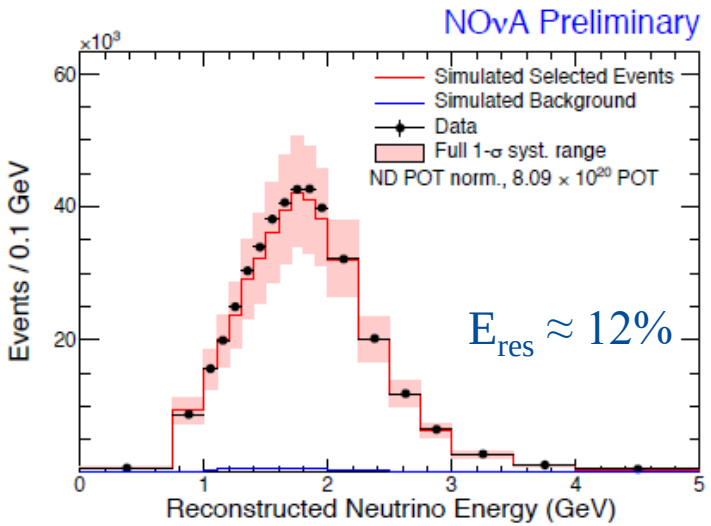
- Reclaim events that fail primary (core) cuts by reexamining with alternate cosmic cuts
  - Forms a peripheral sample (effective 17% exposure gain)
- Separate core events into 3 subsamples by CVN value
  - Higher CVN $\rightarrow$ better purity

ND Selection - ν_μ CC

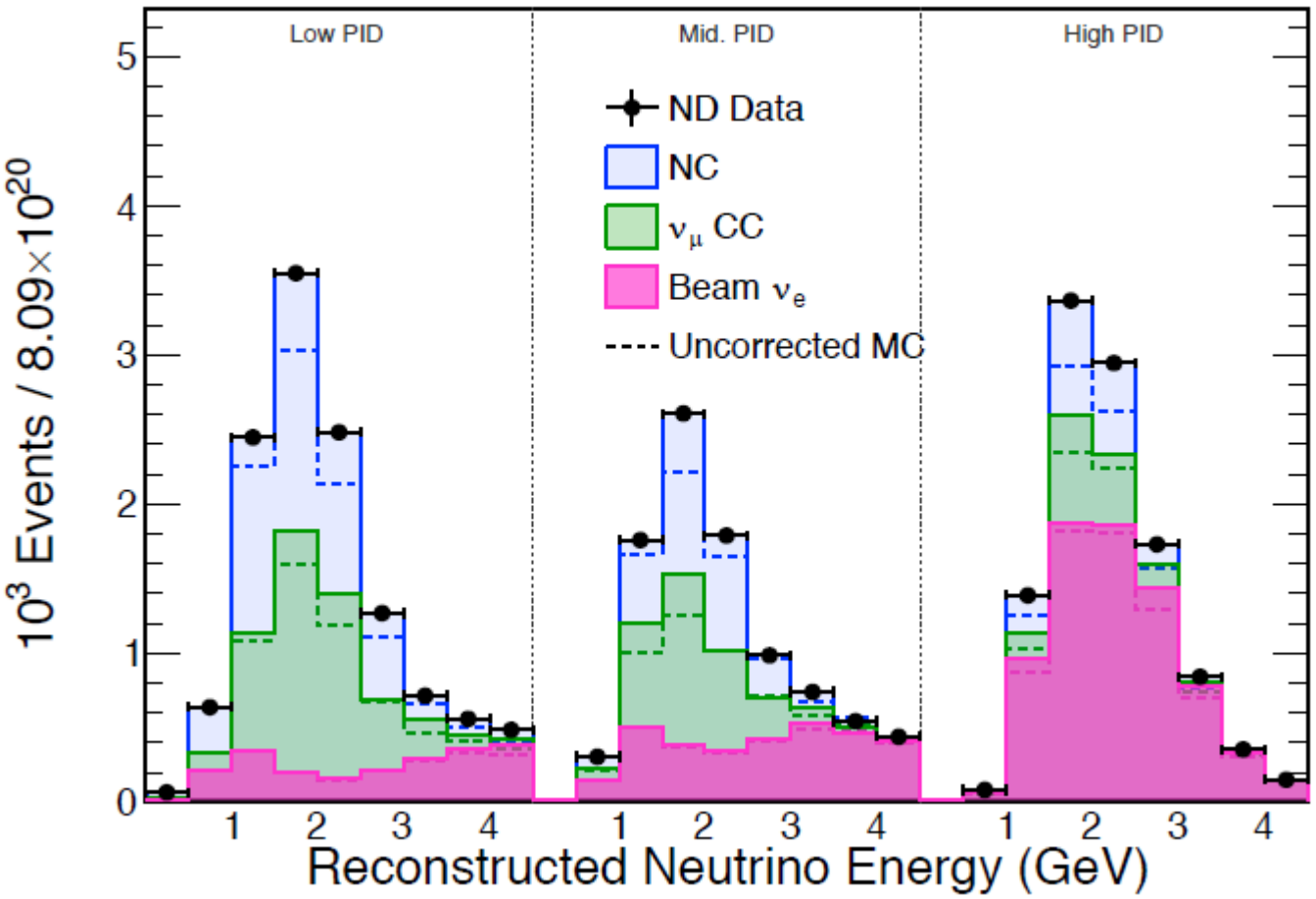






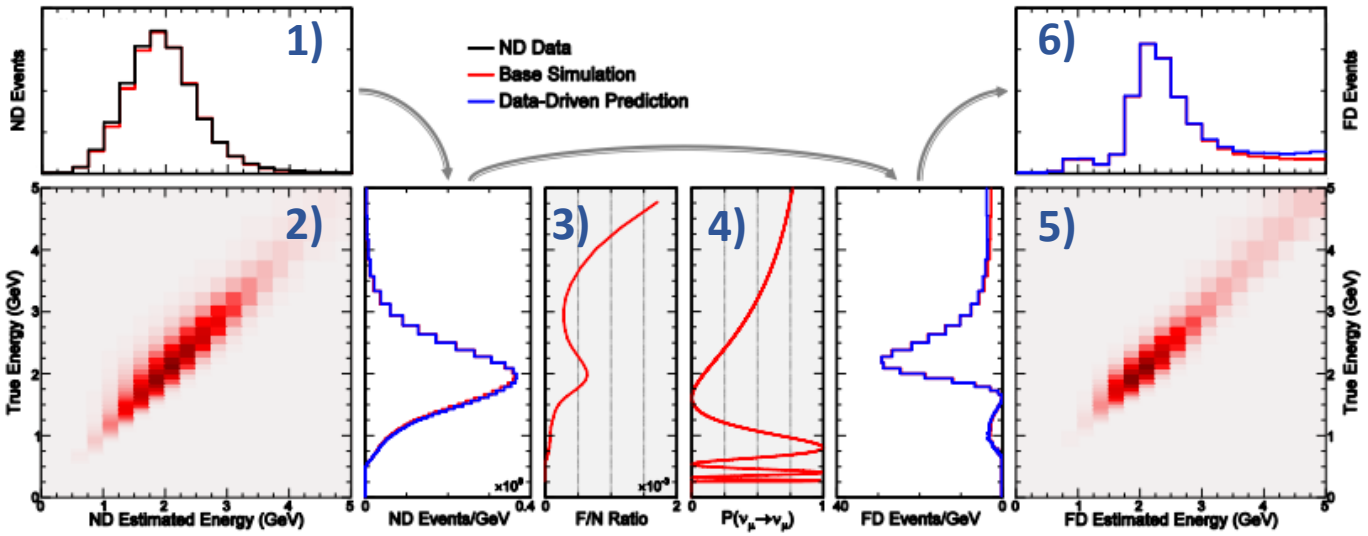


ND Selection - ν_e CC



Extrapolation

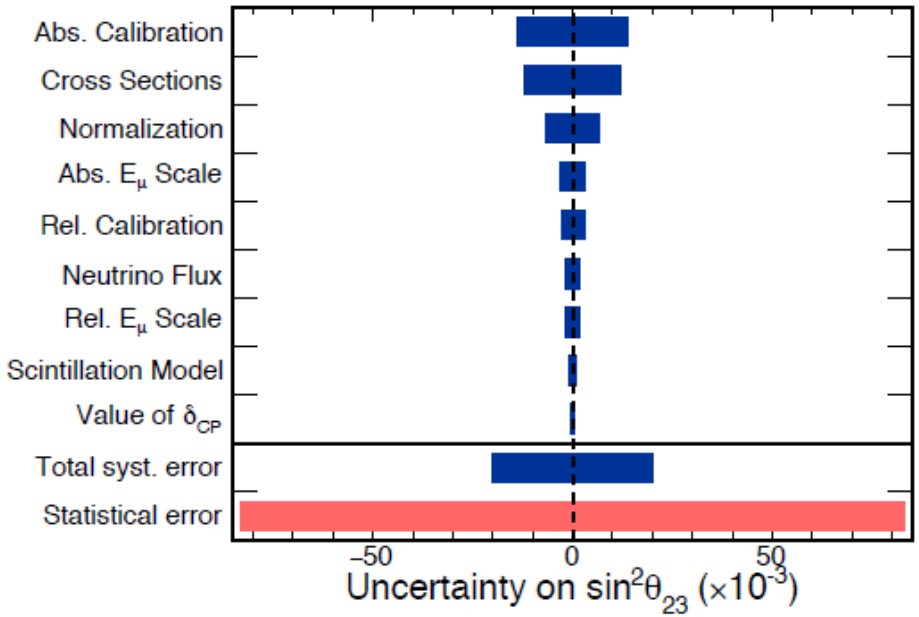
1) Select events in ND (use data)
2) Map ND reco E to true E (use simulation)
3) Apply ratio of FD events to ND events in bins of true E (use simulation)
   Takes into account differences between two detectors
4) Apply oscillation probability on FD true E events (use simulation)
5) Map FD true E to reco E (use simulation)
6) Oscillated FD prediction

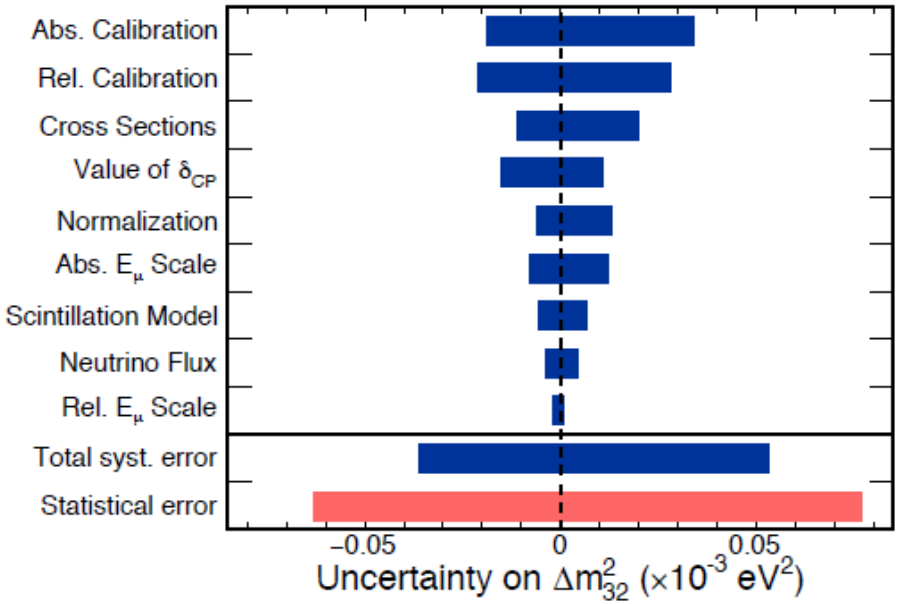


Don't need to separately measure flux, cross-section, efficiencies, etc in ND

Systematics accounted for by altering simulation at steps 2, 3, 4, and 5

Systematics - ν_μ CC

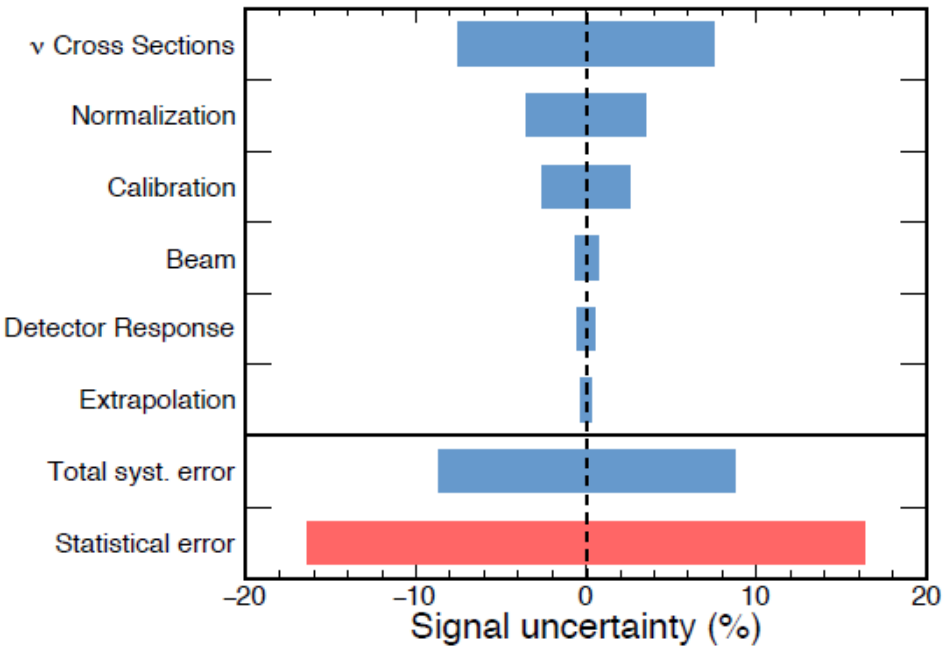


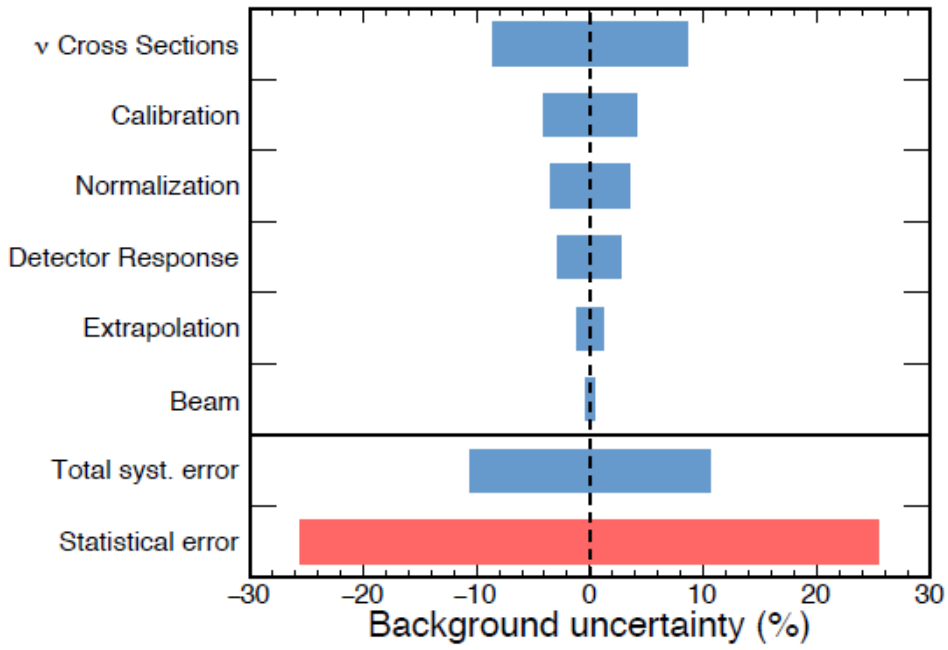


Dominant systematic related to calorimetric energy calibration followed by cross sections

Statistics Limited

Systematics - ν_e CC





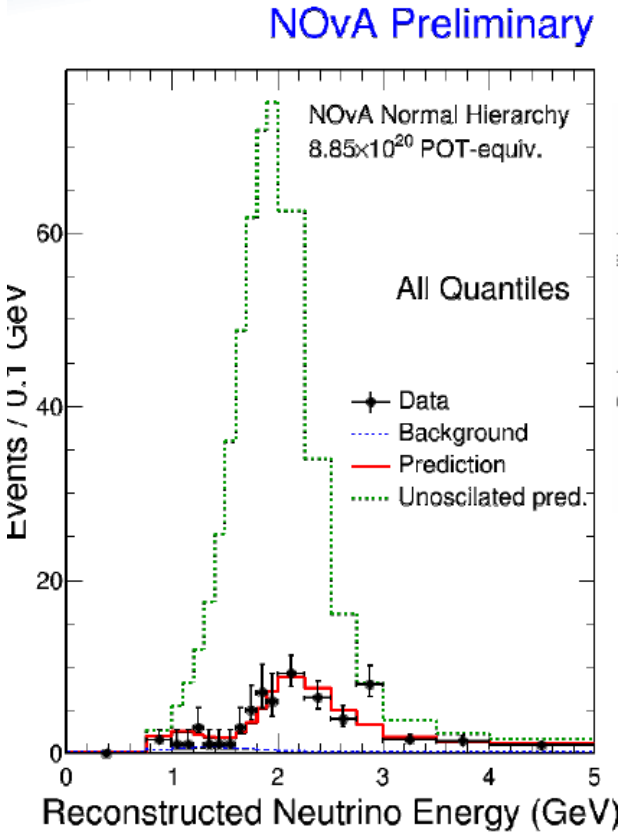
Dominant systematic related to cross sections

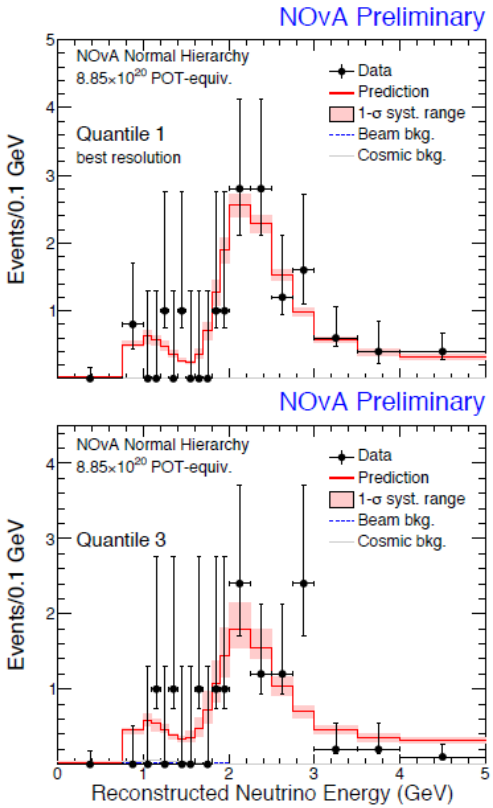
Statistics Limited

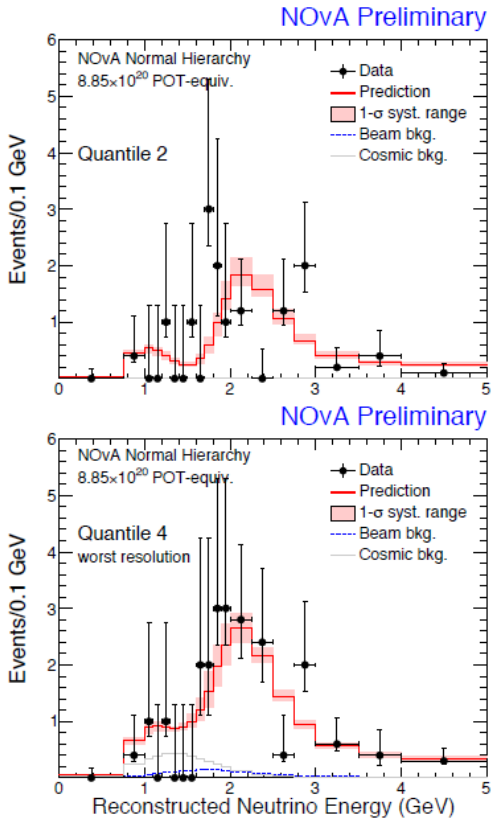
Results

ν_μ CC Disappearance Results

Total Observed	Expectation at Best Fit	Total Background	Cosmic	Neutral Current	Other Beam
126	129	9.24	5.82	2.50	0.96

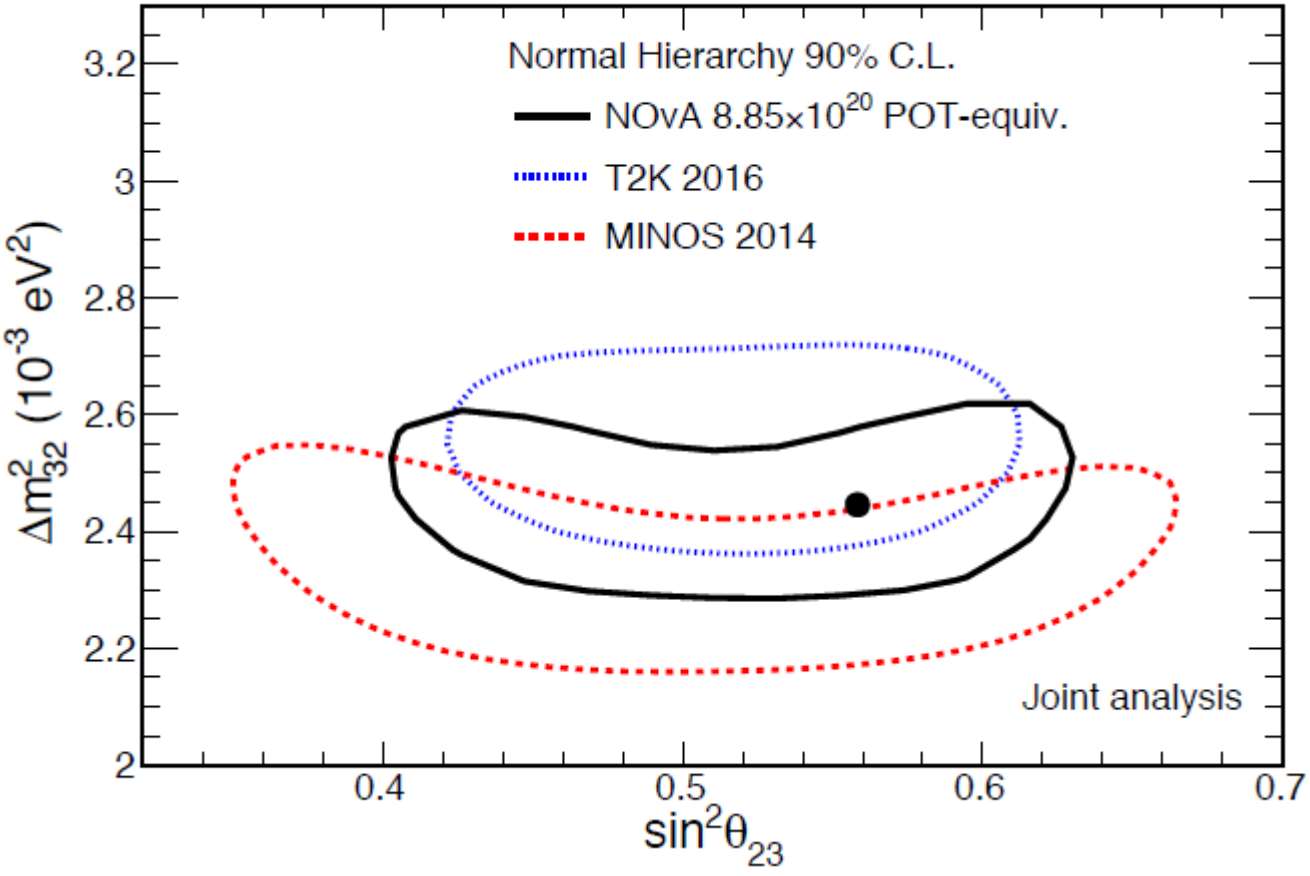






ν_μ CC Disappearance Results

NOvA Preliminary

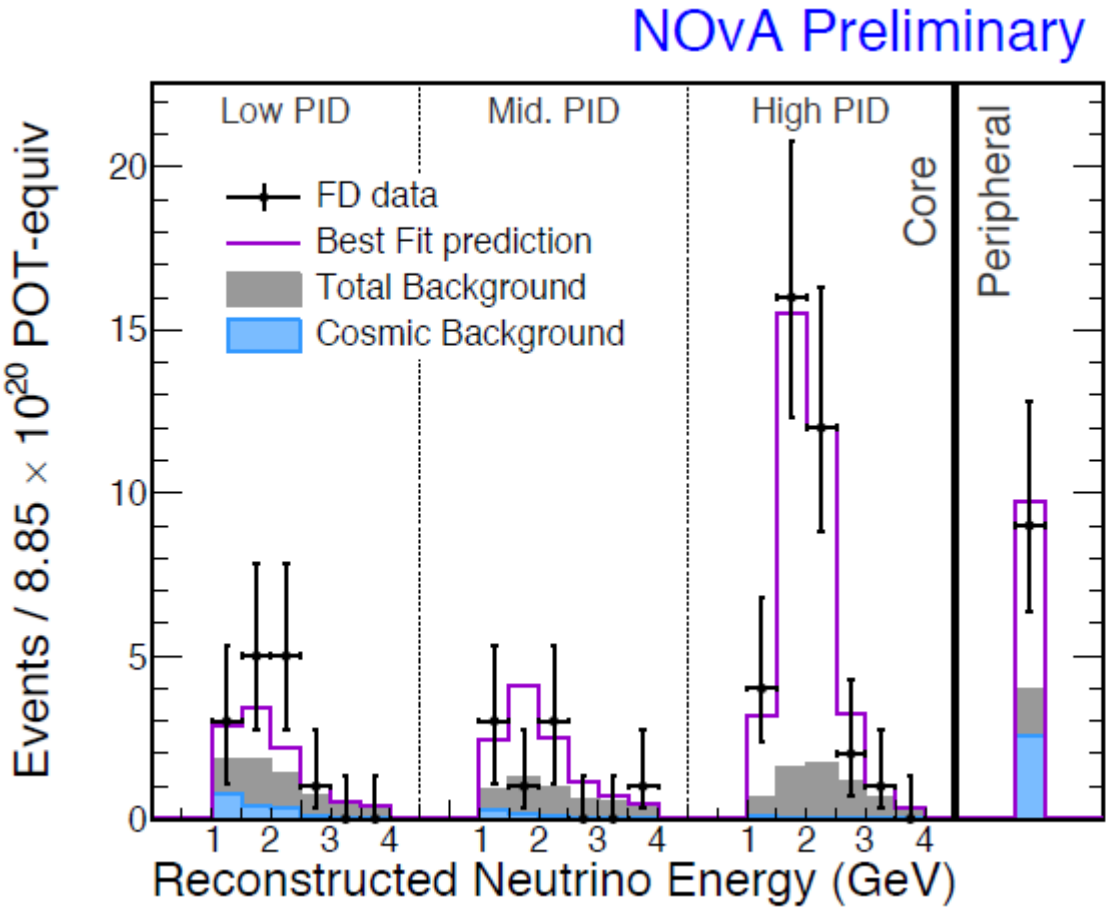


Best Fit

$$\Delta m^2_{32} = 2.444\ ^{+0.079}_{-0.077} \times 10^{-3}\ eV^2$$

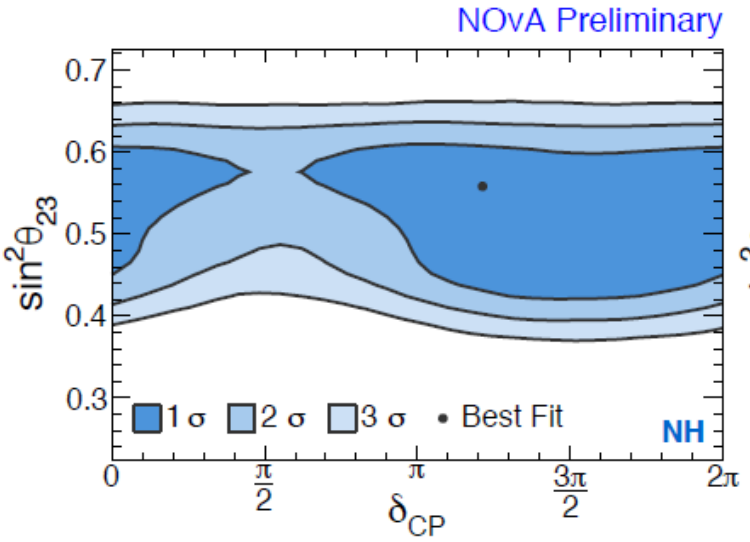
$$\sin^2(\theta_{23}) = 0.475\ ^{+0.036}_{-0.044}\ \ or\ \ 0.558\ ^{+0.041}_{-0.033}$$

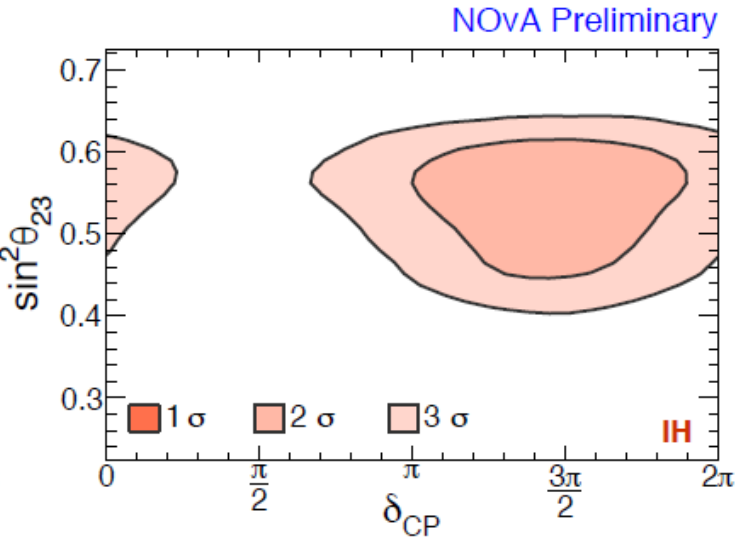
Joint ν_e Appearance Results

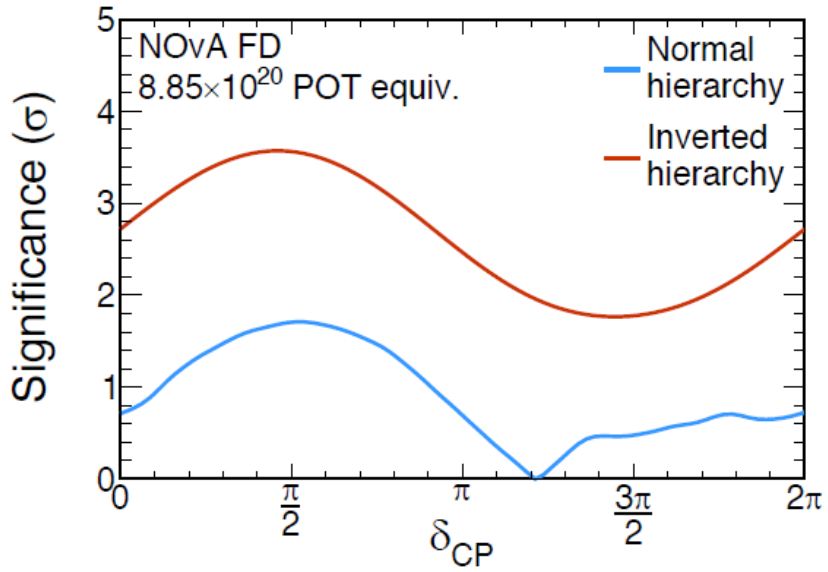


Total Observed	66
Signal Prediction	20-48
Cosmic Bkgd.	4.9
Beam Bkgd.	15.6
Unoscillated	20.5

Joint ν_e Appearance Results







Approaching 2σ rejection of Inverted Hierarchy

Future

NOvA has been recording antineutrino data since last year

- Should have comparable POT exposure to neutrino sample by this summer
- We expect to take equal amount neutrino and antineutrino in future
- Matter and CP violation effects are different for antineutrinos