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NOvA First Results

European Research Council
Established by the European Commission

Jeff Hartnell
University of Sussex

NOvA

Rencontres de Moriond EW

14th March 2016

Introduction

- Long-baseline appearance measurement

- NuMI beam
- NOvA detectors

- Muon neutrino disappearance

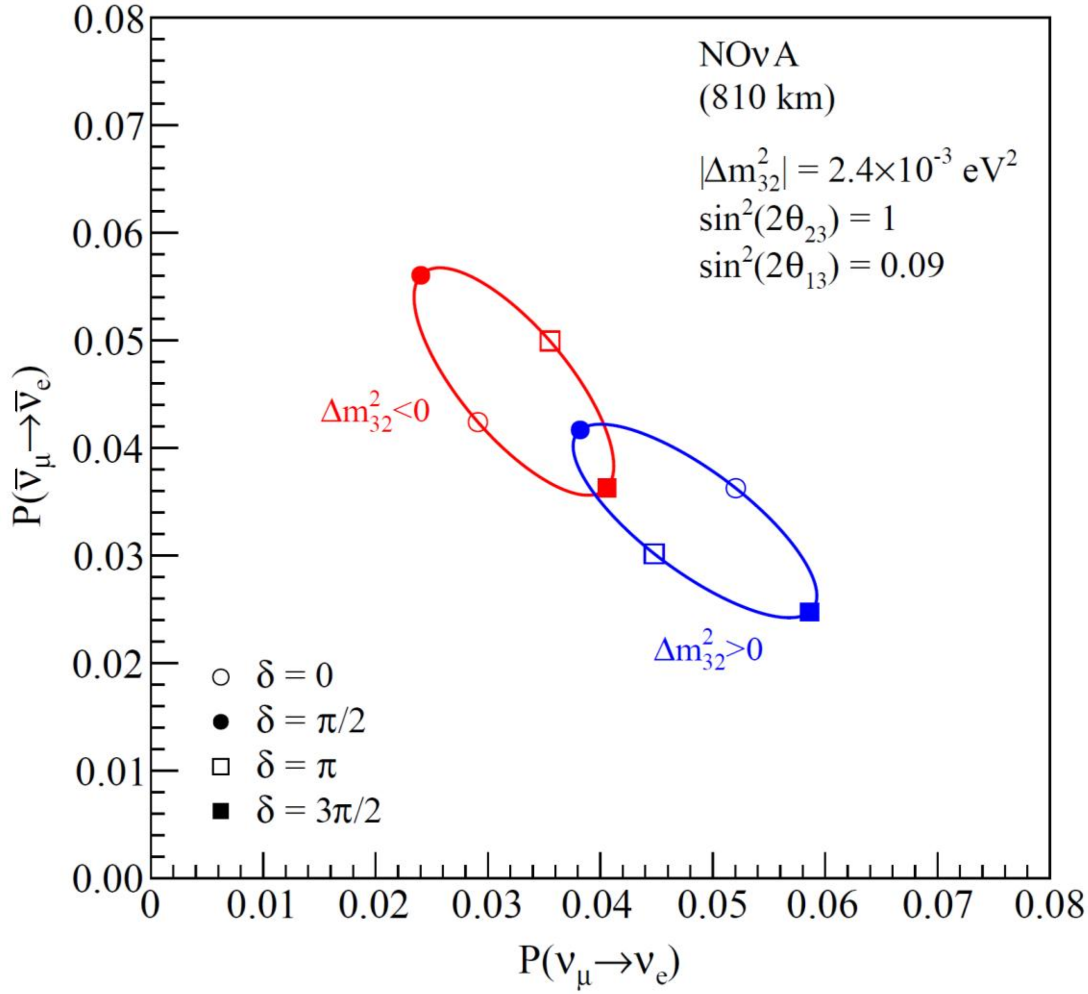
- Electron neutrino appearance

Long-baseline $\nu_\mu \rightarrow \nu_e$

At right:

$P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)$ vs. $P(\nu_\mu \rightarrow \nu_e)$ plotted for a single neutrino energy and baseline

For fixed L/E = 0.4 km/MeV



Long-baseline $\nu_\mu \to \nu_e$

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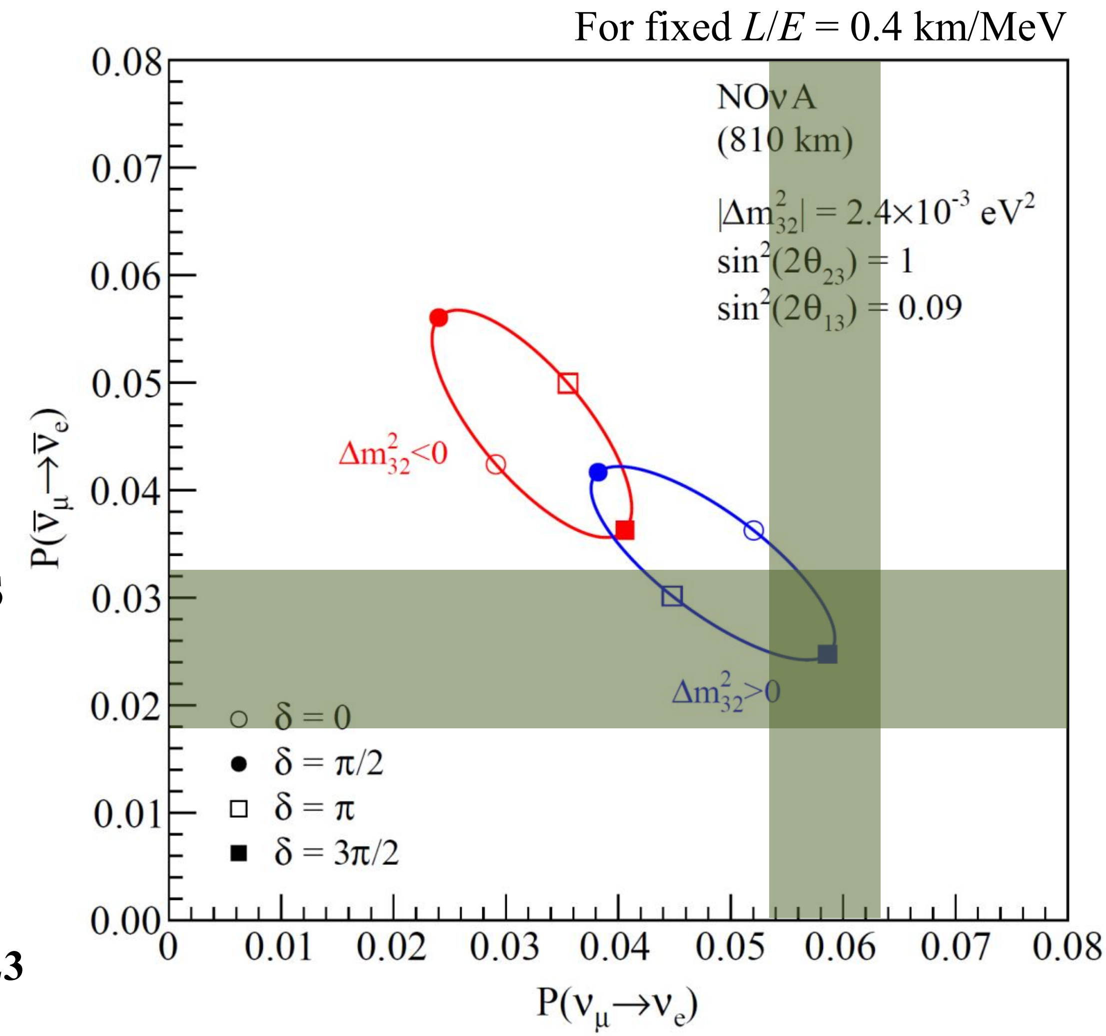


Measure these probabilities

(an example measurement of each shown)

Also:

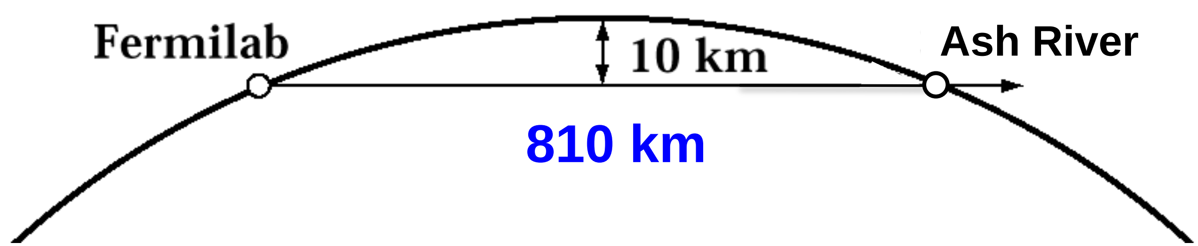
Both probabilities $\propto \sin^2\theta_{23}$

NOvA Overview

- “Conventional” beam
- Two-detector experiment:

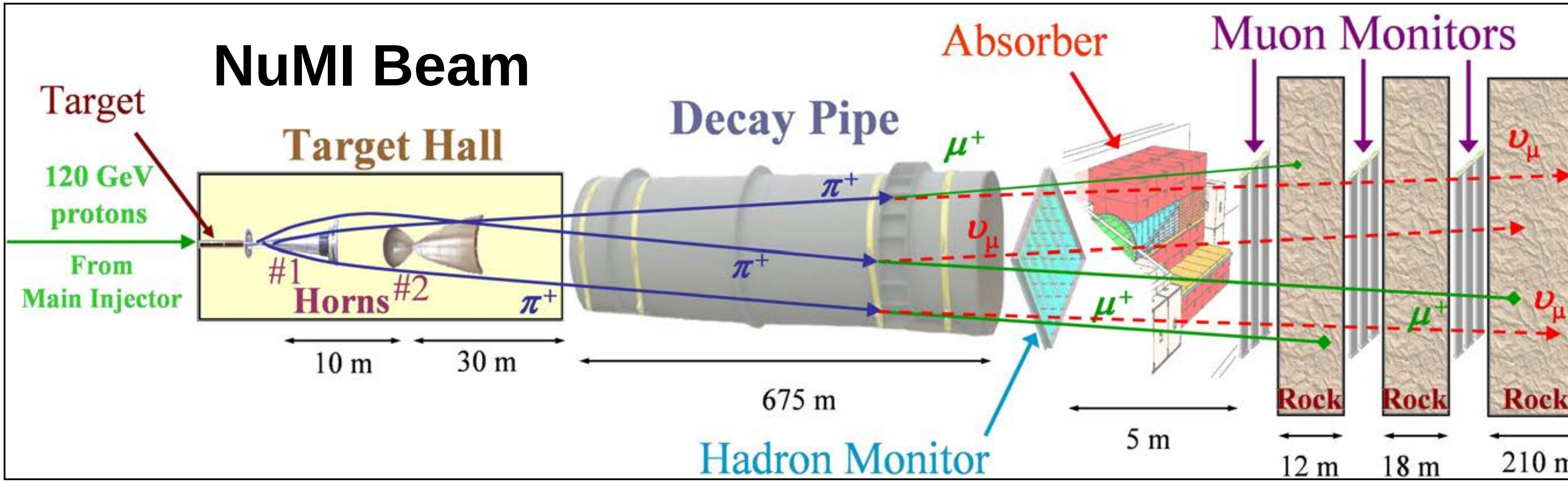
- Near detector
  - measure beam composition
  - energy spectrum

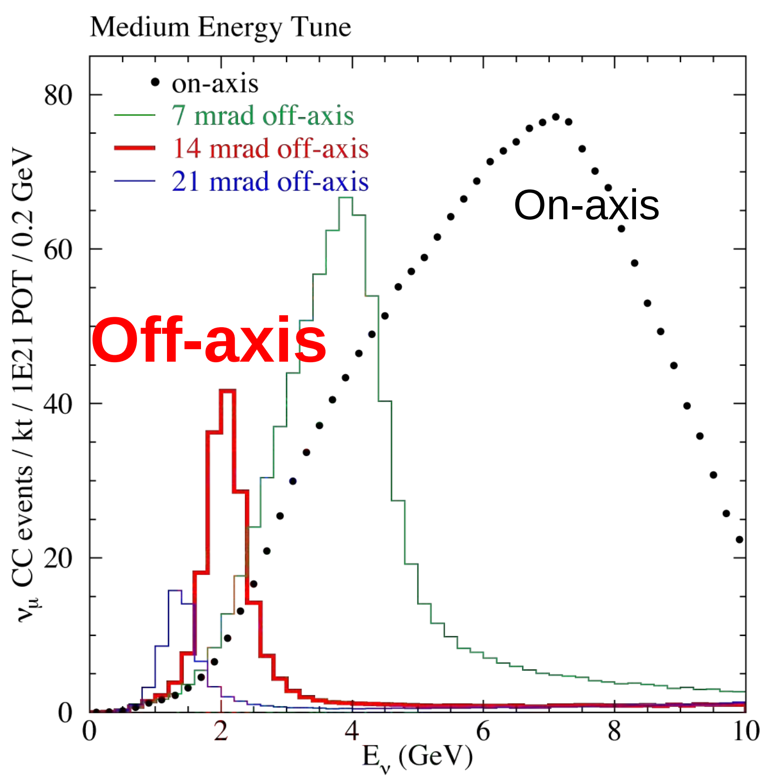
- Far detector
  - measure oscillations and search for new physics



Key Features of 2nd Generation Expt

- Narrow band (off-axis) beam
- Detectors optimised for
  - ν_e flavour identification
  - ν_e appearance maximum (L/E)
- Higher power beam
- NOvA has about triple the matter effect of T2K and higher relative antineutrino xsec

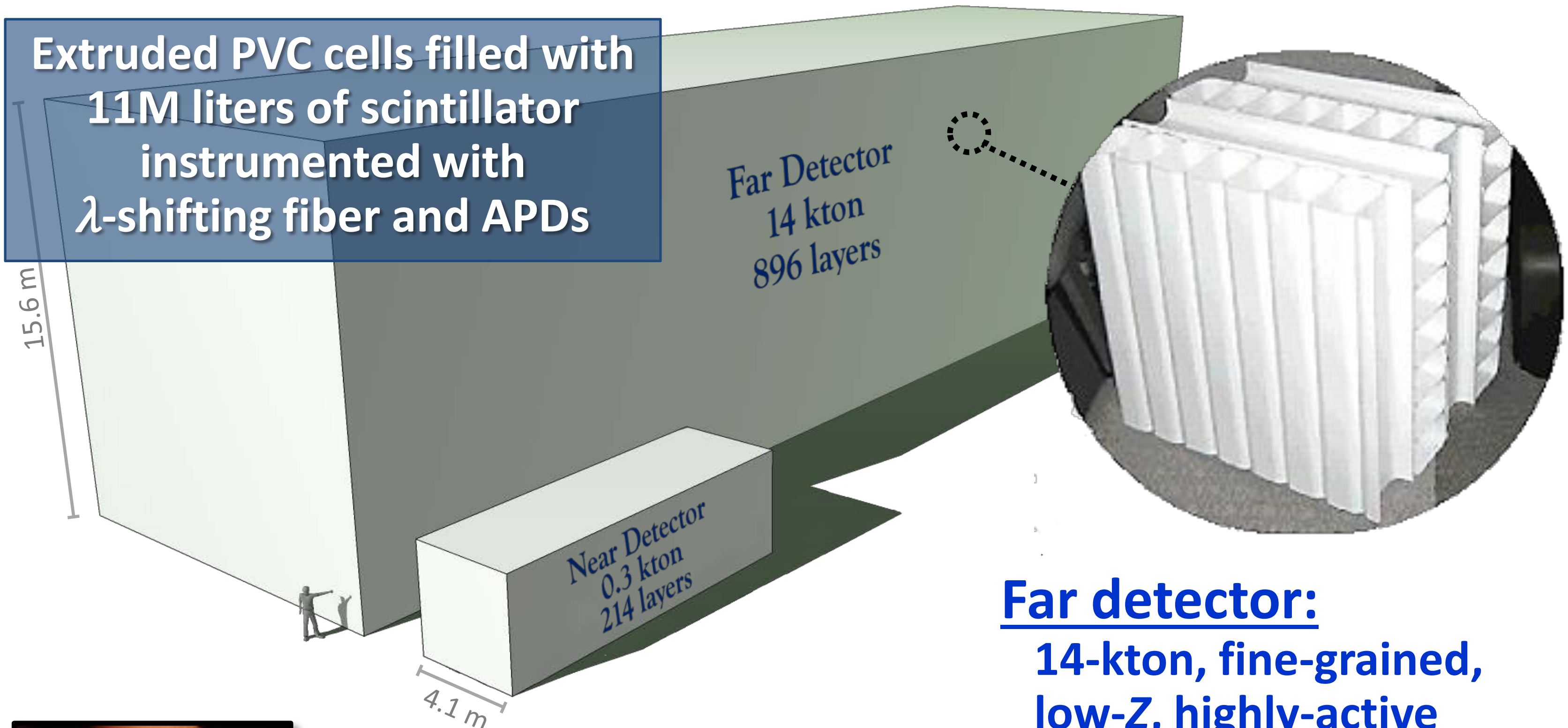

NuMI Beam
Target
120 GeV protons
From Main Injector
Target Hall
#1
Horns
#2
10 m
30 m
Decay Pipe
675 m
Absorber
Muon Monitors
Hadron Monitor
5 m
Rock
Rock
Rock
12 m
18 m
210 m


Medium Energy Tune
on-axis
7 mrad off-axis
14 mrad off-axis
21 mrad off-axis
On-axis
Off-axis
ν_μ CC events / kt / 1E21 POT / 0.2 GeV
E_ν (GeV)

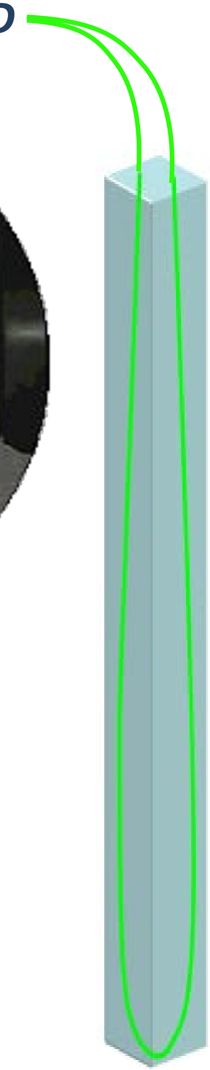
NOvA Detectors

NOνA detectors

Extruded PVC cells filled with 11M liters of scintillator instrumented with λ-shifting fiber and APDs



A NOνA cell



Far detector:

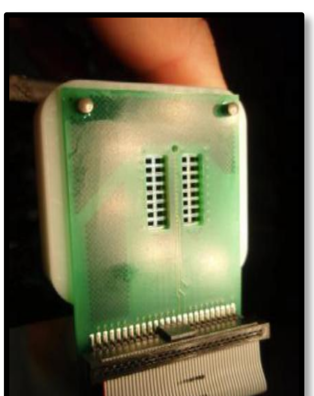
14-kton, fine-grained, low-*Z*, highly-active tracking calorimeter

→ ***344,000 channels***

Near detector:

0.3-kton version of the same

→ ***20,000 channels***



32-pixel APD ←

Fiber pairs from 32 cells →


Far Detector site

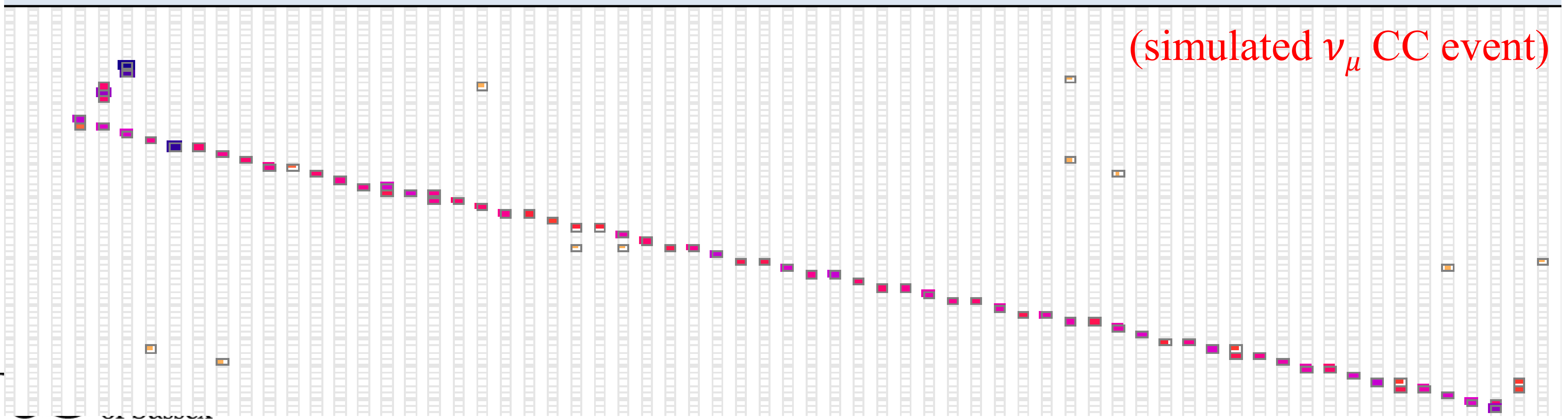

Block construction


Outfitted Far Detector

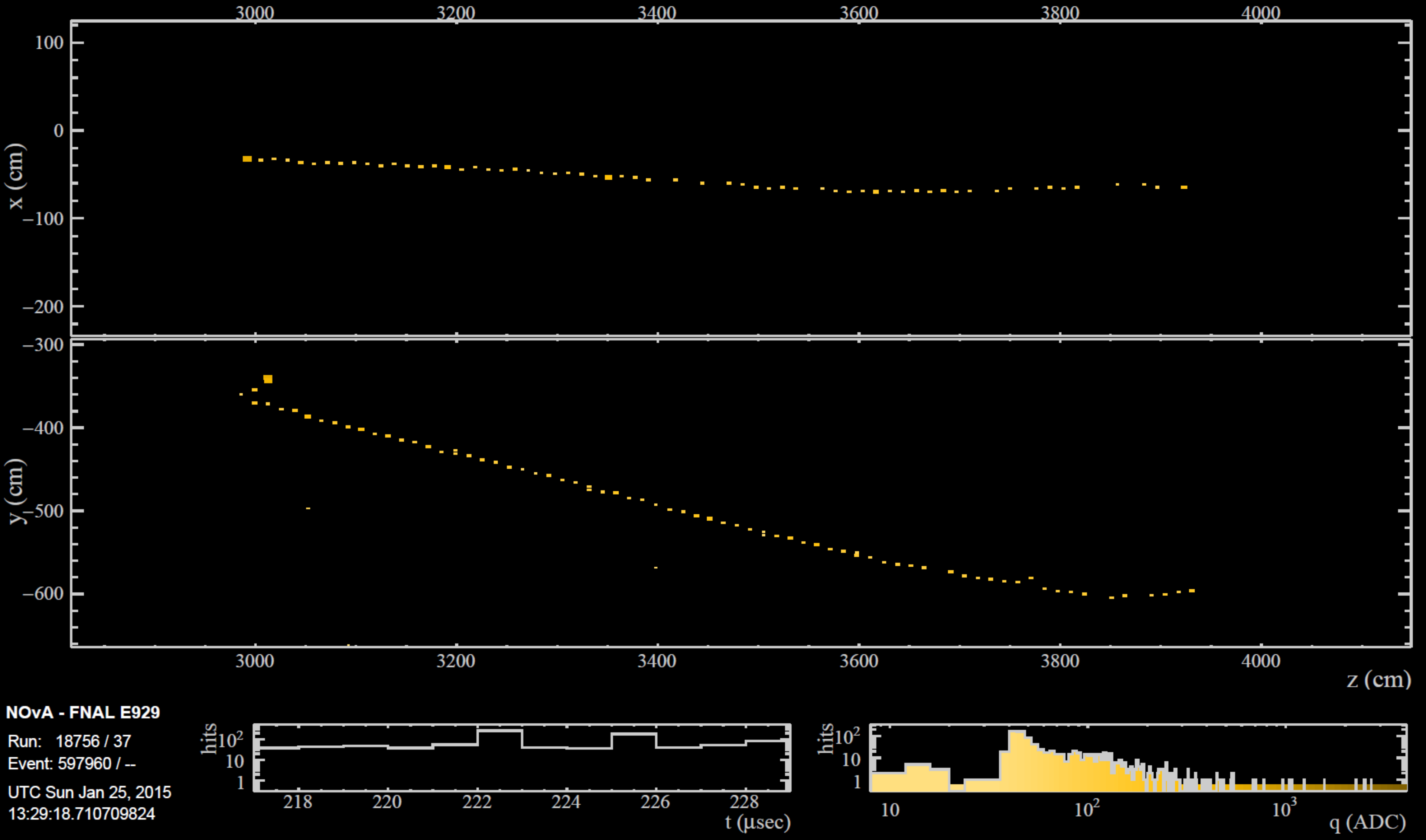

Near Detector

ν_μ disappearance

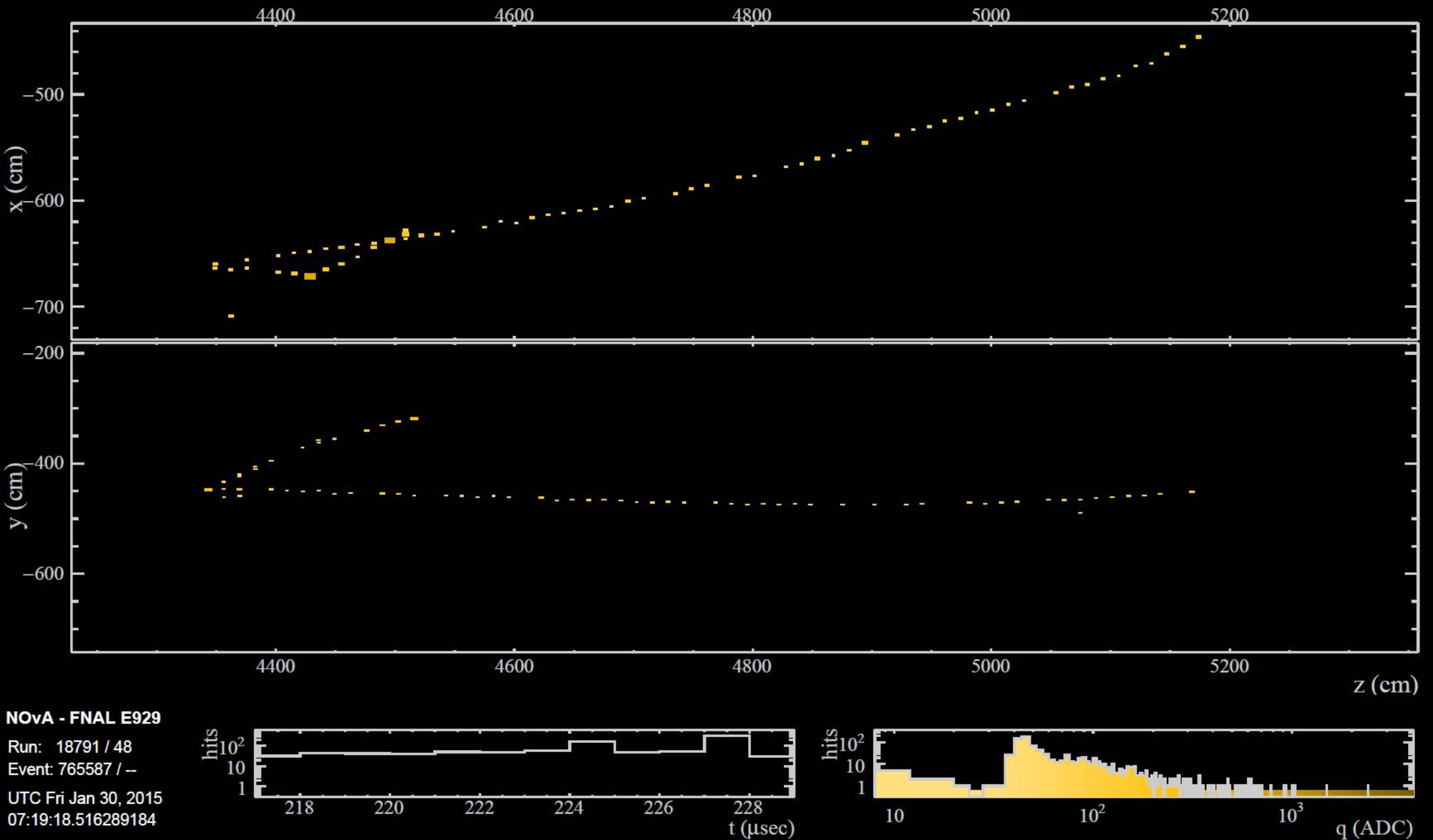
- Identify **contained ν_μ CC events** in each detector
- Measure their **energies**
- Extract oscillation information from differences between the **Far and Near energy spectra**



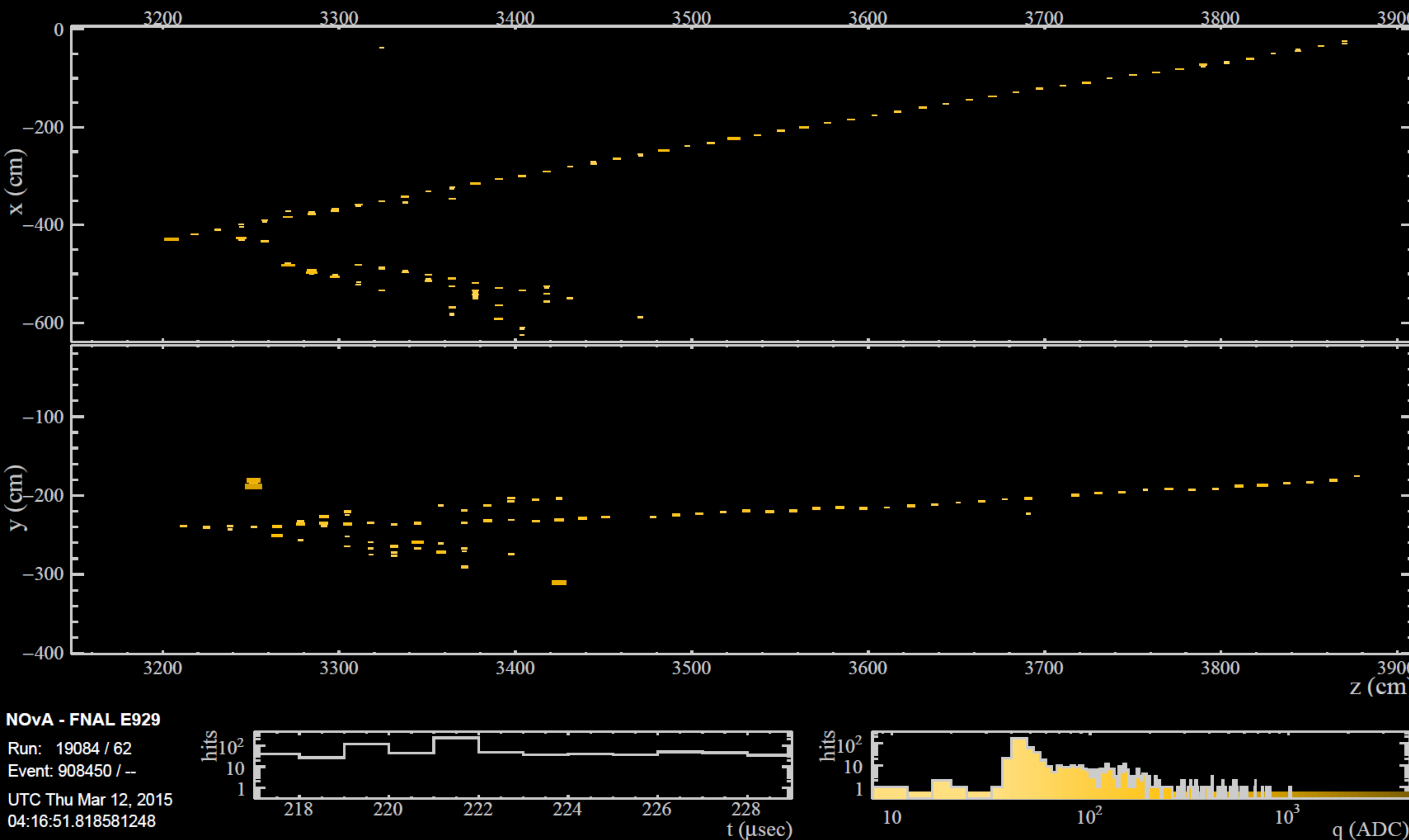
Far Detector selected ν_μ CC candidate



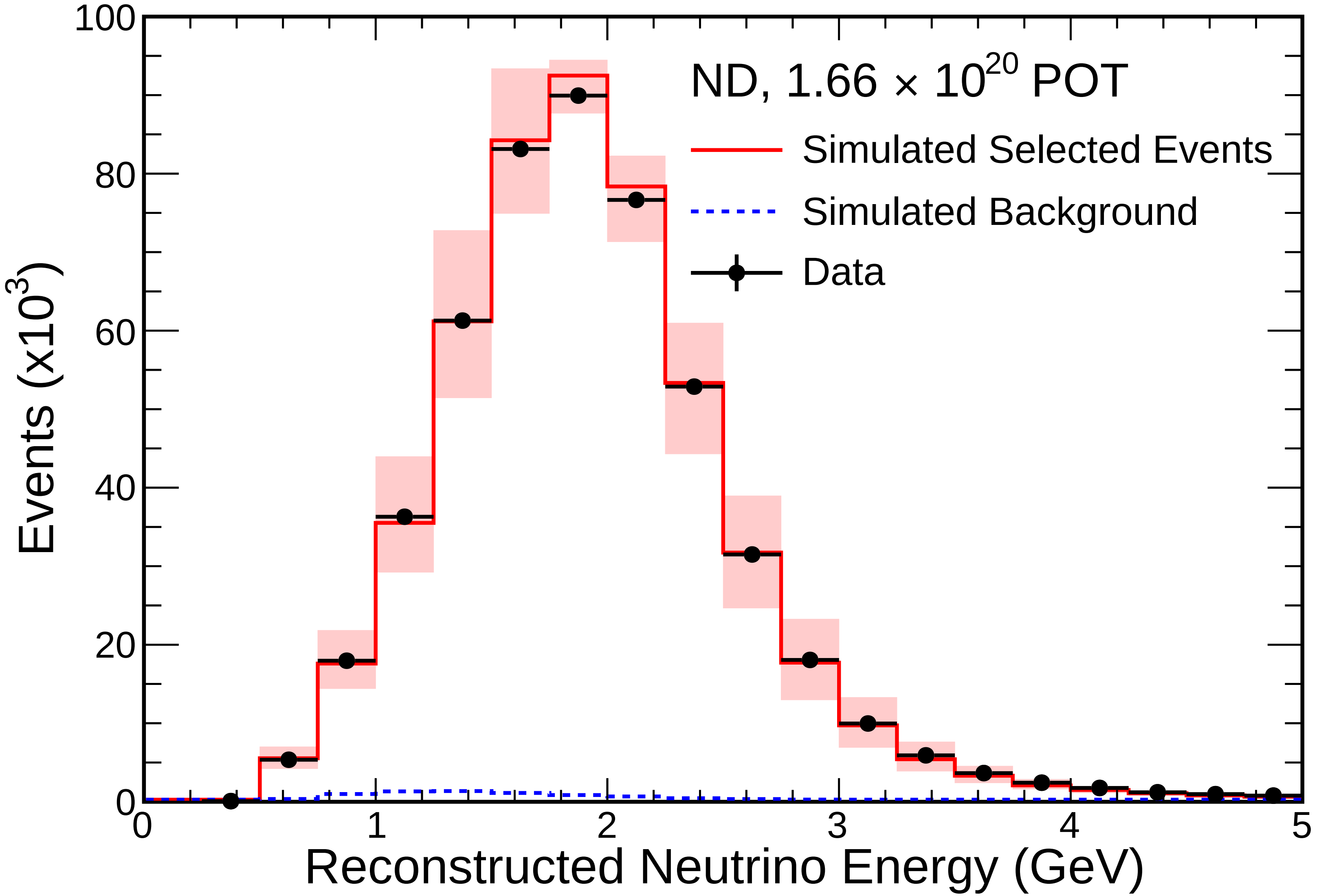
Far Detector selected ν_μ CC candidate



Far Detector selected ν_μ CC candidate



Near Detector NuMu CC Spectrum



MC scaled up by 7.2%
Shape only systematics

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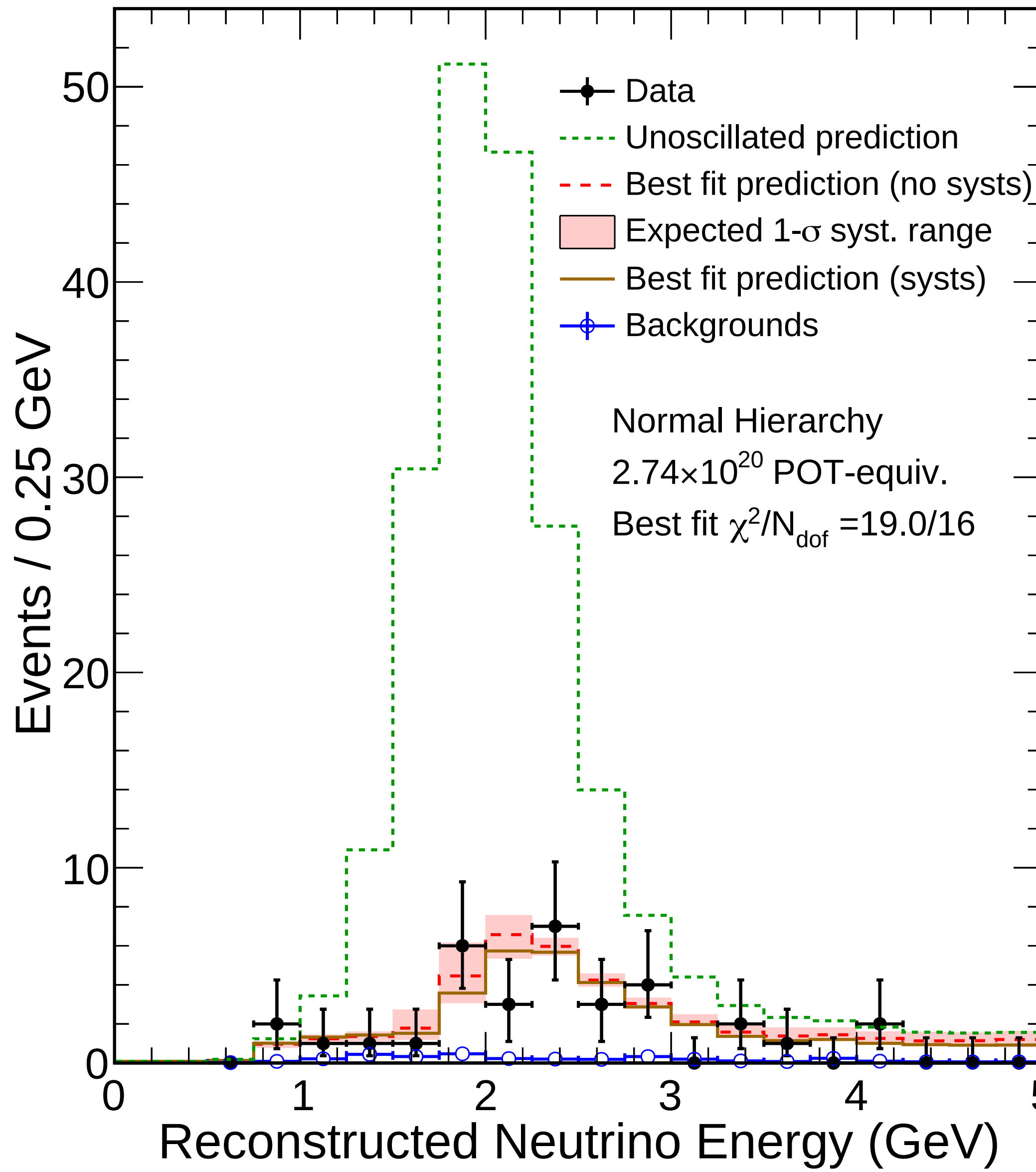
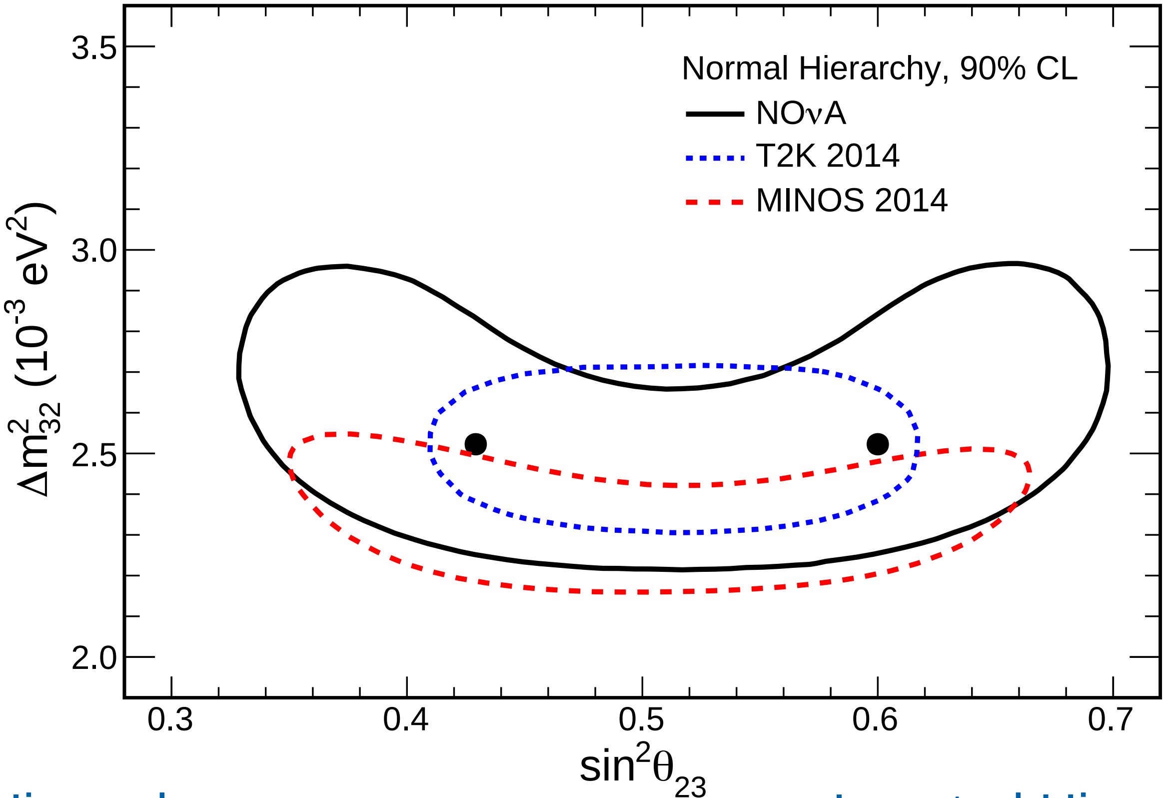
Far Detector

- 211.8 ± 12.5 (syst.) events predicted in the absence of oscillations.
- 33 candidate events between 0 and 5 GeV observed.



arXiv:1601.05037

ν_μ Disappearance Results



Normal Hierarchy

$$\Delta m^2_{32} = (2.52^{+0.20}_{-0.18}) \times 10^{-3}\mathrm{eV}^2$$

$$\sin^2(\theta_{23}) = [0.38, 0.65]$$

(68% CL)

Degenerate best fit points at 0.43 and 0.60

Inverted Hierarchy

$$\Delta m^2_{32} = (-2.52 \pm 0.19) \times 10^{-3}\mathrm{eV}^2$$

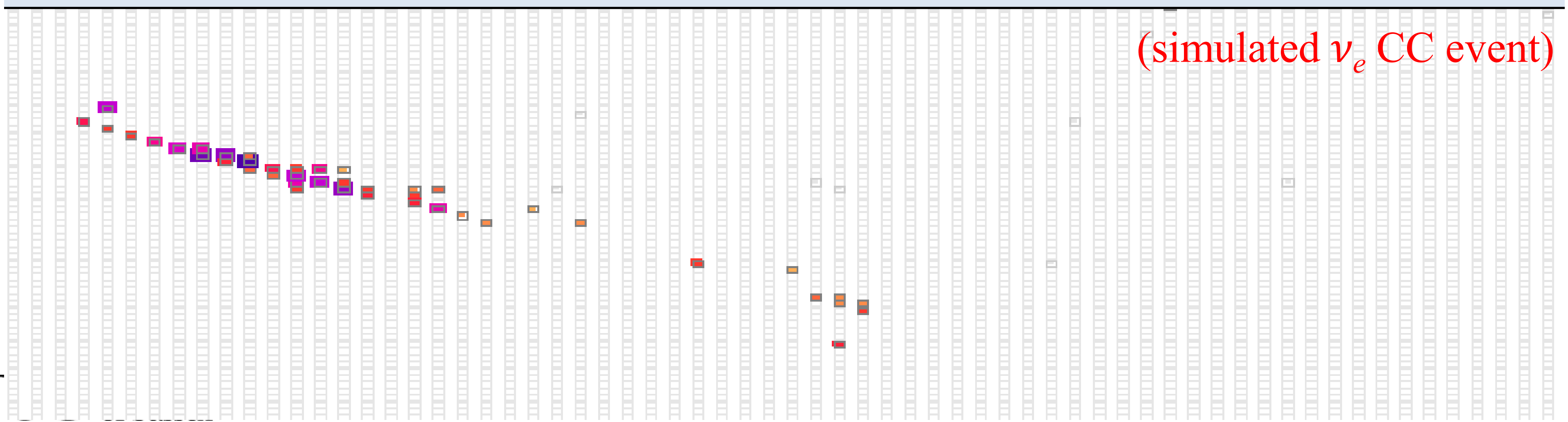
$$\sin^2(\theta_{23}) = [0.37, 0.64]$$

(68% CL)

Degenerate best fit points at 0.44 and 0.59

ν_e appearance

- Identify **contained ν_e CC candidates** in each detector
- Use Near Det. candidates to **predict beam backgrounds** in the Far Detector
- Interpret any **Far Det. excess** over predicted backgrounds as ν_e appearance

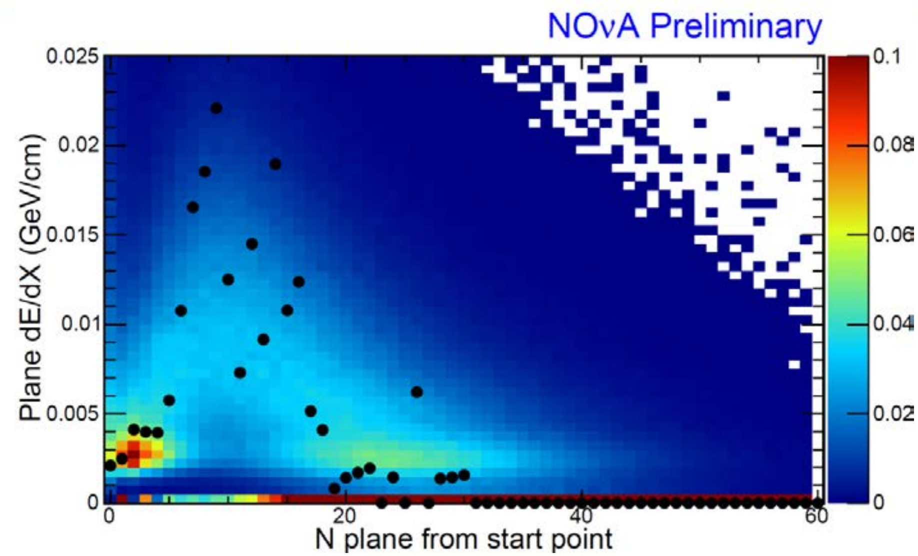


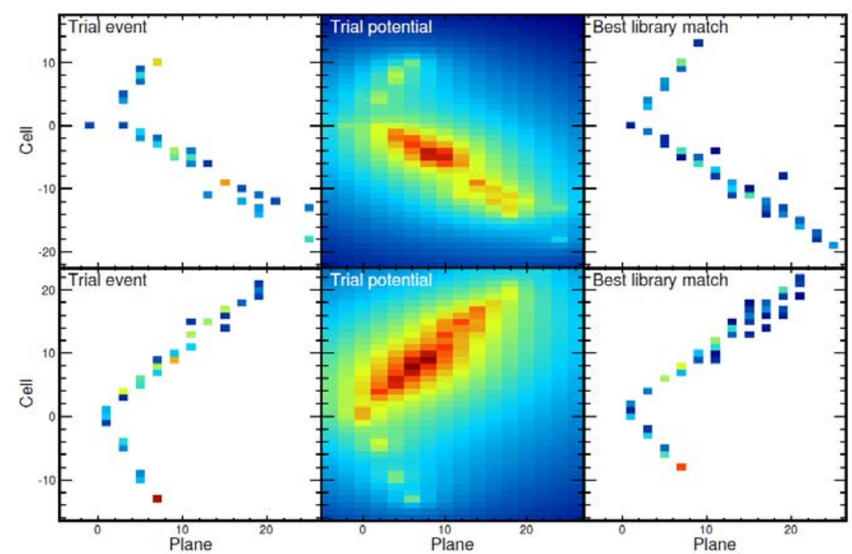
ν_e Selection

- Likelihood Identifier (LID)
  - Compare longitudinal and transverse dE/dx in leading shower to template histograms for $e/p/n/\mu/\pi^{\pm}/\pi^0/\gamma$.
  - Build neural net from these inputs and reconstructed quantities.

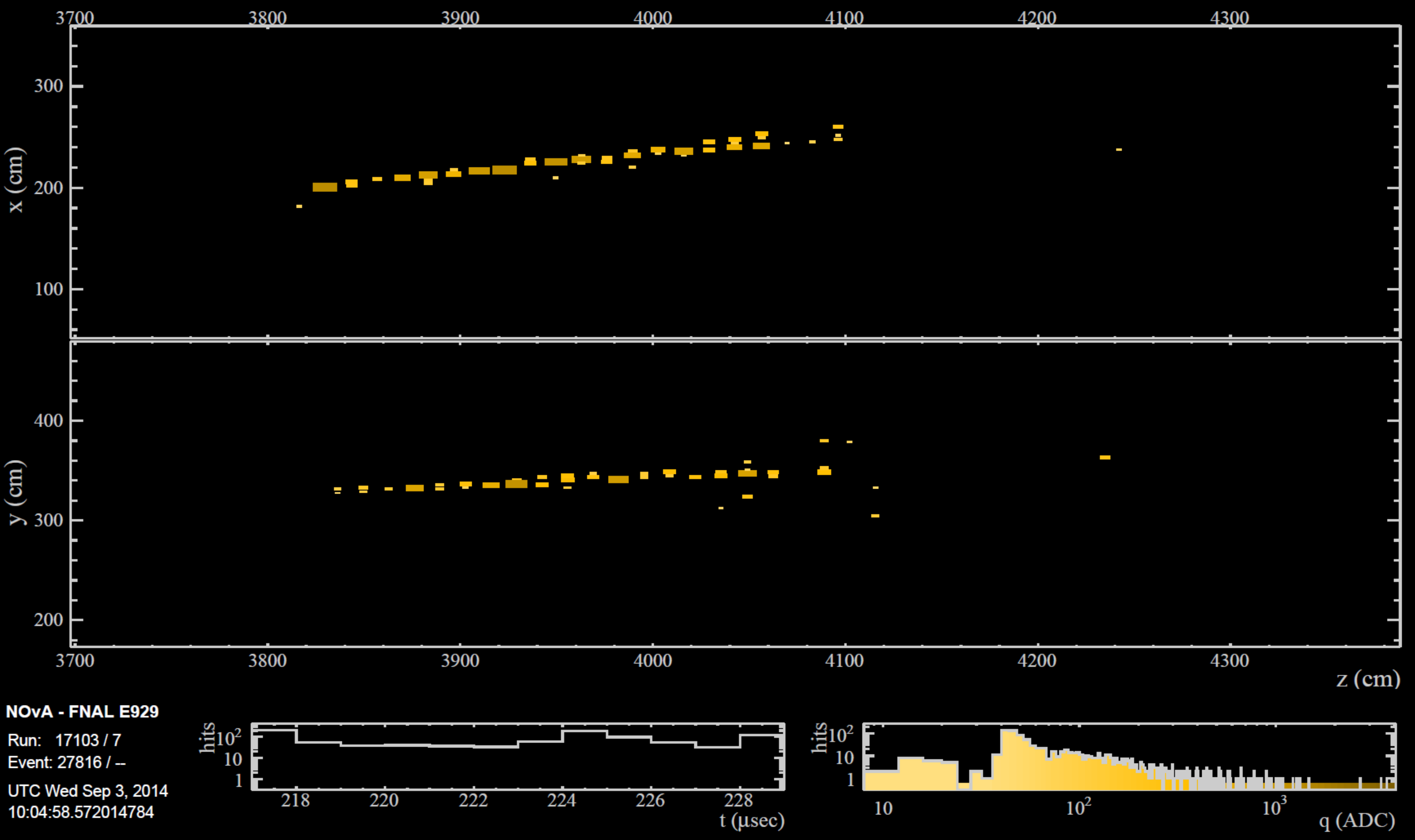
- Library Event Matching (LEM)
  - Compares input event to simulated event library.
  - Properties from most similar events fed into decision tree.

- 62% event overlap between selectors.
- LID chosen before unblinding as primary selector.

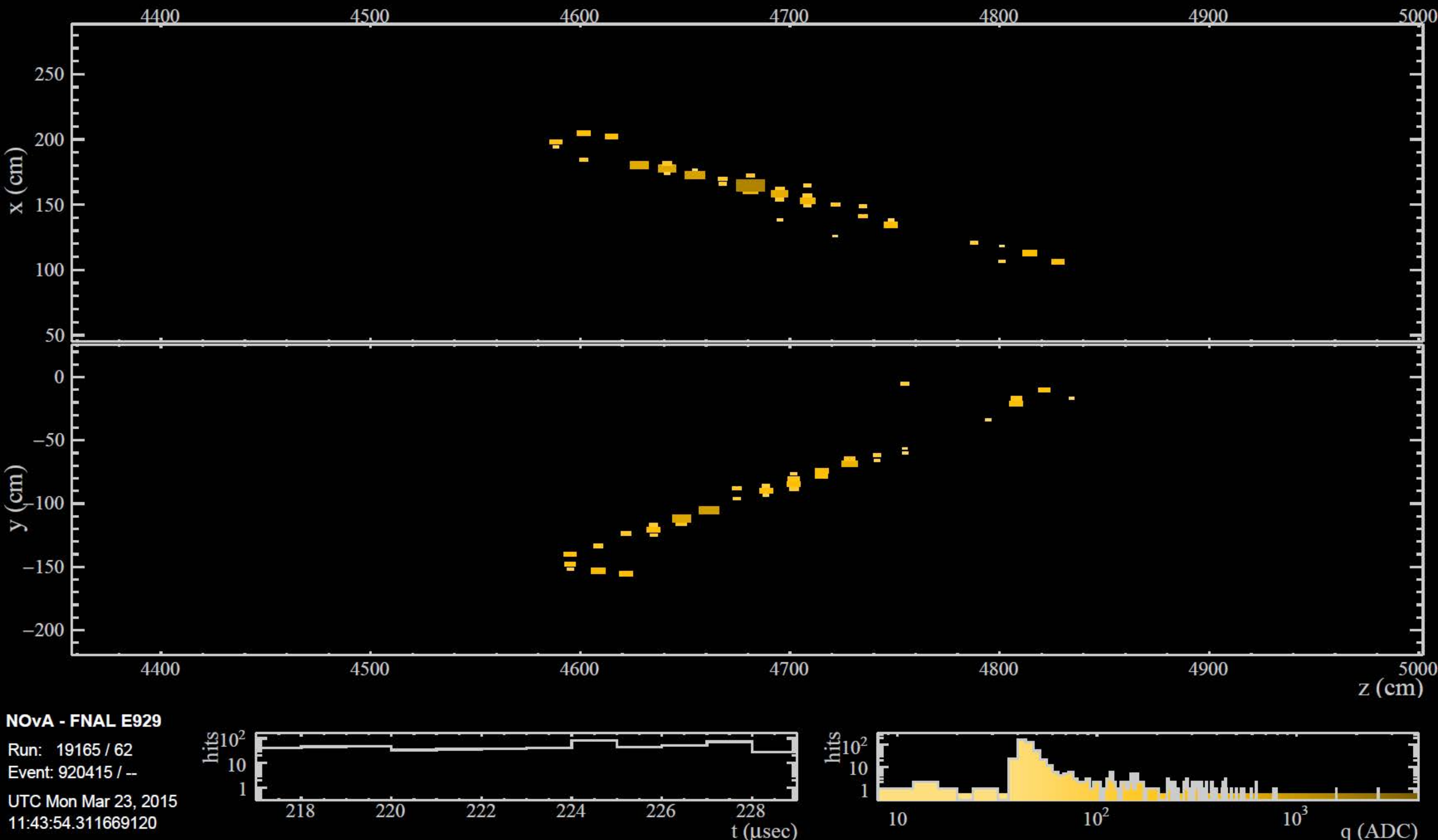




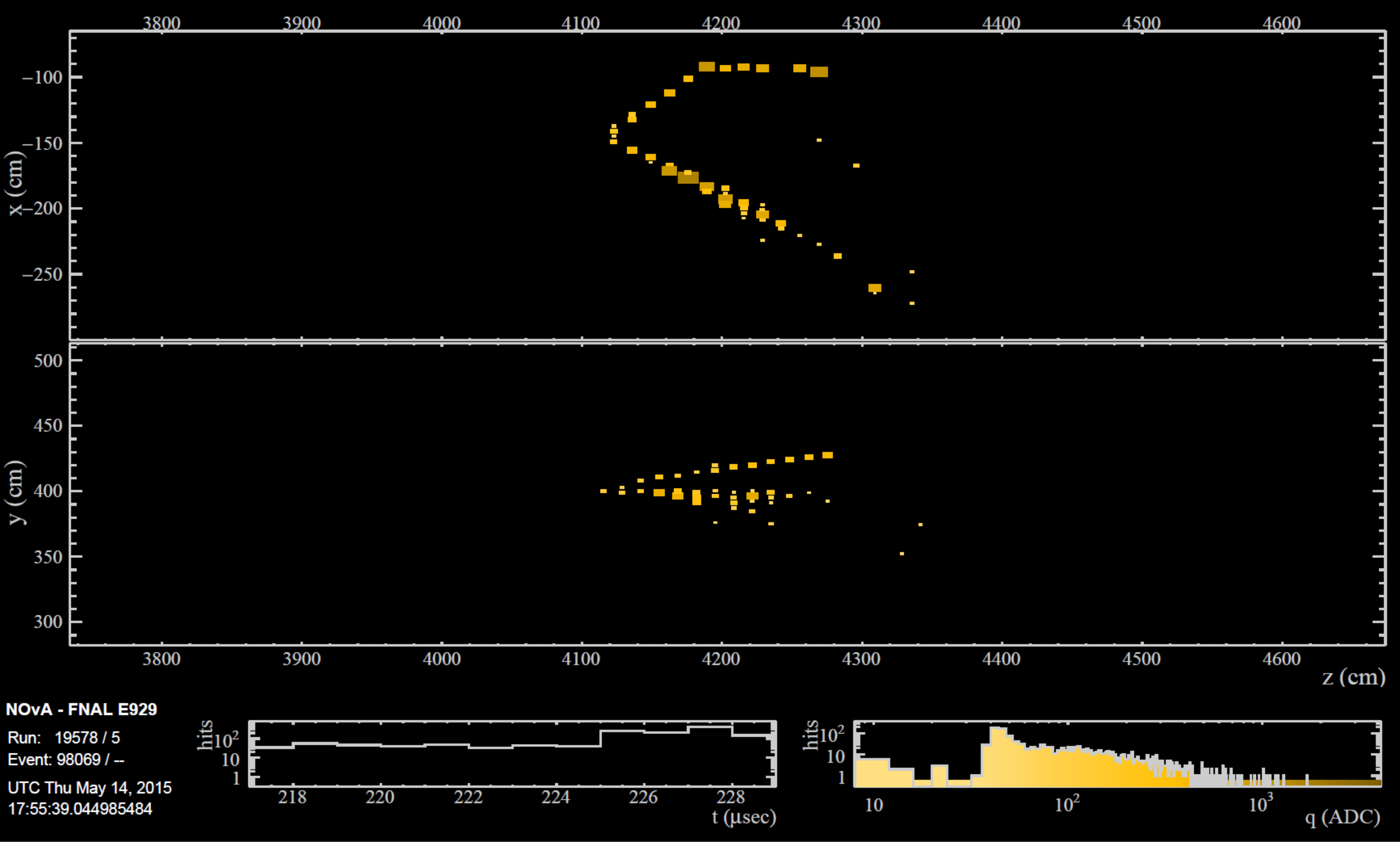
Far Detector selected ν_e CC candidate



Far Detector selected ν_e CC candidate

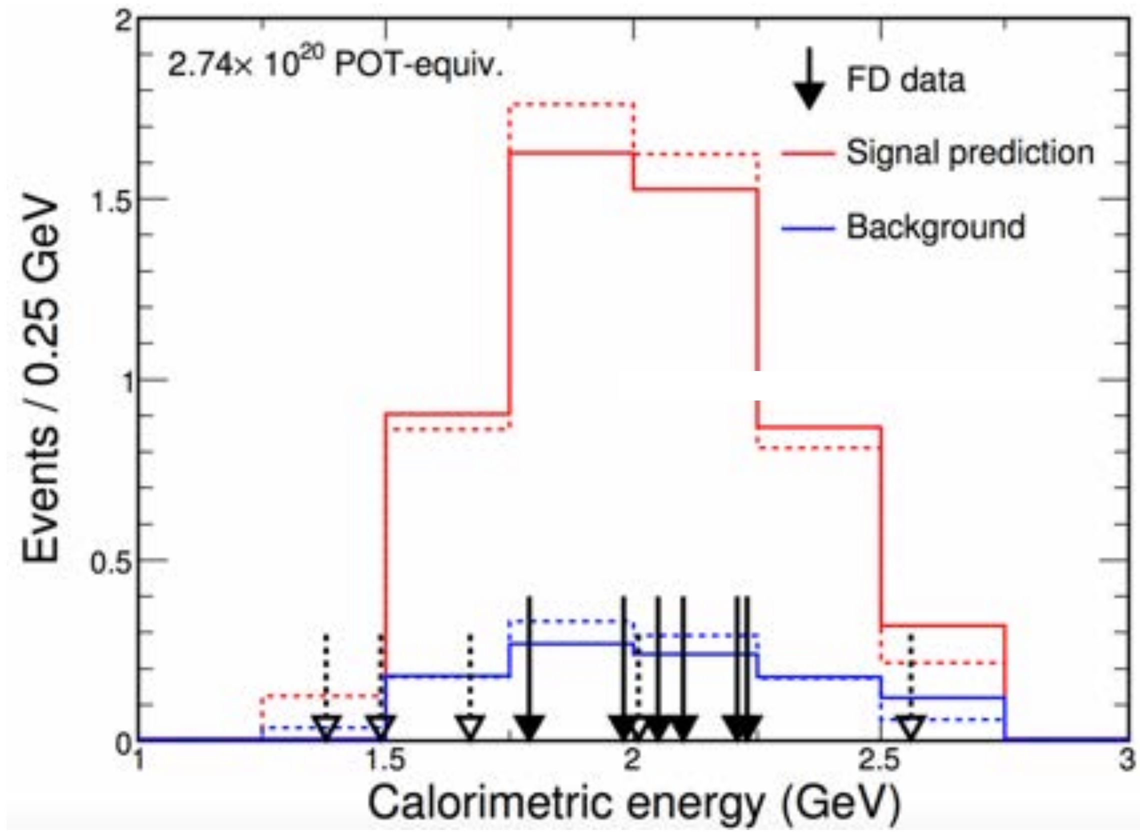


Far Detector selected ν_e CC candidate



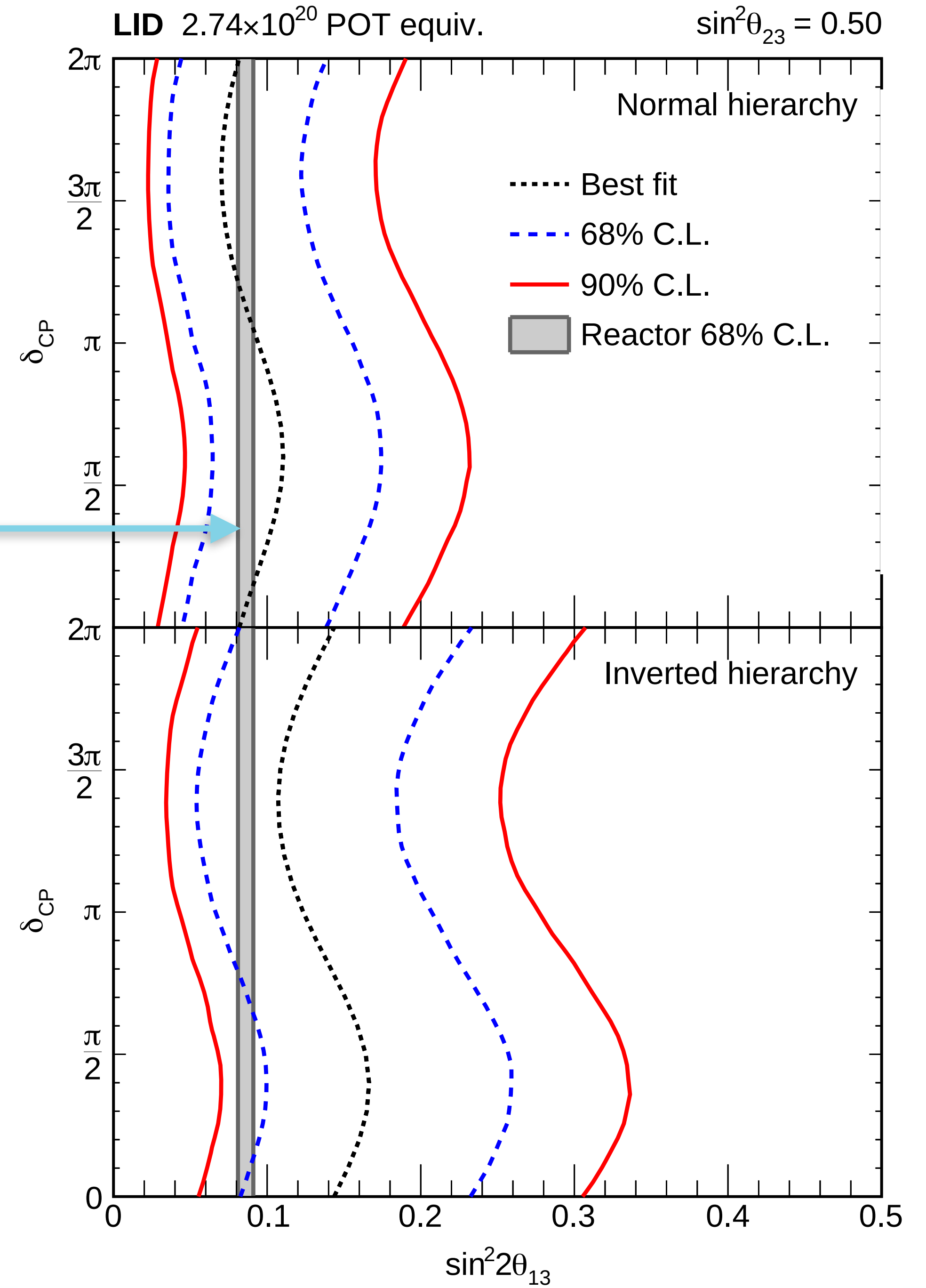
ν_e Appearance

- LID observed 6 events on a background prediction of 0.99±0.11(syst), 3.3σ excess.
- LEM observed 11 events on a background of 1.07±0.14(syst), 5.3σ excess.
- All LID events in LEM set.
- 7.8% probability of this overlap configuration or one less likely.



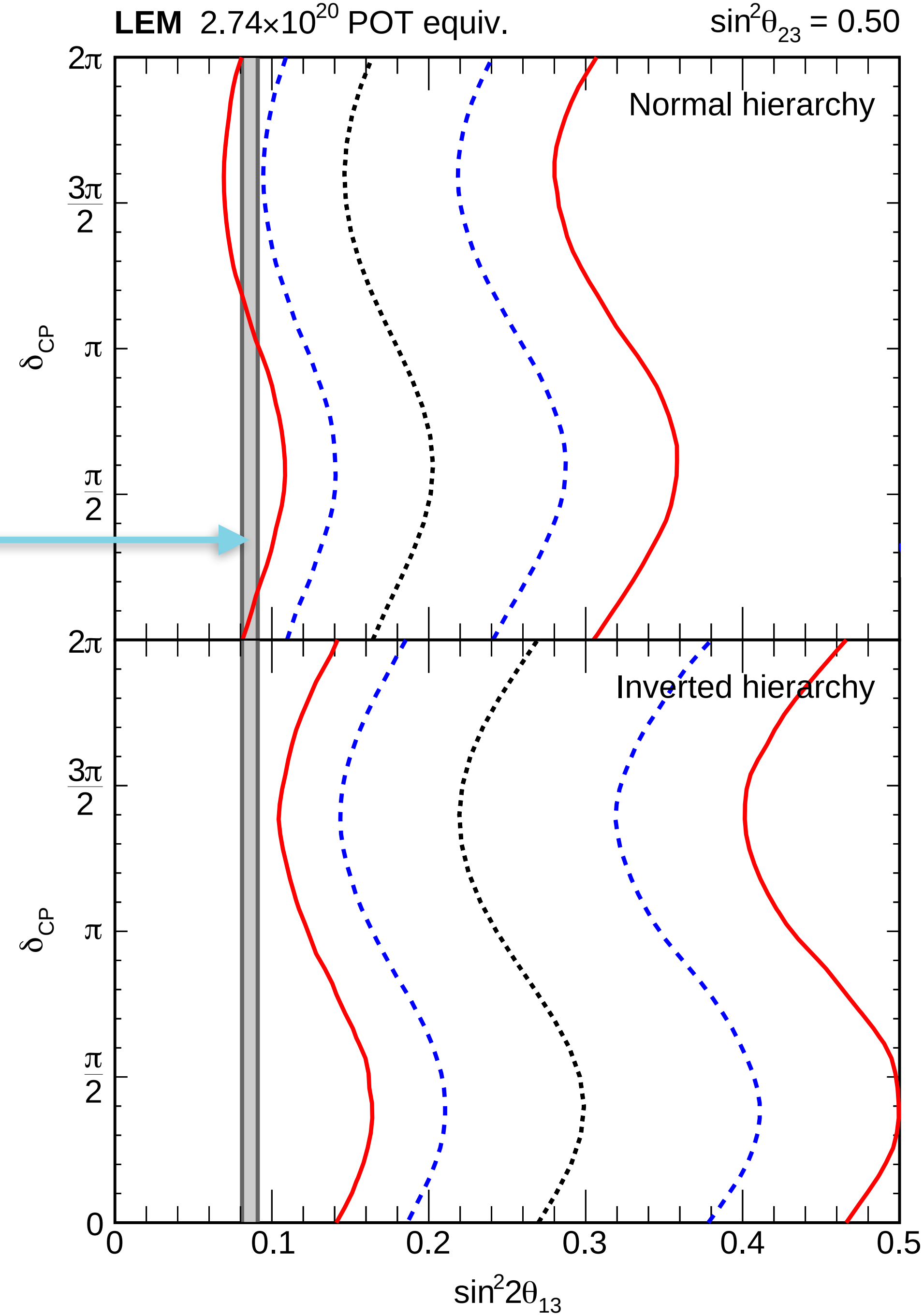
LID Selector

Global best fit from reactor experiments



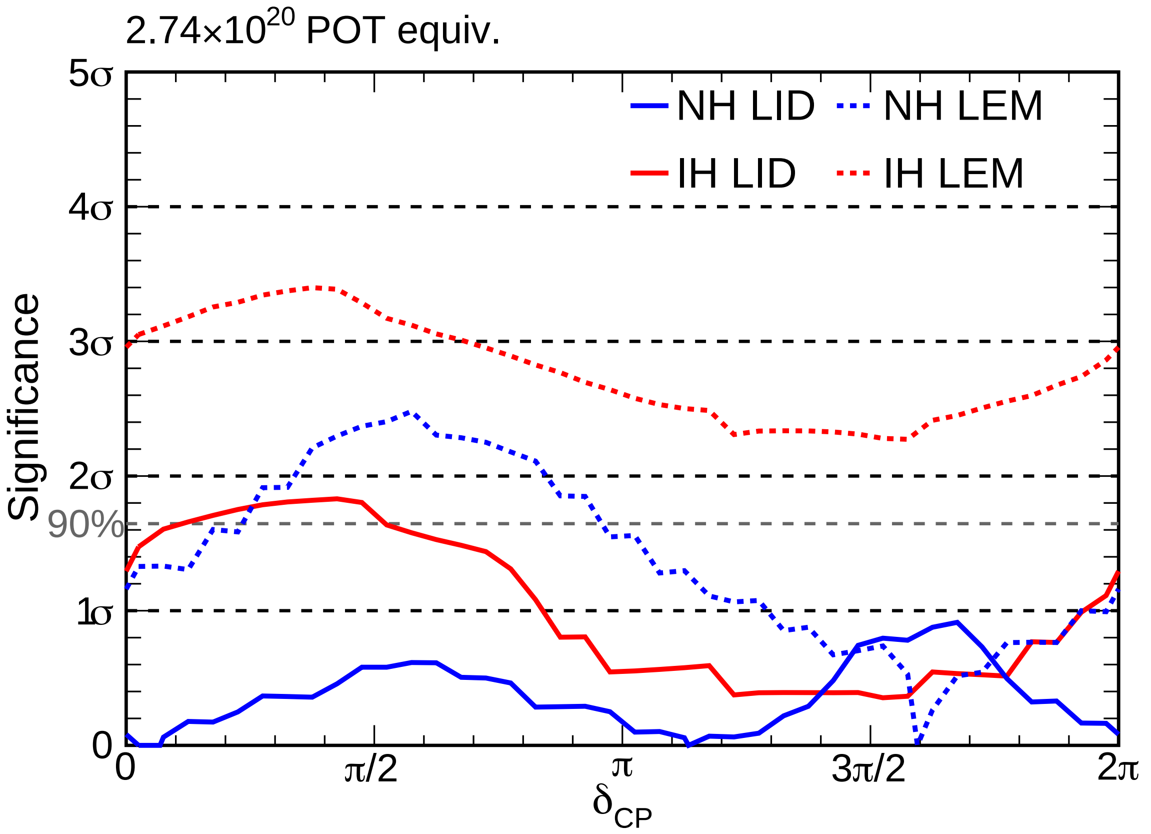
LEM Selector

Global best fit from reactor experiments



Results with Reactor Constraint

- Apply global reactor constraint
  - $\sin^2\theta_{13}=0.086\pm0.05$
- Marginalize over θ_{23}.
- Both selectors weakly prefer normal mass hierarchy and $\pi<\delta_{cp}<2\pi$.
- This preference is consistent with T2K (arXiv:1502.01550)



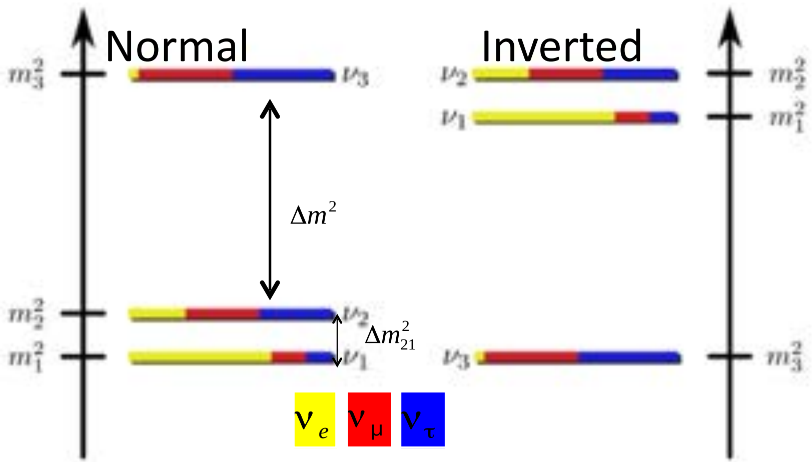
Conclusions

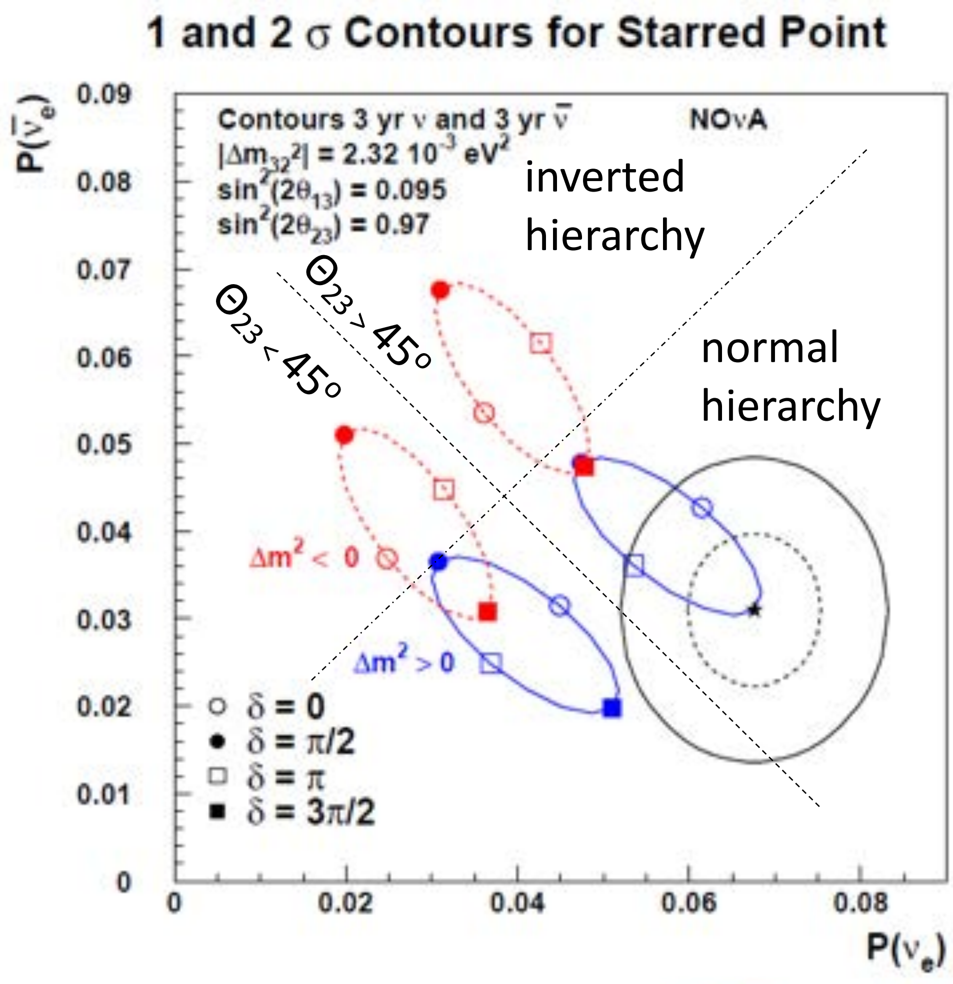
- First NOvA oscillation results with 7.6% of planned exposure
- ν_μ disappearance consistent w/ MINOS & T2K
- ν_e appearance result hints at normal hierarchy and $\pi<\delta_{CP}<2\pi$, consistent with T2K
- Cross-section studies in progress, ν_e CC and coherent π^0 results shown at NuINT
- Planning 2nd result with double the statistics for the summer
- Stay tuned!

Backup slides

Relation of Oscillation Parameters in NOvA

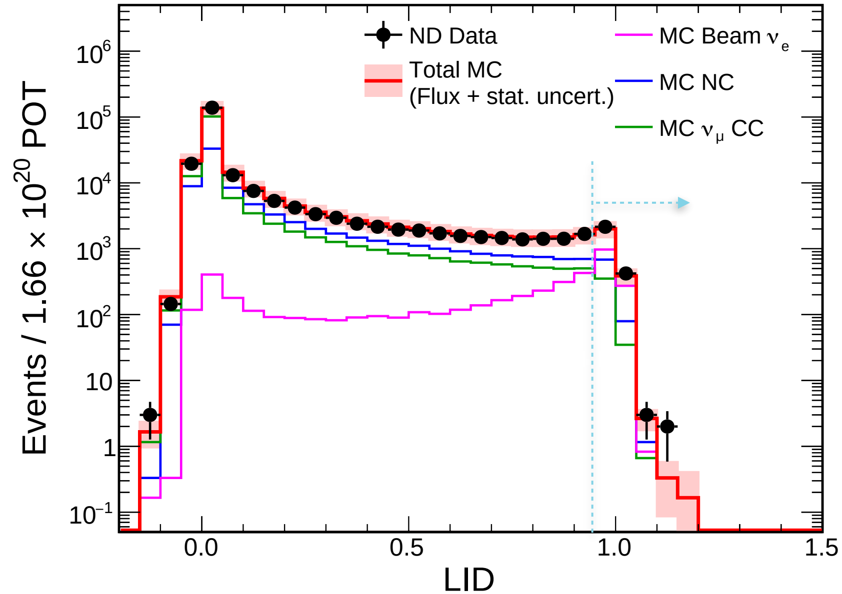
- NOvA makes a measurement of the oscillation probabilities:
  - $P(\nu_\mu \rightarrow \nu_e)$
  - $P(\overline{\nu_\mu} \rightarrow \overline{\nu_e})$
- The measured probabilities depend on the mass hierarchy, θ_{23} octant, and δ_{cp}.

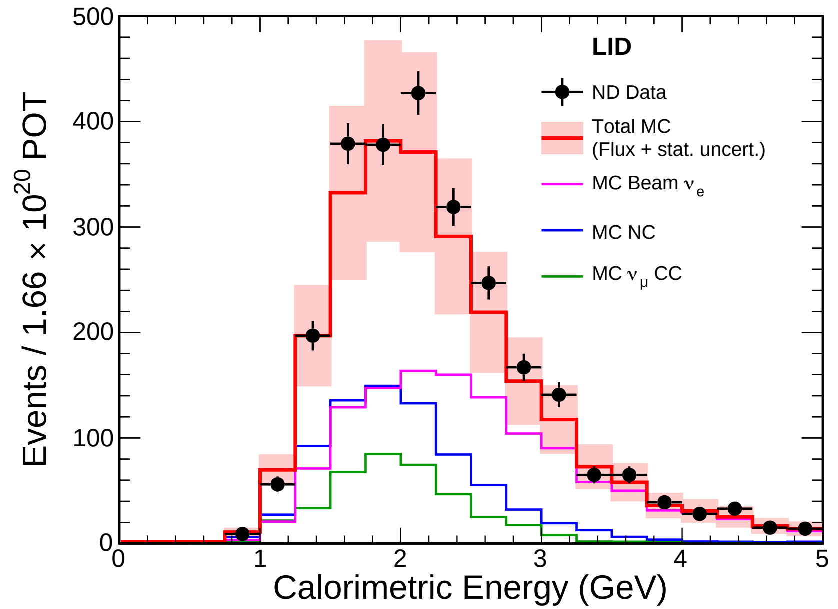




ν_e Appearance Analysis Strategy

- FD background prediction extrapolated from ND
  - ND selects ~7% more background in data relative to simulation.
- Combination of containment, topology and event classifier achieve cosmic rejection factor >10^8. Effective FD fiducial volume of 10 kT.
- "Cut and count" analysis between 1.5 and 2.7 GeV in FD for the primary selector.





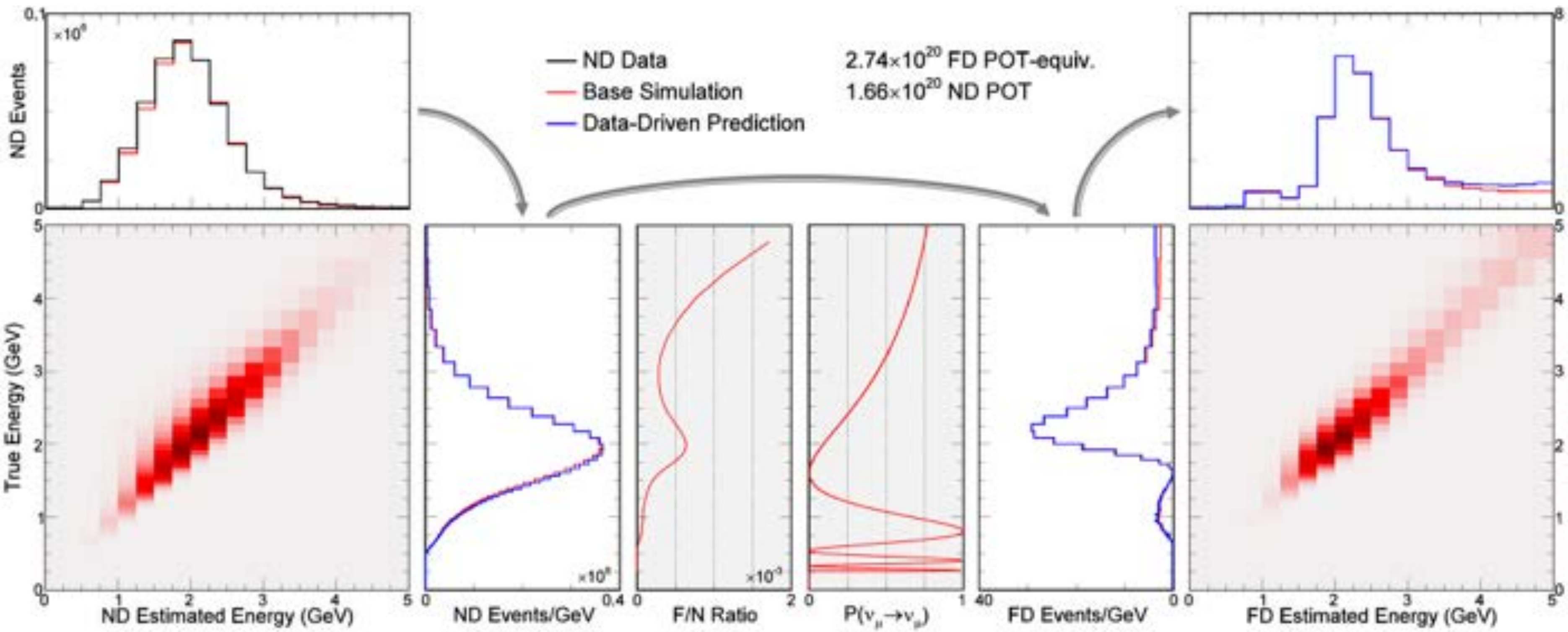
ND energy spectrum with LID>0.95

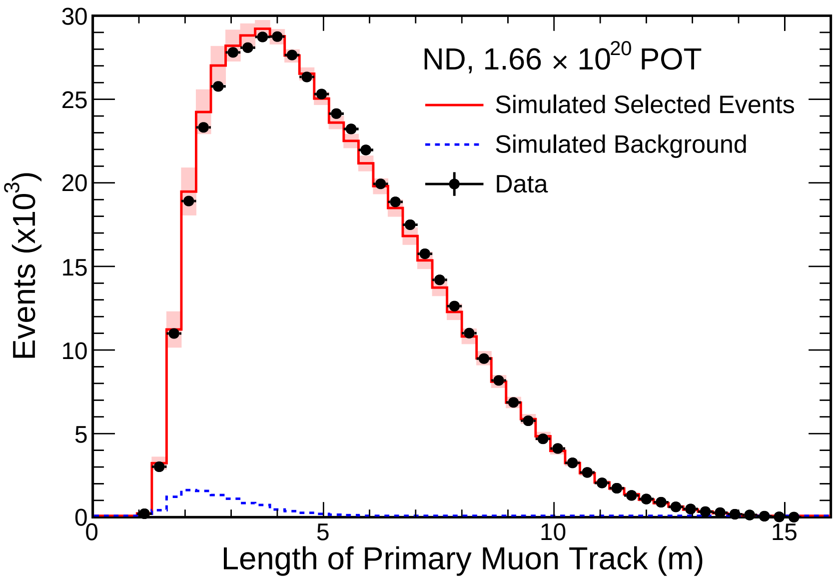
(1) Estimate the underlying **true energy distribution** of selected ND events

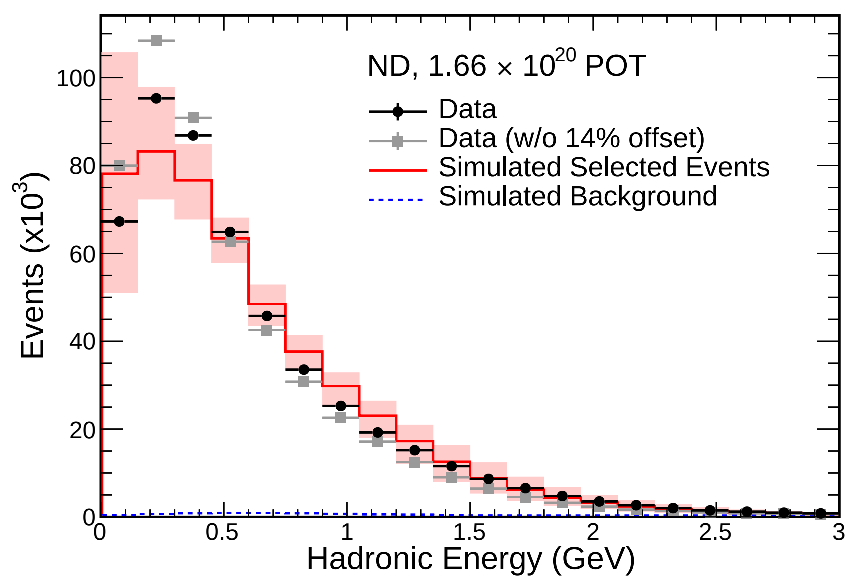
(2) Multiply by expected **Far/Near event ratio** and $\nu_\mu \rightarrow \nu_\mu$ **oscillation probability** as a function of true energy

(3) Convert FD true energy distribution into **predicted FD reco energy distribution**

Systematic uncertainties assessed by **varying all MC-based steps**



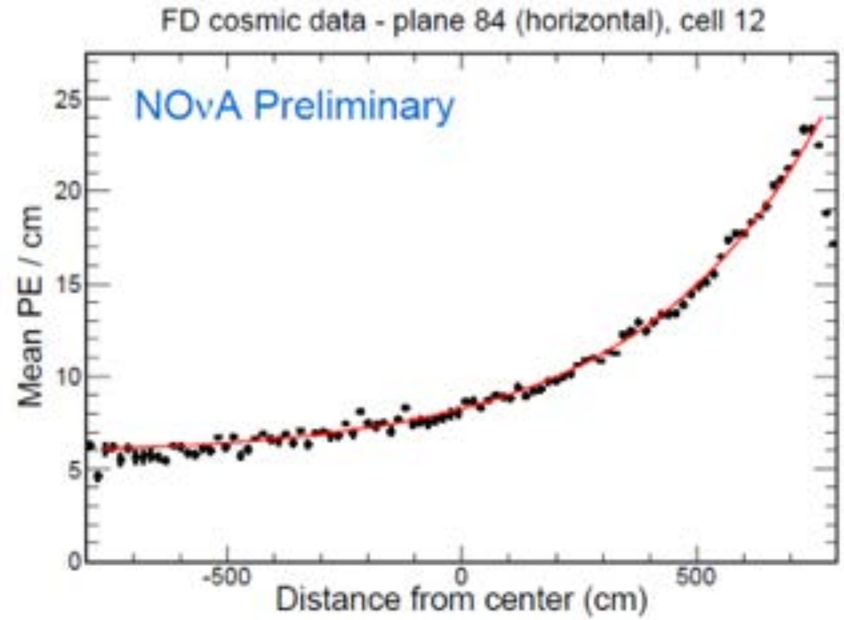


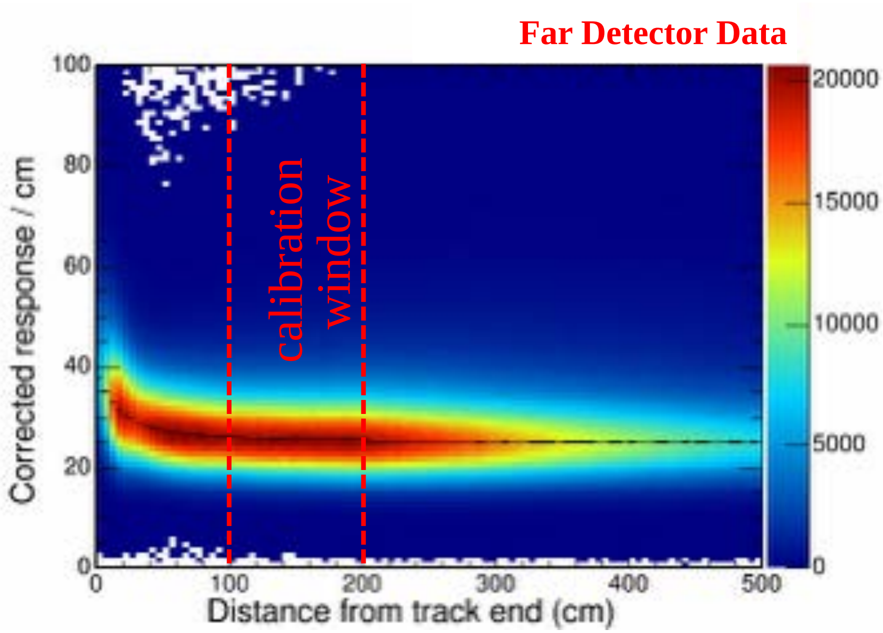


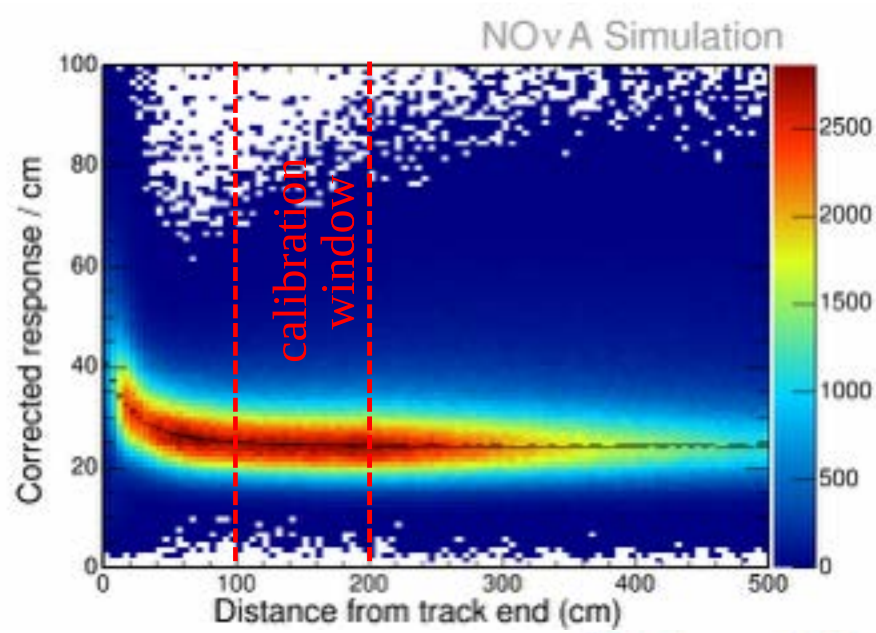
$$E_\nu = E_\mu + E_{\text{hadrons}}$$

- Muon variables in agreement
- Best fit to hadronic energy prefers 14% increase in data

- Correct for attenuation in each cell using through-going cosmic muons (right)
- Set absolute energy scale using stopping muons in data and tuned Monte Carlo (below)



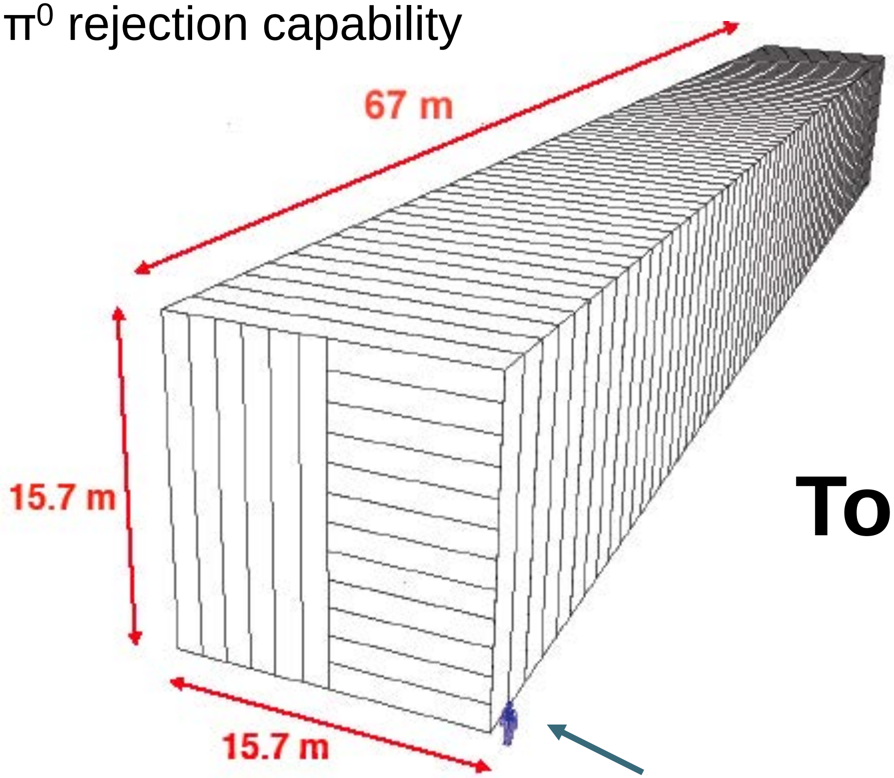




NOvA Far Detector

TASD: Totally Active Scintillator Design

Longitudinal sampling is ~0.15 X_0, which gives:
-- excellent μ-*e* separation
-- π^0 rejection capability

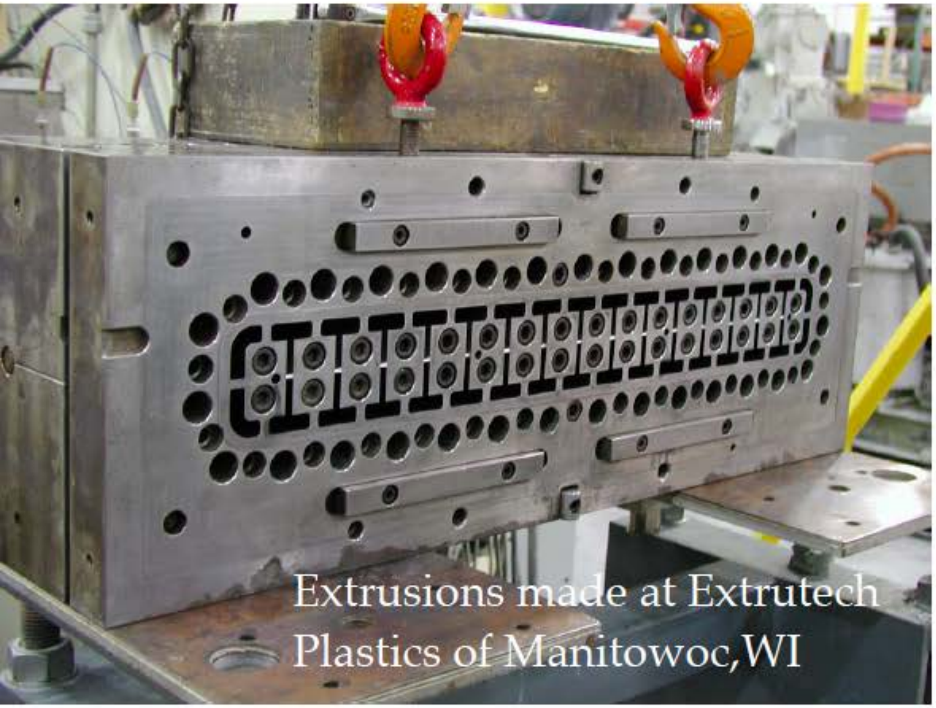


An admirer

Total mass of 14 ktons

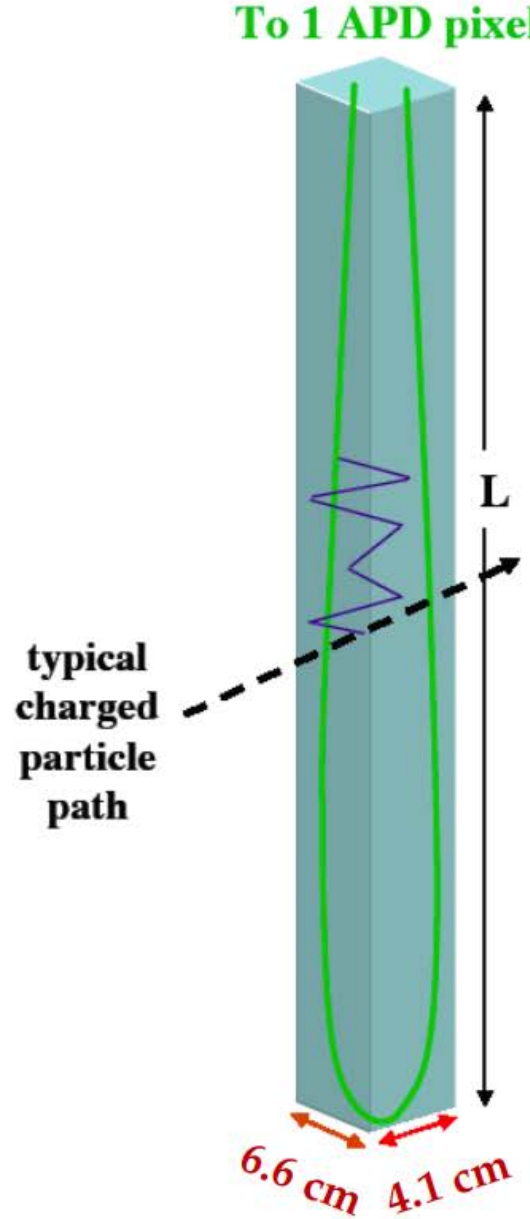
[G. Feldman]

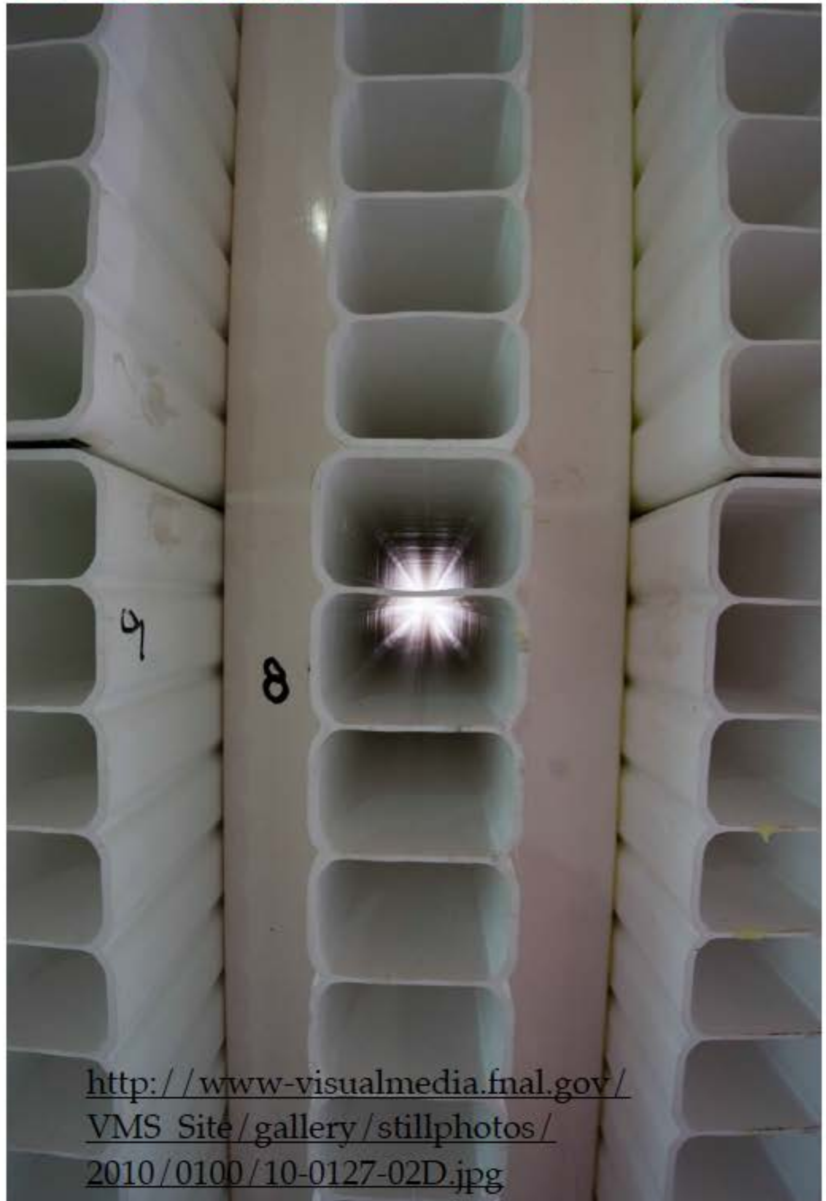
Extrusions



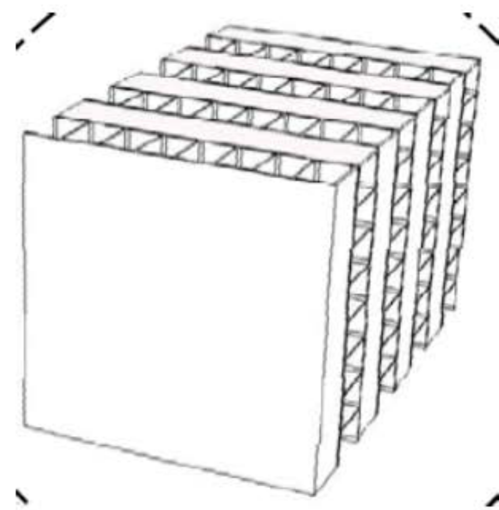
- PVC extruded through die to form 15.7m extrusions
- ~24,000 required for Far Detector.

Detector Elements

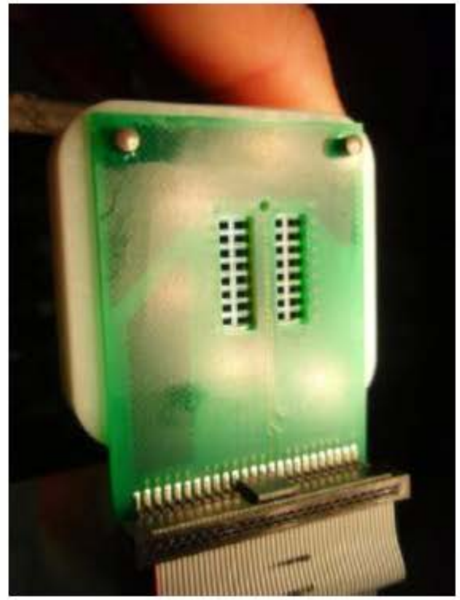




- Cells with liquid scintillator grouped into alternating planes



[L. Corwin]



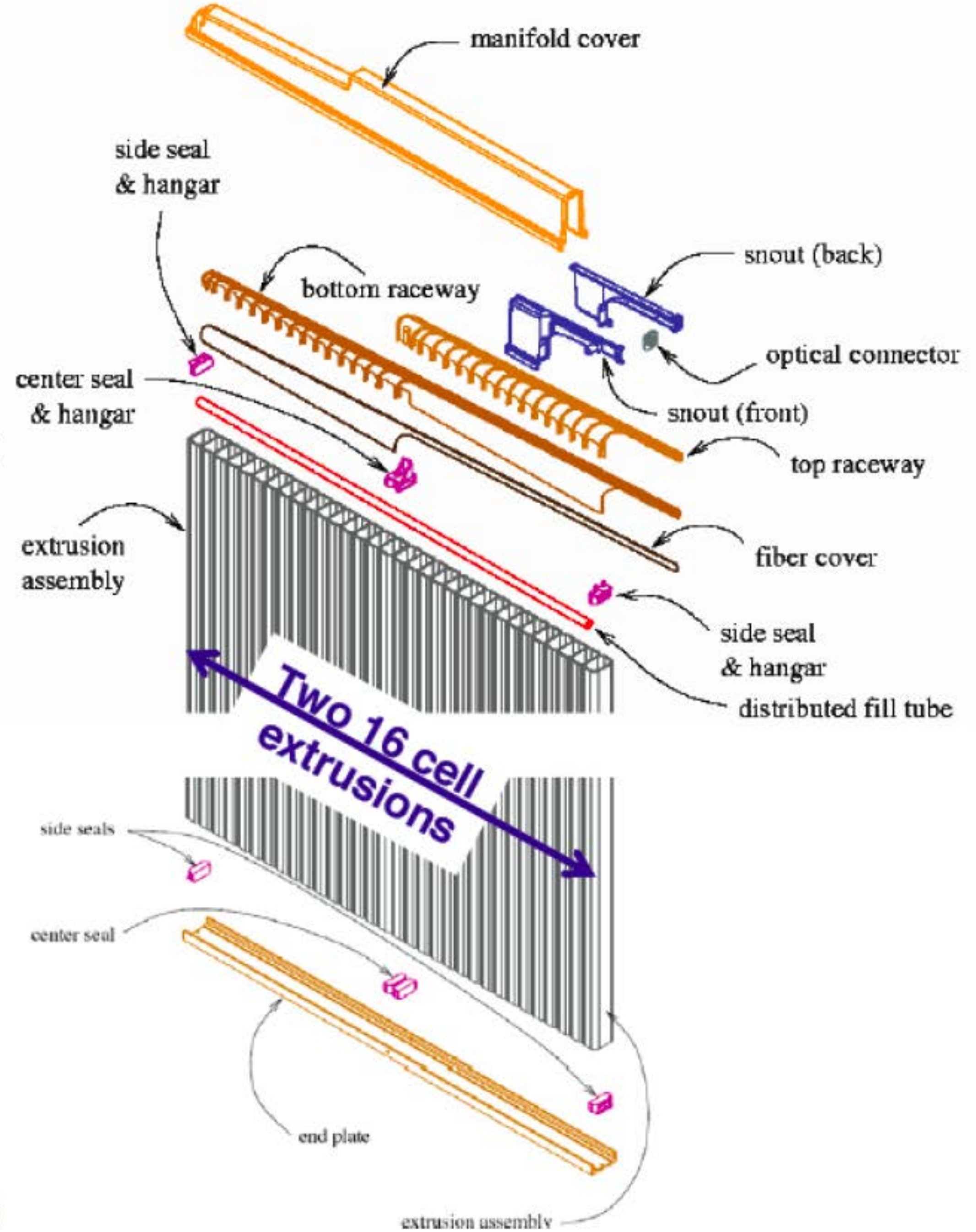
Scintillation light travels along wavelength shifting fibers to end of manifold

Light detected in by avalanche photodiodes (APDs) that are sealed, cooled (to -15 °C) and mated to the detector data acquisition system.

[L. Corwin]

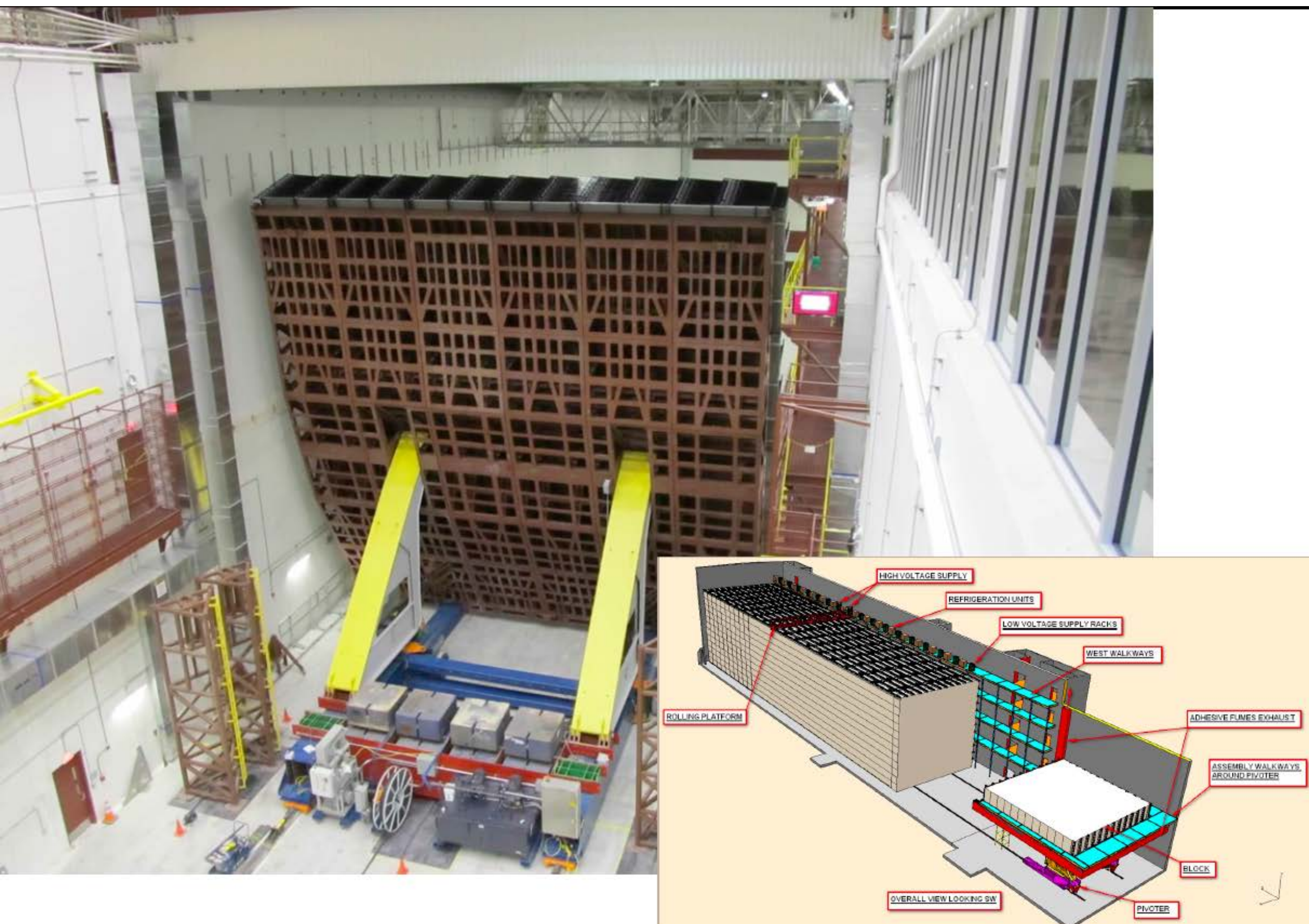
Modules

- Many pieces must be brought together to form an active detector module
- Many undergrads working at module factory at the U of MN
- Cell interiors must be very reflective so scintillation light is not lost.



Assembly

[L. Corwin]


HIGH VOLTAGE SUPPLY
REFRIGERATION UNITS
LOW VOLTAGE SUPPLY RACKS
WEST WALKWAYS
ROLLING PLATFORM
ADHESIVE FUMES EXHAUST
ASSEMBLY WALKWAYS AROUND PIVOTER
BLOCK
OVERALL VIEW LOOKING SW
PIVOTER

[L. Corwin]

Very cool time lapse video: http://www.youtube.com/watch?v=gFpK00WJl90&sns=tw