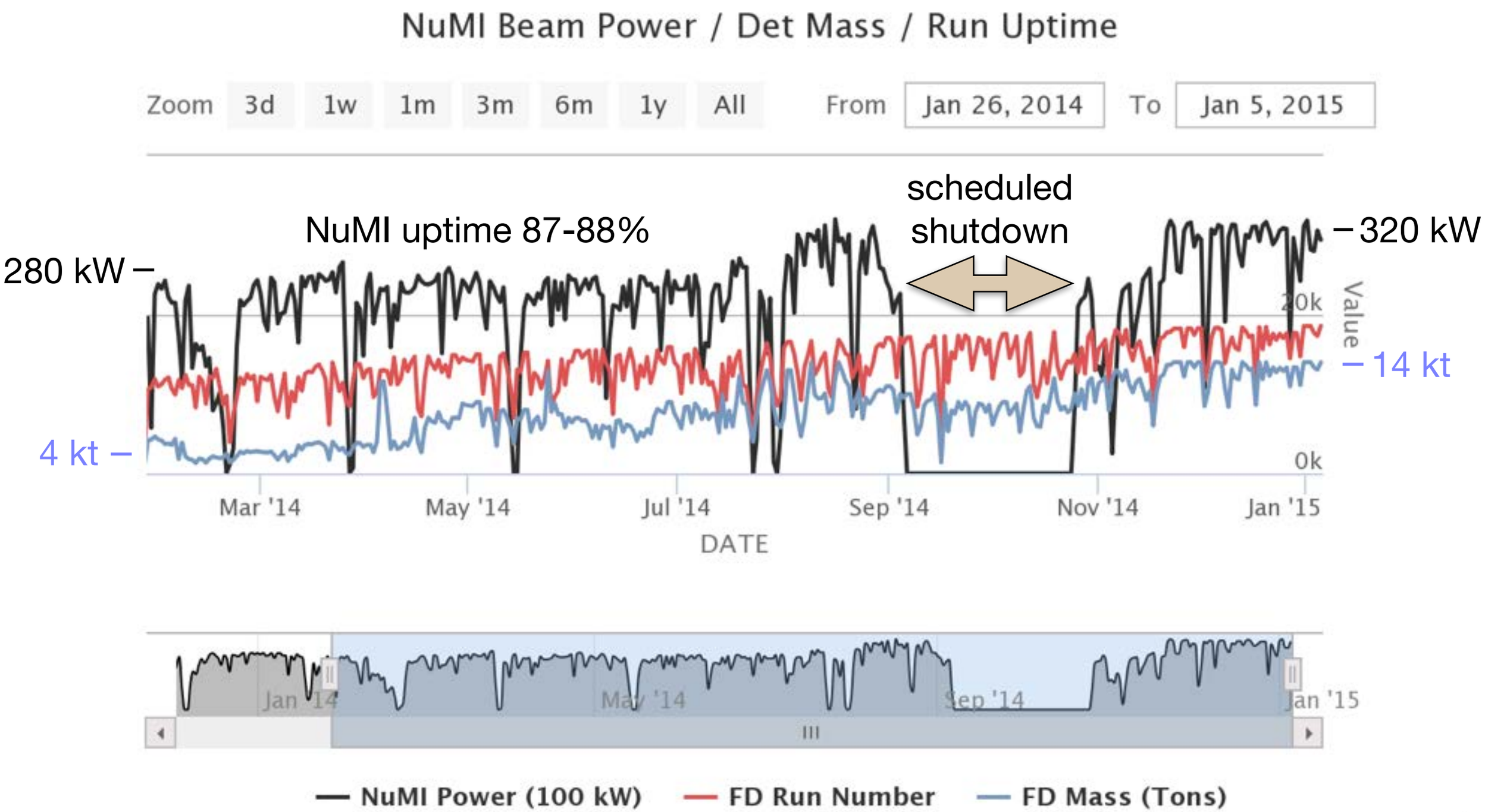
# *NOvA Status and Run Strategy*

Mark Messier
Indiana University

Fermilab Physics Advisory Committee
January 15, 2015

# 2014 - 2015 NuMI and NOvA Summary

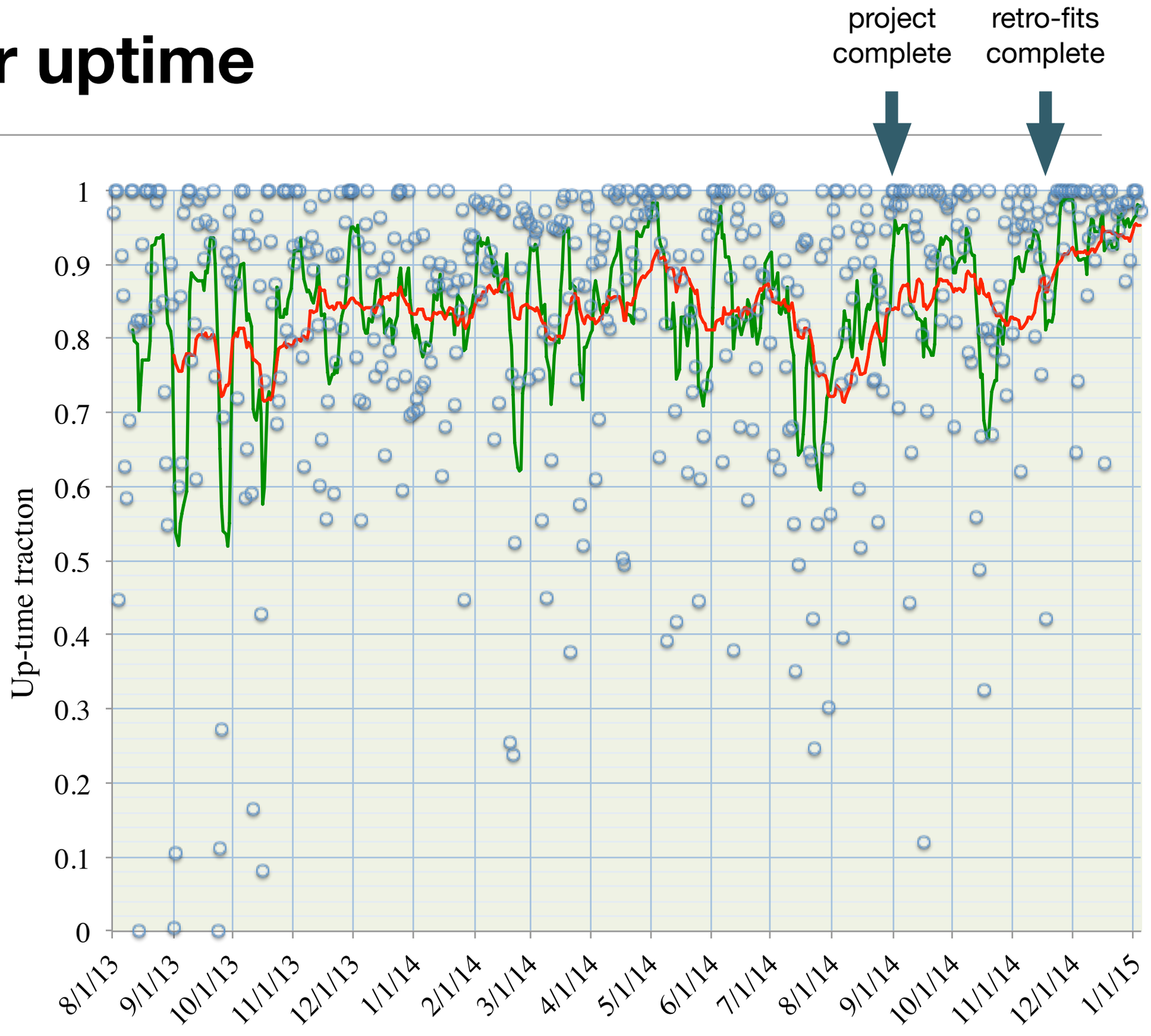


# Project complete

- Project CD4 signed in September, 2014
- Project completed on time and under budget.
- Operations now managed by collaboration in close consultation with Fermilab's Neutrino Division.
- Operations review held on October 29th, 2014.

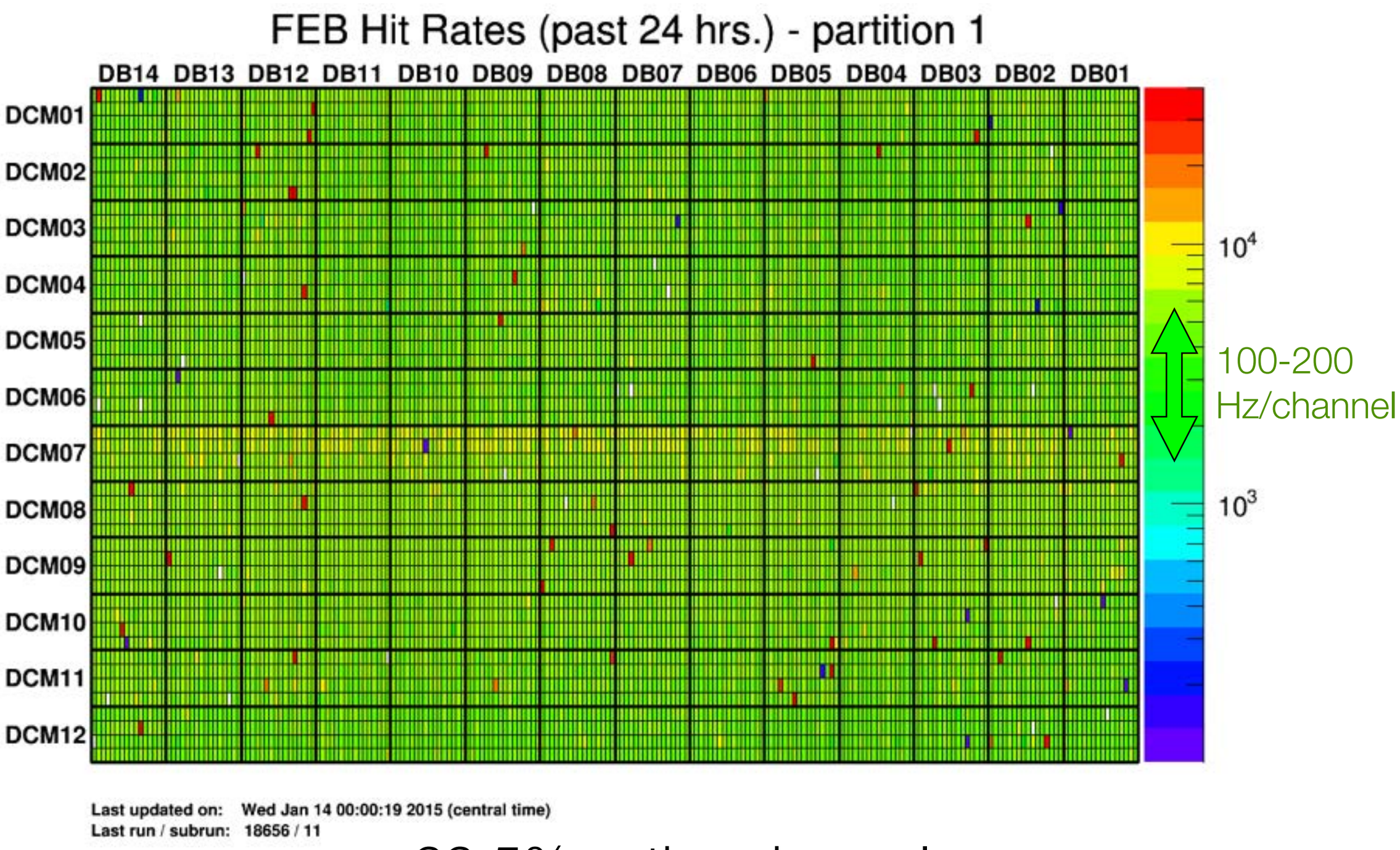
# Far detector uptime

- Retrofit work continued to replace faulty hoses through Nov. 20, 2014 at which point we began routine operations of 14 kt
- Far detector uptime routinely >95%



# NOvA Far Detector Status

10,752 front end boards shown by hardware address

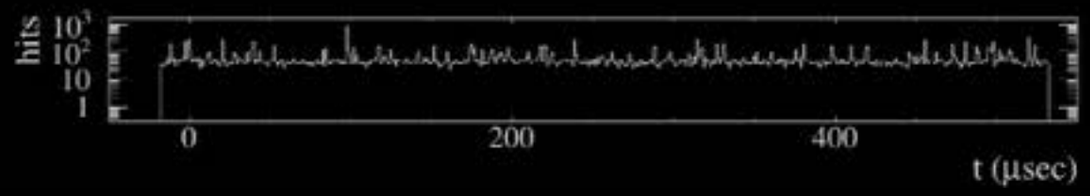


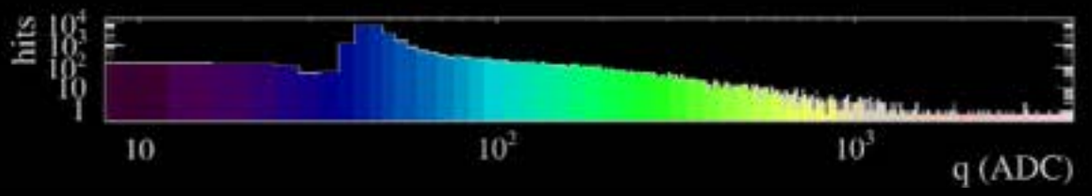

99.5% active channels

**NOvA - FNAL E929**

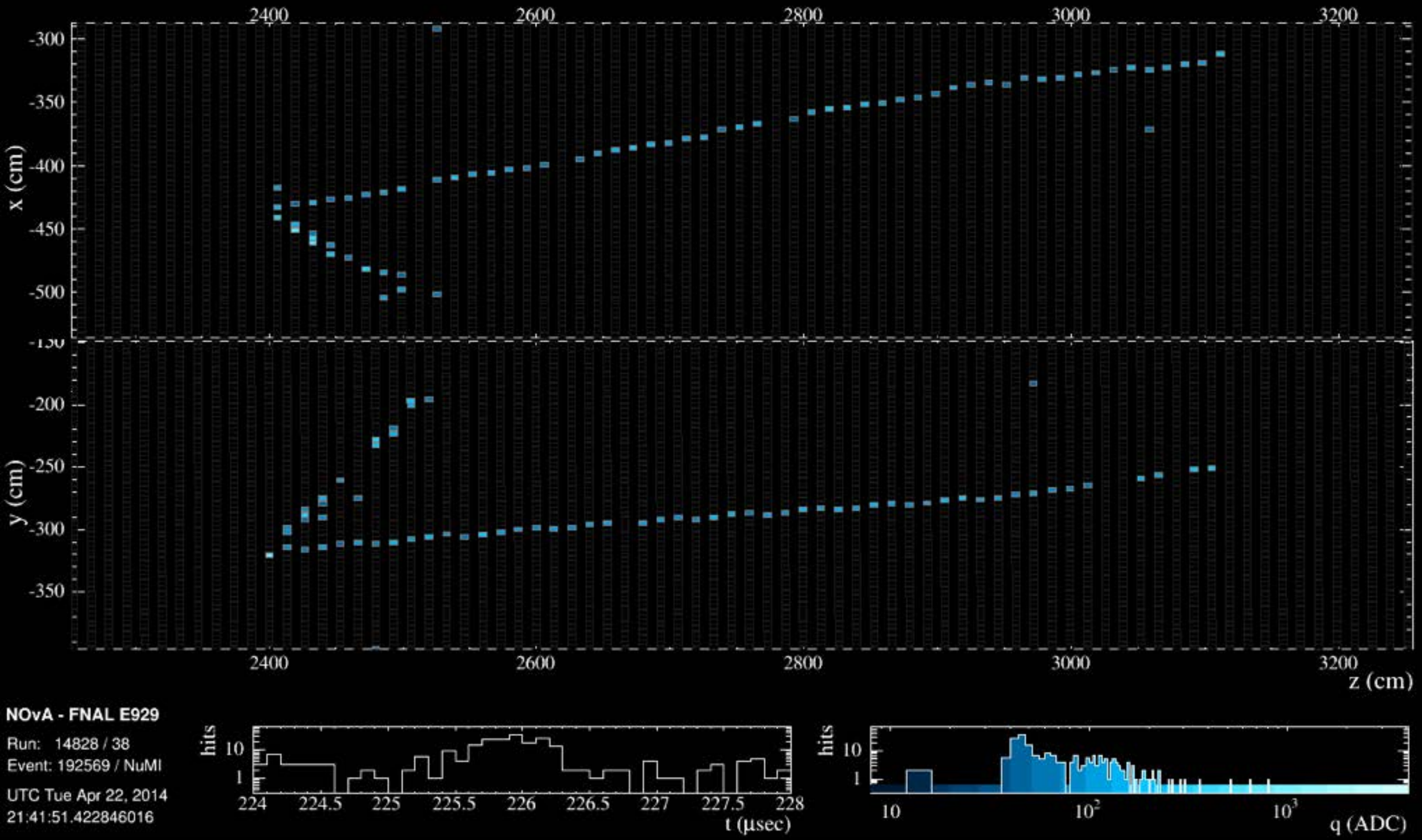
Run: 18605 / 0
Event: 161 / PerCal

UTC Tue Jan 6, 2015
23:25:55.172218000



# NOvA $\nu_\mu$ Charged-current candidate

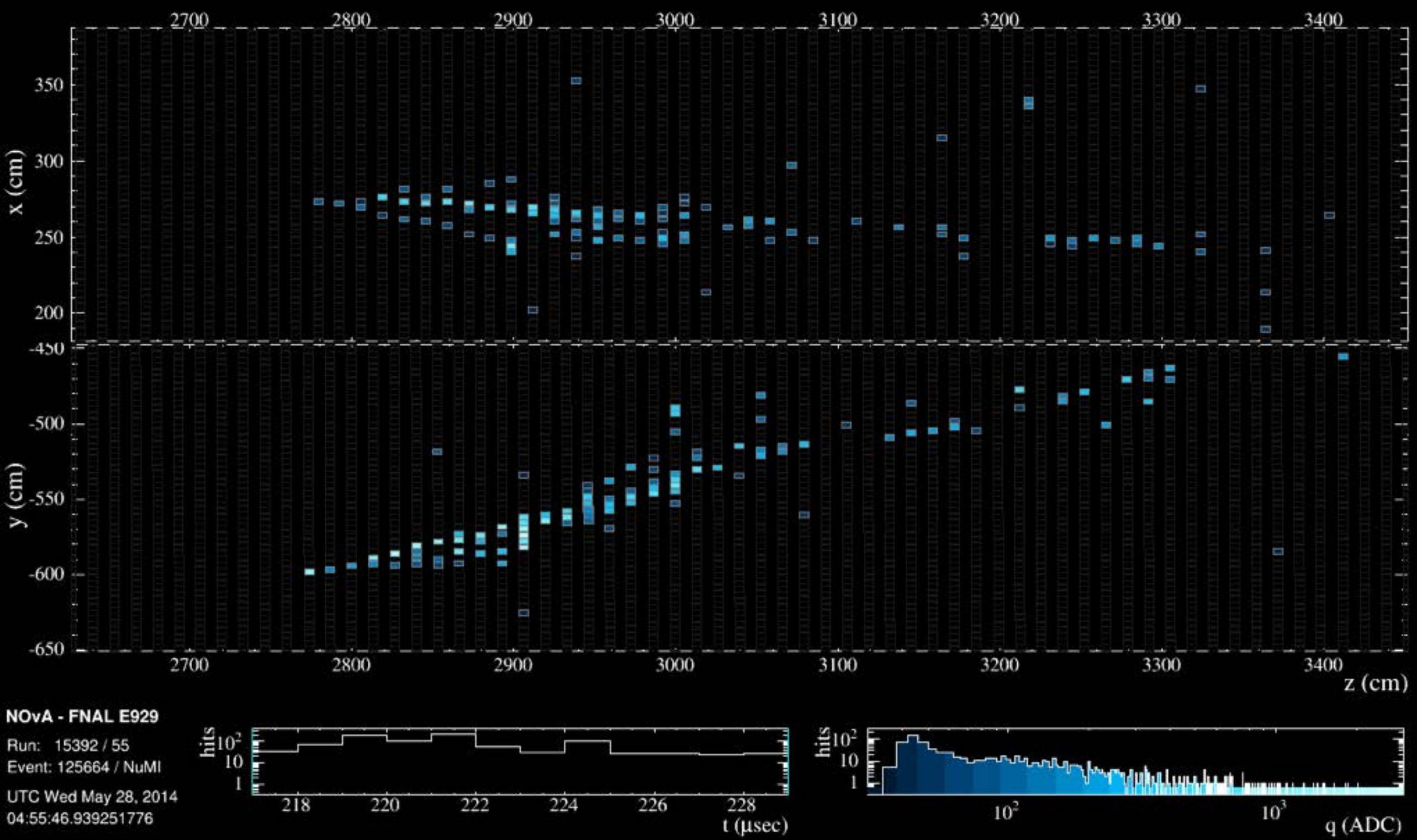



**NOvA - FNAL E929**

Run: 14828 / 38
Event: 192569 / NuMI

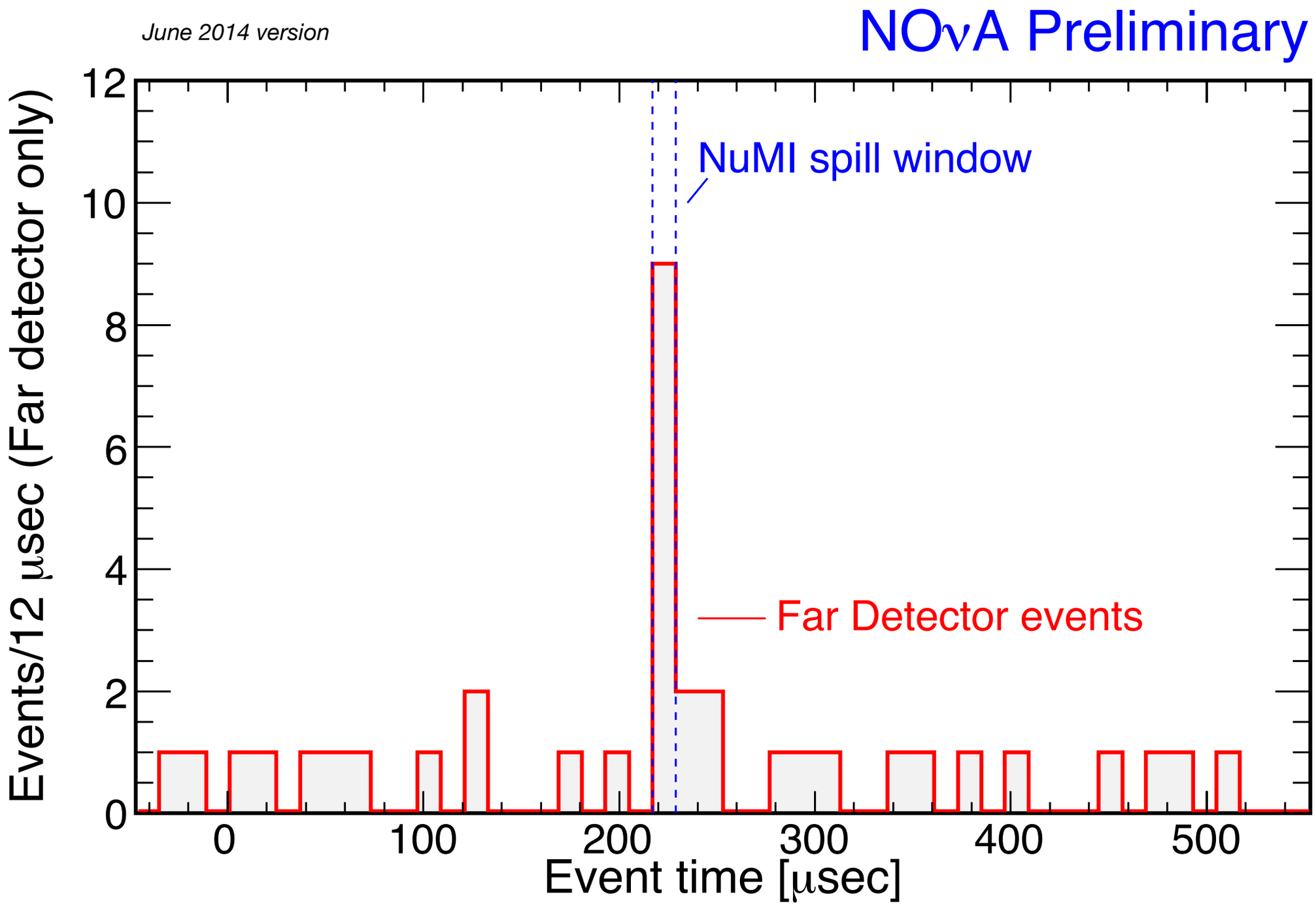
UTC Tue Apr 22, 2014
21:41:51.422846016

# NOvA $\nu_e$* Charged-current candidate

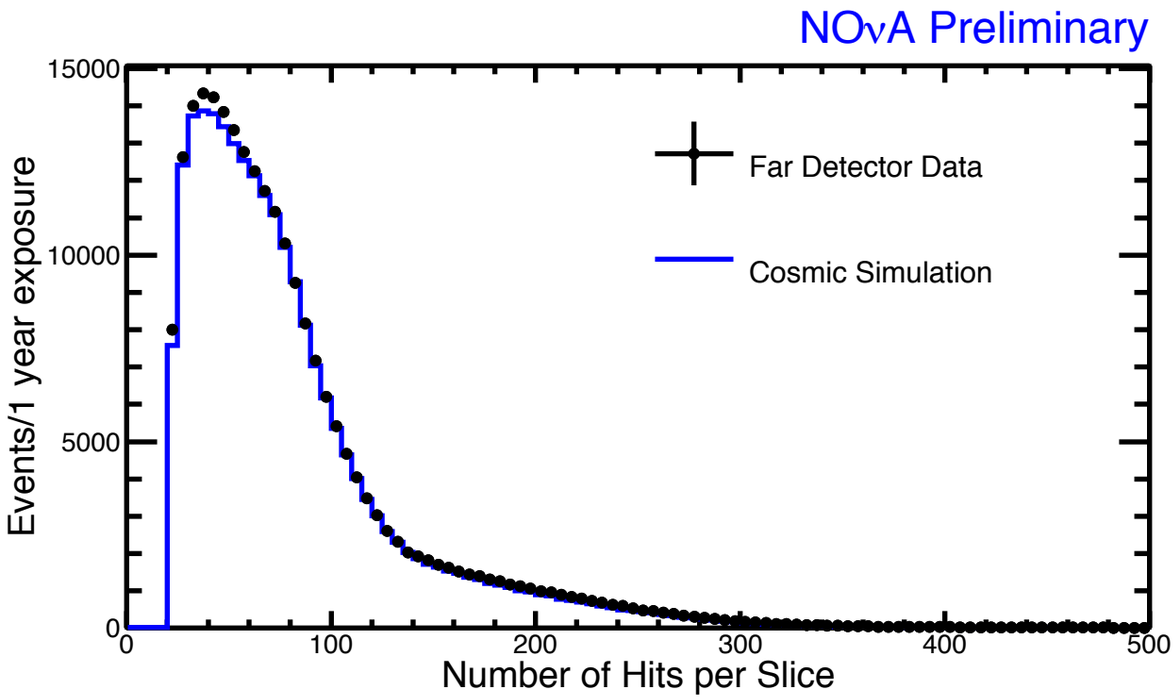


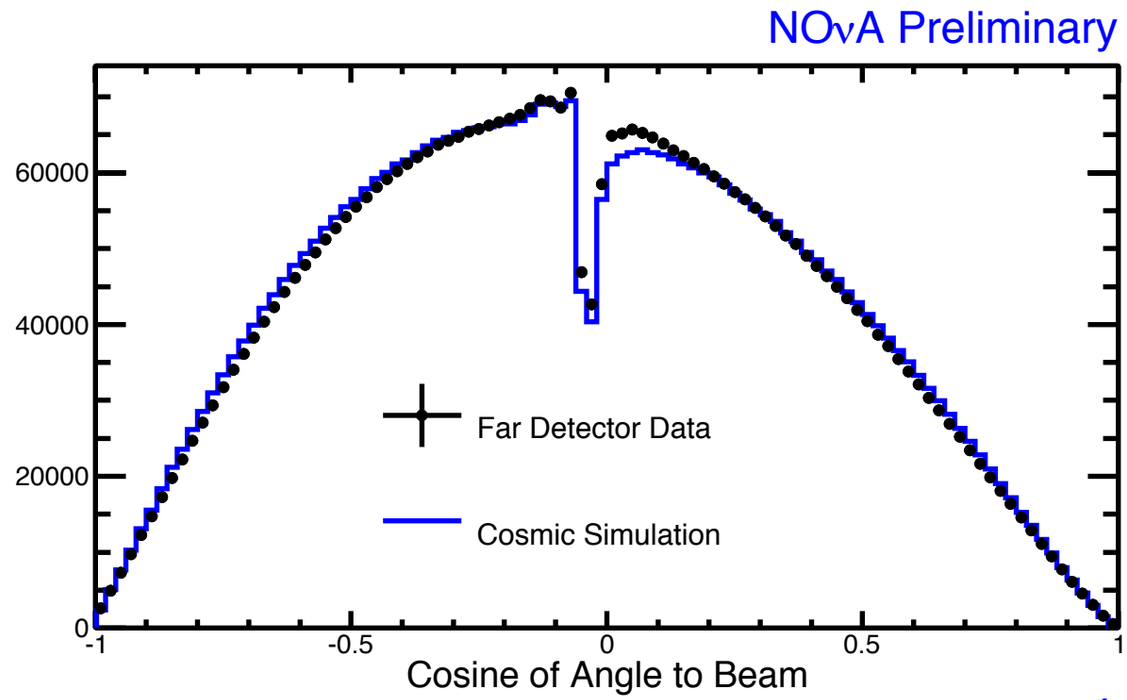

* particle IDs blinded until analysis finalized

# Far detector time peak

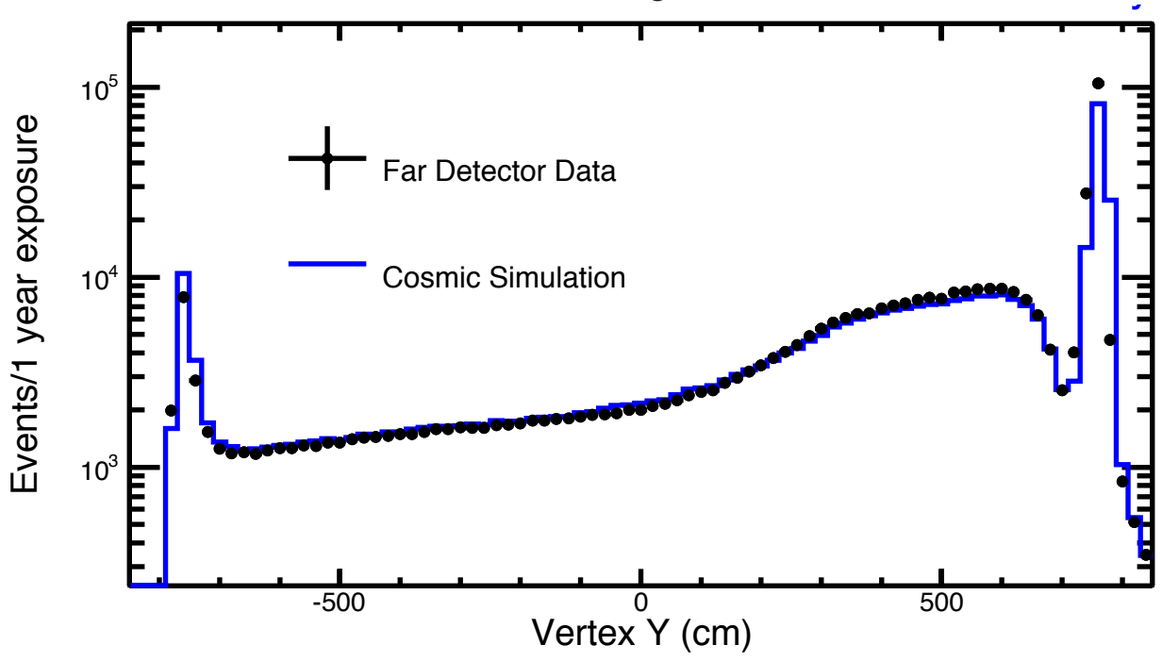


# Far detector cosmic-ray data / simulation comparisons



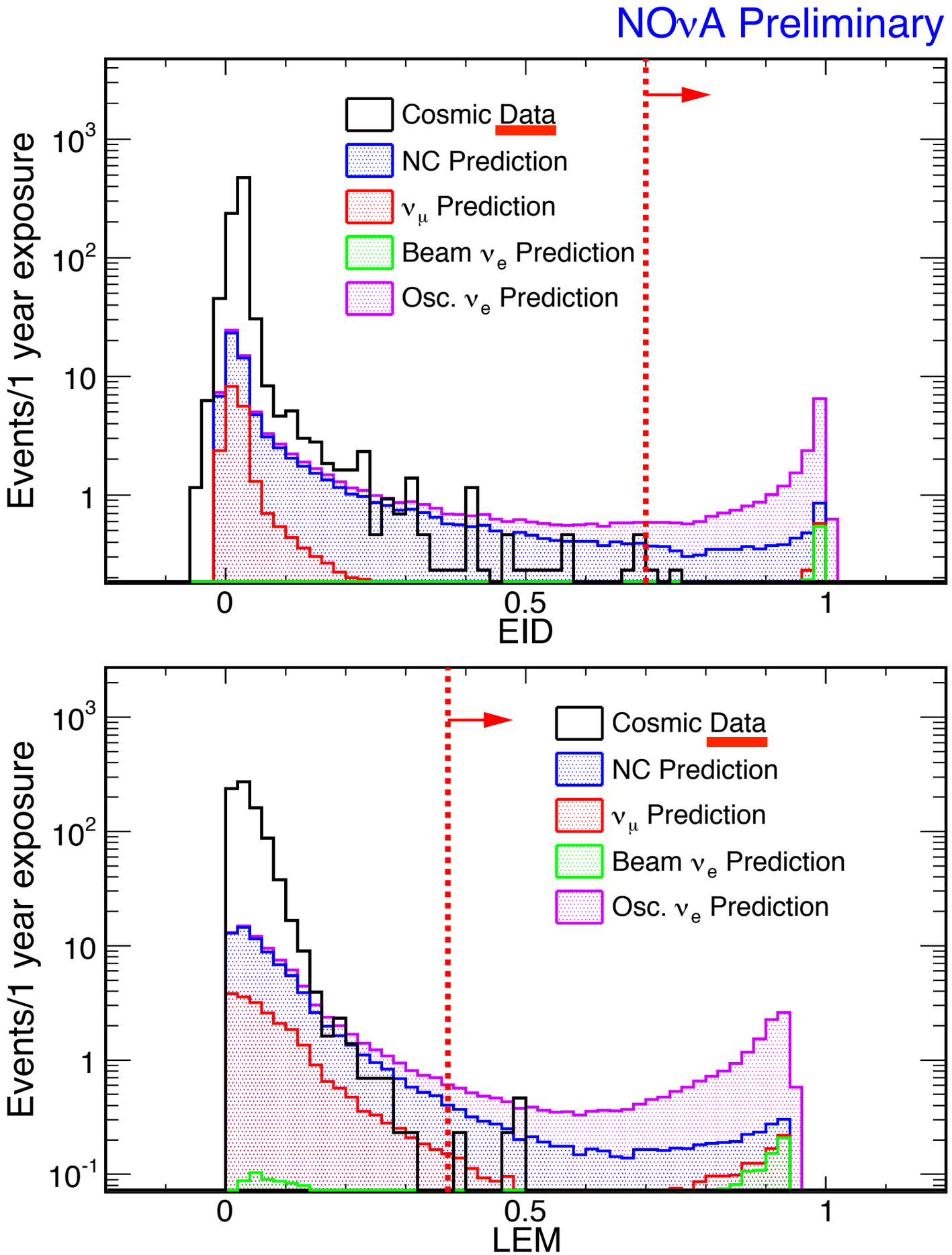




- Results from cosmic-ray fitter. Require 20 or more hits in event (“slice”).
- Compare to CRY cosmic-ray simulation



# $\nu_e$ Event Selection

- Two methods:
  - "EID" (top) is a neural net evaluation of the shower longitudinal and transverse profile
  - "LEM" (bottom) matches the event topologies to large libraries of signal and background events.
- **Both achieve acceptable levels of rejection 40M:1 and 21M:1 against cosmic-rays recorded using the far detector**
- Evaluation of performance on beam neutrinos awaits near detector data.

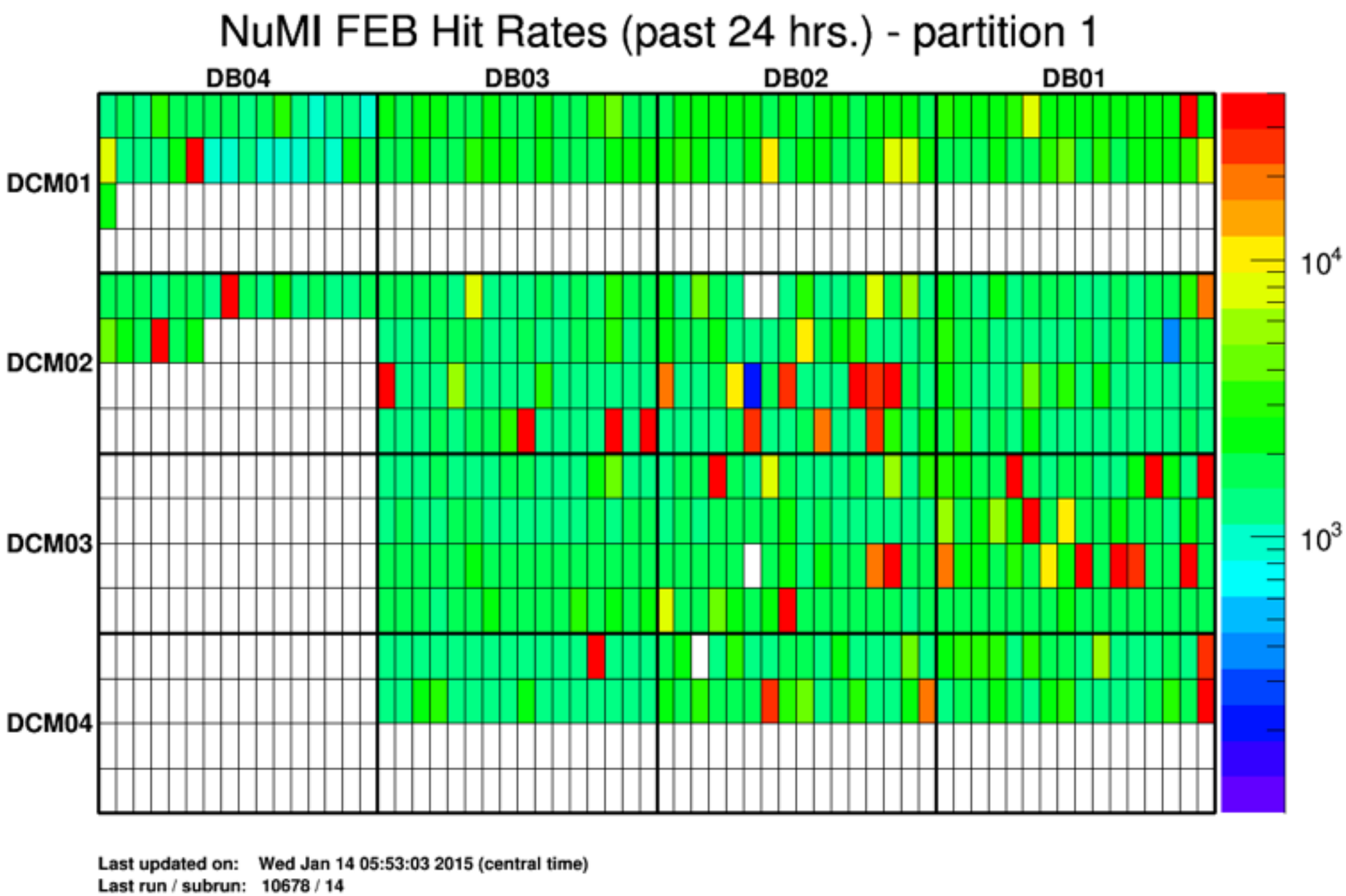


# NOvA Near Detector

ND completed August 2014
Running with >95% uptime
Already recorded 2+M events

# NOvA Near Detector Status

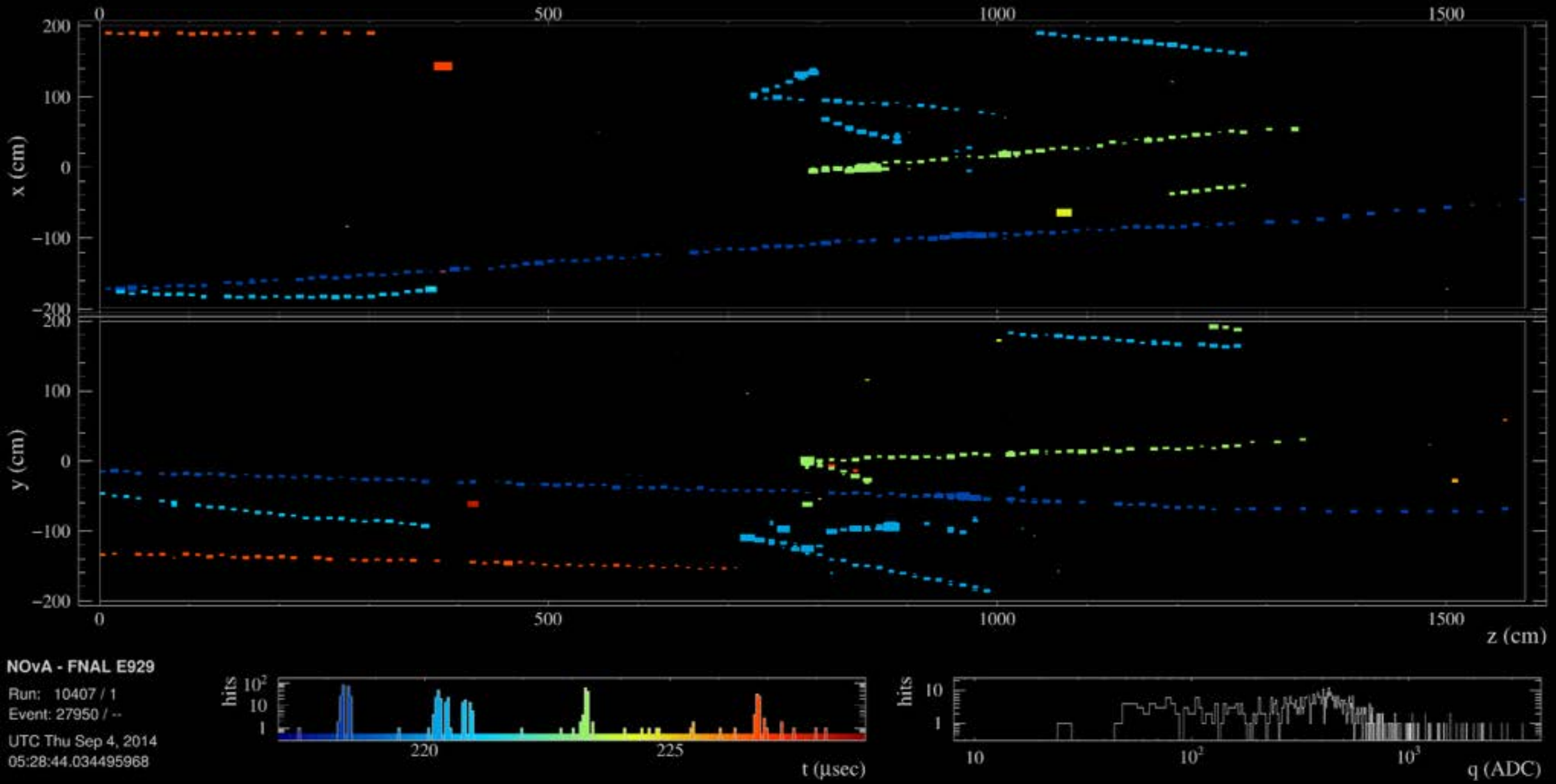
246 front end boards shown by hardware address




97.6% active channels

Working on a ~biweekly install/evaluate/re-install cycle

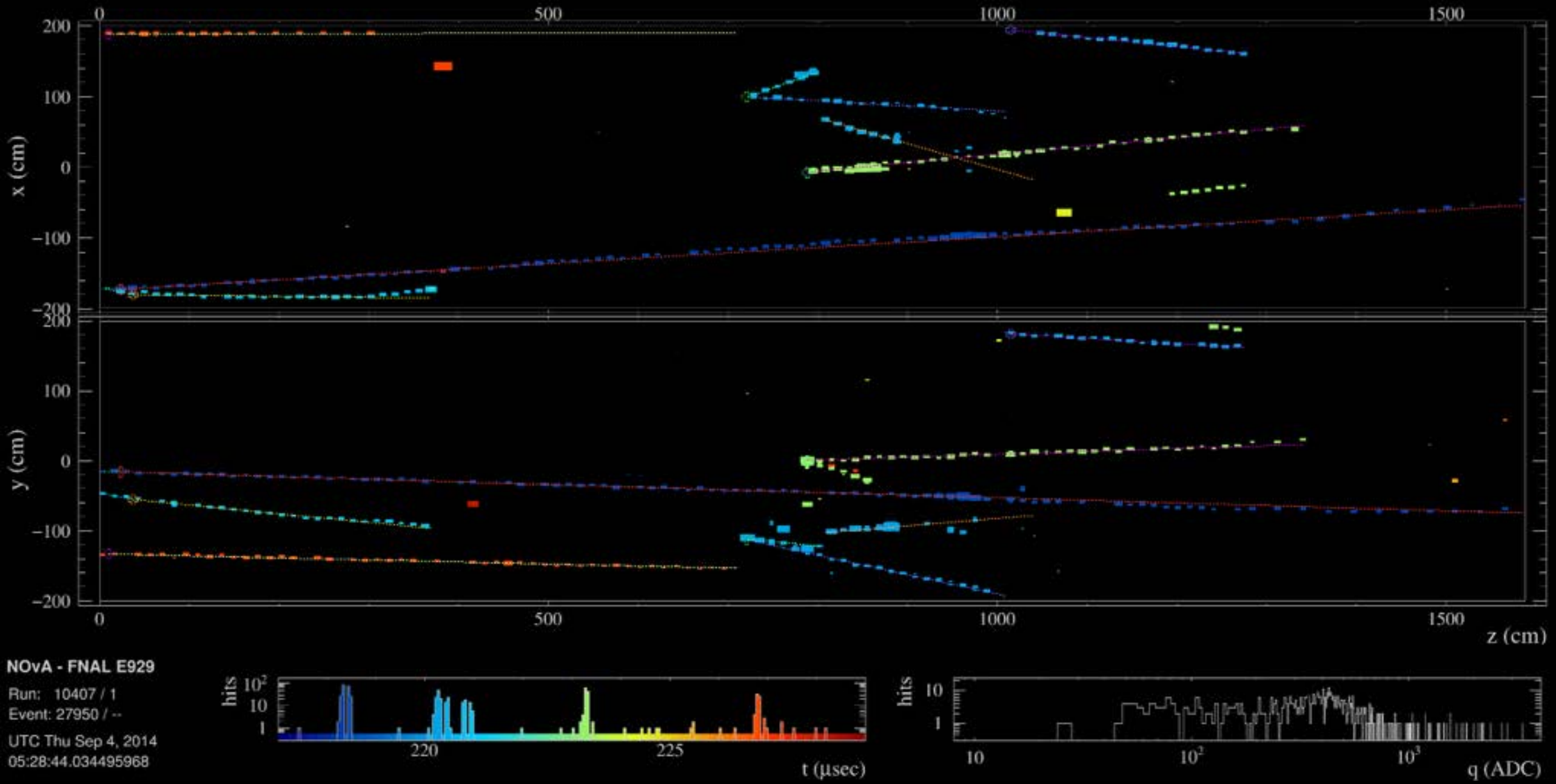
# Near Detector Event Display




Colors show time

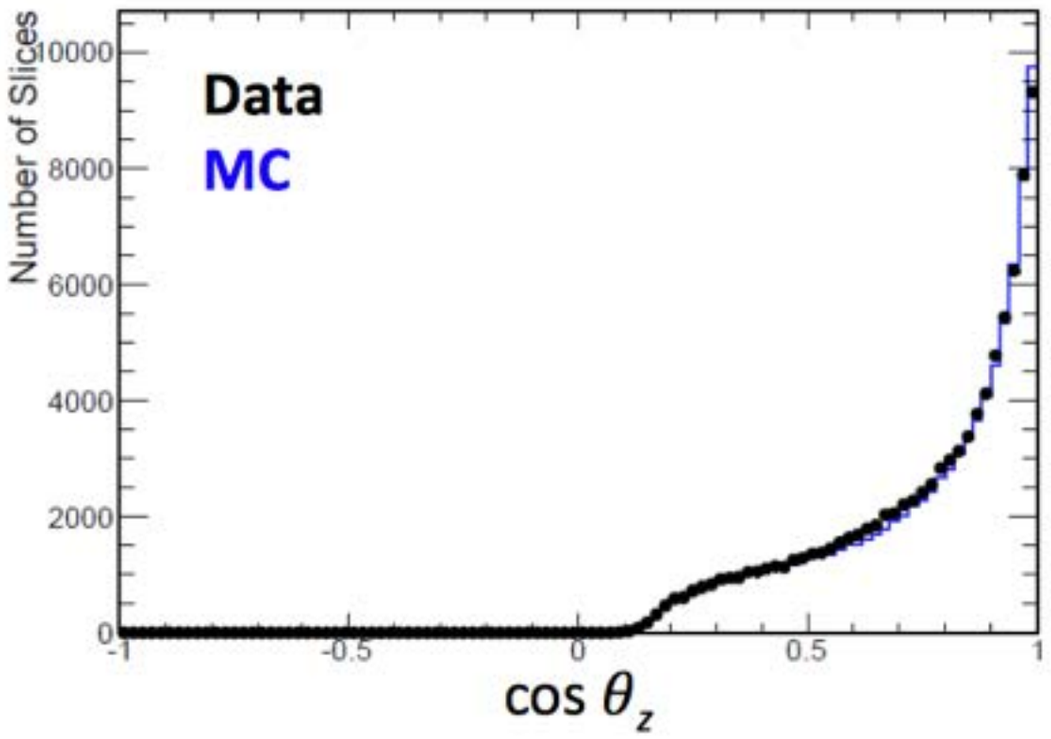
5 neutrino events separated in space and time

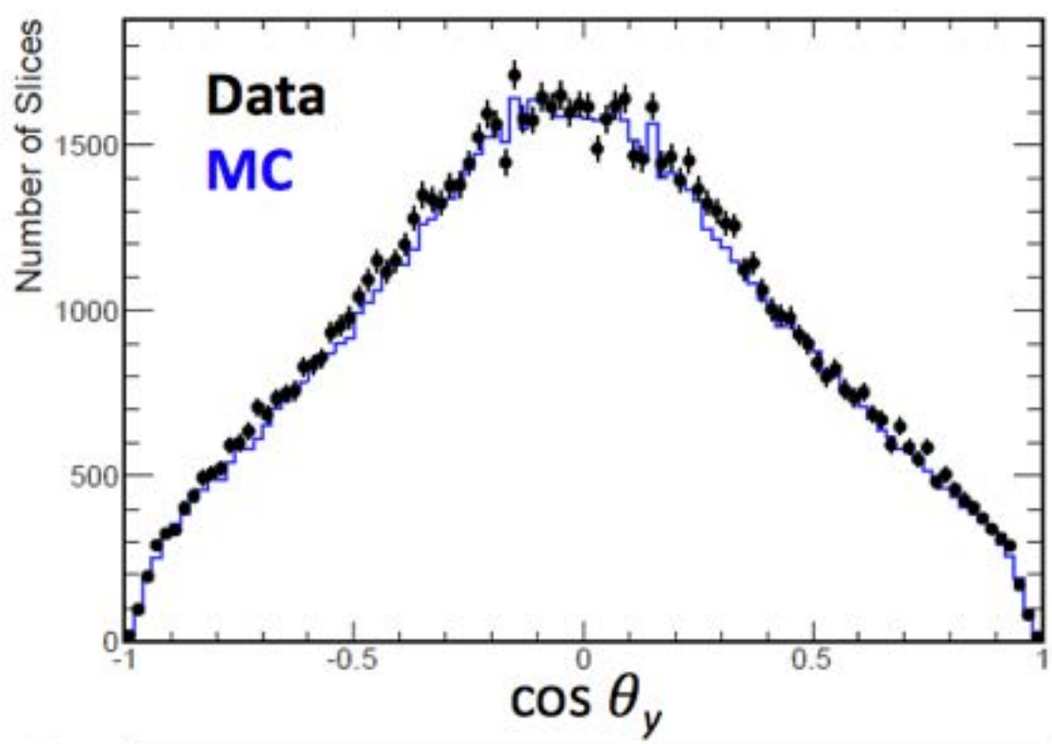
# Near Detector Event Display

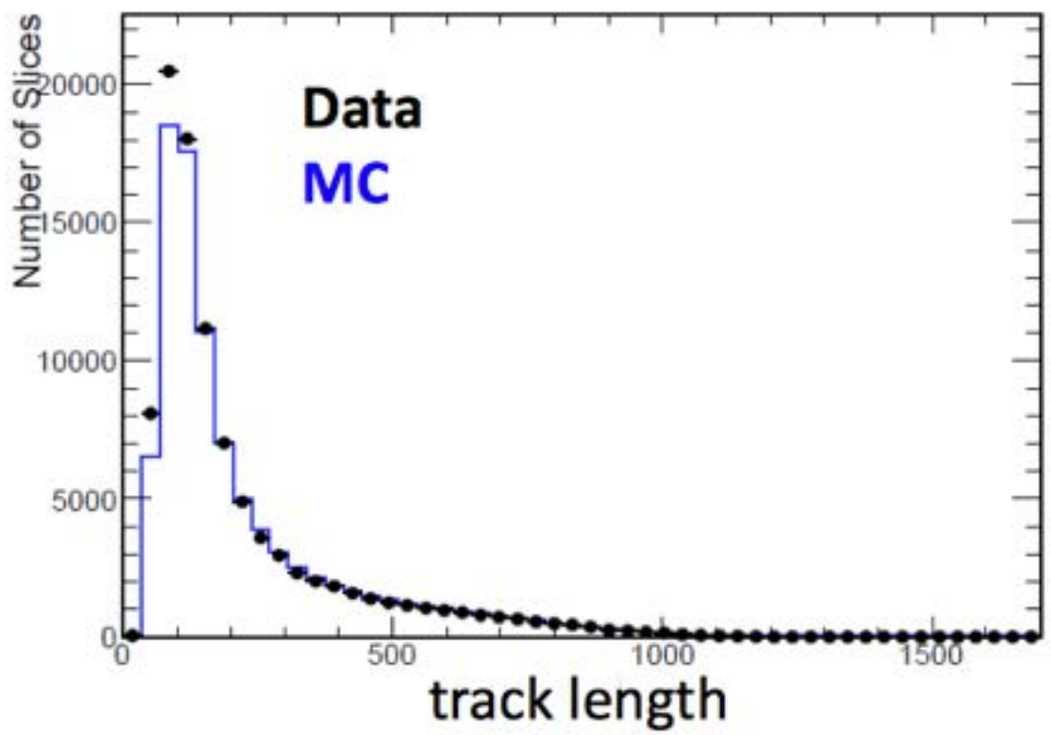


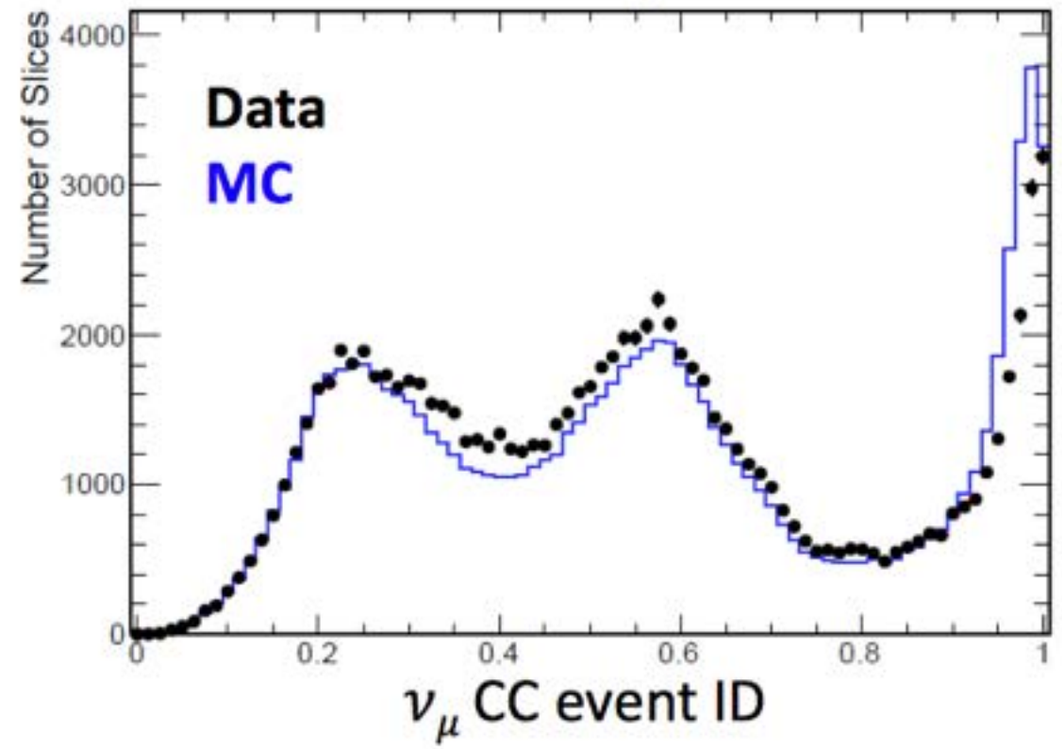

Colors show time
reconstructed tracks and vertices superimposed

# Near Detector Neutrino Distributions



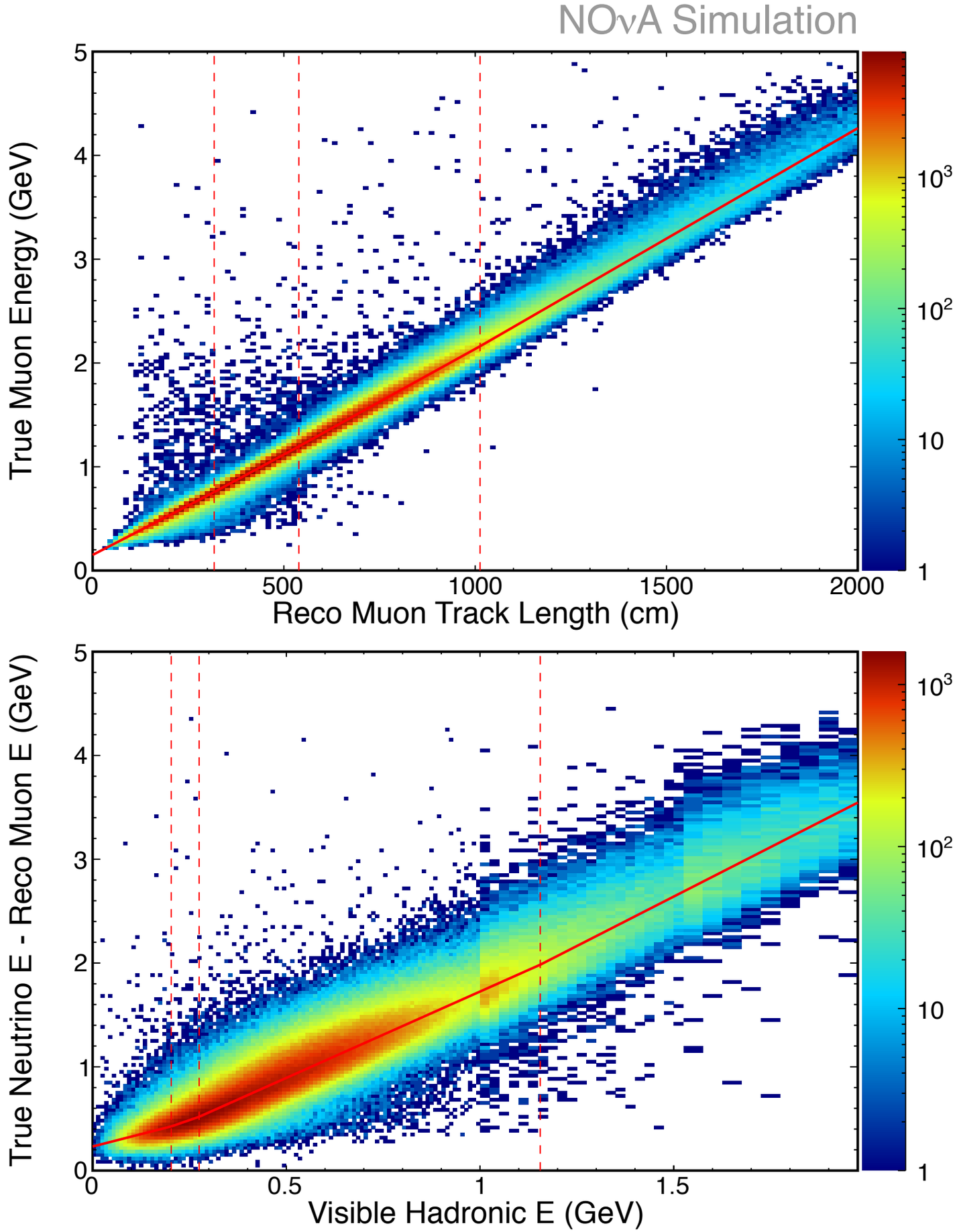



# Analysis progress

- Now working on first analyses. Have 2M+ million events in the near detector to understand the detector physics performance.

- Goal is to release first $\nu_\mu$ and $\nu_e$ results before summer and then update during the fall shutdown.



# NOvA Proton Assumptions for FY15

- **NOvA was delivered 3E20 protons on target (POT) in FY14. A record year for NuMI!**
- **FY2015 numbers are expected to be:**
- **Base POT for FY15: 2.0E20 (1/3 of a NOvA TDR-year)**
- **Design POT for FY15: 2.9E20 (~1/2 of a NOvA TDR-year)**

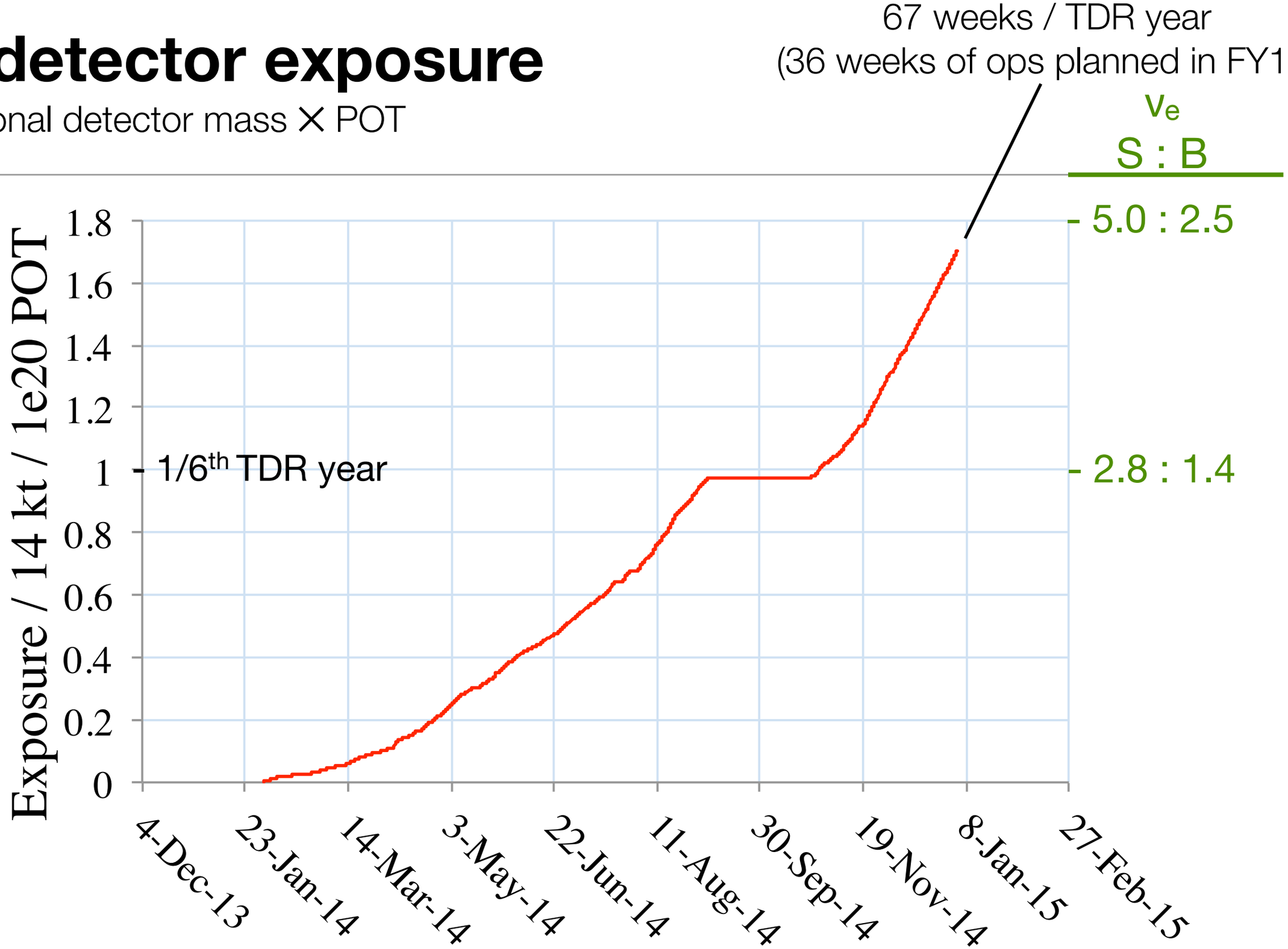
**Inputs to these estimates:**

- **Average power to NuMI in FY15 is projected to be 390 kW:**
  - Booster at 7.5 Hz / 4.3E12 ppp. Booster not reach routine 15 Hz operations in FY15.
    - *NB: Cavity installation proceeding well; on track to have 17 cavities installed by summer*
  - RR 2+6 Slip Stacking (8 total batches, TDR: 12)
    - These combine to give ~433 kW maximum power
  - SY120 Uptime = 90% / SY120 fraction of cycle time 10%
    - SY120 “tax” lowers average power to 390 kW
- **Accelerator x NuMI uptime = 80%x80% = 64%**
  - *NB: Recent running has been 87% efficient.*
- **Start up Oct. 31, 12 week shutdown starting in July = 36 weeks of operations**
  - 36 weeks is 80% of TDR 44-week year

Put these together: **(433 kW/700 kW) * 90% * (64%/64%) * 80% = 44% TDR POT/year** which corresponds to the “design” number above. The numbers in the denominator indicate assumptions we made in the TDR, numerators are current assumptions.

# Far detector exposure

Operational detector mass × POT



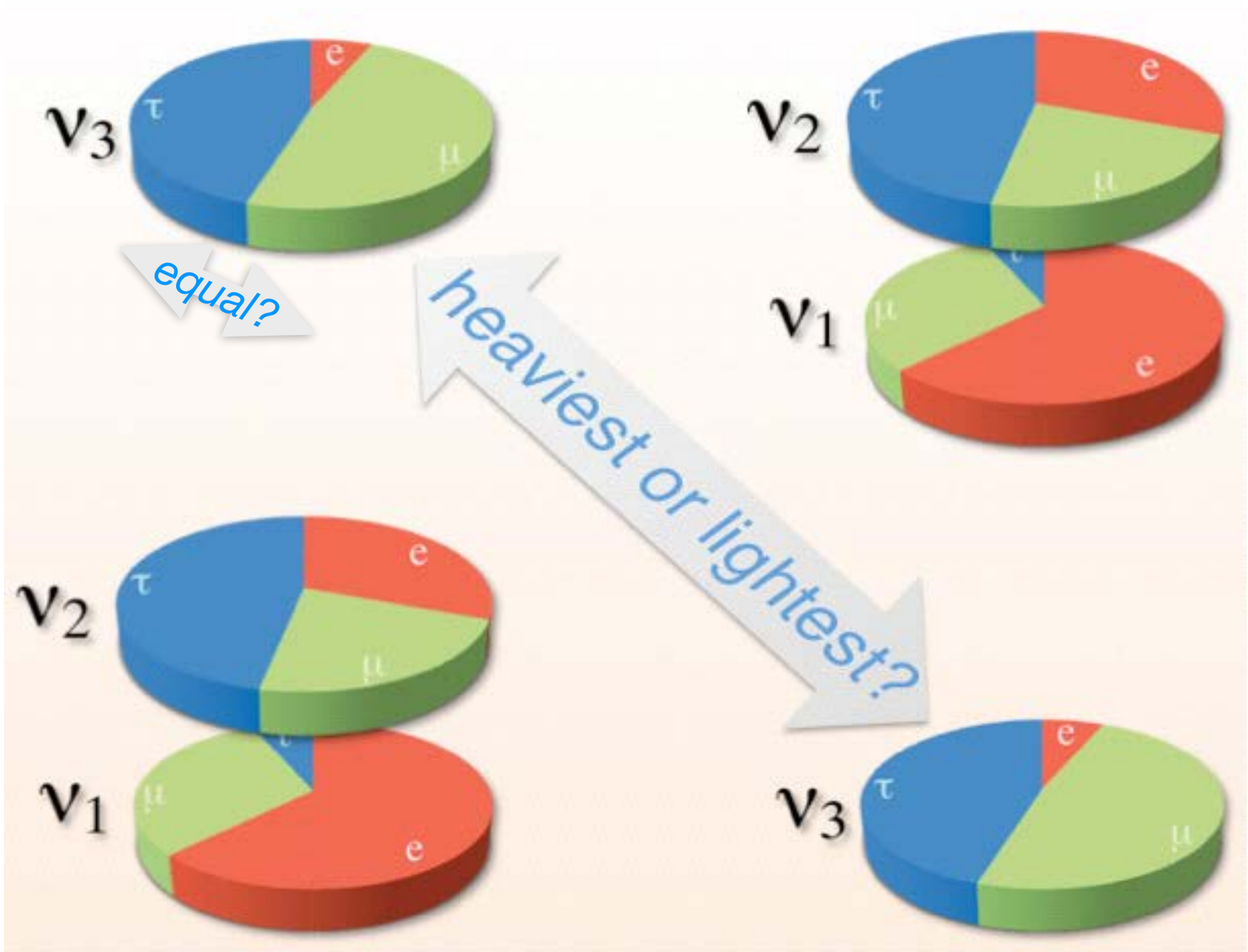

Analysis goals: Release first $\nu_\mu$ and $\nu_e$ results before this summer

Update results around time of next shutdown, ~fall 2015

# NOvA anti-neutrino running decision strategy

# Next Questions In Neutrino Physics

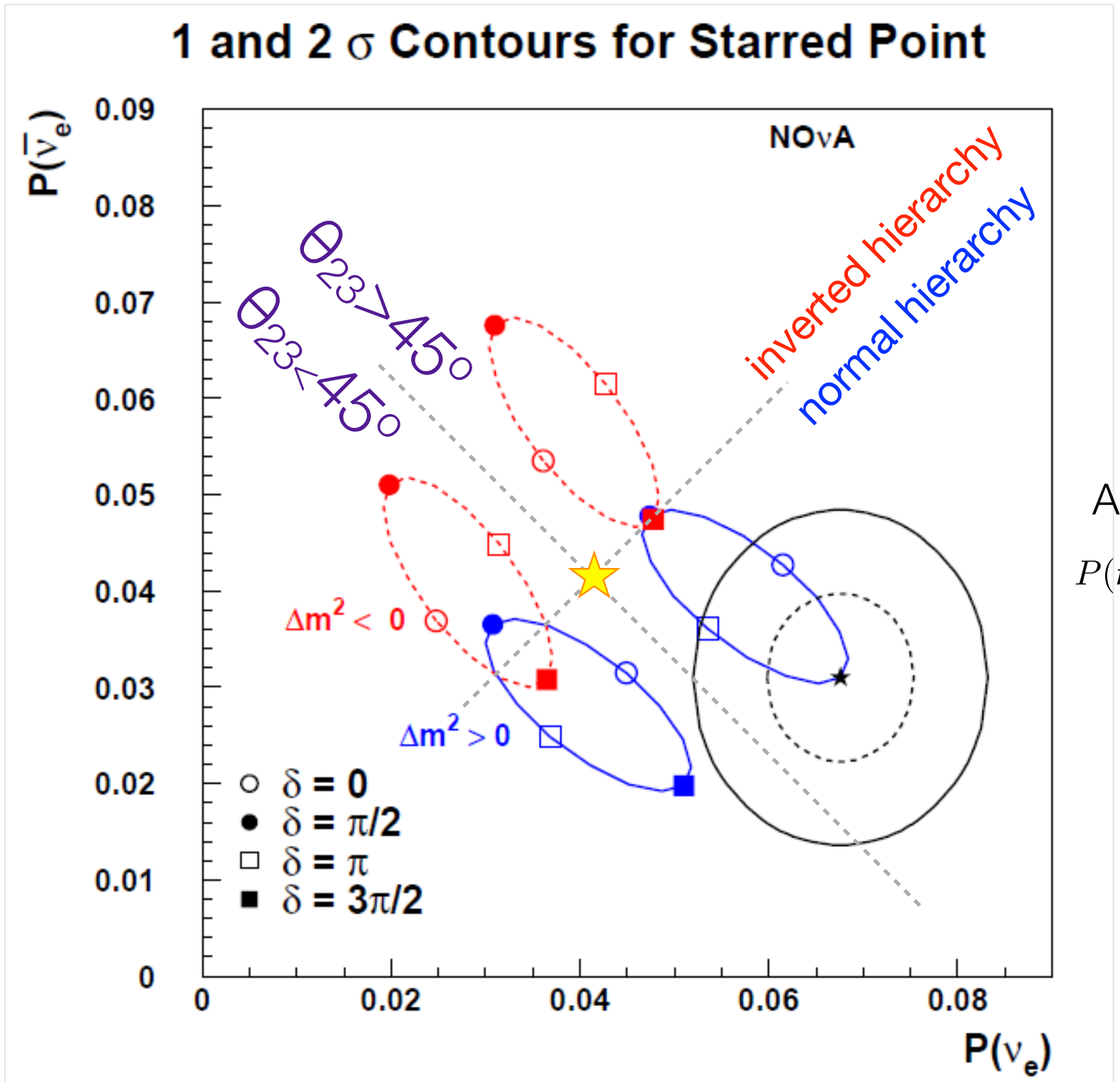
- Mass hierarchy
- Nature of $\nu_3$ - $\theta_{23}$ octant
- Is CP violated?
- Is there more to this picture?




NOvA will answer these questions using four oscillation channels

$$\nu_\mu \rightarrow \nu_e \quad \& \quad \nu_\mu \rightarrow \nu_\mu$$
$$\bar{\nu}_\mu \rightarrow \bar{\nu}_e \quad \& \quad \bar{\nu}_\mu \rightarrow \bar{\nu}_\mu$$

# Impact of remaining unknowns on NOvA oscillation probabilities




A central point used for benchmarks

$$P(\nu_\mu \to \nu_e) = 0.5 \sin^2(2\theta_{13}) \sin^2(1.27\Delta m^2 L/E)$$

# Summary of sensitivity of $\nu_\mu \rightarrow \nu_e$ rates to physics parameters

| Factor | Type | Inverts for $\overline{\nu}$? | NOvA | T2K |
|---|---|---|---|---|
| Matter effect (mass ordering) | Binary | Yes | ±19% | +/-10% |
| CP violation | Bounded, continuous | Yes | [-22…+22]% | [-29…+29]% |
| $\theta$ | Unbounded, continuous | No | [-22…+22]% | [-22…+22]% |

**Nota bene:**

- Calculations are for rate only; there is some additional information in the energy spectrum
- These estimates neglect non-linearities in combining different effects
- In the calculation of the matter effect and CP violation effects the calculated values account for the fact that T2K runs at an energy on the first oscillation maximum while NOvA runs at an energy slightly above the oscillation maximum
- $\theta_{23}$ was varied inside the ±2σ range found by a recent global fit (PRD 90, 093006)

# T2K
# Electron neutrino signal events

**28 events observed with expected 4.9 ± 0.6 background = 23.1±5.3 signal events**

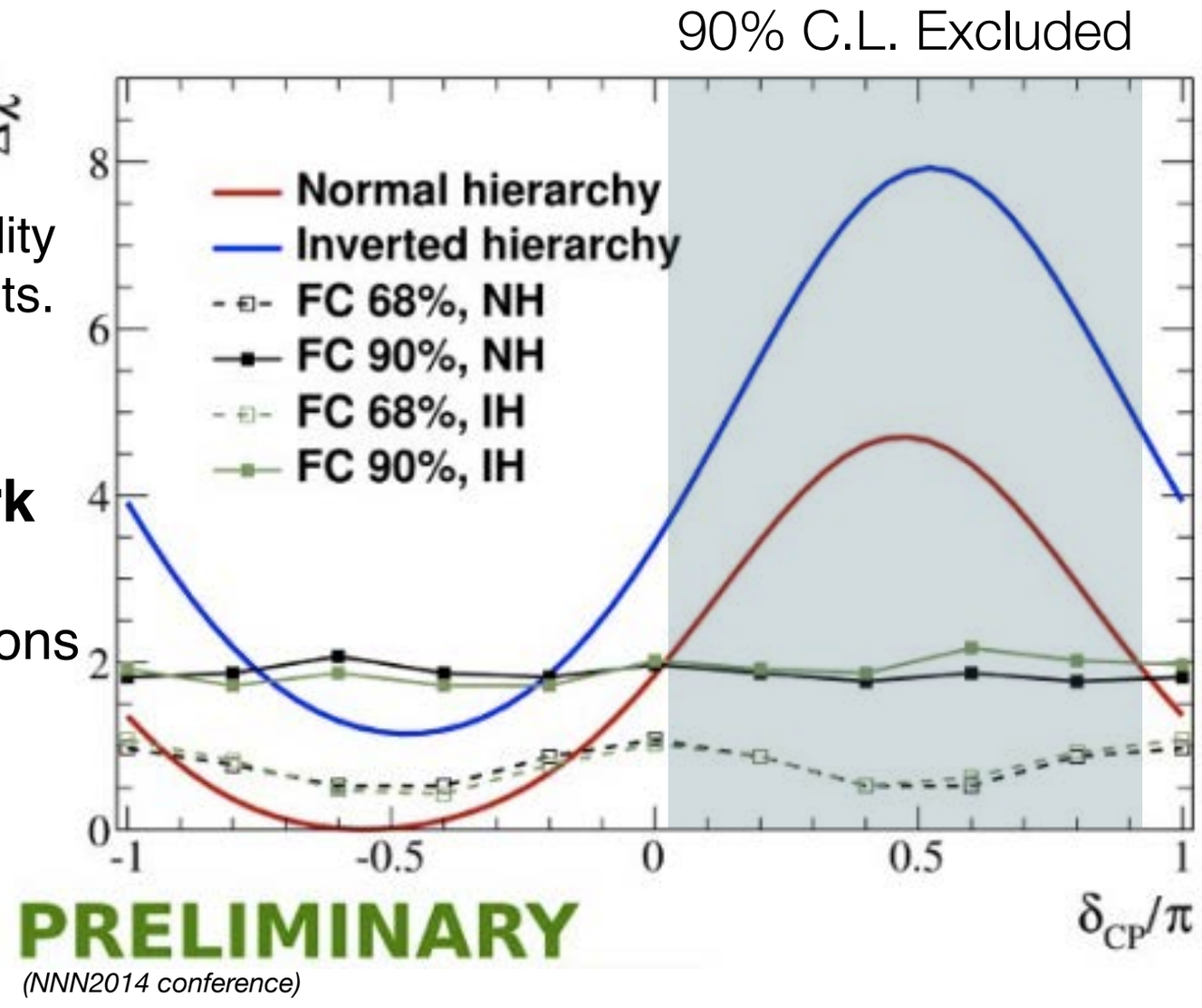
For $\sin^2 2\theta_{13}$=0.09 the benchmark probability suggests they would see 15.0 signal events.

**Observed signal is a 54±35% enhancement over the benchmark**

Pushes best fit values to favor excursions which enhance the neutrino oscillation probability

- normal hierarchy
- $\delta_{CP} = 3\pi/2$ $(-\pi/2)$
- $\theta_{23} > 45^o$

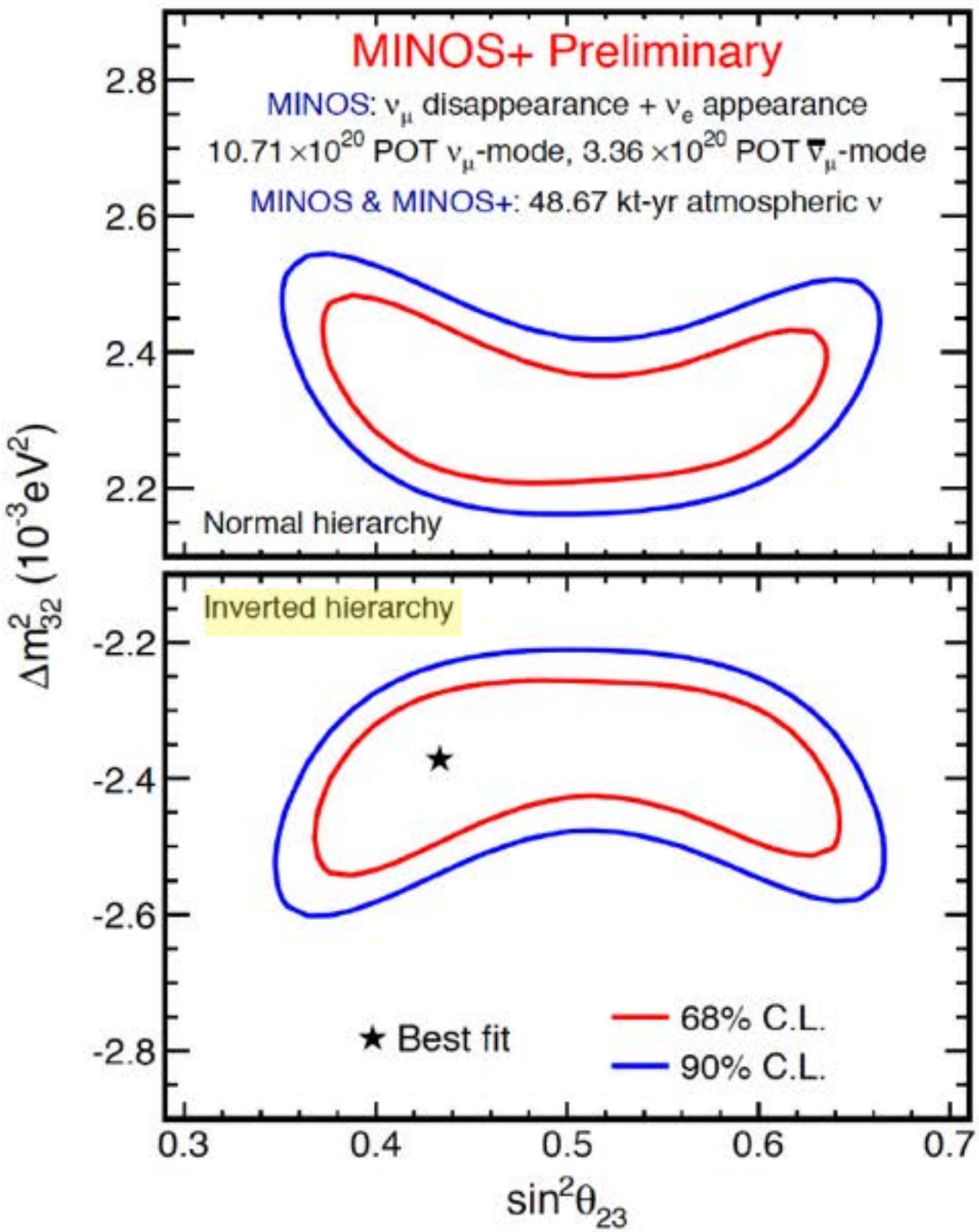
and to disfavor combinations which suppress the neutrino oscillation probability.

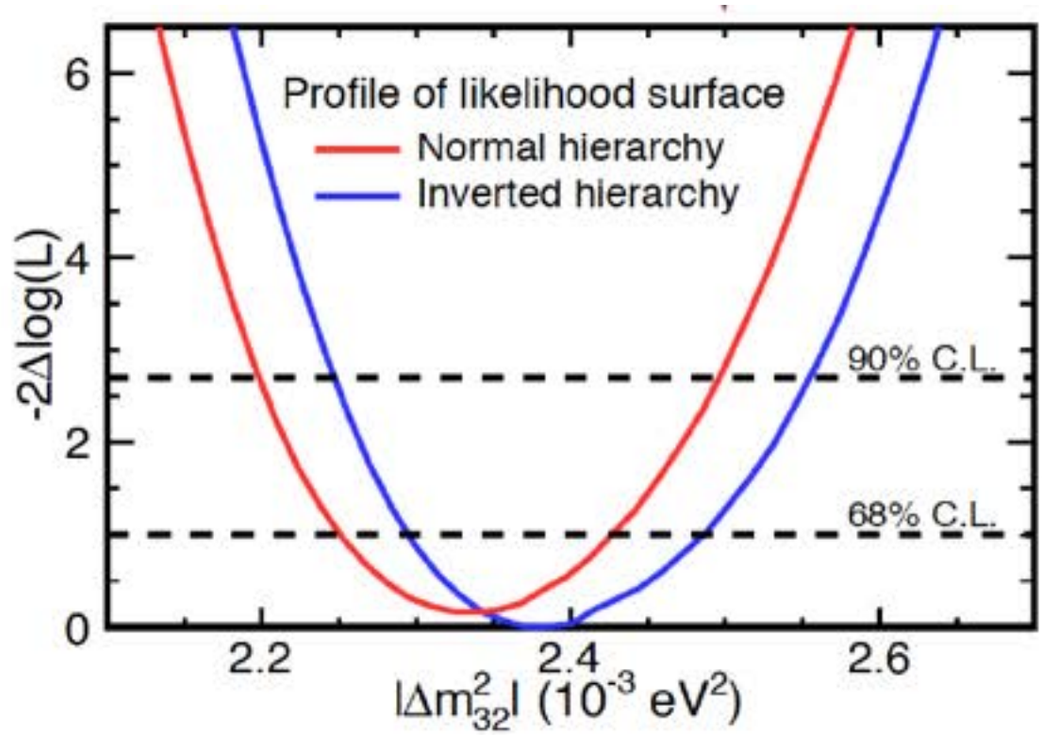


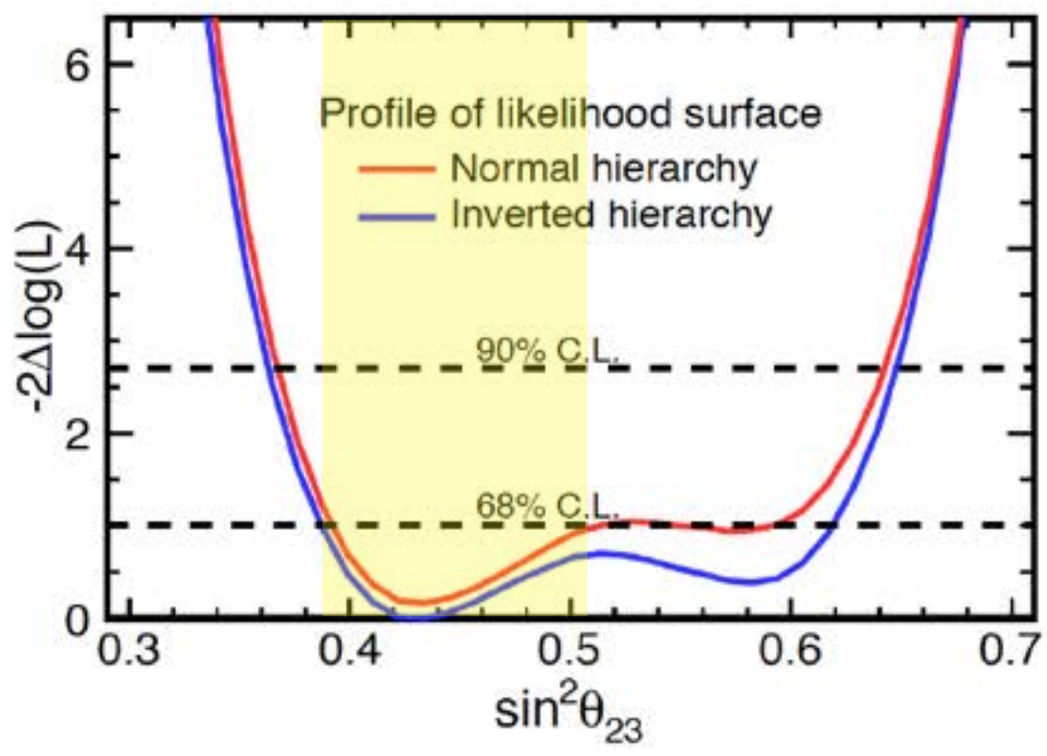

*(NNN2014 conference)*

# MINOS(+)

# Combined fit to beam and atmospheric neutrinos



# NOvA event rates

- Our most convenient unit of exposure is the “TDR year” defined as 6E20 protons on target delivered to a 14 kt detector.

- 6E20 POT is 700 kW NuMI power delivered in 44 weeks of running at 61% overall efficiency (accelerator downtime x NuMI downtime x NOvA downtime x average/peak correction)

- With the current beam schedule we reach 1 TDR year exposure in mid 2016

- Expected “benchmark” $\nu_\mu \rightarrow \nu_e$ event rates for 1 TDR year are:

  - **Neutrinos: 16.6 signal events on a background of 7.6 events**

  - **Antineutrinos: 7.6 signal events on a background of 3.2 events**

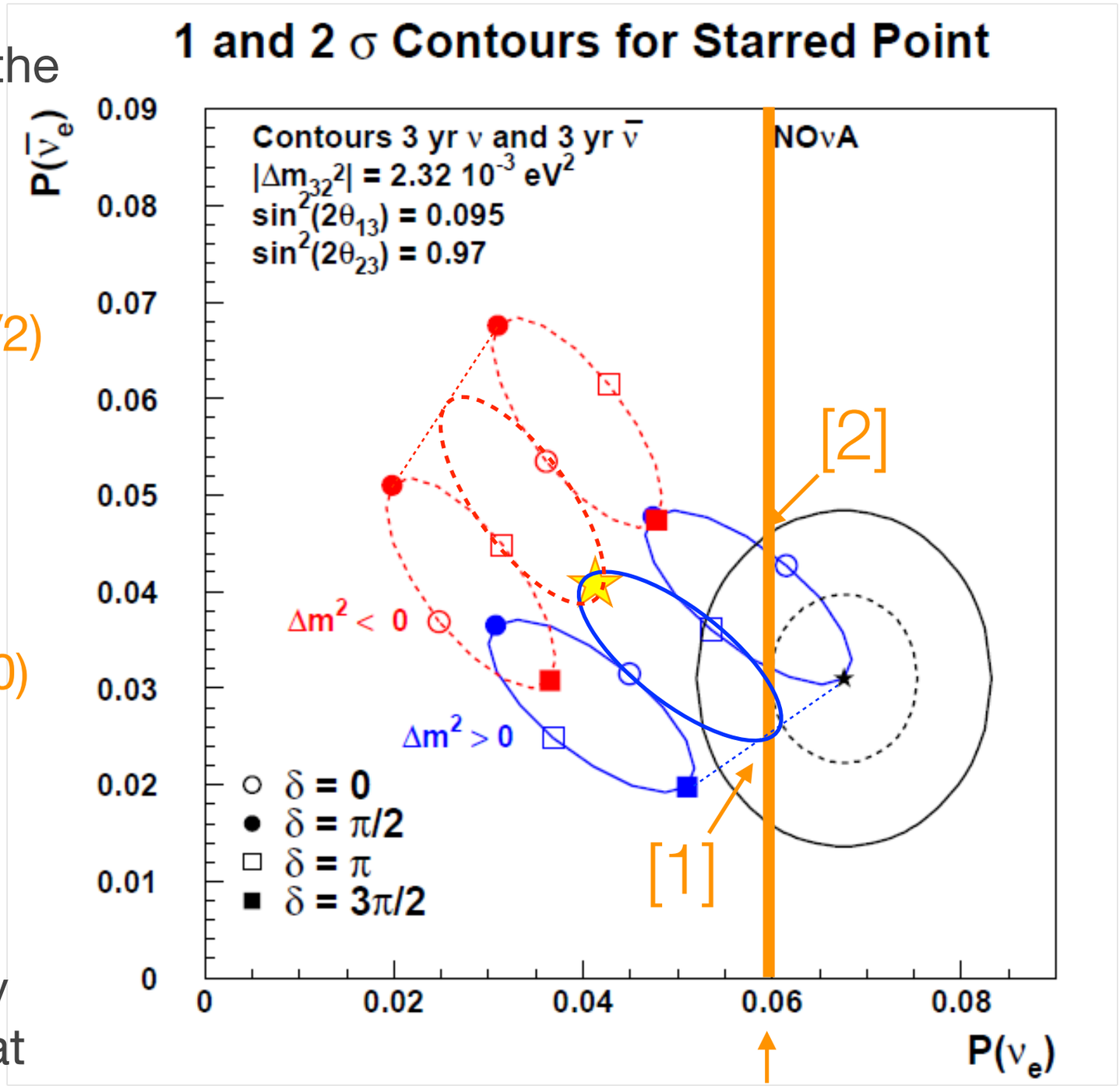
- Signal rates can vary by [-60…+60]% depending on remaining unknowns

# NOvA antineutrino running decision strategy

- The range of possibilities is still rather wide open and we need NOvA data to better understand where we are.
- We need about 1 TDR year of exposure to have a statistically reliable measurement. Expected in mid 2016 based on current beam delivery projections.
- In mid-2016 we can compare our measurements to T2K's
  - From the table of variations we expect our enhancement to be within 20% of the enhancement T2K is seeing. If our neutrino measurement is in agreement with T2K's then we likely will want to switch to antineutrinos and begin exploring the $\theta_{23}$ octant and continue probing the mass ordering.
  - If our neutrino results differ by more than 20% from T2K's we will likely want to stay in neutrino mode to clarify the situation.
- Switching to antineutrinos is a x1/2 hit in event rate. We would not switch to antineutrinos if the beam power in 2016 is significantly below 700 kW (6E20 POT/year) as progress would be too slow.

# For instance…

- Suppose we see a +42% over the benchmark point.
- This could be due to [1]:
  - normal mass ordering
  - maximal CP violation (δ=3π/2)
  - no octant enhancement (maximal $\theta_{23}$)
- or [2]:
  - normal mass ordering
  - minimal CP violation (δ=π/10)
  - 22% octant enhancement
- 3 TDR years of running in anti-neutrinos would give 95% C.L. separation between these two possibilities so we will definitely want to take antineutrino data at some point.



# Summary

**Operations and analysis:**

- NOvA detectors working well. Far detector >99% active channels running with 95% uptime.
- Analysis well underway. Goal is to have first results before summer.
- NuMI uptime has been excellent. Goal is to reach peak operations of 400 kW this year and we are looking forward to 700 kW operations in FY16

**Antineutrino running:**

- Running antineutrinos is a crucial component of the NOvA physics program.
- We should have enough statistics to make a reliable decision in mid-2016
  - If our results agree with T2K results we probably learn more by switching to antineutrinos
  - If our results are in tension with T2K we are likely to want to stay in neutrino mode to clarify
- We are not likely to switch to antineutrinos if intensity remains significantly below 700 kW