Fermilab

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NOvA Status

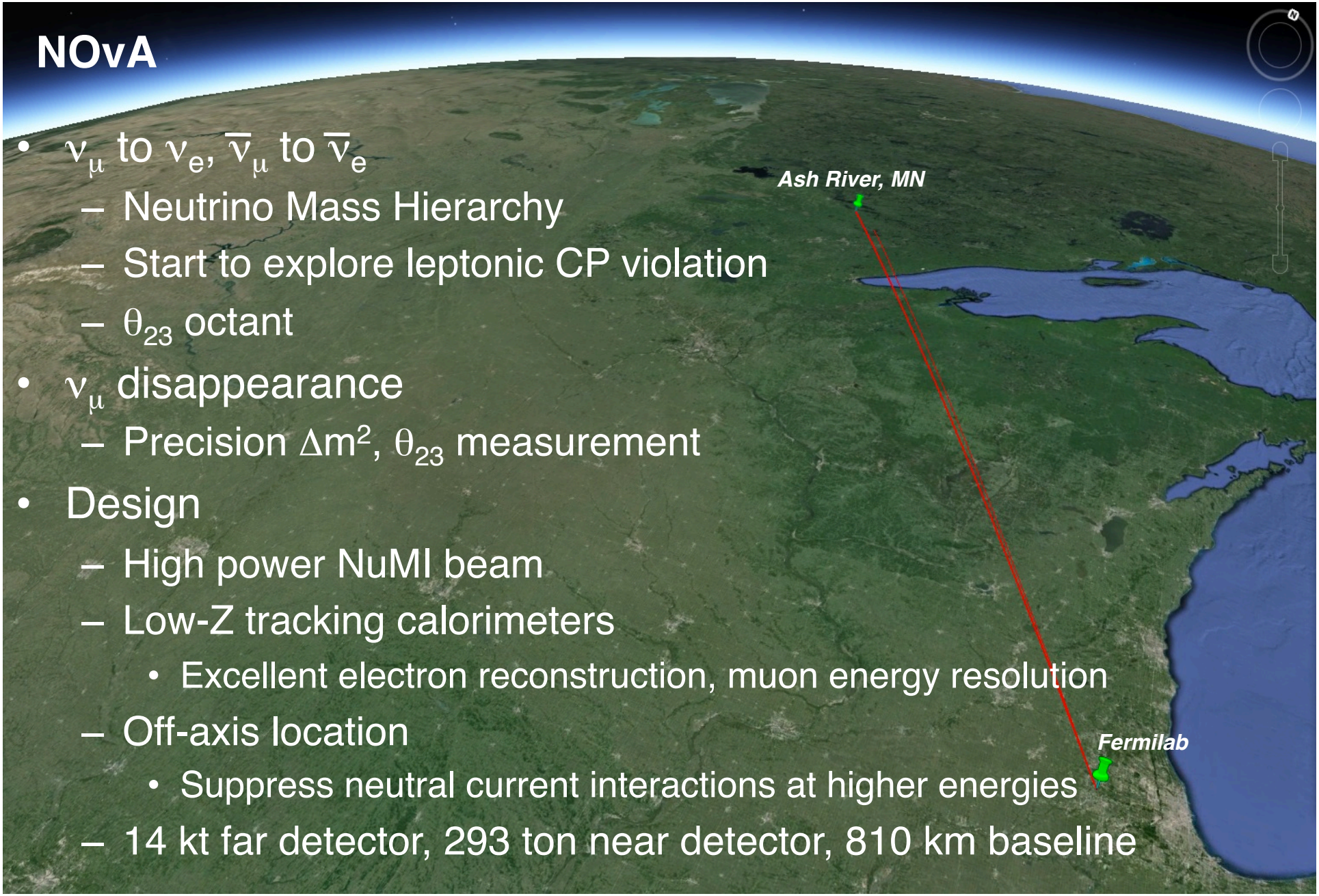
Peter Shanahan

Fermilab PAC Meeting

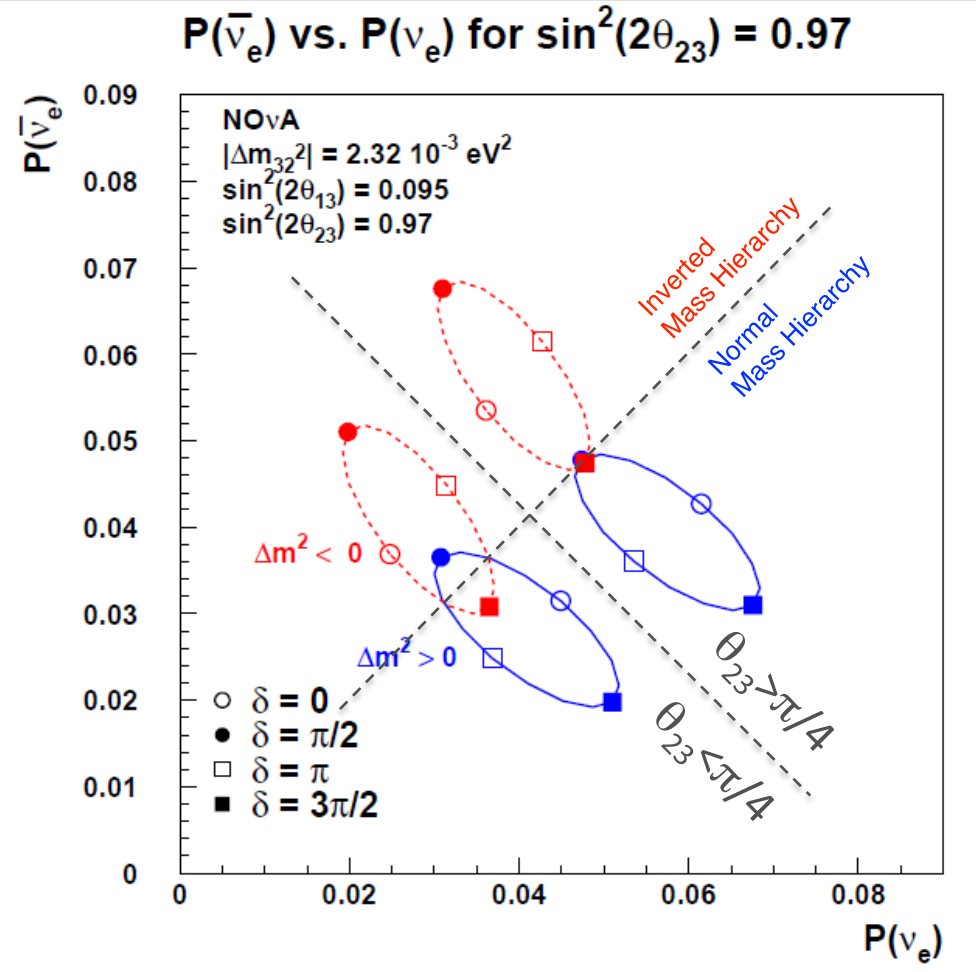
23 June 2015

NOvA

- ν_μ to ν_e, $\bar{\nu}_\mu$ to $\bar{\nu}_e$
  - Neutrino Mass Hierarchy
  - Start to explore leptonic CP violation
  - θ_{23} octant
- ν_μ disappearance
  - Precision Δm^2, θ_{23} measurement
- Design
  - High power NuMI beam
  - Low-Z tracking calorimeters
    - Excellent electron reconstruction, muon energy resolution
  - Off-axis location
    - Suppress neutral current interactions at higher energies
  - 14 kt far detector, 293 ton near detector, 810 km baseline

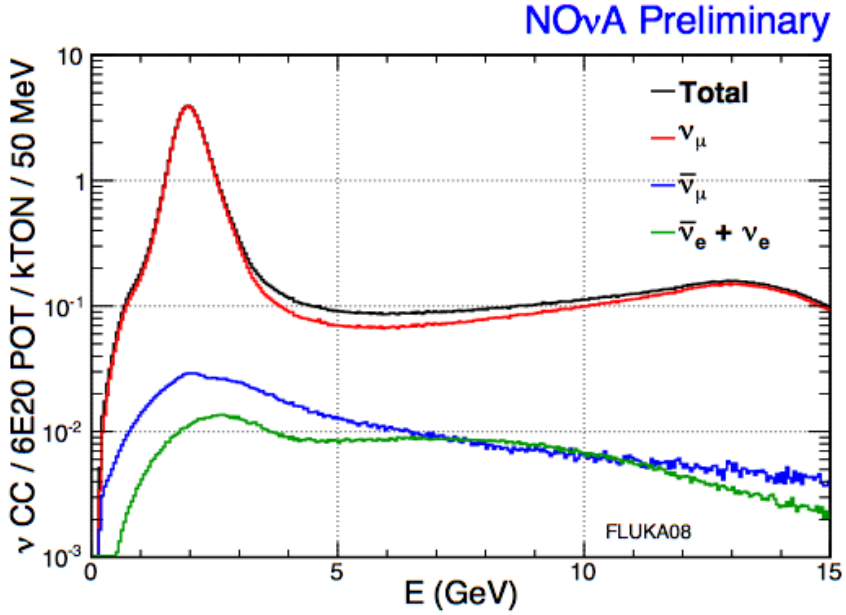


ν_e appearance sensitivities

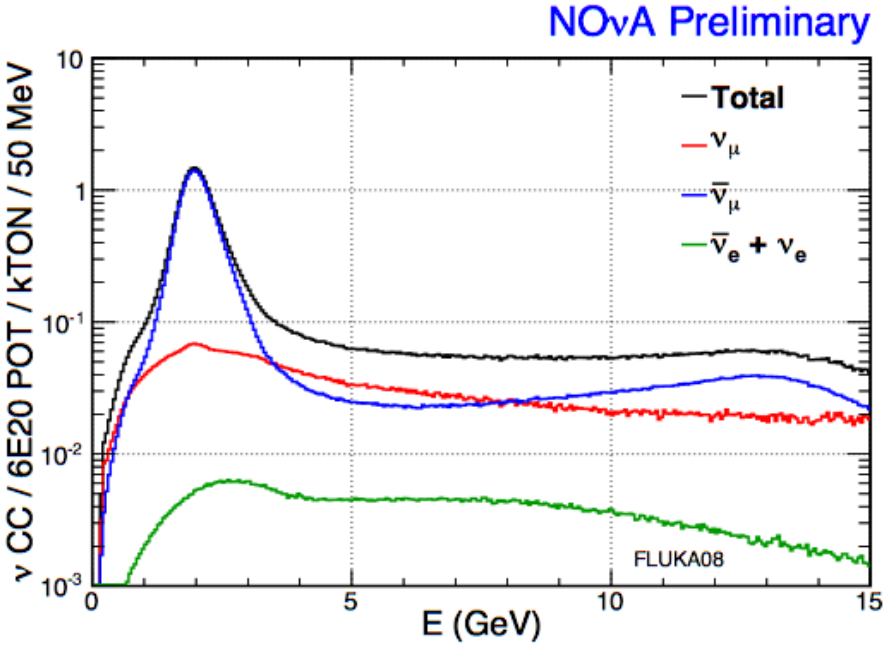


Far Detector Unoscillated Interaction Rates

"Forward Horn Current" - ν_μ beam

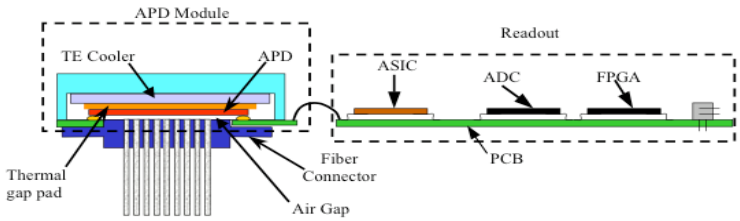


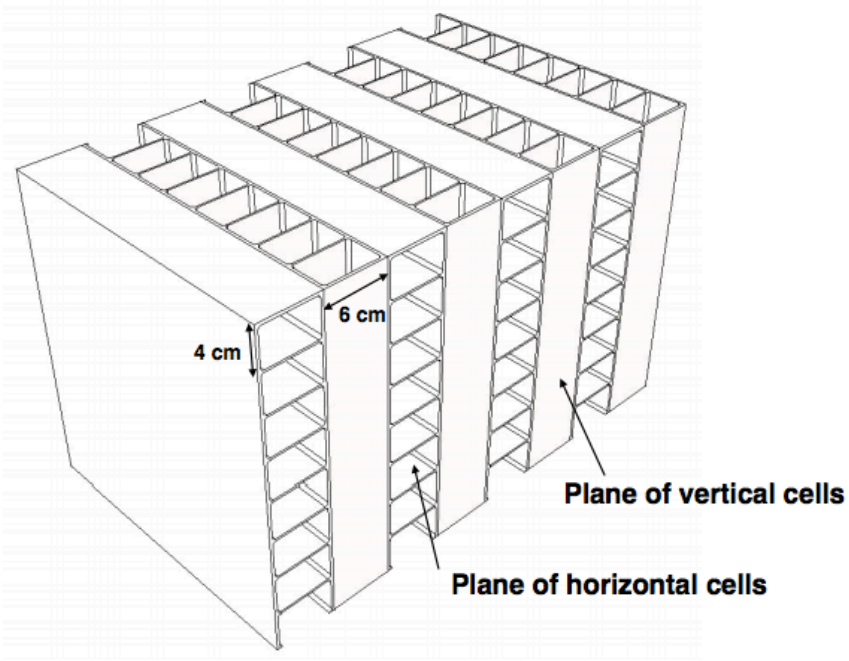
"Reverse Horn Current" - $\bar{\nu}_\mu$ beam



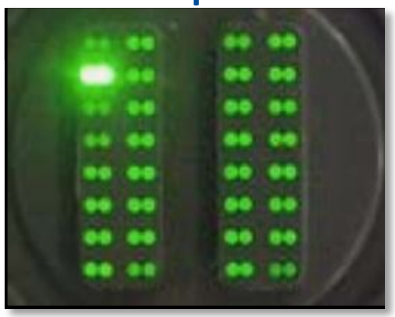
Detector Technology

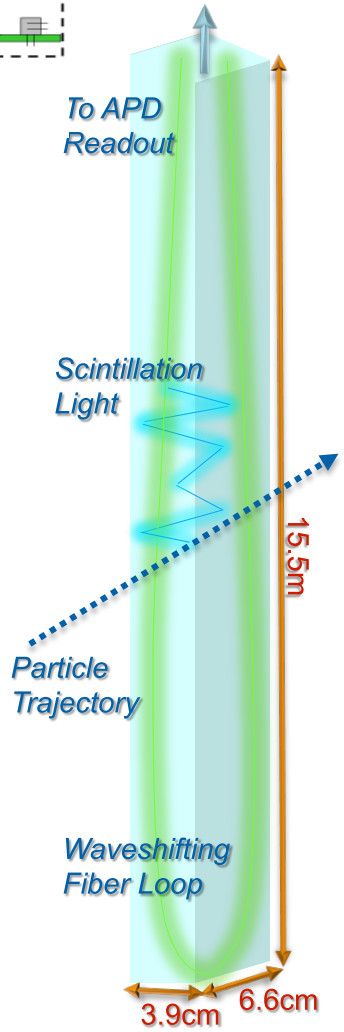
- Low-Z tracking Calorimeter
  - PVC Cell Structure
  - Mineral oil + 5% pseudocumene





32 cells per APD





NOvA Project
Secretary of Energy's Award of Excellence

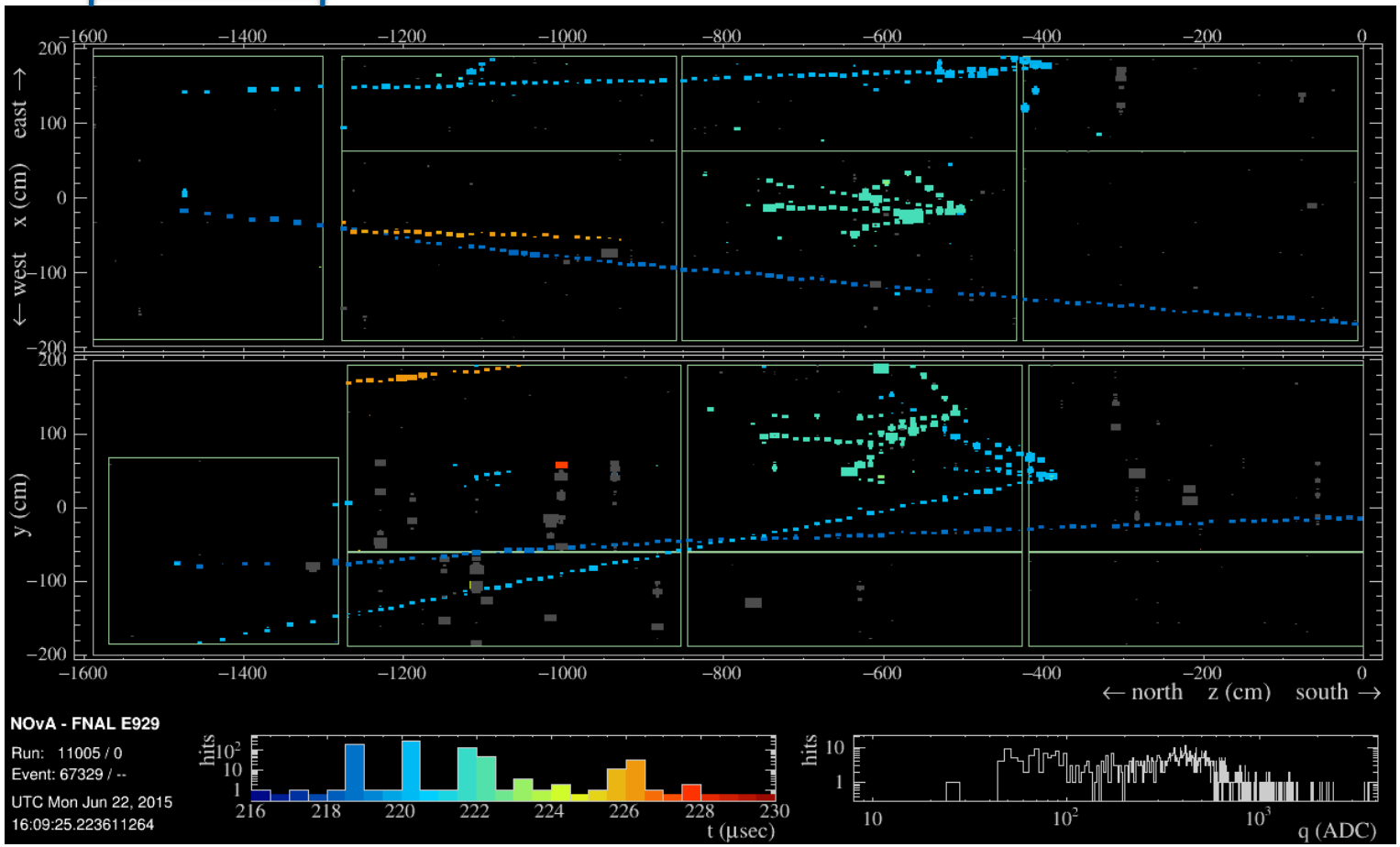
The NOvA Collaboration

38 Institutions from the U.S., India, Czech Republic, Russia, Brazil, and the U.K.
170 Physicists / 38 Post-docs / 51 students

Near Detector

Muon Ranger

293 t, 631 APDs, 20192 channels

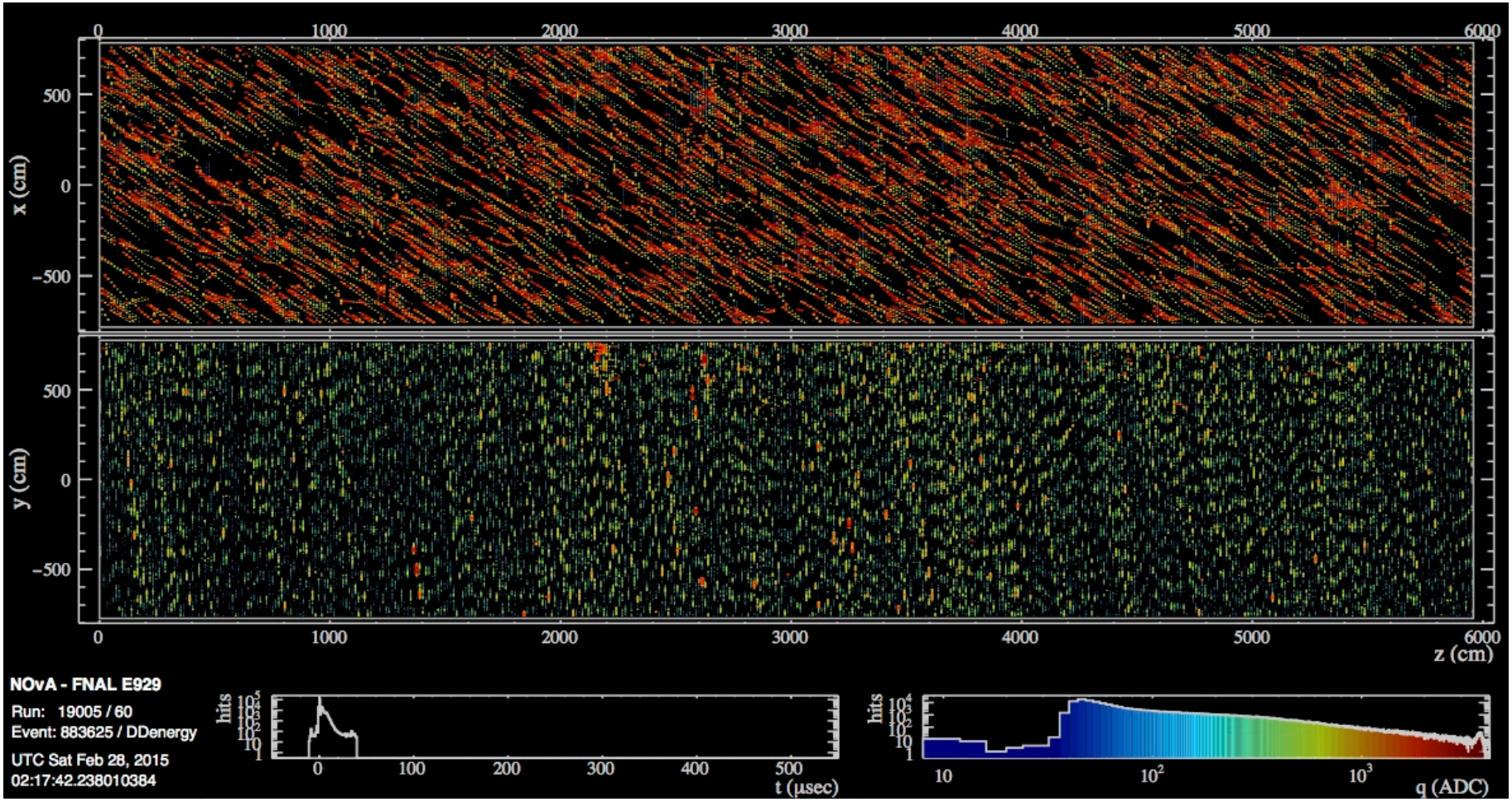


Beam

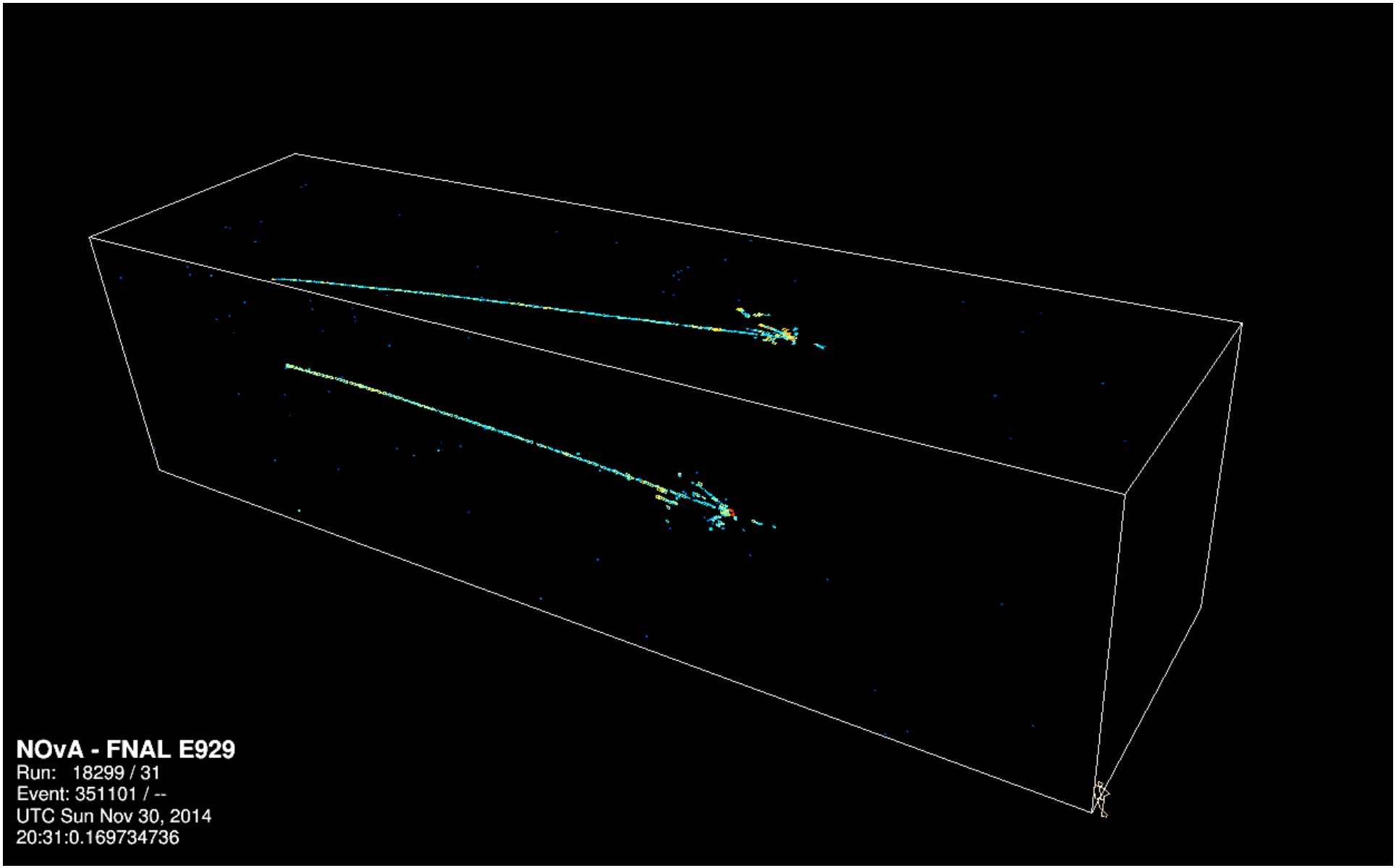
Far Detector

14kt, 344064 cells,10752 APDs

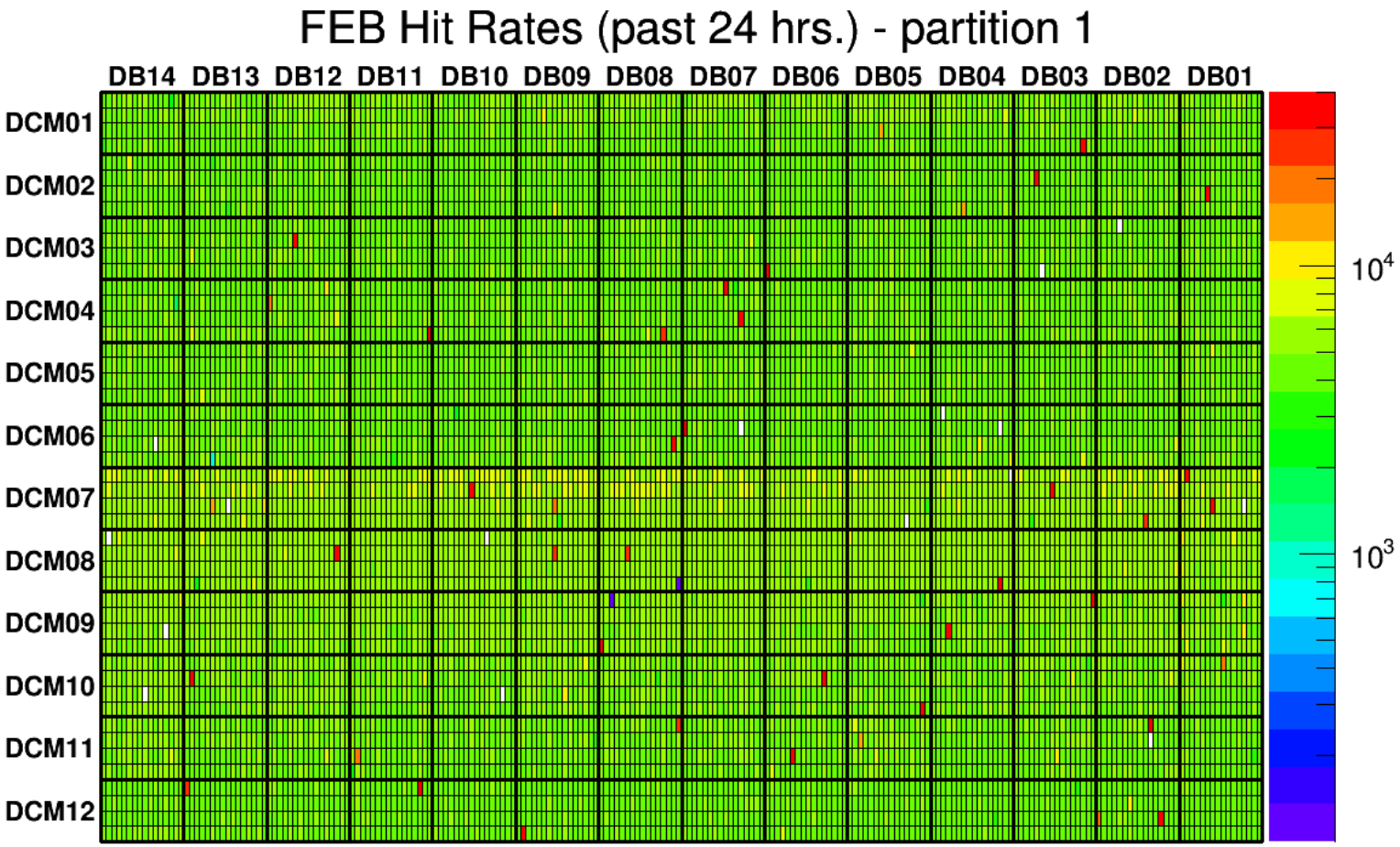
Data-driven trigger multimuon event



Far Detector



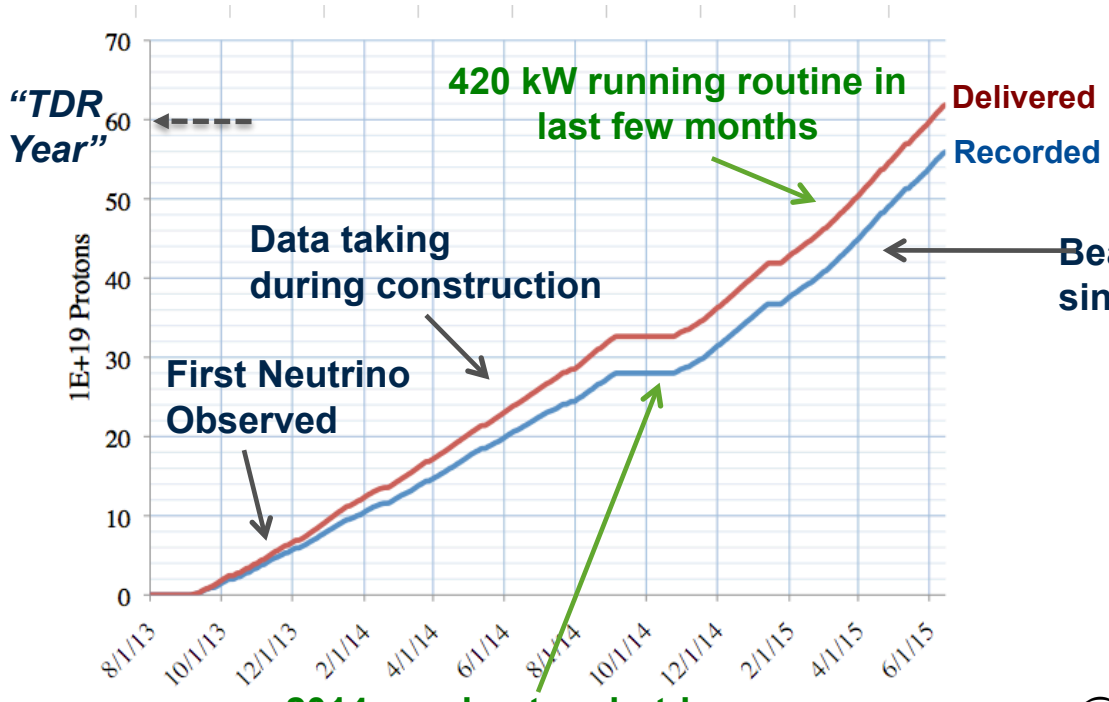
Far Detector Operations



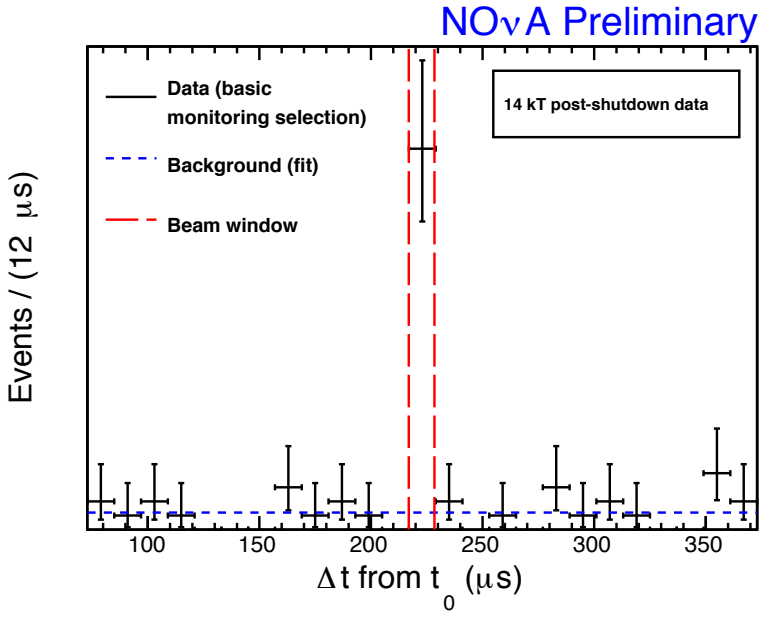
Online-measured hit rate on 10,752 APDs

Very uniform, quite, efficient detector:
typically<100 Hz/cell, 99.6% of channels good

Far Detector Operations



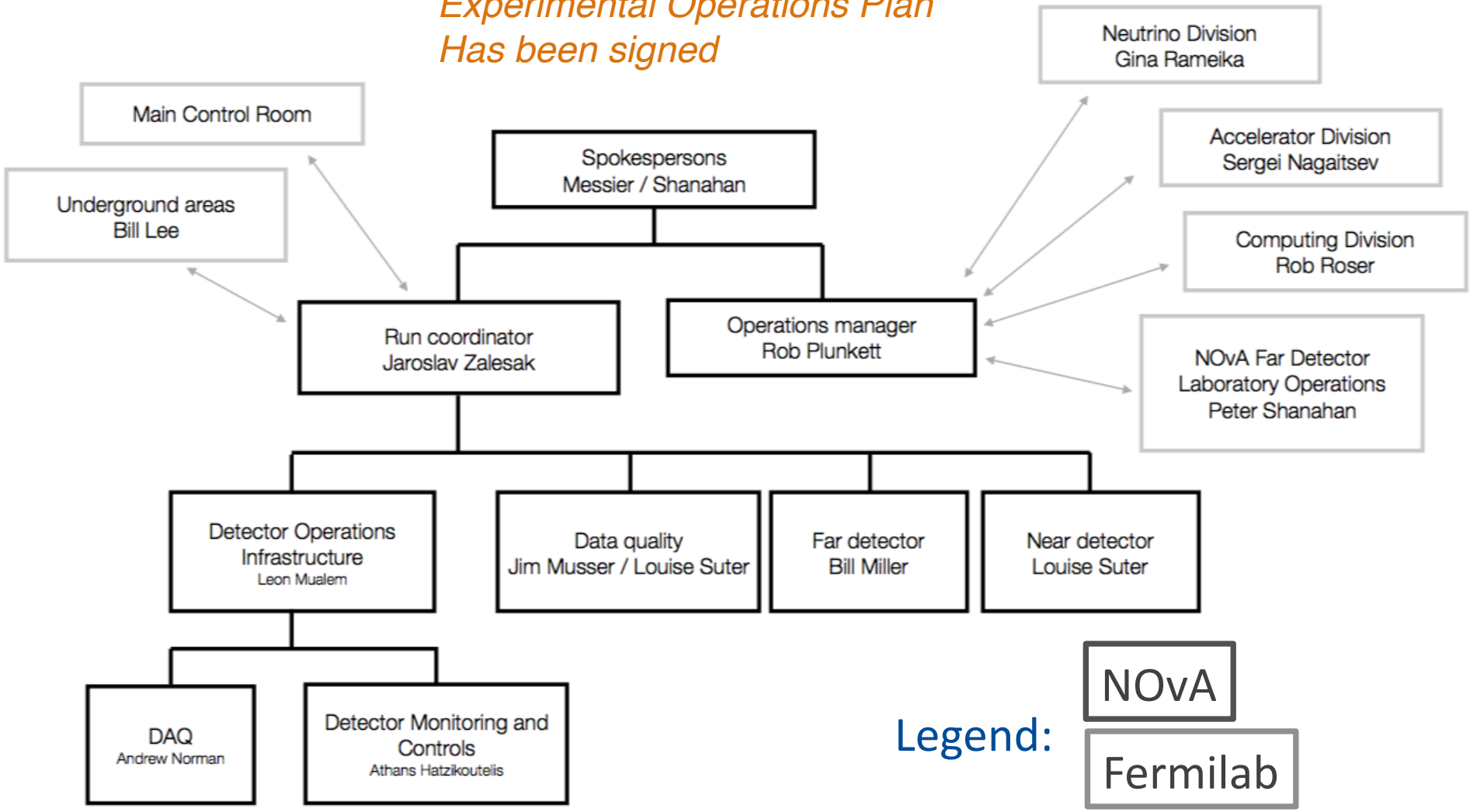
Timing of events passing basic neutrino selection



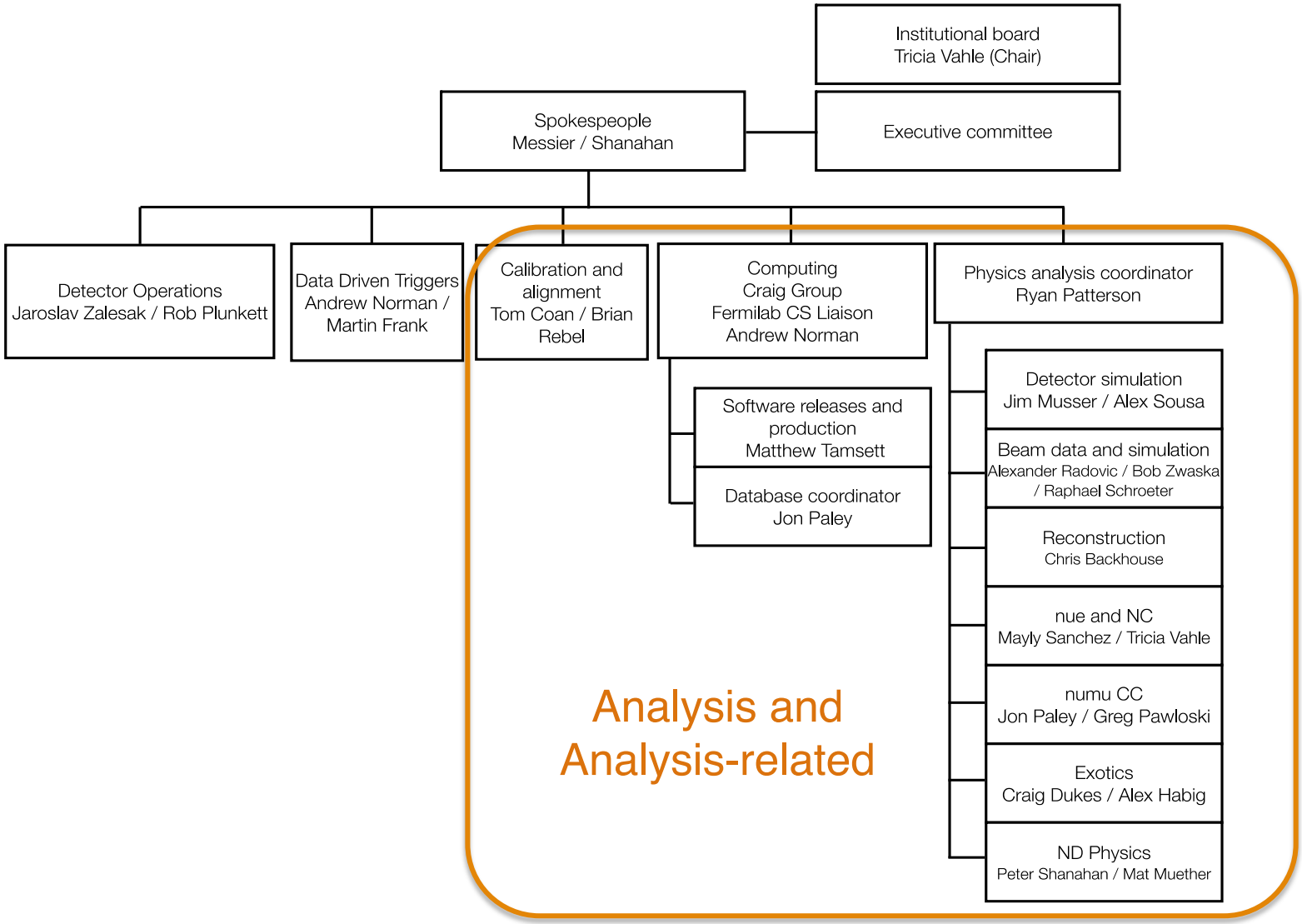
2015 shutdown:
Improvements to computer cooling at Ash River
DAQ stability improvements
Minor detector work

NOvA Operations

Experimental Operations Plan
Has been signed

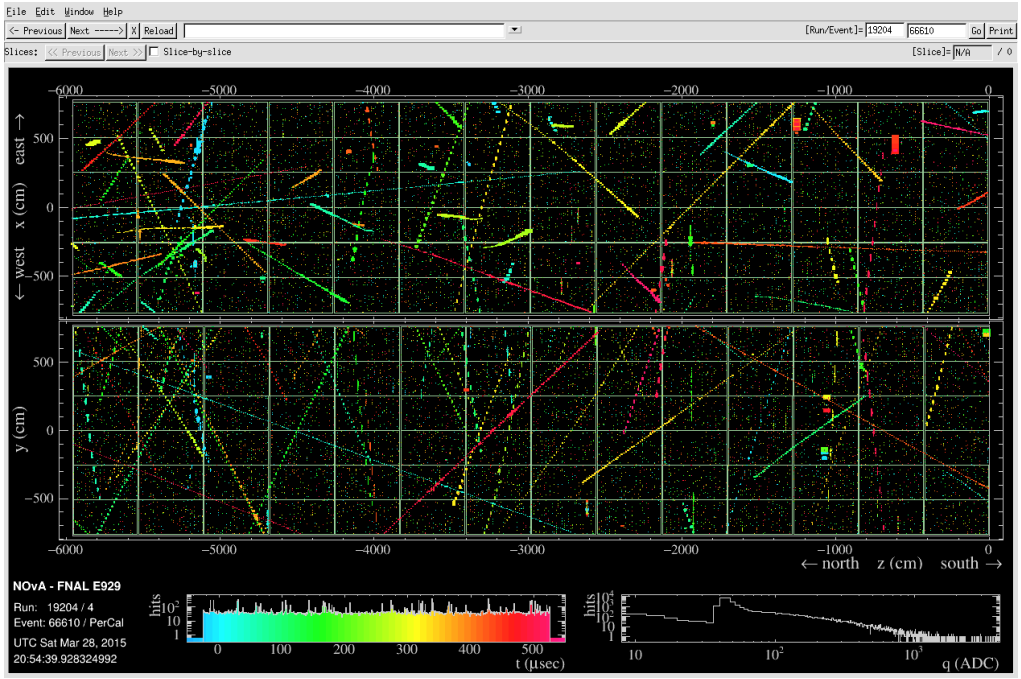


NOvA Analysis Organization

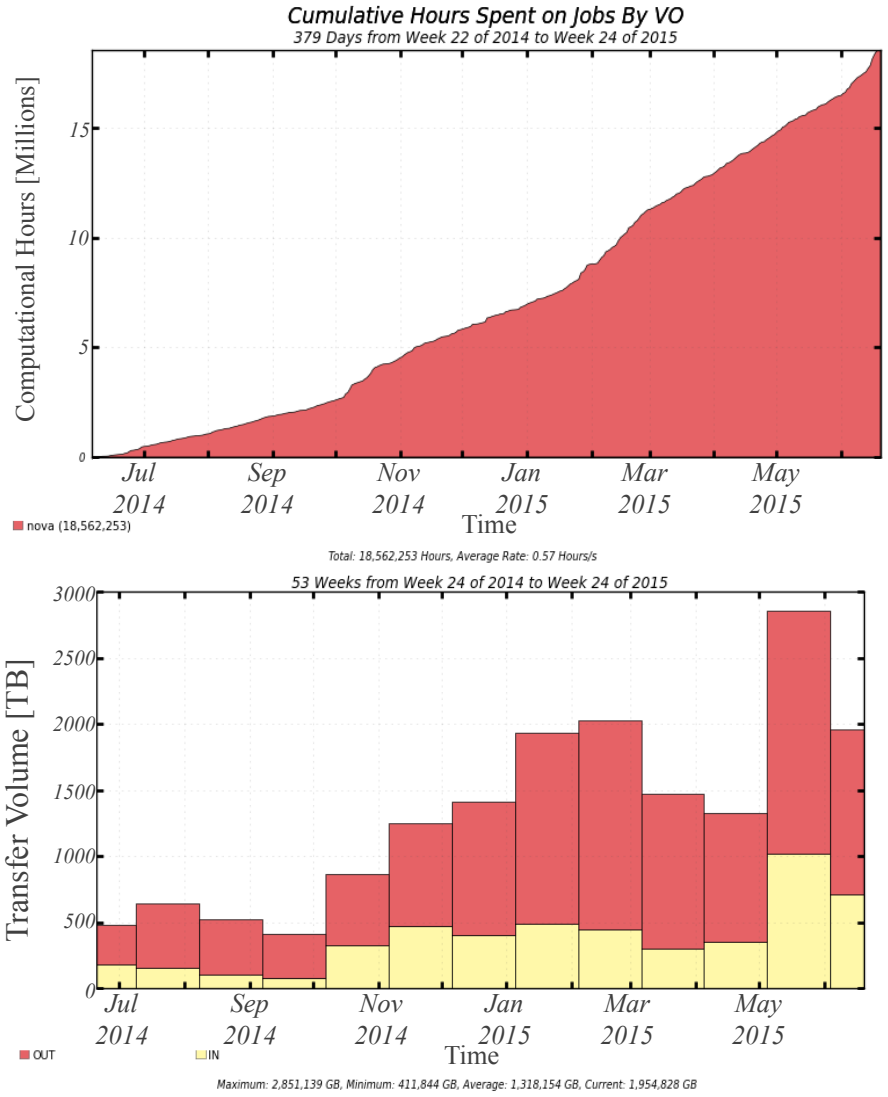


Analysis status

- ν_μ and ν_e analyses are in progress
- First results are anticipated in the coming months
- Blind analyses
  - No examination of neutrino energy, particle IDs for in-time beam events in Far Detector
- Not blind
  - Near Detector beam data
  - Out-of-time Far Detector cosmic data
  - High energy tail in Far Detector beam data



Data Processing

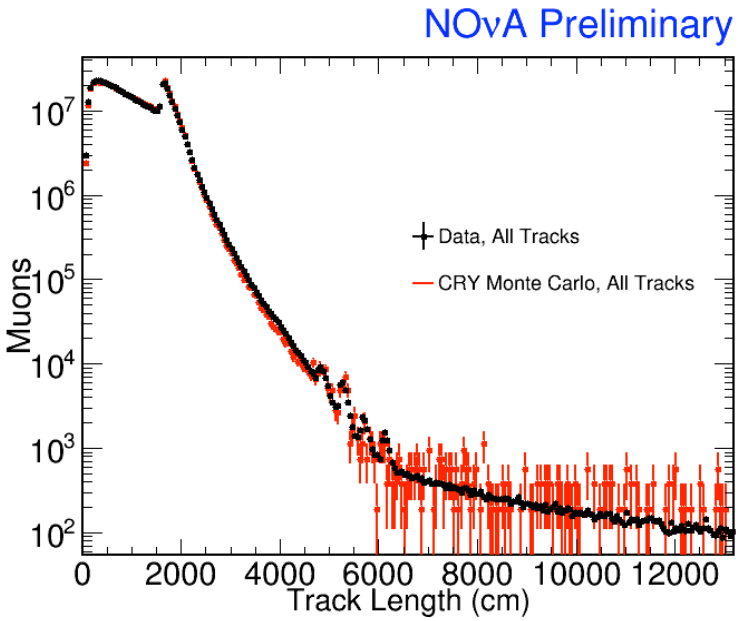


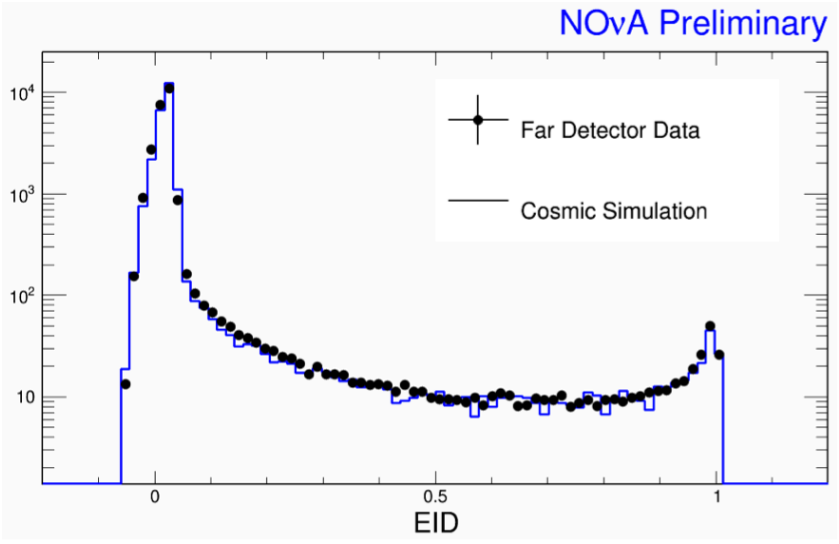
- Detector data
  - 14×10^6 NuMI beam spills
  - 203×10^6 periodic cosmic triggers
- Monte Carlo
  - 65×10^6 beam spills
    - near and far detectors
  - 1.8×10^9 cosmic ray triggers

– 18.5×10^6 CPU hours in 2014

Cosmic Rays

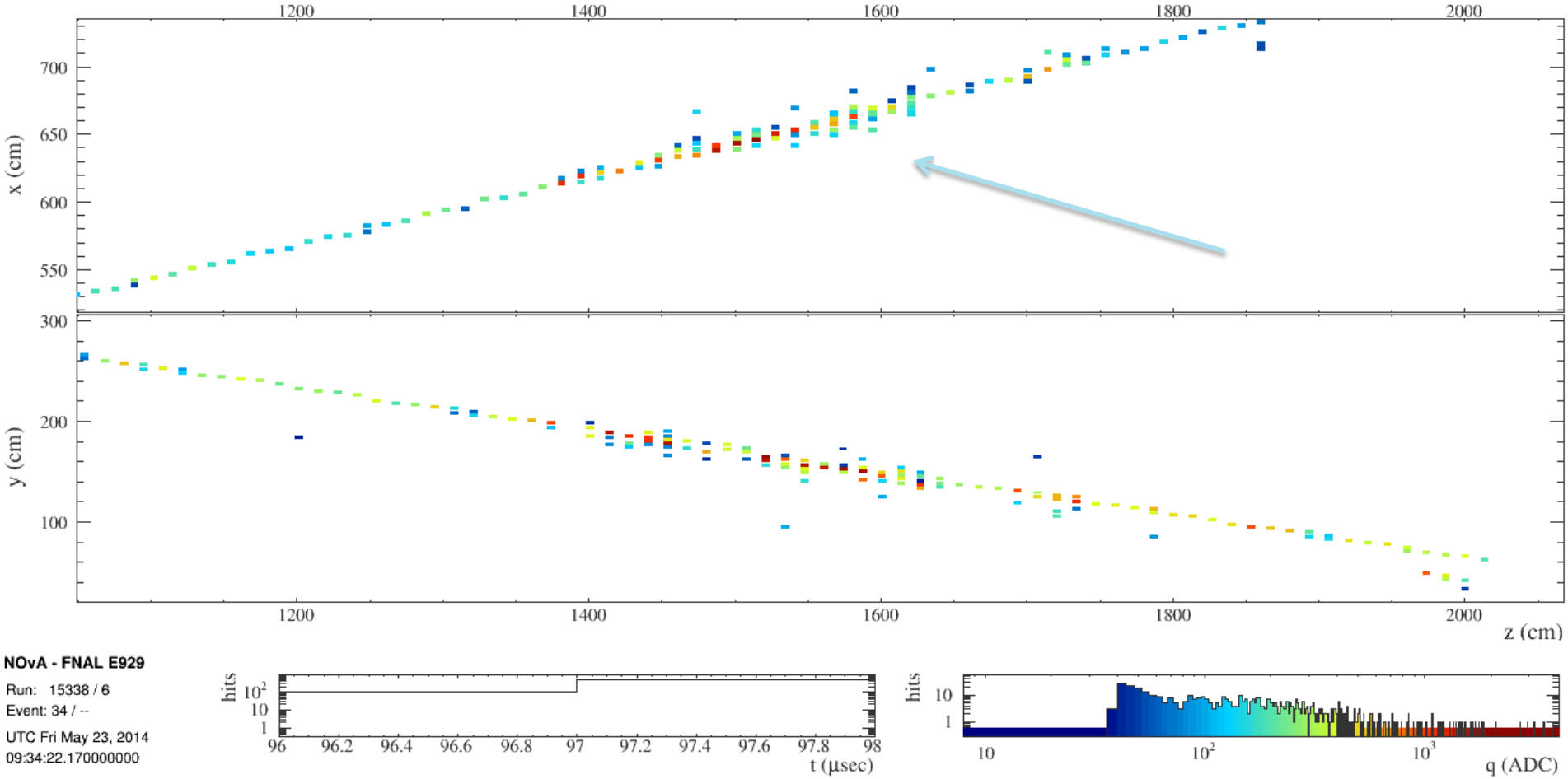
- High statistics cosmic ray sample from Far Detector
  - Calibration
  - Check detector modeling



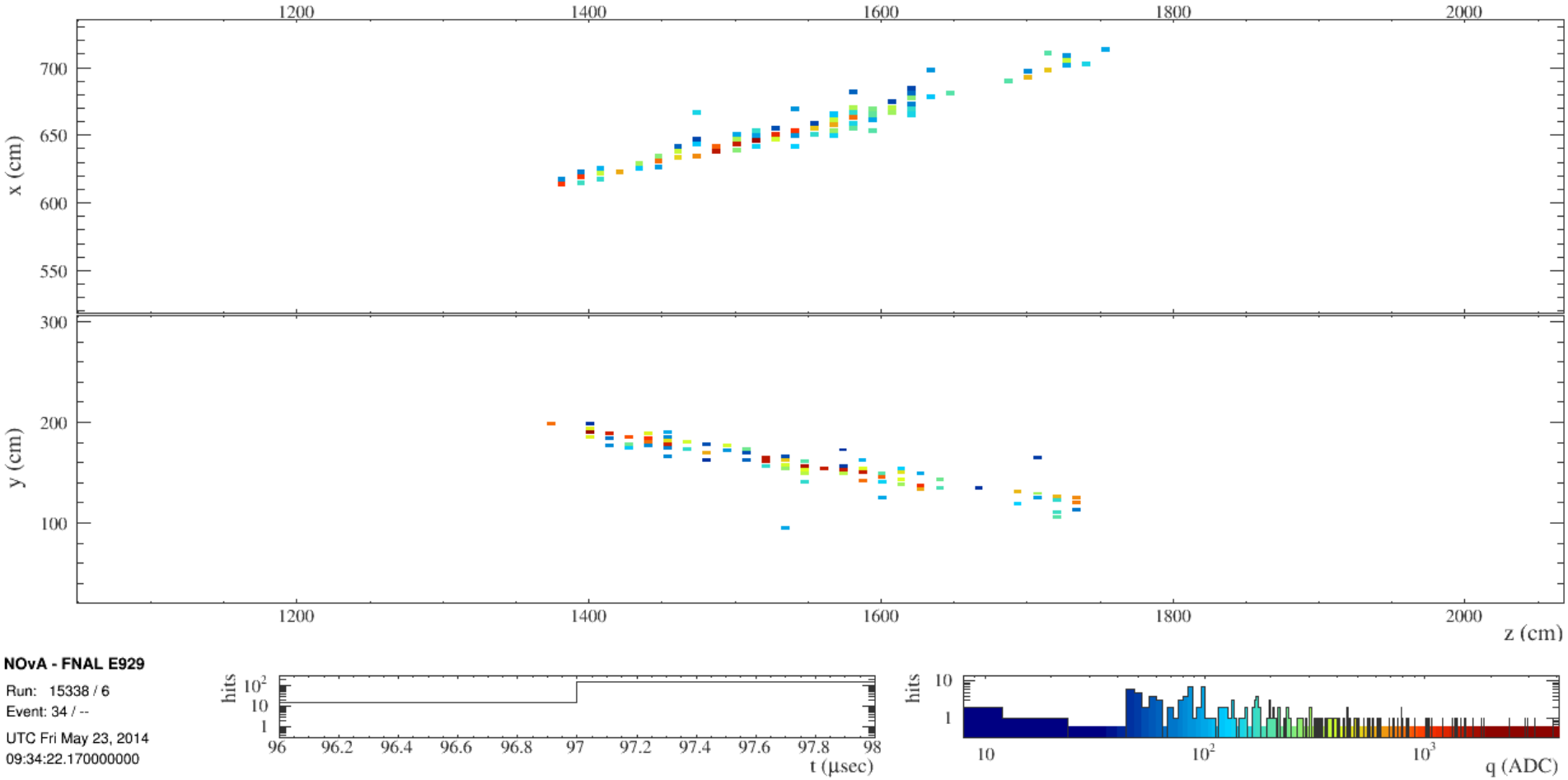


- Benchmark electron particle ID algorithms for cosmic background
- Benchmark for signal using cosmic bremsstrahlung sample

Cosmic-ray induced shower

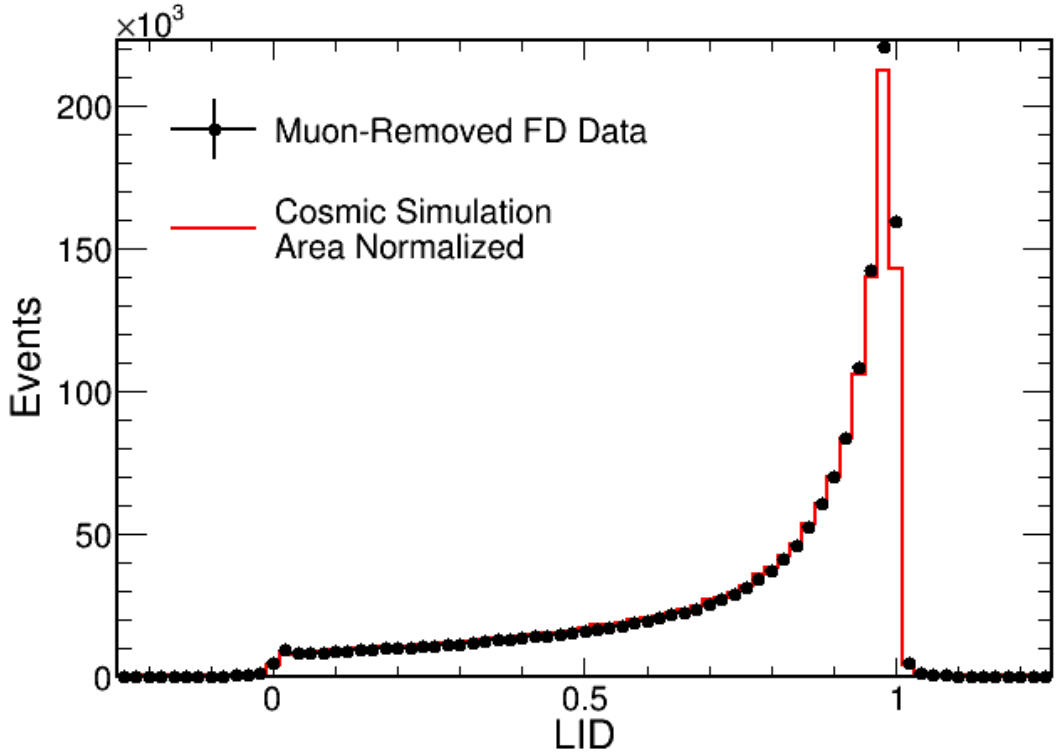


Cosmic-ray induced shower with muon removed



Cosmic Bremsstrahlung

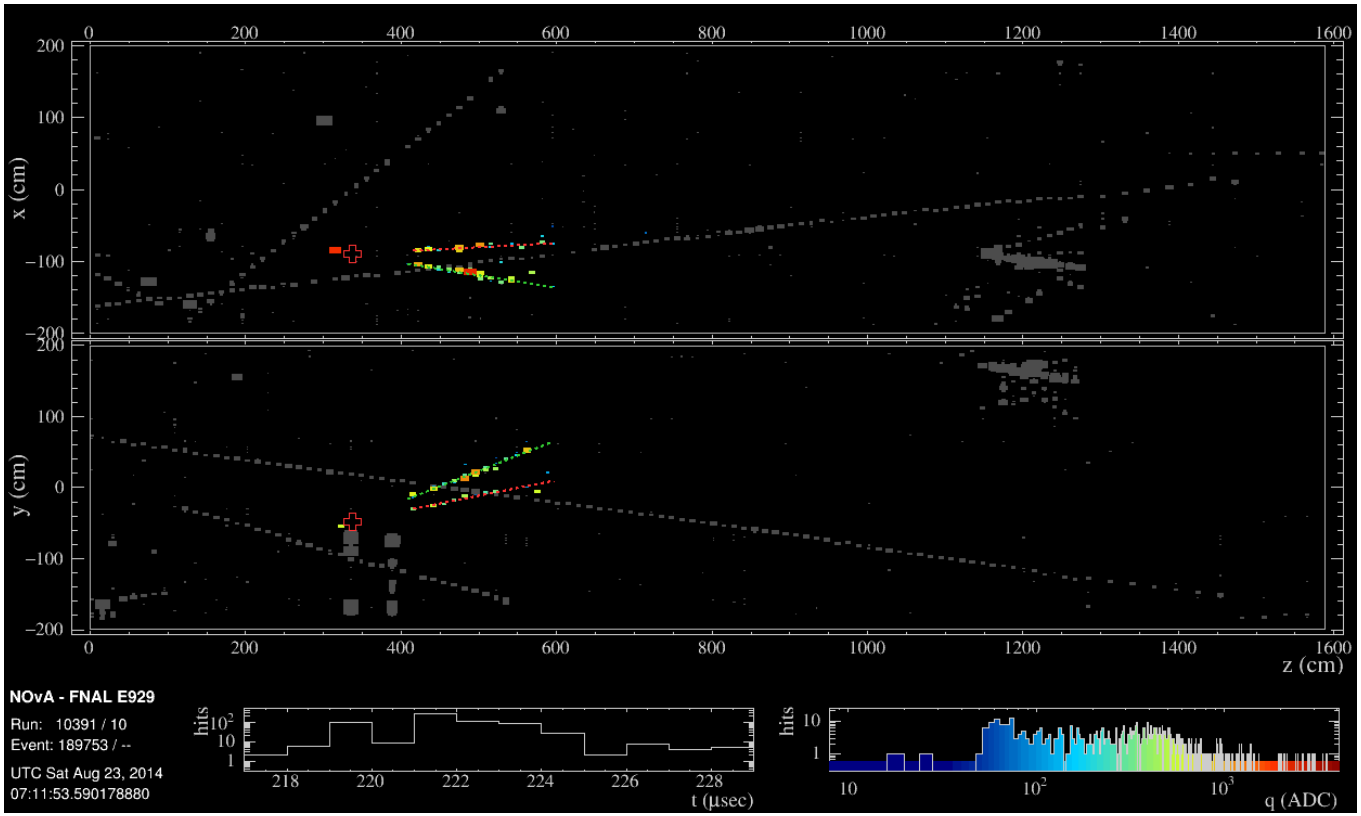
Electron Particle ID for cosmic bremsstrahlung showers



Data-driven check on performance of electron identification algorithms

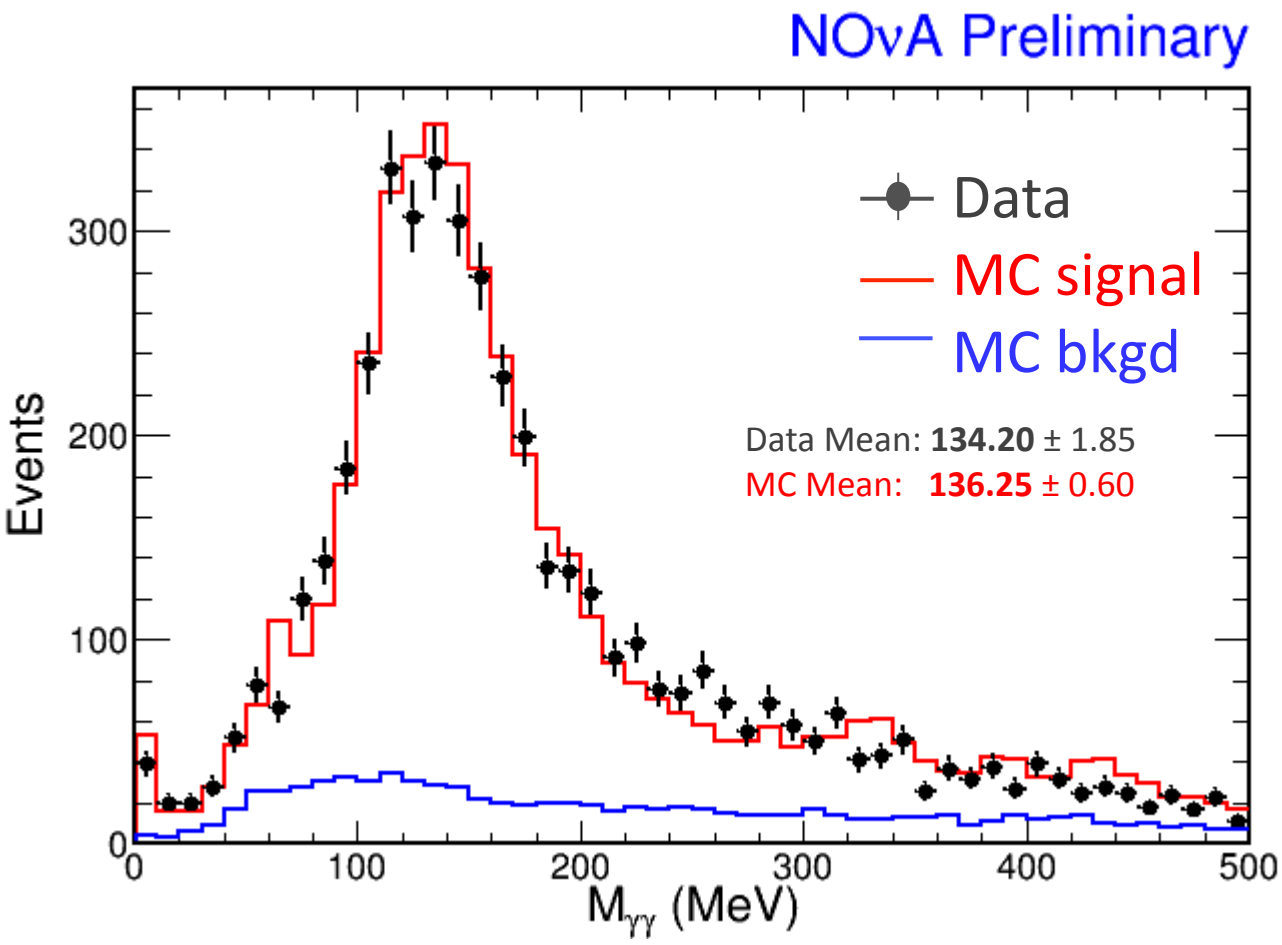
Pi-zeros in Near Detector

- NC π^0 production is important background to ν_e appearance
- π^0 mass provides a useful calibration check
- Select events with 2 contained showers with common vertex



$m^2_{\pi^0}=2E_{\gamma 1}E_{\gamma 2}(1-\cos(\theta_{\gamma 1\gamma 2}))$

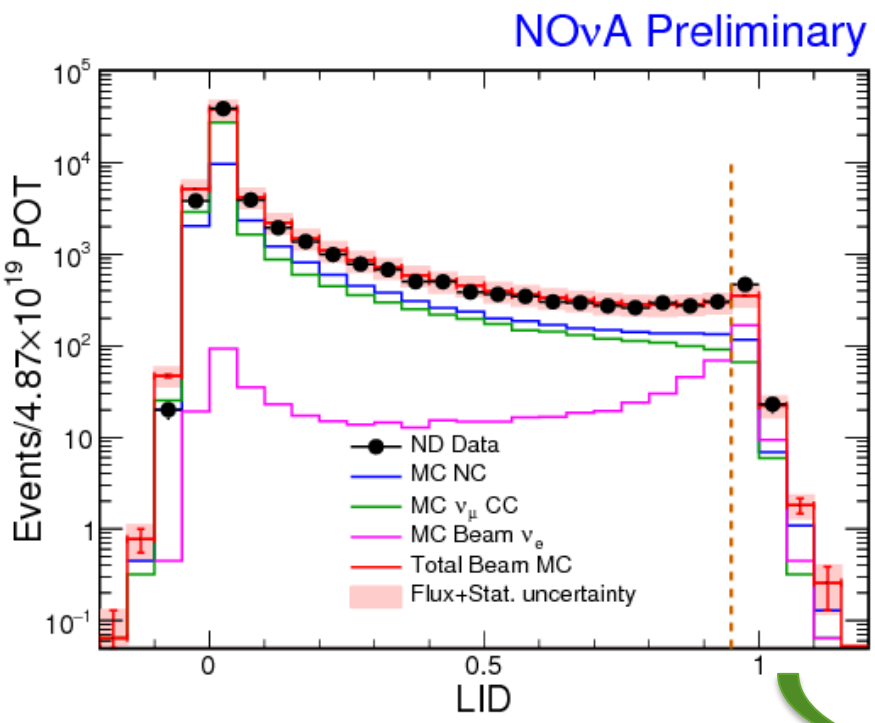
Near Detector π^0 results



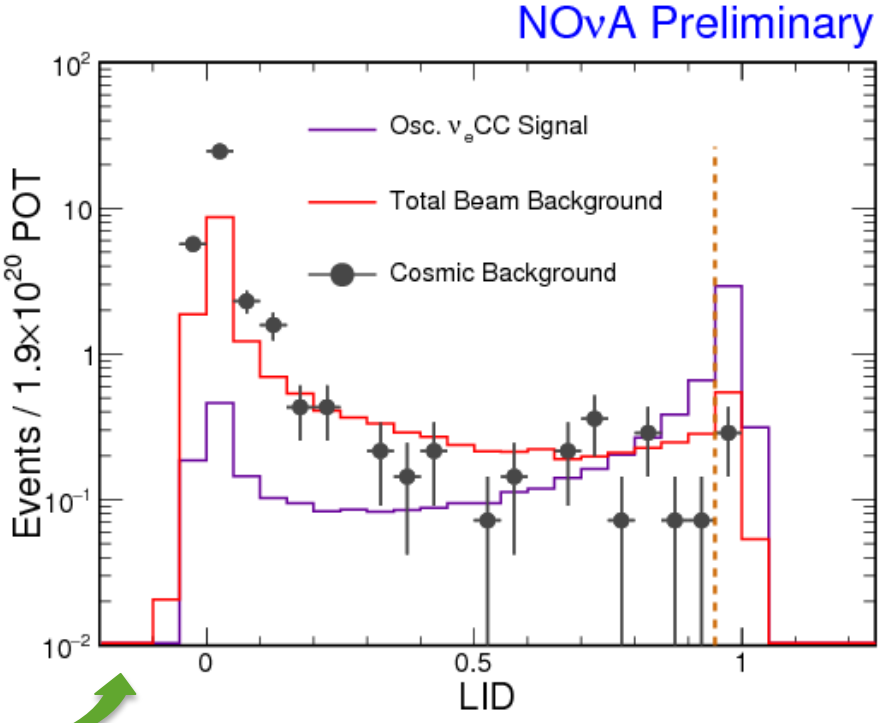
Relatively normalized distributions show good data-MC agreement in π^0 reconstruction

ν_e Prediction for Far Detector Event Rates

LID: Shower-shape likelihood-based classifier



Data-MC comparison in **Near Detector**



Far Detector Prediction:
Extrapolation of beam background and signal, measurement of cosmic background

First Analysis

- Data set through Mar. 14, 2015
  - 1.9×10^{20} POT – 14 kT equivalent exposure
- Preliminary expected yields
  - ν_e appearance

Assuming $\delta_{CP}=0$, no matter effect, $\sin^2(2\theta_{13})=0.095$
Maximal 23 mixing,
Unknowns can change signal by +/- 60%

	Osc. ν_e CC Signal	Total BG	ν_μ CC	NC	Beam ν_e	Cosmic Background
LID	3.25	1.02	0.05	0.32	0.33	0.29
LEM	3.48	1.14	0.05	0.41	0.36	0.29

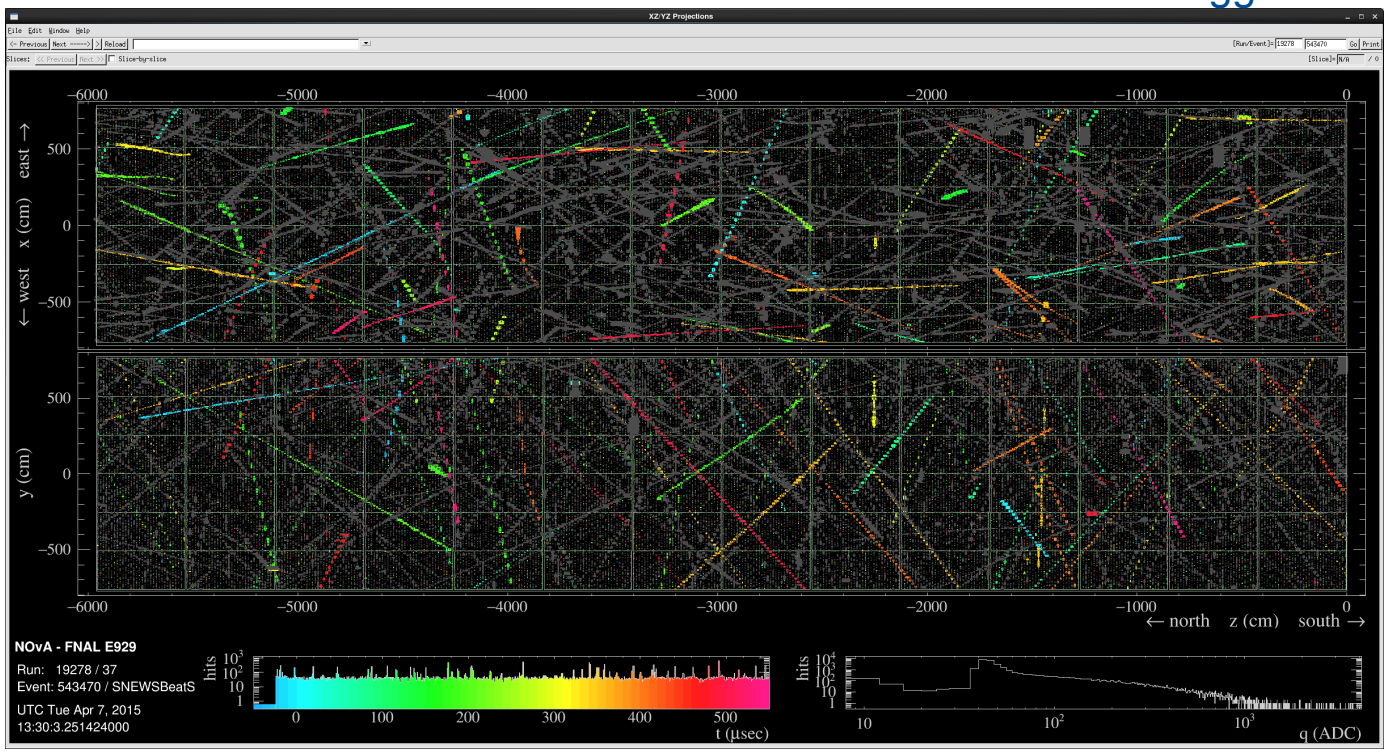
  - ν_μ disappearance

	ν_μ CC Signal	Total BG	Cosmic Background	NC Background
Final Selection	23.7	1.6	0.3	1.3

Non-oscillation Physics Analyses

- Near Detector Physics Group
  - Founded in January 2015
  - Cross sections, flux constraints
- Exotics Group
  - Dark Sector searches
  - Supernova neutrino triggering →
  - Magnetic Monopoles

5ms of 2 seconds continuous data from SNEWS test trigger



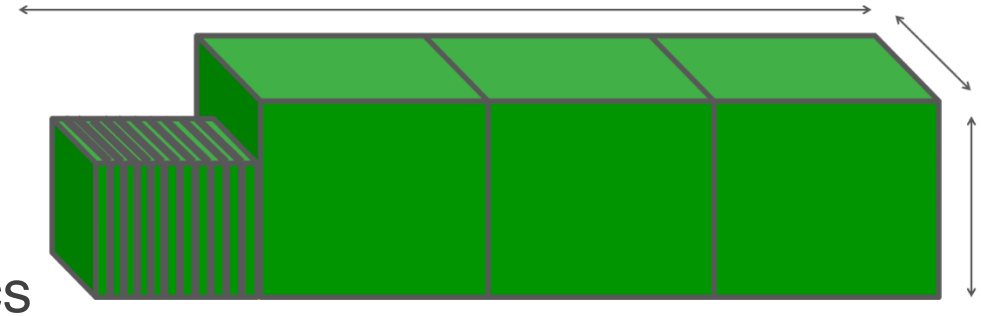
Summary

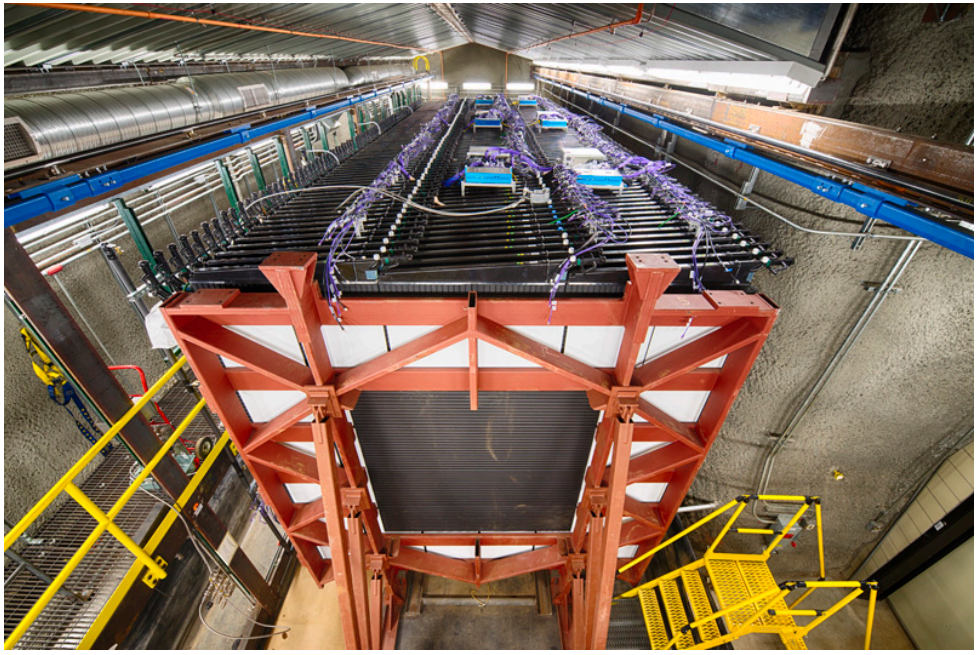
- NOvA will soon complete its first year of operations
  - Good data quality and detector uptimes
  - Recent progress on beam power
    - 420 kW with 2+6 slip stacking is very encouraging
    - We look forward to design power of 700 kW early in CY16
- NOvA has embarked on a rich physics program
  - ν_e appearance
  - ν_μ disappearance
  - neutrino interactions
  - exotic physics
- NOvA is pushing on 1st oscillation analyses
  - ~1/3 nominal “TDR year”

Backup Slides

Near Detector

- Pre-oscillation reference
  - Cross section, flux, acceptance uncertainties
  - Neutrino interaction physics

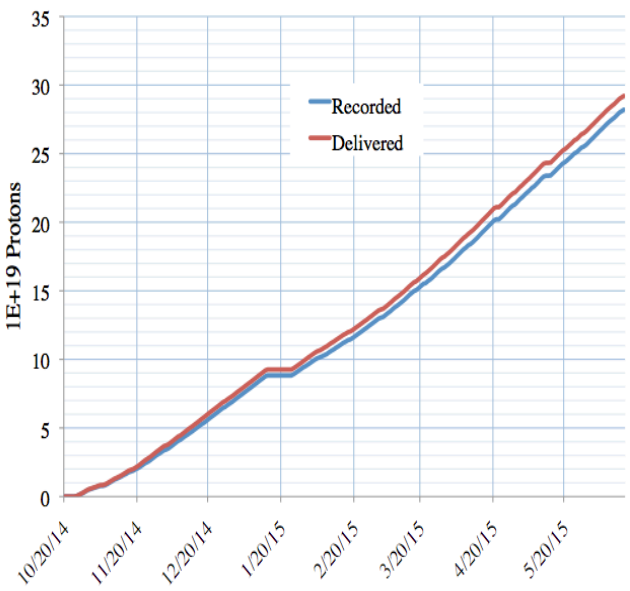




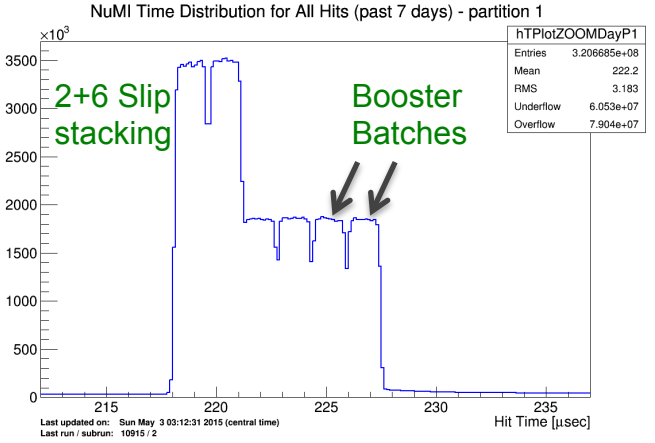
- 300 t, 631 APDs
  - Includes muon catcher
  - Multiple neutrino interactions/beam spill, every 1.33 seconds
- Fermilab NuMI Underground Area

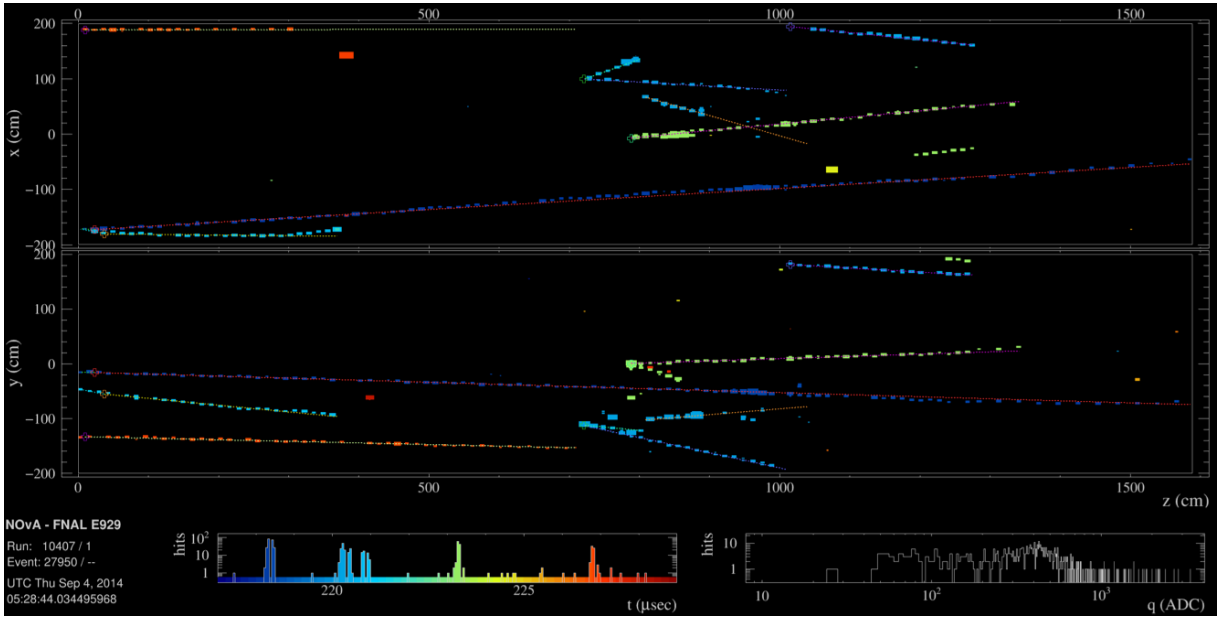
Near Detector Operations

- Near Detector beam-weighted uptime >96% in FY15



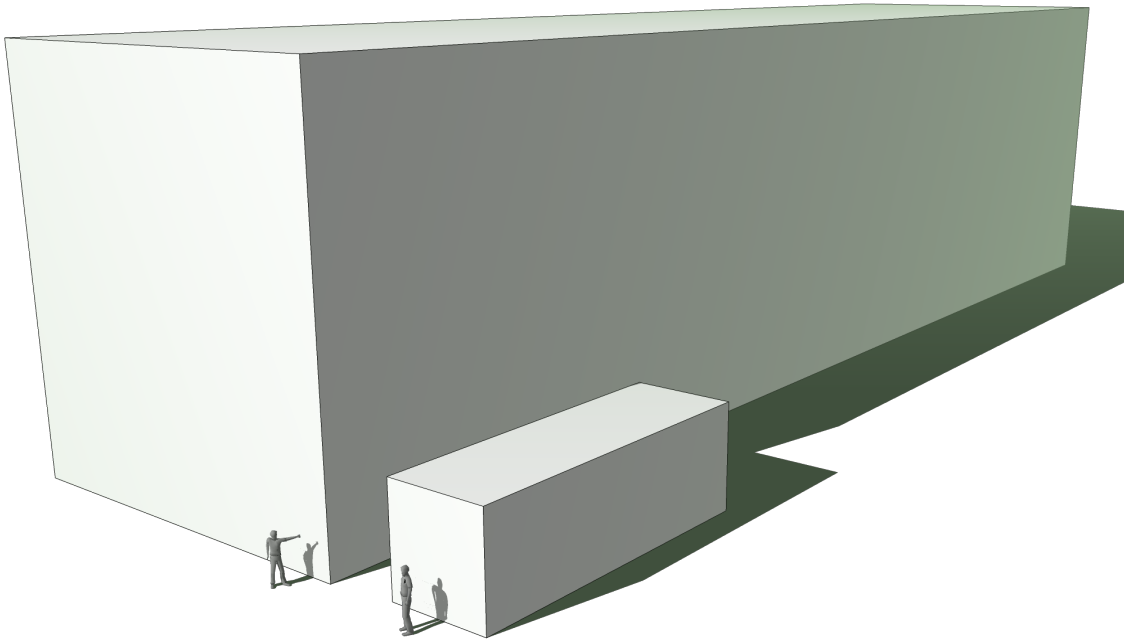
Time of Hits within Spill - Online Monitoring



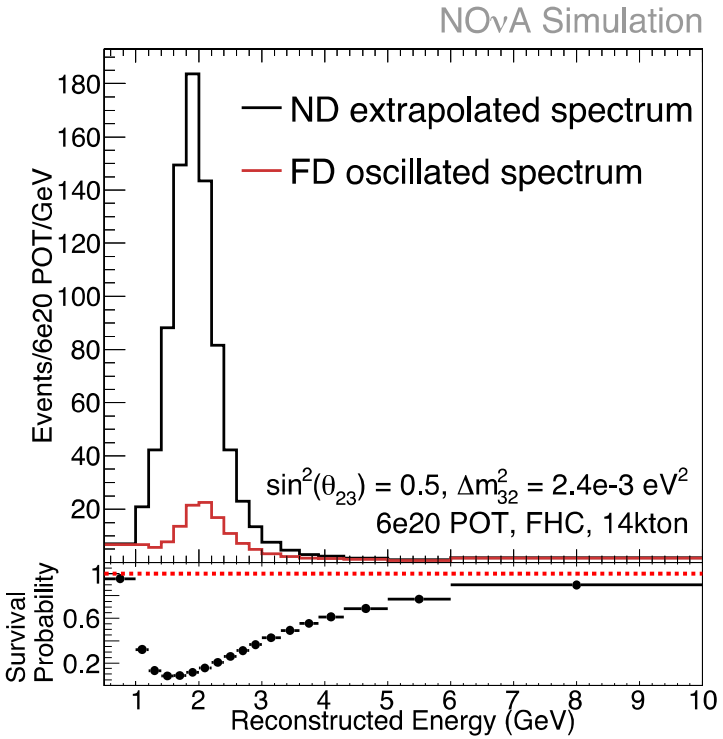


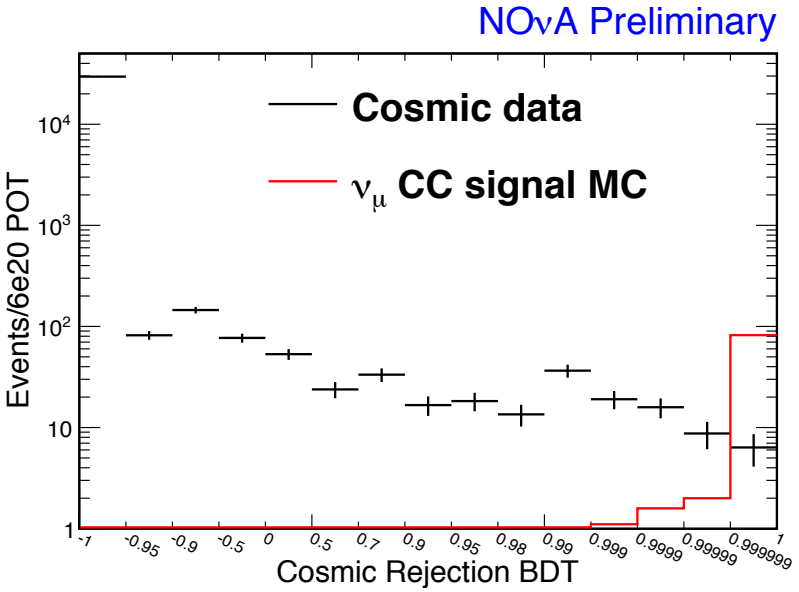
Far Detector

- 14 kt, 344,064 cells, 10752 APDs
- Commissioning finished in August 2014,
- Ash River, Minnesota
  - 810 km baseline



ν_μ nominal TDR year

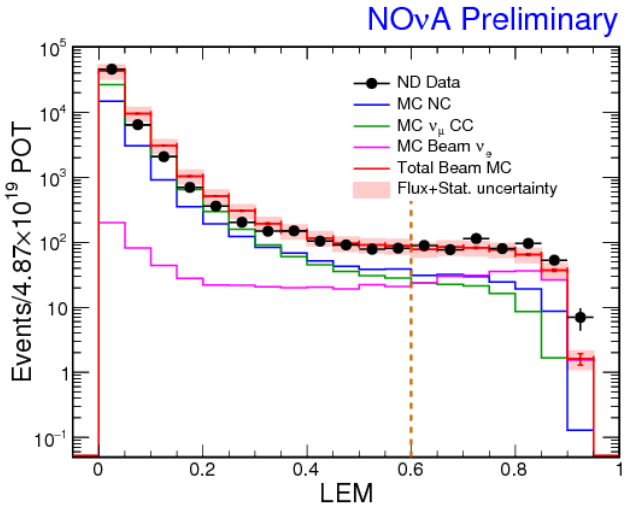




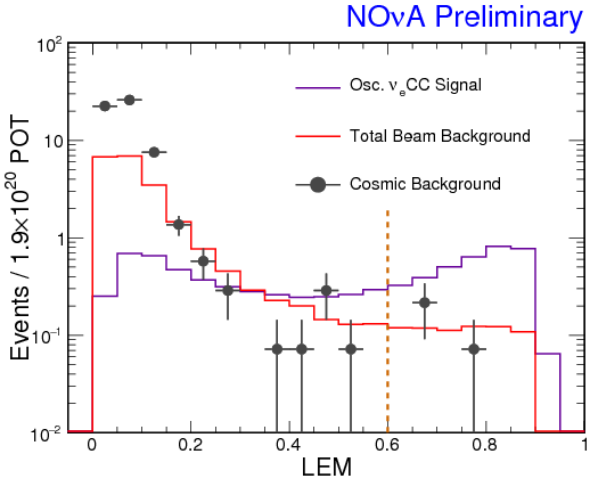
Cosmic background rejection benchmarked to data
20M:1 for ν_μ

ν_e Prediction for Far Detector Event Rates

Library Event Matching classifier

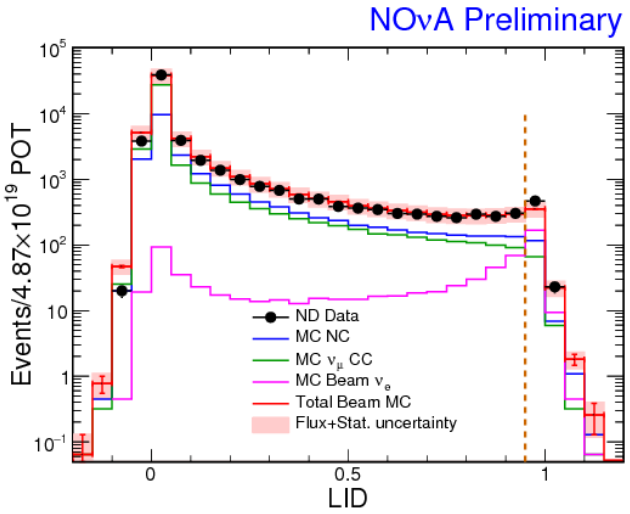


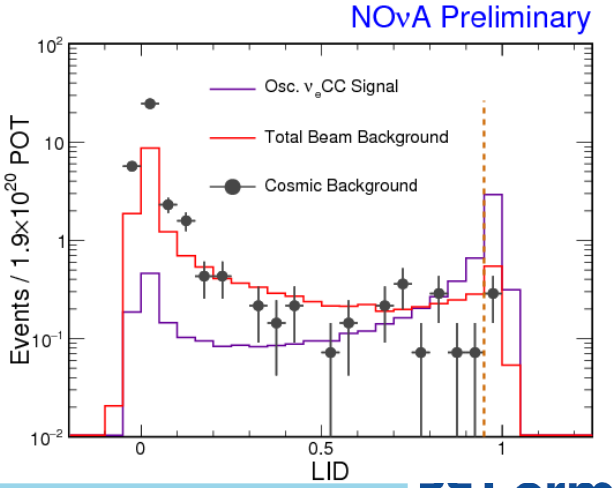
Data-MC comparison in **Near Detector**



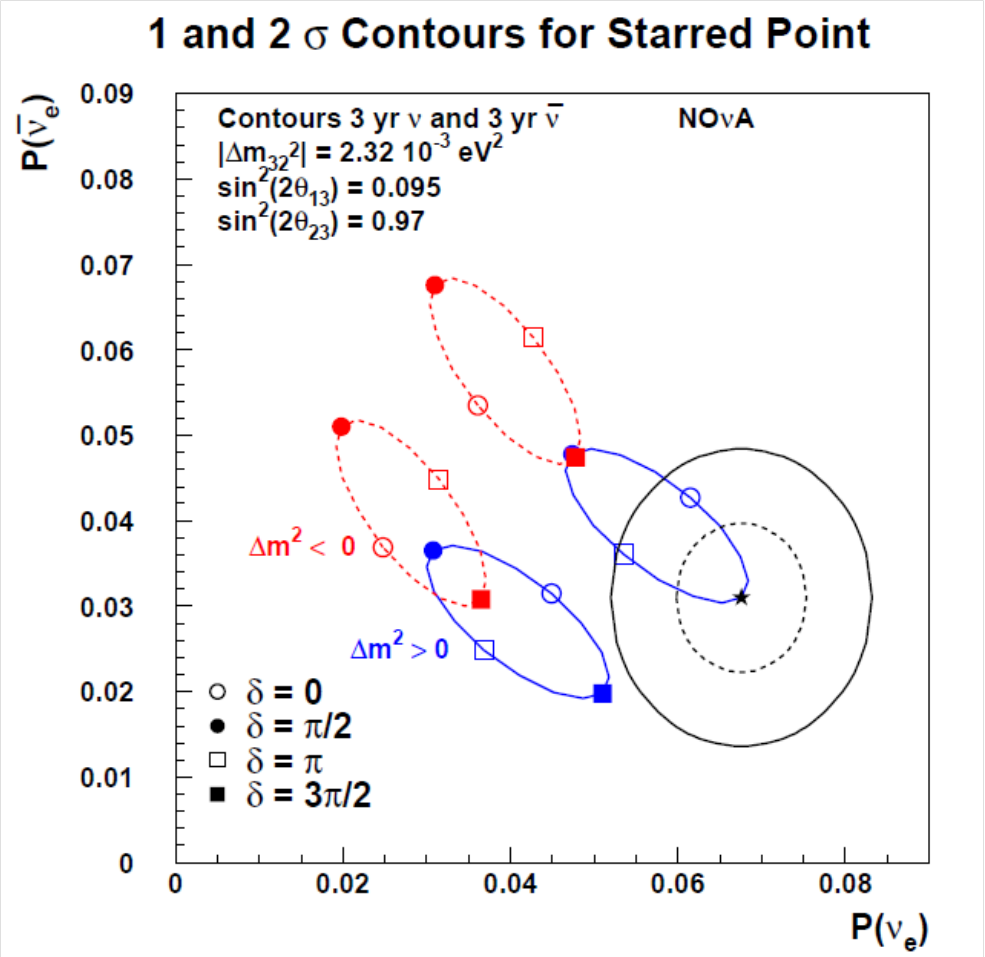
Far Detector Prediction: Extrapolation of beam background and signal, measurement of cosmic background

Shower-shape likelihood-based classifier

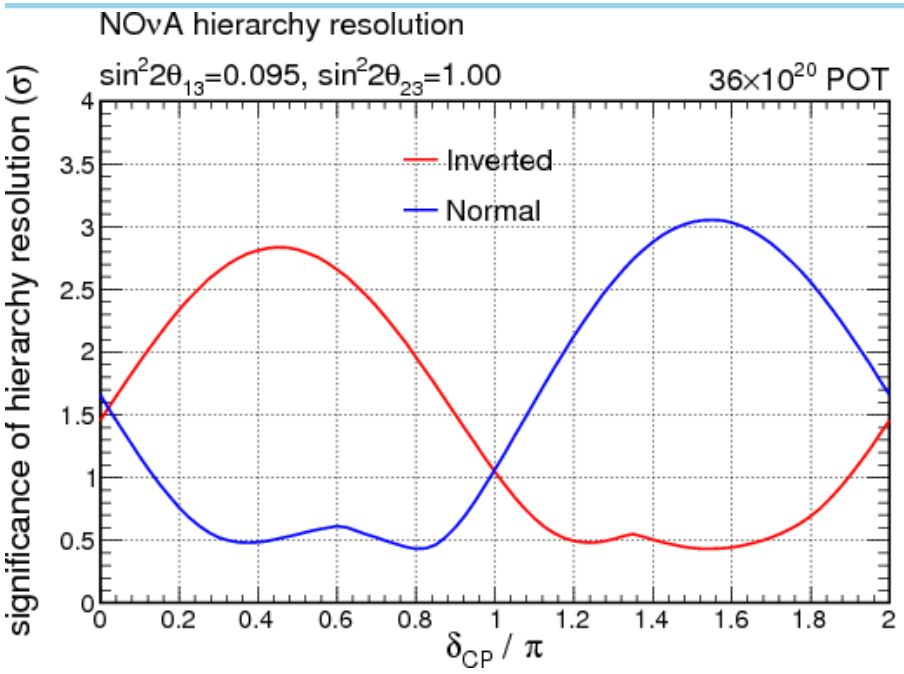


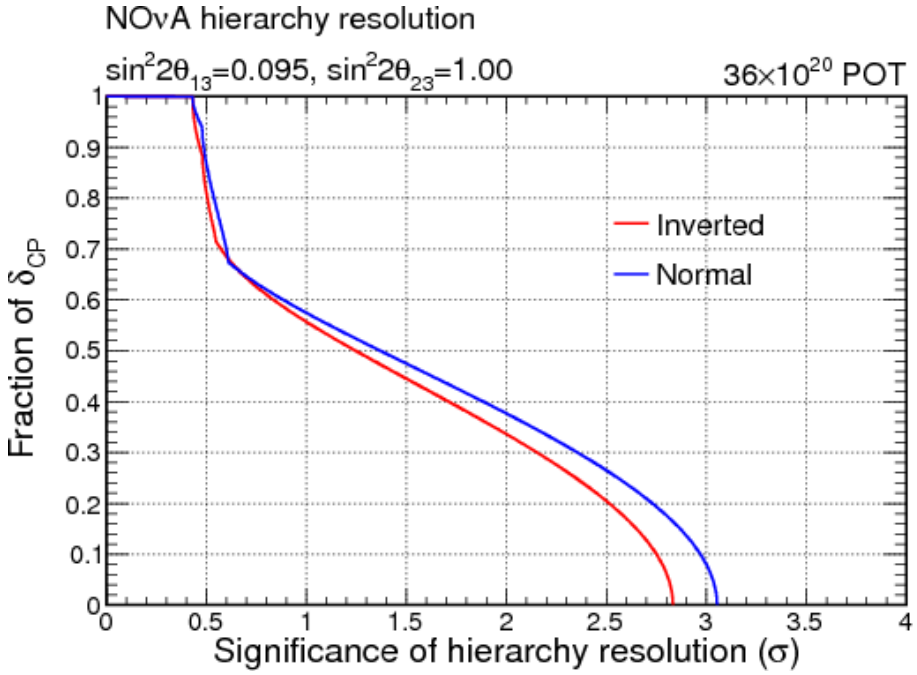


Favorable case

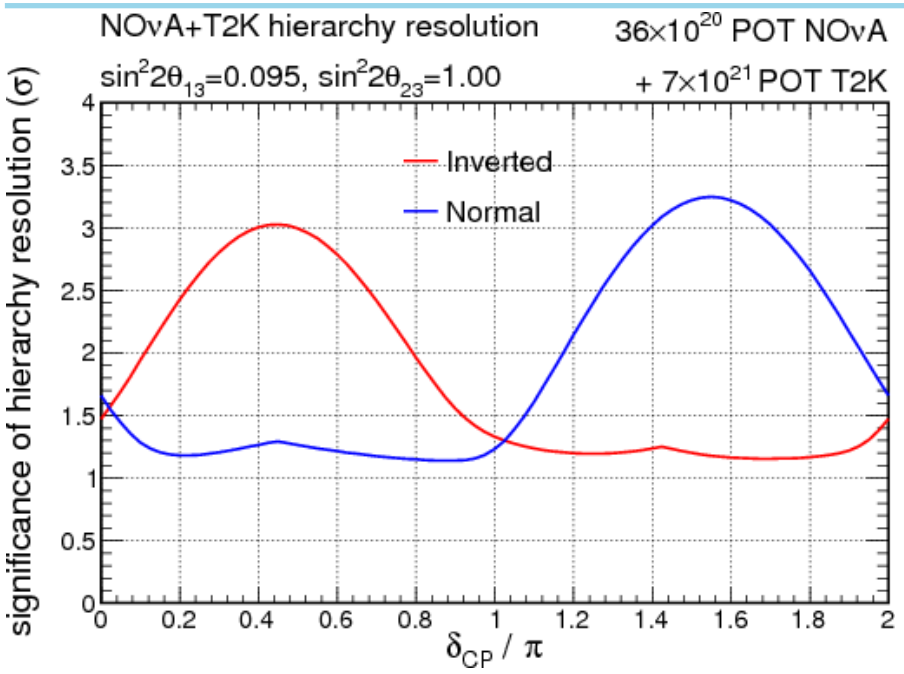


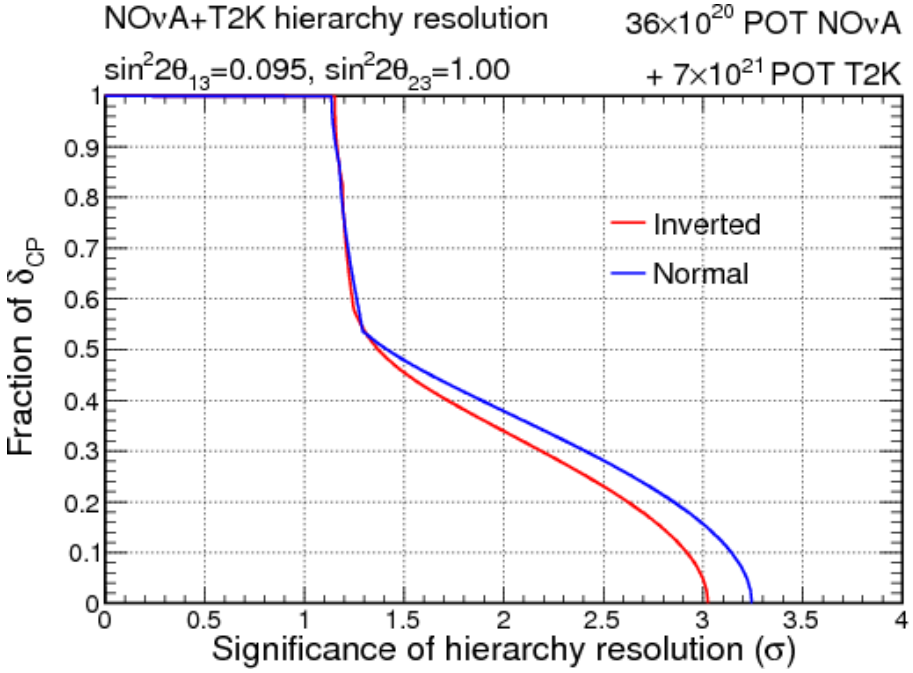
Mass Hierarchy – NOvA Alone





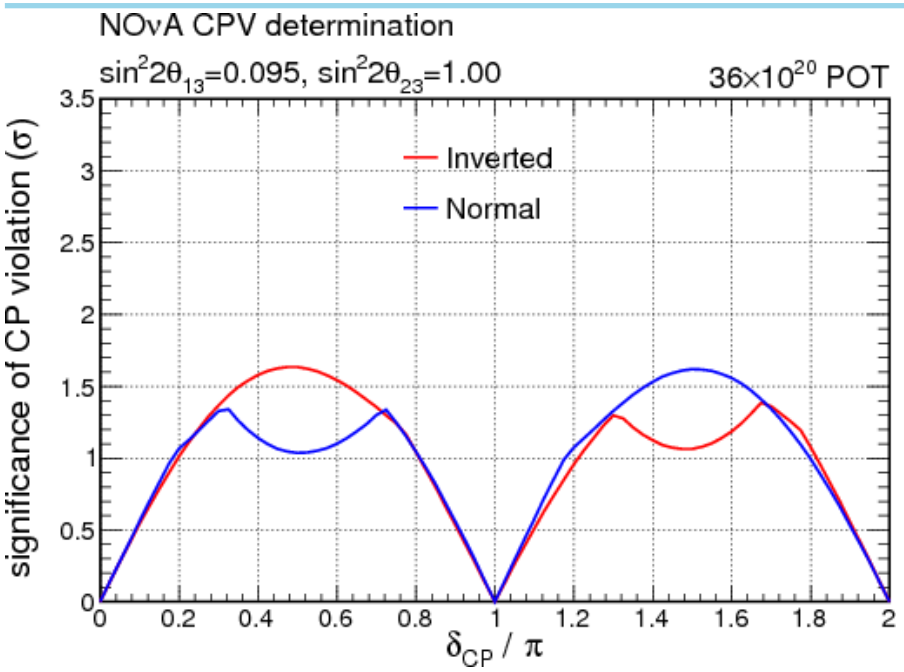
Mass Hierarchy – NOvA + T2K*

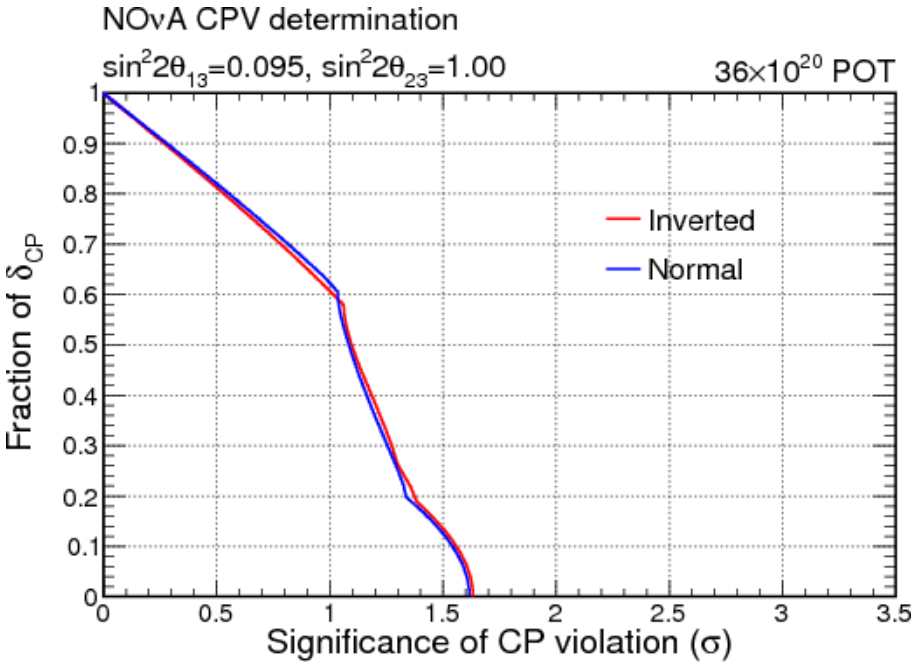




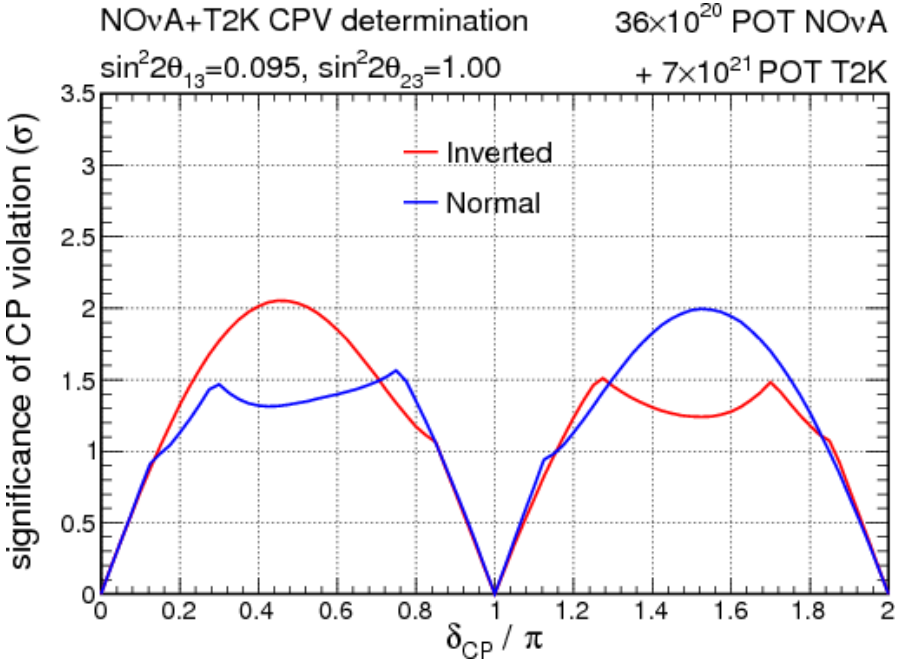
* T2K input based on scaling numbers shown at Neutrino 2012

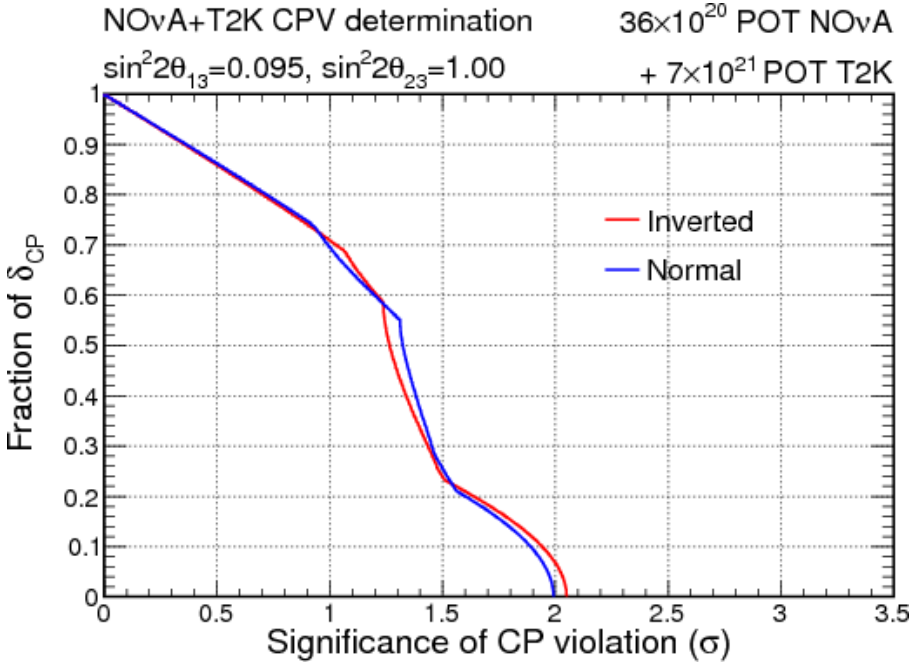
CP Violation – NOvA Alone





CP Violation – NOvA + T2K*

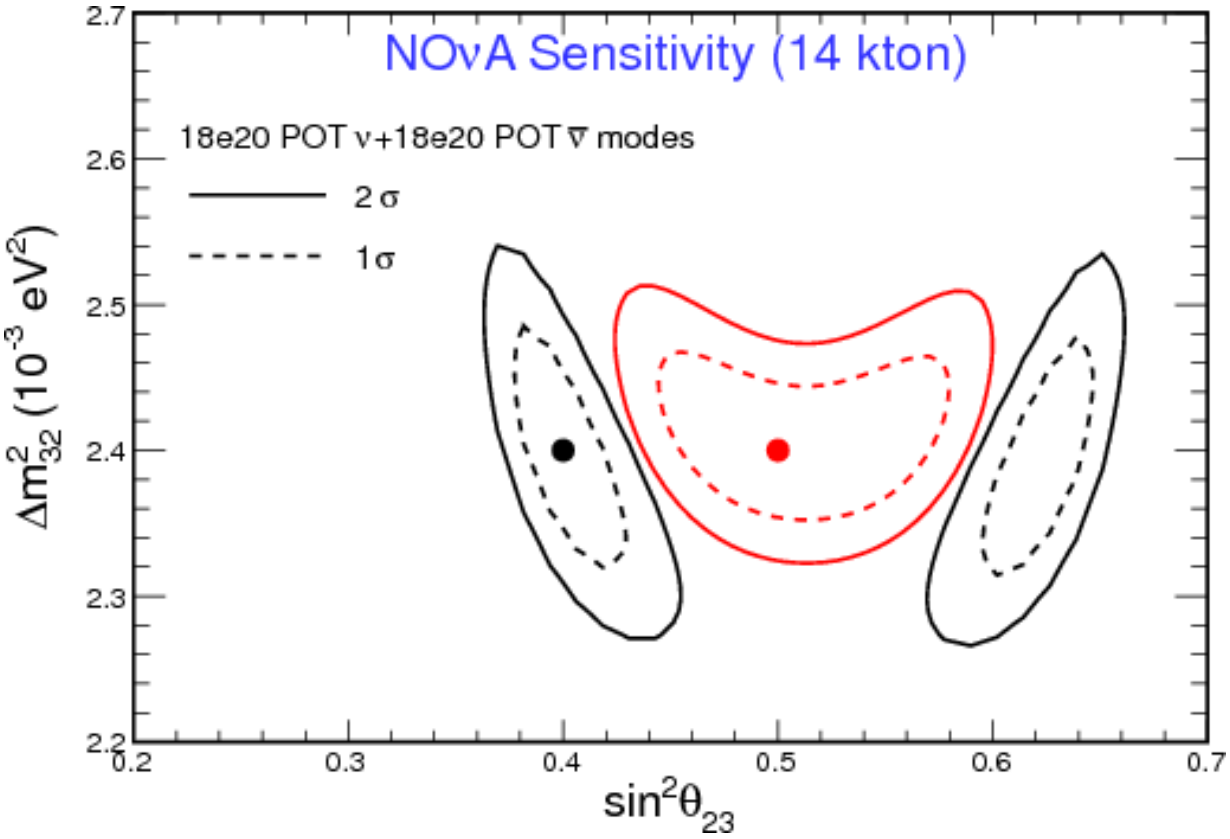




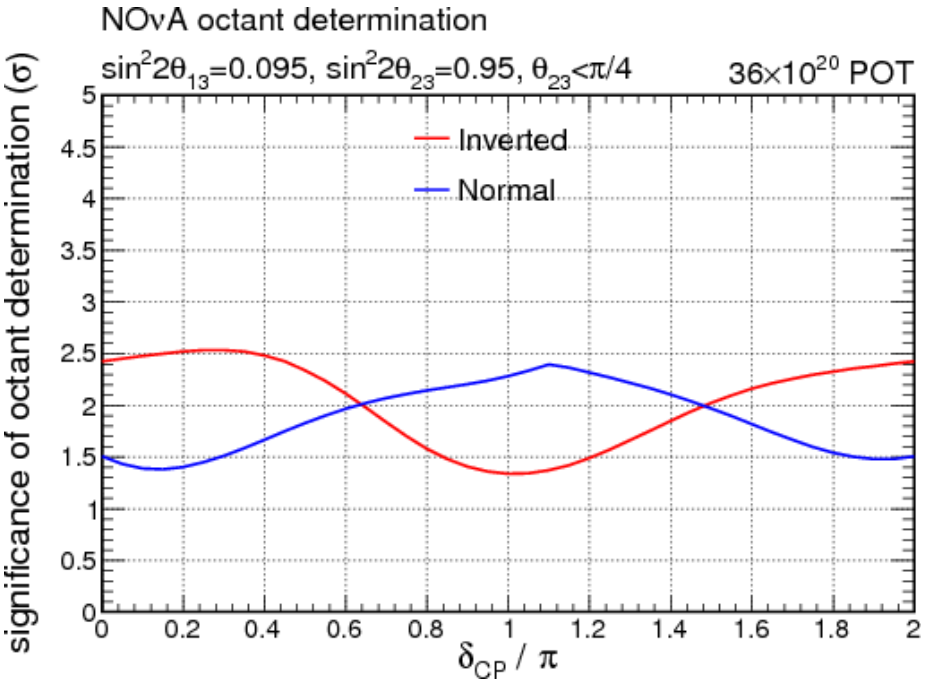
* T2K input based on scaling numbers shown at Neutrino 2012

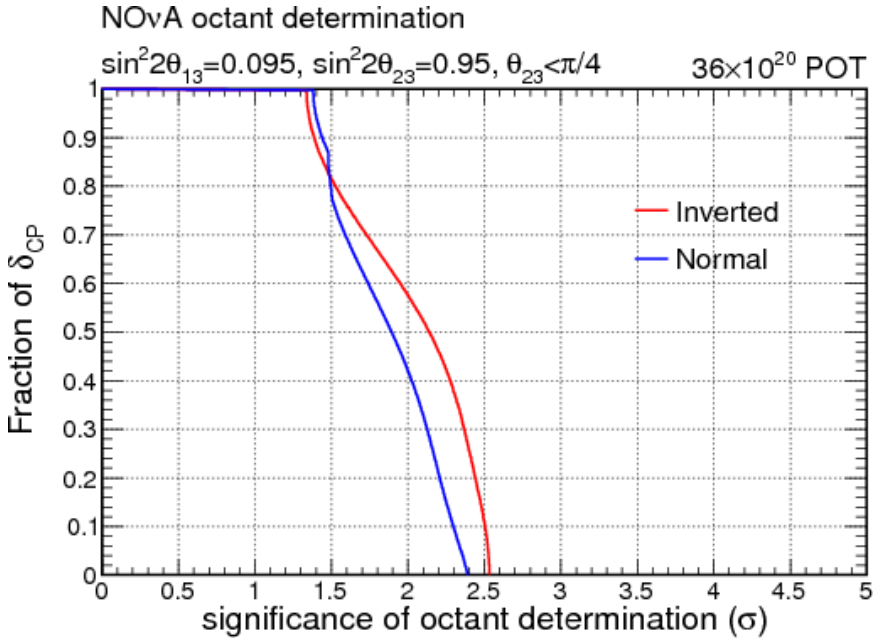
ν_μ disappearance – 3 + 3 years

- Assuming true values indicated by dots

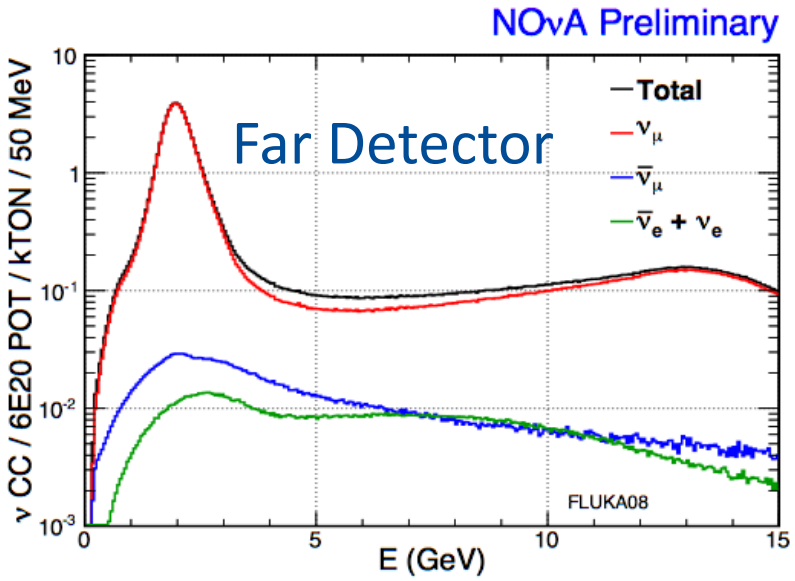


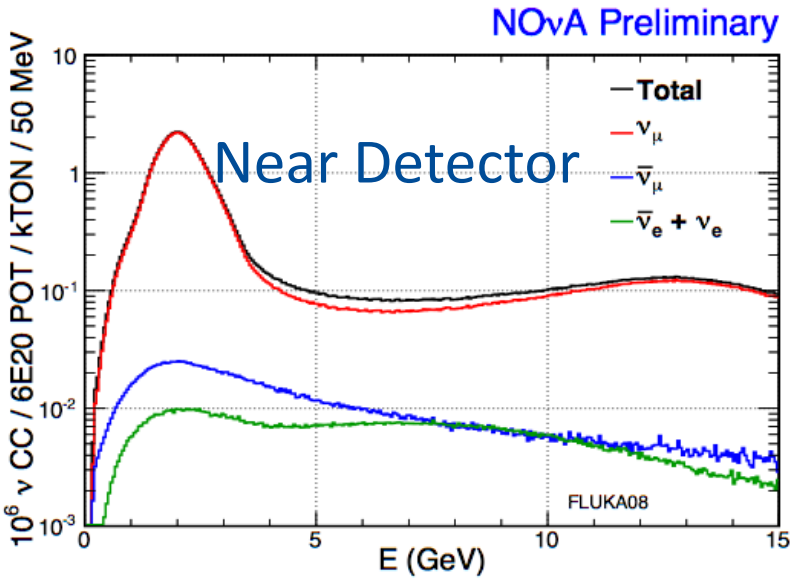
θ_{23} Octant Sensitivity





Forward Horn Current Beam Composition





	[1,3]GeV	[0,120]Gev
Total	63.5	103.8
ν_μ	62.1	97.6
$\bar{\nu}_\mu$	1.0	3.9
$\nu_e + \bar{\nu}_e$	0.4	2.3

[1,3]GeV: $\bar{\nu}_\mu / \nu_\mu$ = 1.6%

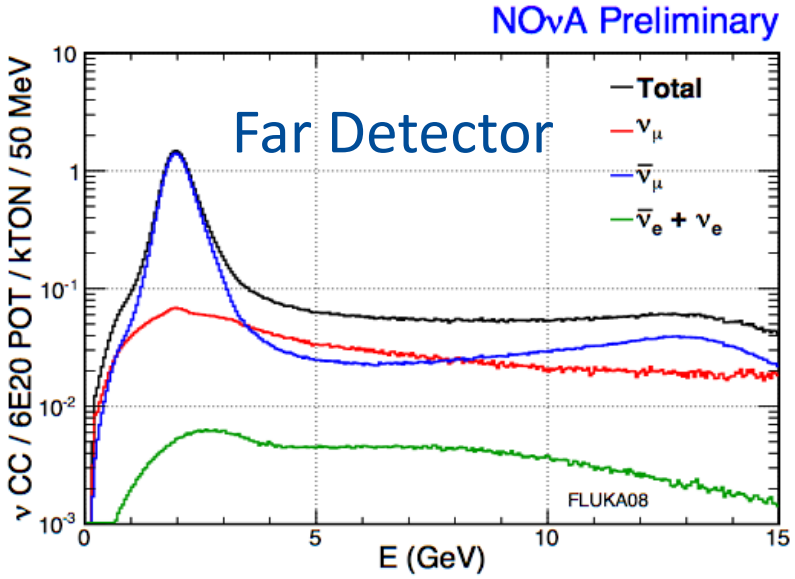
[1,3]GeV: $(\nu_e + \bar{\nu}_e) / \nu_\mu$ = 0.6%

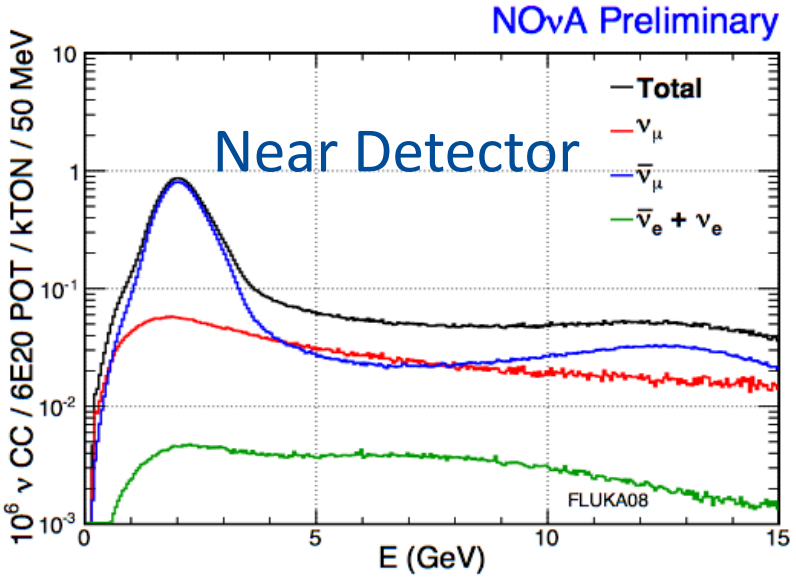
$\times 10^6$	[1,3]GeV	[0,120]Gev
Total	53.9	95.0
ν_μ	52.6	89.5
$\bar{\nu}_\mu$	0.9	3.5
$\nu_e + \bar{\nu}_e$	0.4	2.0

[1,3]GeV: $\bar{\nu}_\mu / \nu_\mu$ = 1.7%

[1,3]GeV: $(\nu_e + \bar{\nu}_e) / \nu_\mu$ = 0.7%

Reverse Horn Current





	[1,3]GeV	[0,120]Gev
Total	25.1	46.7
ν_μ	2.4	13.2
$\bar{\nu}_\mu$	22.5	32.2
$\nu_e + \bar{\nu}_e$	0.2	1.3

[1,3]GeV: $\nu_\mu / \bar{\nu}_\mu$ = 10%

[1,3]GeV: $(\nu_e + \bar{\nu}_e) / \bar{\nu}_\mu$ = 0.8%

$\times 10^6$	[1,3]GeV	[0,120]Gev
Total	21.4	42.3
ν_μ	2.1	11.9
$\bar{\nu}_\mu$	19.1	29.3
$\nu_e + \bar{\nu}_e$	0.2	1.1

[1,3]GeV: $\nu_\mu / \bar{\nu}_\mu$ = 10%

[1,3]GeV: $(\nu_e + \bar{\nu}_e) / \bar{\nu}_\mu$ = 1.0%