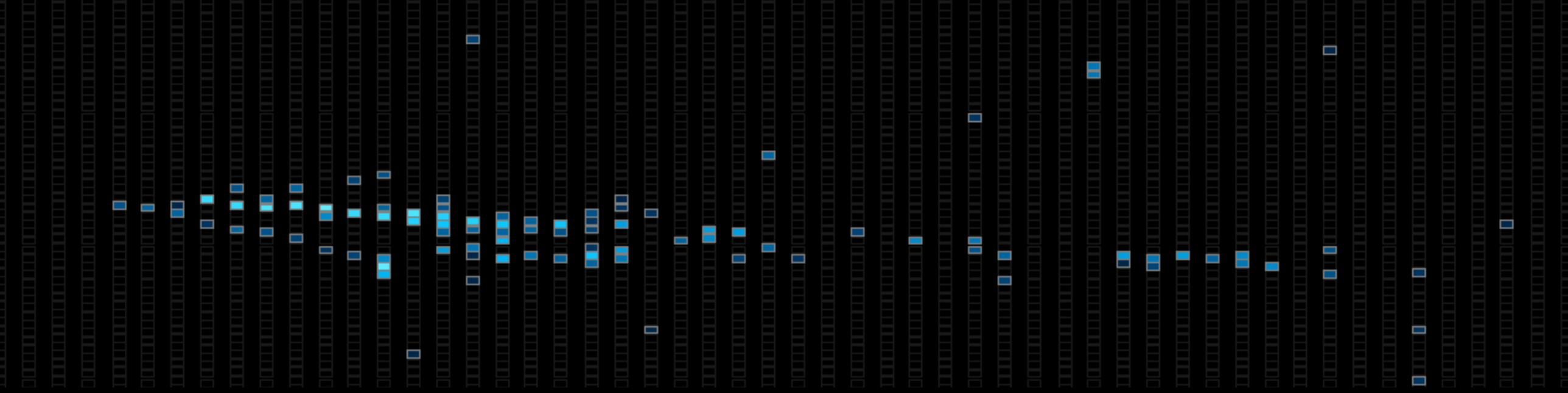


NOvA Update

Mark Messier
Indiana University

Fermilab PAC
January 20, 2016

Fermilab

The NOvA Collaboration

University of Cincinnati
July 2015

ARGONNE NATIONAL LABORATORY • UNIVERSITY OF ATHENS (GREECE) • UNIVERSIDAD DEL ATLANTICO • ANARAS HINDU UNIVERSITY • CALIFORNIA INSTITUTE OF TECHNOLOGY • COCHIN UNIVERSITY OF SCIENCE AND TECHNOLOGY • INSTITUTE OF PHYSICS, THE CZECH ACADEMY OF SCIENCES • CHARLES UNIVERSITY IN PRAGUE, FACULTY OF MATHEMATICS AND PHYSICS, INSTITUOTE FOR PARTICLE AND NUCLEAR PHYSICS • UNIVERSITY OF CINCINNATI • COLORADO STATE UNIVERSITY • CZECH TECHNICAL UNIVERSITY, FACULTY OF NUCLEAR SICENCES AND PHYSICAL ENGINEERING • UNIVERSITY OF DELHI • JOINT INSTITUTE FOR NUCLEAR RESEARCH, DUBNA • FERMILAB • UNIVERSIDADE FEDERAL de GOIAS • INDIAN INSTITUTE OF TECHNOLOGY, GUWAHATI • HARVARD UNIVERSITY • INDIAN INSTITUTE OF TECHNOLOGY, HYDERABAD • UNIVERSITY OF HYDERABAD • INDIANA UNIVERSITY • IOWA STATE UNIVERSITY • UNIVERSITY OF JAMMU • LEBEDEV PHYSICAL INST. • UNIVERSITY COLLEGE LONDON • MICHIGAN STATE UNIVERSITY • UNIVERSITY OF MINNESOTA - DULUTH • UNIVERSITY OF MINNESOTA • INSTITUTE FOR NUCLEAR RESEARCH, MOSCOW • PANJAB UNIVERSITY • UNIVERSITY OF SOUTH CAROLINA • SOUTH DAKOTA SCHOOL OF MINES AND TECHNOLOGY • SOUTHERN METHODIST UNIVERSITY • STANFORD UNIVERSITY • UNIVERSITY OF SUSSEX • UNIVERSITY OF TENNESSEE • UNIVERSITY OF TEXAS AT AUSTIN • TUFTS UNIVERSITY • UNIVERSITY OF VIRGINIA • WICHITA STATE UNIVERSITY • COLLEGE OF WILLIAM AND MARY • WINONA STATE UNIVERSITY

* institutions added in 2015

First results: $\nu_\mu \rightarrow \nu_e$ Appearance

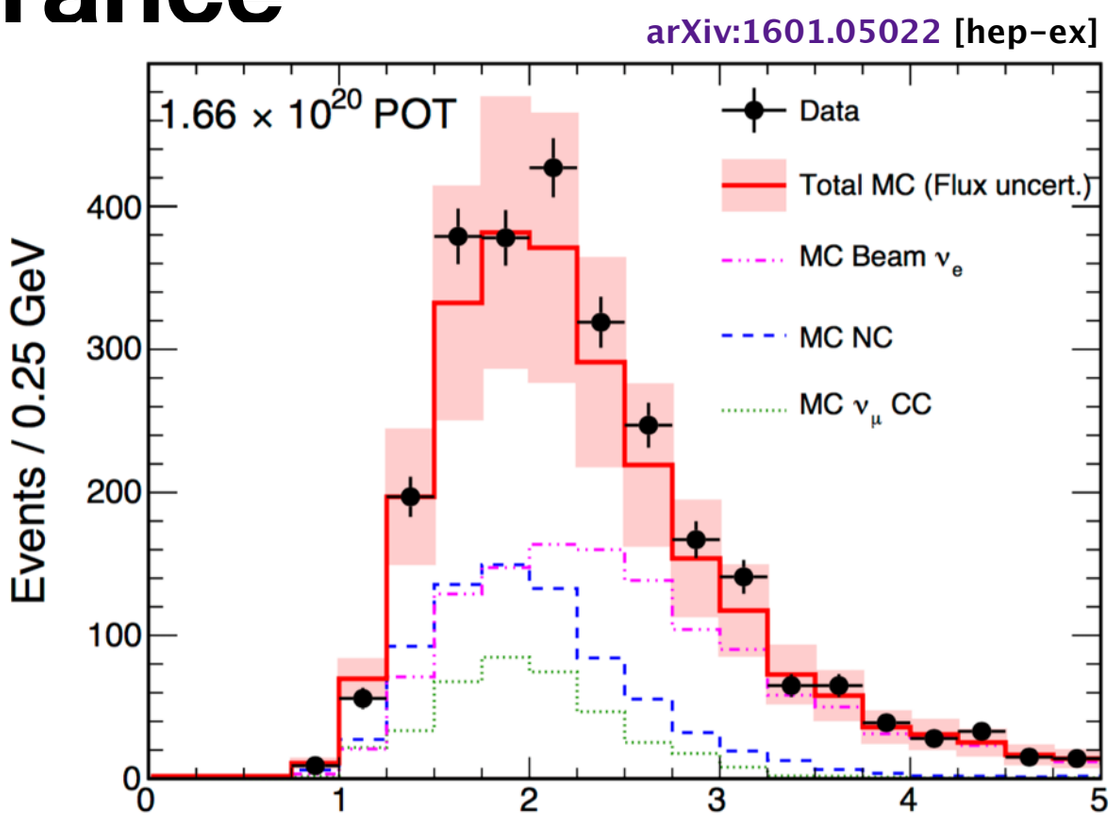
2.74E20 POT Equivalent
Data recorded through May 2015

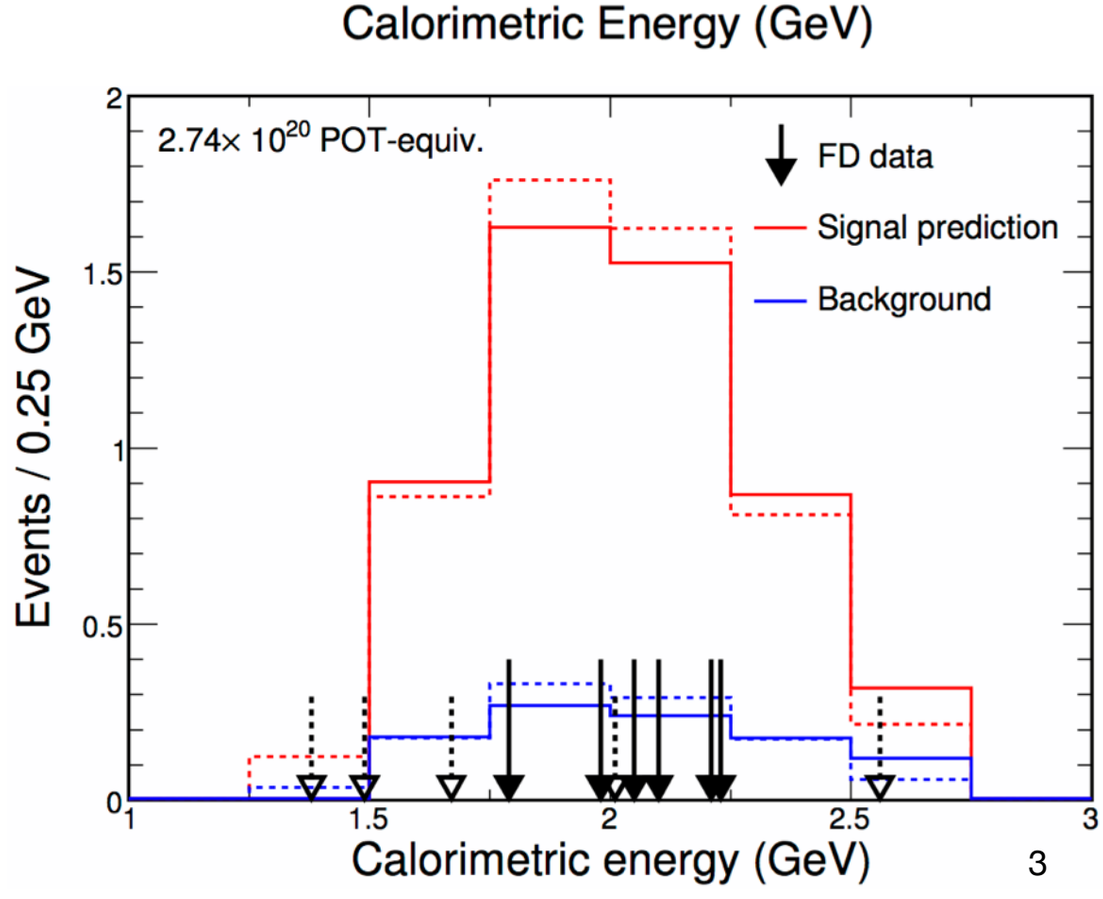
- First analysis using a new detector in a new beam running on surface: Decided to implement two independent particle IDs: “LID” and “LEM”

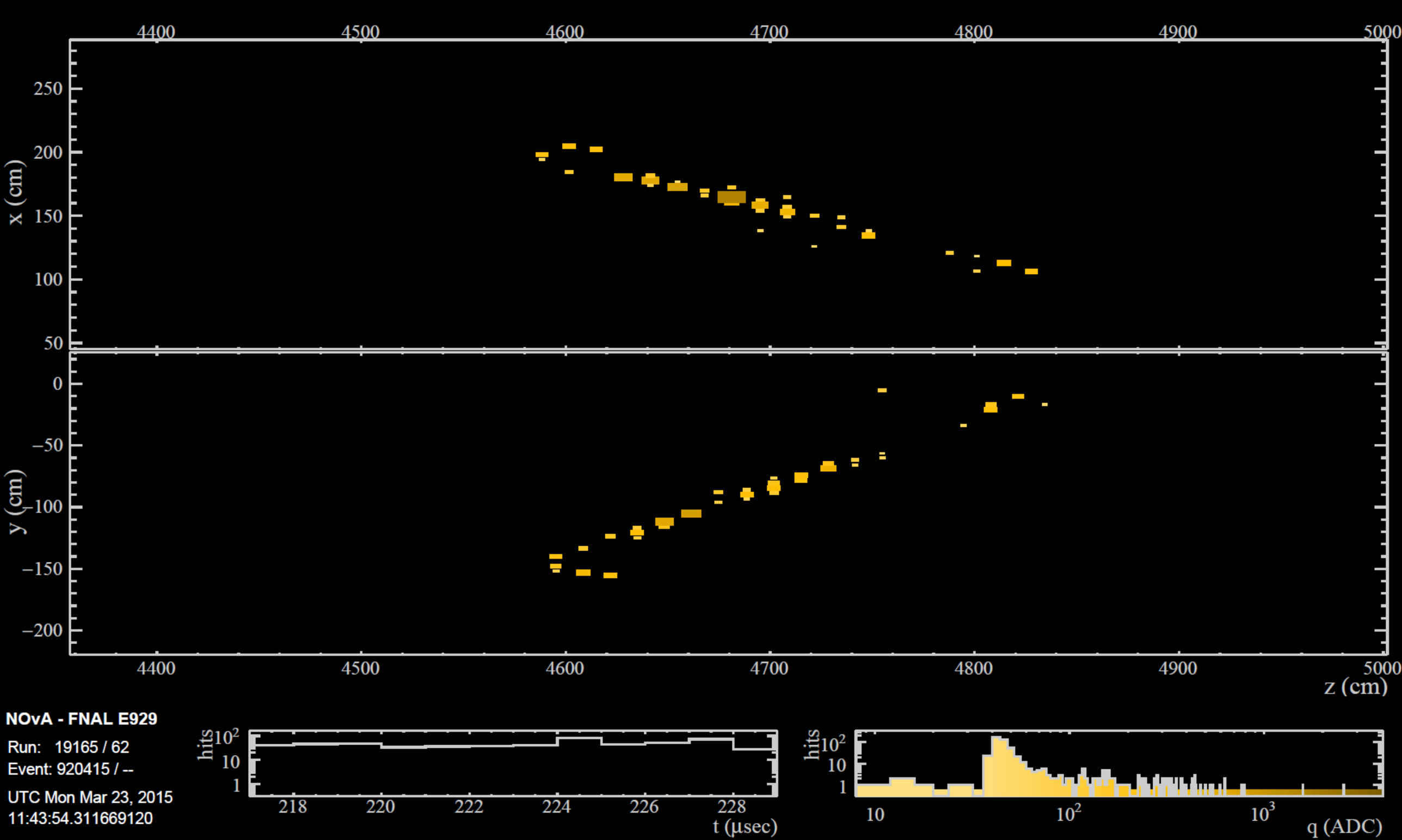
- These select **6 (LID)** and **11 (LEM)** events. All 6 of the LID events are selected by LEM. Expected **background is 1 event** for each. These are **3.3σ** and **5.5σ** significant excesses over background.

- LID and LEM have 62% overlap, determined from simulation and checked in NOvA near detector. The P-value for selecting the combination (11:6/5/0) is 7.8%.

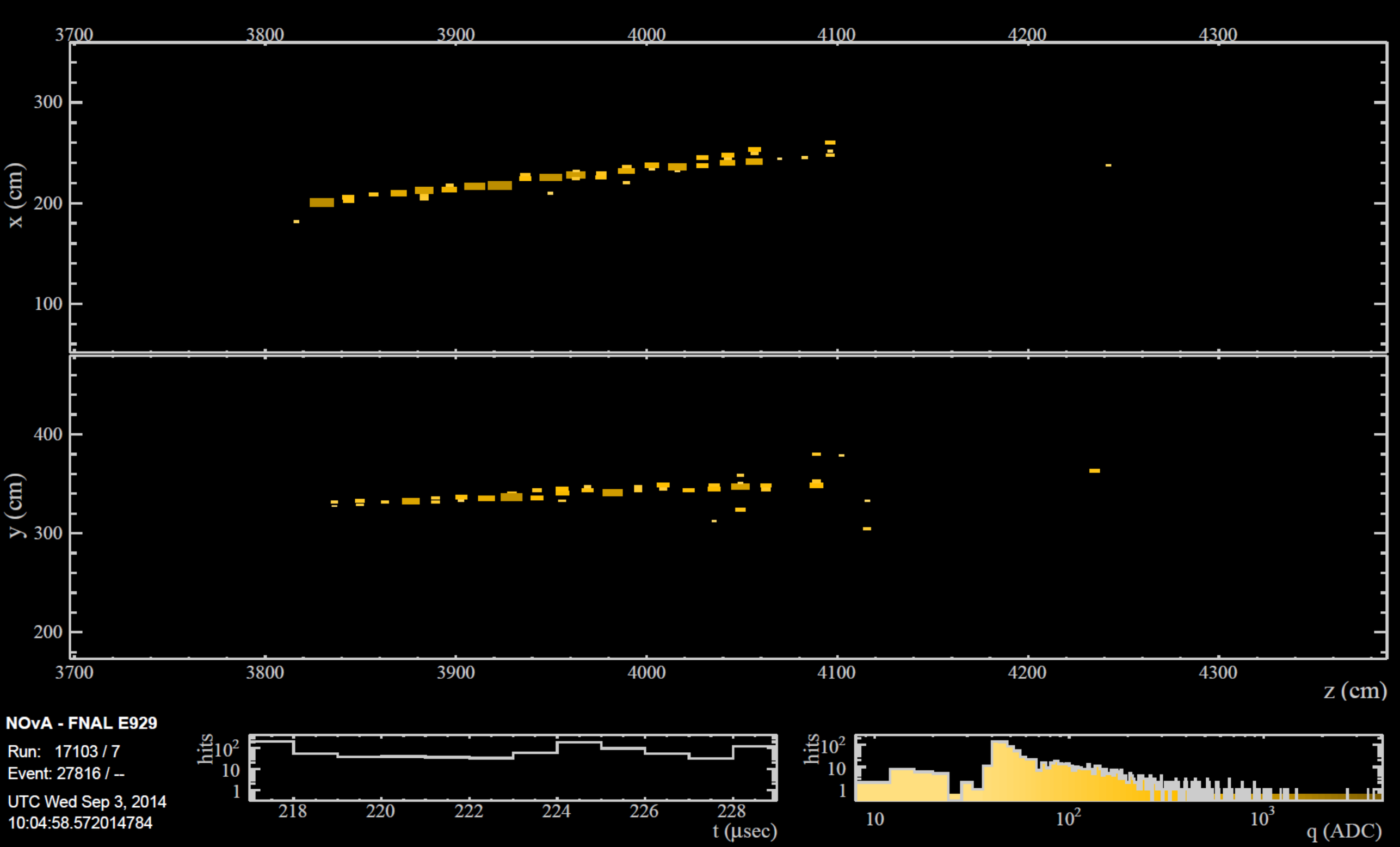
- Top plot shows the ND energy spectrum of e-like candidates. Bottom plot shows the energy spectrum of the 11 events. LID are in black, LEM in gray.







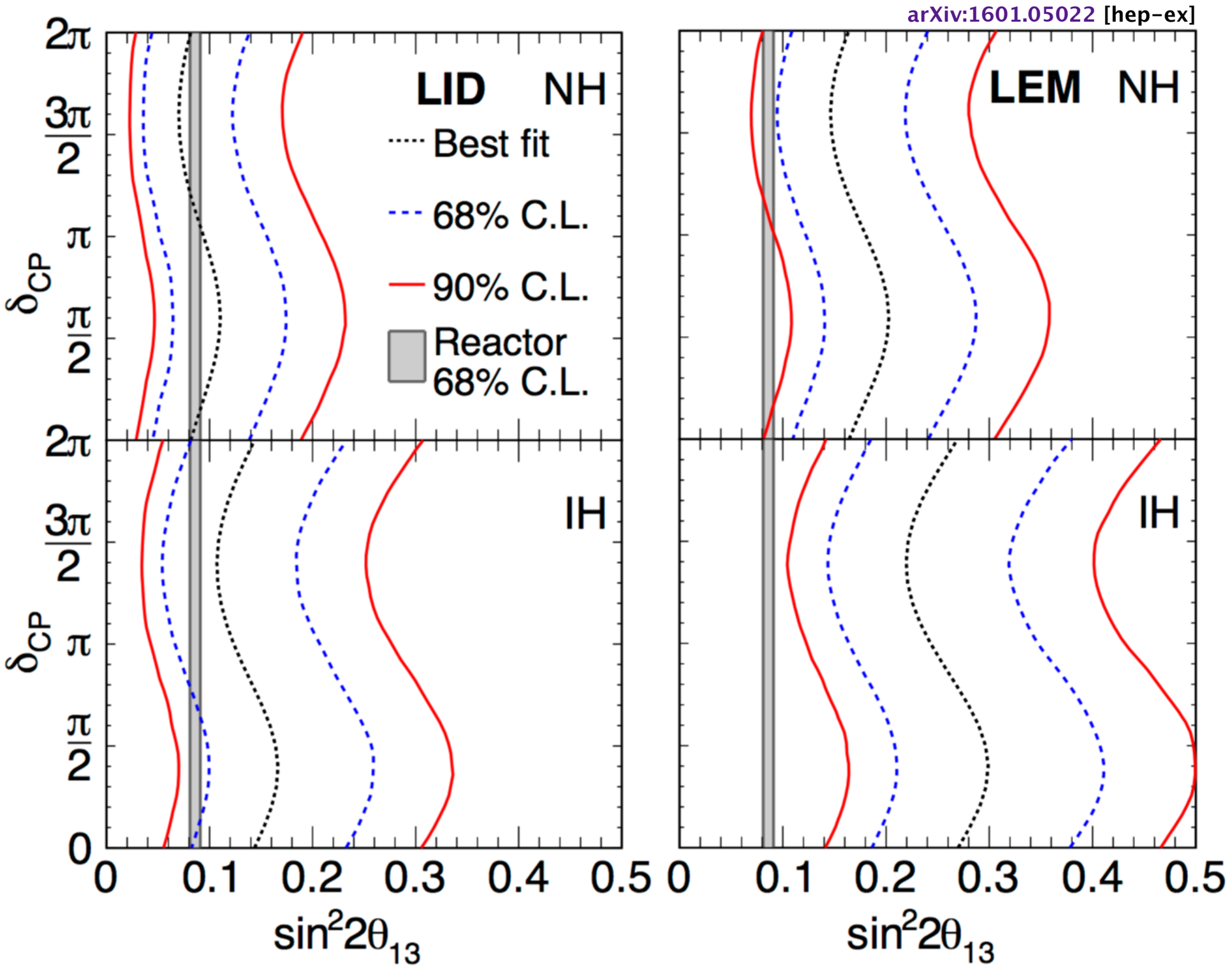
A NOvA ν_e Candidate



Another NOvA ν_e Candidate

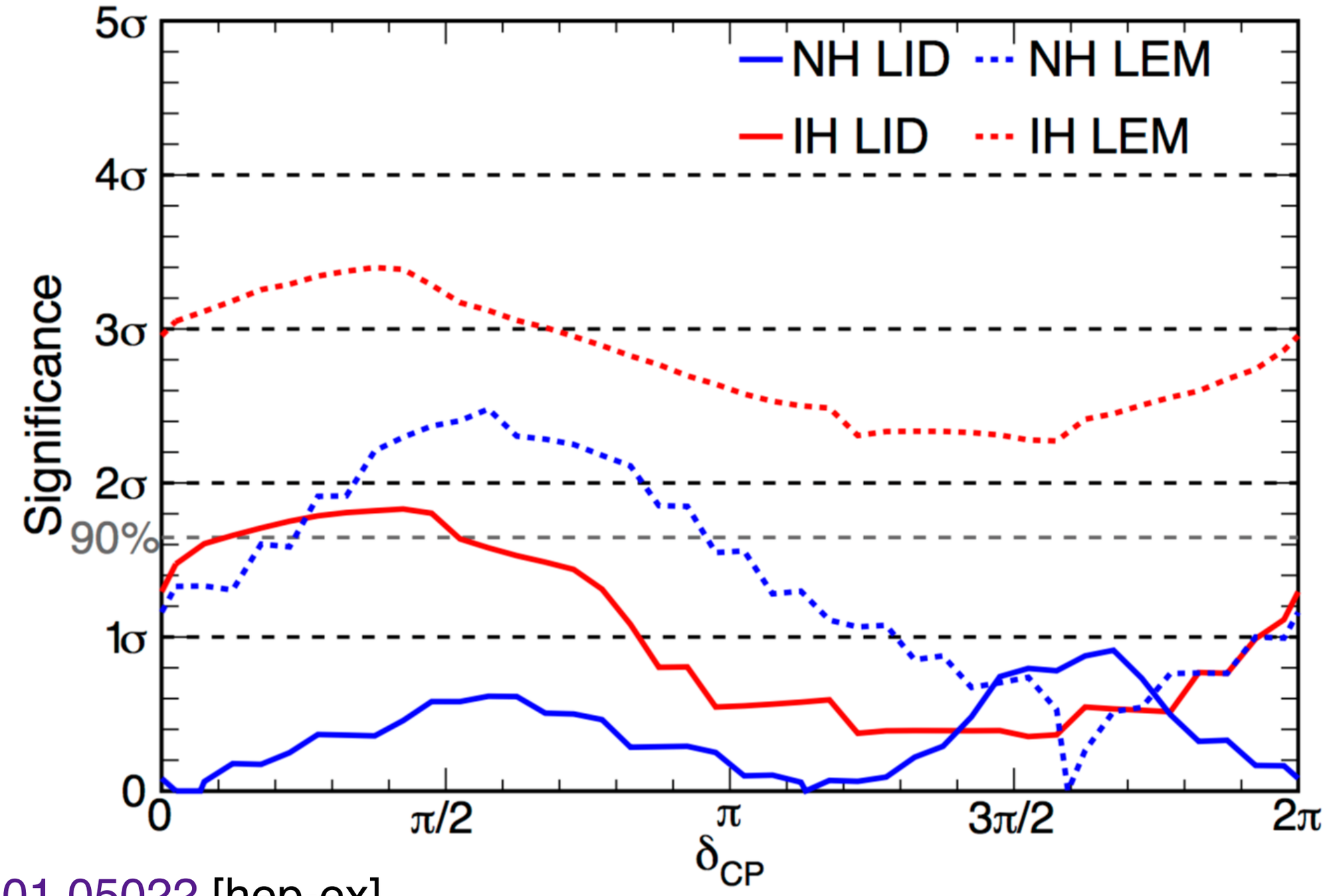
First results: $\nu_\mu \rightarrow \nu_e$ Appearance

2.74E20 POT Equivalent
Data recorded through May 2015

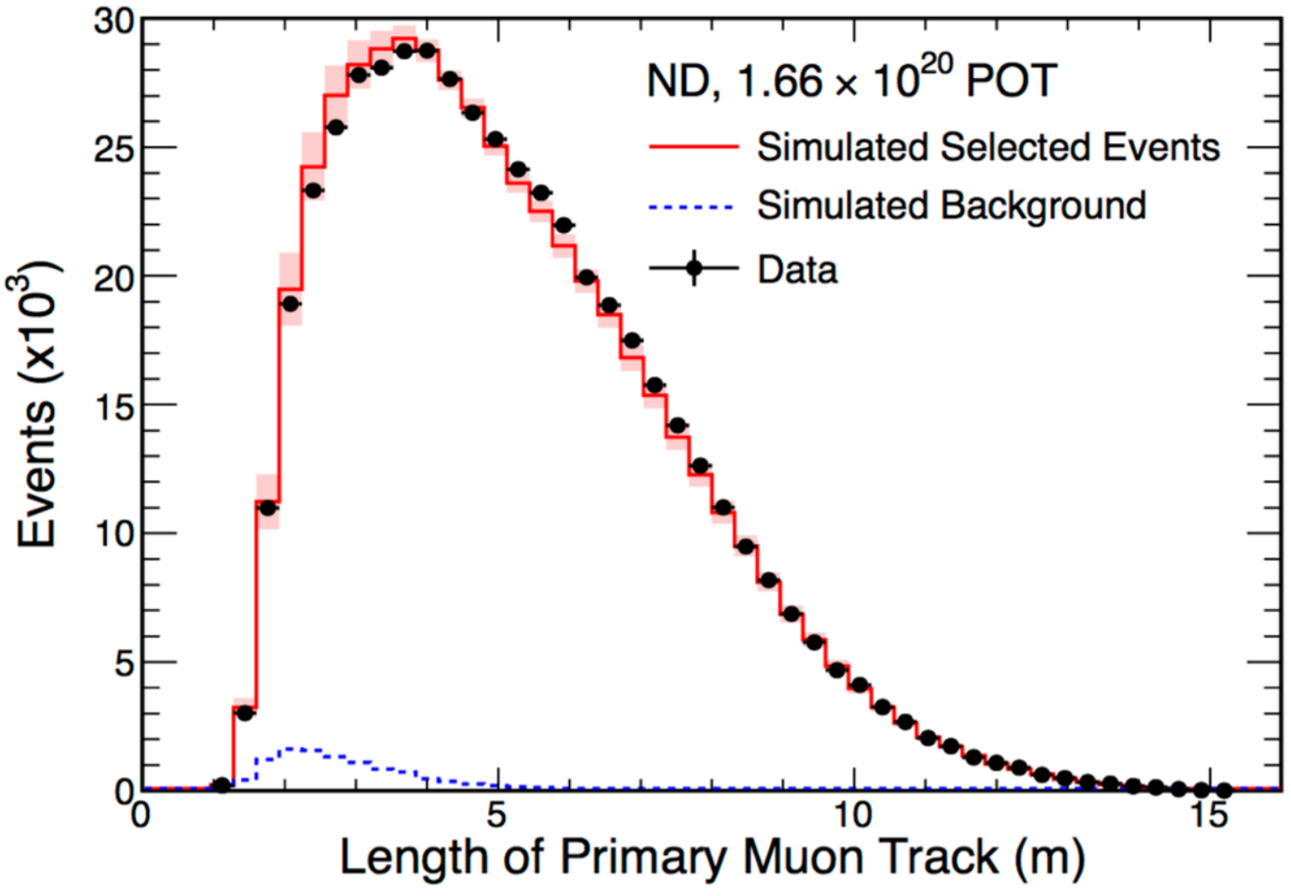


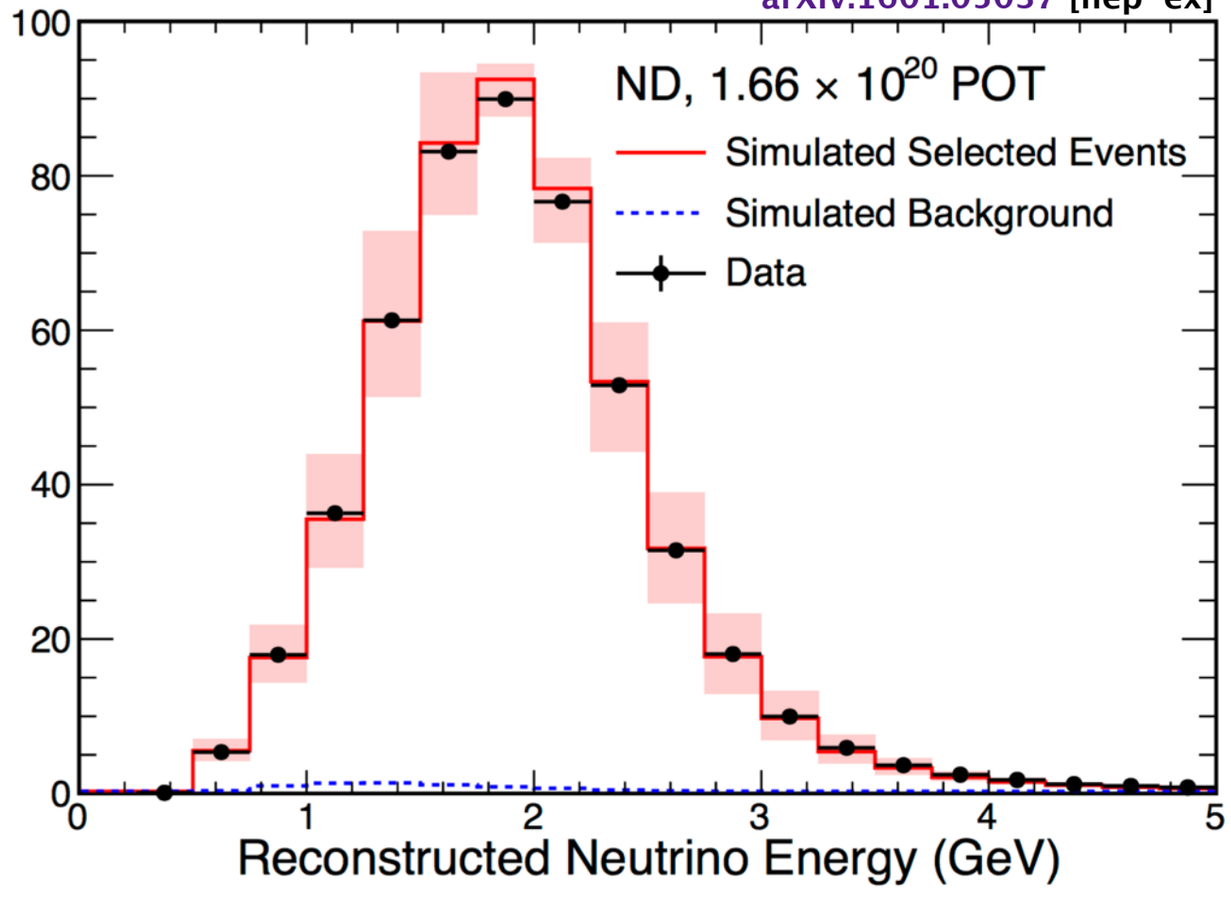
First results: $\nu_\mu \rightarrow \nu_e$ Appearance

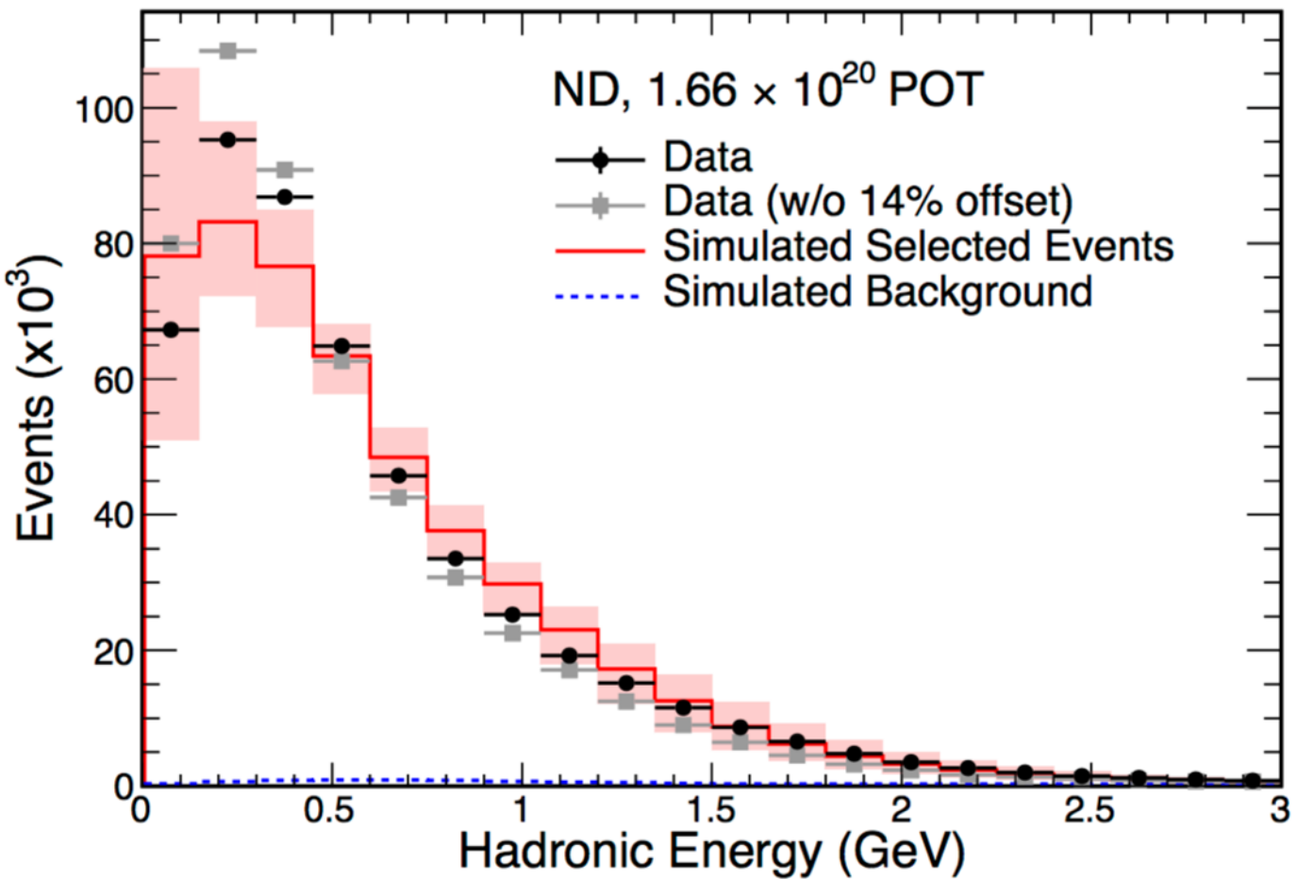
2.74E20 POT Equivalent
Data recorded through May 2015



arXiv:1601.05022 [hep-ex]
Submitted to Physical Review Letters





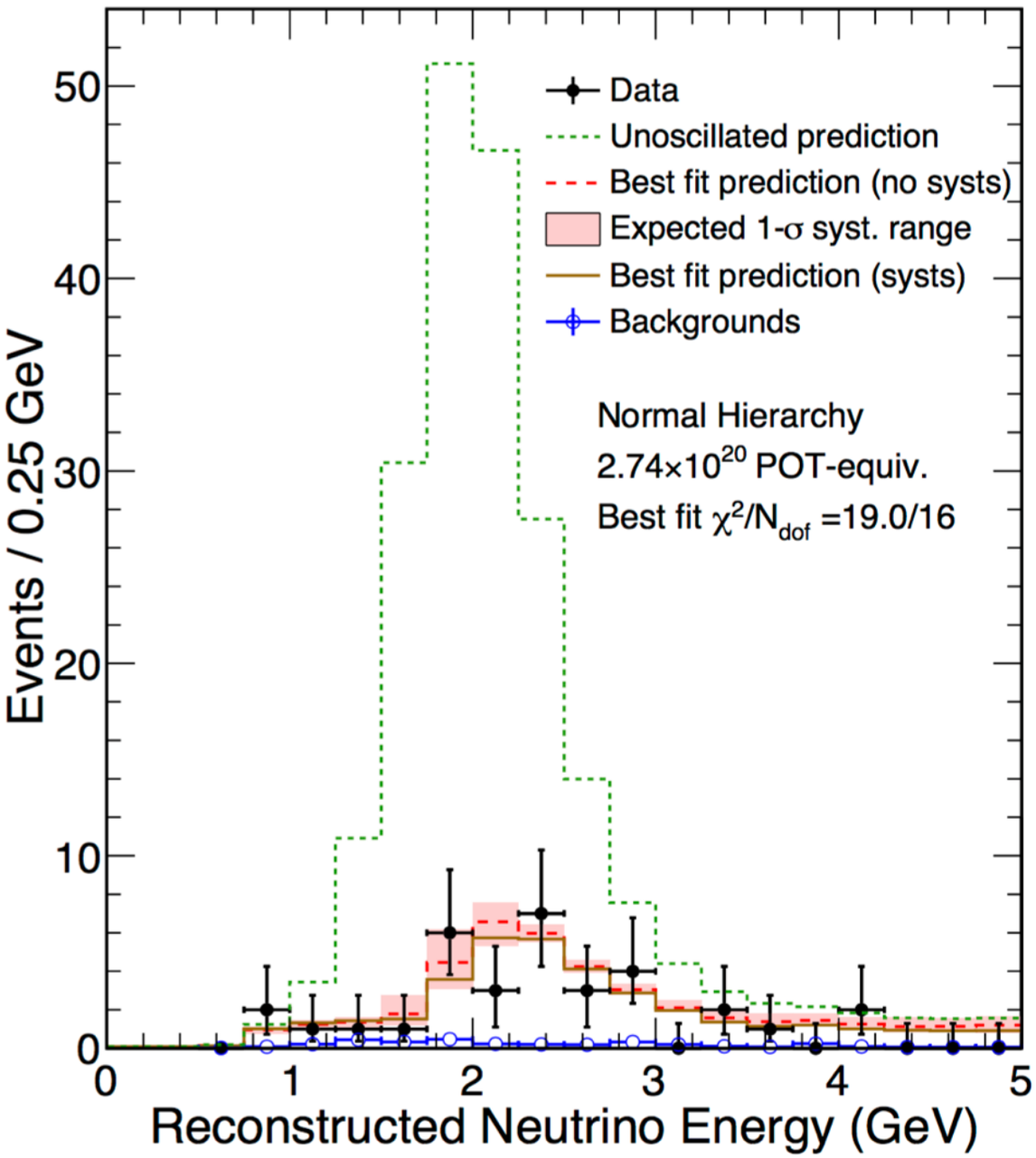


First results $\nu_\mu \rightarrow \nu_\mu$ Disappearance

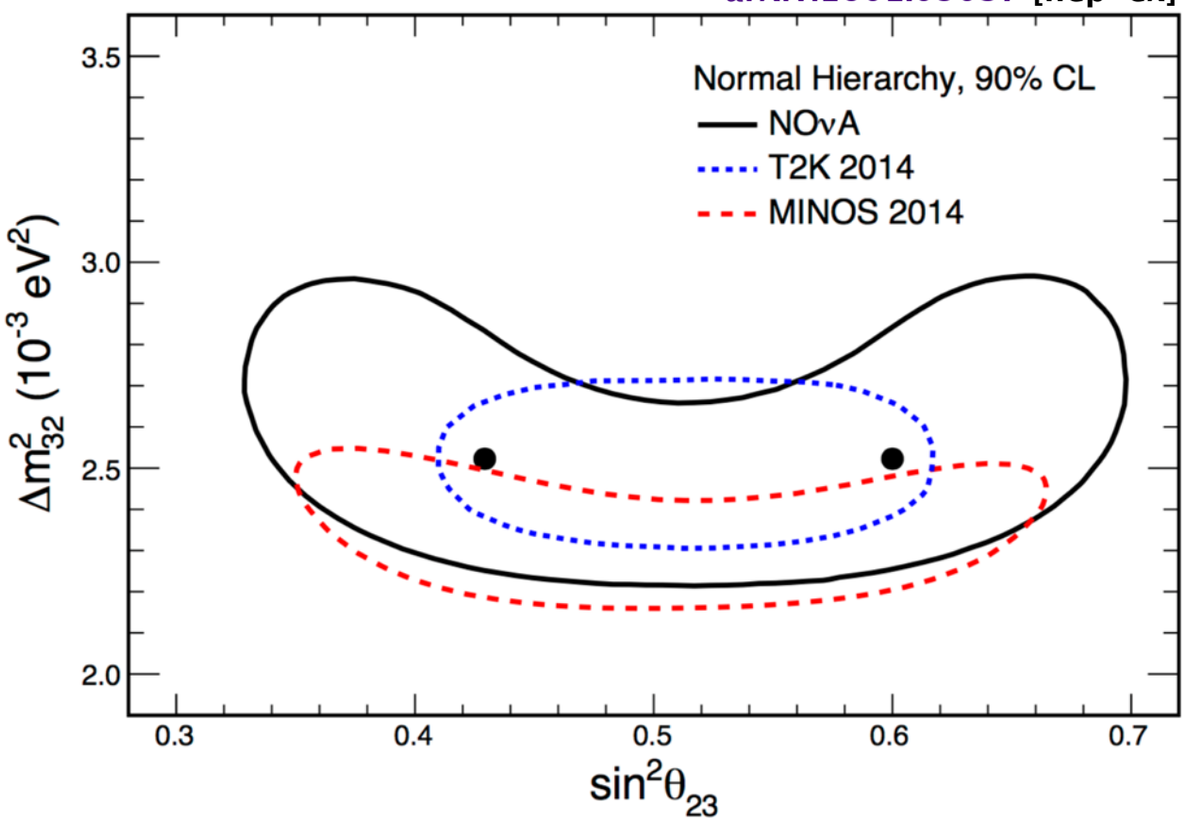
- top left: Muon path length in ND
- bottom left: Hadronic energy in ν_μ-CC events in ND
- top right: ν_μ-CC neutrino energy spectrum in ND

First results: $\nu_\mu \rightarrow \nu_\mu$ Disappearance

2.74E20 POT Equivalent
Data recorded through May 2015



arXiv:1601.05037 [hep-ex]



$$0.38 < \sin^2\theta_{23} < 0.65 \quad (68\%\ \text{C.L.})$$
$$\Delta m^2 = 2.52^{+0.20}_{-0.18}\ \text{meV}^2$$

arXiv:1601.05037 [hep-ex]
Submitted to Physical Review D, RC

Cross-section results presented at NuInt'15

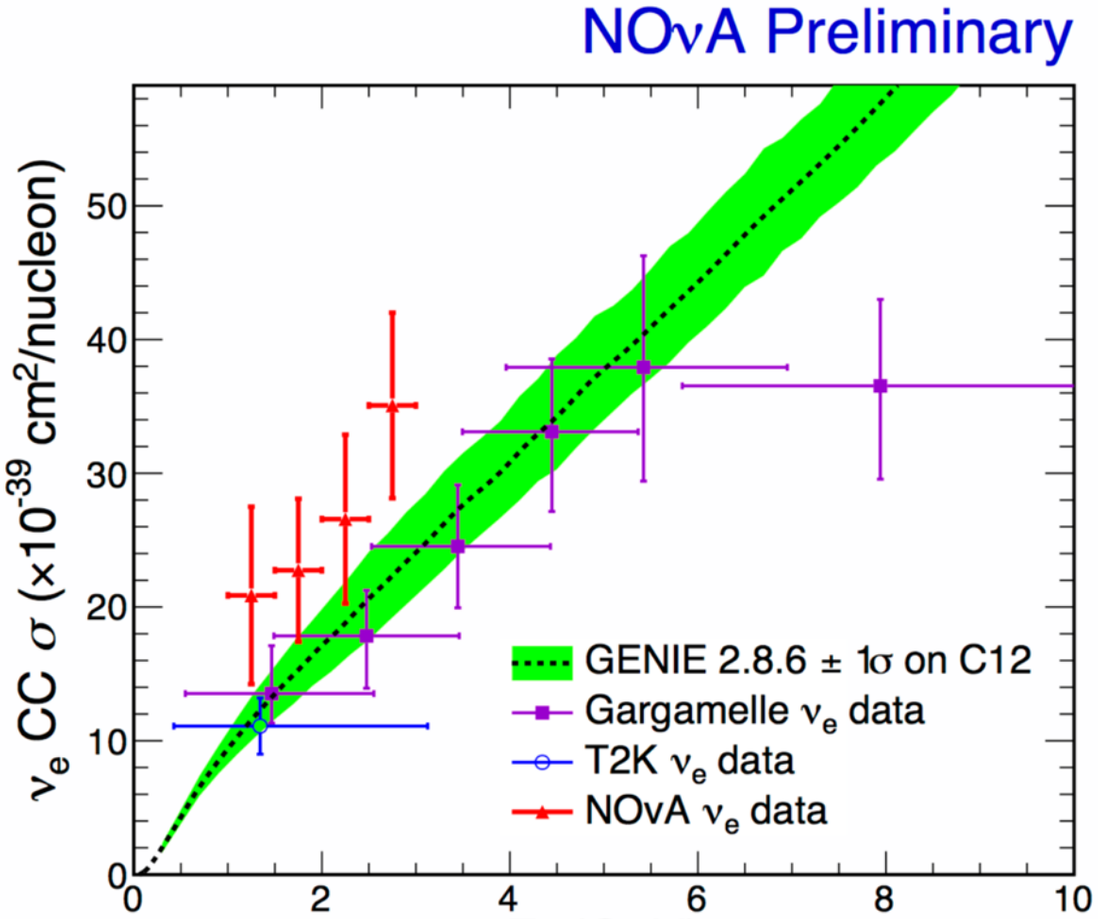
10th International Workshop on Neutrino-Nucleus Interactions in the Few-GeV Region (NuInt15)

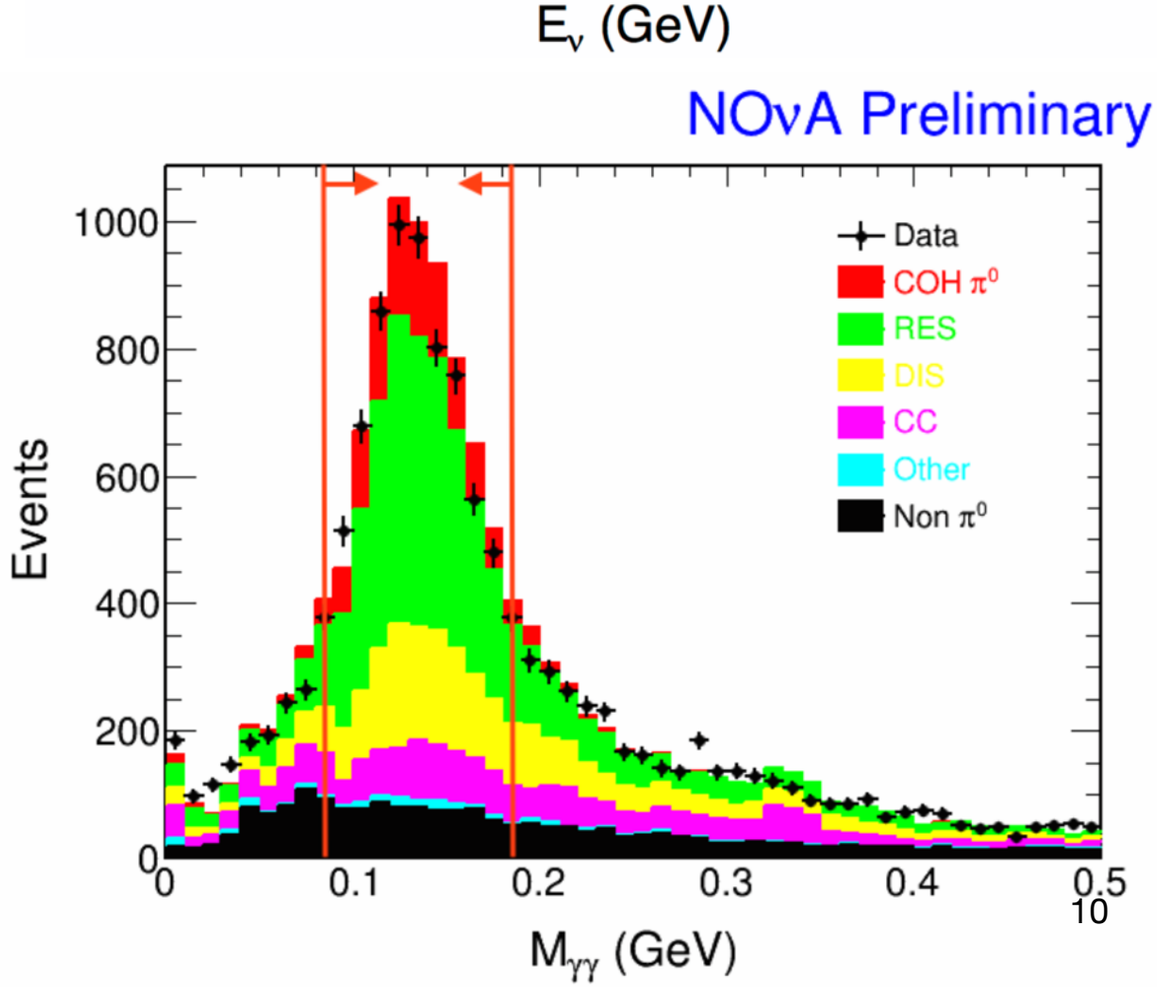
16-21 November 2015 *Icho-Kaikan, Osaka University Suita Campus*
Asia/Tokyo timezone

- Top: electron-neutrino inclusive cross-section presented by Xuebing Bu (Fermilab)

- Bottom: coherent π^0 production presented by Hongyue Duyang (U. South Carolina)

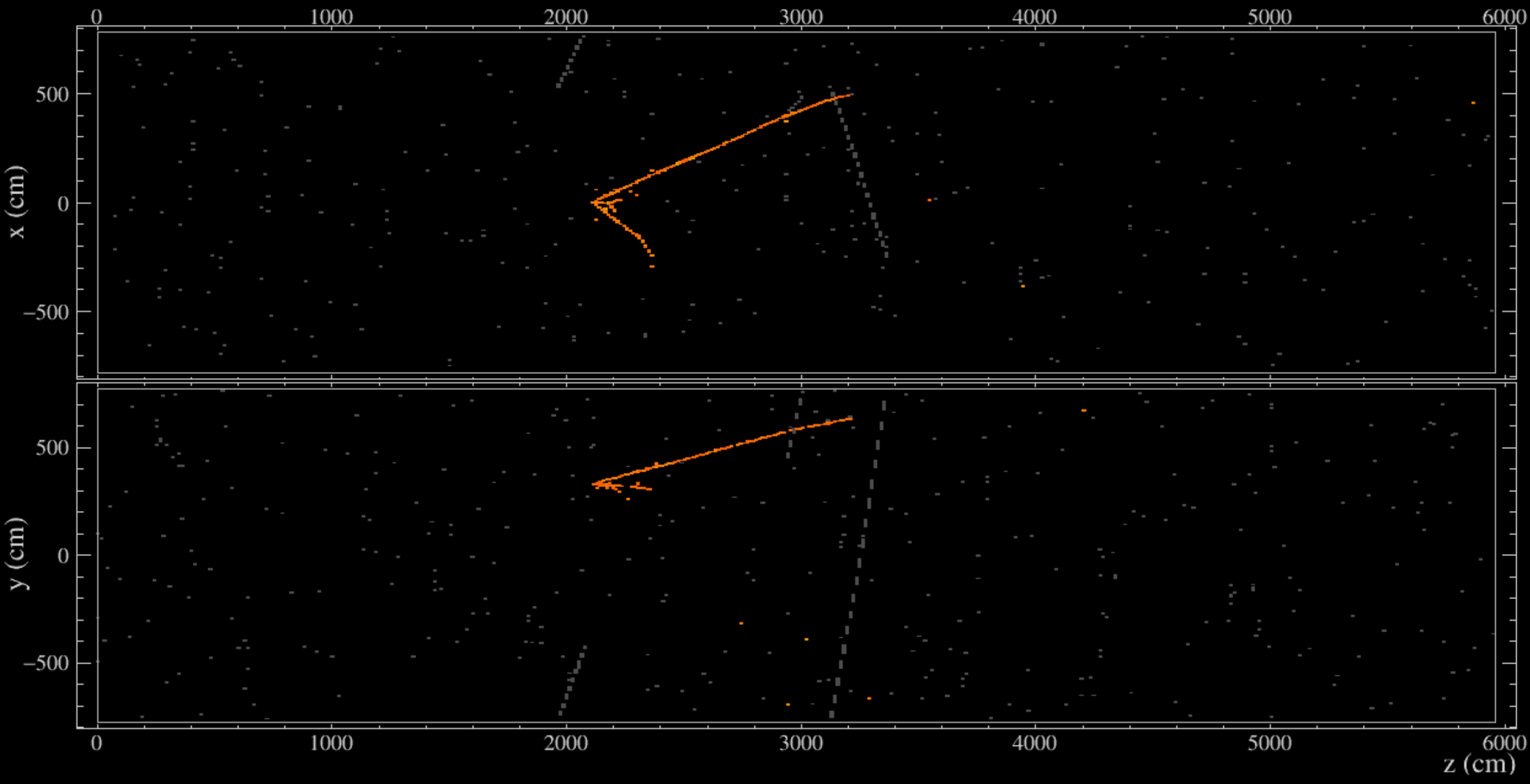
- Both results now in preparation for publication





NOvA Thesis Count

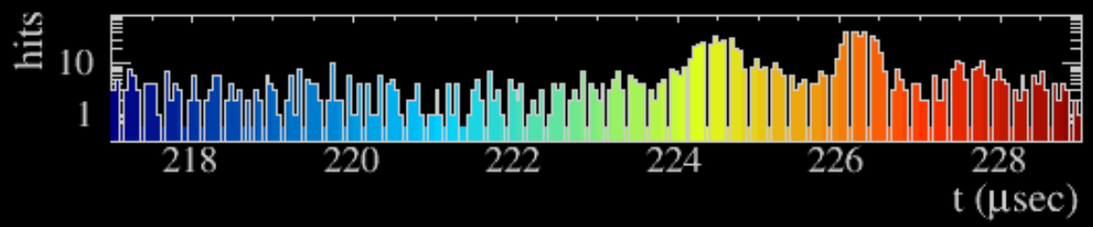
Roman	Klokov	7/7/15	BS	JINR	Selection of quasi elastic neutrino scattering events in the near detector of NOvA experiment
Timothy	Kutnik	1/7/13	MS	ISU	Detector response calibration for the NOvA quasi-elastic cross-section measurement
Lyudmila	Kolupaeva	6/1/15	MS	INR	Optimization of long baseline accelerator neutrino experiment sensitivity for measuring neutrino mass hierarchy
Fernanda	Psihas	7/15/13	MS	UM,D	Muon Energy Reconstruction Through the Multiple Scattering Method in the NOvA Detectors.
Dmitry	Rodkin	7/2/15	MS	INR	Estimation of the rate of nu_e signal and background events in NOvA experiment
Marco	Del Tutto	10/27/15	MS	SUR	Neutrino Beam Simulations and Data Checks for the NOvA Experiment
Minerba	Betancourt	6/7/13	PhD	UM	Study of Quasi-Elastic Scattering in the NOvA Detector Prototype
Enrique	Arrieta Diaz	11/11/14	PhD	MSU	Observation of Muon Neutrino Charged Current Events in an Off-Axis Horn-Focused Neutrino Beam Using the NOvA Prototype Detector
Eric	Flumerfelt	7/15/15	PhD	UT	DAQ Software Contributions, Absolute Scale Energy Calibration and Background Evaluation for the NOvA Experiment at Fermilab
Zukai	Wang	7/24/15	PhD	UVA	Search for Magnetic Monopoles with the NOvA Far Detector
Evan	Niner	8/10/15	PhD	IU	Observation of Electron Neutrino Appearance in the NuMI Beam with the NOvA Experiment
Susan	Lein	8/11/15	PhD	UM	Muon Neutrino Contained Disappearance in NOvA
Michael	Baird	8/14/15	PhD	IU	An Analysis of Muon Neutrino Disappearance from the NuMI Beam Using an Optimal Track Fitter
Kanika	Sachdev	8/21/15	PhD	UM	Muon Neutrino To Electron Neutrino Oscillation in NOvA
Philip	Mason	8/21/15	PhD	UT	Search for the Forbush Decrease in NOvA Cosmic Rays

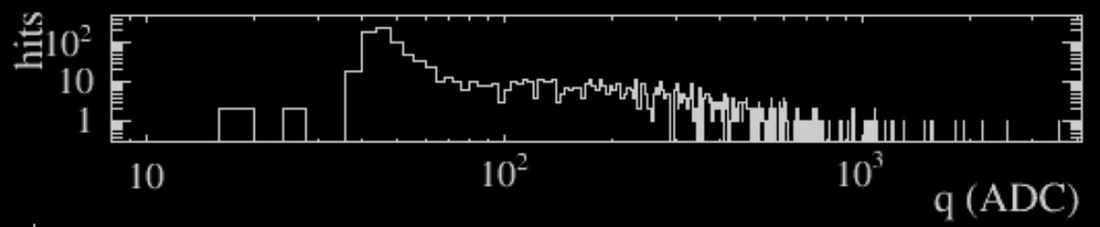


NOvA - FNAL E929

Run: 20948 / 45
Event: 908922 / --

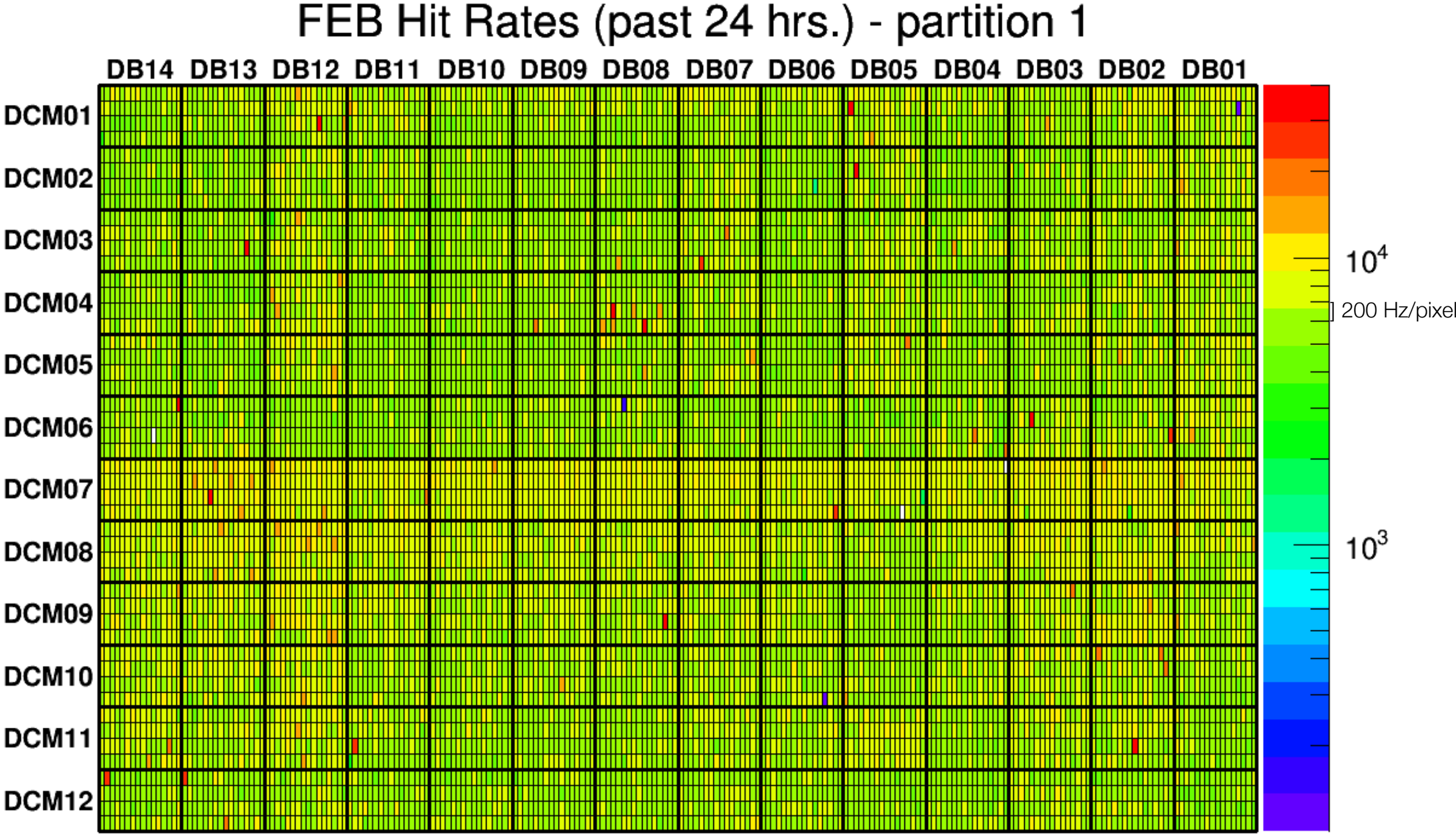
UTC Mon Oct 26, 2015
08:37:28.496535232





NOvA Far Detector

First event of the FY2016 Run



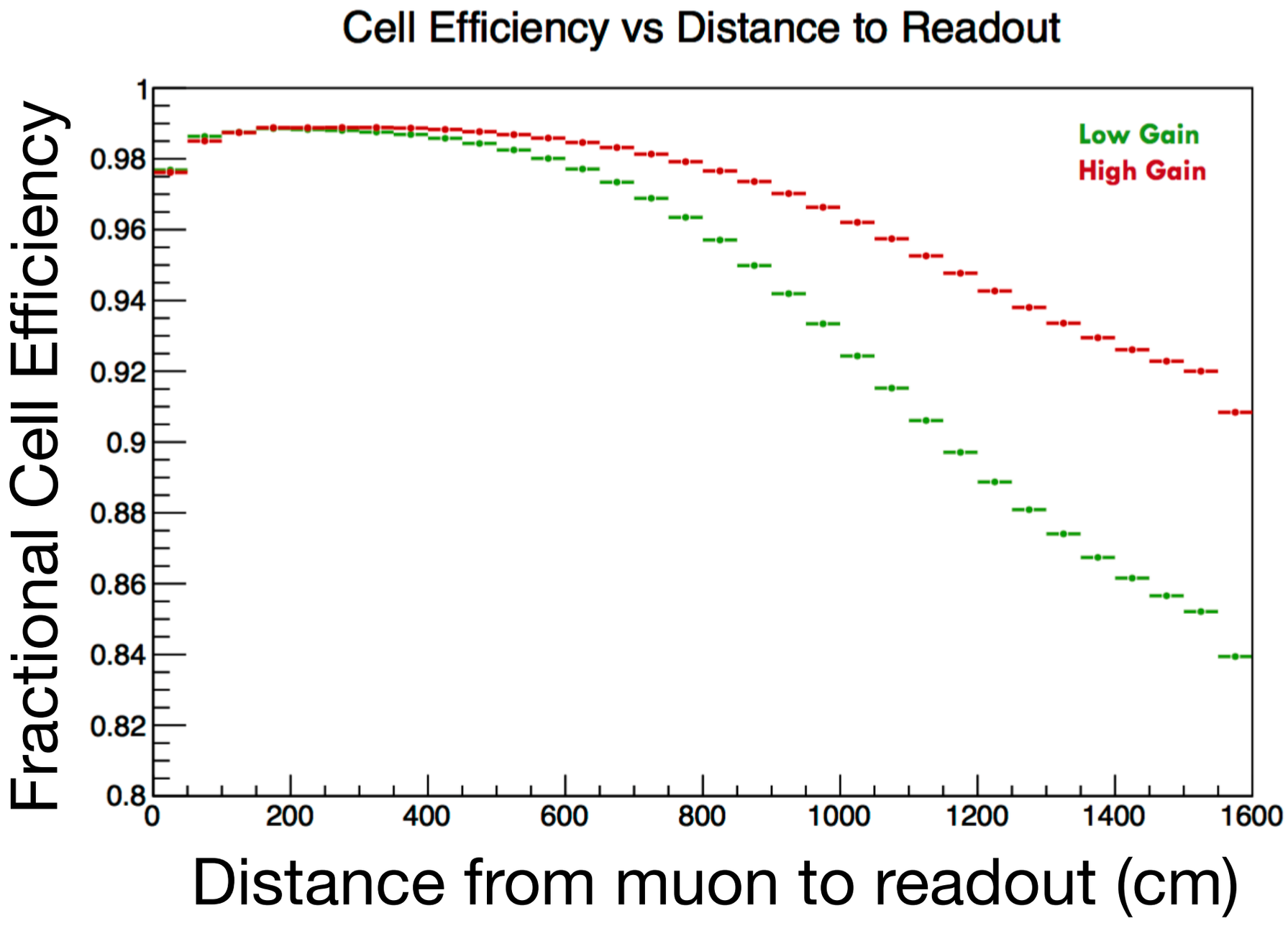
Far Detector Status

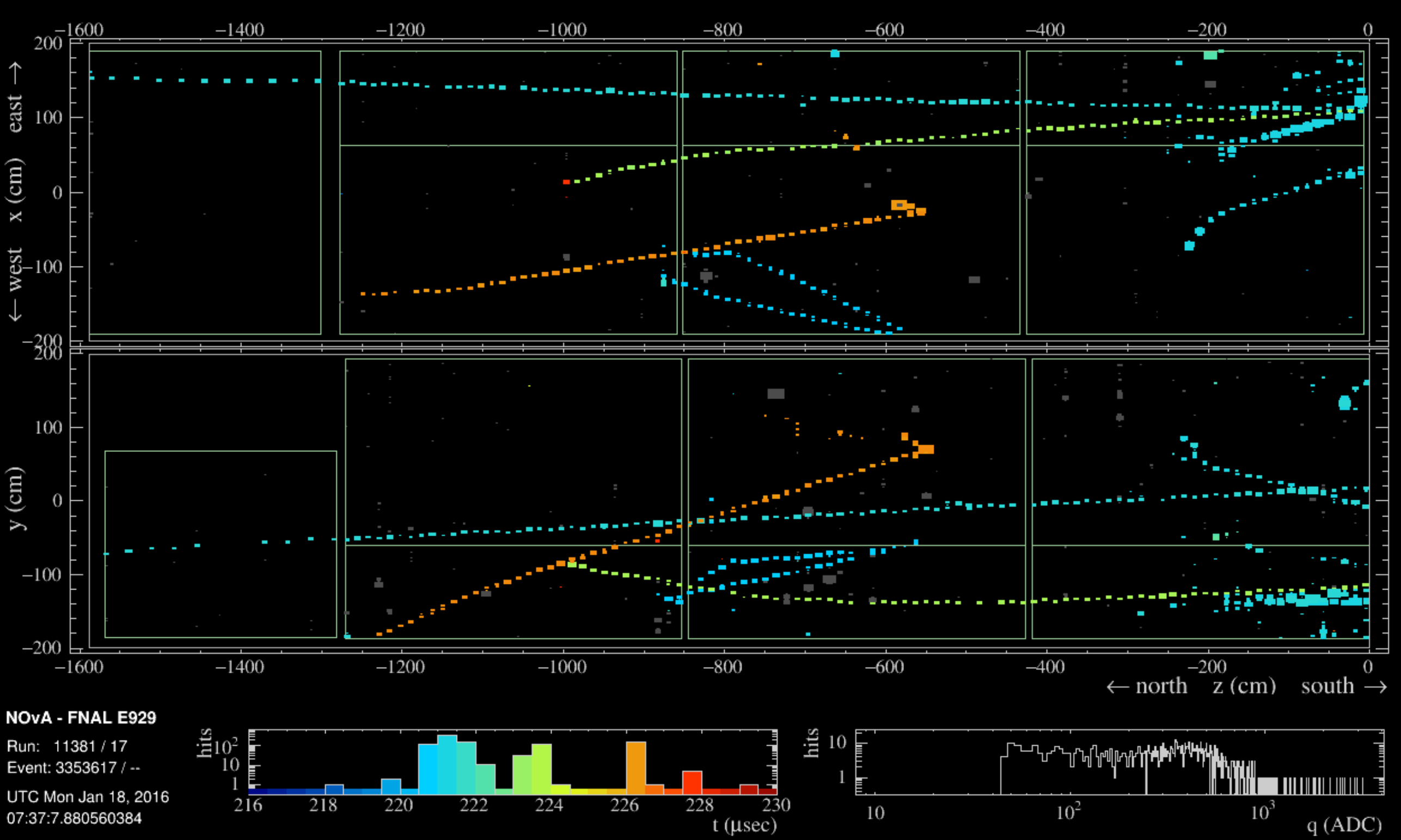
- After summer maintenance, 99.9% of channels operational
- Running with 94% uptime. Contributions to our DAQ from FNAL Scientific Computing Division have been much appreciated.

Far Detector Status

- Took advantage of lower-than-spec APD noise to run far detector at higher gain (100→150)

- Tracking efficiency up from 85% to 92% at far end of 15.5 m long cells





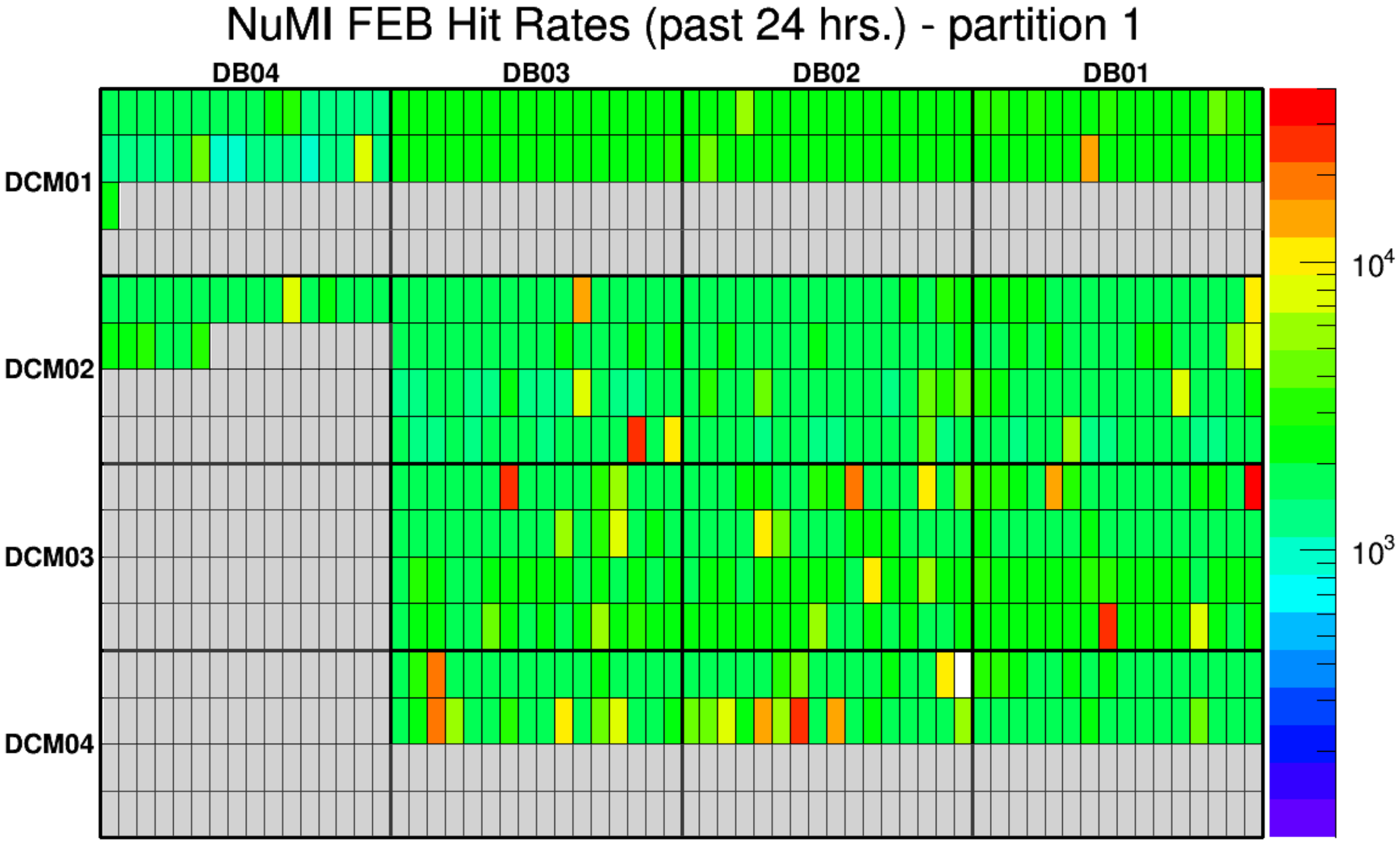
NOvA - FNAL E929

Run: 11381 / 17
Event: 3353617 / --

UTC Mon Jan 18, 2016
07:37:7.880560384

NOvA Near Detector

Pulled from live event stream
http://nusoft.fnal.gov/nova/public/



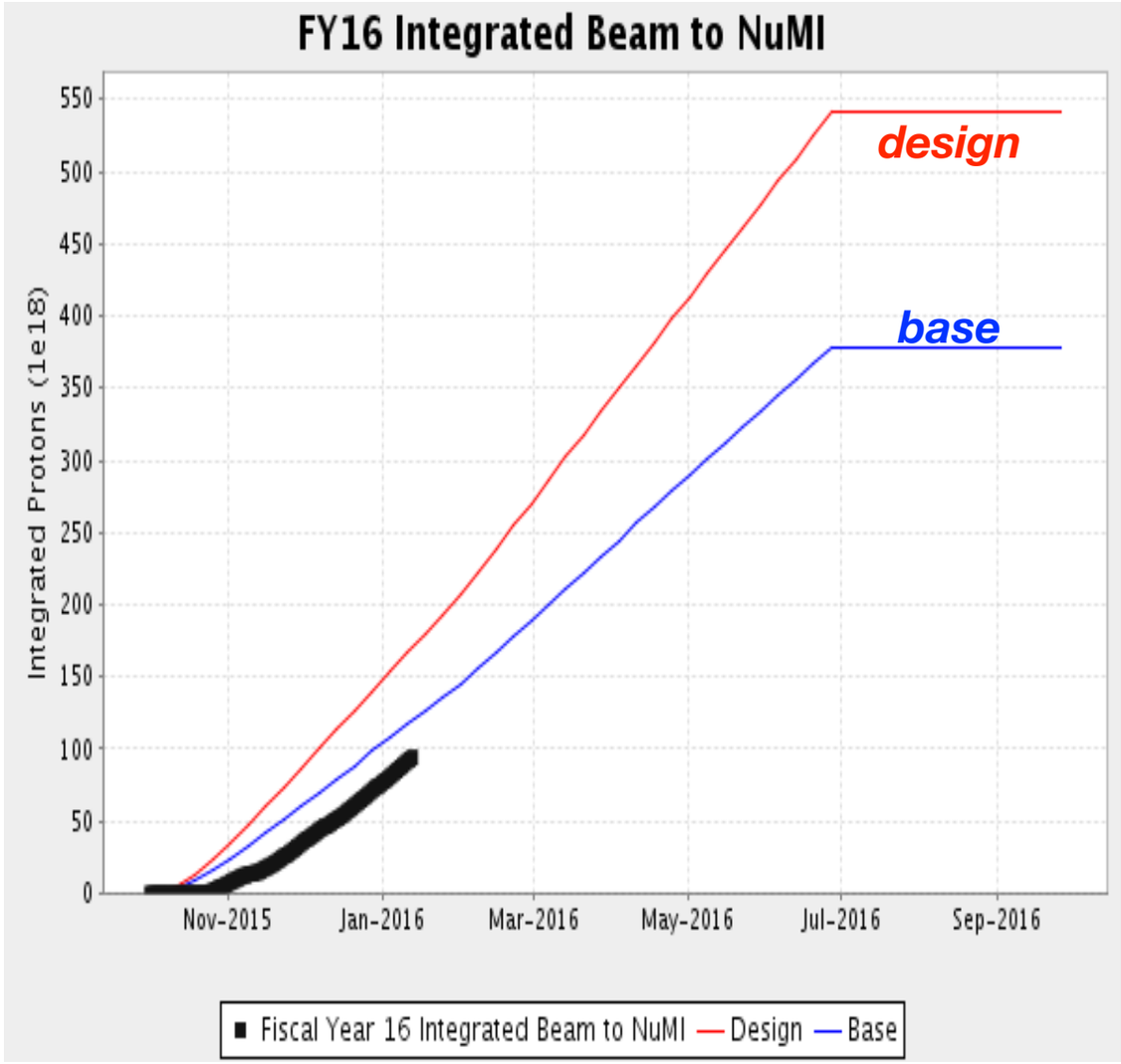
Near Detector Status

99.8% of channels operational

Running with >99% uptime

FY16 beam delivery

- Delivered 94E18 POT through Jan. 17, 2016. Design: 156E18, Base 111E18
- Below base due to 3 week delay in start of run and numerous equipment problems which delayed establishment of 4+6 slip stacking
- Routine 4+6 Slip Stacking started on January 14, 2016
- Running at 425 kW when running concurrently with slow spill (470 kW when slow spill is off)
- Planned ramp to ~470 kW (525 kW) into February
- Improved slope should bring delivered beam above base. Further improvements to power possible in spring.
- Goal is to establish 700 kW operation with 6+6 slip stacking for at least one hour this year
- **Consistent operations at 700 kW requires work during next shutdown:**
  - **Complete installations of vacuum ion-pumps in remaining sections of Recycler Ring (1/3 this year, 1/3 next year)**
  - ***Construction and installations of collimators in Recycler Ring***
  - **We would like this work to be a high priority**



Strategy to decide when to start antineutrino run

- NOvA needs antineutrinos to complete its physics program

- Super-Kamiokande atmospheric neutrinos, T2K+Daya Bay, and NOvA+Daya Bay all hint towards normal hierarchy and δ_{CP} near **3π/2**. This is a special "best case" point for NOvA.

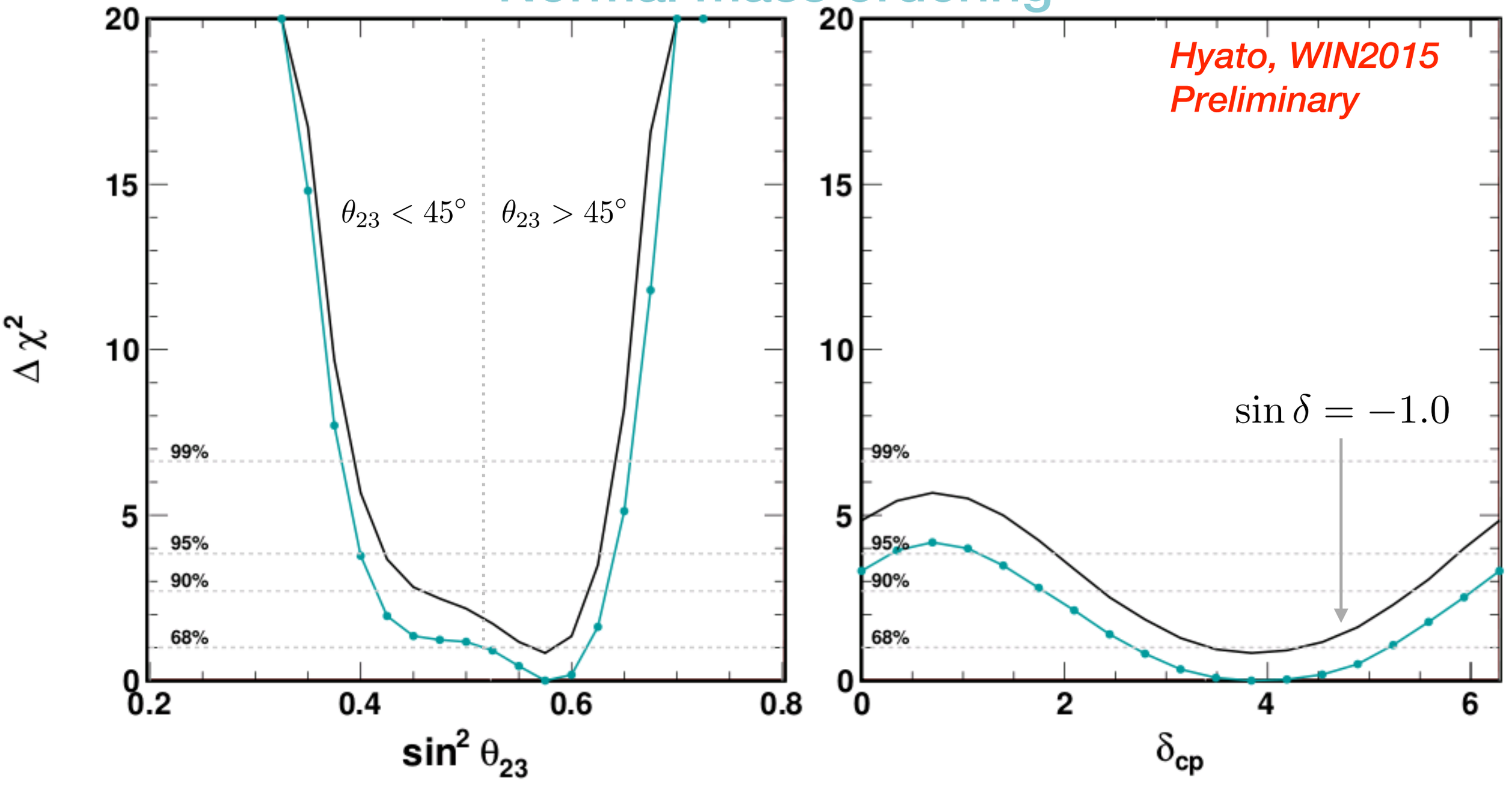
- At Neutrino 2016 there will be important updates from T2K (antineutrinos) and NOvA (2x more data than first results with neutrinos).

- Excesses seen in neutrinos should imply a very strong suppression of the antineutrino rate: -22% from CP phase, -20% from matter effect (hierarchy) in NOvA.

- We are likely to request through Program Planning ~2 weeks of antineutrino running this year to verify ν_e backgrounds in the near detector and collect data on hadronic energy distributions.

Inverted mass ordering

Normal mass ordering

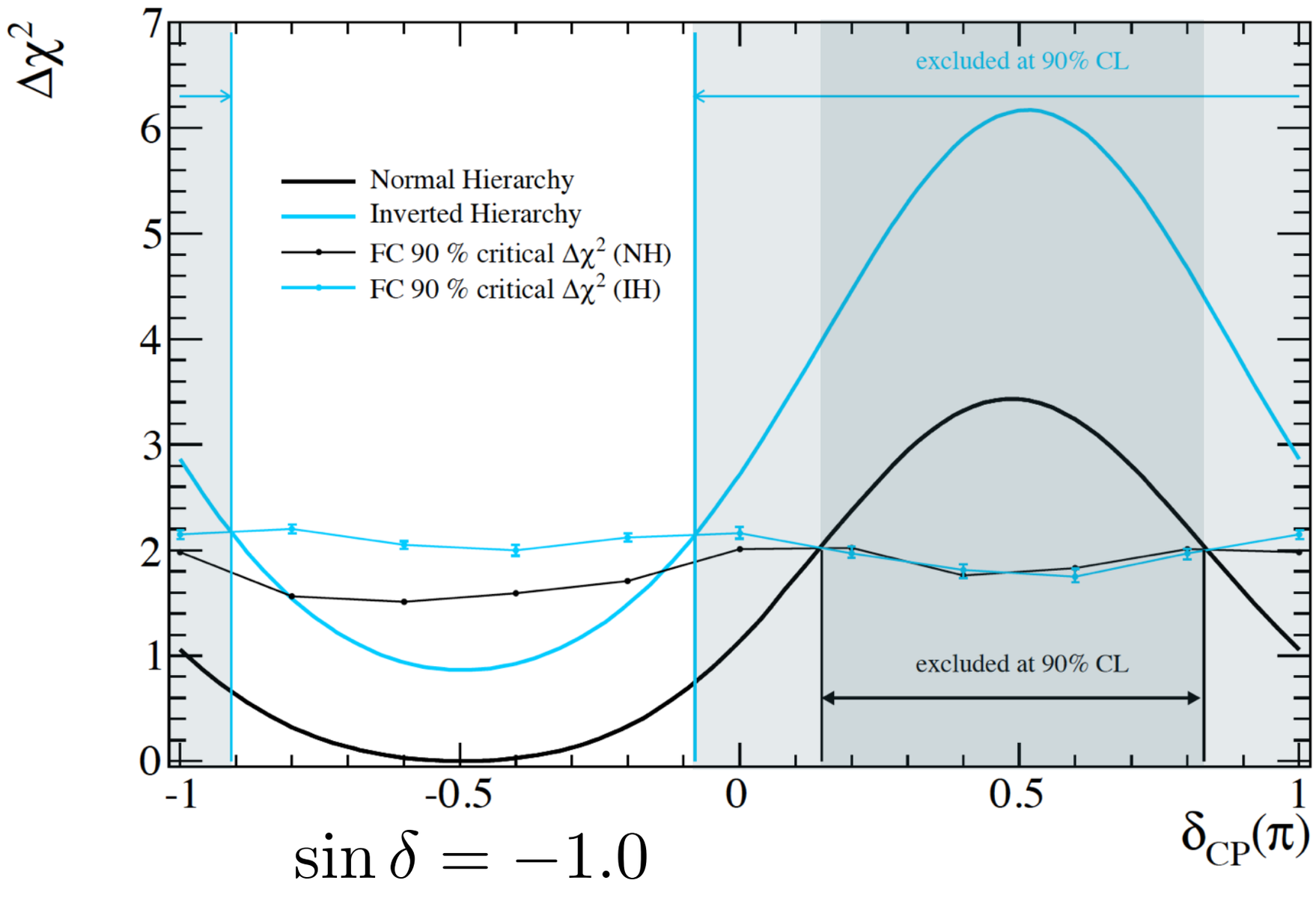


Super-Kamiokande Atmospheric Neutrinos

~1 sigma preference for

- normal mass ordering
- $\theta_{23}>45°$
- $\pi<\delta_{CP}<2\pi$

Combining T2K with Reactors

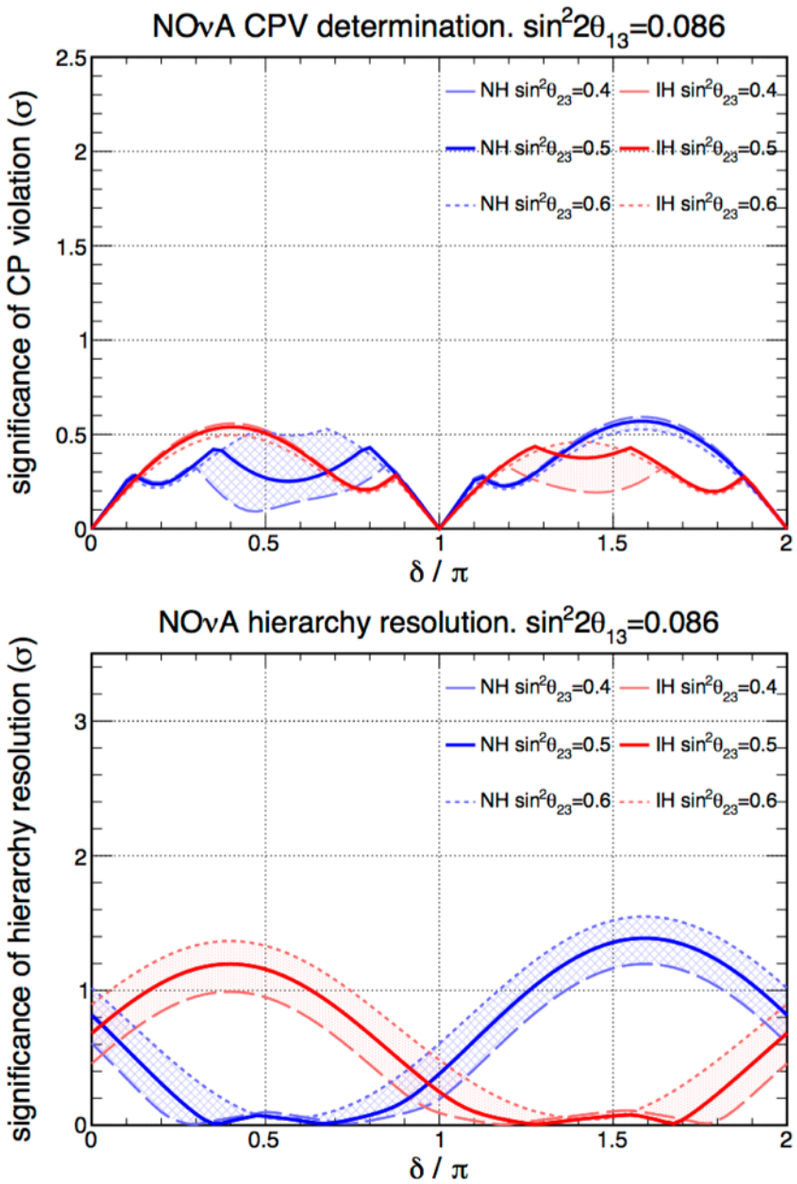


The tension with reactors gives some early sensitivity to δ_{CP}
T2K data prefers the normal hierarchy with $\delta_{CP}<0$ at ~90% C.L.

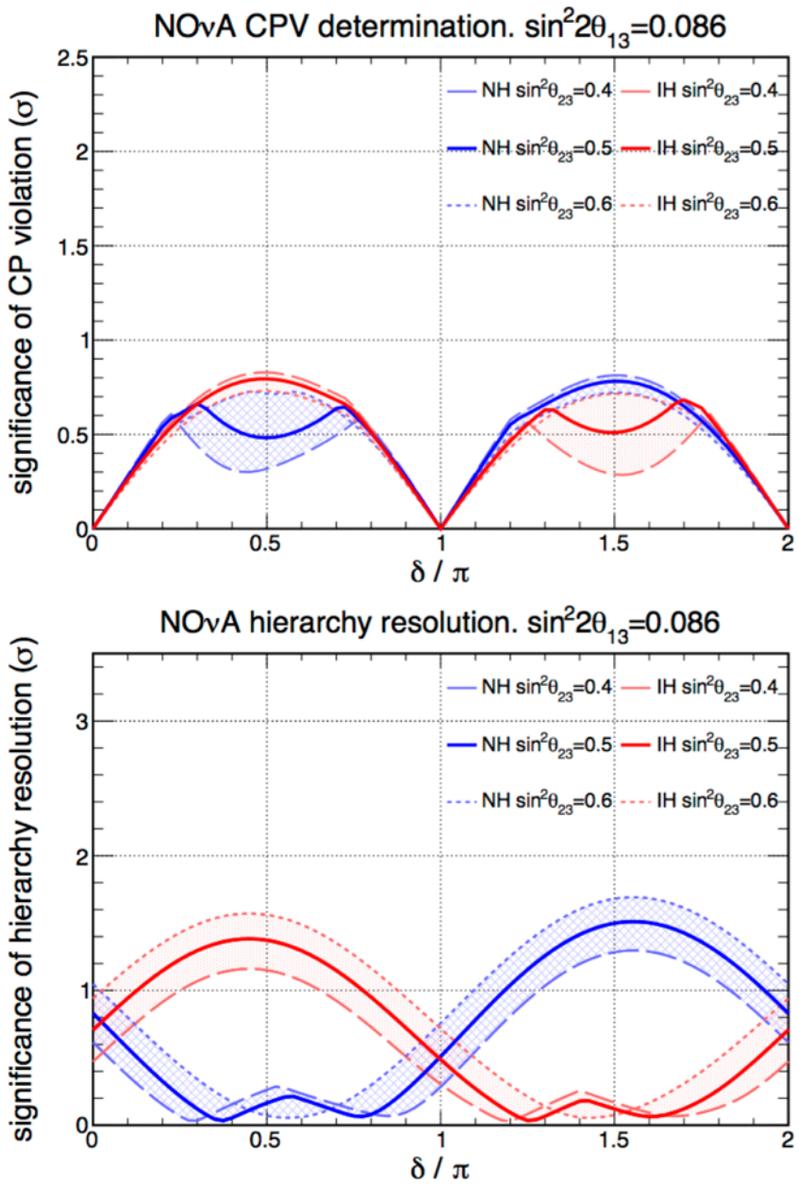
Hierarchy (bottom) and CPV (top) sensitivity for

(A) Data set end this year (B) Next year in antineutrinos (C) Next year in neutrinos

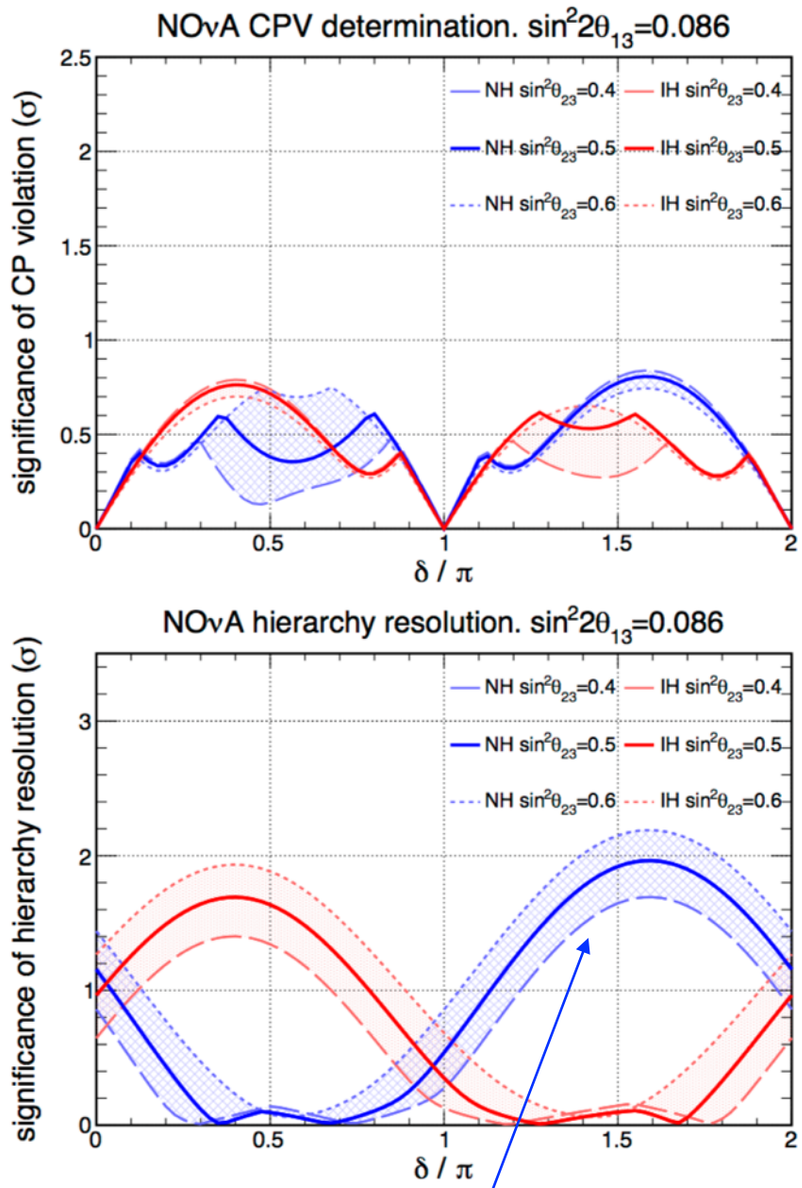
A) 6E20 POT FHC



B) + 6E20 RHC



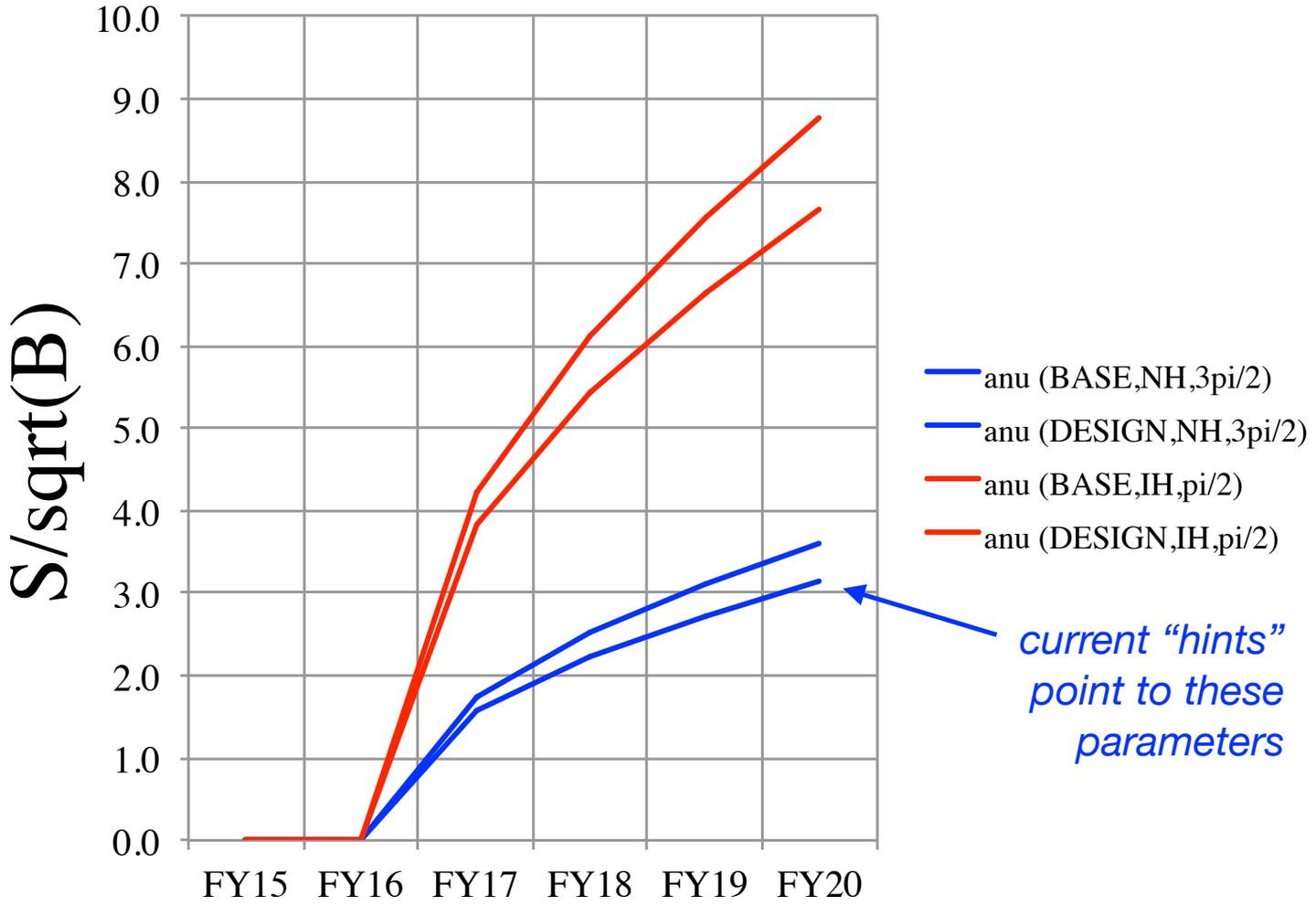
C) 12E20 POT FHC



Opportunity for early 2σ data on mass hierarchy if we stay in neutrino mode

$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ at >3σ

- Demonstration of $\bar{\nu}\mu \rightarrow \bar{\nu}e$ oscillations at 3 sigma with antineutrinos requires between 1 (IH,$\delta_{CP}=\pi/2$) and 3 year (NH, $\delta_{CP}=3\pi/2$)
- For (NH, $\delta_{CP}=3\pi/2$) NOvA takes more of a hit in antineutrinos than does T2K due to additional suppression from matter effect which is useful for physics measurements but makes establishment of this channel harder.
- T2K has 3 sigma as a goal for 2018.



(assumes a switch to antineutrinos in FY17)

Strategy

- If the parameters are normal hierarchy and $\delta_{CP}=3\pi/2$, we have an opportunity to make a big impact on the mass hierarchy determination by end of next year using neutrino data.

- New data to be presented at Neutrino 2016 (July'16)

  - T2K antineutrino results

  - 2x more neutrino data from NOvA

  will be an important input.

Summary

First analyses

- $\nu_\mu \rightarrow \nu_e$: arXiv:1601.05037 [hep-ex]. Submitted to PRDRC
- $\nu_\mu \rightarrow \nu_\mu$: arXiv:1601.05022 [hep-ex]. Submitted to PRL
- Cross-section program underway
- Burst of newly minted NOvA PhD's

New run underway

- Far detector and near detector both generally in very good health
- POT currently below base but should recover as power ramps from 420 kW to ~500 kW over next month.
- Should see some 700 kW running this year. Sustained running at 700 kW depends on work to be done during summer'16 shutdown.
- Expect x2 more data to report on at Neutrino'2016

Antineutrino strategy

- Antineutrinos are an important part of our physics program
- Current SK/T2K/NOvA/Reactor indications point to a special case point which gives NOvA an opportunity to make significant progress on mass hierarchy using neutrino mode
- Need to remain flexible to react to new T2K and NOvA results to be presented at Neutrino'2016 in July