Readiness Review: NOvA

Mark Messier
Indiana University
8 February 2013

Outline

- **Detector construction progress**
- **Detector instrumentation**
  - APD update
  - Outfitting progress and schedule
- **Detector operations**
  - Data acquisition
  - Control room and shifts
  - Commissioning plans and tools
- **Near detector**
- **Data analysis**
  - Mock data challenge
  - Neutrinos in the prototype near detector on the surface (NDOS)

NOvA Collaboration

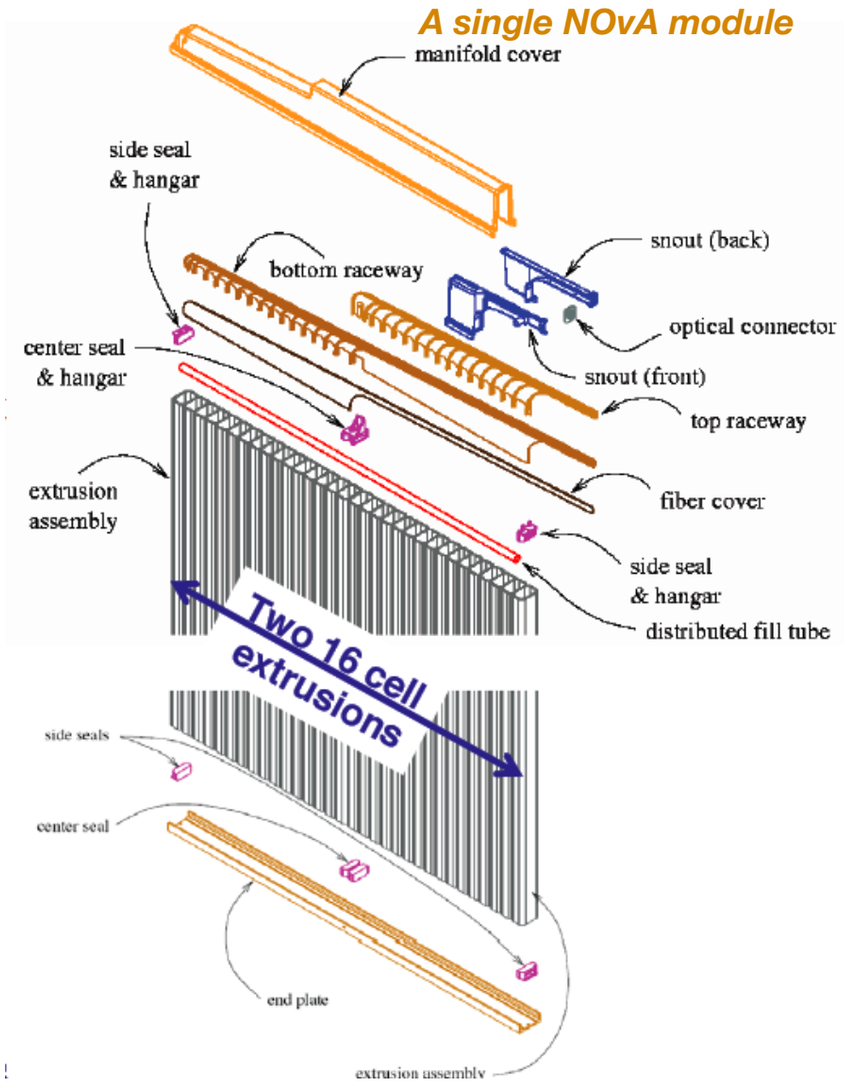
34 Institutions from 6 countries
180 collaborators
121 PhD physicists/ 23 Graduate students

Argonne National Laboratory · University of Athens · Banaras Hindu University · California Institute of Technology · Institute of Physics of the Academy of Sciences of the Czech Republic · Charles University, Prague · University of Cincinnati · Czech Technical University · University of Delhi · Fermilab · Indian Institute of Technology, Guwahati · Harvard University · Indian Institute of Technology · University of Hyderabad · Indiana University · Iowa State University · University of Jammu · Lebedev Physical Institute · Michigan State University · University of Minnesota, Crookston · University of Minnesota, Duluth · University of Minnesota, Twin Cities · Institute for Nuclear Research, Moscow · Panjab University · University of South Carolina · 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

NOvA Terminology / Numerology

- The basic unit of NOvA construction and readout is the **module** which is composed of 32 **cells** formed by gluing two 16-cell **extrusions** together
  - A cell is a column 4 x 6 cm x 15 m long containing liquid scintillator and a looped wavelength shifting fiber
  - Readout at end by a single 32-channel avalanche photodiode (**APD**)
- 12 modules are assembled into a **plane**
  - 12 APDs/plane
  - 384 channels/plane
- 32 planes are assembled into a **block**
  - 384 modules/block
  - 384 APDs/block
  - 12,288 channels/block
- 28 blocks are assembled into the final 14 kt detector
  - **0.5 kt/block**
  - 10,752 modules
  - 10,752 APDs
  - 344,064 channels
- For outfitting the preferred units is the **diblock** = 2 blocks
  - 12 power distribution box (**PDB**) and 12 data concentrator modules (**DCM**) per diblock
- Key performance parameter is pinned to the "**super-block**" an archaic unit equal to 5 blocks

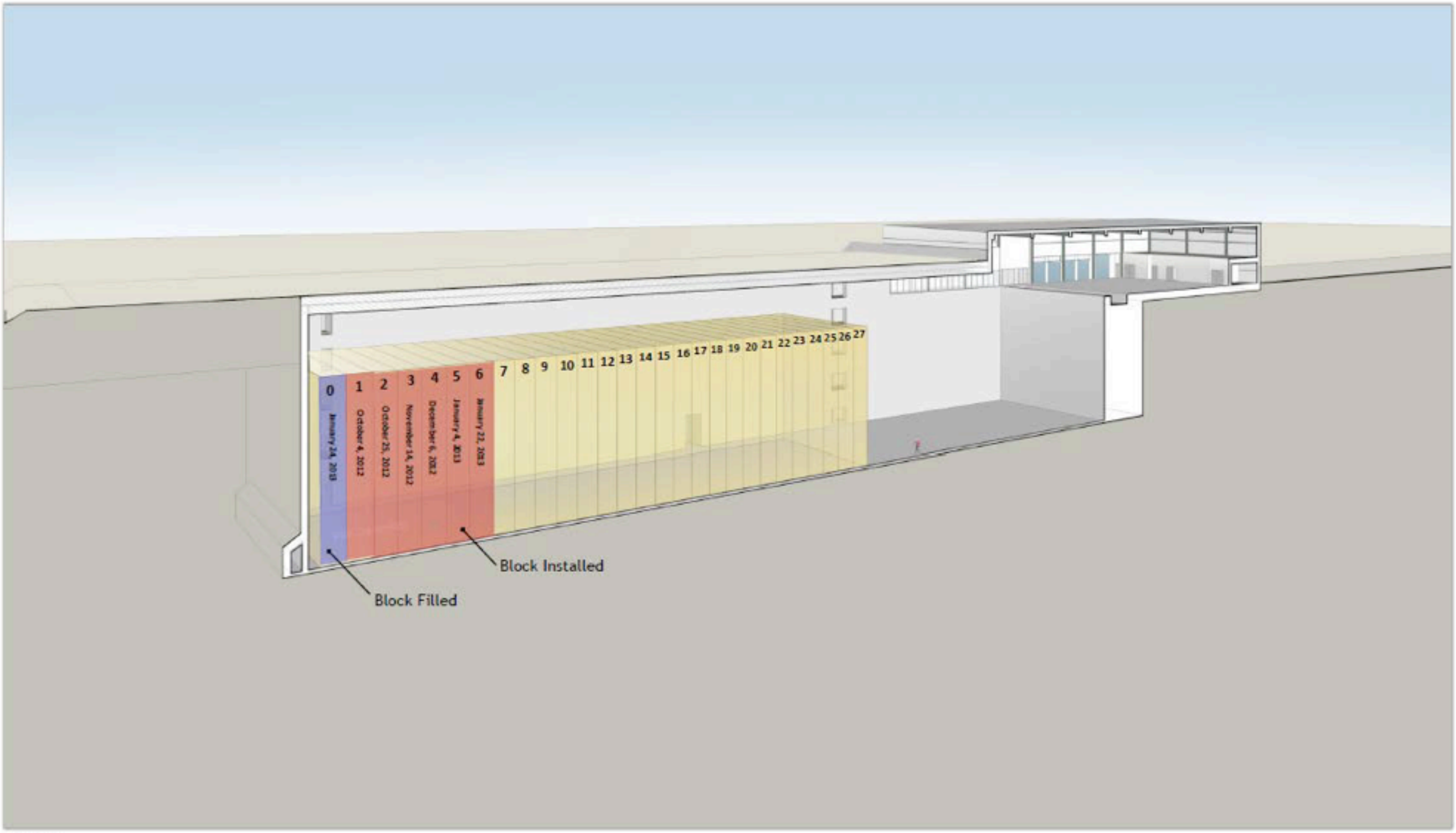
A single NOvA module



DETECTOR CONSTRUCTION

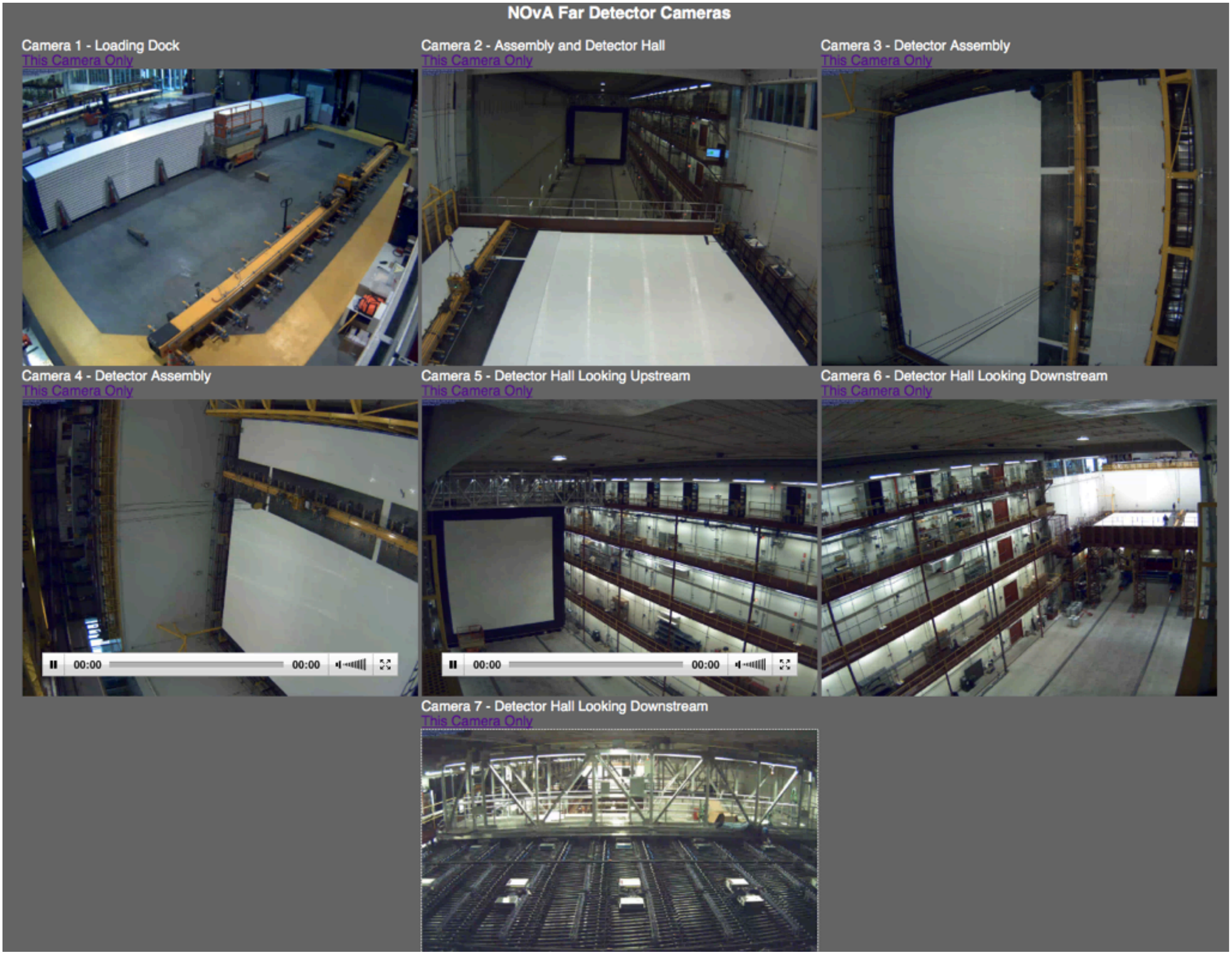
Far Detector Assembly Progress

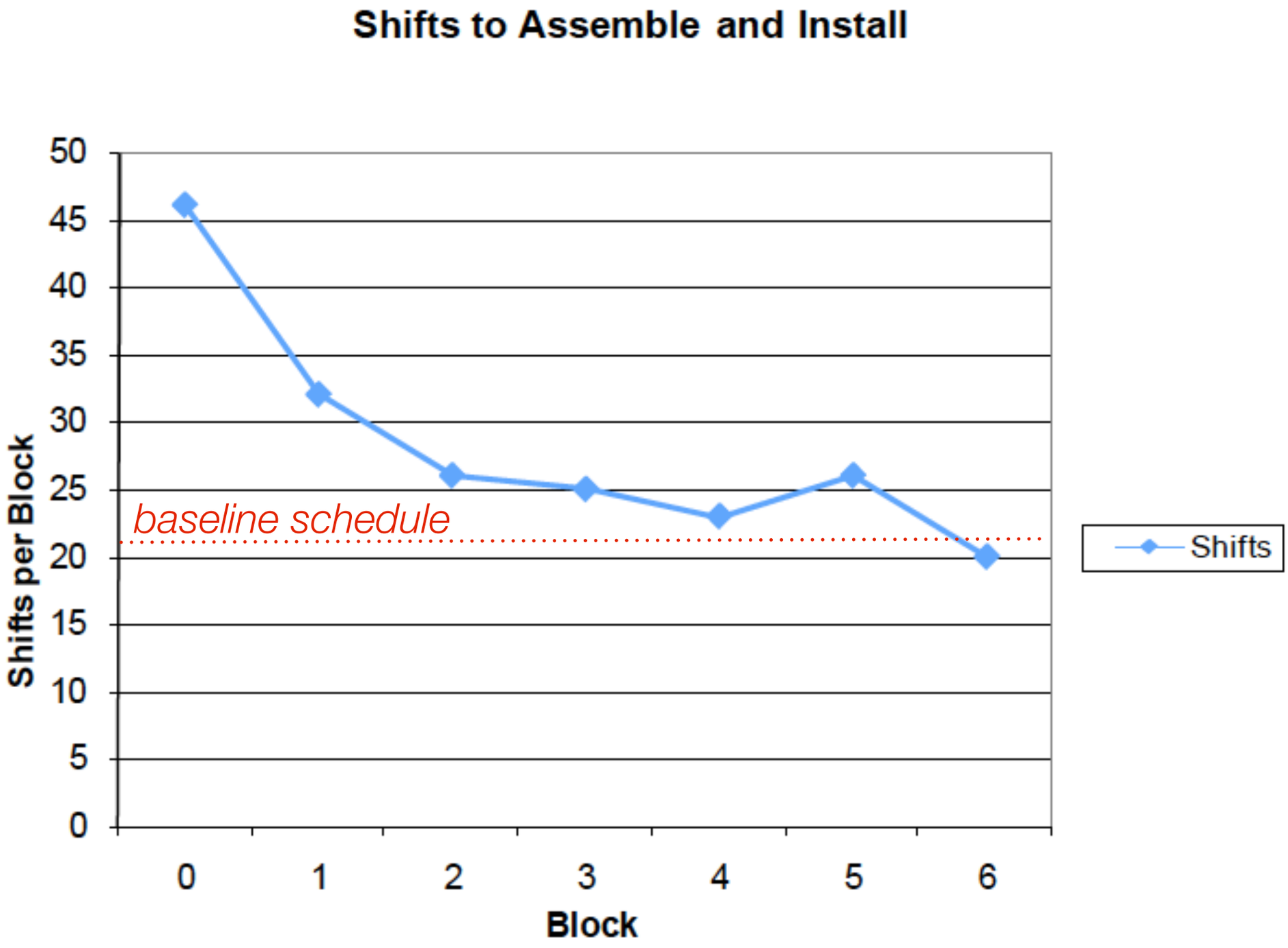
NOvA Far Detector Assembly Progress



24 Jan 2013

http://vmsstreamer1.fnal.gov/live/novawebcams.htm

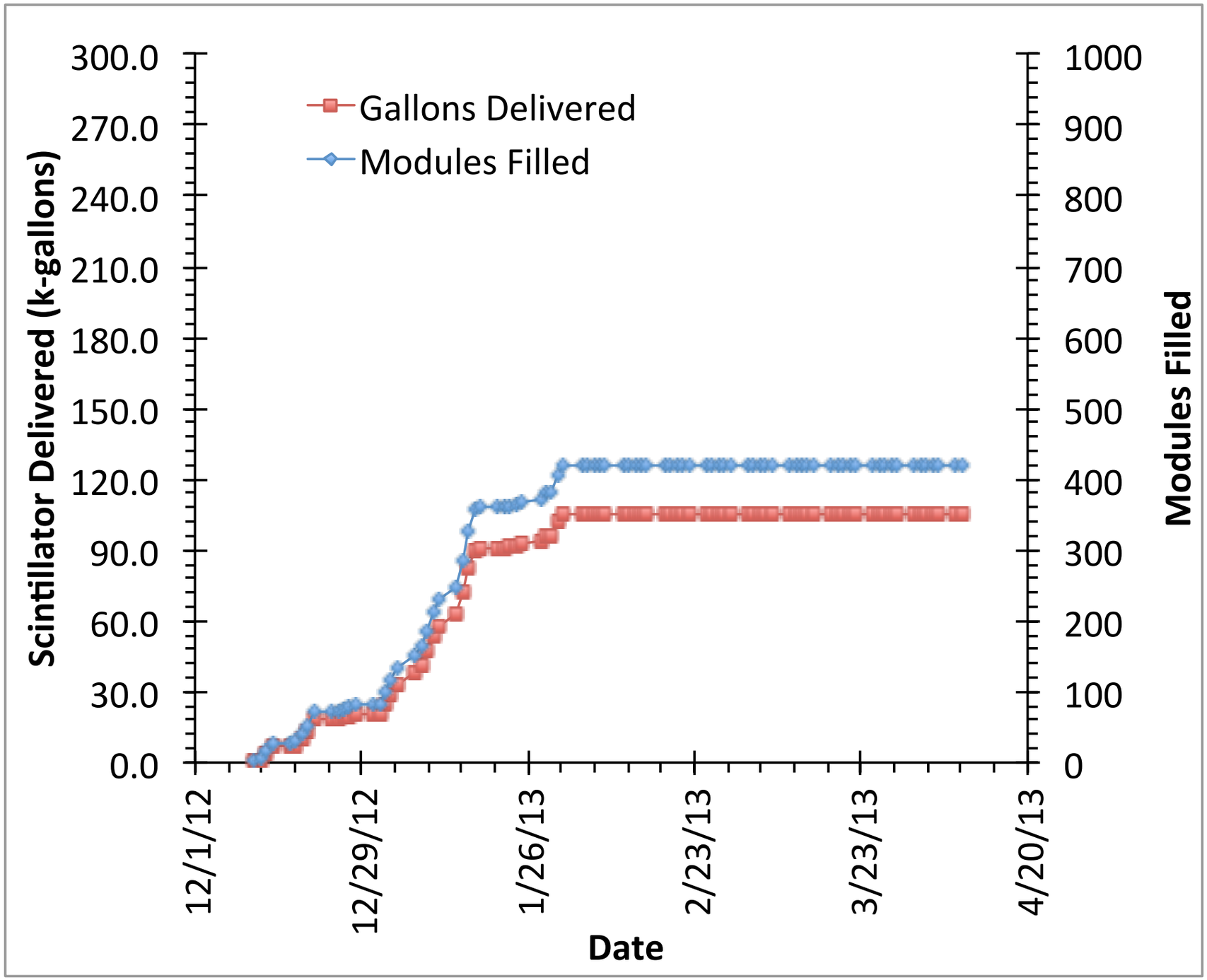




Far detector assembly progress

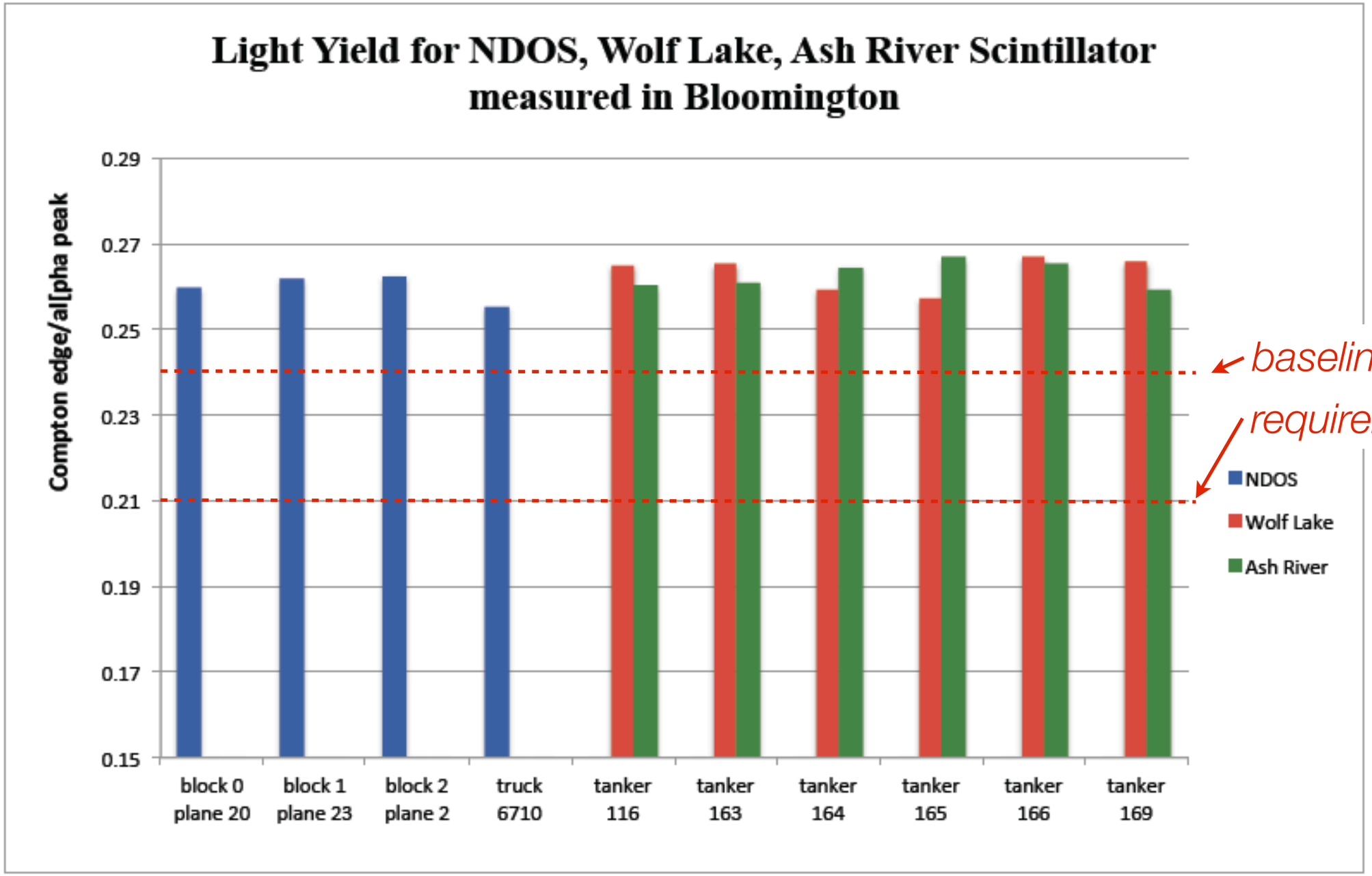
1 week = 8 ten-hour shifts
21 shifts ~ block every 18 days

Scintillator delivery and filling



Comparison of Scintillator Samples Shipped from Wolf Lake and Delivered to Ash River, Measured Consistently in Bloomington

The results were compared with random samples of NDOS scintillator



All samples look the same, including the aged scintillator

Scintillator filling summary

2 FEB 2013

Block 00

Vertical Modules

Position	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31
0	252	252	252	311	252	252	252	252	252	252	252	252	252	252	252	252
1	252	252	252	366	252	252	252	252	252	252	252	252	252	252	252	252
2	252	252	288	252	252	252	252	252	252	252	252	252	252	252	252	252
3	252	252	252	252	252	252	252	252	252	255	252	252	252	252	252	252
4	252	252	252	252	252	252	252	252	252	252	252	252	252	252	252	252
5	252	252	252	252	252	252	252	252	252	252	252	252	252	252	252	252
6	252	252	252	252	252	252	252	252	252	252	252	252	252	252	252	252
7	252	252	252	252	252	252	252	252	252	252	252	252	252	252	252	252
8	252	252	252	252	252	252	252	252	252	252	252	252	252	252	252	252
9	252	252	252	252	252	252	252	252	252	252	252	252	252	252	252	252
10	252	252	252	252	252	252	252	252	252	252	252	252	252	252	252	252
11	252	252	382	252	252	252	252	252	252	343	252	252	252	252	252	252

Horizontal Modules

Position	0	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30
11	243	246	244	245	235	245	236	229	242	248	231	229	236	249	245	249
10	249	250	239	241	244	241	231	217	250	244	242	249	237	241	251	248
9	259	254	242	247	261	244	234	238	244	238	239	246	270	248	251	252
8	251	254	243	251	244	239	235	239	244	248	240	245	215	249	248	247
7	252	253	250	254	249	249	239	242	245	242	241	246	241	246	248	248
6	251	246	242	239	241	247	242	238	250	247	239	242	239	249	236	248
5	253	250	248	240	248	250	248	221	244	236	254	245	237	247	238	248
4	252	250	246	247	250	249	240	240	249	245	249	240	232	249	240	251
3	251	246	249	244	242	247	249	244	249	244	240	250	244	250	241	238
2	250	251	251	240	238	236	239	255	251	248	240	250	252	251	249	238
1	254	253	251	247	251	249	236	247	253	251	245	248	251	246	248	248
0	254	257	250	245	248	249	237	243	246	244	241	252	244	248	246	247

Block 01

Vertical Modules

Position	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31
0																
1																
2																
3																
4																
5																
6																
7																
8																
9																
10																
11																

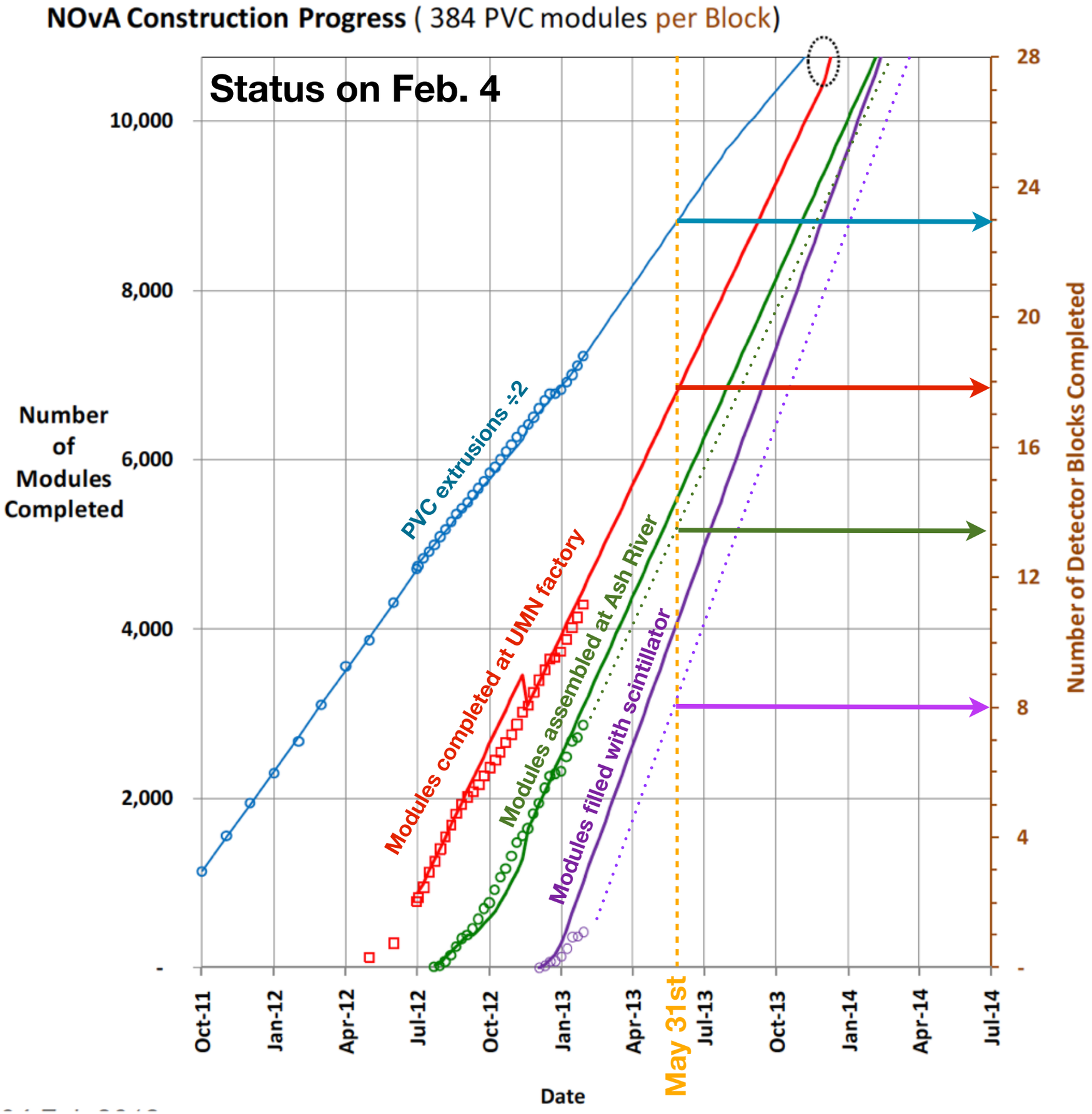
Horizontal Modules

Position	0	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30
11																
10																
9																
8																
7																
6																
5																
4																
3																
2			250	250			227	247			250	248			245	246
1	250	246	247	250	245	226	234	246	249	247	246	242	248	244	239	248
0	250	245	250	249	195	241	227	249	240	245	249	238	241	238	240	247

Number of gallons filled by module

No leaks

Horizontals require “top up” after swelling / bubbles work themselves out



Projections to 31 May 2013

23 blocks-worth of extrusions produced

18 blocks-worth of modules assembled

13 blocks assembled and in place

8 blocks filled with scintillator:

4 kt of detector mass in place

Scintillator filling competes with APD deliveries (see later slides) to be limiting factor on total operational mass by May 31

INSTRUMENTATION

APD lessons learned from Near Detector Prototype on the Surface (NDOS)

- APDs installed on NDOS had several problems which have been corrected
  - Several cases of physical contact with APD →parts redesigned for far detector
  - Bare silicon → thin optical coating (parylene, silicone also tested)
  - Passive dry air system → active dry air system
- We were able to test the coatings and the air system on NDOS
  - 140/178 silicone coated APDs operating cold (79%)
  - 92/107 parylene coated APDs operating cold (86%)
- Using all new parts, we built a 30 APD test stand and have operated it since November 2012
- In total 87 APDs have been cycled through this test stand and operated cold. Of those 2 failed to operate when cold: 97.7% success rate.

APD Test Stand

Electronics delivery schedule

- **DAQ hardware production is largely complete**
  - Slave Timing Distribution Unit: 46 received, 46 passed. Order complete
  - Master Timing Distribution Units: 14 received, 14 passed. Order complete
  - Power distribution box: 118 shipped to Ash River (19 blocks-worth)
  - Data Concentrator Modules: Production complete. 247/250 passed tests
- **Front End Boards**
  - 12609+ enough for far detector
- **APDs**
  - Receiving APDs at rate of >150/wk from Hamamatsu
  - Coating / testing / assembly at Caltech takes 2-3 weeks to turn them around. Still ramping this process up; exact rate is unknown. Expect it to be ~100 / wk initially. Will ramp to keep up with Hamamatsu delivery rate.
  - This either just keeps up with installation rate at Ash River or falls slightly behind.

Di-Block Outfitting

Detector side outfitting is a di-block ahead of detector top

Detector outfitting schedule

Block	Filled	APDs Installed	Commissioned	kt operational
0	1/30	4/01	4/09	1
1	2/25			
2	3/13	4/23	5/01	2
3	4/01			
4	4/16	5/29	6/05	3
5	5/02			
6	5/21	7/02	7/10	4
7	6/10			

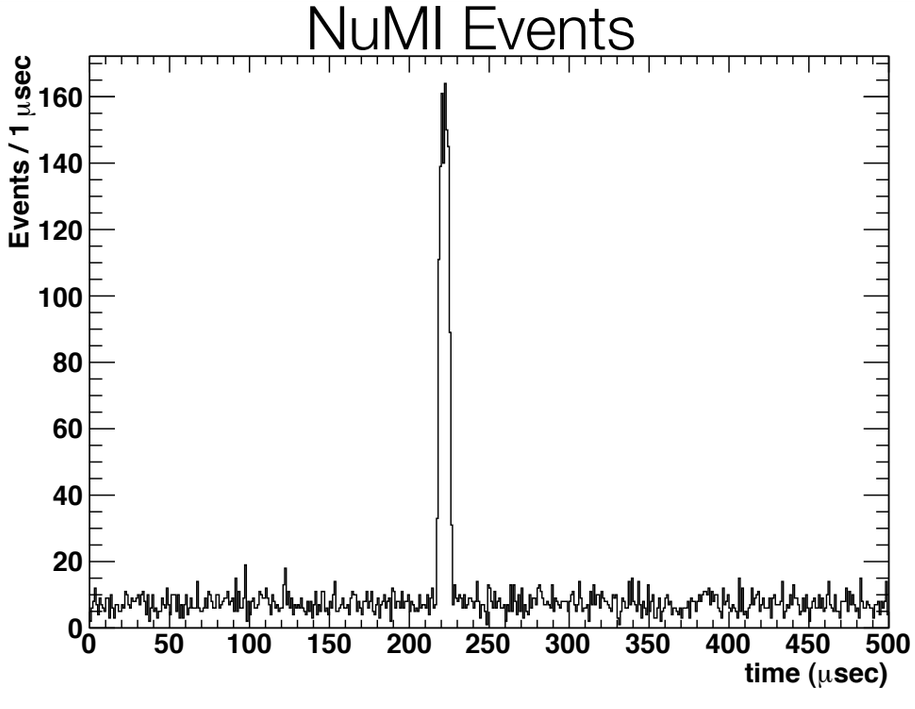
APD installation begins at the end of this month when first diblock is filled.
Routine commissioning runs to start 11 March
This schedule assumes a delivery rate of 150 APDs to Ash River per week. Actual rate TBD.

DETECTOR OPERATIONS and COMMISSIONING

Detector Operations: NDOS

We operated NDOS 24/7 during NuMI beam November 2010 - May 2012 and since have operated it 24/7 largely unattended in cosmic-ray mode using volunteer shifters. We have all the infrastructure in place for operations:

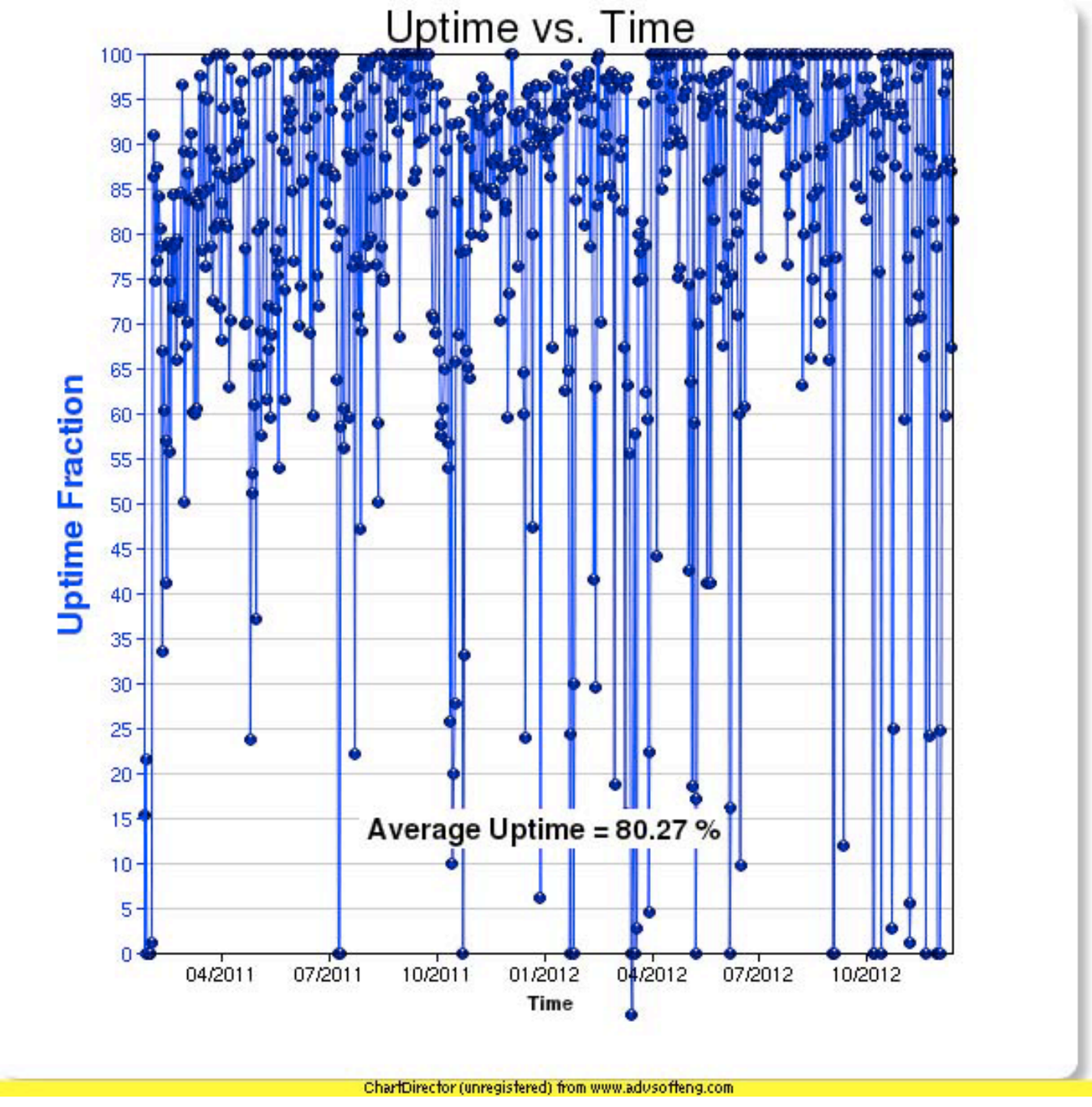
- Control room
- Shift scheduling / Run coordinator
- Electronic log book (ECL)
- Data Acquisition
- NuMI spill timing / triggering
- Data quality monitoring
- Slow controls and monitoring



Detector operations

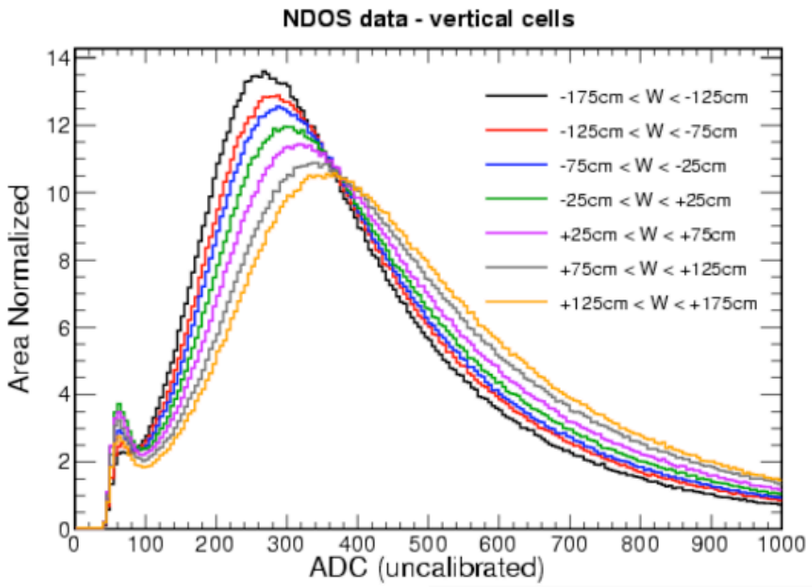
- We are operating NDOS and the APD test stand now using volunteer shifters. Steve Magill (ANL) is our run coordinator taking the reins from Mat Muether (FNAL)
- We will continue to operate the test stand until the number of APDs at the far detector out number the number on the test stand (~April)
- We will continue to operate NDOS at least until the near detector underground is ready (possibly as late a February of next year)
  - Provides confirmation of correct timing of NuMI spill ~4 hours of data
  - Valuable testbed for near detector electronics
  - Valuable testbed for continued DAQ development
- Planning a workshop for late February to tweak the control room layout for simultaneous operation of NDOS and far detector
- We have opened our shift schedule
  - 11 March - 31 May : 1 shift / day 8A - 5P M-F at FNAL to aid detector commissioning
  - June 1+ : 24/7 operations at FNAL for physics running and detector commissioning
- University of Minnesota is preparing for remote shifts, but we don’t expect to run remote shifts until commissioning is complete and operations are routine

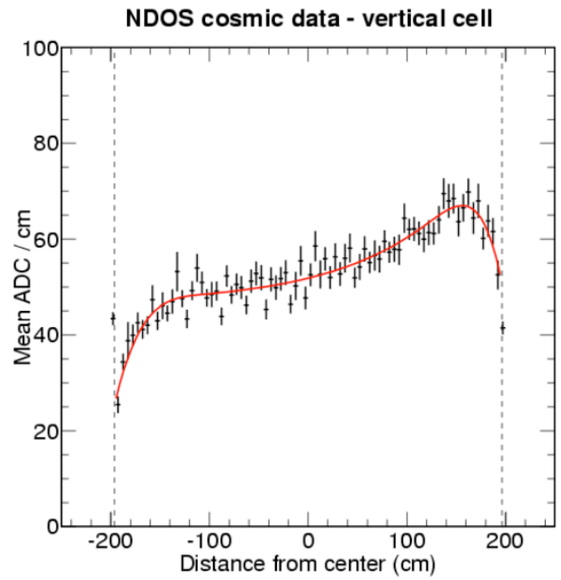
NDOS Operations: Data Acquisition



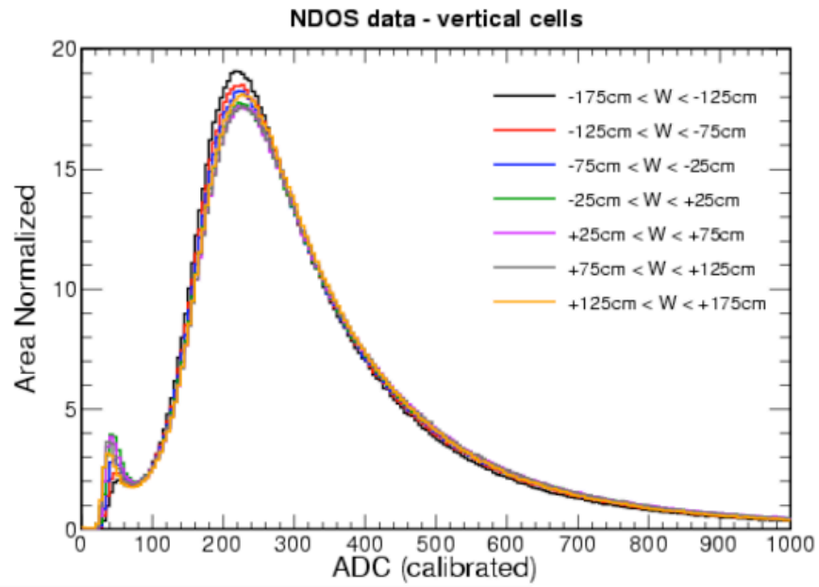
- NDOS has been an excellent test bed for DAQ development
- Total uptime is 80%.
- During day NDOS is often used for tests
- Overnight uptime is ~100%
- Ran 12 days straight unattended over Christmas/New Year holidays
- System architecture is identical to far detector. Only version numbers change.

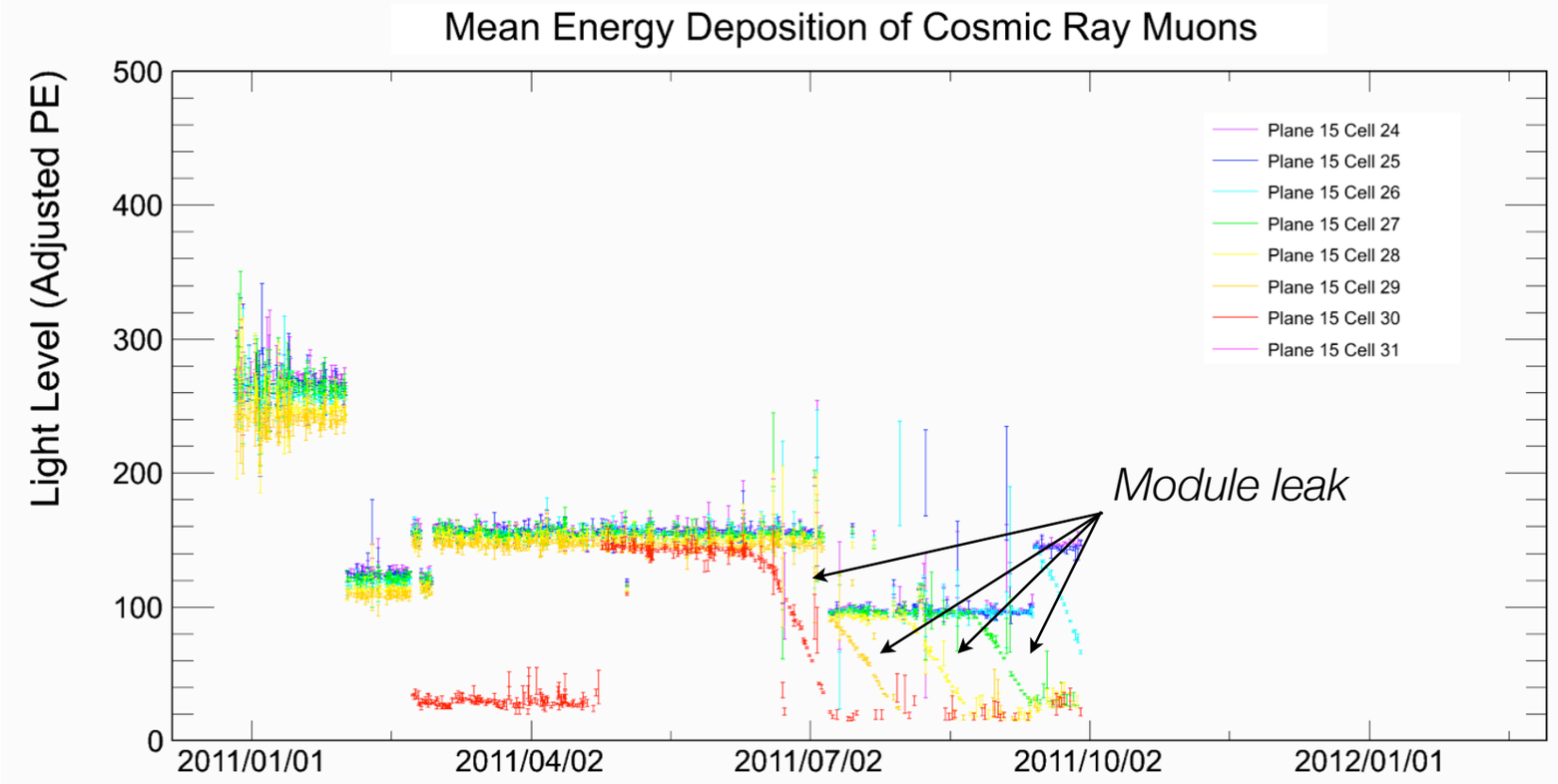
Raw MIP response





After attenuation correction





Long term monitoring of muon response

NDOS Operations | Calibration

Calibration:

Hit efficiency and Scintillator level

NDOS prior to “top up” of horizontal cells

Far Detector Commissioning

See slides from Commissioning Parallel Session (S.Magill)

Far Detector Commissioning Overview (sequence backup slides: slide 13):

- Components (DCM,FEB, APD) pass installation tests
- Scans to determine APD operating point (warm/cold)
- Overnight cosmic ray runs to identify problems
- Fix problems until 99% channels live (Ash River)

Commissioning based at Fermilab control room done by shift personnel

- 1 day shift 5 days/week
- Ash River outfitting crew shifts:
  - Day: T-F 06:30 - 17:00
  - Eve: M-Th 17:00 - 03:30

Detector portion is "commissioned" when it has passed thresholds:

- 99% channels live for ~ 1 week
- noise measured in all channels using information from APD/FEB
- # PE for all cells measured for normal incident muon at end of cell away from APD
- response as a function of distance along cell measured for all modules
- scintillator level measured in all modules
- neutrino event (vertex) observed in superblock

➡ These items would form input into NOvA Detector NIM article.

Tools for commissioning

- **Digital oscilloscope mode: “DSO”**
  - Special DAQ operation allows full waveform readout from APDs to be read out. Used to measure and monitor noise rates and possible sources (Hz), measure pedestals
  - Time consuming - OK for commissioning, but likely to need streamlining for operations.
- **Online monitoring/Event Display**
  - Provides rapid (~1 minute) feedback on low level hardware performance (hit rates, charge, time, trigger rates, error bits, etc.)
  - Results displayed in control room in ~real time. Histogram files archived for reference and comparison.
  - Currently running on NDOS and APD test stand. Ready for far detector, but may need tweaks to layout to display all channels clearly.
  - Does not currently provide feedback directly to the DAQ
- **DataCheck**
  - Series of hit-level analysis modules that run on a completed subrun
  - Summary metrics (#active channels, event size, cosmic rates, in-time event rate, etc.) are written to database and used for by analysis groups for good-run selection and long-term tracking of detector performance.
  - Provides feedback to shifters within ~1.5 hours on data quality via web interface
  - Weekly summaries of results presented at Monday ops meetings
- **Nearline**
  - Outgrowth of DataCheck. Incorporates fast reconstruction to monitor the NuMI timing, find timing out-of-sync errors, etc.
  - Feedback to shifters ~1.5 hours via web interface
  - Currently runs on NDOS. Should be straight forward to deploy for far detector.
  - Need to incorporate analysis modules from calibration and alignment group

Far Detector Commissioning

See slides from Commissioning Parallel Session (S.Magill)

Far Detector Commissioning Overview (sequence)

- Components (DCM,FEB,APD) pass installation tests
- Scans to determine APD operating point (warm/cold)
- Overnight cosmic ray runs to identify problems
- Fix problems until 99% channels live (Ash River)

Part of installation procedures

"DSO" scans

Online monitoring/Datacheck/Nearline

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Online monitoring and Datacheck

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- scintillator level measured in all modules
- neutrino event (vertex) observed in superblock

➡ These items would form input into NOvA Detect

DSO scans

"Nearline" calibration

tools exist but needs to be moved to Nearline processing

Nearline

Detector operations

A few concerns regarding detector operations

- We maintain a direct video link between the FNAL control room and the Ash River site. For NDOS operations we relied on EVO for this. Planning to use SeeVogh which is a paid replacement for EVO ($5k/yr). Other experiments are likely to use it too. Is there a Fermilab-wide license?
- Beam monitoring infrastructure: Support for the “JAS” viewer which was used by MINOS has been withdrawn and the underlying technology (xmlrpc) is no longer supported. Development of a replacement database is coming along and much of the backend is in place, but we don’t have the software in place for displaying and, in some cases, computing, all the data on spill quality that MINOS has during its run. I think we can lend a person to this effort, but it should probably be coordinated among experiments.
- Space: With NOvA activity ramping up this summer (shifts + near detector installation work) space is likely going to be very tight up on WH12

Commissioning:
Key Performance Parameter

- We have a KPP which states that a super-block (5 blocks) is not commissioned until we have seen a neutrino event in it with a contained vertex.
- Remember: We have a narrow-band beam on the oscillation maximum - most of the muon neutrinos will have disappeared!
- Using a standard set of oscillation assumptions we expect:
  - 0.3 NC events / 0.3 ν_μ CC events / 0.05 ν_e CC events per 4e18 POT per super-block
  - 0.65 events total per 4e18 POT per super-block
  - 4E18 POT is 1 week at 300 kW
- ~7% probability that after a month we will not have seen a neutrino vertex in first super-block just due to statistics
- KPP counts events that span super-blocks, so downstream blocks will be faster than this.
- ***Early beam performance is crucial to satisfying the KPP and moving on to operations phase***

NEAR DETECTOR

Near detector: Cavern excavation is complete

Contractor Tasks:	*Start*	*Finish*
Mobilization	**6/1/12**	**8/16/12**
Site Preparation and Utility Relocation	**6/1/12**	**8/15/12**
Tunnel & Hall Excavation	**8/15/12**	**11/5/12**
Outfitting	**11/5/12**	**5/1/13**
Demobilization	**12/3/12**	**6/14/13**

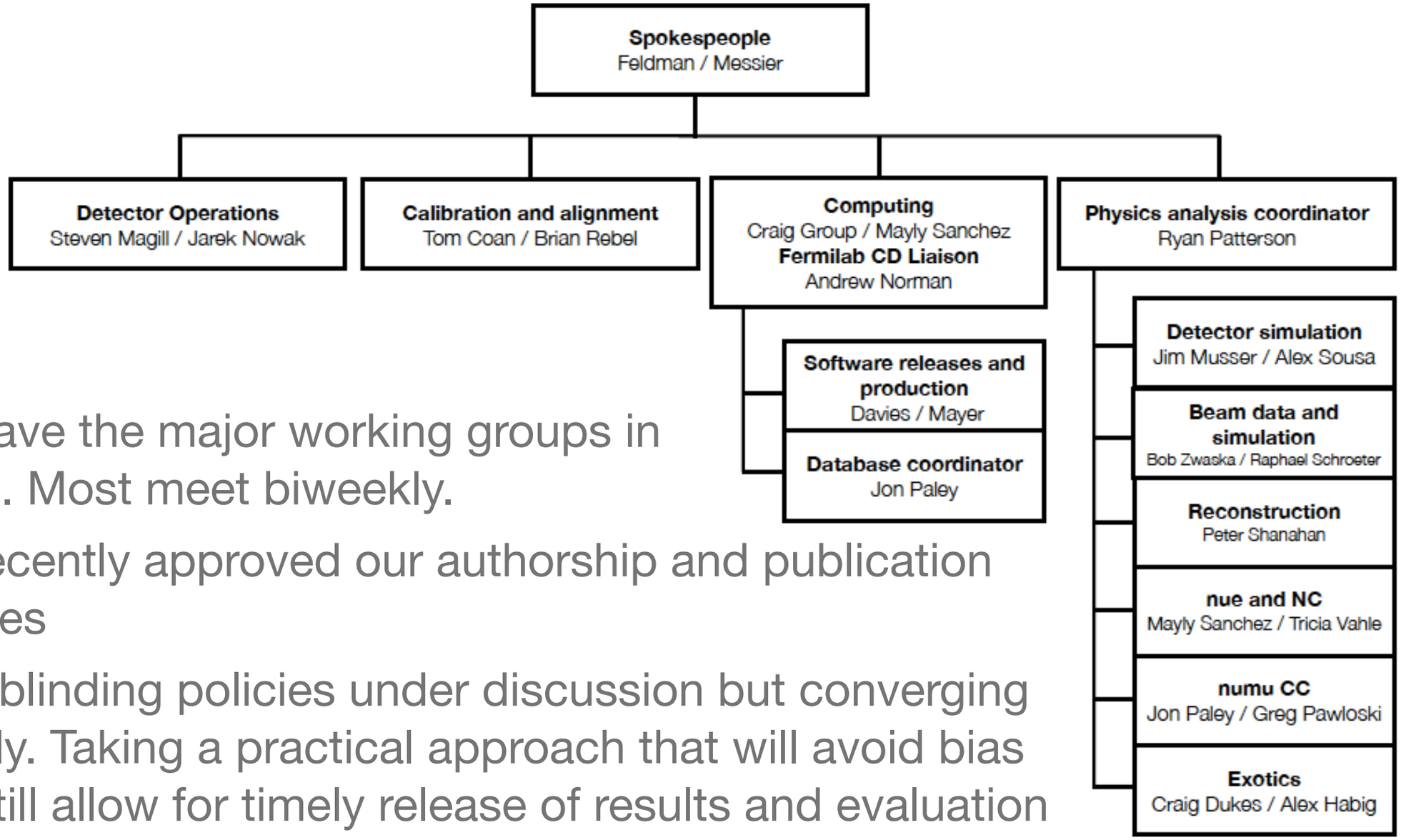
Near detector schedule

		2013 July				August				September				October				November				December				2014 January				February			
	Week	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Muon catcher	Leak test				2	2	2	2																									
	Fill				4	4	4	4																									
	Support structure Install								2	2																							
	PDB/DCM install								2	2	2																						
	APD cooling install										2	2	2																				
	APD dry gas install										2	2	2																				
Block 7-8	Leak test									2	2	2	2																				
	Fill									4	4	4	4																				
	Support structure Install													2	2																		
	PDB/DCM install													2	2	2																	
	APD cooling install															2	2	2															
	APD dry gas install															2	2	2															
Block 5-6	Leak test													2	2	2	2																
	Fill													4	4	4	4																
	Support structure Install																	2	2														
	PDB/DCM install																	2	2	2													
	APD cooling install																			2	2	2											
	APD dry gas install																			2	2	2											
Block 3-4	Leak test																	2	2	2	2												
	Fill																	4	4	4	4												
	Support structure Install																					2	2										
	PDB/DCM install																					2	2	2									
	APD cooling install																							2	2	2	2						
	APD dry gas install																							2	2	2	2						
Block 1-2	Leak test																						2	2	2	2							
	Fill																						4	4	4	4							
	Support structure Install																										2	2					
	PDB/DCM install																										2	2	2				
	APD cooling install																												2	2	2		
	APD dry gas install																												2	2	2		
	TOTAL FTE:	0	0	0	6	6	6	6	4	10	12	10	10	4	10	12	10	10	10	10	12	10	8	10	12	10	10	4	4	6	4	4	0

Collaborator effort dedicated to near detector installation

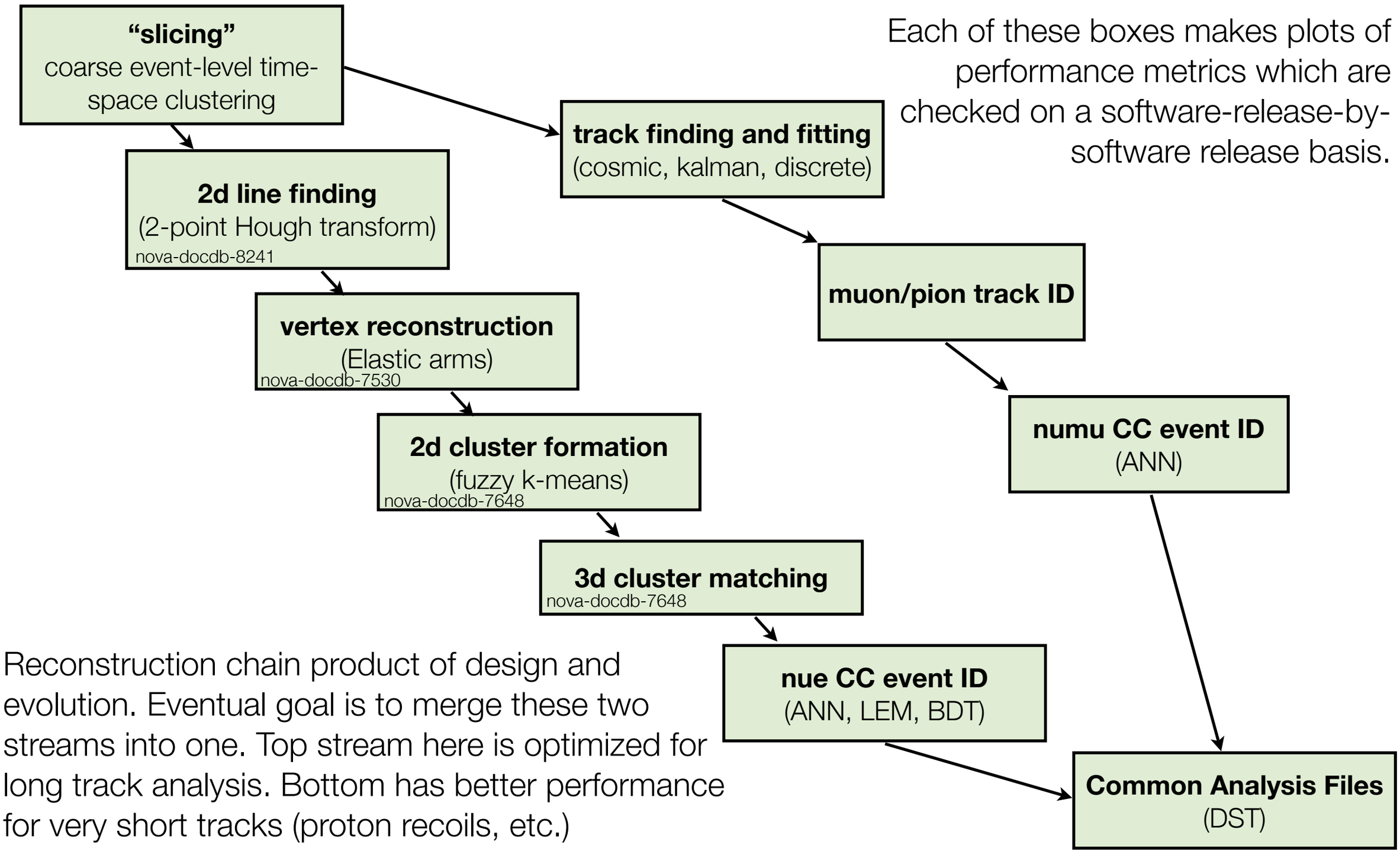
DATA ANALYSIS

Analysis infrastructure



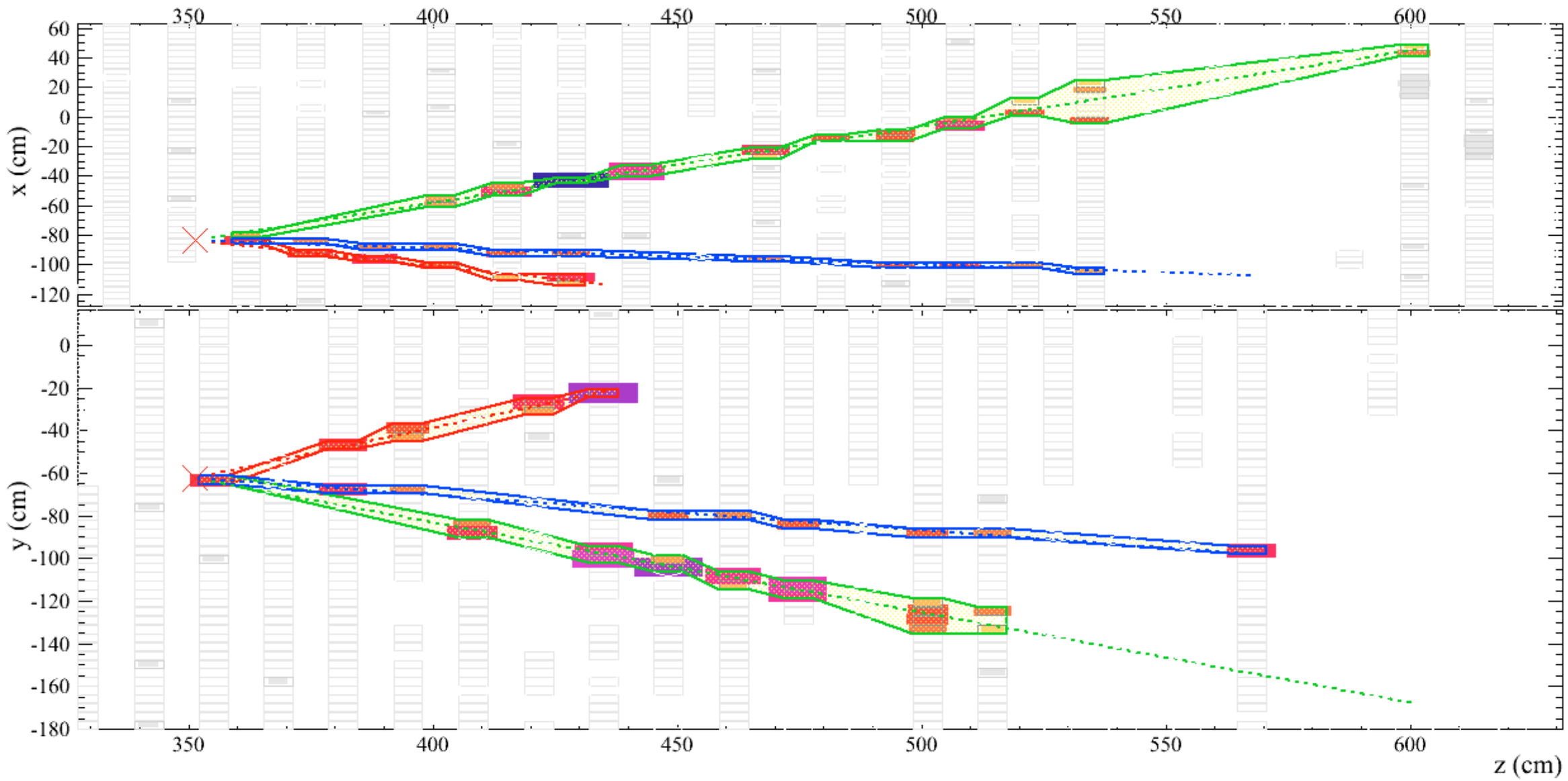
- We have the major working groups in place. Most meet biweekly.
- We recently approved our authorship and publication policies
- Data blinding policies under discussion but converging rapidly. Taking a practical approach that will avoid bias but still allow for timely release of results and evaluation of detector and reconstruction performance on real data

Event Reconstruction



Each of these boxes makes plots of performance metrics which are checked on a software-release-by-software release basis.

Reconstruction chain product of design and evolution. Eventual goal is to merge these two streams into one. Top stream here is optimized for long track analysis. Bottom has better performance for very short tracks (proton recoils, etc.)

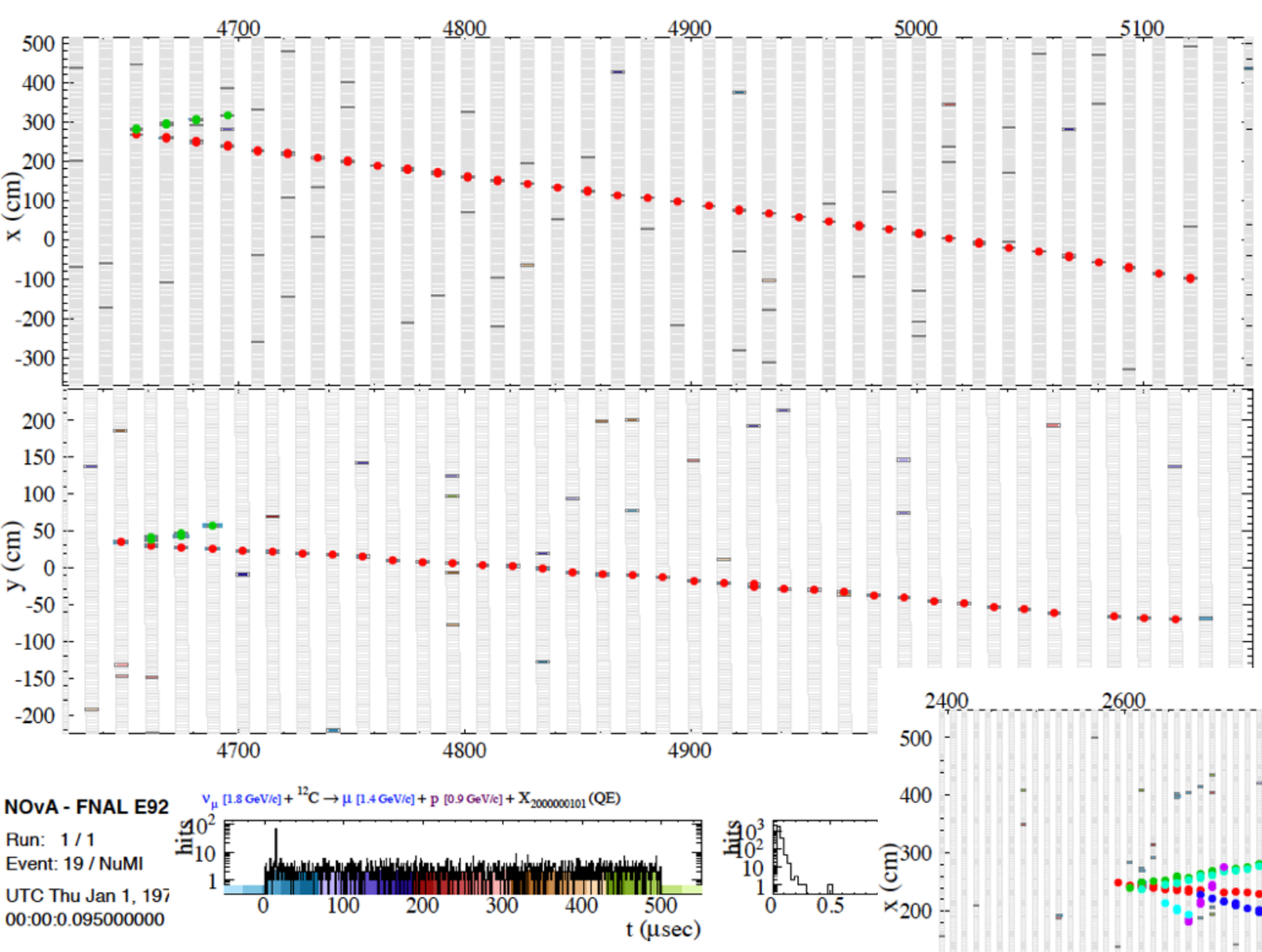


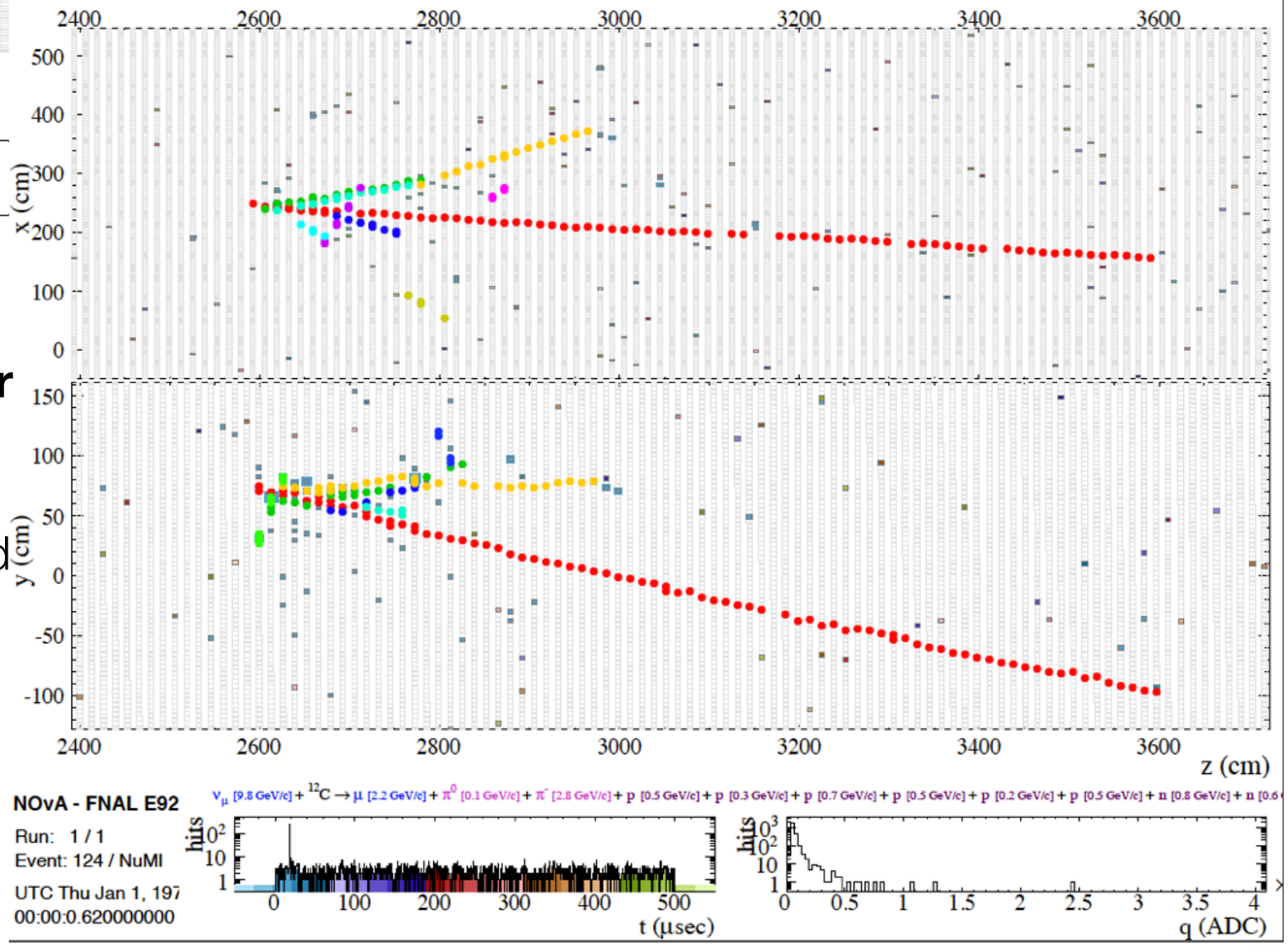
$\nu_\mu + n \rightarrow p + \mu^- + \pi^0$ candidate in NDOS

Reconstruction works even in the sparsely instrumented NDOS detector (shown here).
Performance on fully instrumented far detector is much better.

Mock Data Challenge (MDC)

- During fall of 2012 we undertook a mock data challenge. Final results presented at our January 2013 meeting.
- Two data sets (“MDC0” and “MDC1”) corresponding to 3 years of neutrino running were prepared using hidden oscillation parameters. The data sets were meant to look as much like real data as possible. All Monte Carlo “truth” information was stripped out of them.
- These files and sets of “ordinary” Monte Carlo were processed on the grid through our calibration, reconstruction, particle ID chain to final DSTs from which the oscillation signals were extracted.
- Focus was on making the whole chain work end-to-end and to identify stumbling blocks. *We did not focus on implementation of optimized algorithms. Since the MDC many analysis improvements have been implemented, many motivated by the MDC results.*
- Important short-cut we would like to correct in a future MDC: We did not generate near detector mock data, but rather assumed that we would have a far detector extrapolation similar to MINOS’s as input to the analyses
- Lessons learned are documented in:
  - nova-docdb-8620
  - nova-docdb-8623





Simulated ν_μ-CC events in far detector

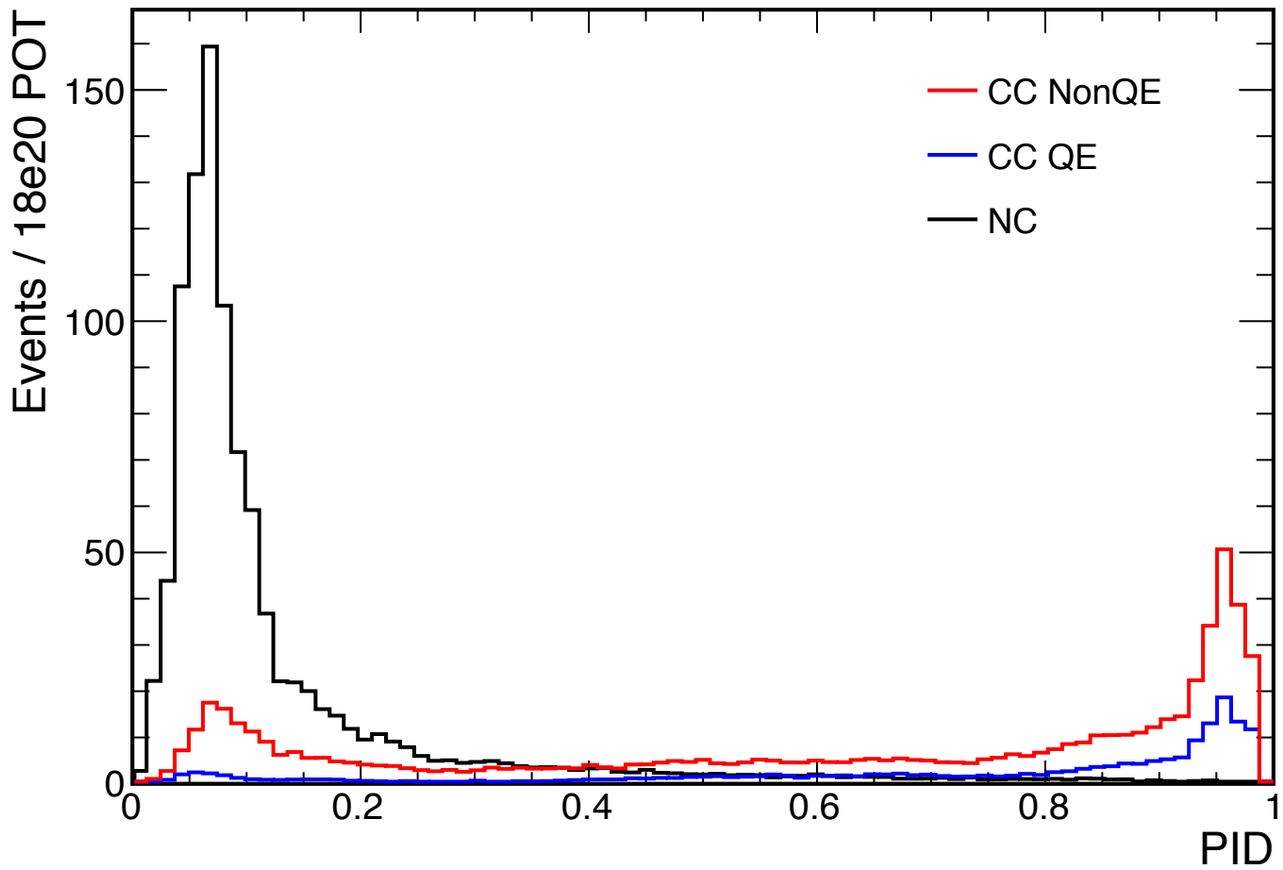
QE (top)

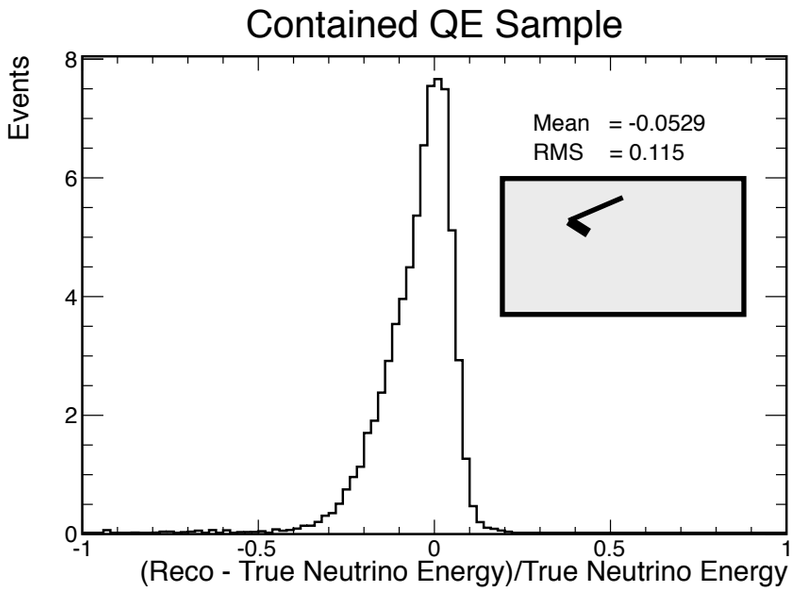
non-QE (right)

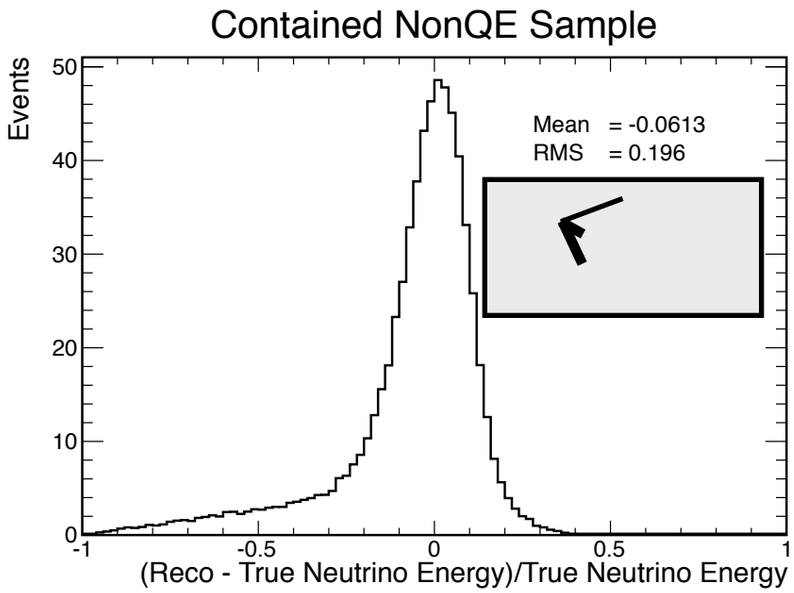
Hit color shows cluster/track ID associated

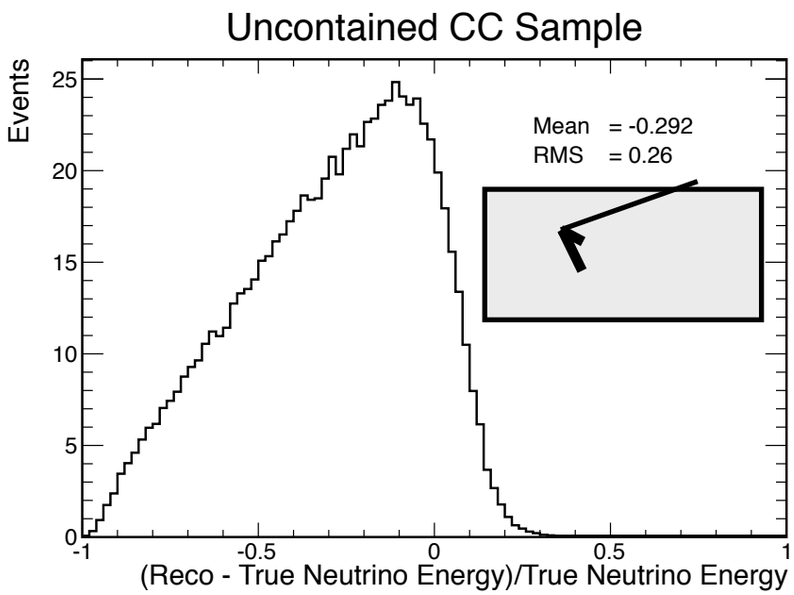
$\nu_\mu \rightarrow \nu_\mu$ MDC

Event ID and Energy reconstruction

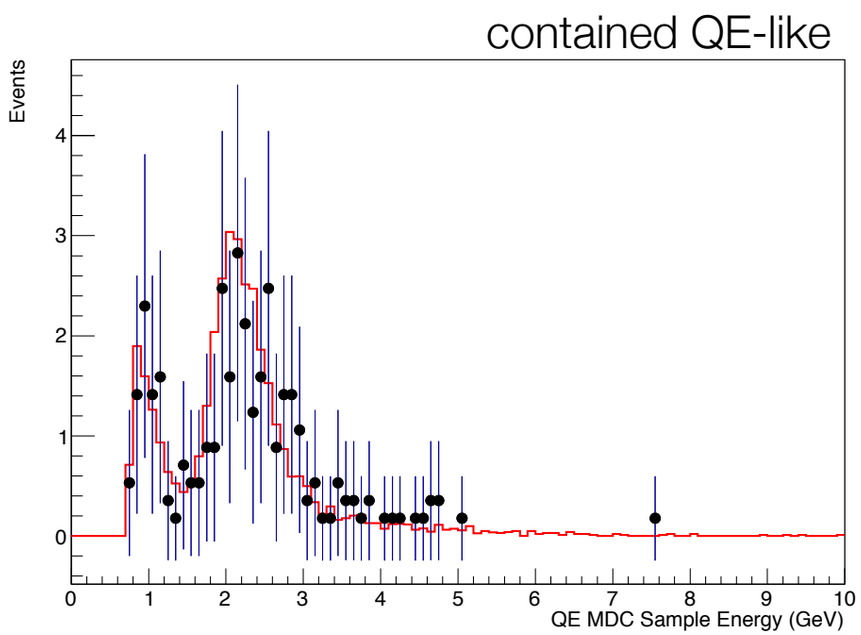


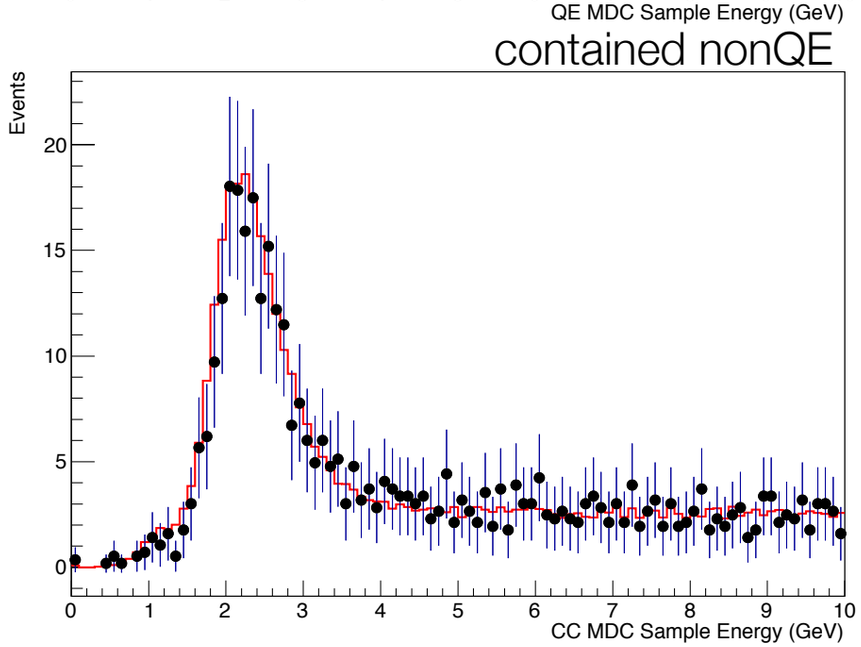


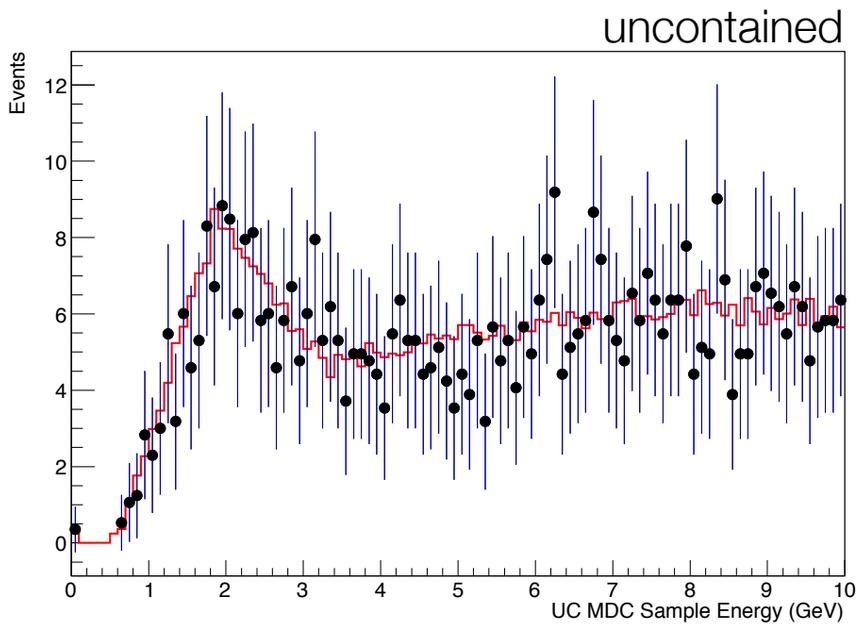


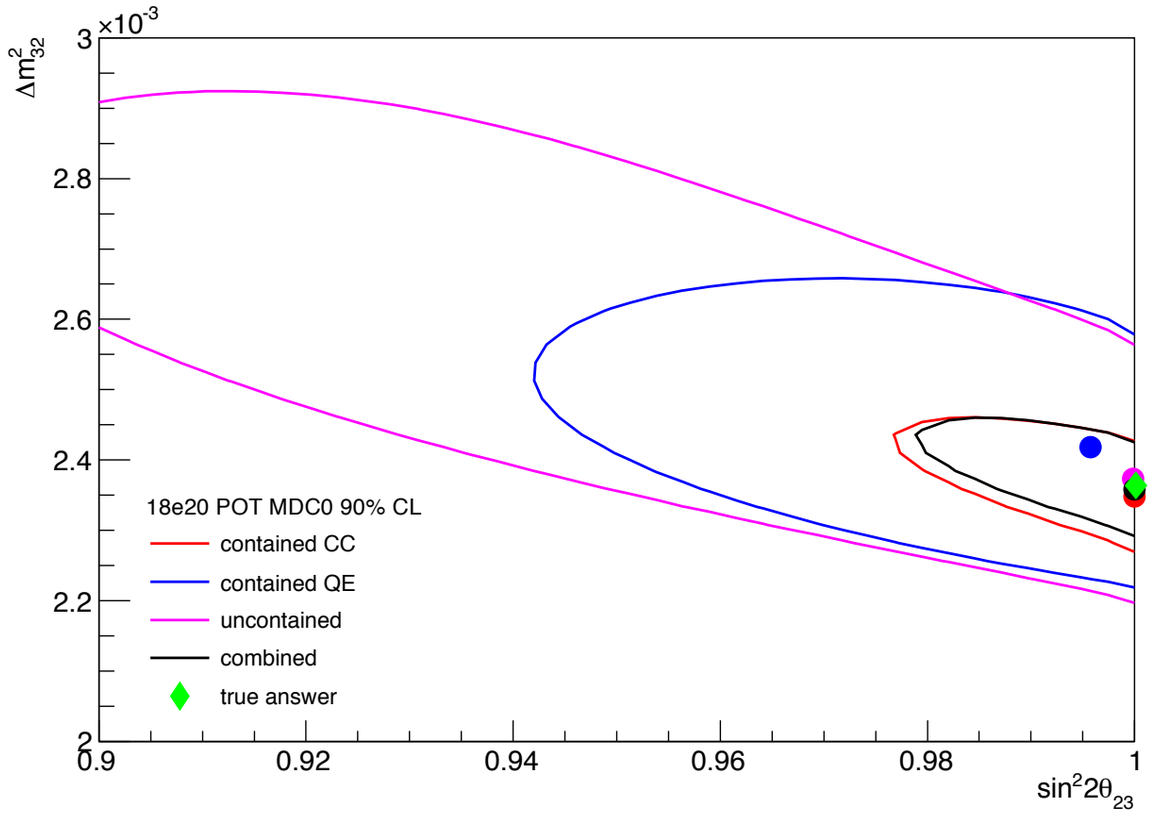


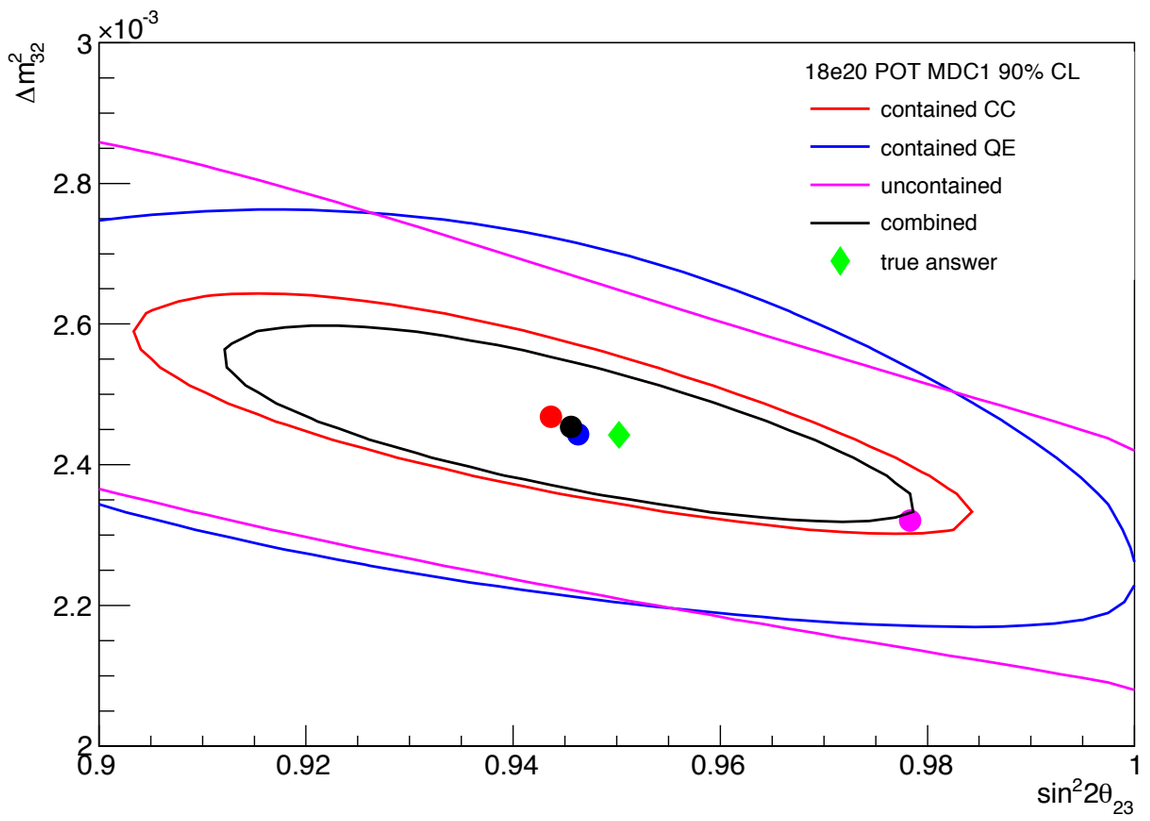
$\nu_\mu \rightarrow \nu_\mu$ MDC Results

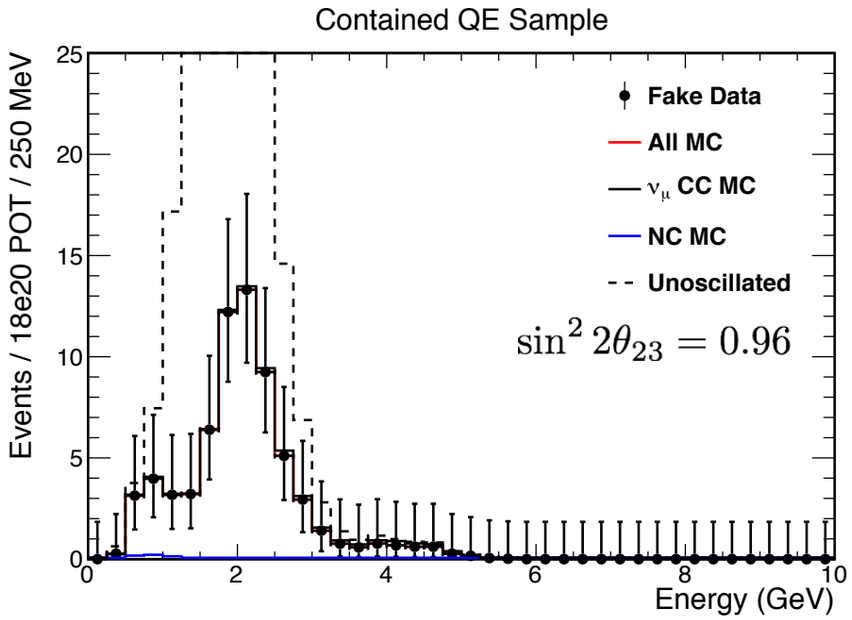


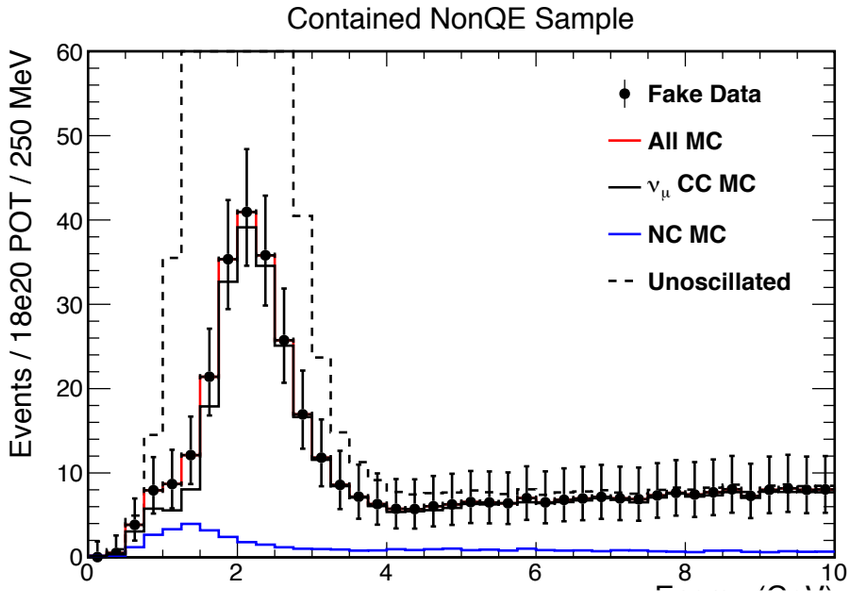


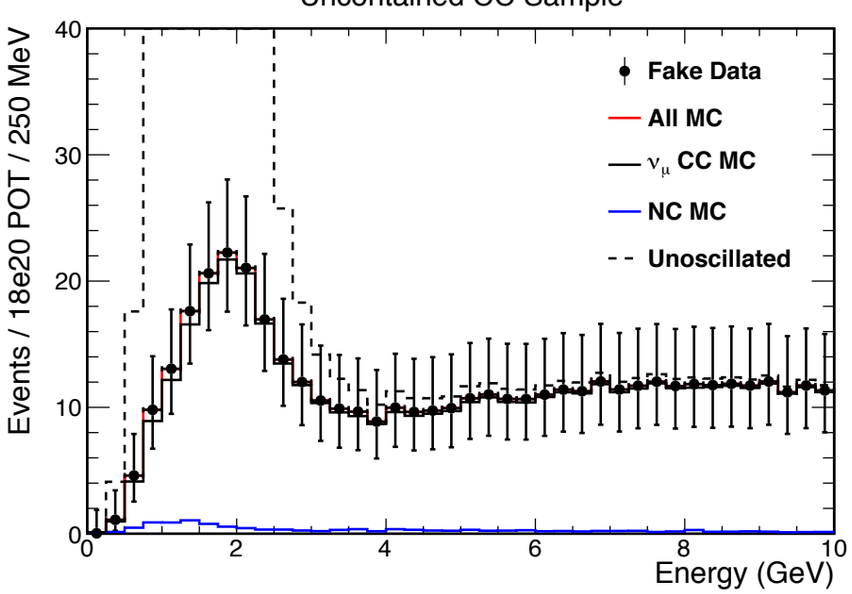


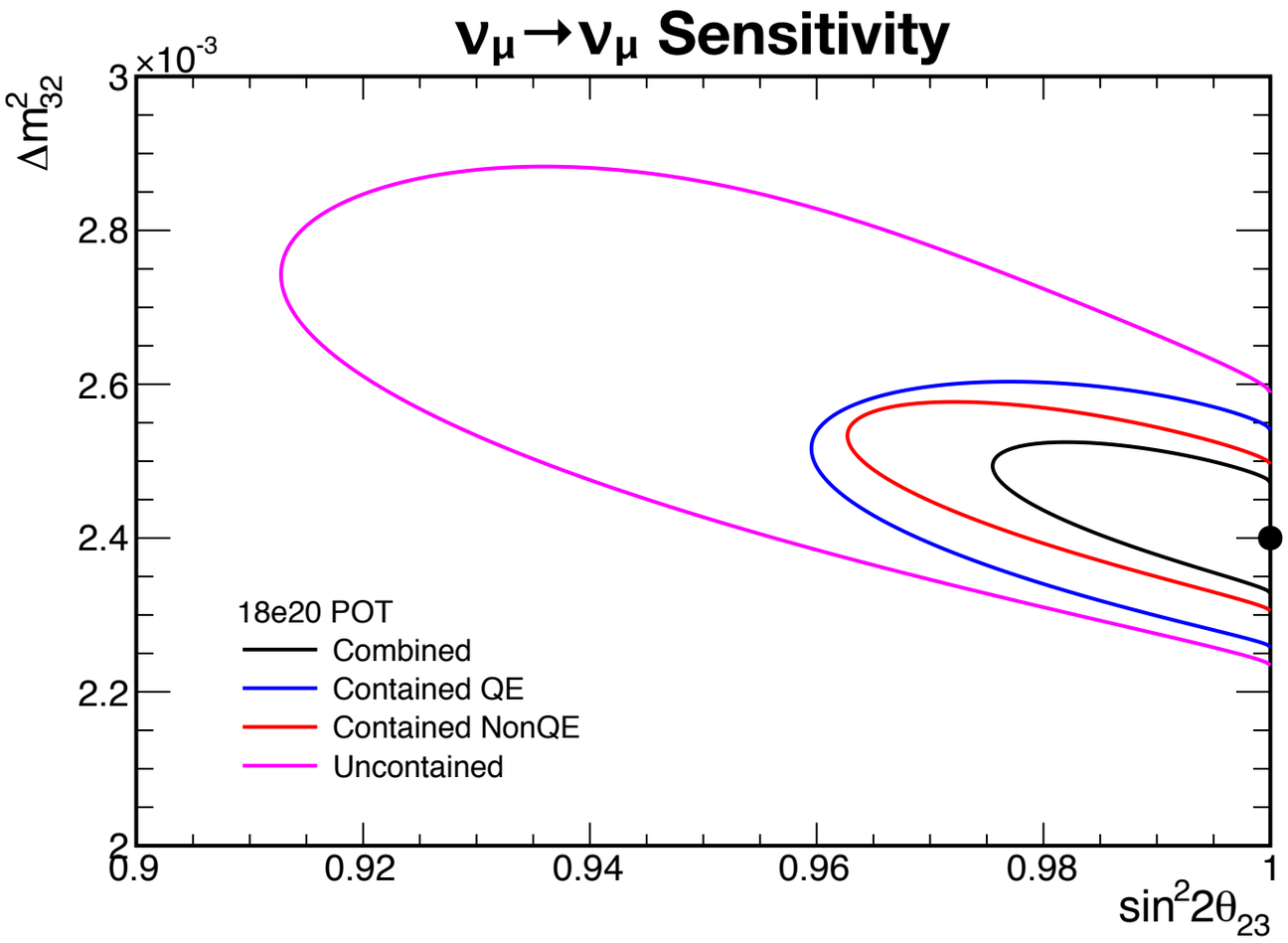


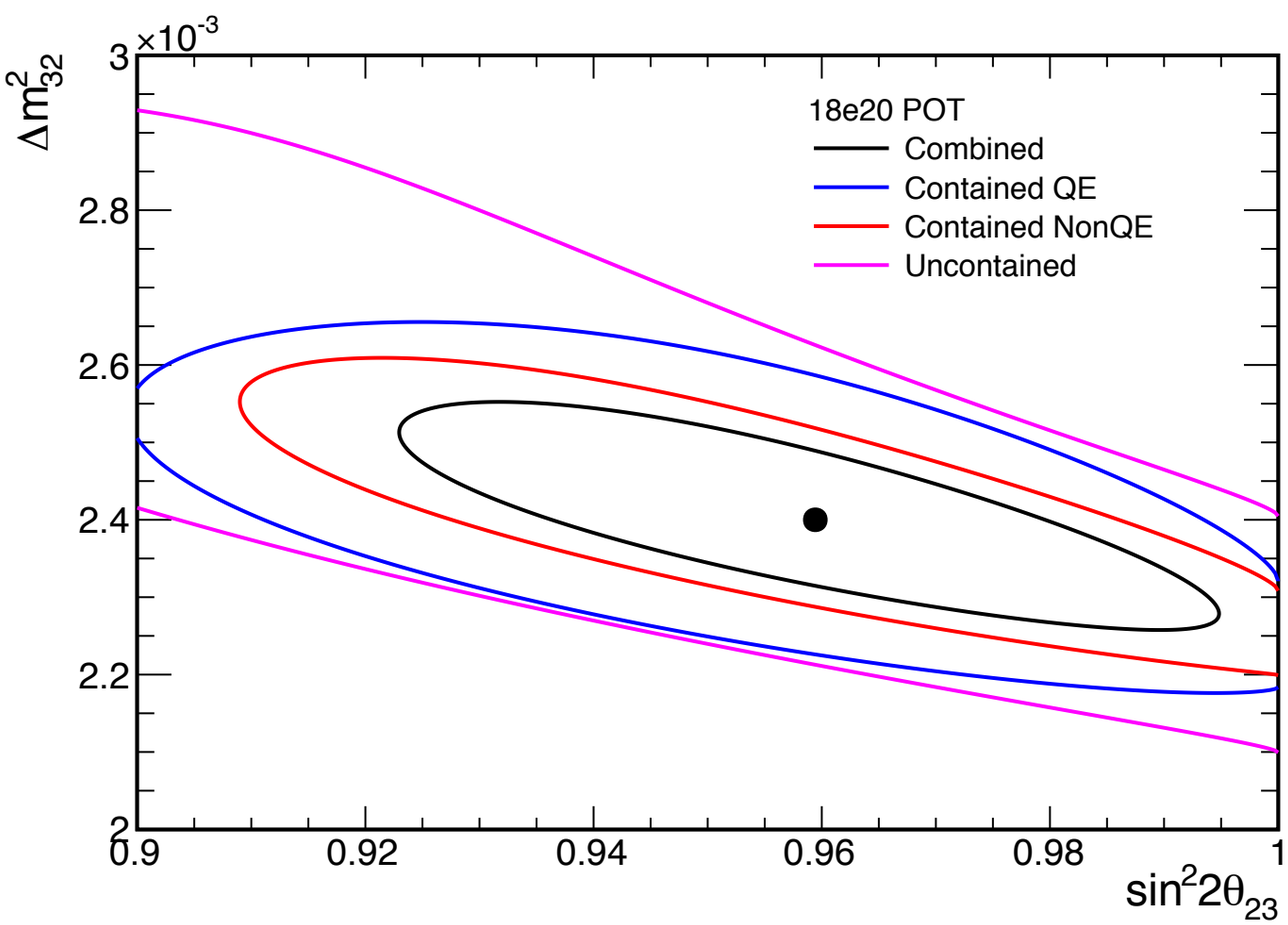


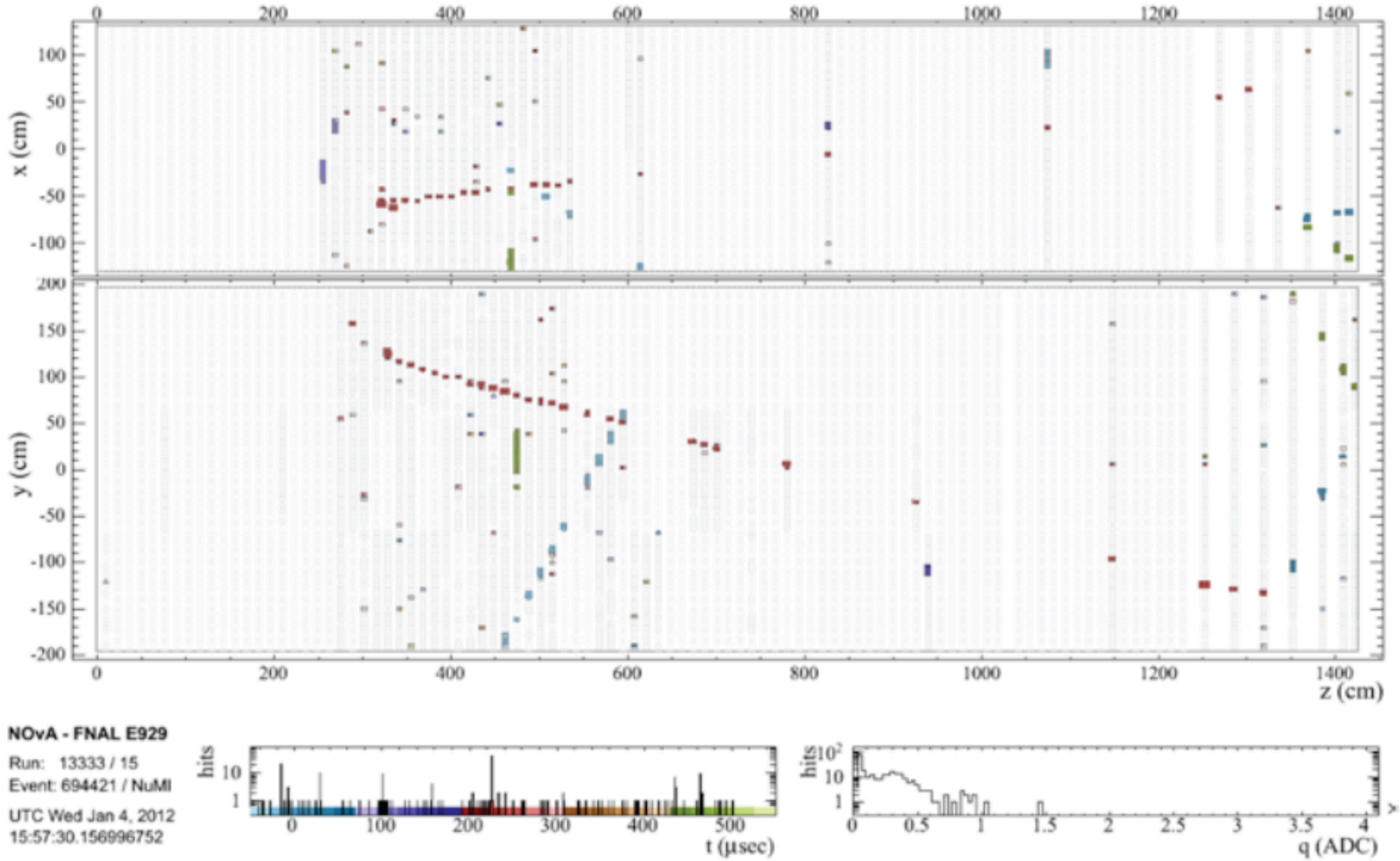

Contained QE Sample
Events / 18e20 POT / 250 MeV
Energy (GeV)
Fake Data
All MC
ν_μ CC MC
NC MC
Unoscillated
$\sin^2 2\theta_{23} = 0.96$


Contained NonQE Sample
Events / 18e20 POT / 250 MeV
Fake Data
All MC
ν_μ CC MC
NC MC
Unoscillated


Uncontained CC Sample
Events / 18e20 POT / 250 MeV
Energy (GeV)
Fake Data
All MC
ν_μ CC MC
NC MC
Unoscillated


$\nu_\mu \rightarrow \nu_\mu$ Sensitivity
Δm^2_{32}
$\times 10^{-3}$
$\sin^2 2\theta_{23}$
18e20 POT
Combined
Contained QE
Contained NonQE
Uncontained

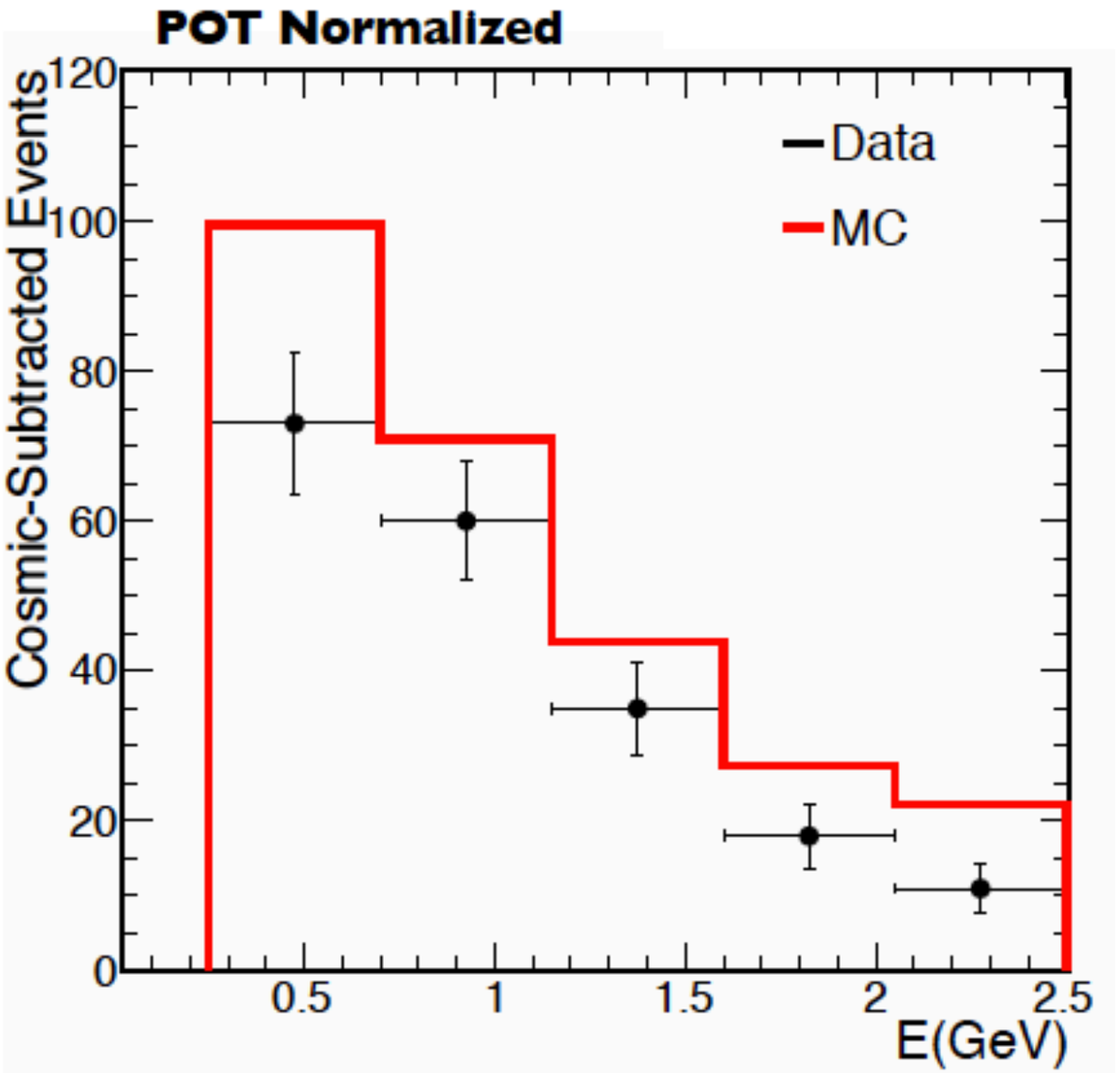

Δm^2_{32}
$\times 10^{-3}$
$\sin^2 2\theta_{23}$
18e20 POT
Combined
Contained QE
Contained NonQE
Uncontained

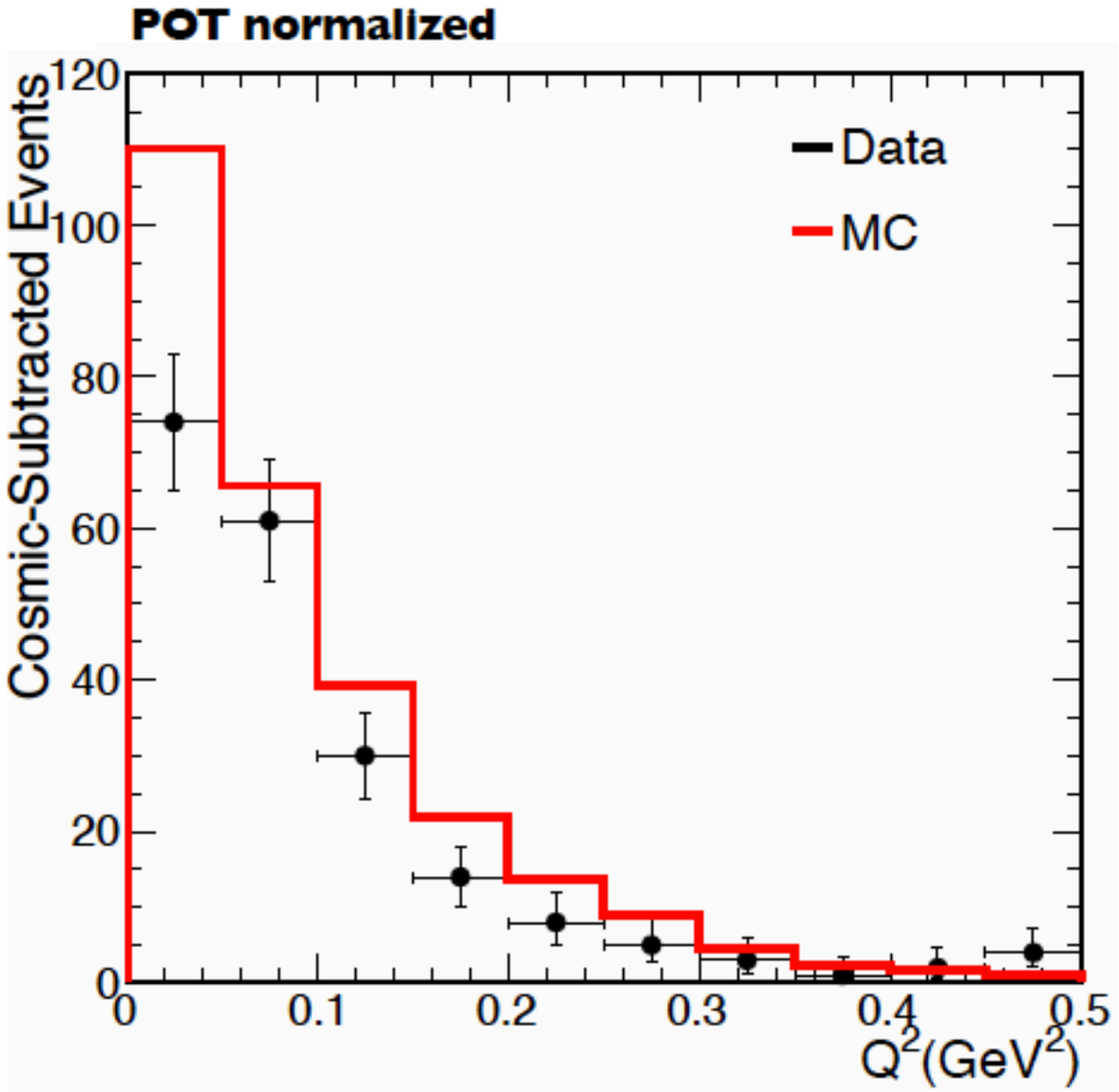


ν_μ charged-current quasi-elastic event at NDOS

Thesis topic: Minerba Bentacourt (UMN)

ν_μ charged-current quasi-elastic events in NDOS

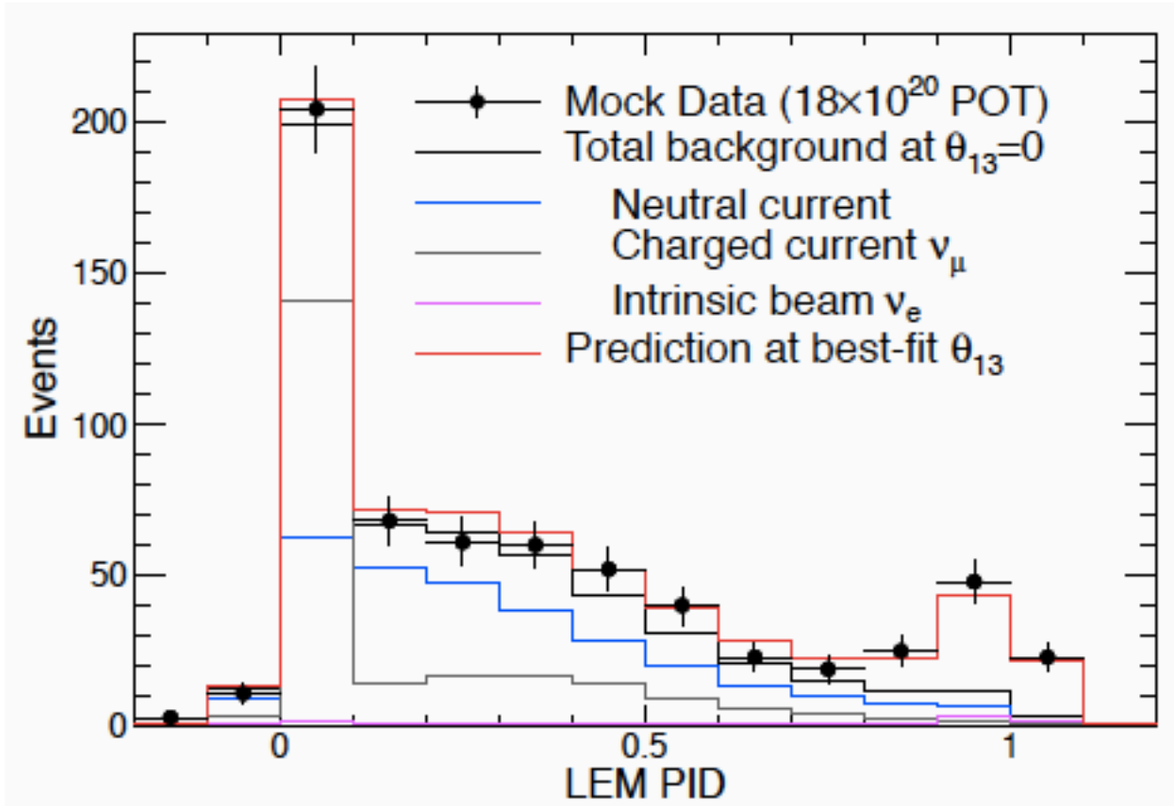


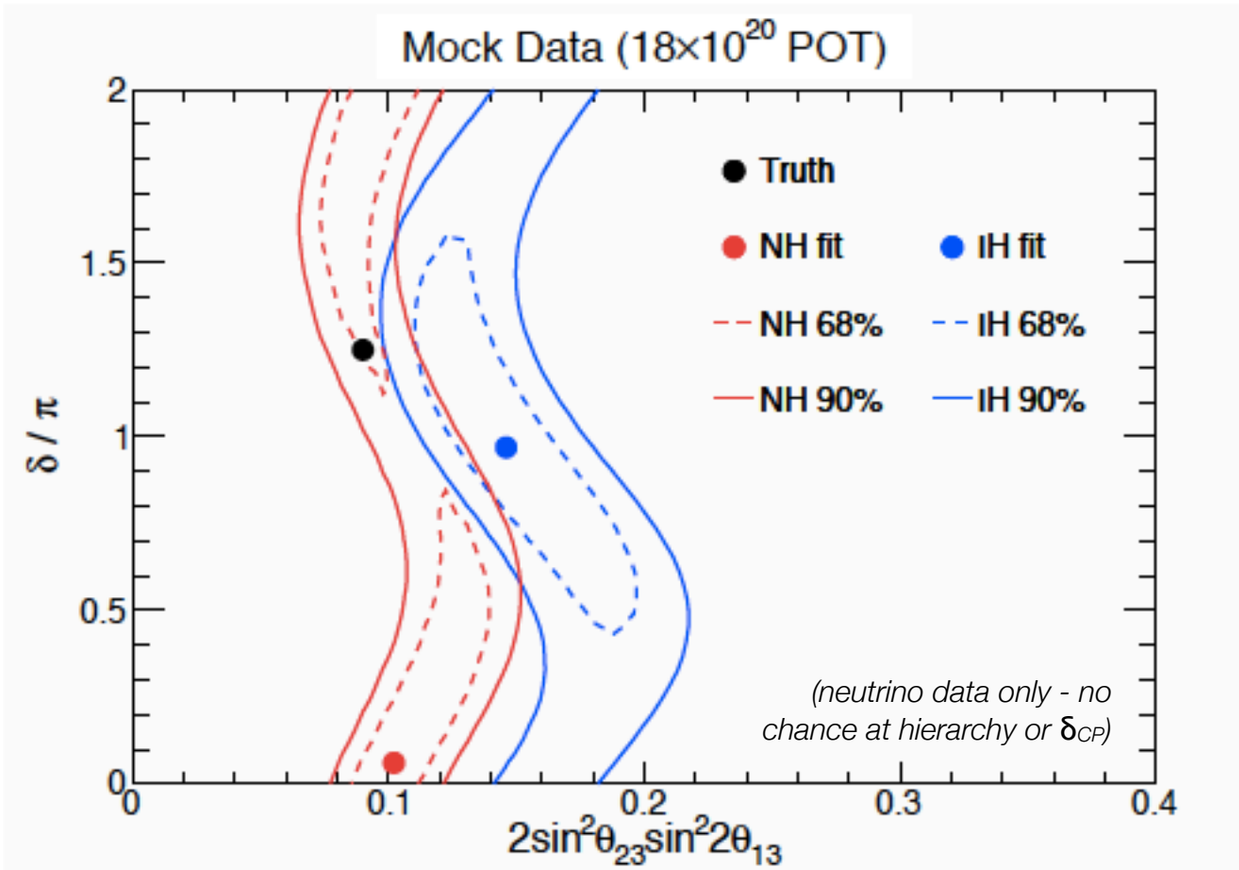


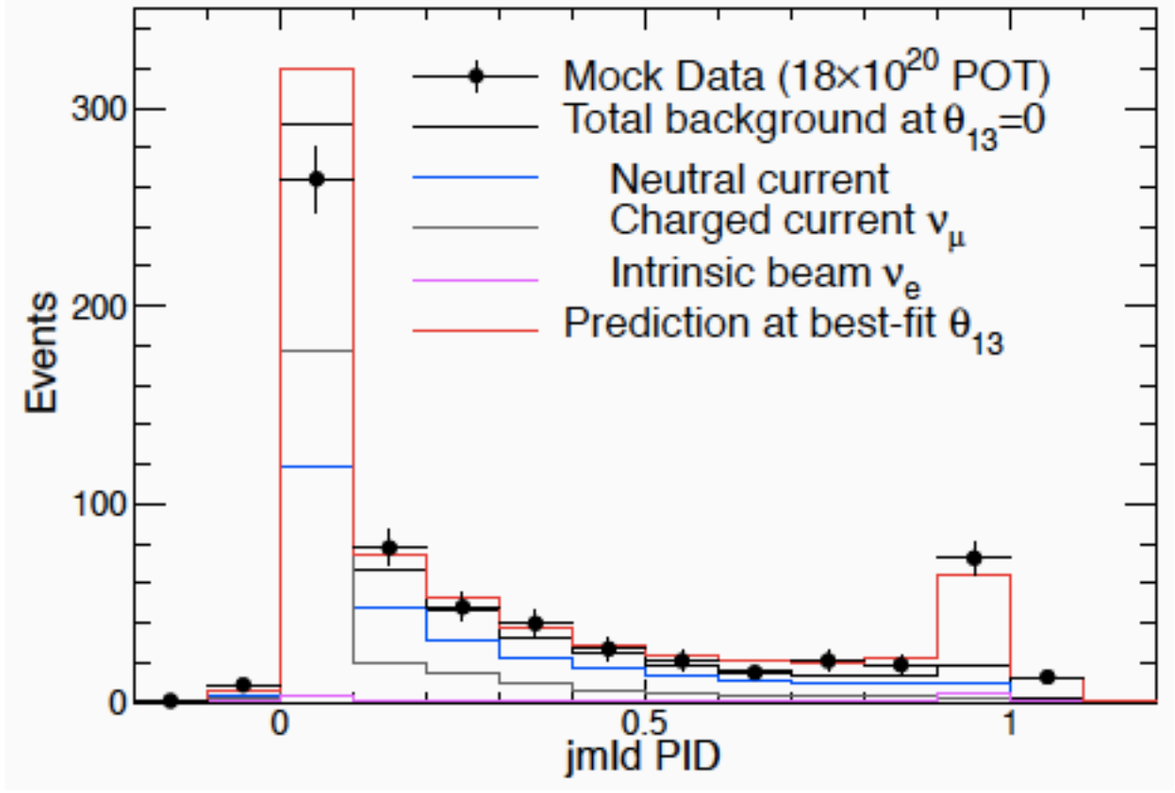
Likely to be NOvA's first paper

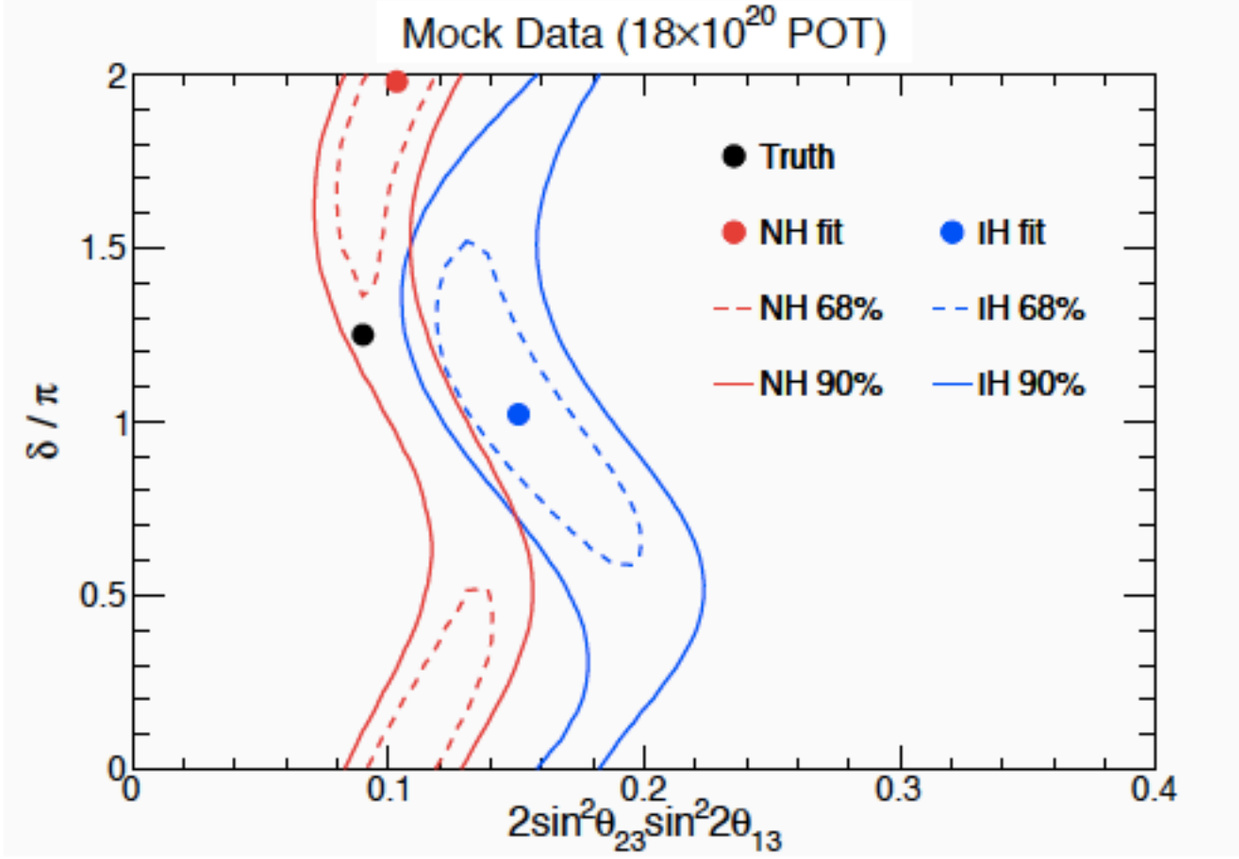
Thesis topic: Minerba Bentacourt (UMN)

$\nu_\mu \rightarrow \nu_e$ MDC Results



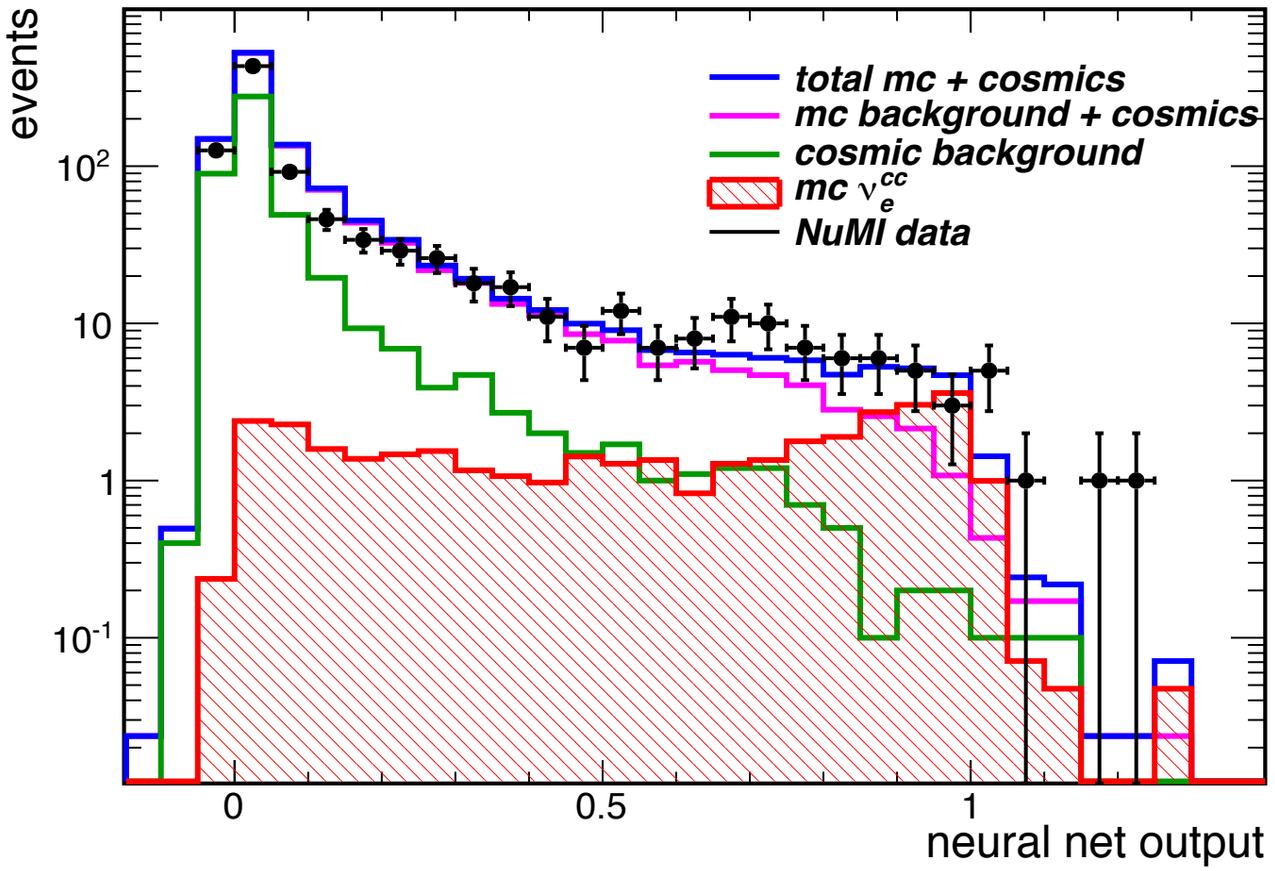


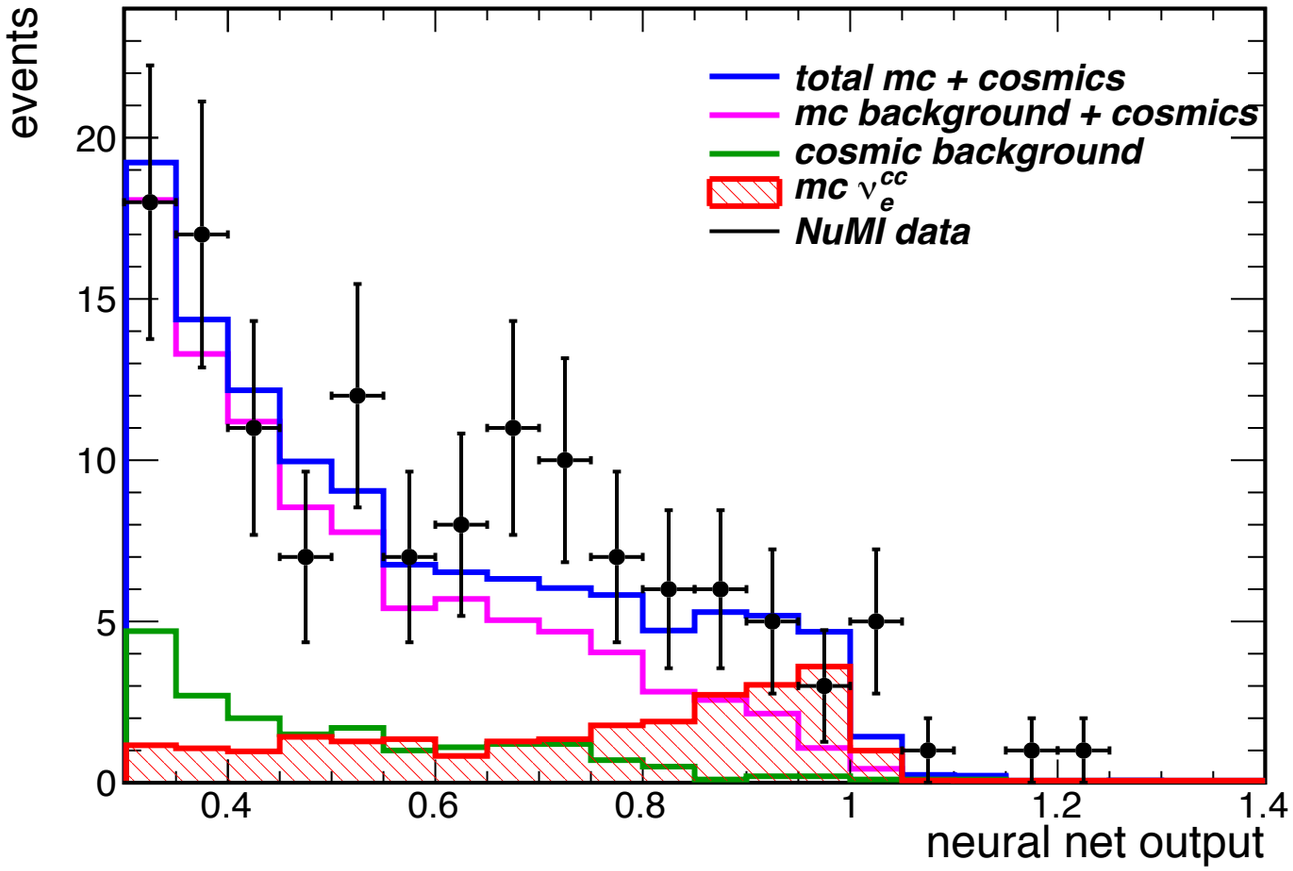


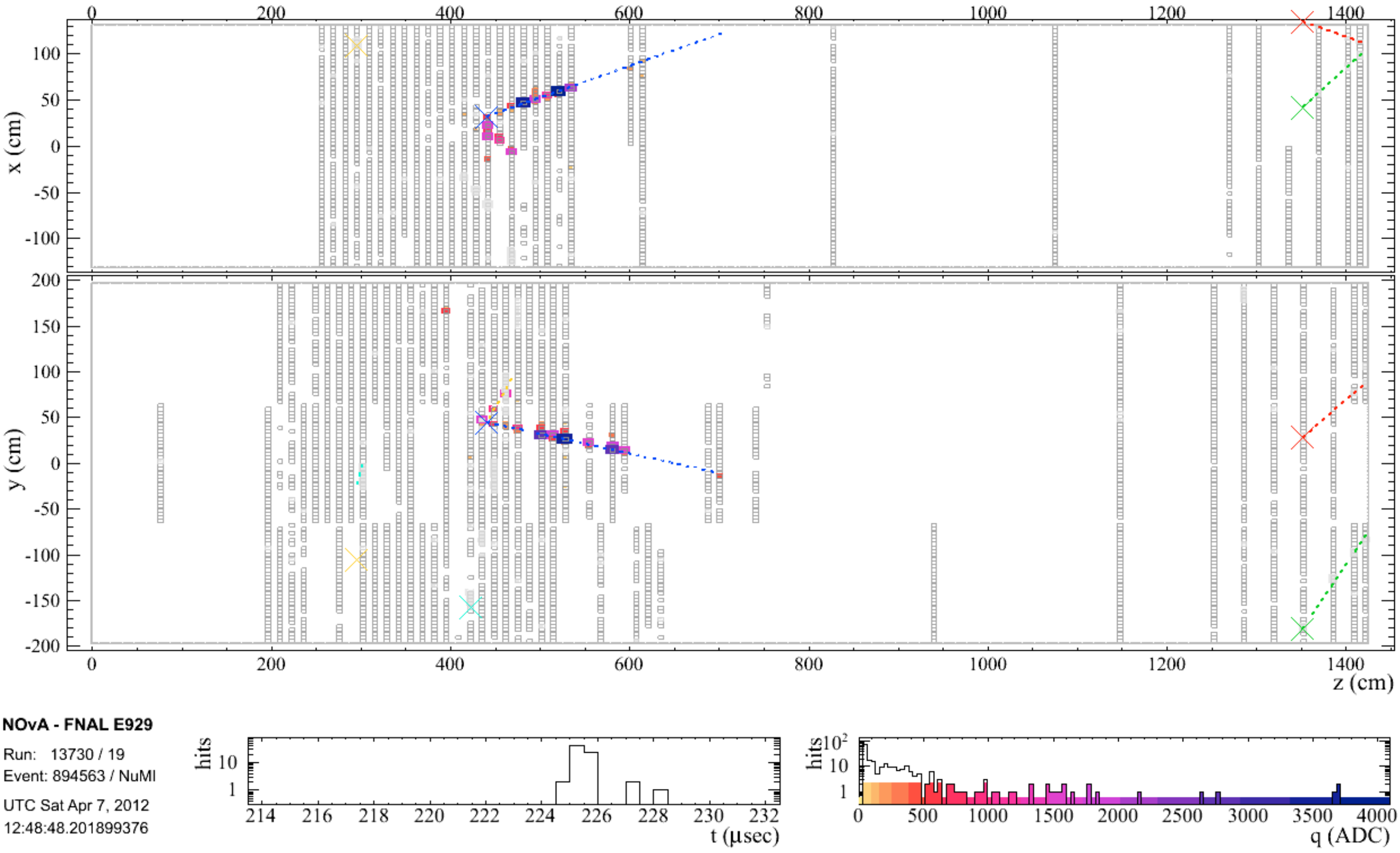


Electron neutrinos in NDOS

- In addition the the MDC we ran the analysis chain on the NuMI data recorded at NDOS
- Ran it “as is”. Situation at NDOS is much harder than far detector will be
  - Sparsely instrumented
  - No overburden
  - Large surface area / volume ratio
  - Lower energy neutrino spectrum
- Measured the electron neutrino component of the beam (data pulls away from magenta histogram):



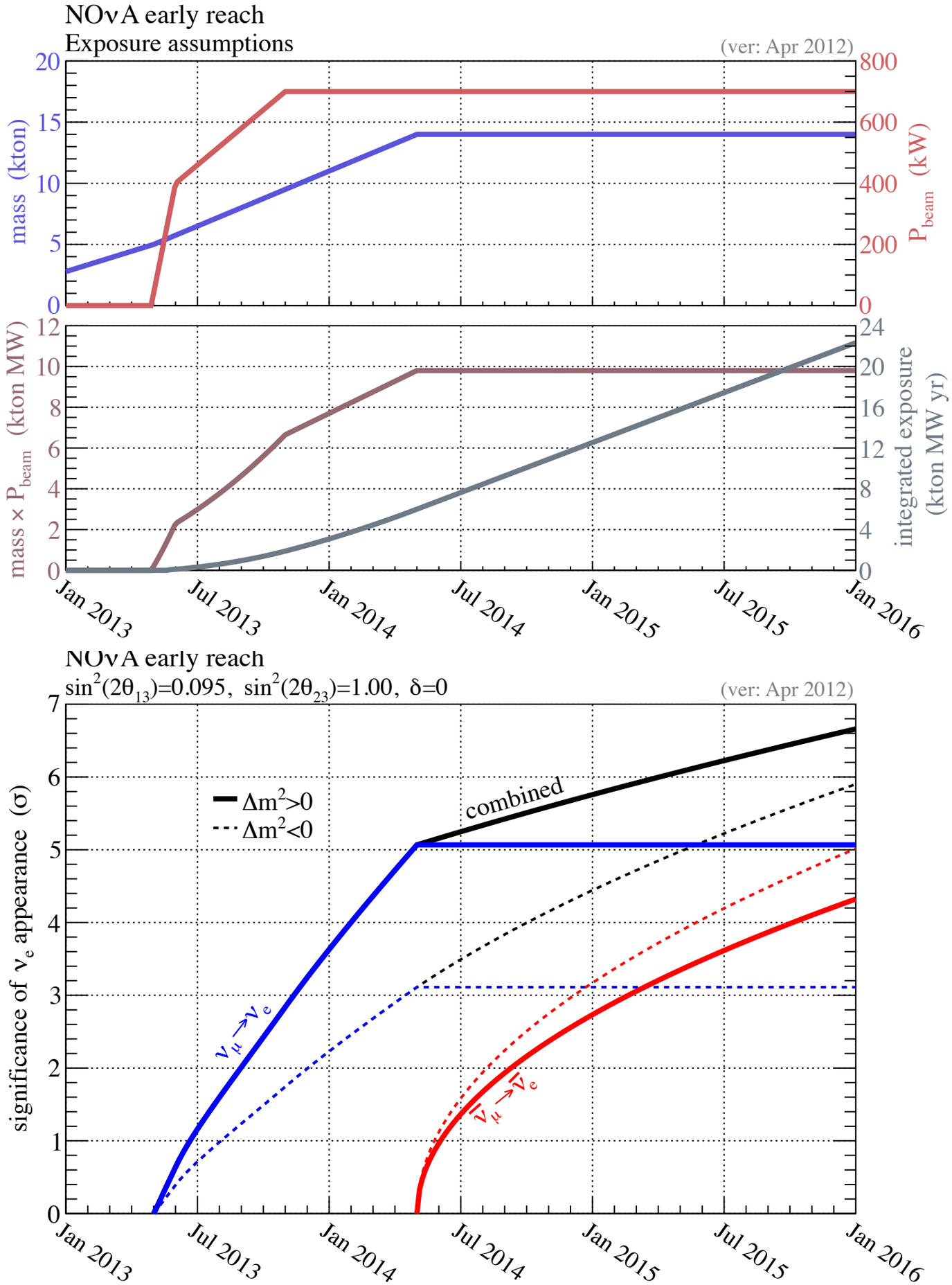




ν_e charged-current quasi-elastic event at NDOS

NOvA Early Data 2013-2014

- Old assumptions : Roughly slide the x-axis back one month
- 5-sigma signal (normal hierarchy) 3-sigma signal (inverted hierarchy) just as construction is finishing
- On track for release of first results for Neutrino 2014



Summary

- Construction and outfitting are proceeding well. Expect to have 3 kt of far detector reading out on May 31st
- APD test stand has a 98% success rate and indicates that APD installation at far detector will keep pace with the schedule.
- Critical path is a tie between filling rate / APD delivery rate to Ash River.
- All tools we need for commissioning exist
- Shifts begin 9hrs/day, 5days/wk on March 11th, 24/7 on June 1st.
- Early beam delivery is likely limiting factor to satisfying key commissioning performance parameter
- All pieces needed for ν_μ and ν_e data analysis are in place and have been tested on mock data and on ***real data*** from prototype detector
    - Near detector schedule is likely critical path for first analysis results by Neutrino 2014
    - Looking for ways to advance this schedule