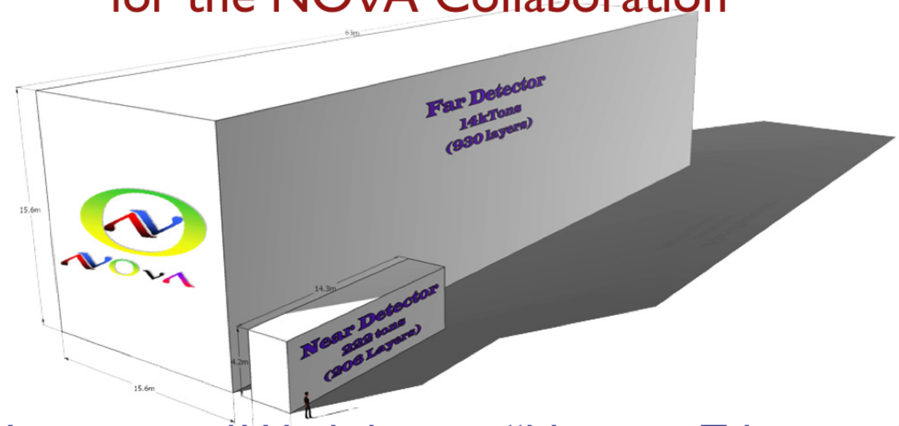
Status of NOνA

Alexandre Sousa
Harvard University
for the NOνA Collaboration

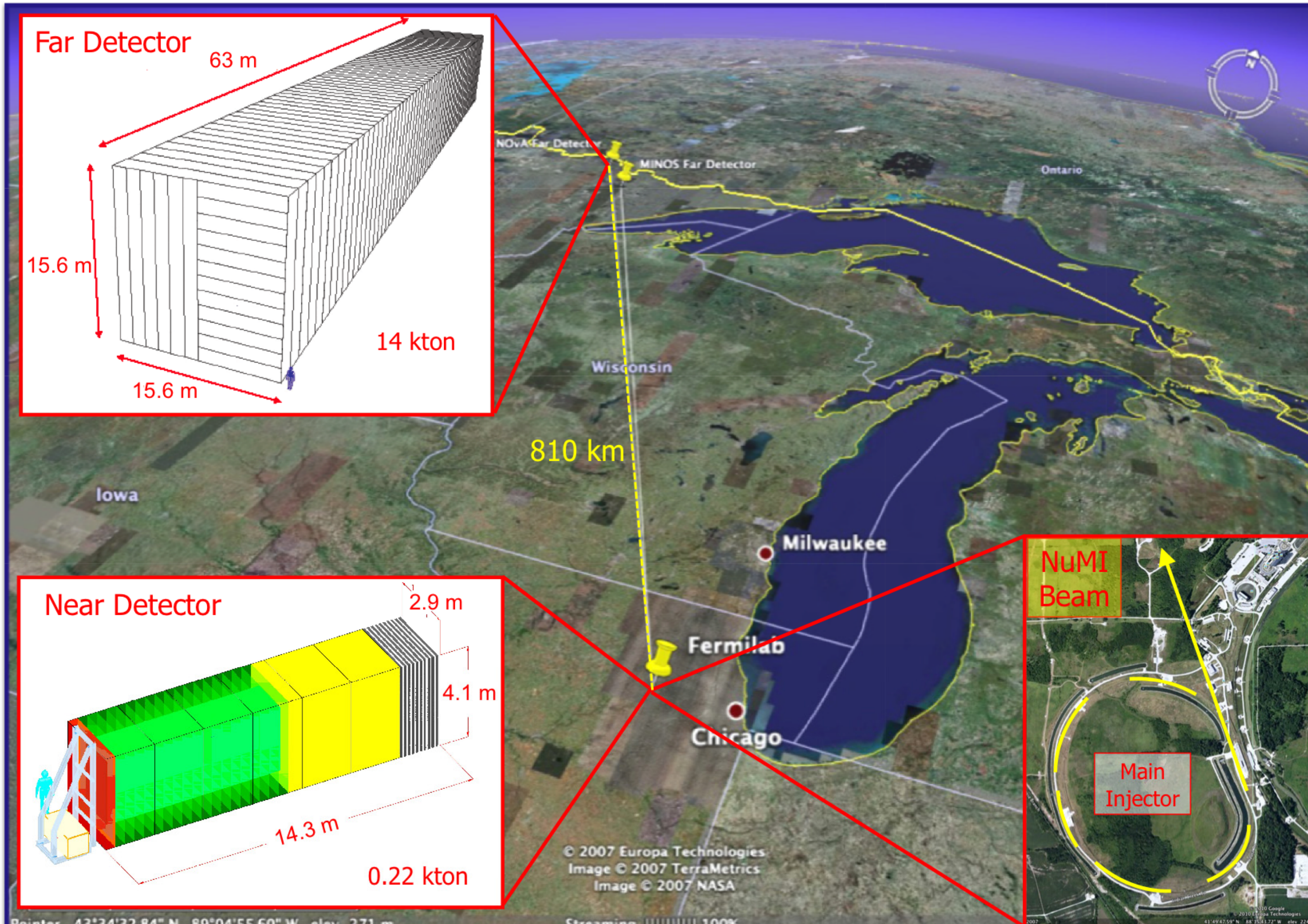


XIV International Workshop on "Neutrino Telescopes"
Palazzo Franchetti, Venice
March 16, 2011

NOvA Overview

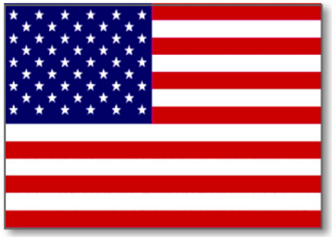
NuMI Off-Axis ν_e Appearance Experiment

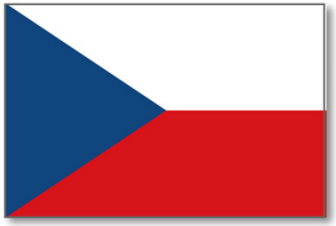
- 810 km baseline from Fermilab to Ash River, in northern MN
- 700 kW NuMI neutrino beam
- Near and Far detectors placed 14 mrad off the NuMI beam axis
- Search for $\nu_\mu \rightarrow \nu_e$ and $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ oscillations to:
  - Measure θ_{13}
  - Determine the neutrino mass hierarchy
  - Constrain δ_{CP}



The NOvA Collaboration

140 Collaborators in 26 Institutions from 4 Countries

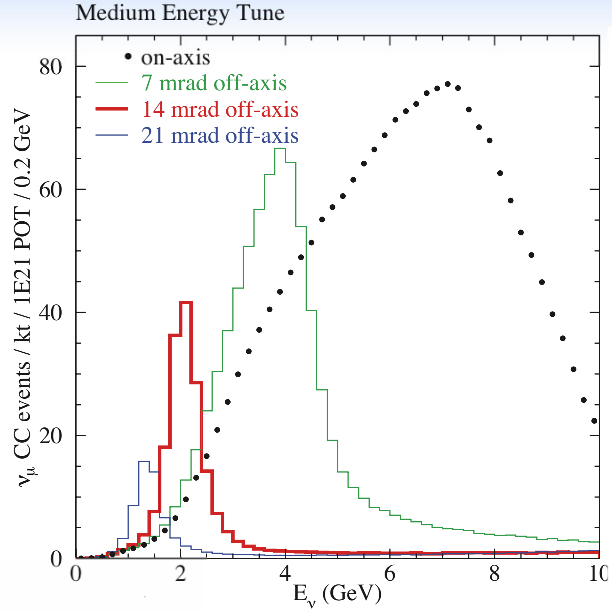


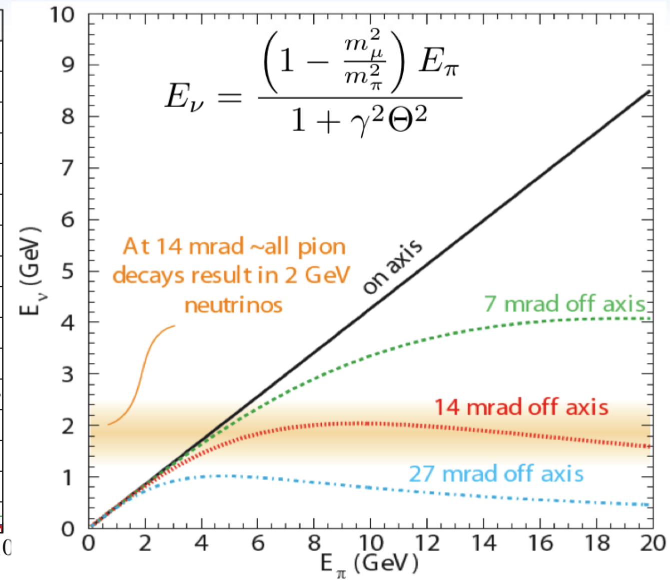


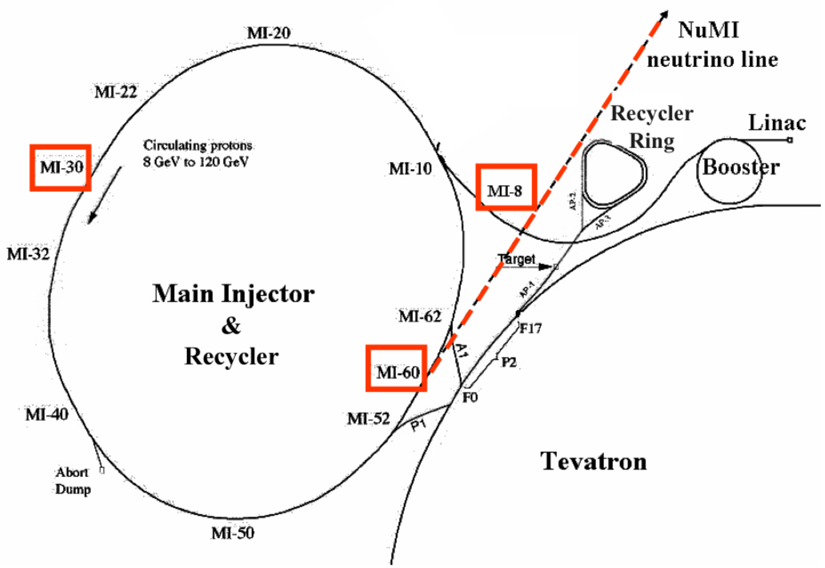
Argonne, Athens, Caltech, Charles, CTU Prague, Fermilab, FZU, Harvard, Indiana, Lebedev Physical Institute, Michigan State, Minnesota-Twin Cities, Minnesota-Duluth, INR Moscow, Iowa State, P.U.C. Rio de Janeiro, South Carolina, SMU, Stanford, Tennessee, Texas-Austin,Texas-Dallas, Tufts, Virginia, Wichita State, William & Mary

Off-Axis NuMI Beam

- Medium Energy NuMI configuration most favorable to look for $\nu_\mu \rightarrow \nu_e$ oscillations over 810 km baseline
- Placing the NOvA detectors 14 mrad off the beam axis results in narrow band beam peaked at E_ν=2 GeV
  - Drastic reduction of NC backgrounds







- NuMI will be upgraded from ~320 kW to 700 kW during 2012 shutdown
- Reduce cycle time from 2.2 to 1.33 seconds
  - via slip-stacking in the Recycler prior to Main Injector
- Increase intensity/cycle with 12 Booster batches instead of 11 by using new injection kicker magnet
- Upgrade beam components, such as target and horns
- 10 μsec beam pulse every 1.33 sec
- 4.9×10^{13} POT/pulse => 6.0×10^{20} POT/year of running

Off-Axis NuMI Beam

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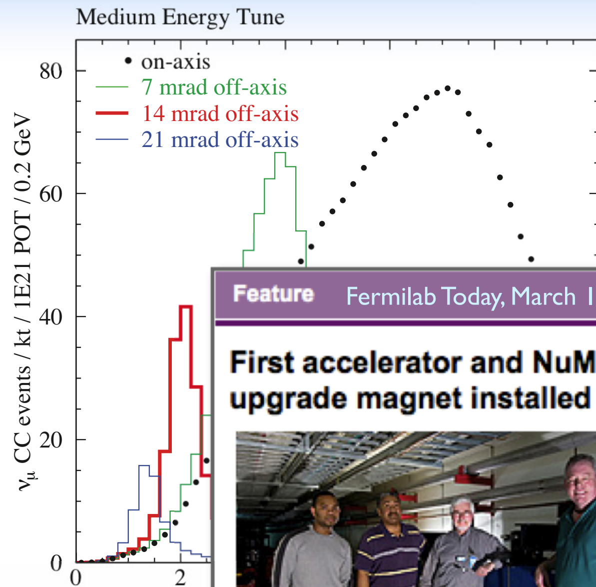
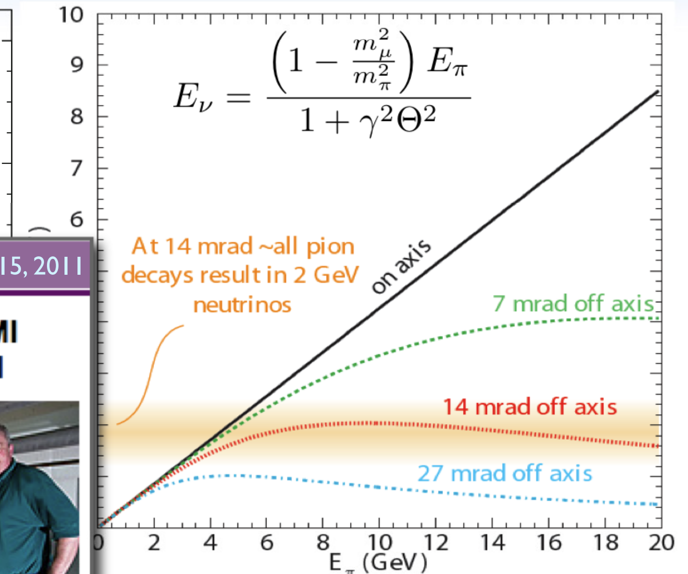




Feature Fermilab Today, March 15, 2011

First accelerator and NuMI upgrade magnet installed

Bradly Verdant, Jack Moore, Bill Markel and Jeff Duncan, the crew who installed the first magnet. Not pictured are Kyle Kendziora and Jerry Nelson. *Photo: Marty Murphy*

Although this month's shutdown of the Accelerator Complex lasted only five days, it was enough time for Fermilab to get one step closer to turning on the NOvA experiment.

On Wednesday, March 9, Accelerator and NuMI Upgrade Coordinator Cons Gattuso led the safe and successful installation of the first dipole magnet in the 8 GeV tunnel for the new Booster to Recycler injection line, a necessary step to upgrade existing facilities for the NOvA running era.

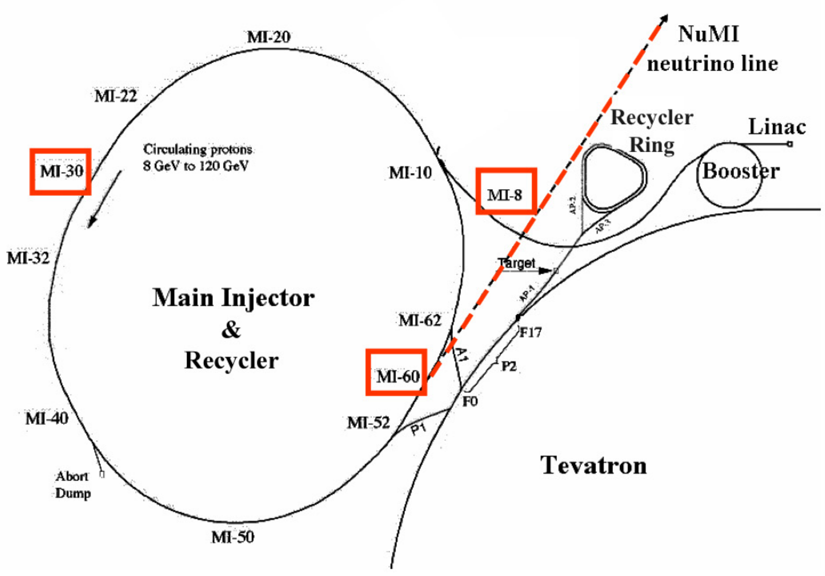
om ~320 kW to 700 kW during

.2 to 1.33 seconds
ecycler prior to Main Injector

ith 12 Booster batches
v injection kicker magnet
its, such as target and horns

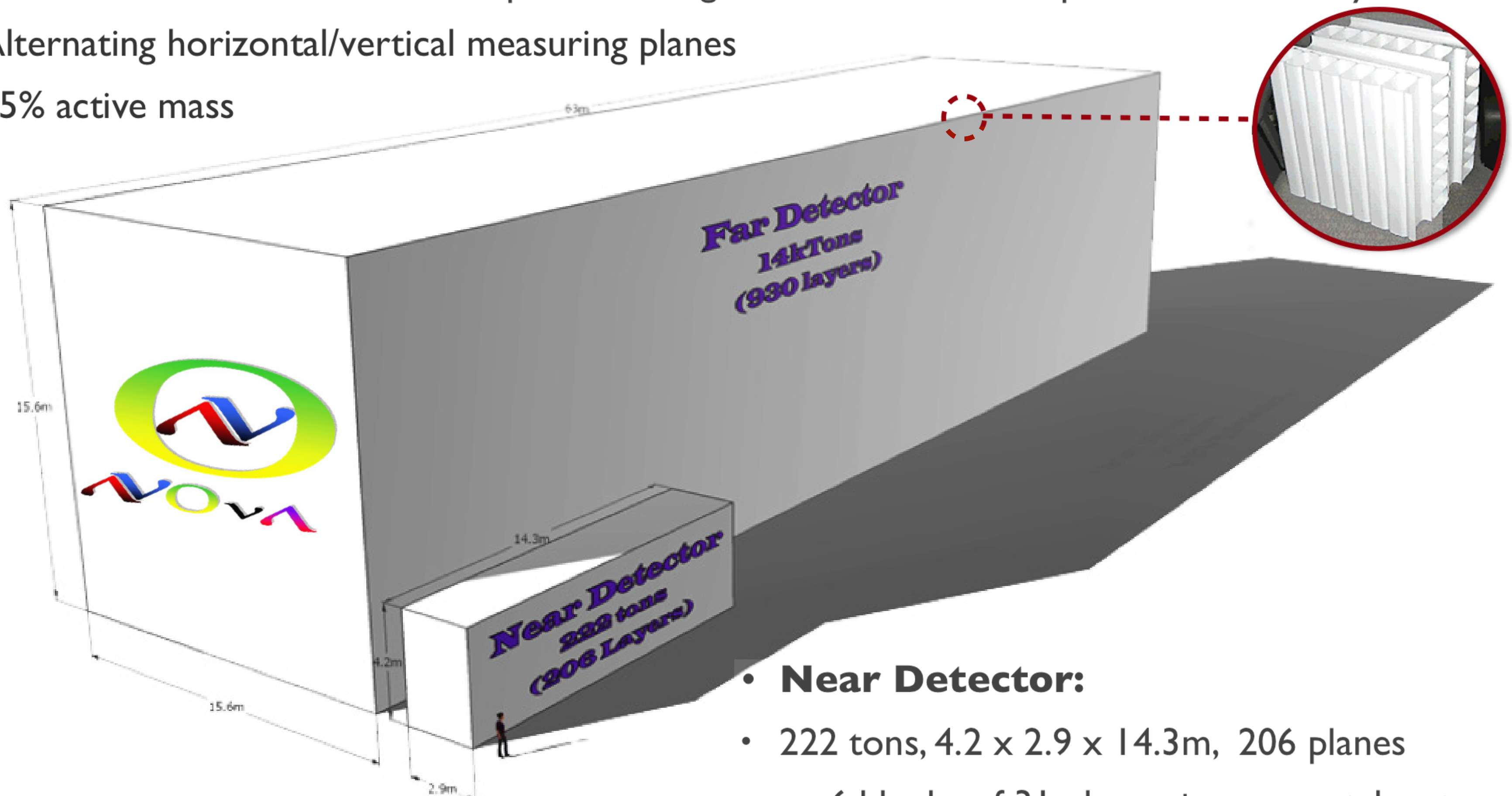
/ 1.33 sec

0x10[20] POT/year of running



NOvA Detectors

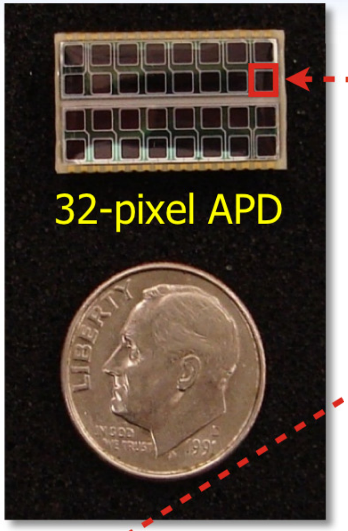
- **Far Detector:**
- 14 ktons, 15.6 x 15.6 x 63m, 930 planes arranged in 30 blocks of 31 planes for assembly
- Alternating horizontal/vertical measuring planes
- 65% active mass

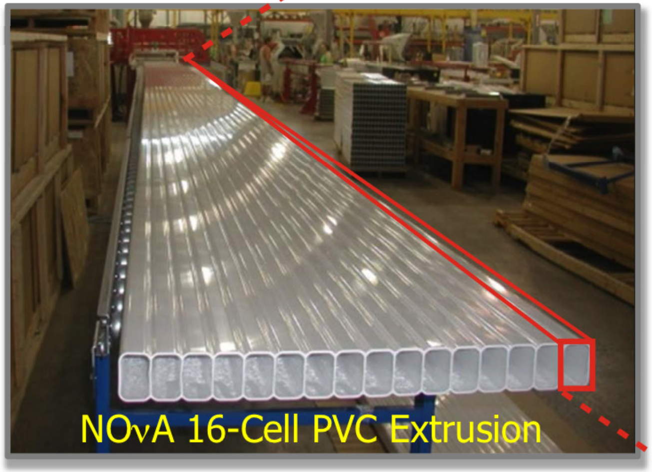


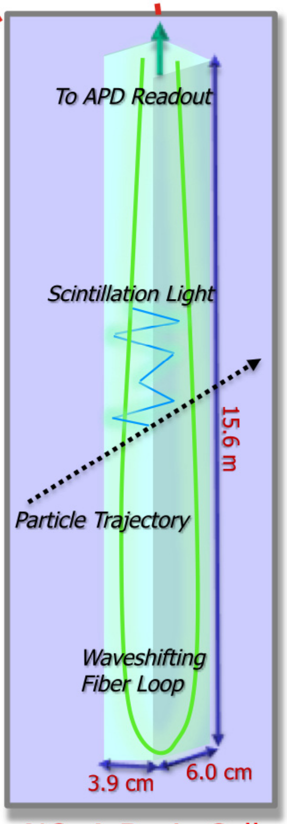
- **Near Detector:**
- 222 tons, 4.2 x 2.9 x 14.3m, 206 planes
  - 6 blocks of 31 planes + muon catcher to range out muons
- To be placed 14 mrad off-axis next to MINOS ND

Detector Technology

- Near and Far detectors composed of highly reflective 16-cell PVC extrusions (15% TiO_2)
  - Two extrusions glued together into 32-cell module
  - 24 extrusions/plane in Far detector (384 cells/plane)
  - 357 120 cells in Far Detector
- Extrusions filled with liquid scintillator (mineral oil + 5% pseudocumene)
- Each cell read out by a wavelength-shifting fiber into one pixel of a 32-pixel avalanche photodiode (APD)
  - 30 p.e. from far-end of cell into APD

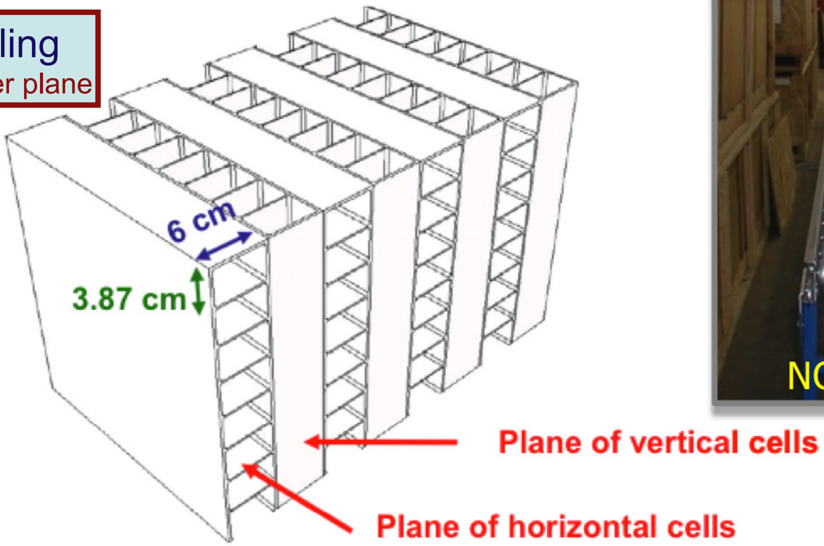






NOνA Basic Cell

Sampling
$0.15\ X_0$ per plane

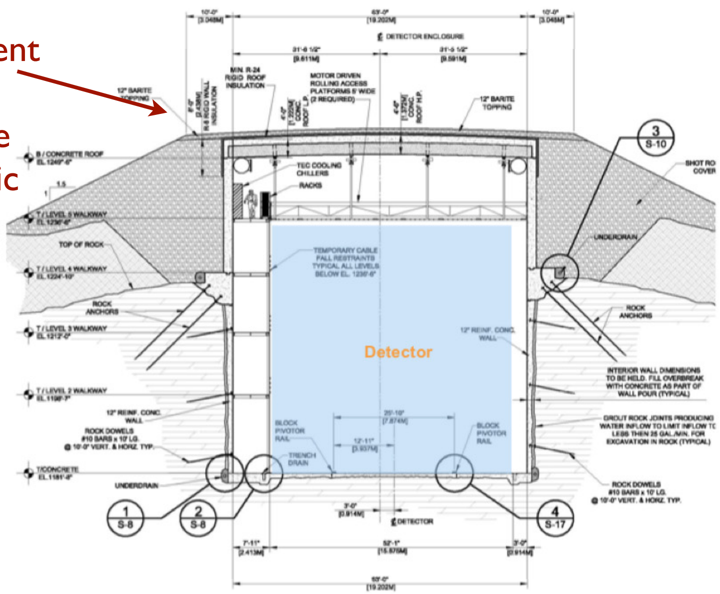


Far Detector Construction


Far Detector Building, Ash River, MN - Jan 24, 2011

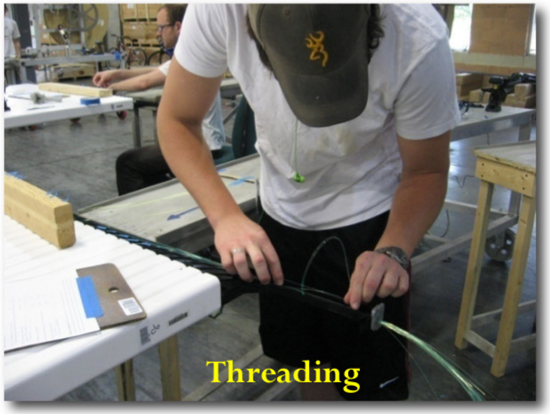
- Beneficial occupancy well under way
- Far Detector by the numbers:
  - 11.9 million liters of scintillator
  - 12 050 km of 0.7 mm optical fiber
  - 11 160 PVC modules and APDs

3m earth-equivalent overburden of Barite/Concrete to reduce cosmic backgrounds



Far Detector Factory

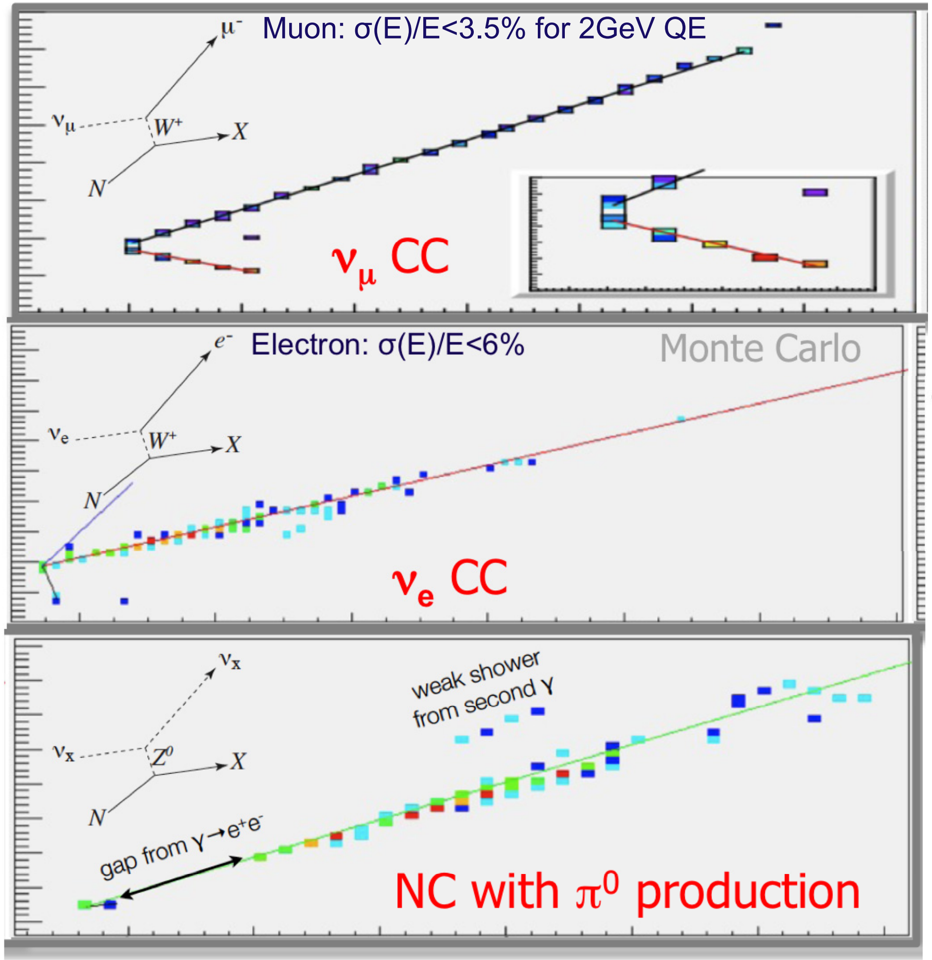
- Industrial-scale production and storage of FD modules will proceed in large warehouse at University of Minnesota - Expect participation of ~200 undergraduate students



- Module assembly into blocks will happen at the Far Detector Building in Ash River

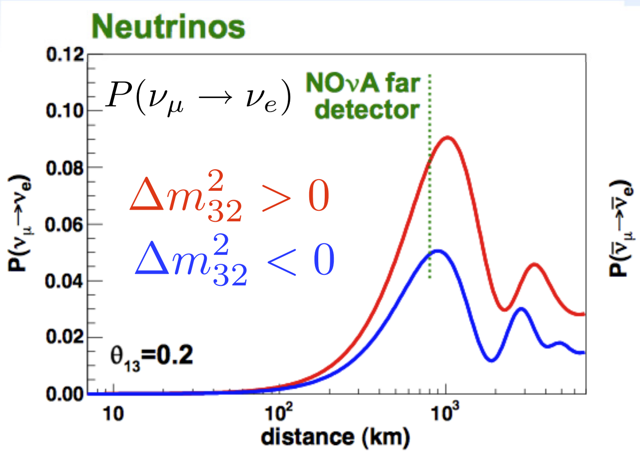
Simulated Events

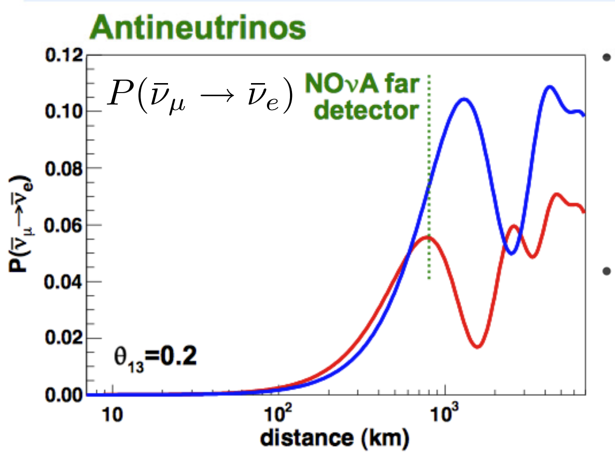
Topologies for simulated events in the NOνA detectors



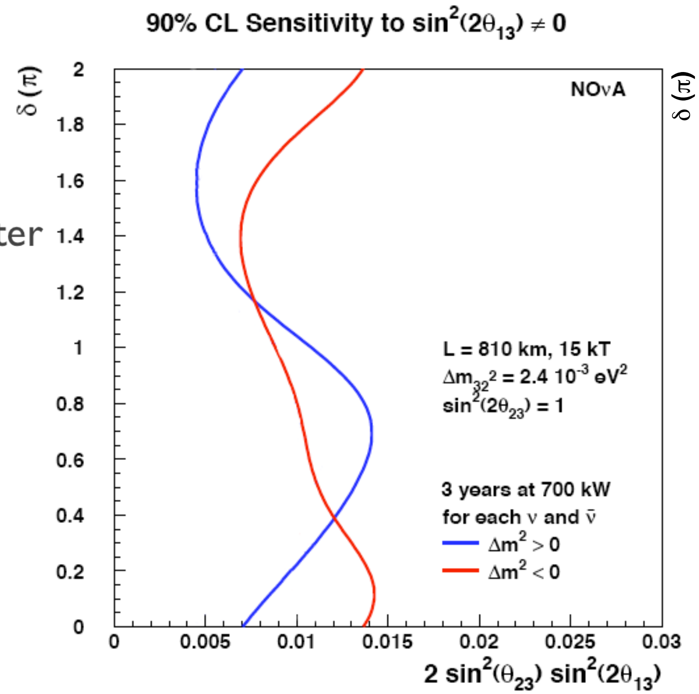
- ν_μ Charged-Current:
  - Long well-defined muon track, proton identified as short track with large energy deposition at the track end
- ν_e Charged-Current:
  - Single shower with characteristic electromagnetic shower development
- NC with π^0 in final state:
  - Possible gaps near event vertex, multiple displaced electromagnetic showers

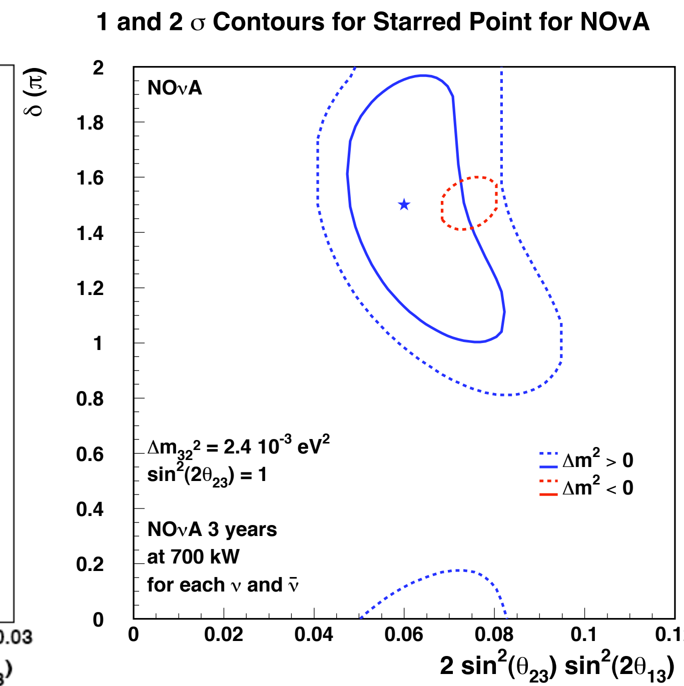
NOvA Physics Reach





- NOvA plans to run for 3 years in neutrino and 3 years in antineutrino mode
- Take advantage of large matter effects => 30% enhancement/suppression of oscillation probability (11% in T2K)

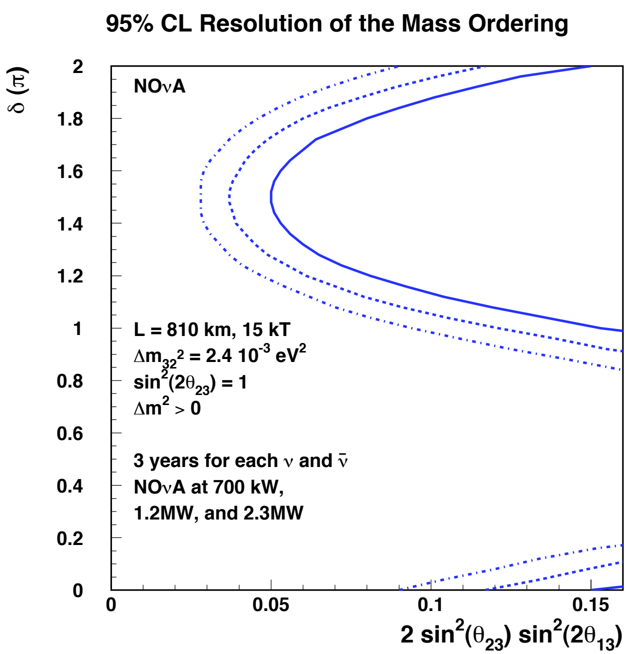




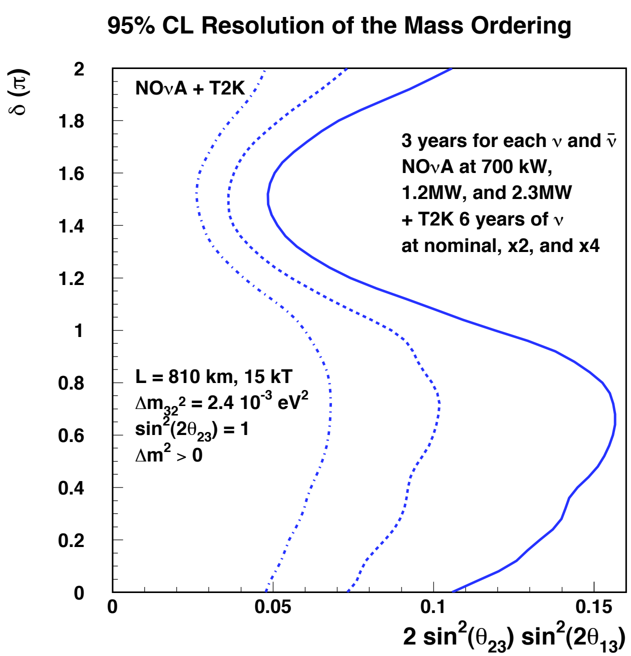
- NOvA's sensitivity to θ_{13} is one order of magnitude better than the limit from CHOOZ ($\sin^2 2\theta_{13} < 0.15$, 90% CL)
- NOvA may also begin to constrain the δ_{CP} parameter space

NOνA Physics Reach

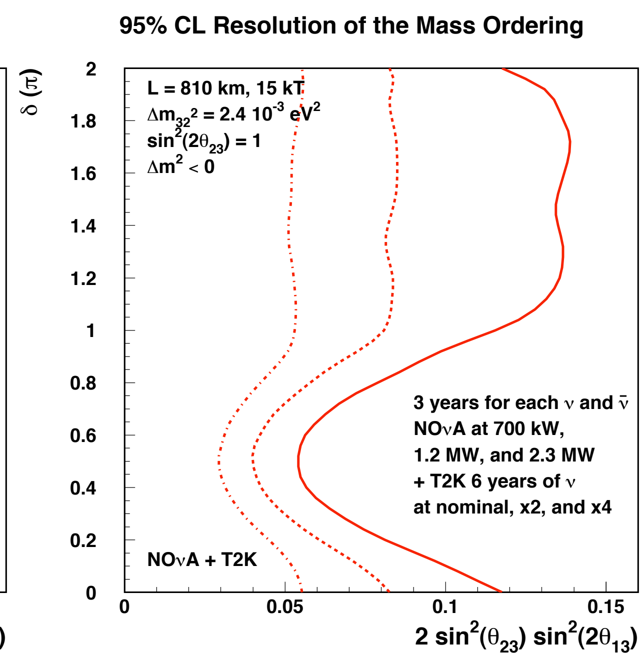
- NOνA is able to resolve ordering of neutrino mass hierarchy for large enough values of $\sin^2 2\theta_{13}$
- 95% CL resolution of mass hierarchy for values of $\sin^2 2\theta_{13}$ to the right of the curves
- Can improve sensitivity by including additional information from a different baseline



Normal Hierarchy
NOνA alone



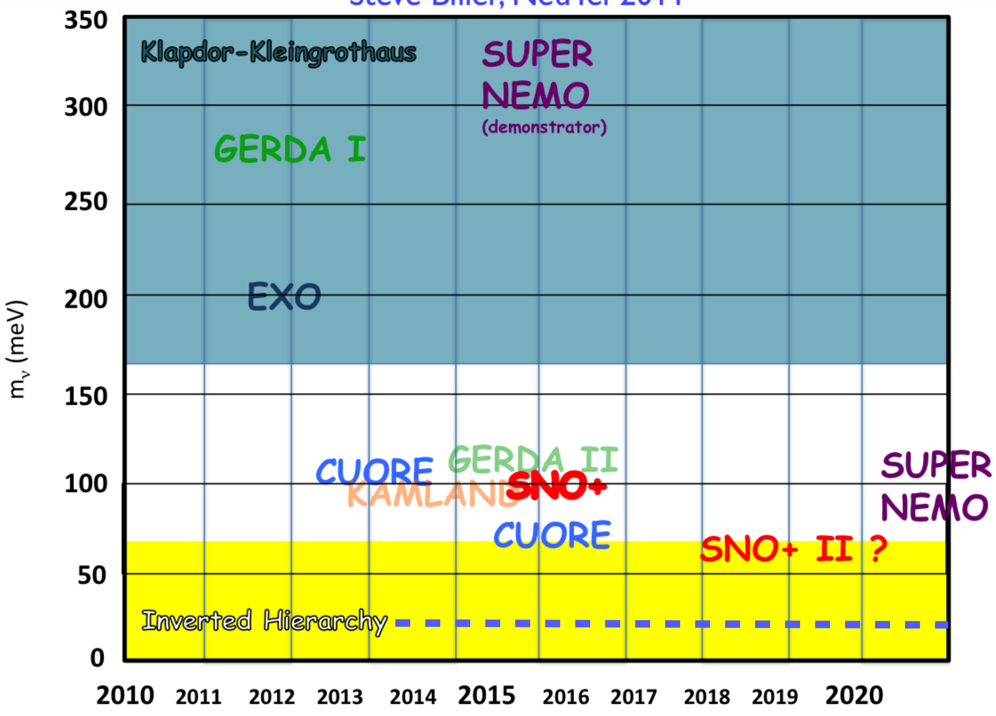
Normal Hierarchy
NOνA+T2K



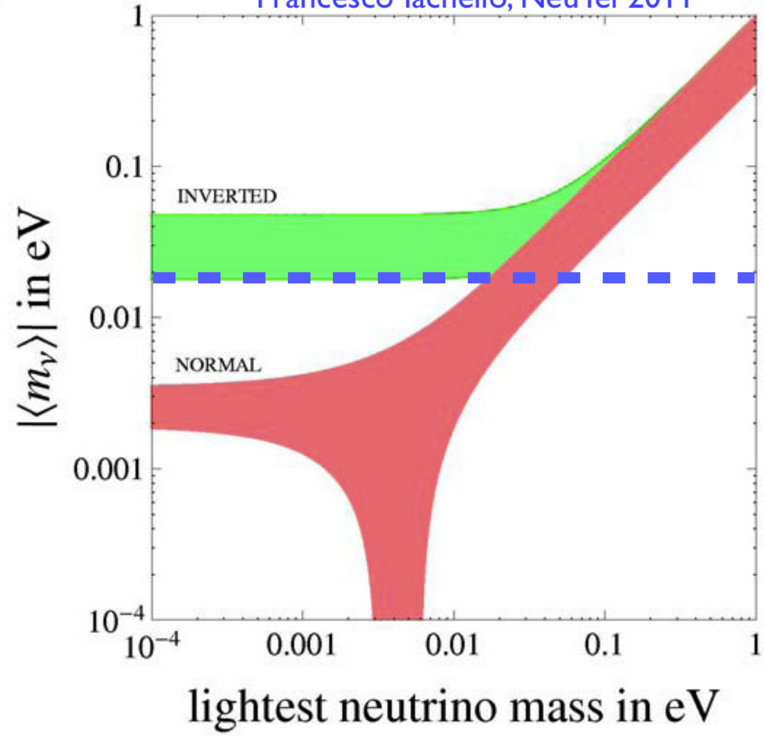
Inverted Hierarchy
NOνA+T2K

Mass Hierarchy and 0νββ Decay

Steve Biller, NeuTel 2011



Francesco Iachello, NeuTel 2011

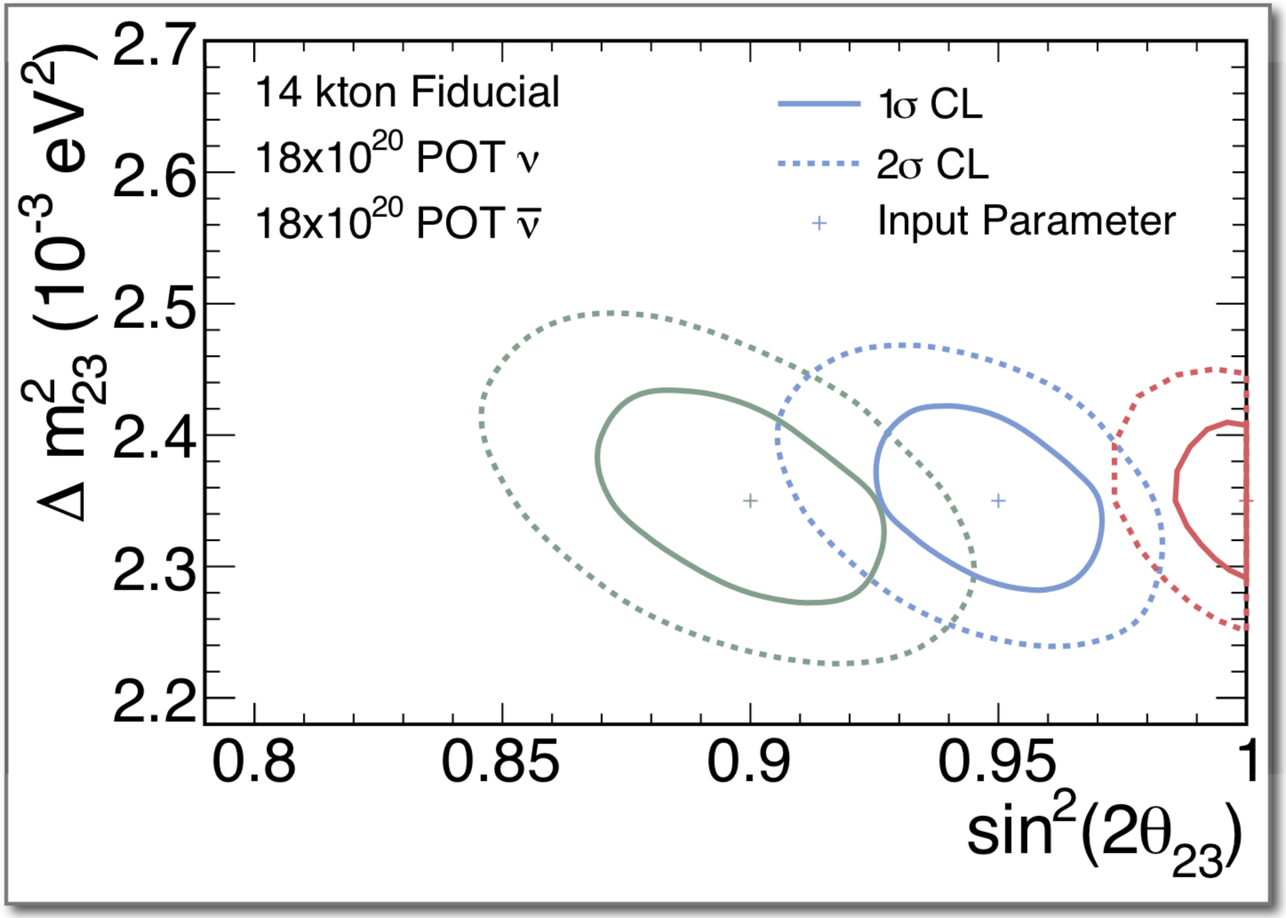


- $\langle m_\nu \rangle$ ~ 20 meV could be confirmed or ruled out in the next 10-20 years (?) by 0νββ experiments - CUORE, SuperNEMO, GERDA, SNO+, KAMLAND, etc.
- If NOνA establishes inverted ordering of the neutrino mass hierarchy and 0νββ experiments see no signal, then neutrinos are not Majorana particles

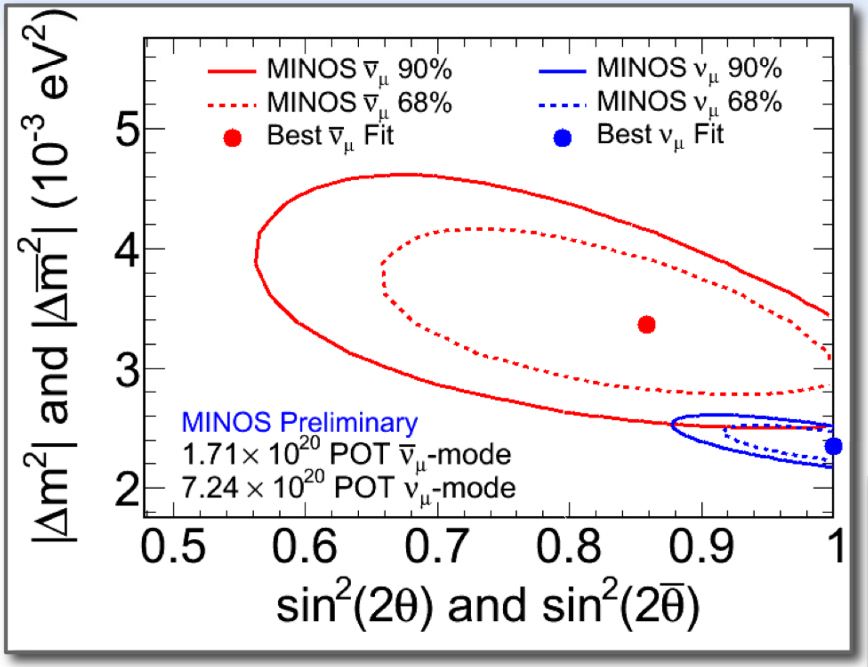
Δm^2_{32}, θ_{23} Measurement

- NOνA will improve the MINOS measurement of Δm^2_{32} and can measure $\sin^2 2\theta_{23}$ to better than 2% thanks to large statistics and excellent energy resolution

- Plot shows sensitivity contours for Δm^2_{32} at the MINOS best fit value of 2.35×10^{-3} eV^2 and different input values for $\sin^2 2\theta_{23}$

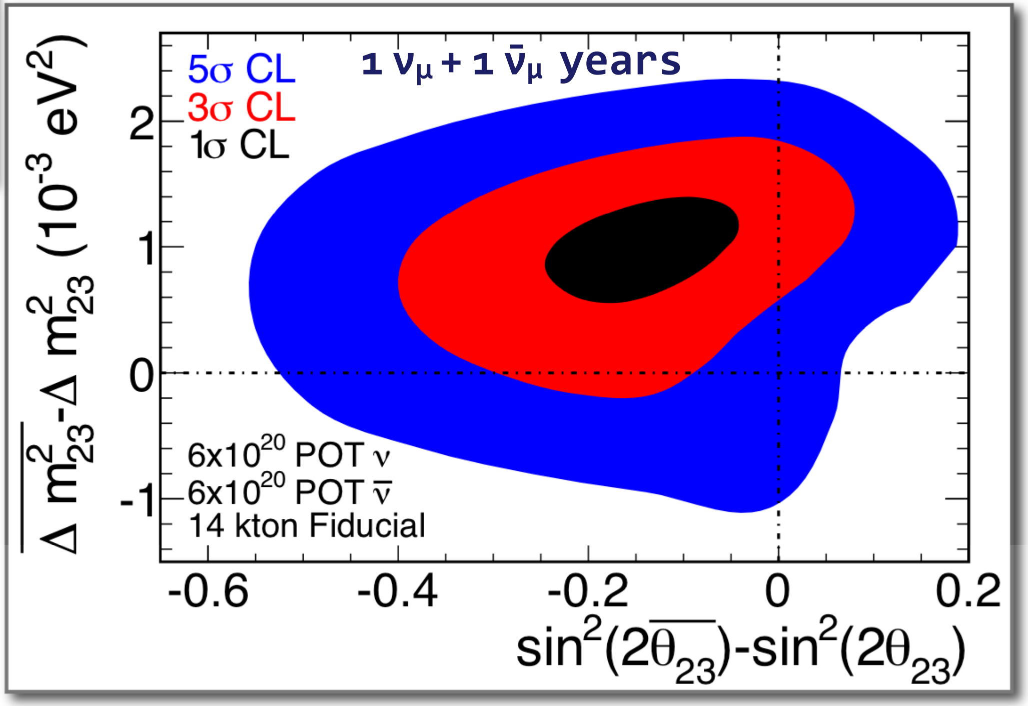


ν, ν̄ Oscillation Parameters

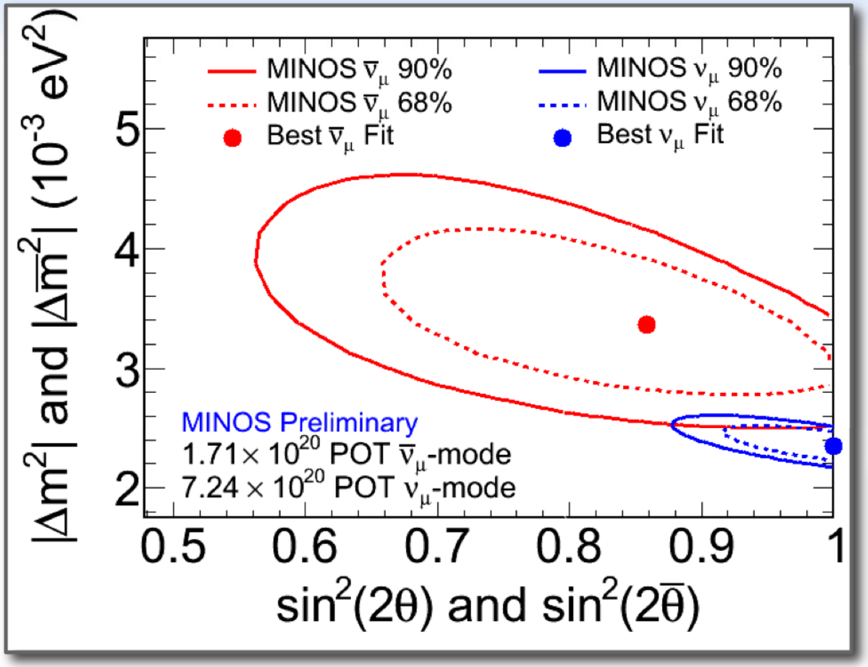


- MINOS reported a ~2σ difference between best fit values for neutrino and antineutrino oscillation parameters (see L. Corwin's presentation)

- With 1 year each of running in neutrino and antineutrino mode, assuming the MINOS results hold, NOνA can exclude null asymmetry by more than 3σ

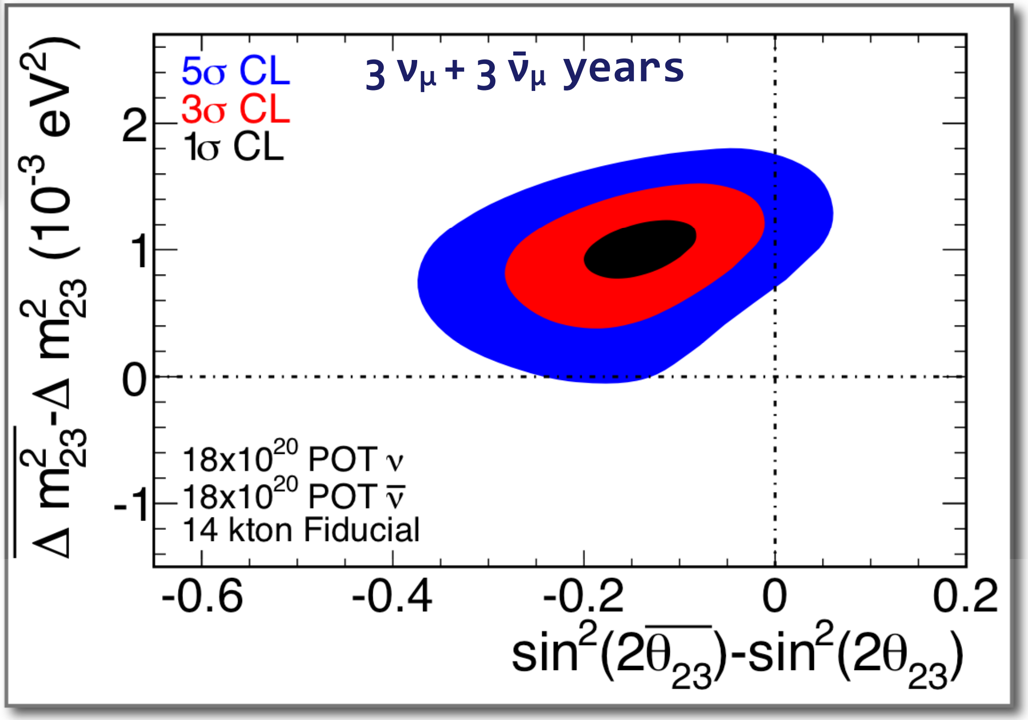


ν, ν̄ Oscillation Parameters



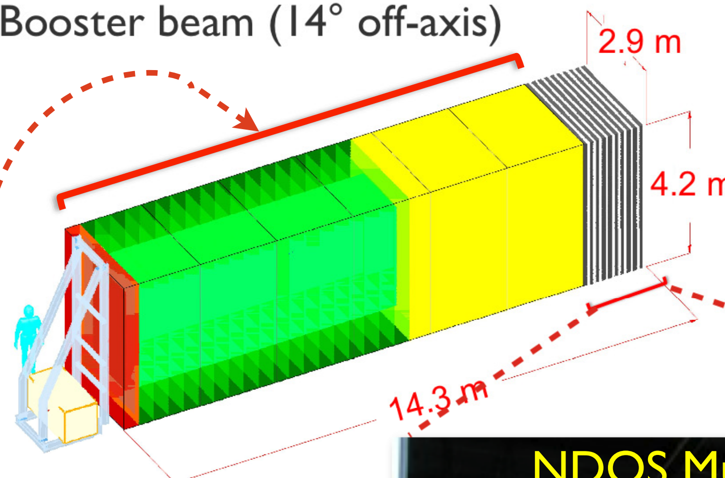
- MINOS reported a ~2σ difference between best fit values for neutrino and antineutrino oscillation parameters (see L. Corwin's presentation)

- With 3 year each of running in neutrino and antineutrino mode, assuming the MINOS results hold, NOνA can exclude null asymmetry by more than 5σ



NDOS Status

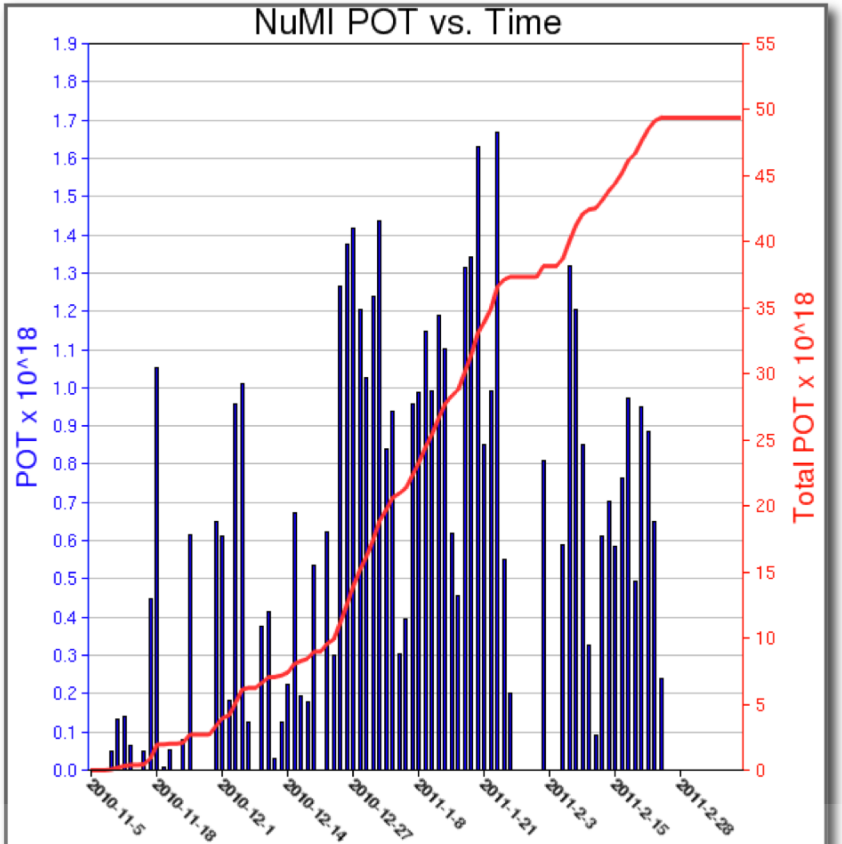
- **N**ear **D**etector **O**n the **S**urface
- Located in new surface building at Fermilab
- Exposed to NuMI beam (6.4° off-axis) and Booster beam (14° off-axis)

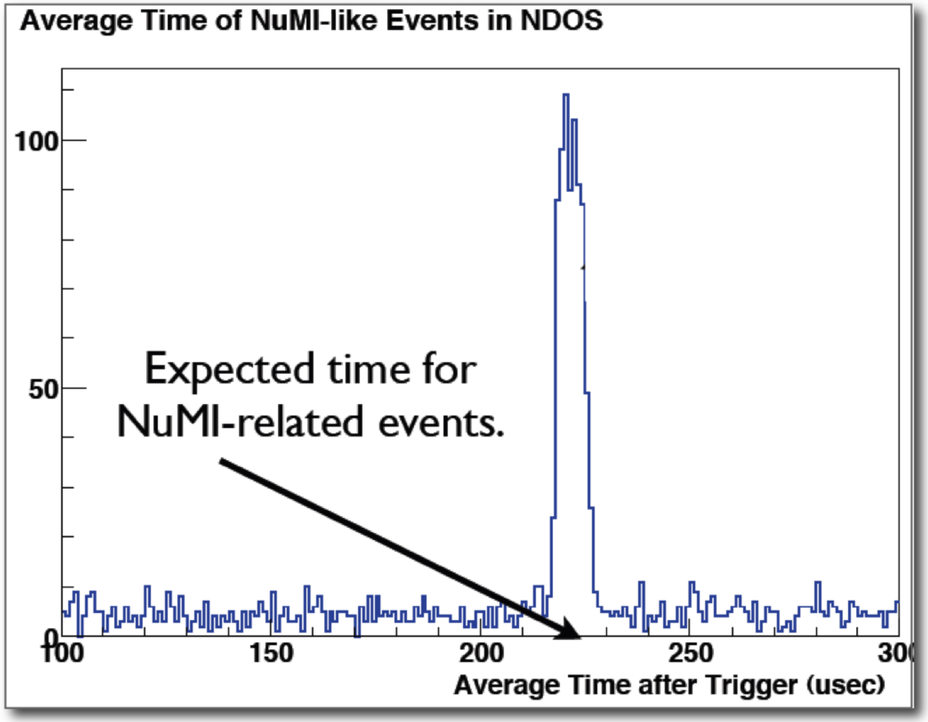


- Muon Catcher:
  PVC + scintillator planes interleaved with iron plates
- Installation completed last week, commissioning ongoing
- NDOS fully assembled and taking data!

NDOS Live Time

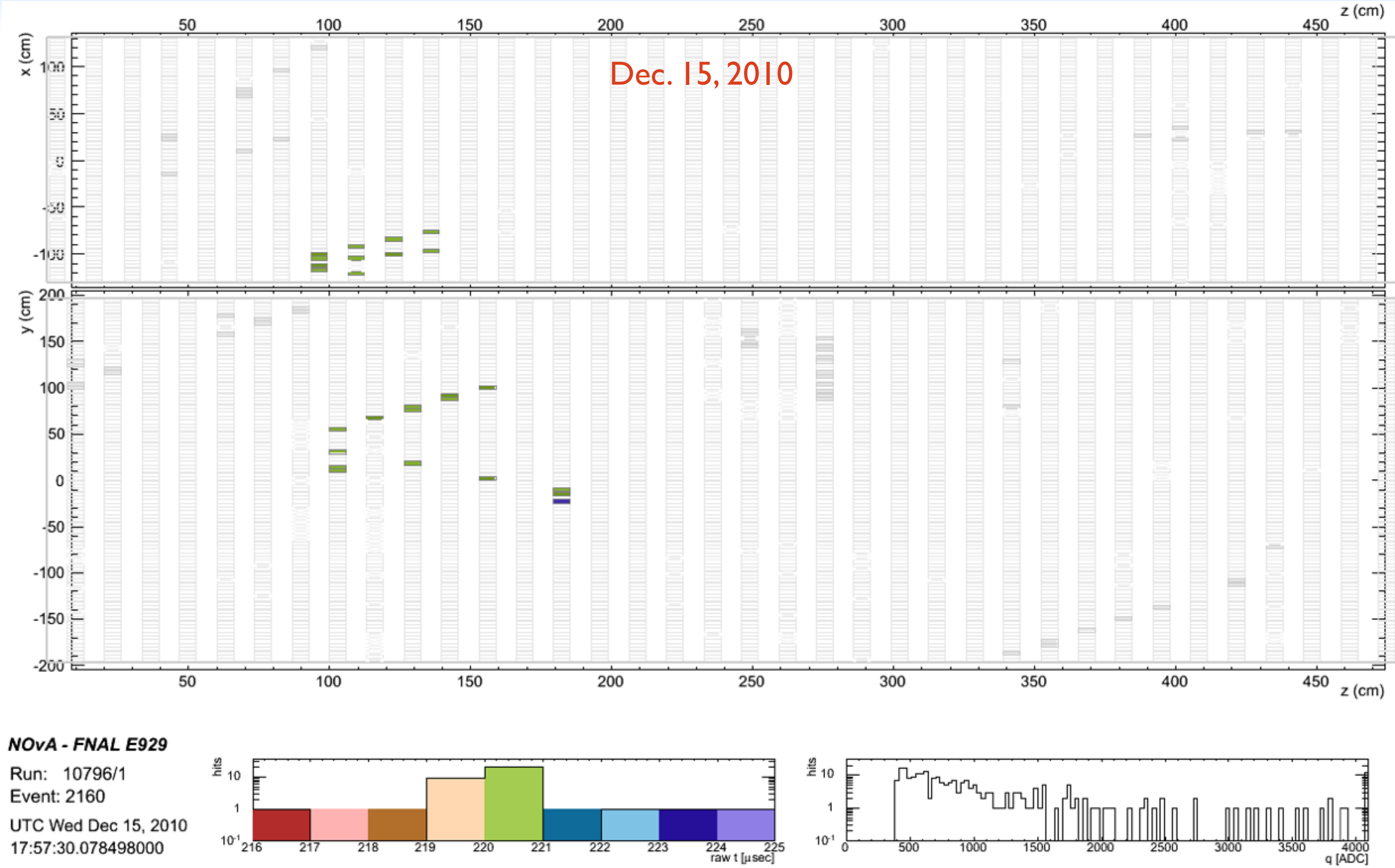
- Plot below shows NuMI protons on target (POT) collected during NDOS physics runs
- Already ~5×10^{19} POT of integrated NuMI exposure



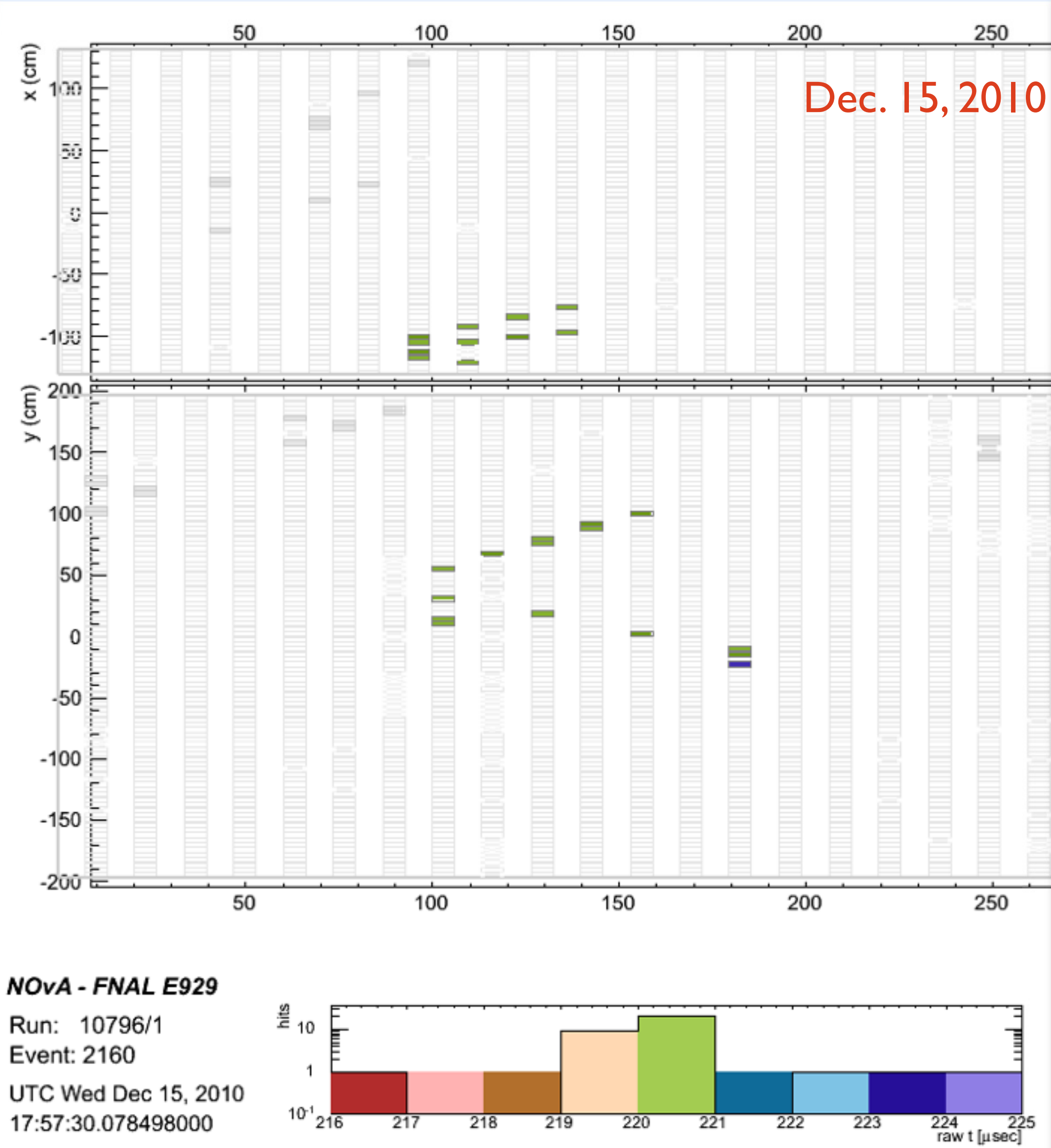


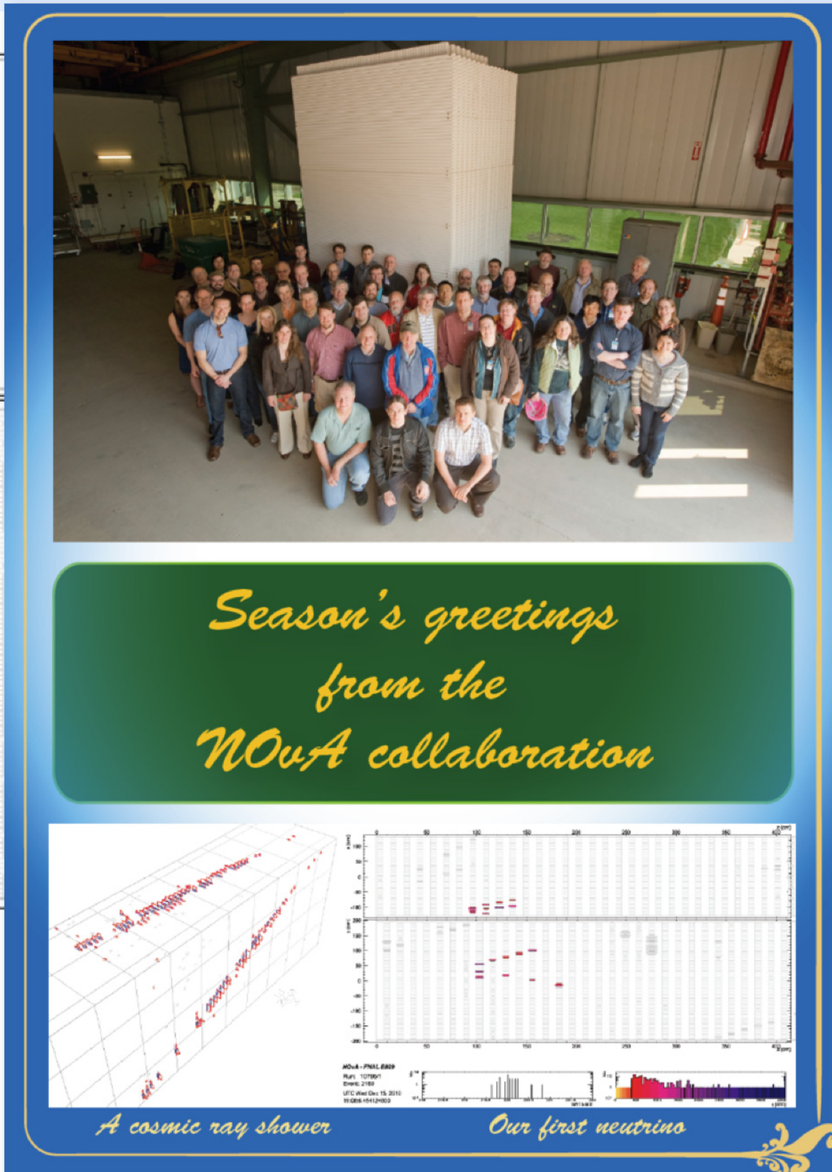
- Peak in event time distribution coincides with NuMI spill times
- NuMI neutrinos are clearly being seen in the NDOS
- Ongoing search for Booster beam neutrinos

NOvA's 1st Beam Neutrino!

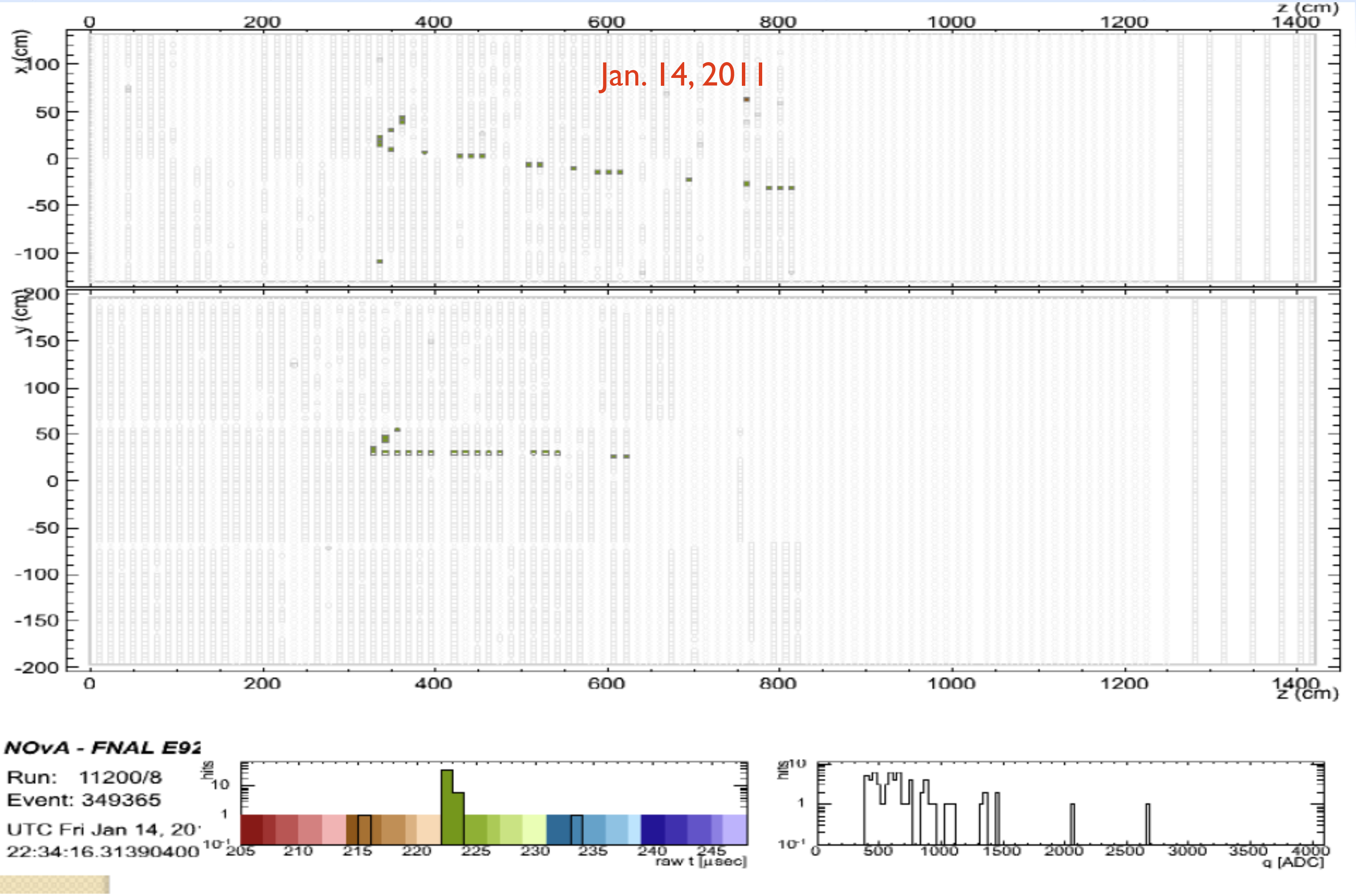


NOvA's 1st Beam Neutrino!



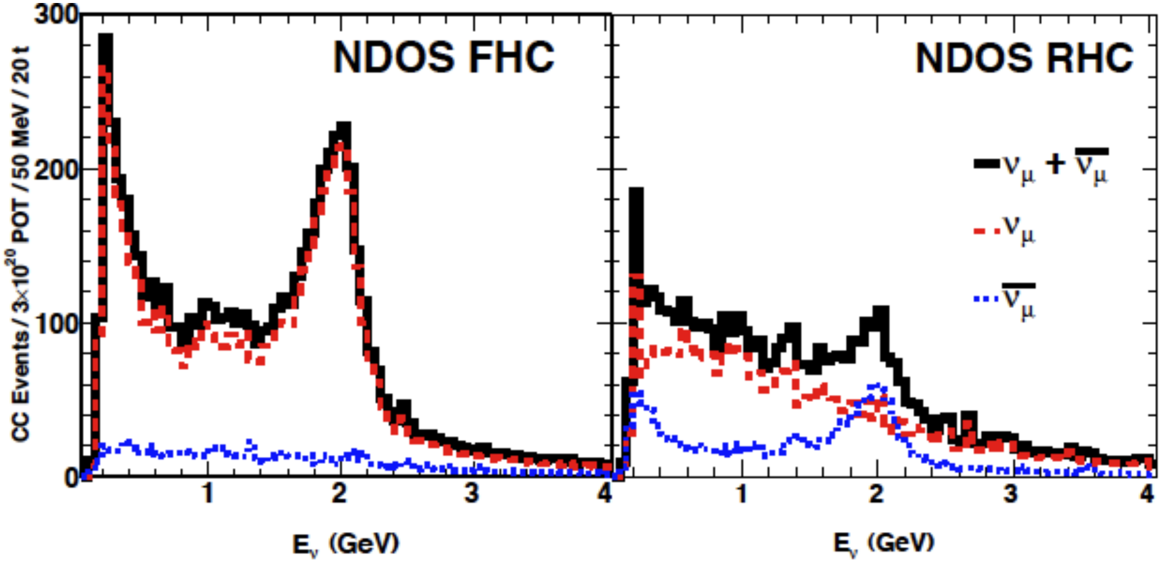


QE ν_μ CC Candidate



NDOS Physics

- Expected neutrino and anti-neutrino NuMI energy spectrum in the NDOS for 2×10^{20} POT of Forward-Horn-Current running and 1×10^{20} POT of Reversed-Horn-Current running



- Use data to better understand detector response
  - Improve MC simulation
  - Develop reconstruction and event selection algorithms
- Physics opportunities:
  - Measure ν_μ QE cross section at 2 GeV
  - Measure ν NC/CC single π production cross section

FHC	2×10^{20} POT
ν_μ+anti-ν_μ CC	4500
(in 2 GeV peak	1500)
ν_e+anti-ν_e CC	200
NC	2000

RHC	1×10^{20} POT
ν_μ+anti-ν_μ CC	1650
(in 2 GeV peak	400)
ν_e+anti-ν_e CC	80
NC	800

NOvA Schedule

NDOS first beam neutrino	December 2010
NDOS fully commissioned	June 2011
First block of Far Detector installed	December 2011
Start of accelerator shutdown	March 2012
5 kt of Far Detector completed	October 2012
End of accelerator shutdown	December 2012
Start Near Detector operations underground	March 2013
Far Detector completed	October 2013

- All additives and 35% of total fiber on hand. All mineral oil, PVC, extrusion production, and remaining fiber purchased or contracted.
- NOvA's schedule is technically driven

Outlook

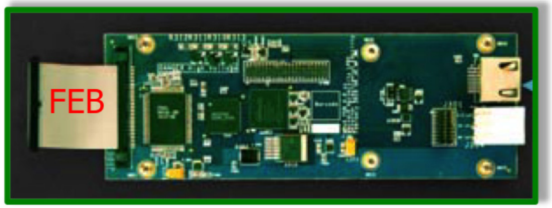
- NOνA is the flagship project of Fermilab's Intensity Frontier initiative
- On track to make several important contributions:
  - Measurement of θ_{13}
  - Determination of neutrino mass hierarchy
  - High precision measurements of Δm^2_{32} and θ_{23}
- NDOS fully assembled and actively taking data. Fundamental to understanding fabrication and assembly procedures, detector response, and will provide the first physics results from NOνA
- NuMI beam upgrades and Far Detector construction on schedule to start 700 kW operations with 14 ktons in 2013
- Watch this space!

http://www-nova.fnal.gov

Backup Slides

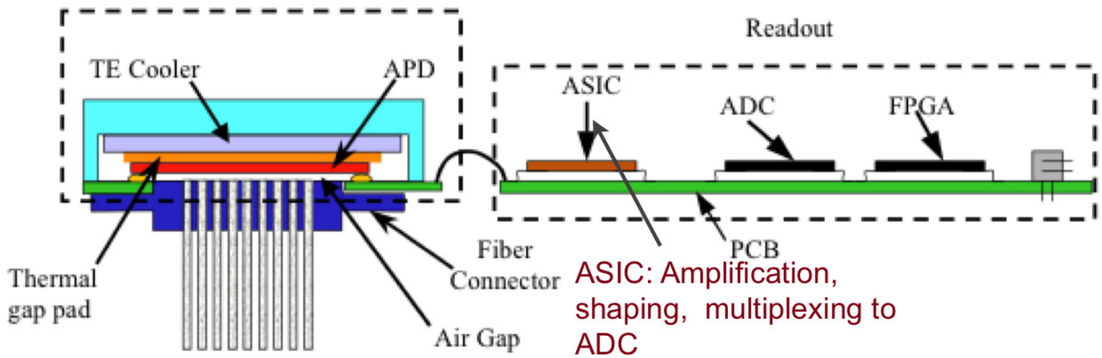
Readout

- APDs sampled at 2MHz by FE electronics
- Signal recognition/zero supression done in real time by FPGA
- Minimum 30 sec full data buffer for trigger decision
- Software-based event trigger with no dead time



Avalanche Photo Diodes:
- 85% Quantum Efficiency
- Gain~100
- cooled to -15C for 2PE dark noise

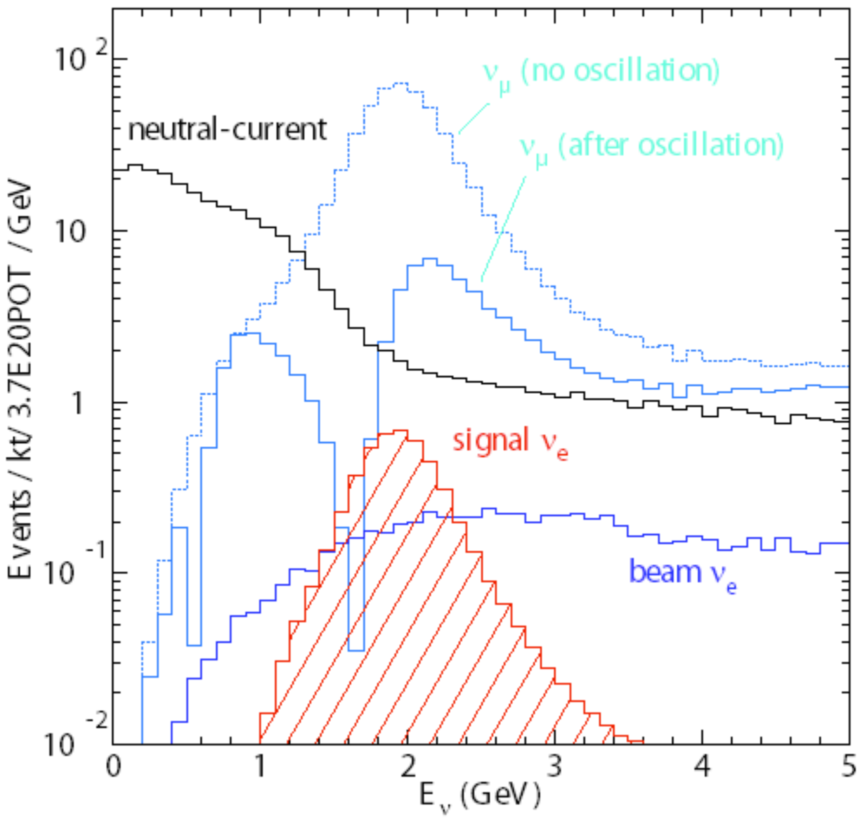
APD Module - 32 channels



Response:
- ~30 photo-electrons from μ at far end of cell
- 4 P.E. total noise

Detector Requirements

- Large: 14 kT
- Required background suppression
  - ~50:1 for ν_μ CC (easy!)
  - ~100:1 for NC
  - Maximize Hadronic/EM Separation ➠ *Low Z, Fine Sampling per Radiation Length*
- Energy Resolution
  - Small compared to width of signal peak
- ⇒ Liquid Scintillator in PVC Structure

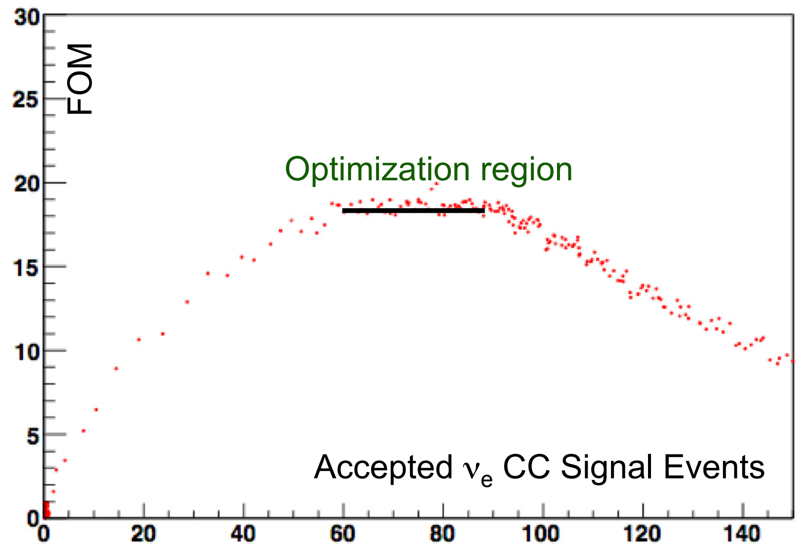


Interaction spectra at 810km, 12km off-axis.
Oscillations: $\Delta m^2=2.5\times10^{-3}eV^2$, $\sin^2(2\theta_{13})=0.01$

Signal Selection

ν_e CC signal selection uses artificial neural net based on reconstructed parameters of the electron and the event:
shape, signal profiles, topology, etc.

ANN cut chosen to maximize
Figure of Merit (FOM)=S/√B

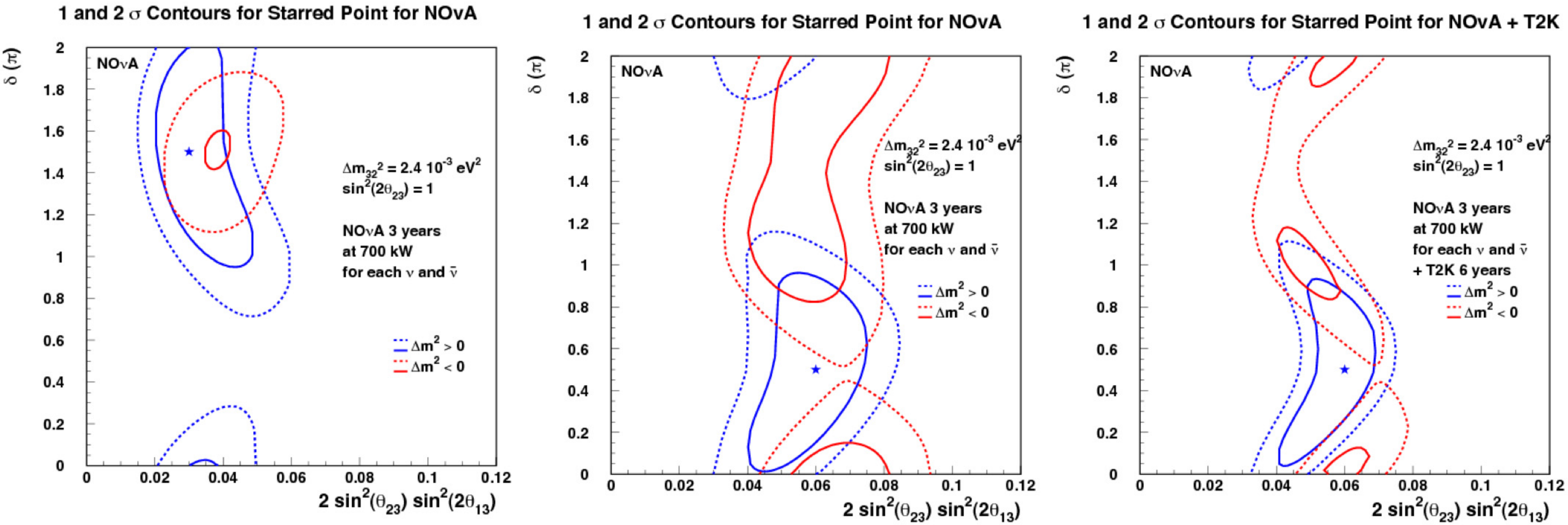


3yrs each mode, 15 kT, 700 kW	Neutrino Running	Anti-neutrino Running	Efficiency*
ν_e CC signal	75.0	29.0	36%
Backgrounds	14.4	7.6	
NC	6.0	3.6	0.23%
ν_μ CC	0.05	0.48	0.004%
Intrinsic Beam ν_e	8.4	3.4	14%

* Efficiency includes effect of fiducial cut

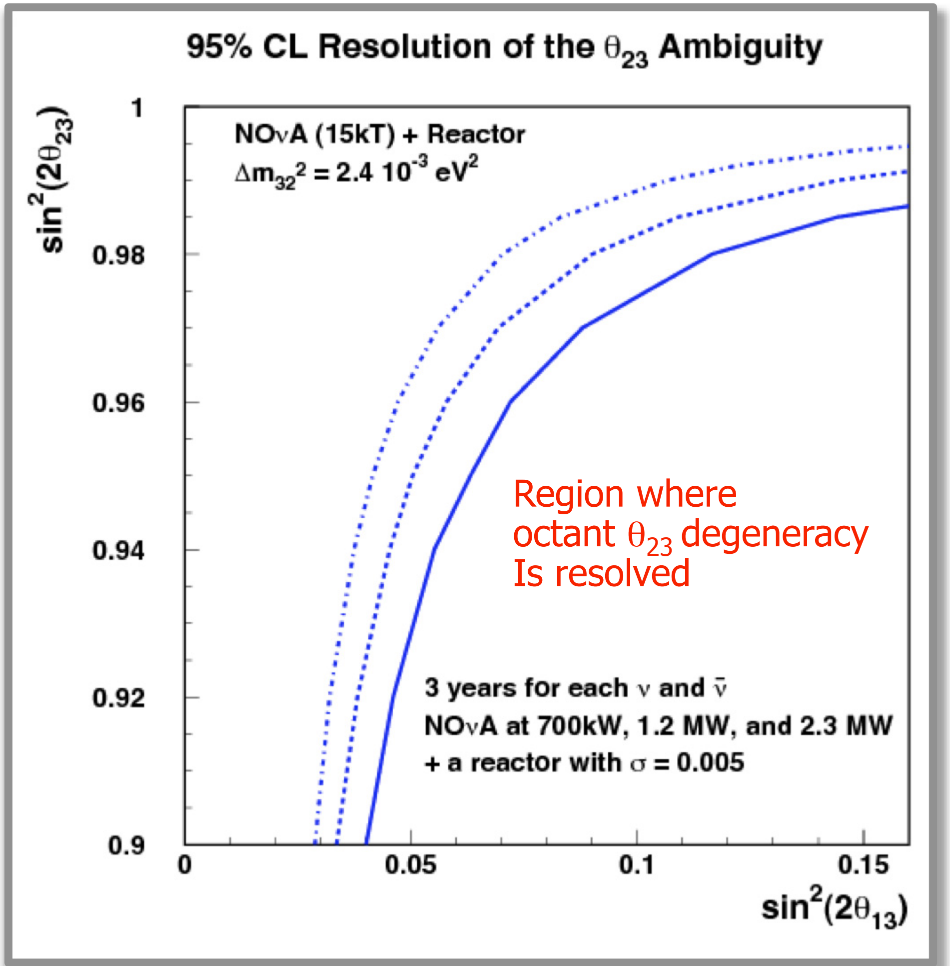
Assumptions:
$\sin^2(2\theta_{13})=0.1$
$\sin^2(2\theta_{23})=1.0$
$\Delta m^2=0.0024$ eV^2
$\delta=0$ and no matter effects

Constraining δ_{CP}



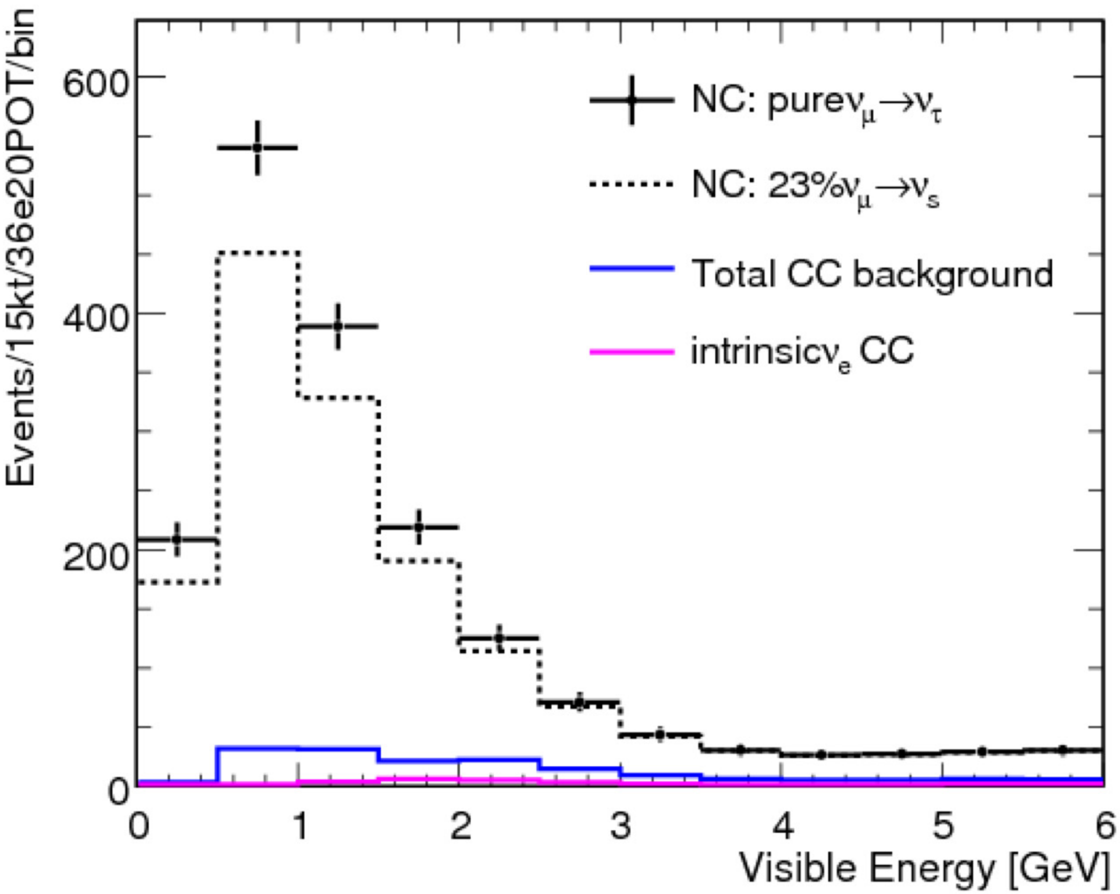
θ_{23} Octant Ambiguity

- In combination with a reactor experiment, NOνA can lift the octant θ_{23} degeneracy i.e.: $\theta_{23} > \pi/4$ or $\theta_{23} < \pi/4$



Sterile Neutrinos

- NOνA can search for oscillations into sterile neutrinos by looking for energy-dependent depletion of neutral current events in the Far Detector
- Plot showing NC energy spectrum assumes a 23% fraction of the ν_μ oscillate into sterile neutrinos



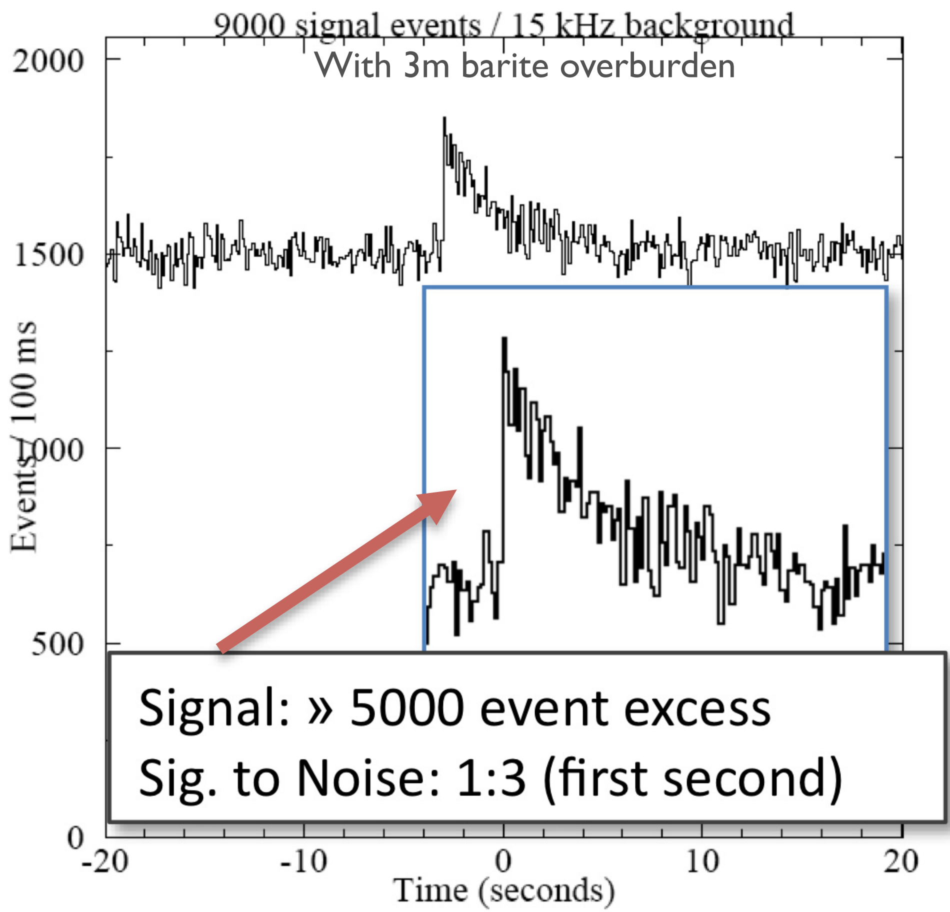
Supernova Signal

- Primary SuperNOνA Signal:

$$\bar{\nu}_e + p \rightarrow e^+ + n$$

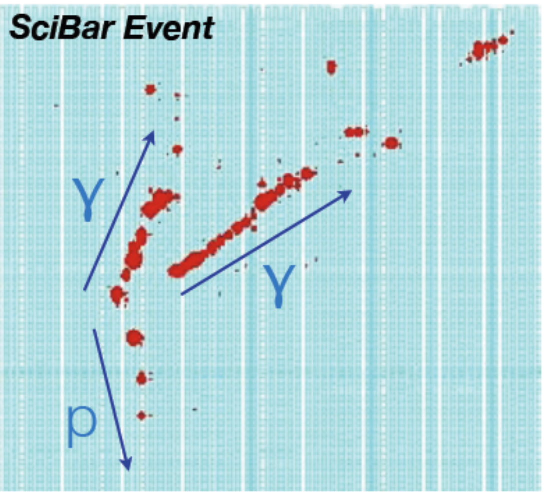
- For a supernova at 10kpc the total signal is expected to contain:
  - 5000 total interactions over a time span of $\approx$ 10s
  - Half the interactions in the first second
  - Energy peaks at 20MeV and falls off to $\sim$ 60MeV
- Challenge is triggering in real time
  - Need data driven open triggering
  - Long event buffering ($\sim$ 30sec)

- NOνA – farm 180 trigger/buffer PCs (min 30s total event buffering)

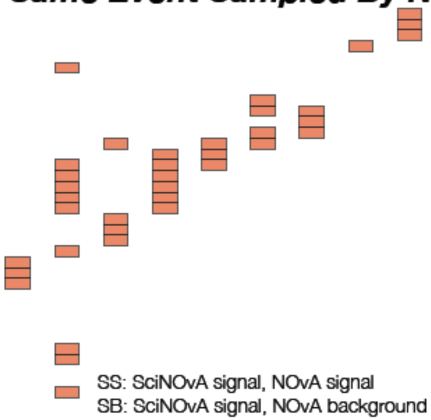


SciNOvA Proposal

- Use the solid scintillator SciBar detector (6x finer-grained than the NOvA ND) as a second NOvA Near Detector to cross-check background rates (e.g. NC with π^0 production)
- Opportunity for improved cross-section measurements
- $3 million investment needed. Requires additional institutional involvement in the NOvA Collaboration to provide manpower in building detector



Same Event Sampled By NOvA



SS: SciNOvA signal, NOvA signal
SB: SciNOvA signal, NOvA background
BS : SciNOvA background, NOvA signal
BB : SciNOvA background, NOvA background

	N_{ss}	N_{sb}	N_{bs}	N_{bb}	χ^2
Nominal	15500	50300	66600	10867600	-
γ_N higher by 10%	-	-	+4300	-4300	279
γ_N and γ_{SB} higher by 10%	-	+2200	+4300	-6500	371
B higher by 10%	-1500	-2800	-2300	+6600	403

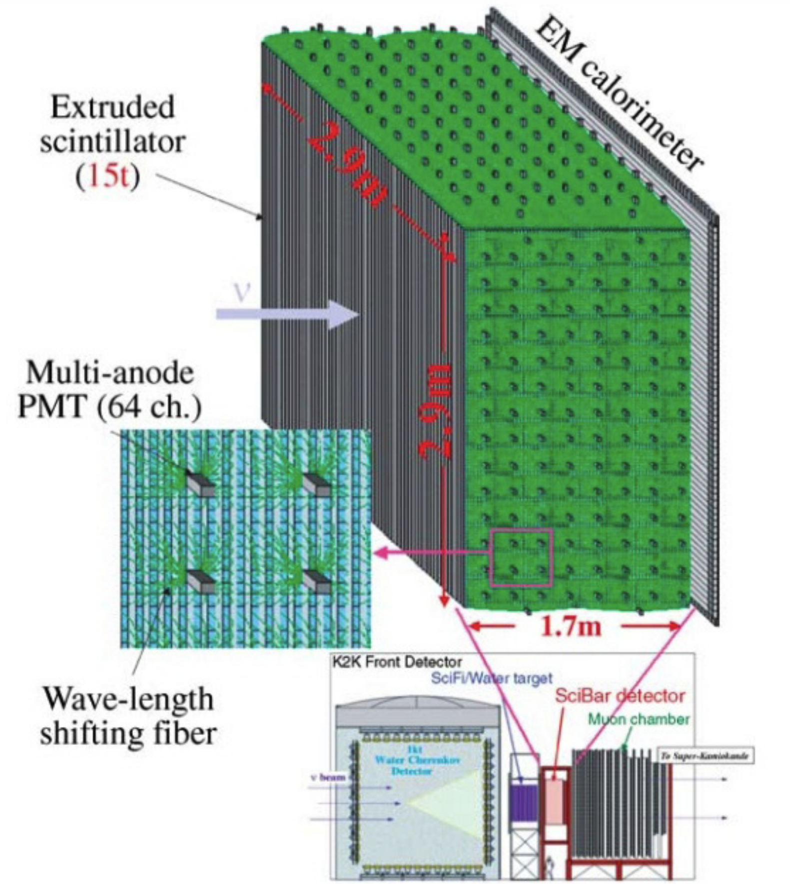


Fig. 1. Schematic drawing and description of the SciBar detector.