Status of NOvA

NuMI Off-Axis ν_e Appearance Experiment

Luke A. Corwin for the NOvA Collaboration
Indiana University

International Workshop on Neutrino Telescopes, Venice, Italy
2013 March 13

Outline

- Who? (Collaboration)
- Were? (Geographic Overview)
- Why? (Physics Goals)
- How? (Methods and Sensitivities)
- What? (Detector Description)
- When? (Status, schedule and outlook)

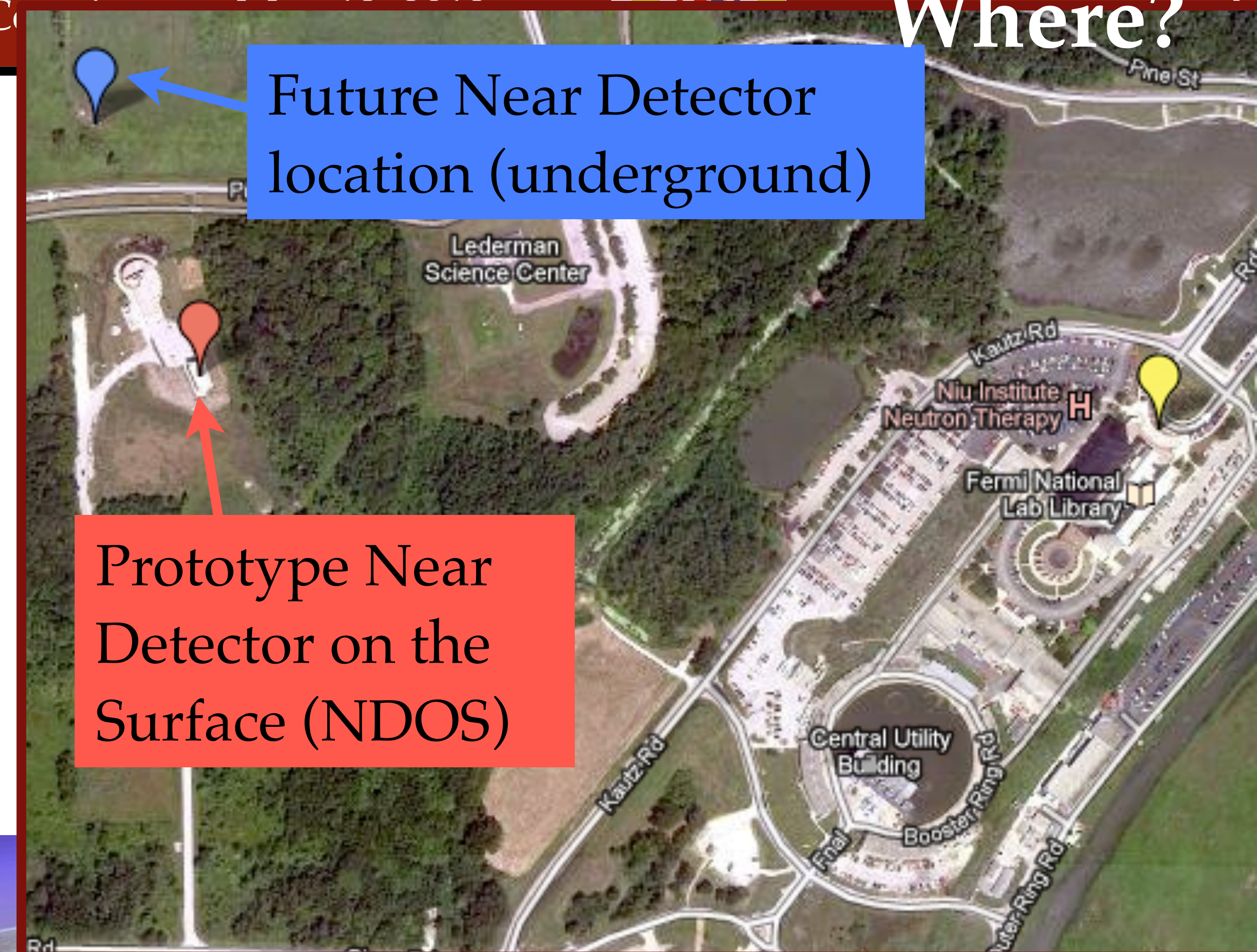
Who: The Collaboration

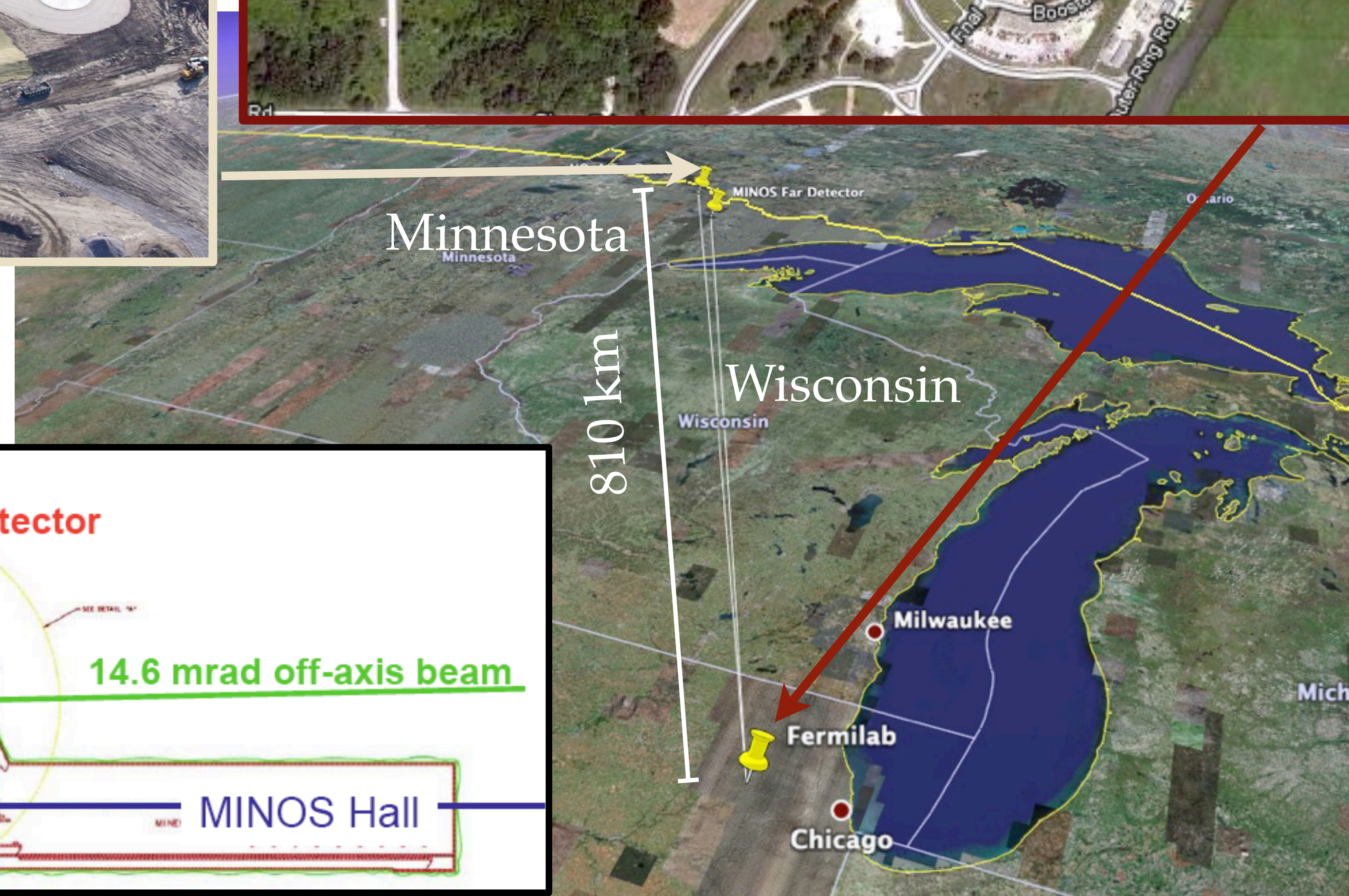
6 Nations
34 Institutions
180 Collaborators

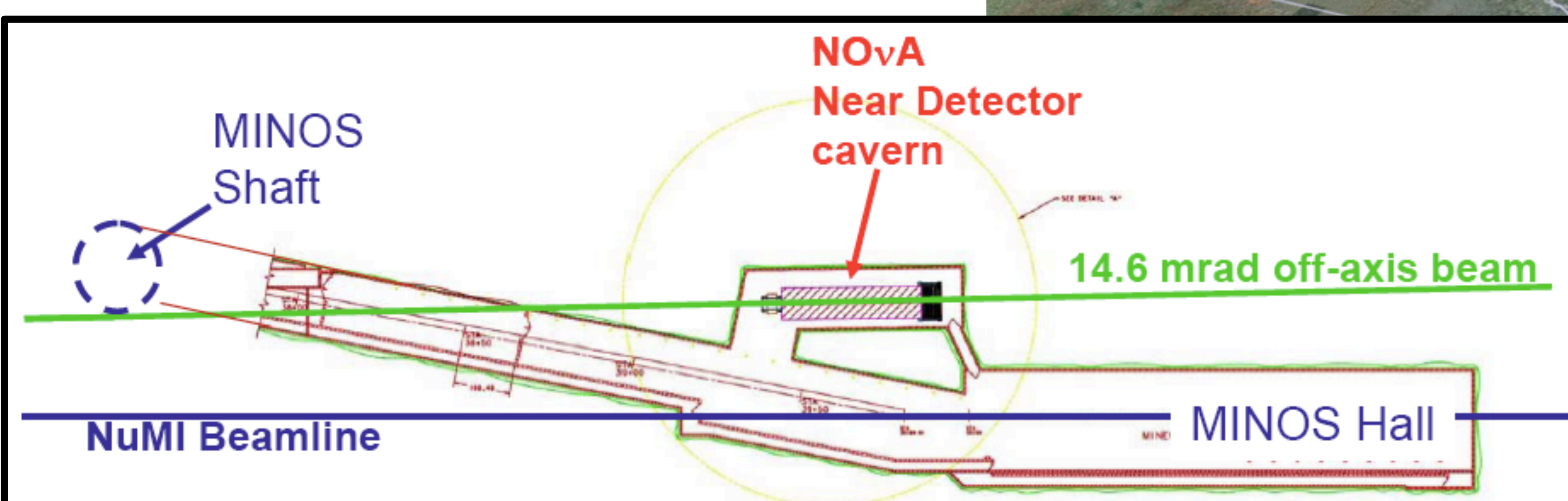
www.twitter.com/NOvANuz www.facebook.com/novaexperiment

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

Where is NOvA?



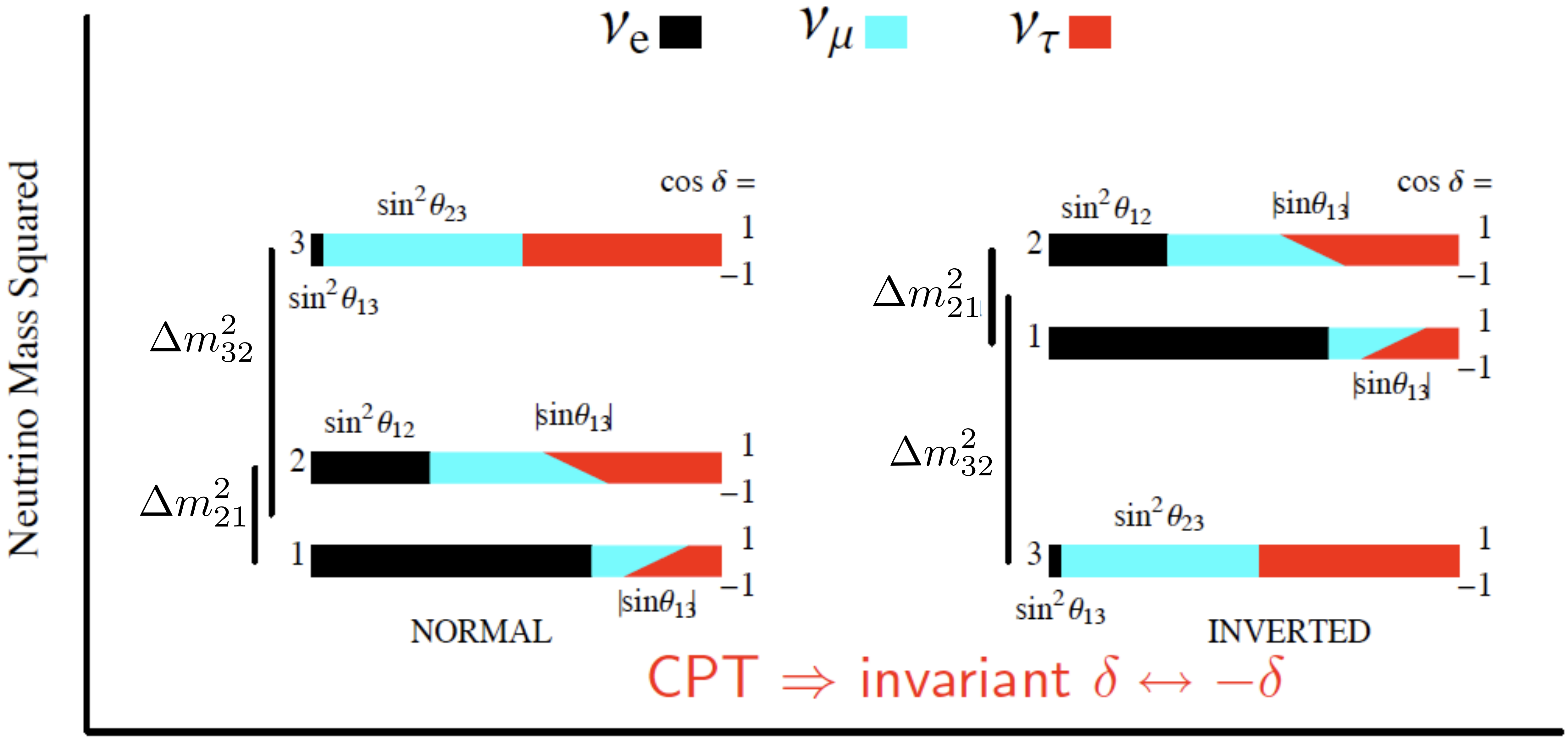




Why: NOvA Physics Goals

$$P(\nu_\alpha \to \nu_\beta) = \left| \sum_j U_{\alpha j} e^{-\frac{i m_j^2 t}{2E}} U_{j\beta}^* \right|^2$$

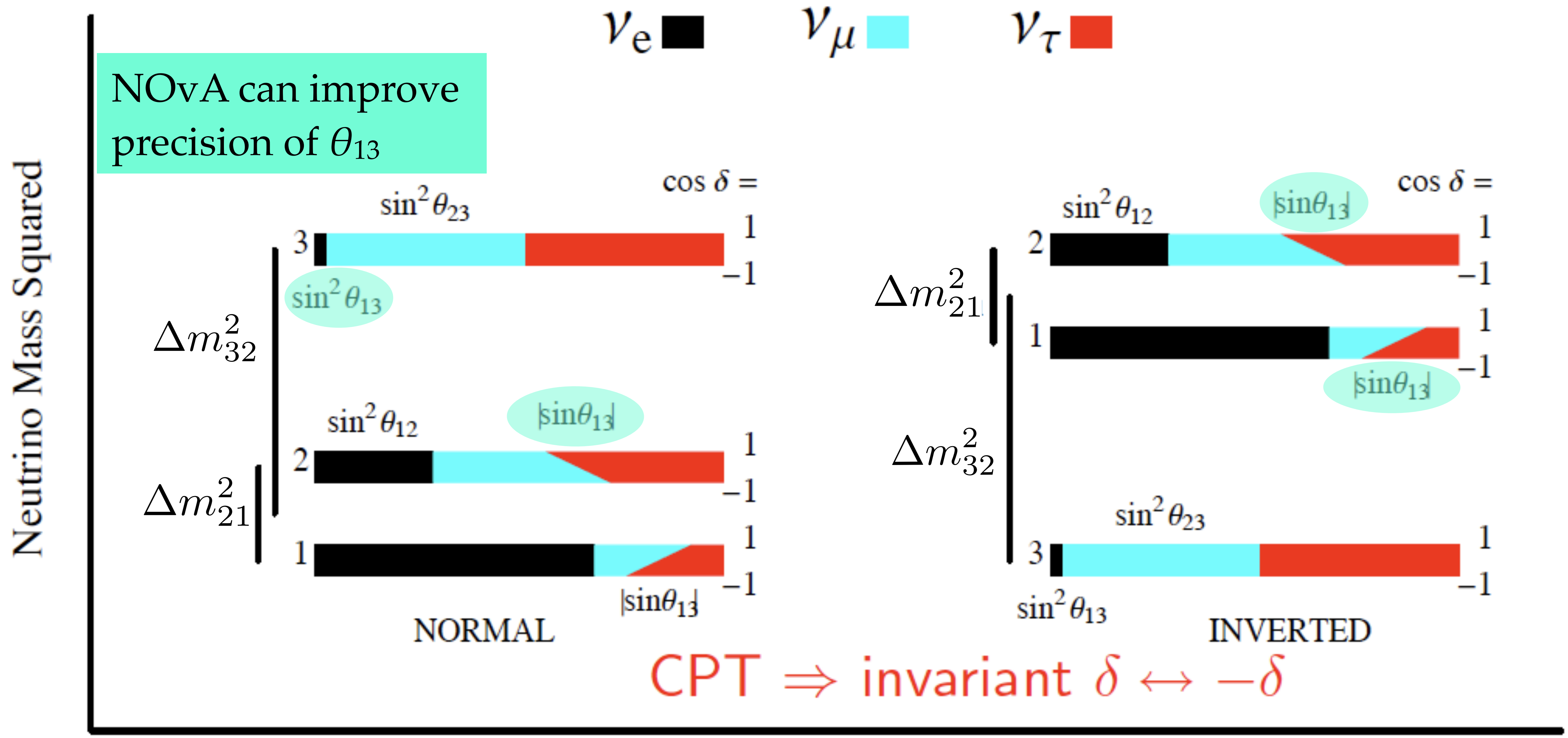
From Stephen Parke "Mixing Parameters II," Int'l Neutrino Summer School, Fermilab, 14 July 2009



$$\Delta m^2_{ij} \equiv m_i^2 - m_j^2$$

Why: NOvA Physics Goals

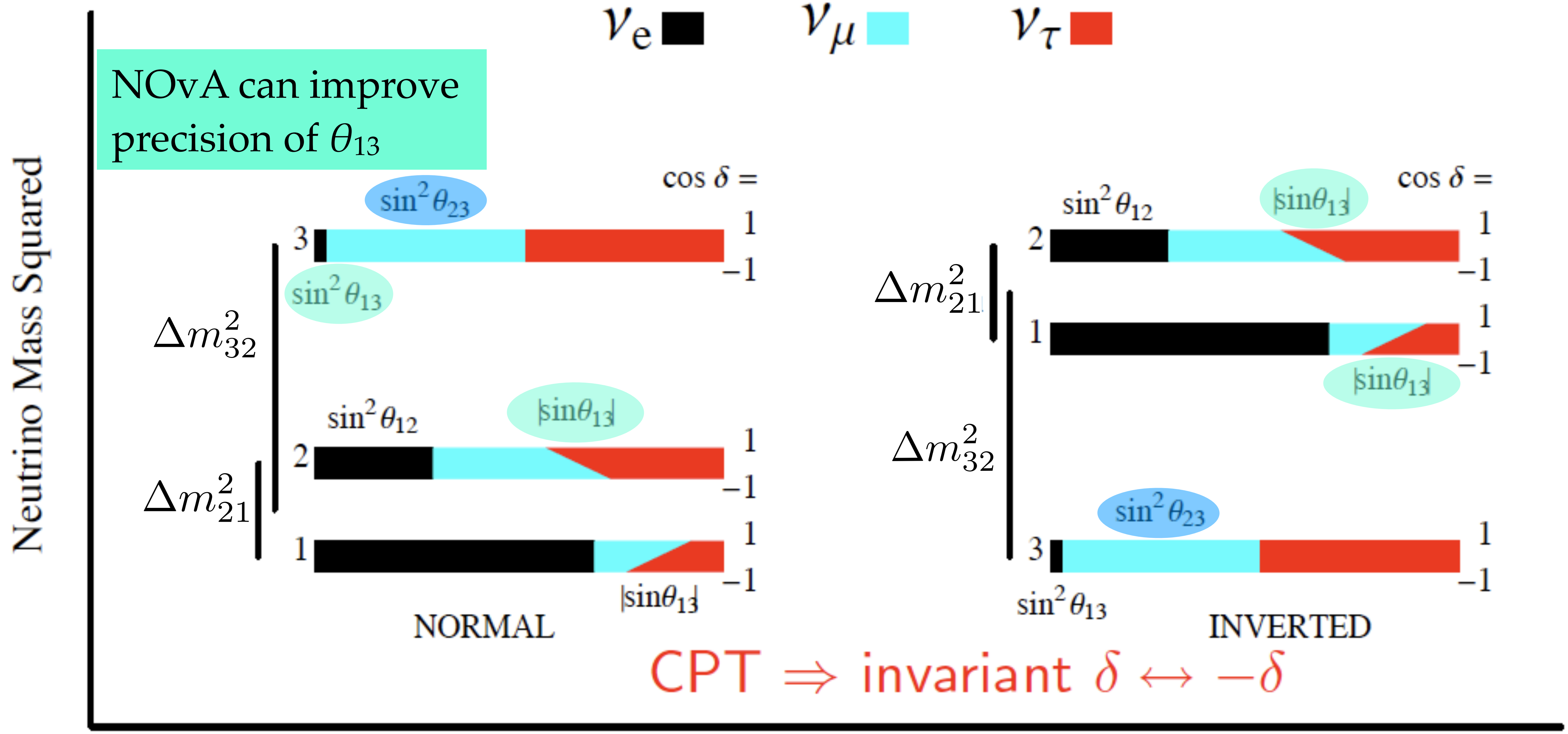
$$P(\nu_\alpha \to \nu_\beta) = \left| \sum_j U_{\alpha j} e^{-\frac{i m_j^2 t}{2E}} U^*_{j\beta} \right|^2$$



$$\Delta m^2_{ij} \equiv m_i^2 - m_j^2$$

Why: NOvA Physics Goals

$$P(\nu_\alpha \rightarrow \nu_\beta) = \left| \sum_j U_{\alpha j} e^{-\frac{i m_j^2 t}{2E}} U_{j\beta}^* \right|^2$$



If $\sin^2(2\theta_{23}) \neq 1$, NOvA might determine $\theta_{23} < 45^o$ or $> 45^o$

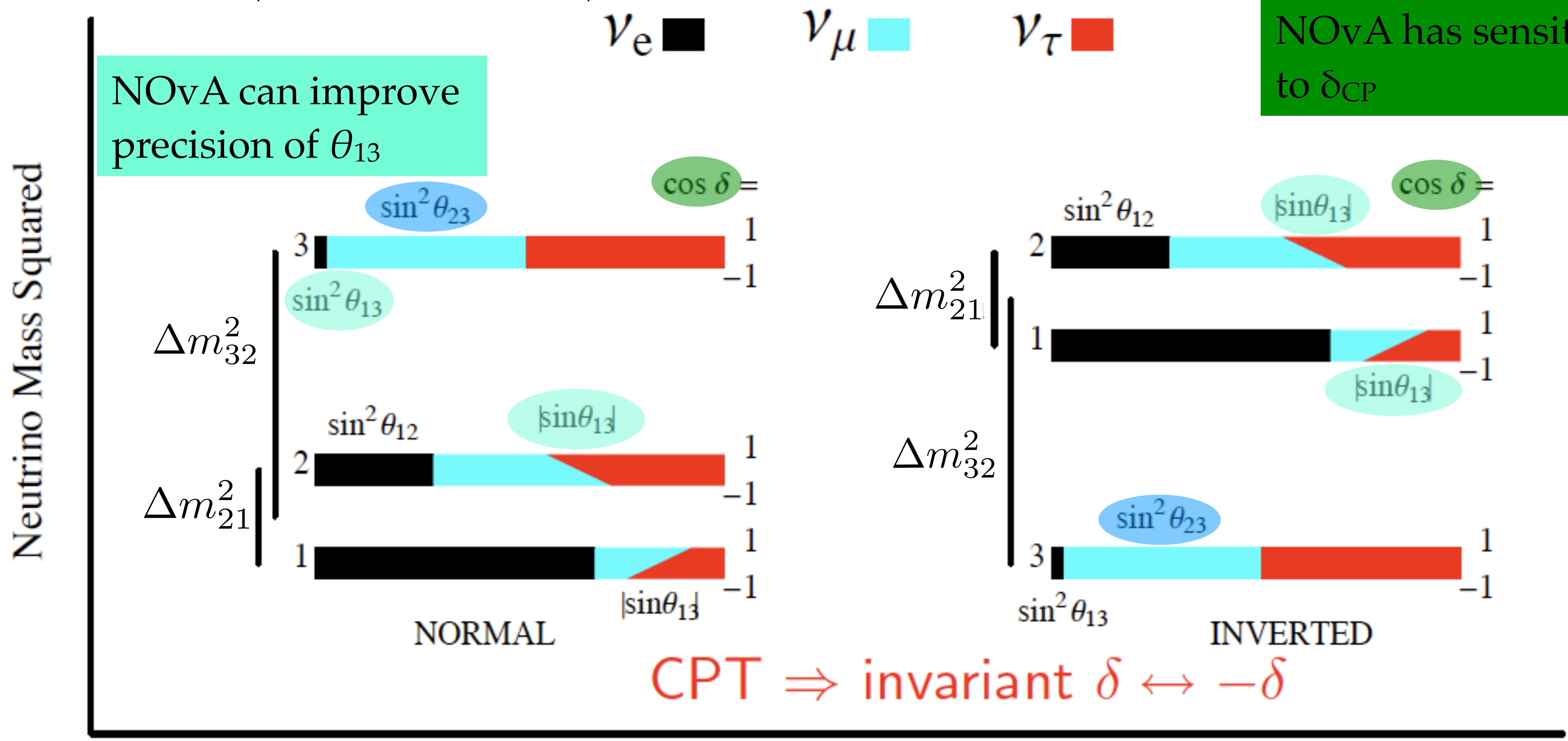
$$\Delta m^2_{ij} \equiv m_i^2 - m_j^2$$

Why: NOvA Physics Goals

$$P(\nu_\alpha \to \nu_\beta) = \left| \sum_j U_{\alpha j} e^{-\frac{i m_j^2 t}{2E}} U^*_{j\beta} \right|^2$$

NOvA has sensitivity to δ_{CP}

NOvA can improve precision of θ_{13}



CPT ⇒ invariant $\delta \leftrightarrow -\delta$

If $\sin^2(2\theta_{23}) \neq 1$, NOvA might determine $\theta_{23} < 45^o$ or $> 45^o$

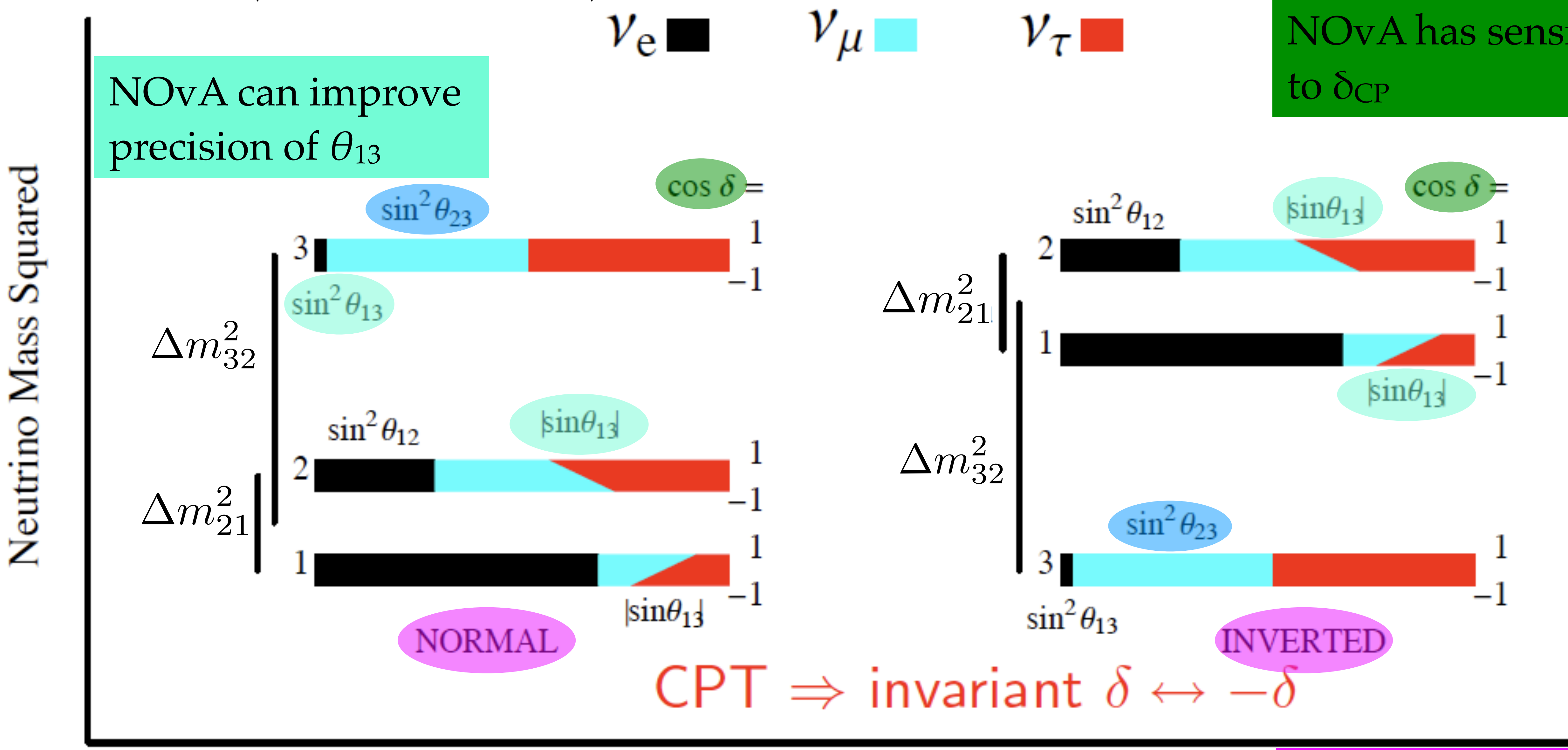
$$\Delta m^2_{ij} \equiv m_i^2 - m_j^2$$

Why: NOvA Physics Goals

$$P(\nu_\alpha \to \nu_\beta) = \left| \sum_j U_{\alpha j} e^{-\frac{i m_j^2 t}{2E}} U^*_{j\beta} \right|^2$$

NOvA can improve precision of θ_{13}

NOvA has sensitivity to δ_{CP}



If $\sin^2(2\theta_{23}) \neq 1$, NOvA might determine $\theta_{23} < 45^\circ$ or $> 45^\circ$

$$\Delta m^2_{ij} \equiv m_i^2 - m_j^2$$

NOvA's long baseline provides sensitivity to the hierarchy

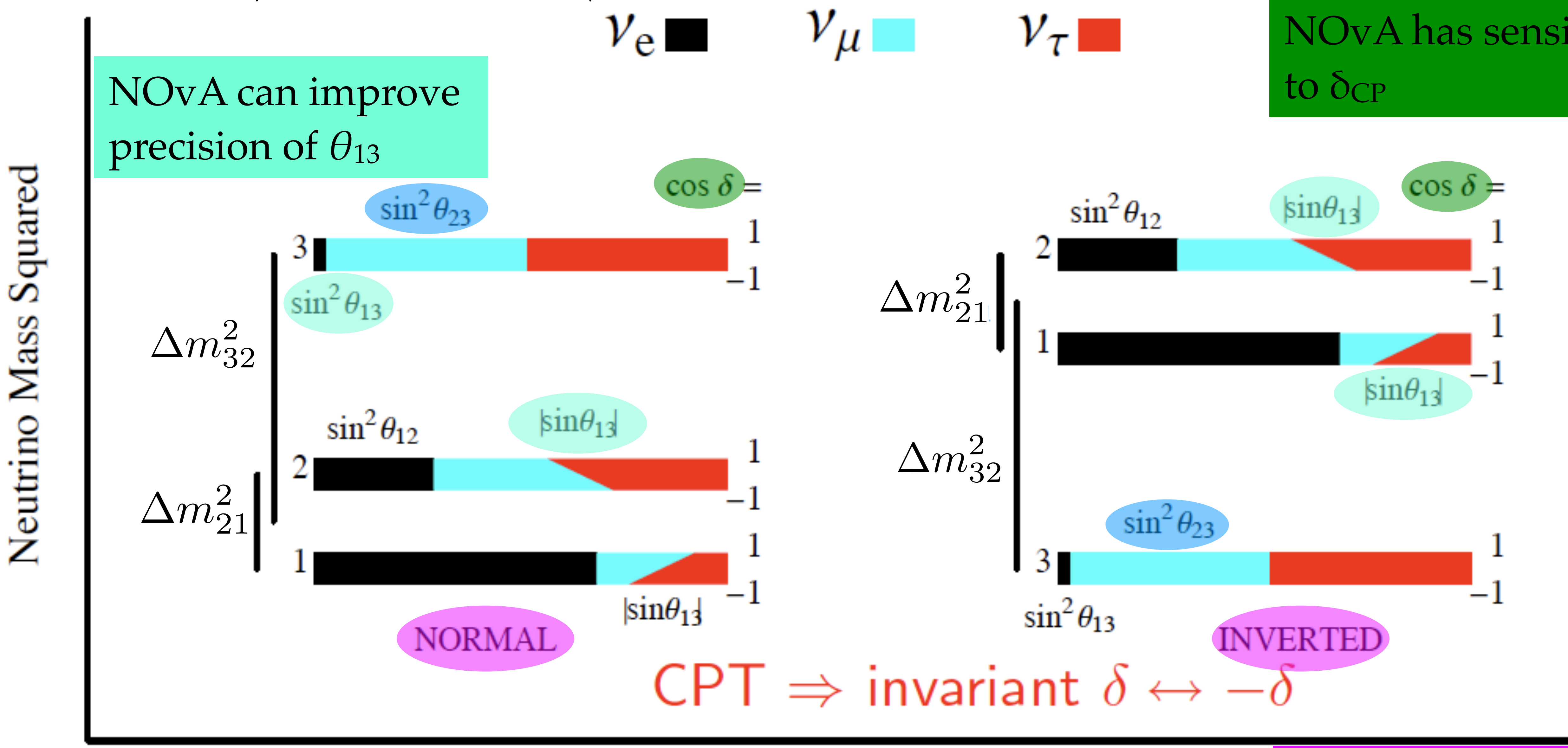
Why: NOvA Physics Goals

Supernova Neutrinos

$$P(\nu_\alpha \rightarrow \nu_\beta) = \left| \sum_j U_{\alpha j} e^{-\frac{i m_j^2 t}{2E}} U^*_{j\beta} \right|^2$$

NOvA has sensitivity to δ_{CP}

NOvA can improve precision of θ_{13}



If $\sin^2(2\theta_{23}) \neq 1$, NOvA might determine $\theta_{23} < 45^o$ or $> 45^o$

$$\Delta m^2_{ij} \equiv m_i^2 - m_j^2$$

NOvA's long baseline provides sensitivity to the hierarchy

How do we find out?

$$P(\nu_\mu \to \nu_e) = \left| \sum_j U_{\mu j} e^{-\frac{i m_j^2 t}{2E}} U_{je}^* \right|^2$$

V. Barger, *et al.* *Phys Rev. D* **22**:2718 (1980)
Nunokawa, Parke, and Valle, *Prog. Part. Nucl. Phys.* **60** (2008) 338-402

$$\approx P_{\text{atm}} + P_{\text{sol}} + \sqrt{P_{\text{atm}} P_{\text{sol}}} (\cos \Delta_{32} \cos \delta \mp \sin \Delta_{32} \sin \delta)$$

+ for ν
- for $\bar{\nu}$

$$P_{\text{atm}} = \sin^2(\theta_{23}) \sin^2(2\theta_{13}) \sin^2(\Delta_{31})$$

$$P_{\text{sol}} = \cos^2(\theta_{23}) \cos^2(\theta_{13}) \sin^2(2\theta_{12}) \sin^2(\Delta_{21})$$

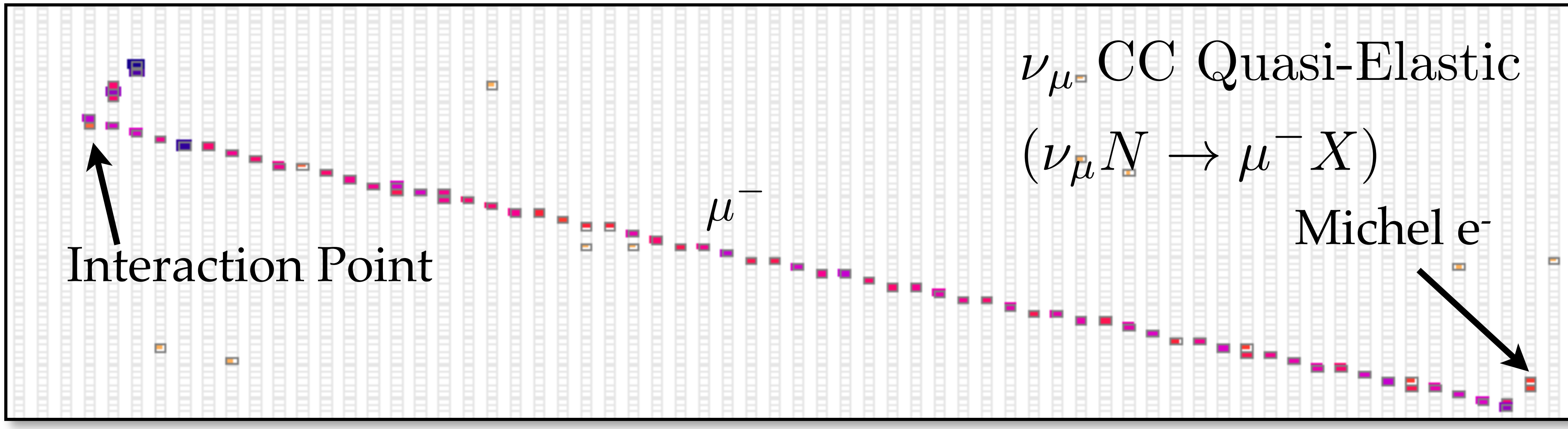
$$\Delta_{ij} = \frac{1.27 \Delta m_{ij}^2 [\text{eV}^2] L[\text{km}]}{E[\text{GeV}]}$$

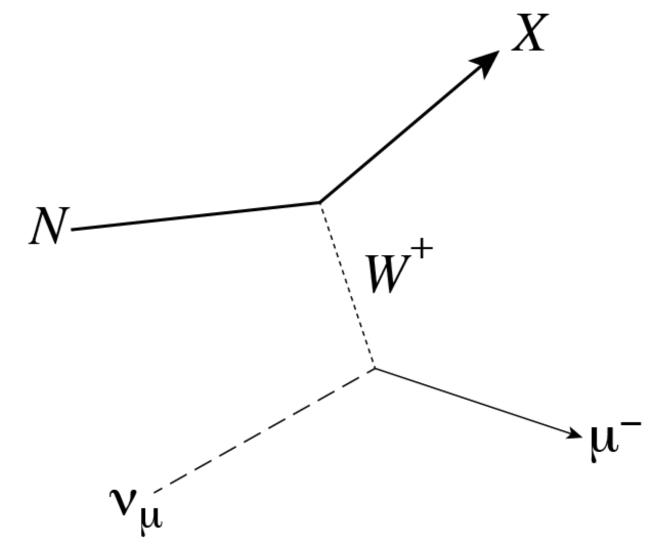
$$P_{\text{matter}}(\nu_\mu \to \nu_e) \approx \left(1 + \frac{E \Delta m_{32}^2}{2\sqrt{2} G_F N_e}\right) P_{\text{vacuum}}(\nu_\mu \to \nu_e)$$

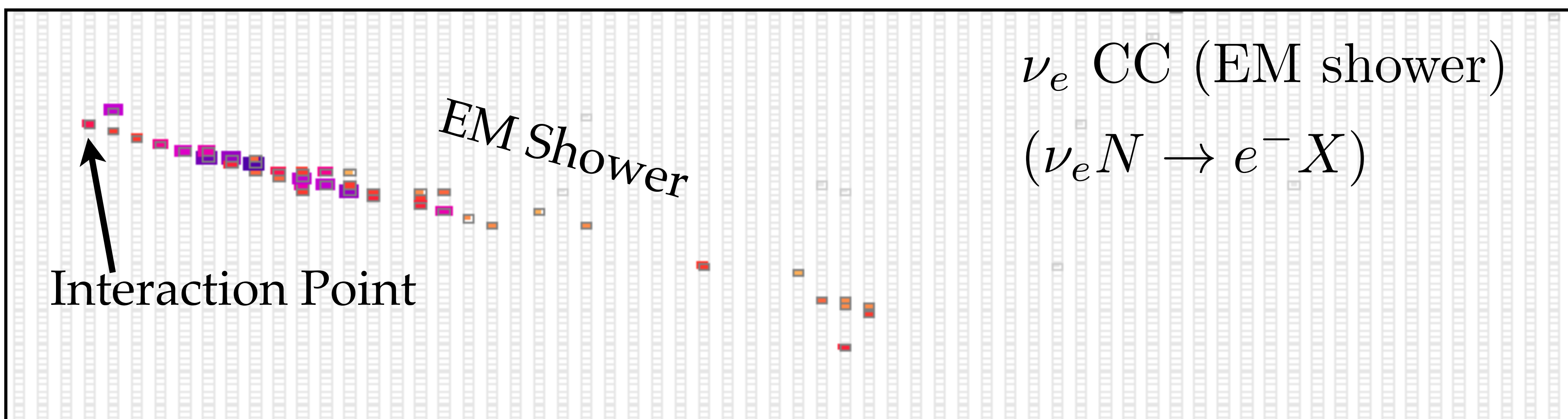
How: Measurements

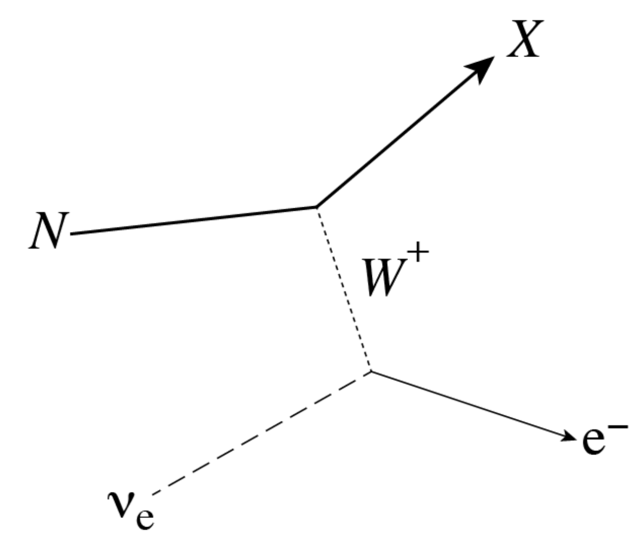
- Take data with neutrino and antineutrino beams
  - Measuring with both is necessary in much of the possible phase space
- Detect ν_μ and ν_e with near and far detectors
  - $P(\nu_\mu \to \nu_\mu)$, $P(\nu_\mu \to \nu_e)$ + charge conjugates
  - Energy spectra

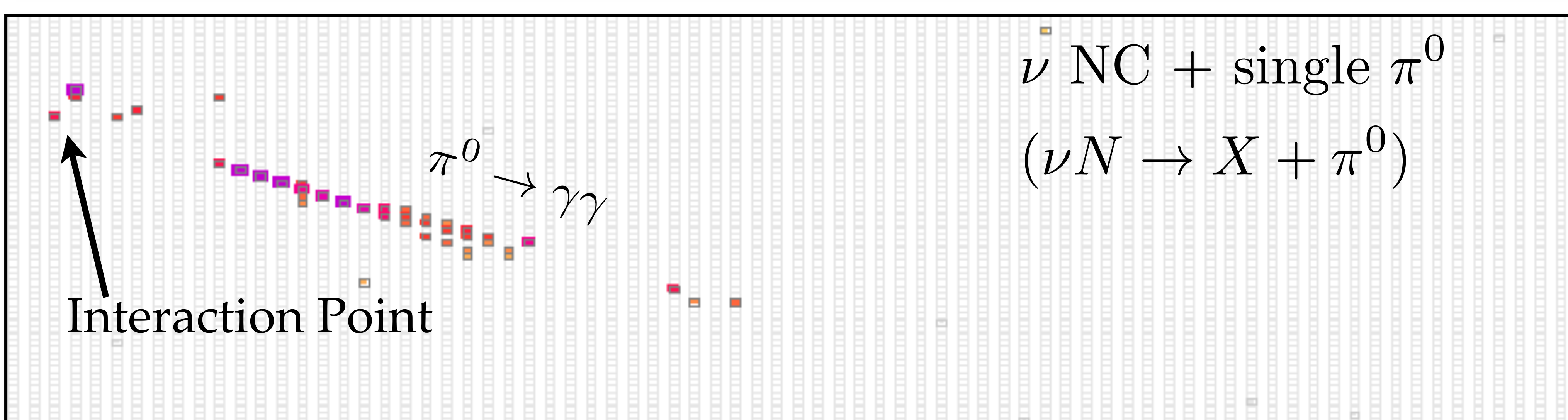
Simulated Events

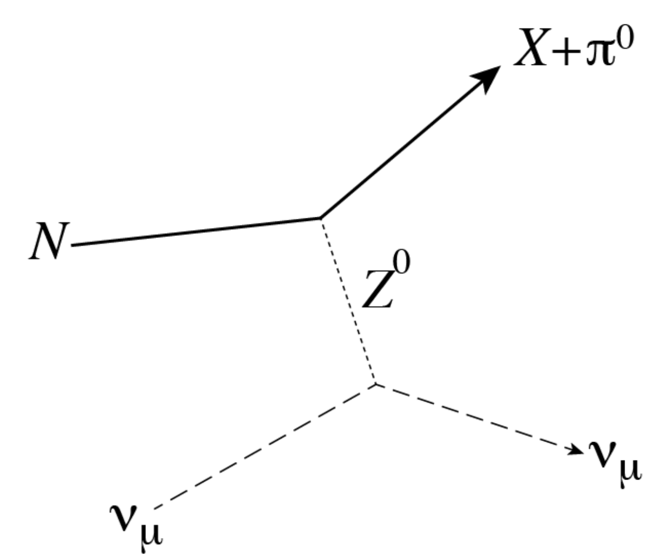




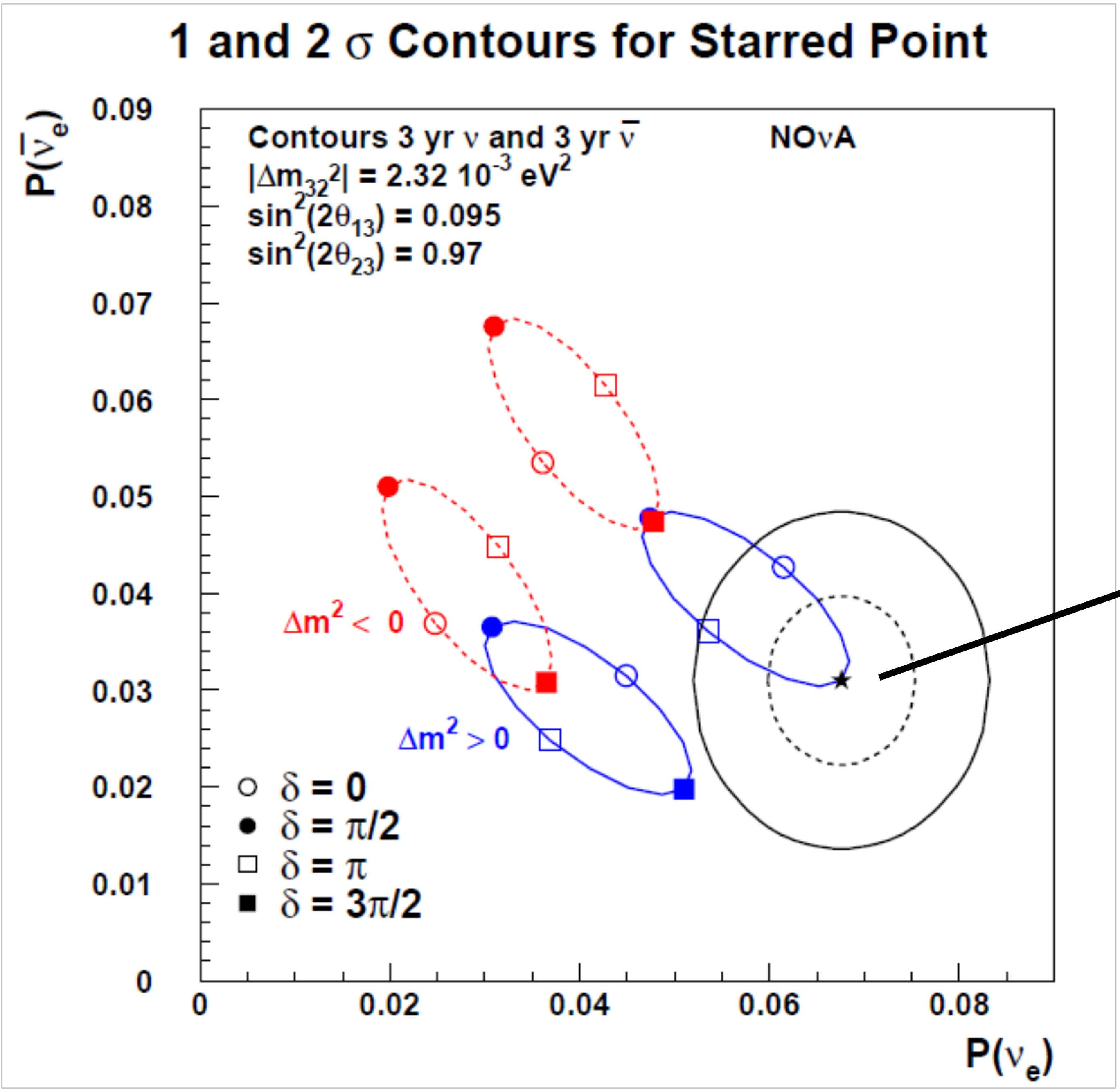


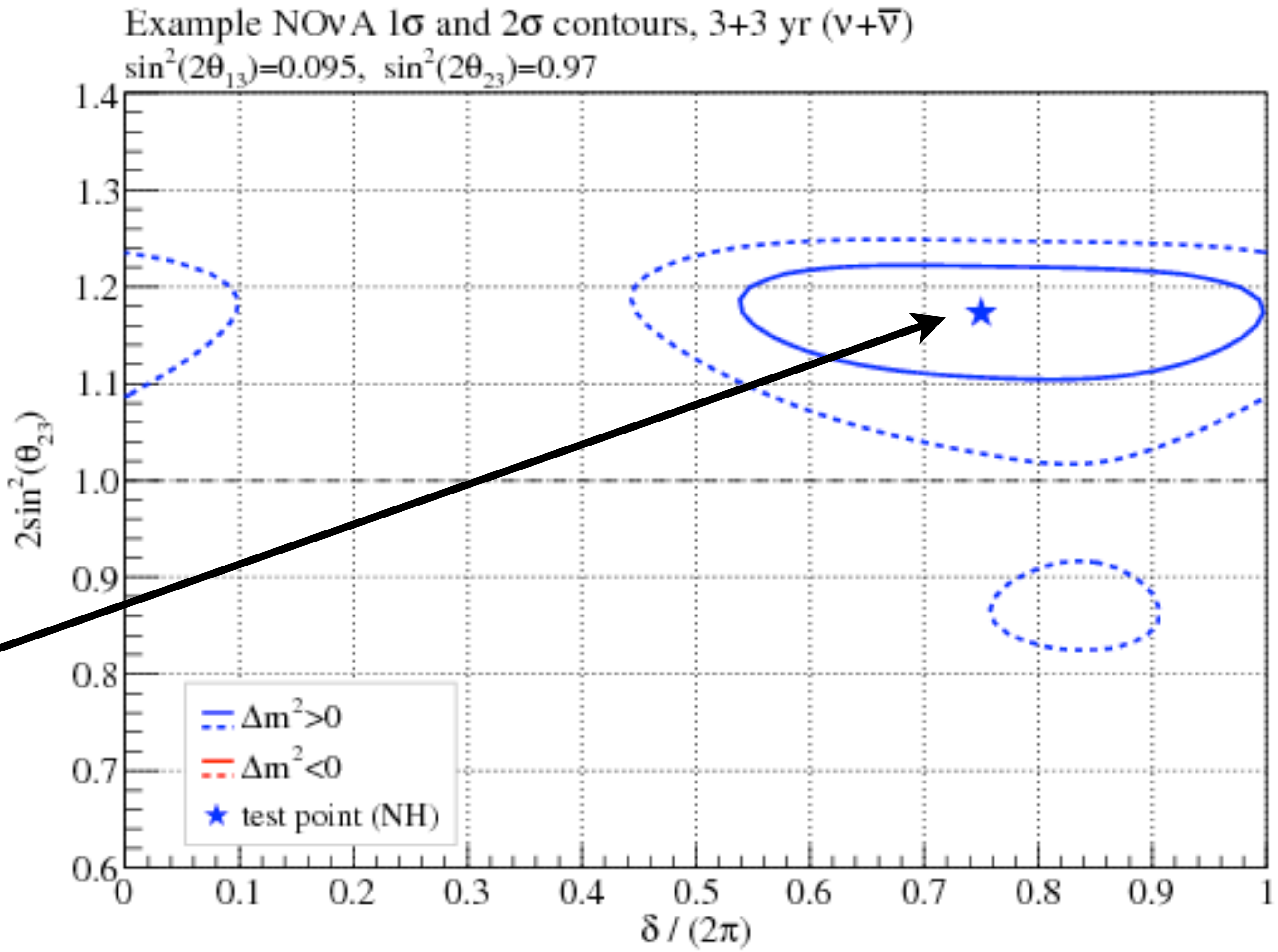






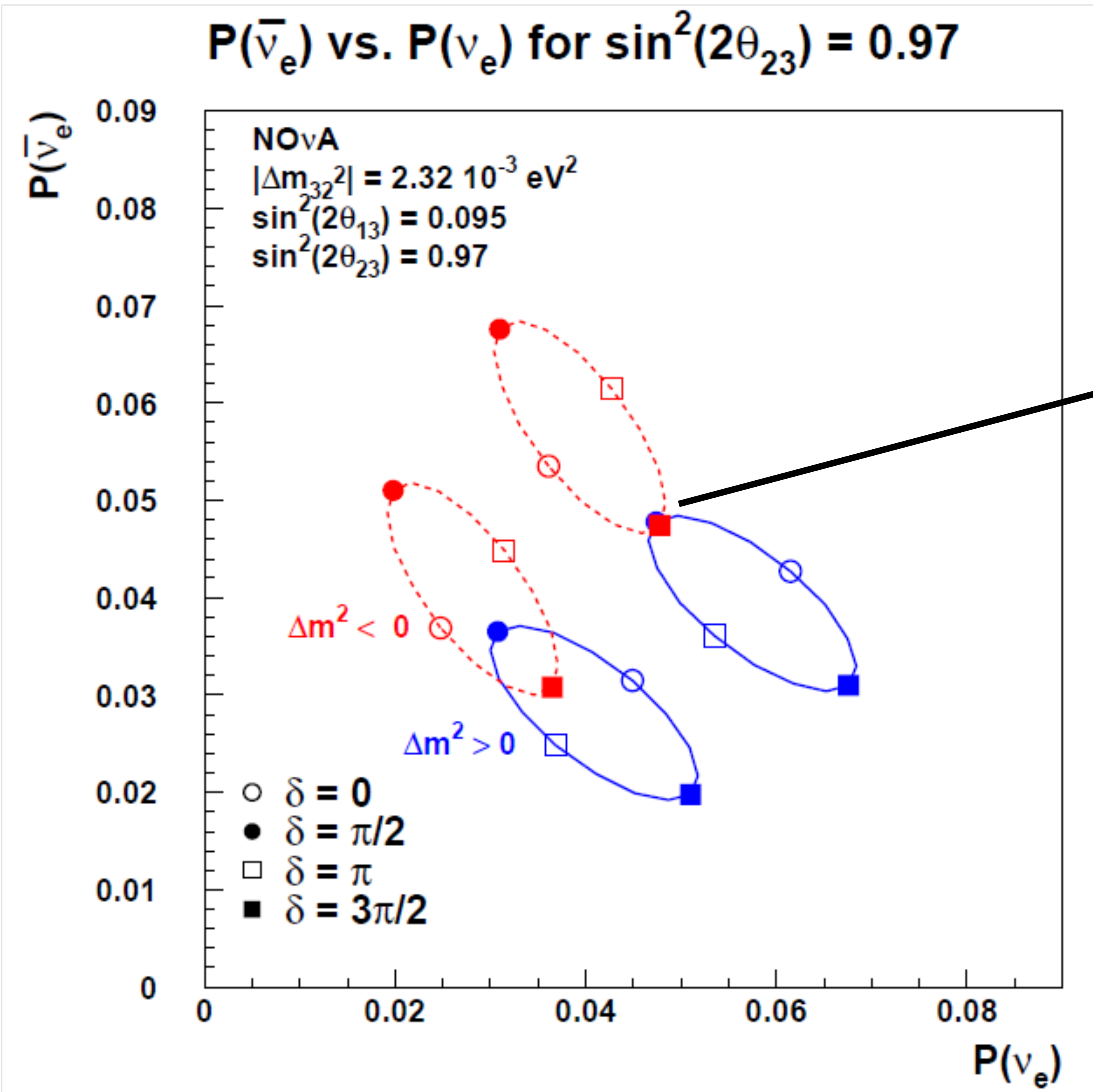
Physics Sensitivities (if we're lucky)

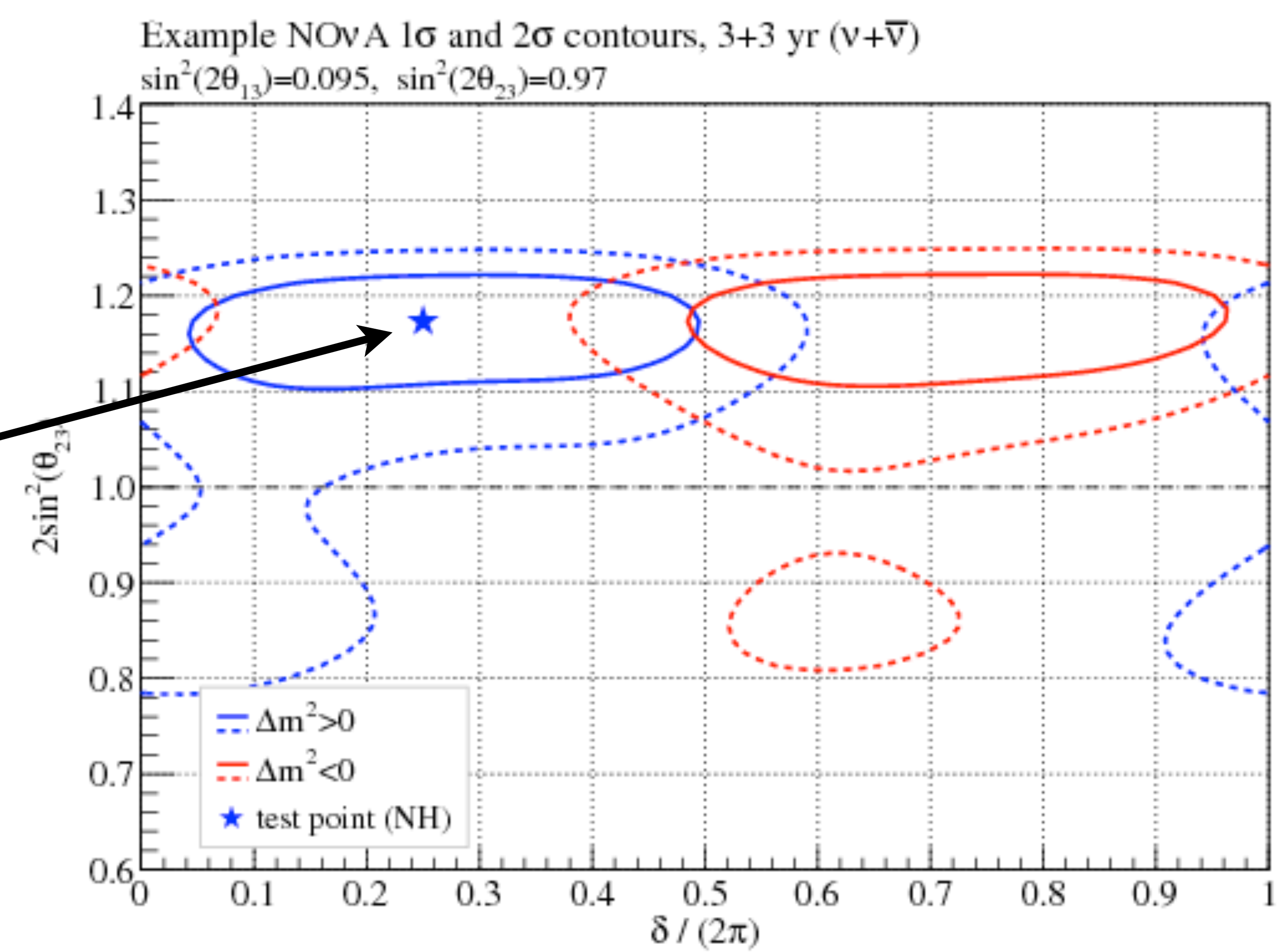




At this best-case point, we exclude the wrong hierarchy and a good fraction of δ_{CP} at 2σ.

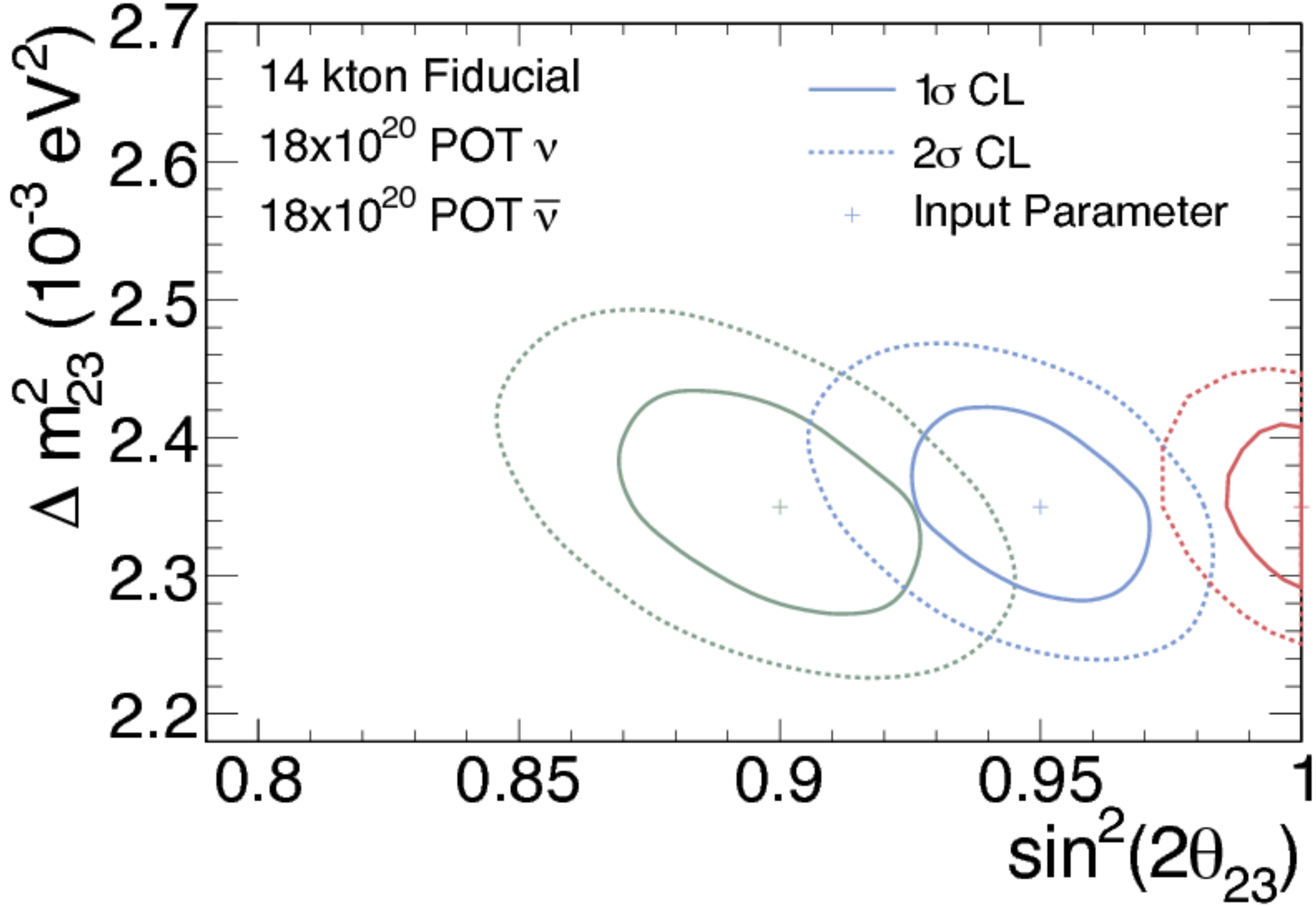
Physics Sensitivities (if we're unlucky)





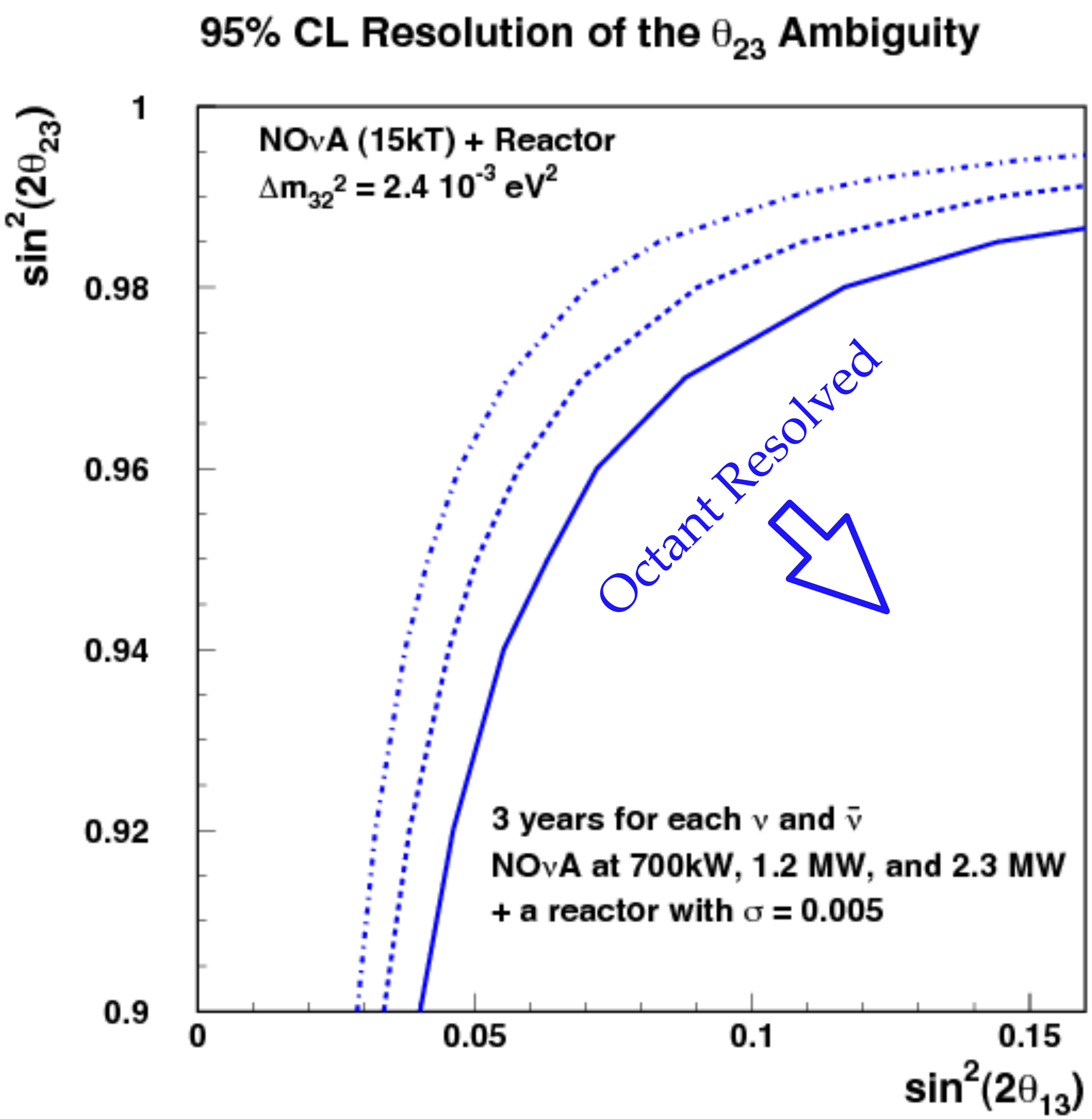
At this point, we cannot determine the hierarchy, but we can make conditional statements about it and δ_{CP}. In both cases, we select $\theta_{23} > 45^o$ at 1σ

θ_{23} Sensitivity



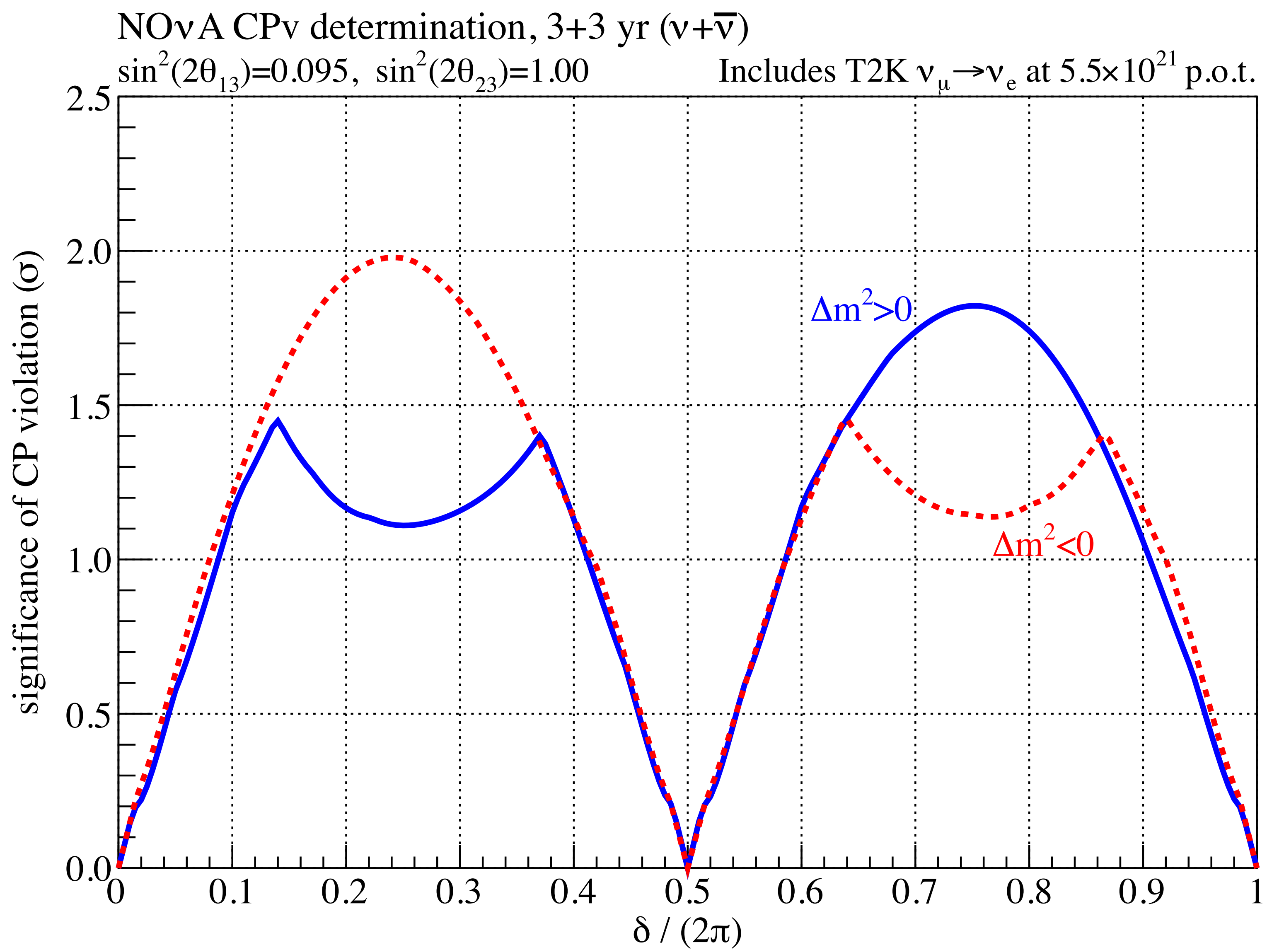
- NOvA has good sensitivity to whether θ_{23} is maximal

θ_{23} Octant

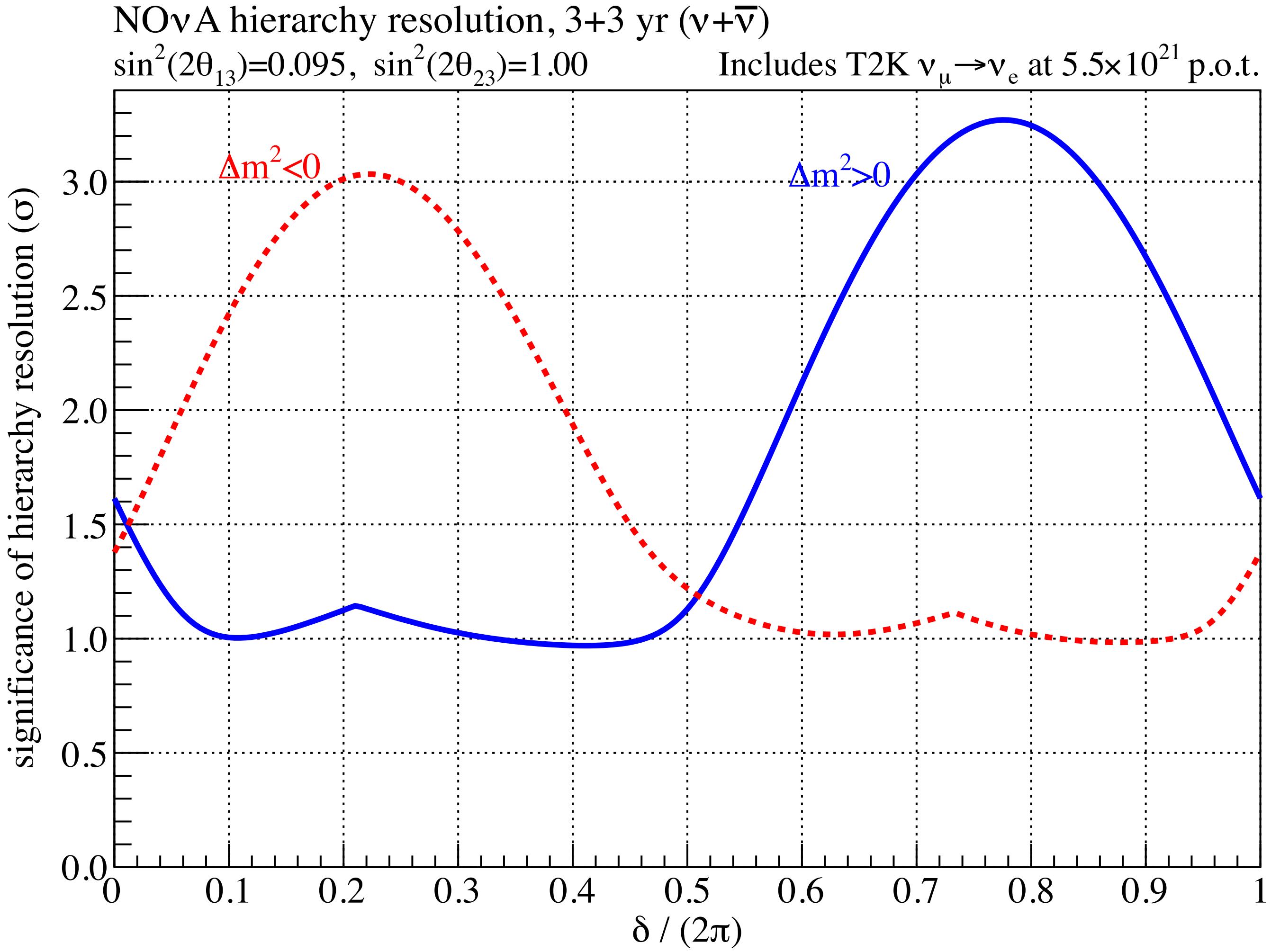


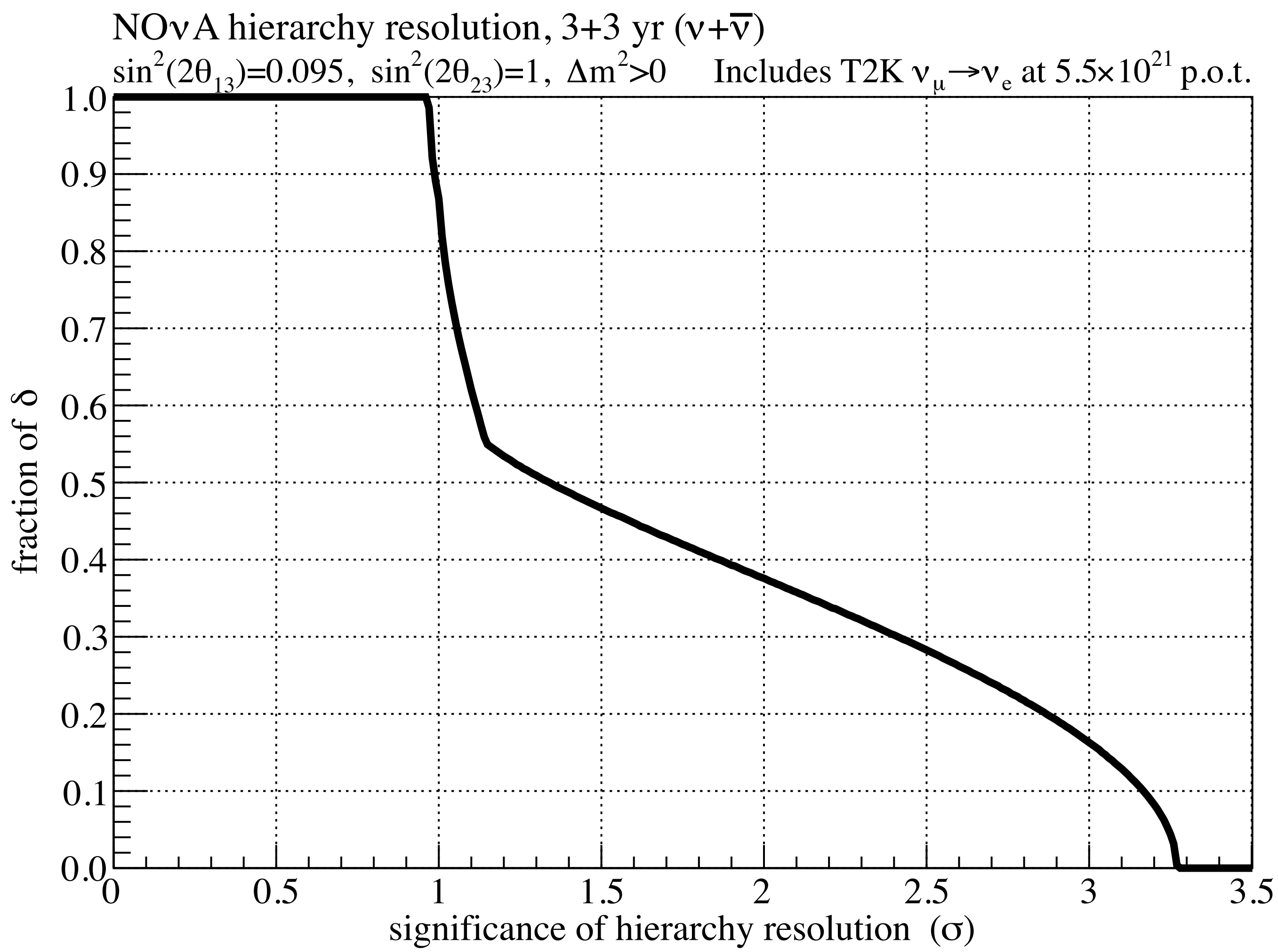
- Combining NOvA data with precision reactor data could determine the octant for a large range of values

δ_{CP} Sensitivity



- With complimentary data from T2K, we can determine δ_{CP} at 1σ over a good fraction of possible values.

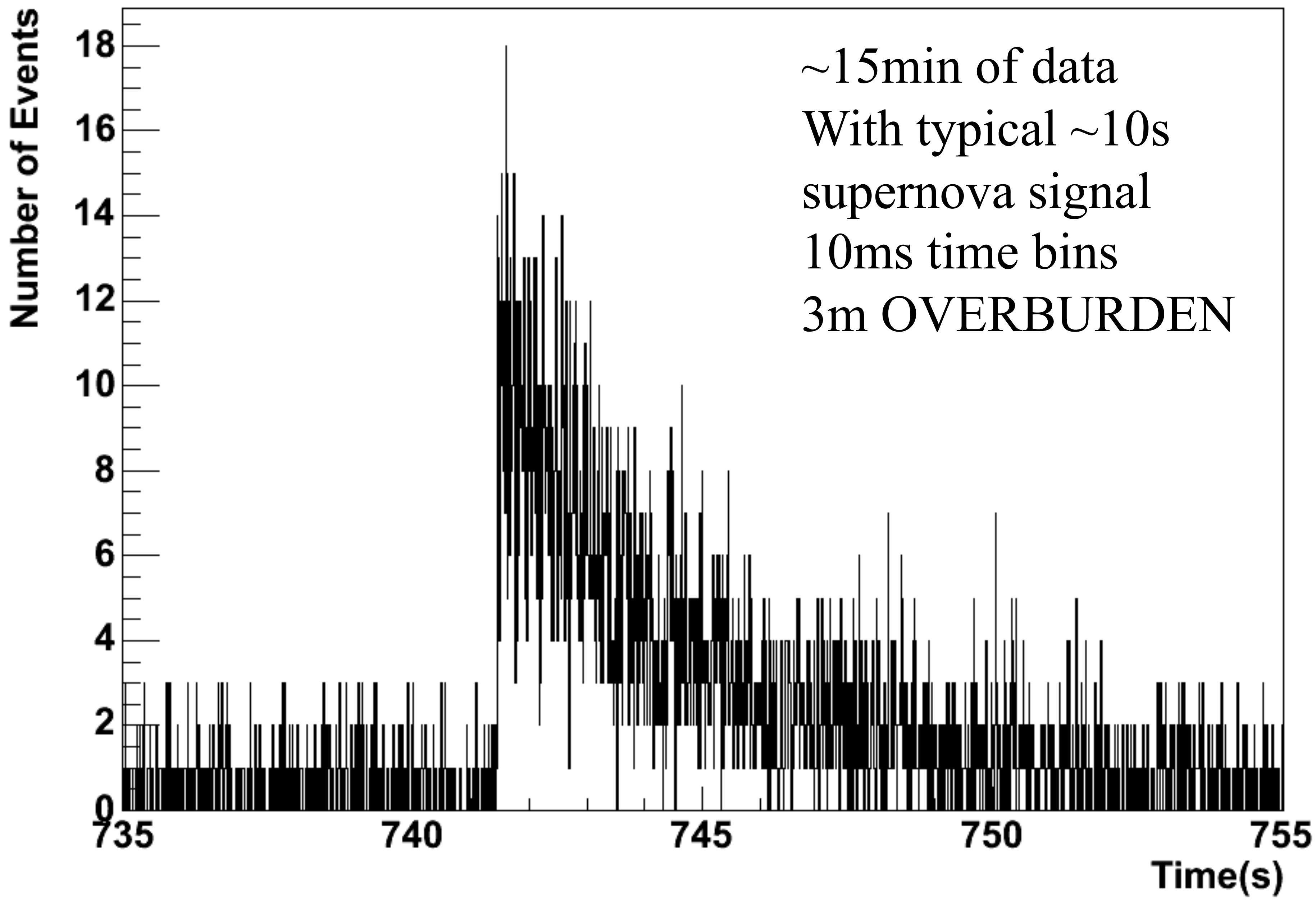




Hierarchy

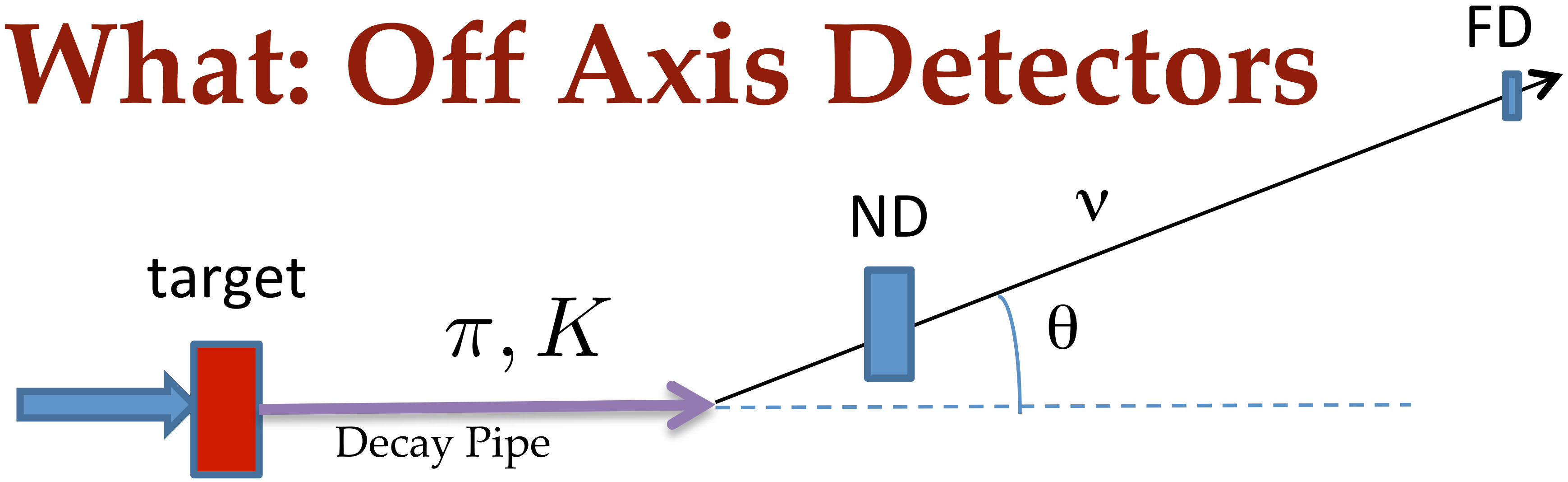
- With complimentary data from T2K, NOvA could be able to determine the hierarchy at 1σ for almost all values of δ_{CP}.

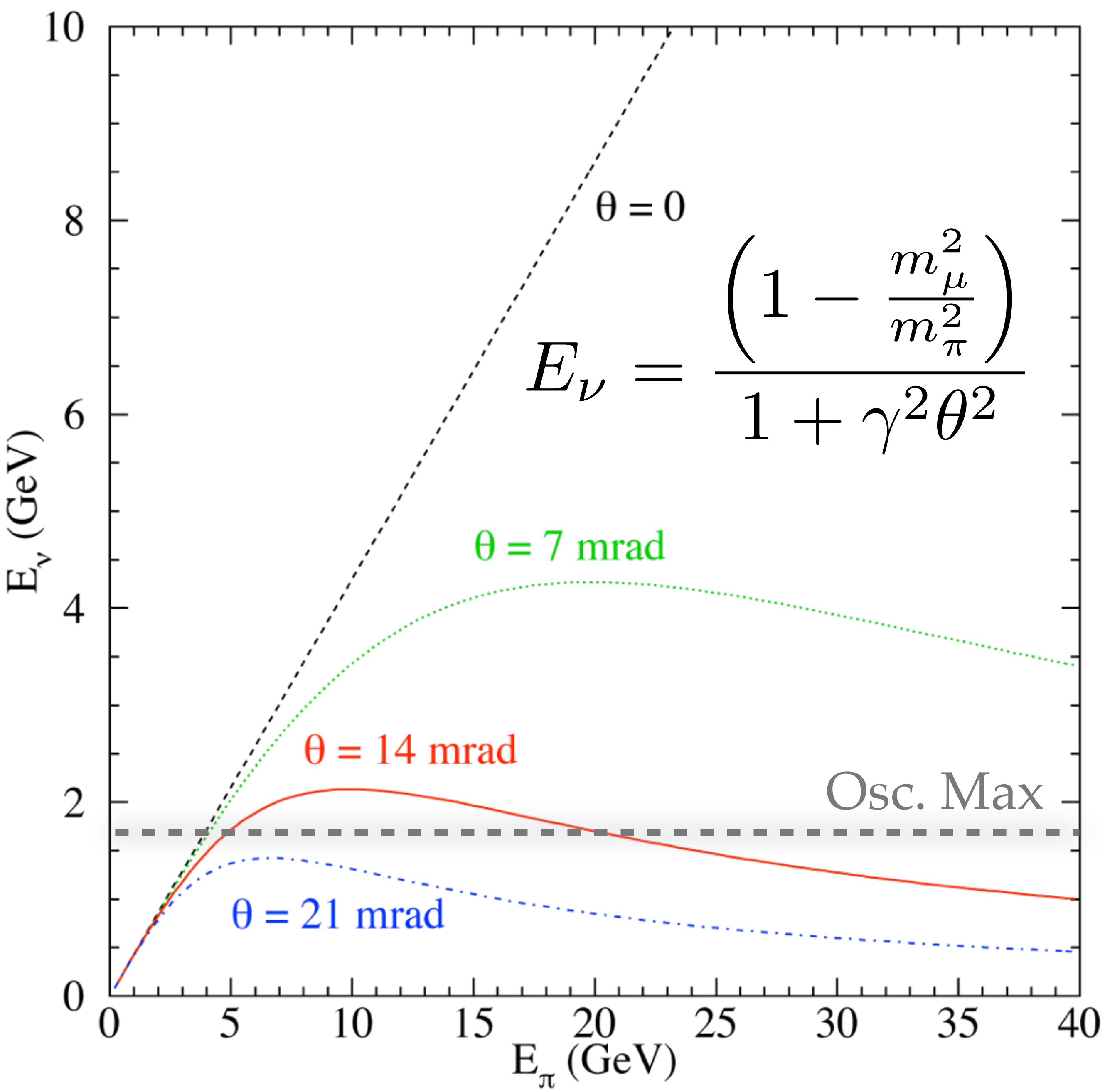
Supernova Neutrinos

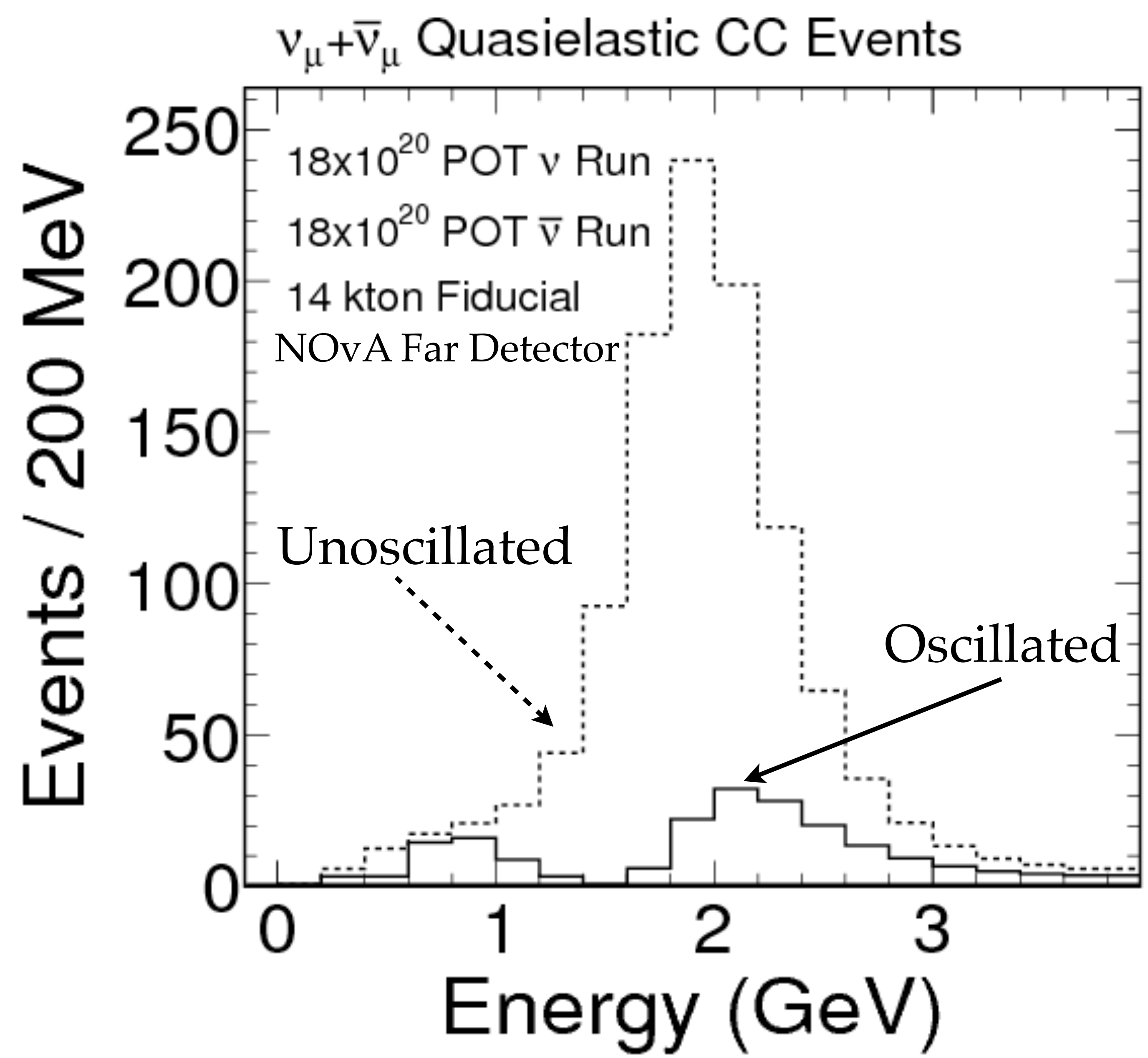


- NOvA Far Detector would see a bust of 5000 neutrinos from a supernova at the center of the galaxy

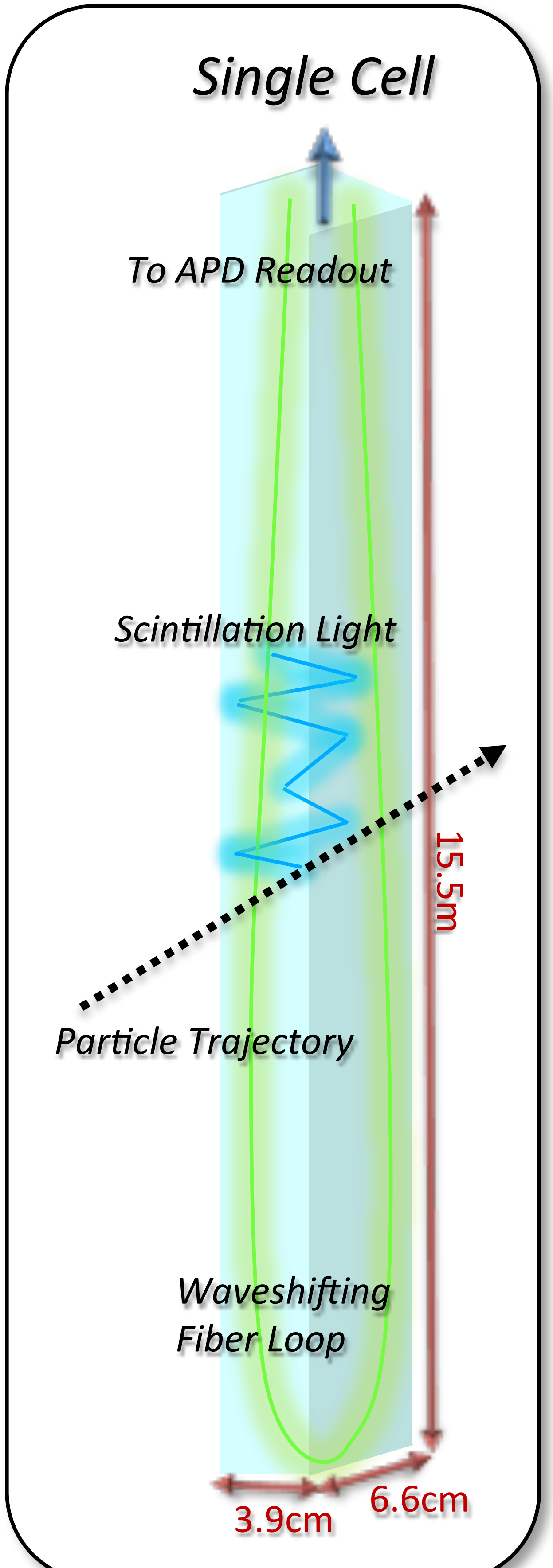
What: Off Axis Detectors

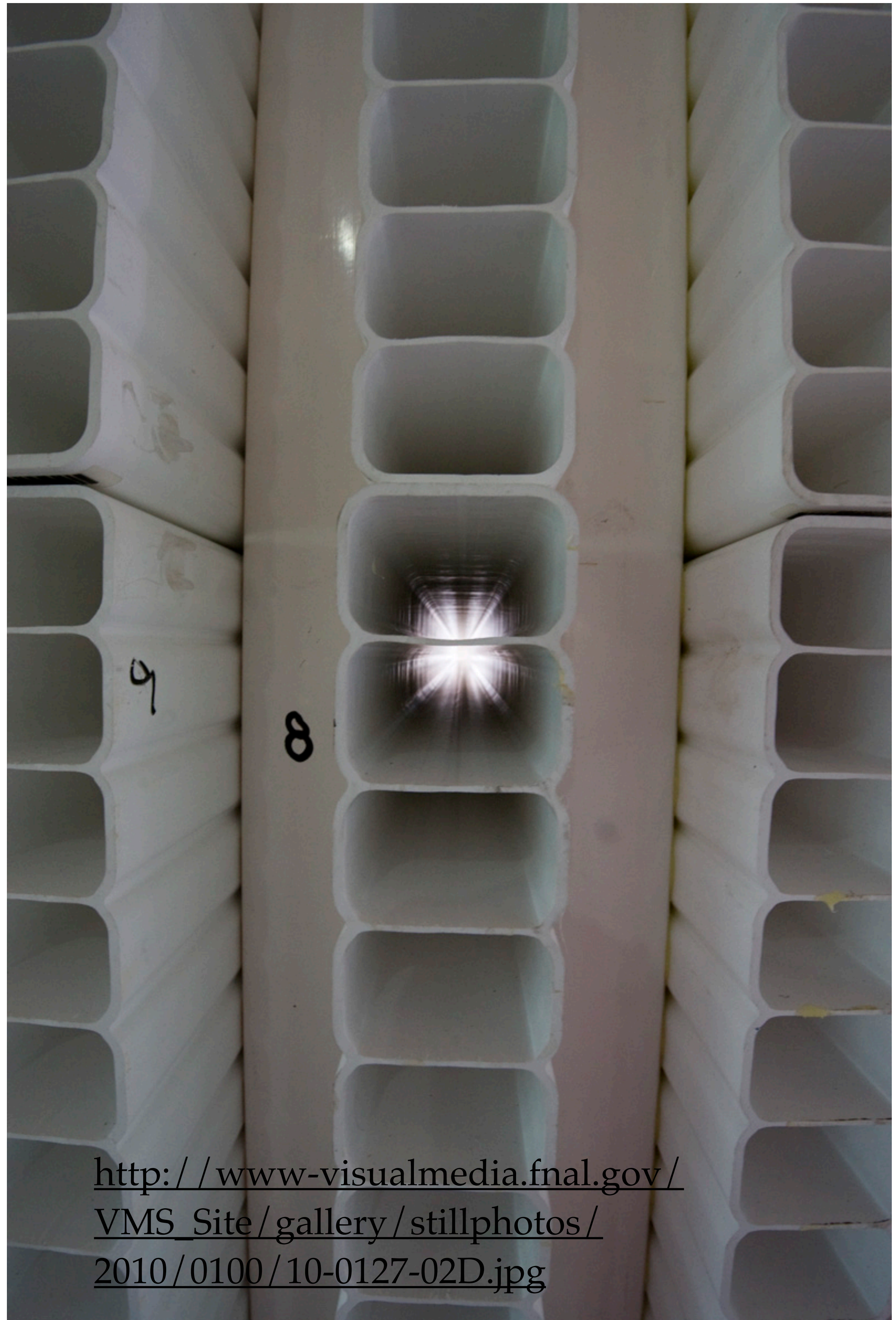






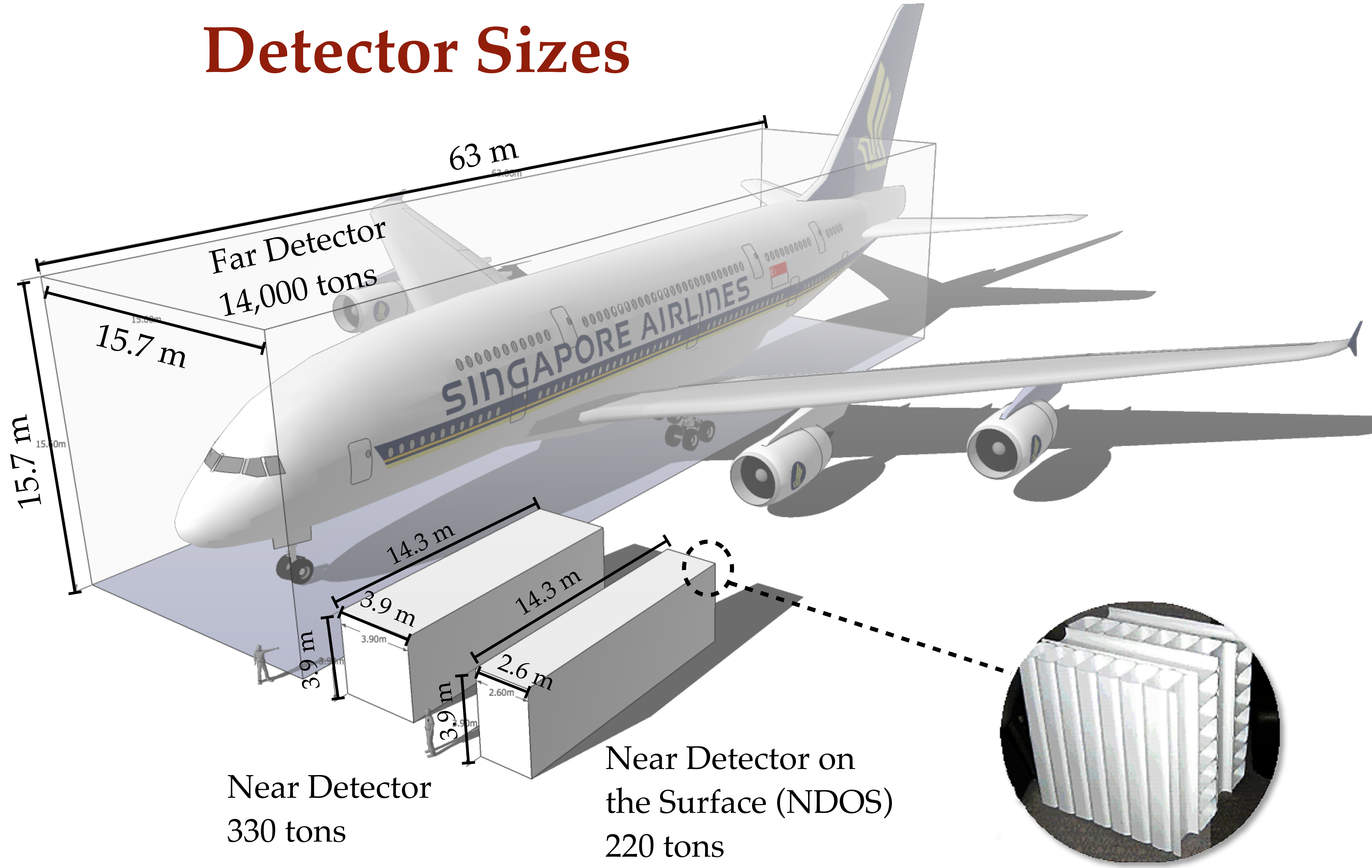
Detector Elements





- PVC Cells are filled with liquid scintillator and grouped into alternating planes

Detector Sizes



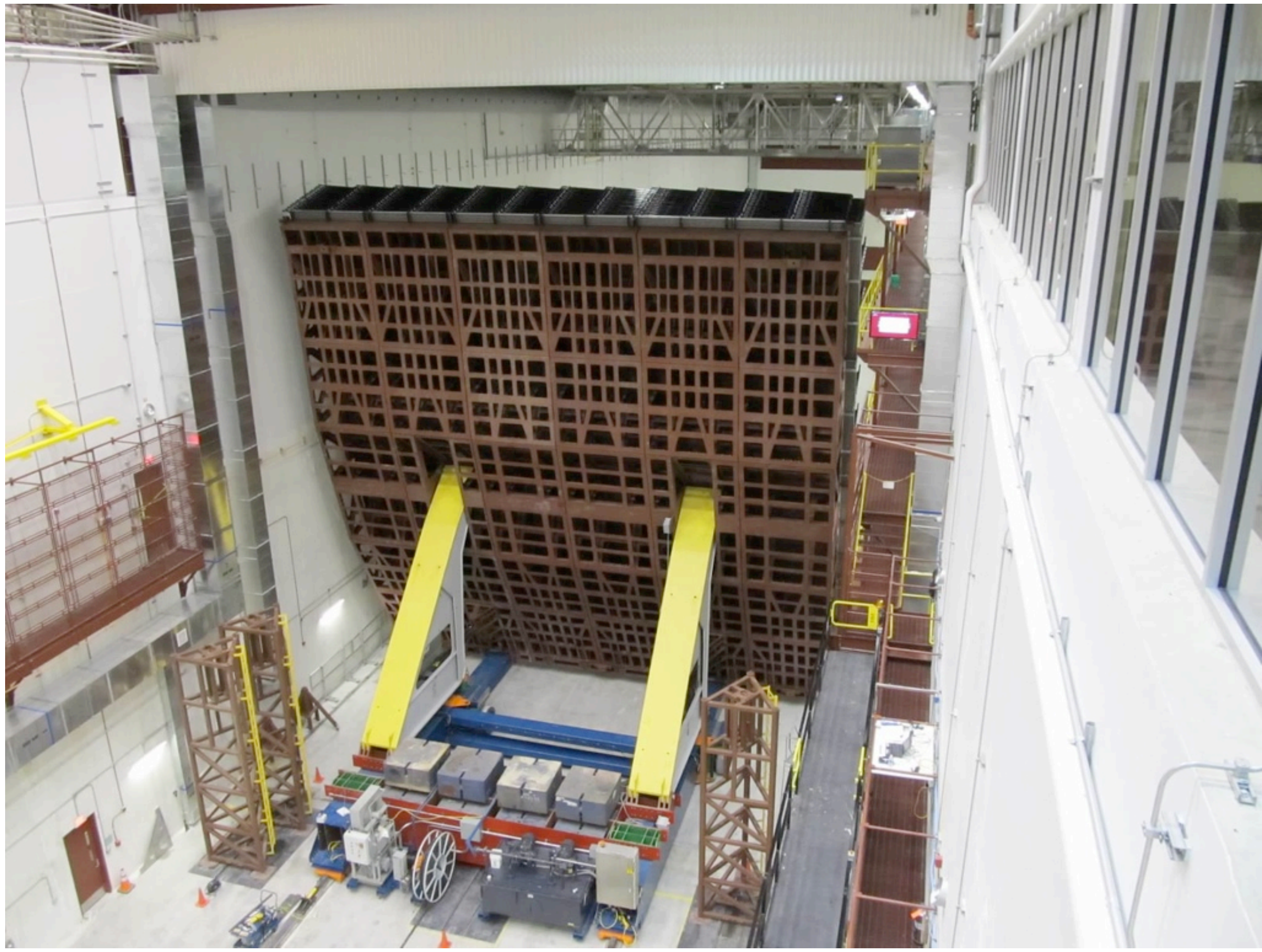
NDOS

- **N**ear **D**etector **O**n the **S**urface
- Our prototype near detector
- Operational since Oct. 2010
- Collected NuMI beam data
- Taught us much about detector assembly
- Not fully instrumented
- Instrumented in multiple different configurations
- Has been remarkably productive and useful

Near Detector Cavern

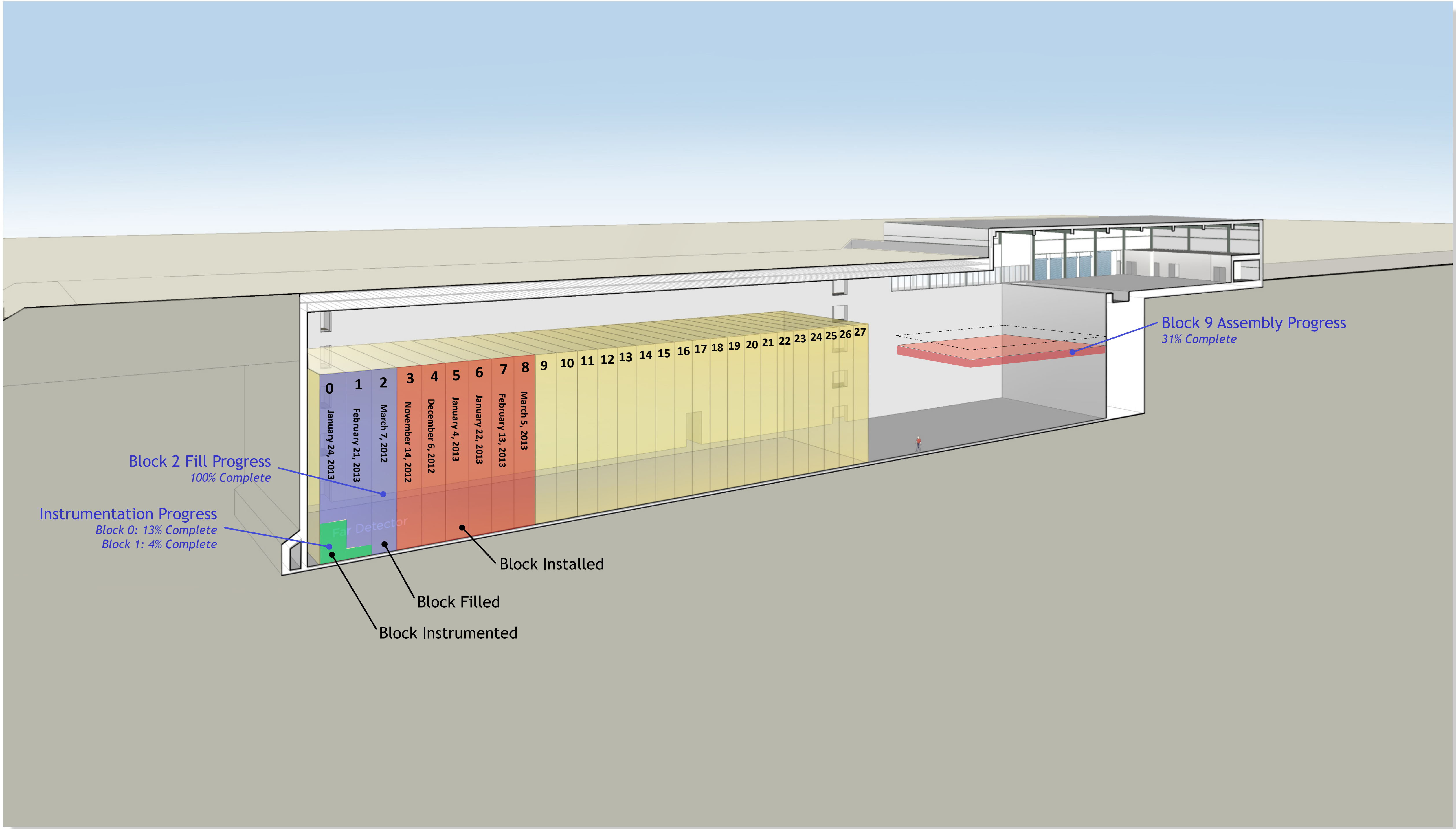
- Cavern almost complete
- Installation scheduled for July 2013 - Feb. 2014

Far Detector Assembly in Progress



- Modules assembled in to blocks on pivoter
- Driven to the end of the hall and placed
- Filled with scintillator
- Outfitted with electronics

NOvA Far Detector Assembly Progress

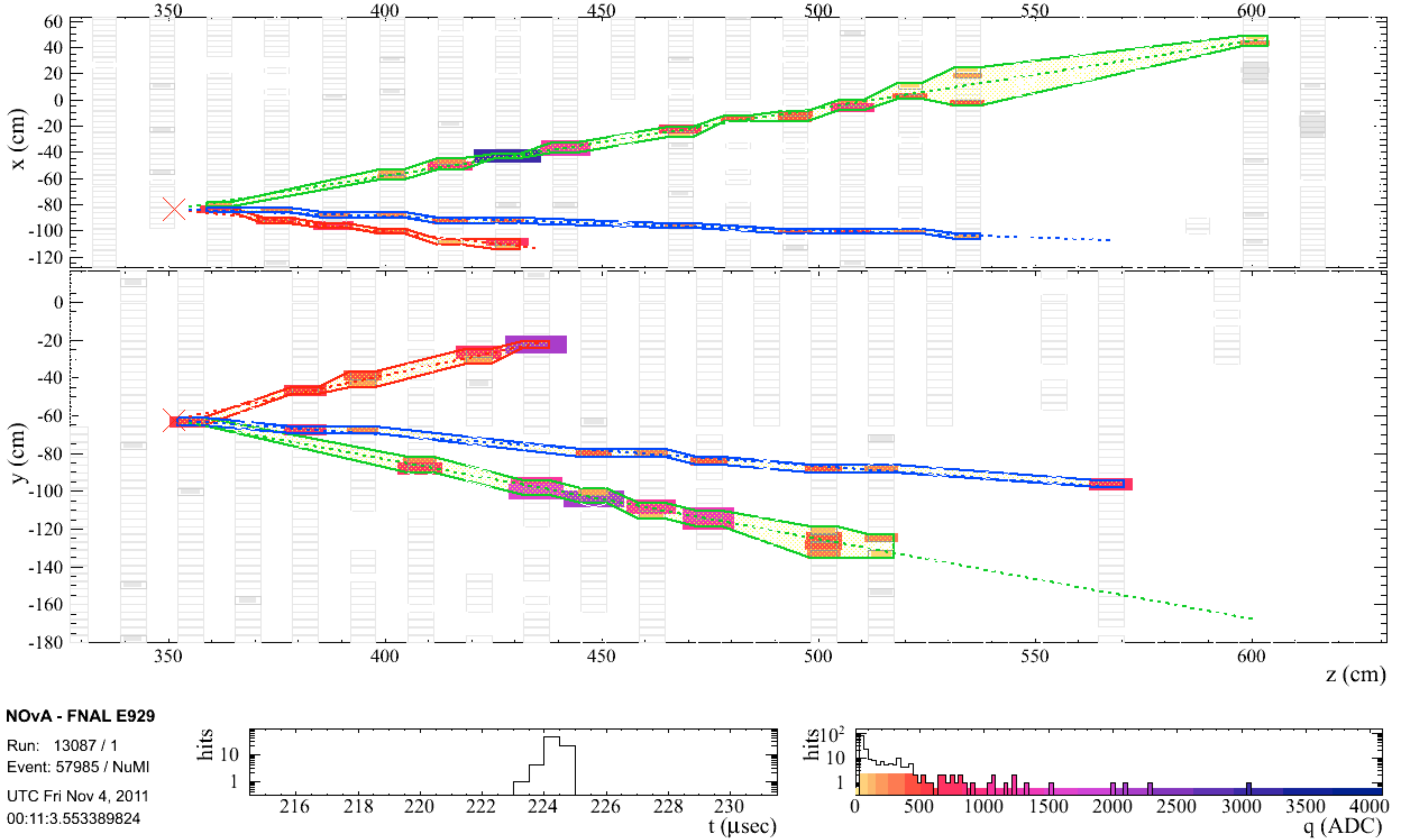


Mar 11, 2013

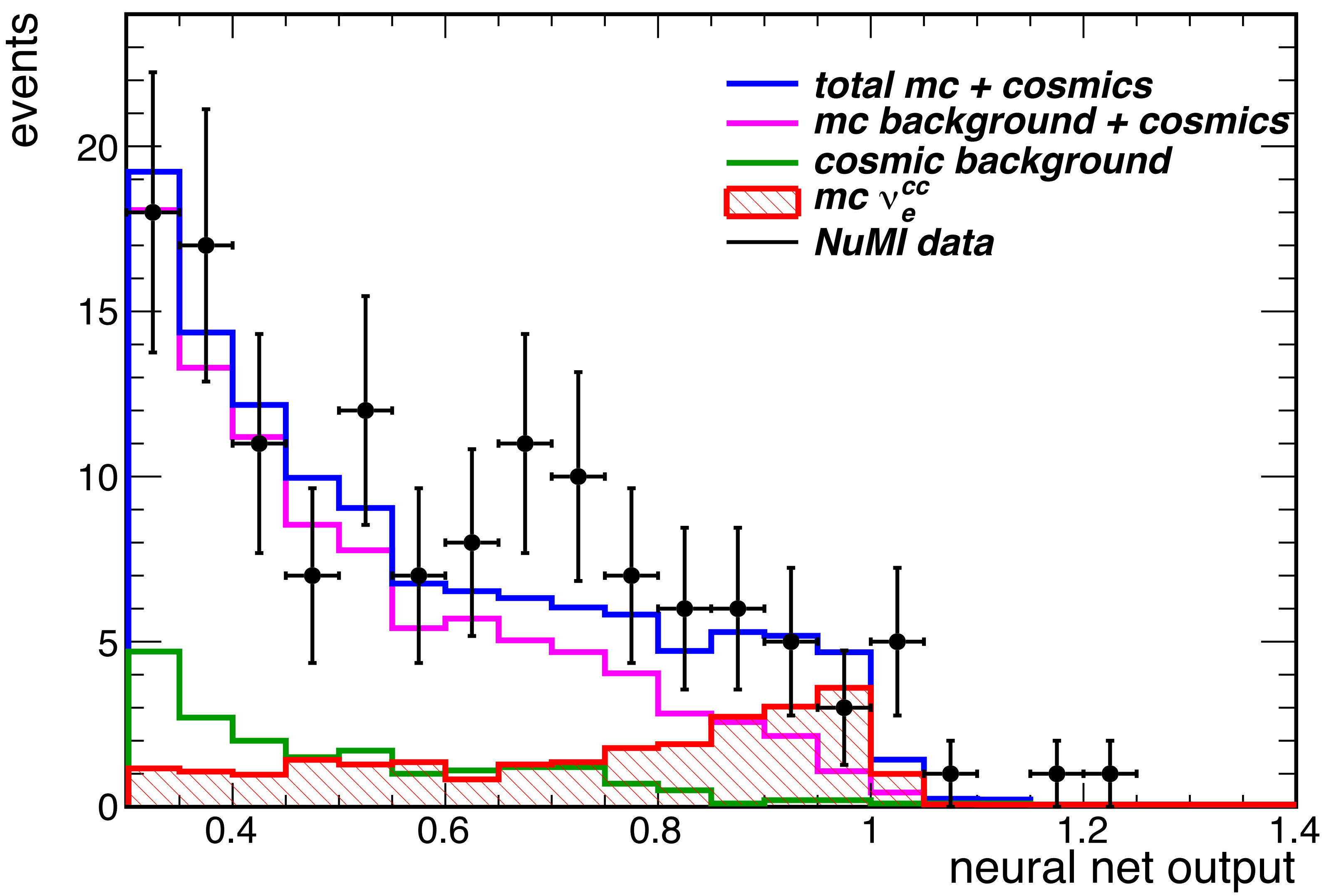
Habemus primam lucem!

- **We have first light** at the far detector!
- First cells have complete electronics chain installed
- APDs not yet cooled
- Many commissioning tasks ahead
- Cosmic rays have generated the first real light detected and recorded by the NOvA Far Detector
- Far Detector expects beam data in June
- Scheduled to be complete by Nov. 2014

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

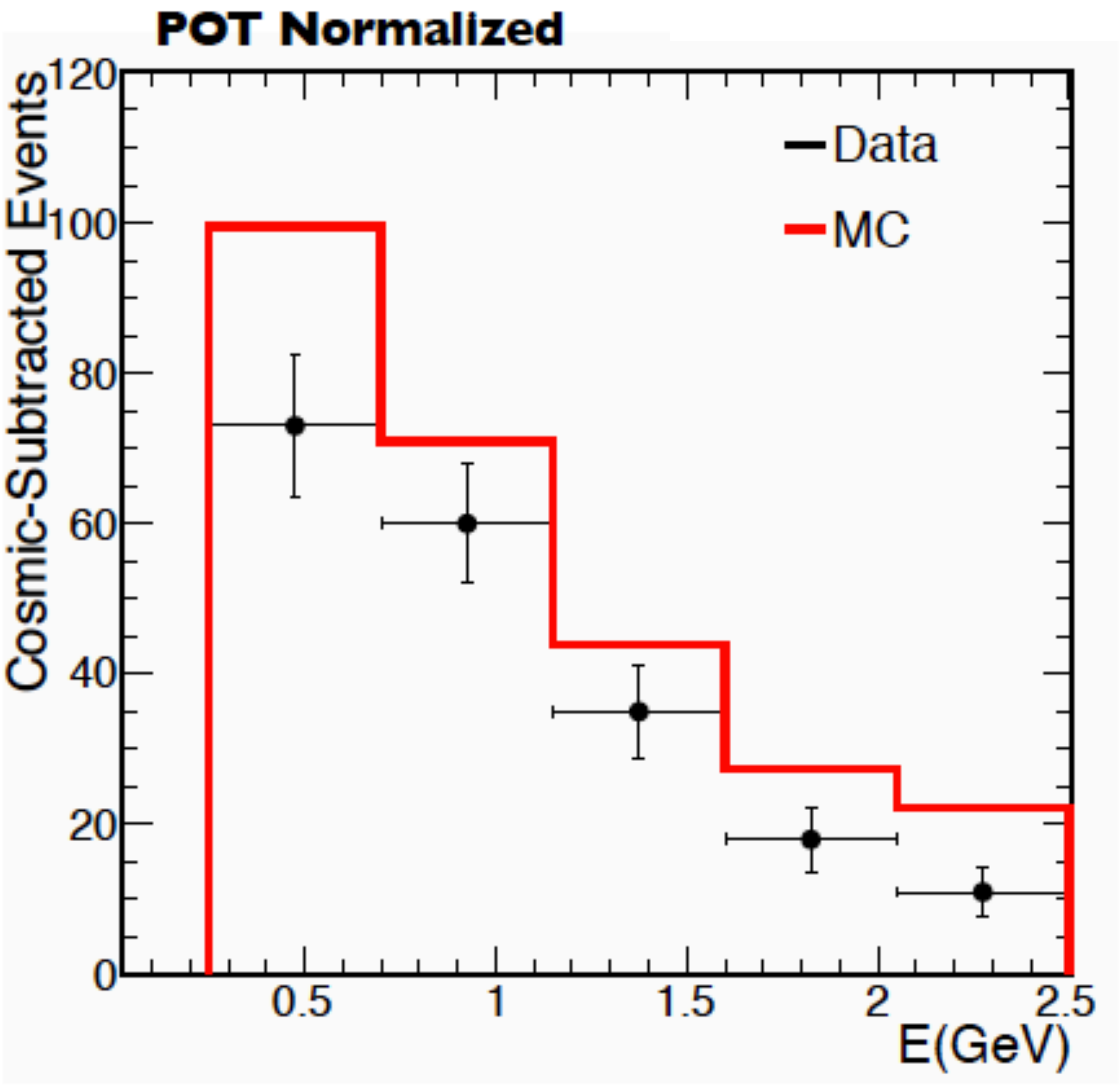


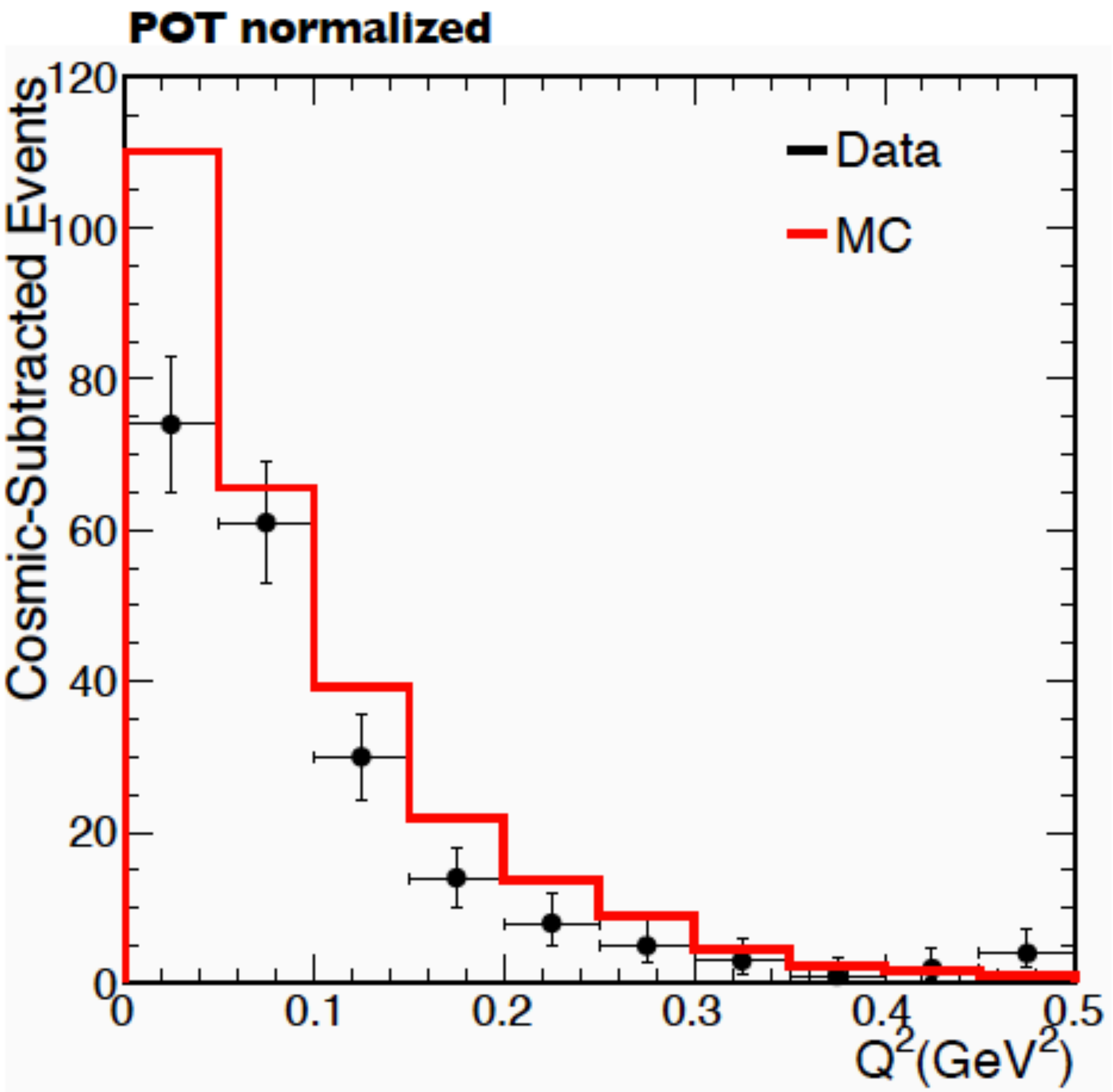
ν_e in NDOS



- Even with sparse instrumentation, we have identified electron neutrino events
- See data excess above backgound
- Promising for fully instrumented detectors

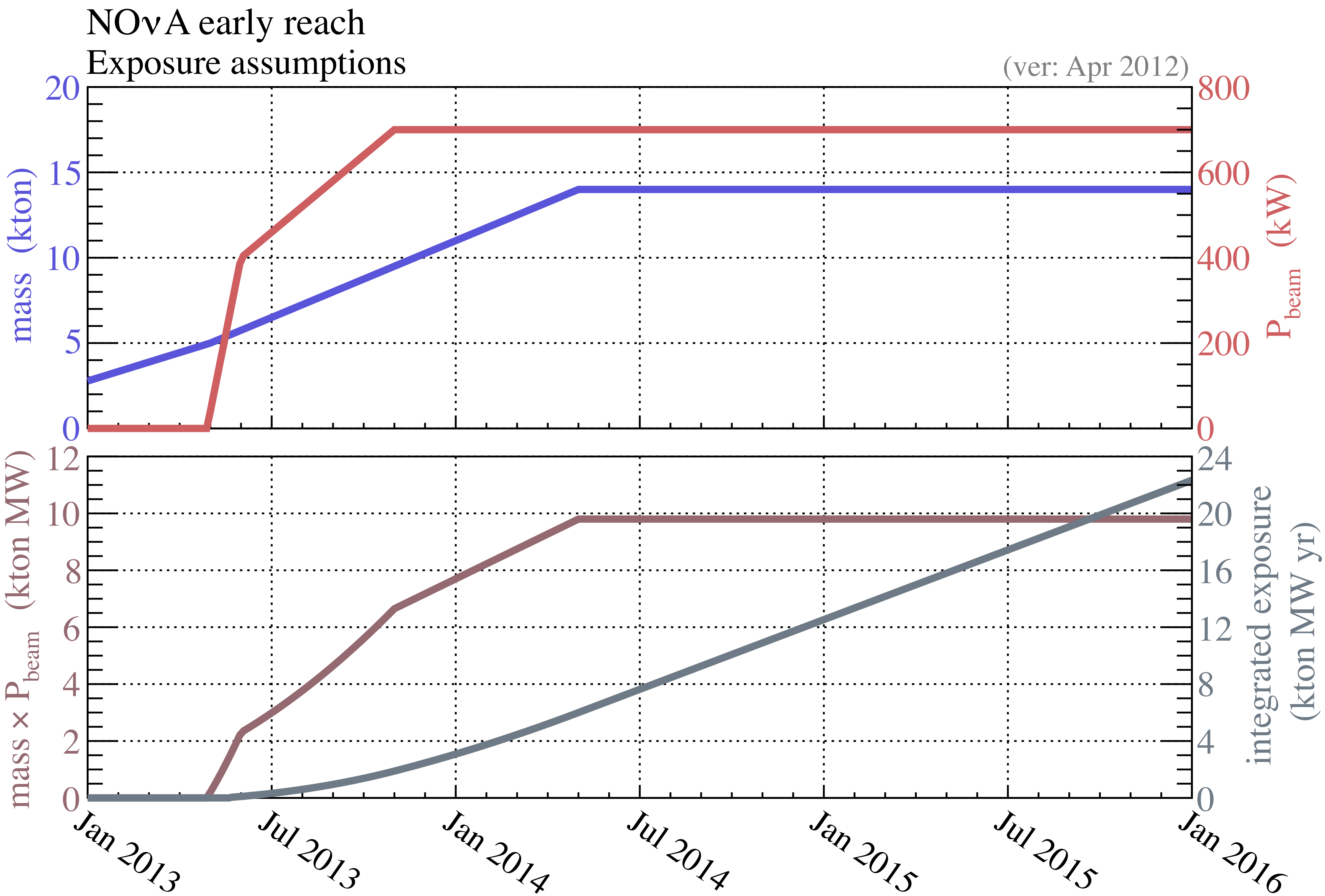
ν_μ Charged Current Quasi-Elastic Rates



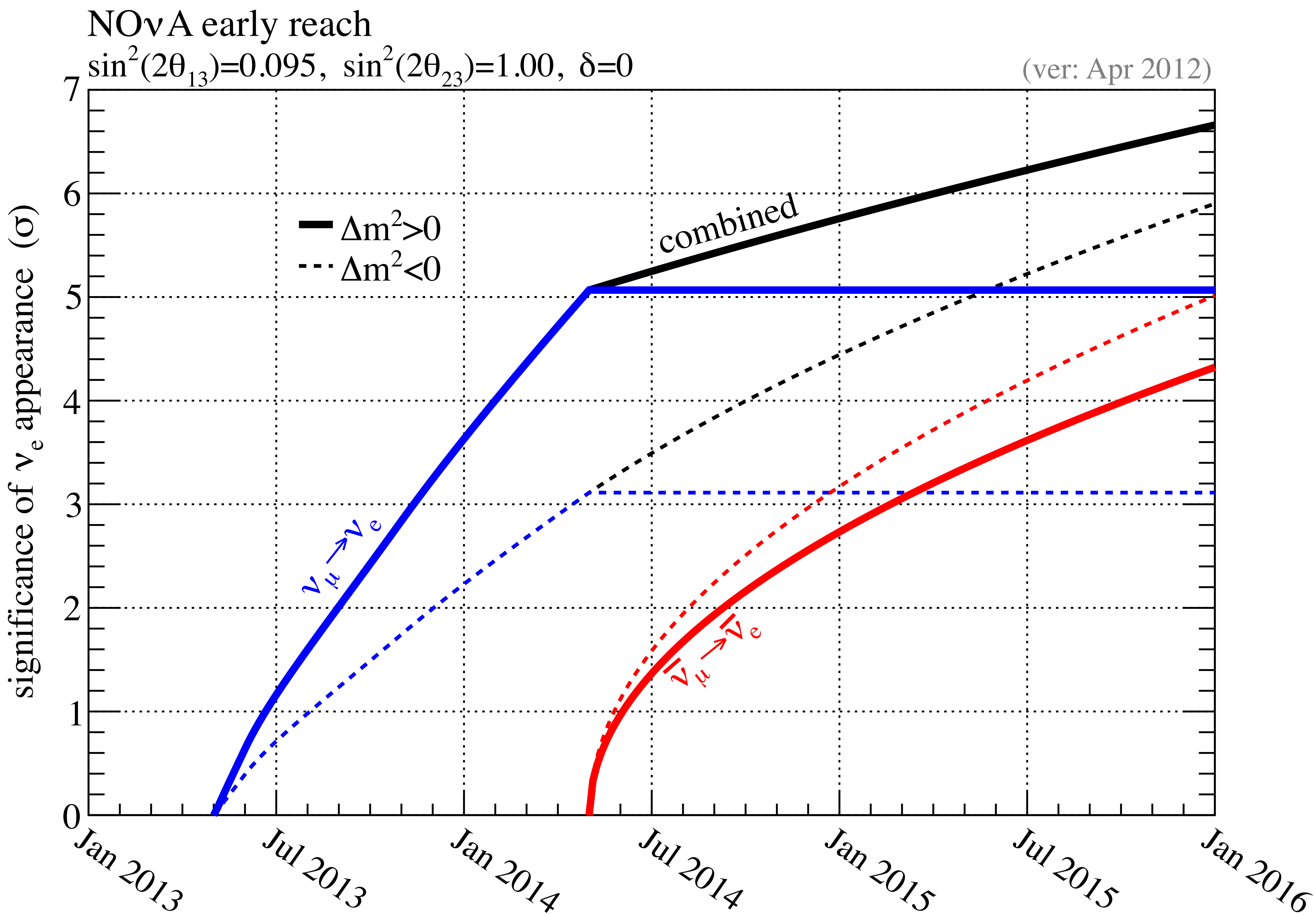


- Thesis topic of Minerba Betancourt (U of Minnesota)

Expected Exposure



Expected ν_e Appearance Sensitivity

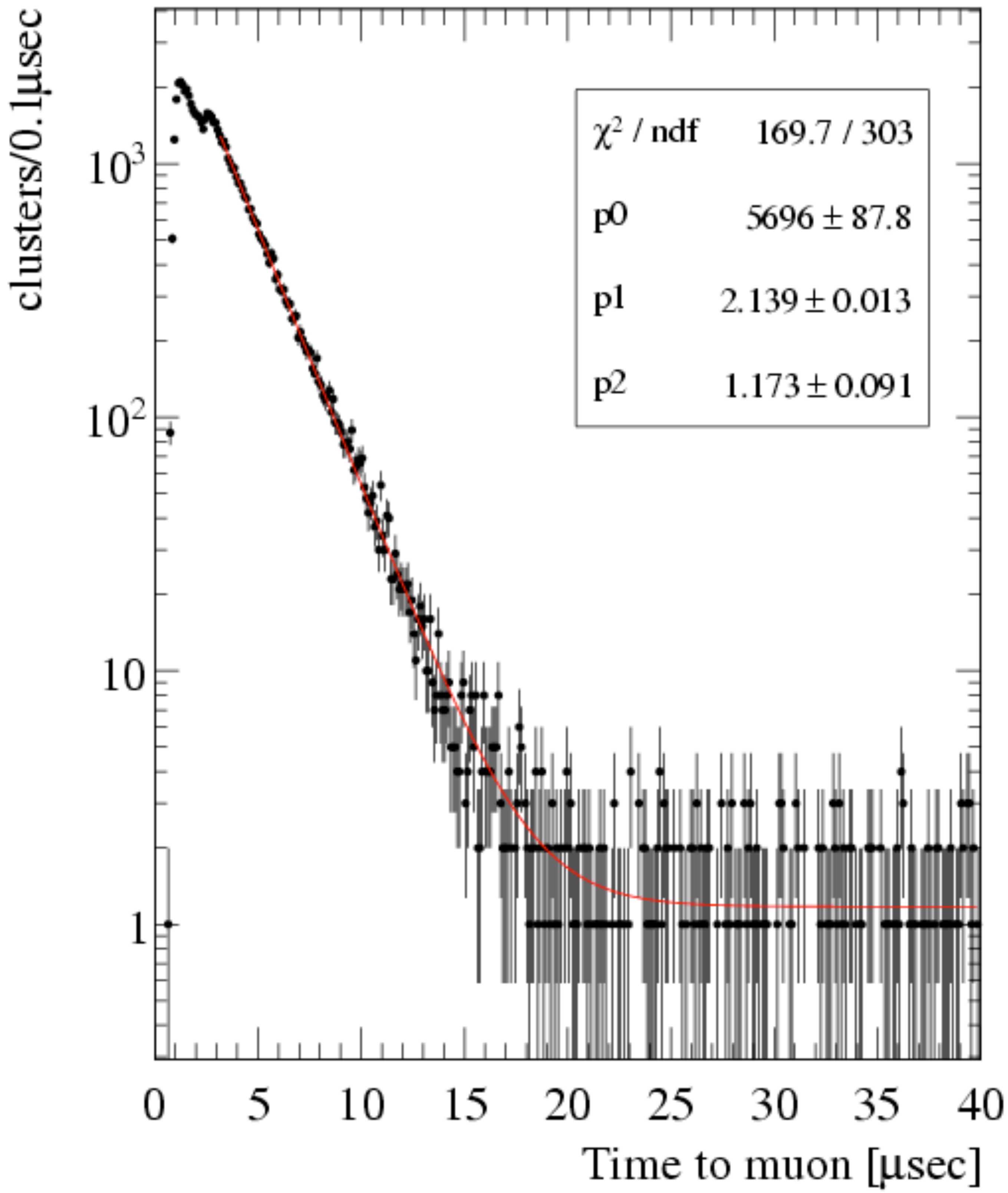


Schedule & Outlook

- Partial Far Detector (3kt) reading out beam data in June 2013
- Near Detector Complete Feb. 2014
- Far Detector Complete by Nov. 2014
- First analyses already well underway
- First two-detector analyses for Neutrino 2014
- Thank you!

Backup Slides

Michel Electrons in the NDOS



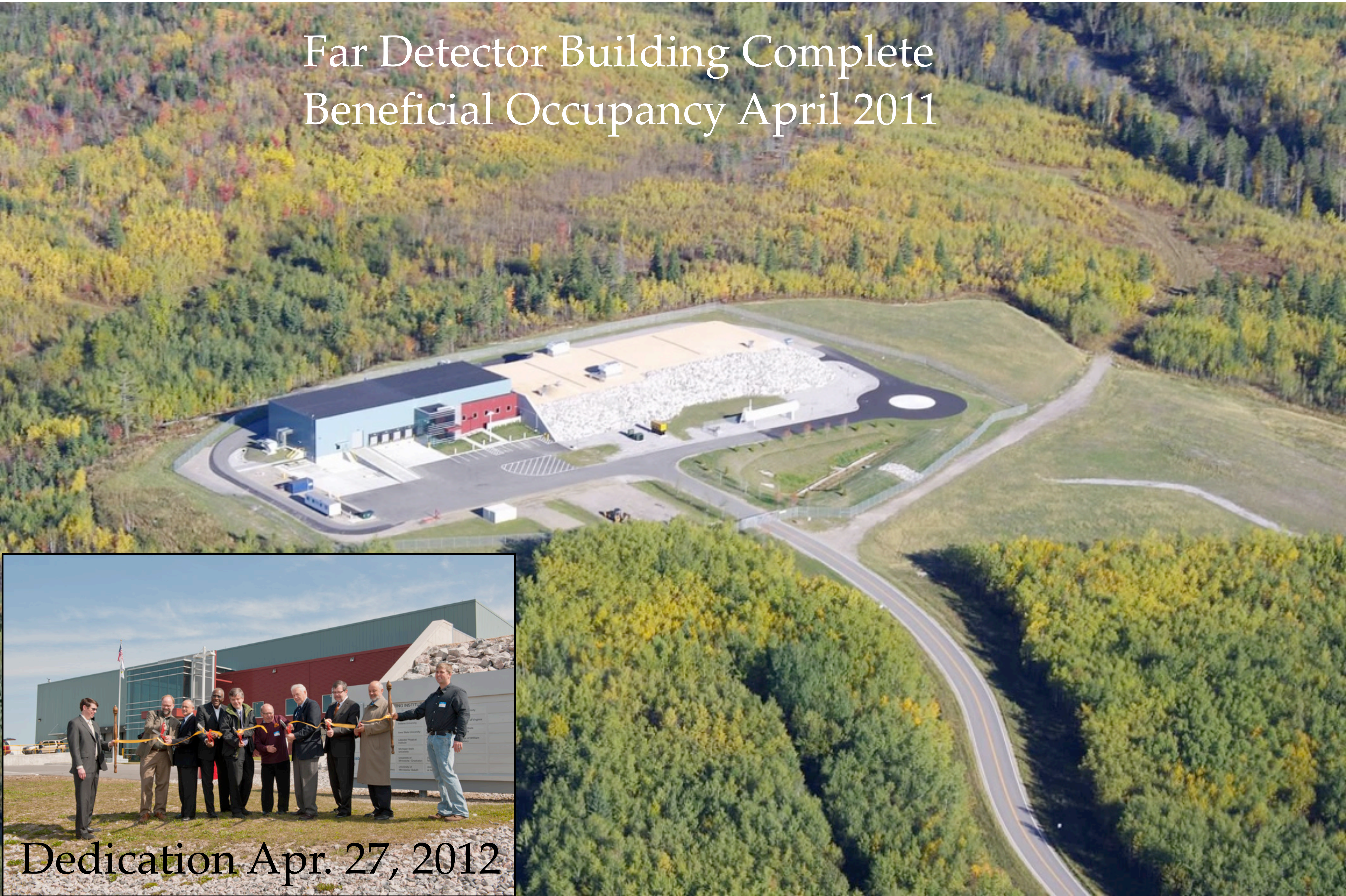
- We have measured a large sample of stopping muon decays
- Detect Michel electrons and measure muon lifetime
- Our fit:

$$\tau_\mu = 2.139(13) \times 10^{-6} s$$

- PDG:

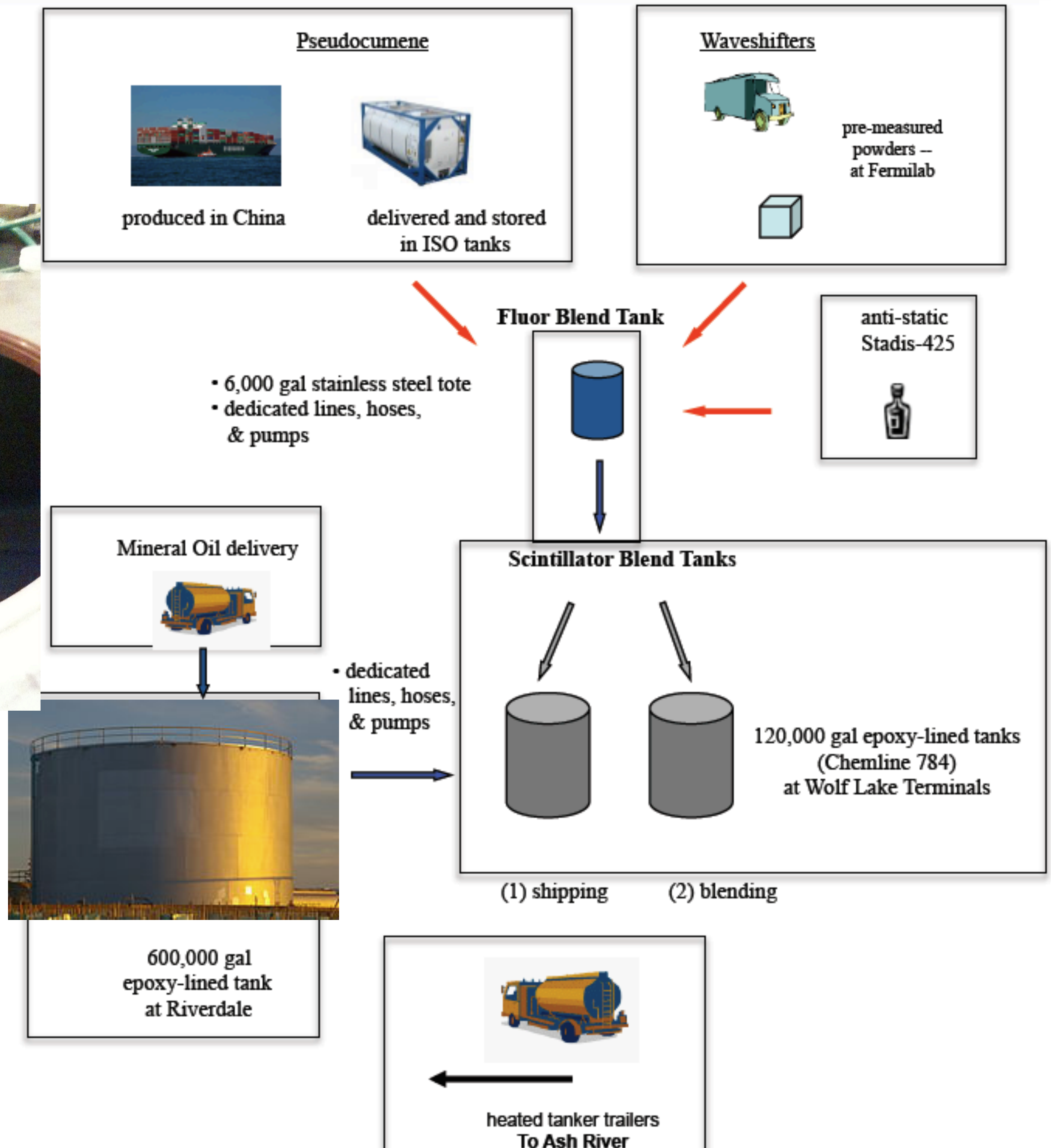
$$\tau_\mu = 2.1969811(22) \times 10^{-6} s$$

Far Detector Building Complete
Beneficial Occupancy April 2011



Dedication Apr. 27, 2012

Scintillator



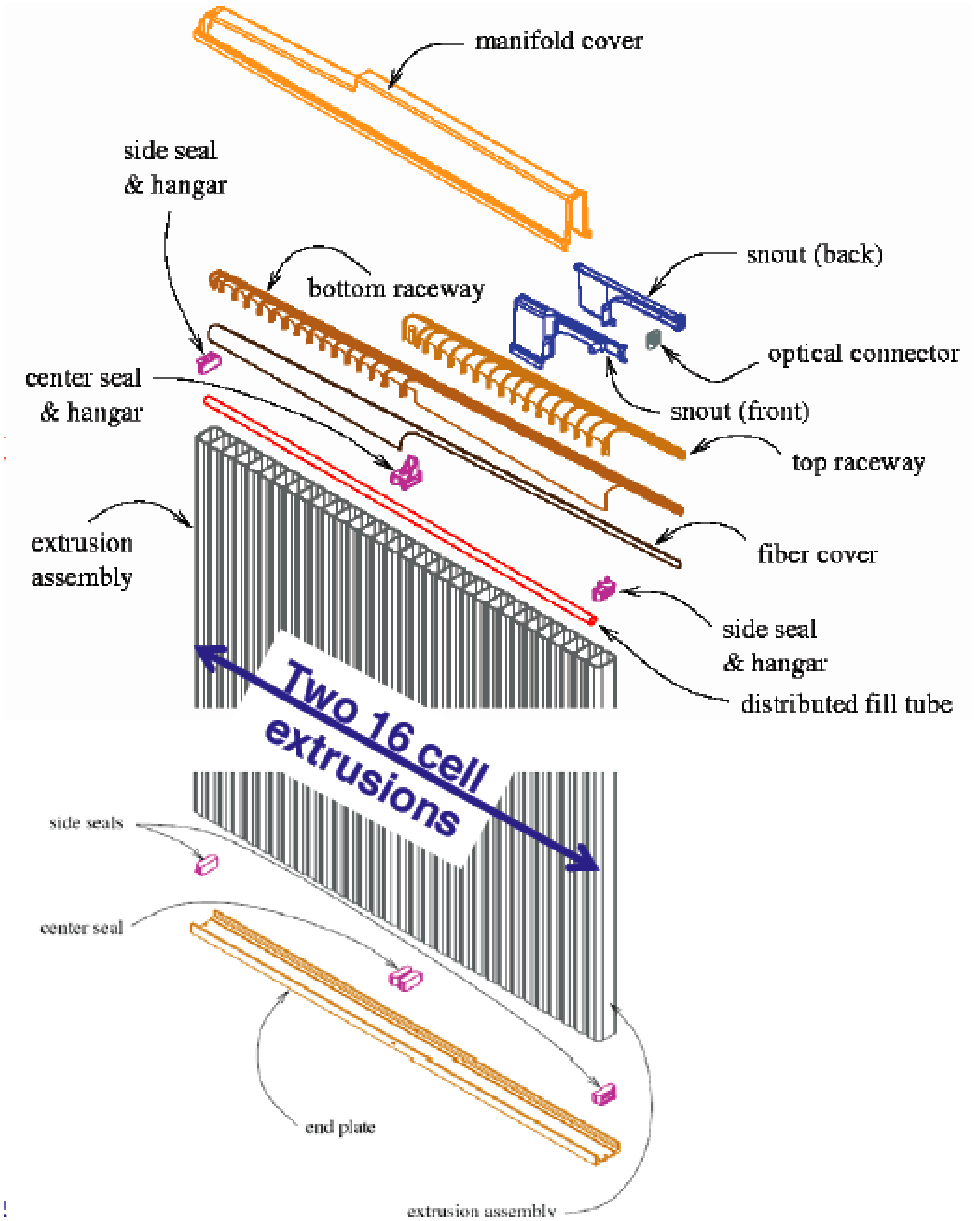
storage tank cleaned and holding our oil

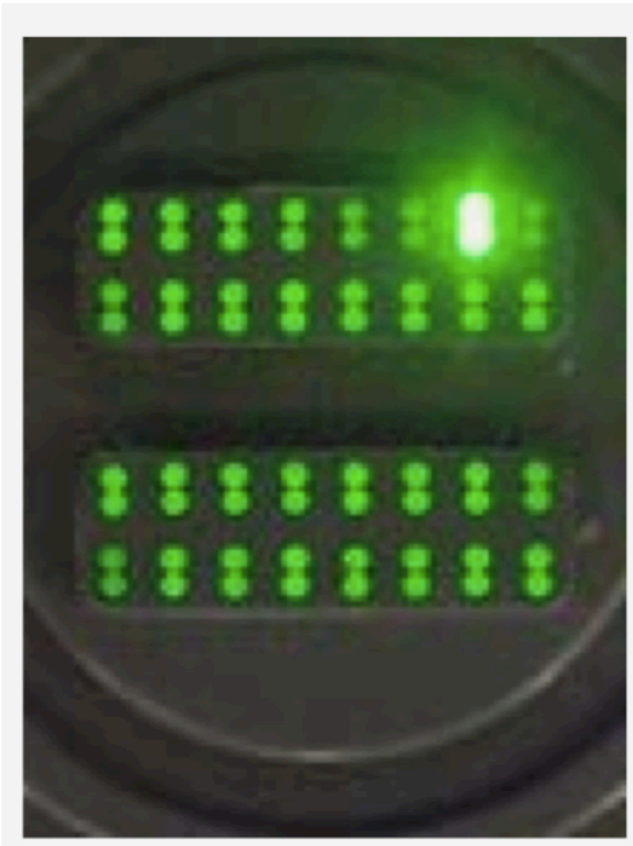
Have enough of everything except mineral oil and pseudocumene for full far detector

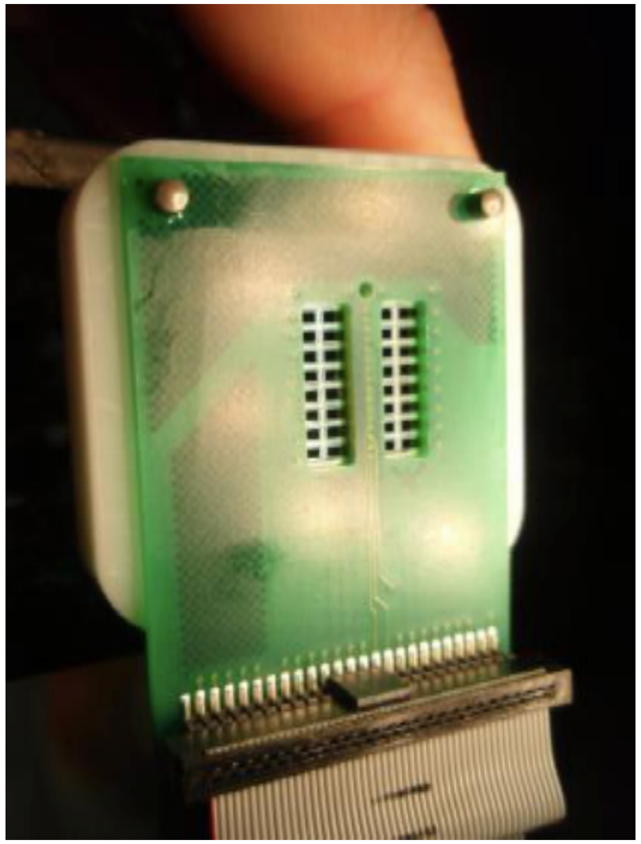
Hired private contractor (Renkert Oil) to deliver mineral oil and mix ingredients

Modules

- Many pieces must be brought together to form an active detector module
- Many undergrads working at module factory at the U of MN
- Cell interiors must be very reflective so scintillation light is not lost.

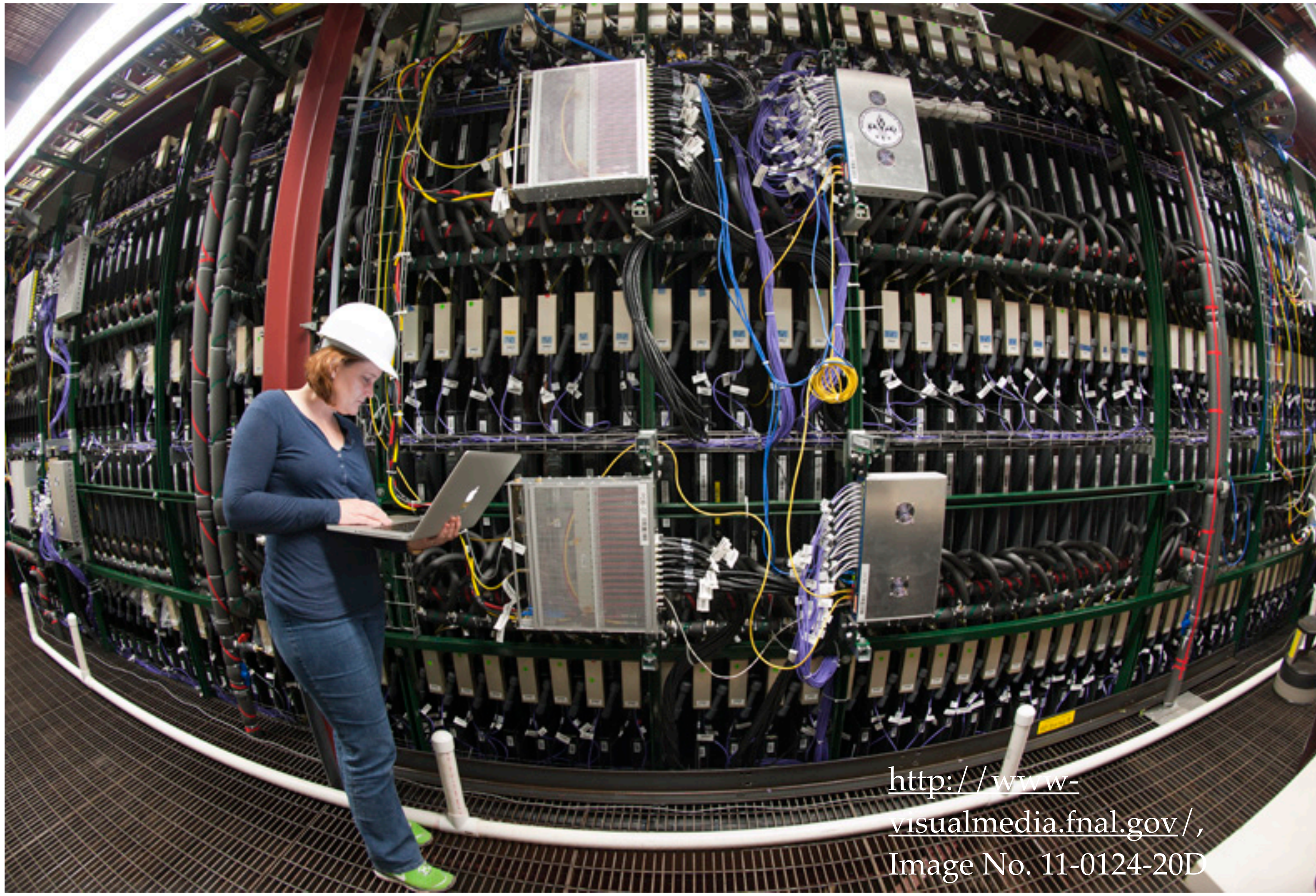






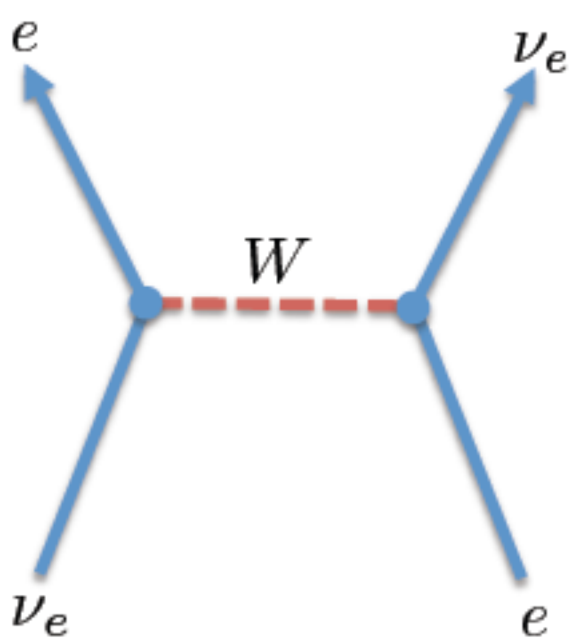
Scintillation light travels along wavelength shifting fibers to end of manifold

Light detected in by avalanche photodiodes (APDs) that are sealed, cooled (to -15 °C) and mated to the detector data acquisition system.



http://www-visualmedia.fnal.gov/, Image No. 11-0124-20D

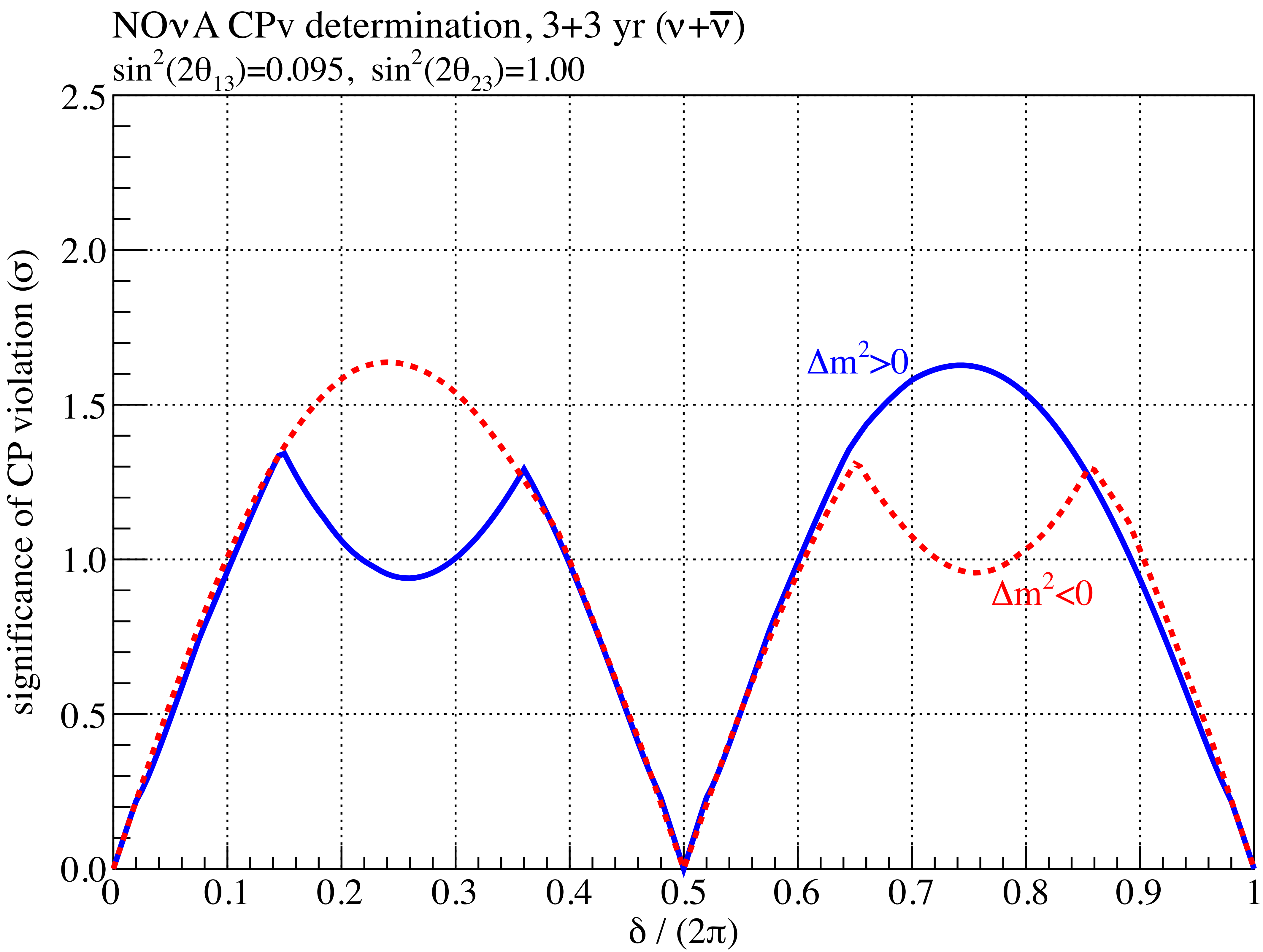
How: MSW Effect and Hierarchy



- As electron neutrinos propagate through matter, they scatter off of electrons
  - Electron anti-neutrinos do not
- The NuMI beam travels through 810 km of matter en route to the far detector
- This produces a hierarchy-dependent effect on electron neutrino appearance

$$P_{\text{matter}}(\nu_\mu \to \nu_e) \approx \left(1 + \frac{E\Delta m^2_{32}}{2\sqrt{2}G_F N_e}\right) P_{\text{vacuum}}(\nu_\mu \to \nu_e)$$

δ_{CP} Sensitivity without T2K



Hierarchy without T2K