Status of NOvA

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October, 2010

Outline

- Open Questions in Neutrino Oscillations
- Overview of NOνA
- NuMI Beam
- NOνA Status
- NOνA Sensitivities

What Next?

Atmospheric | Cross Terms | Solar/KamLAND

$$U = \begin{bmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{bmatrix} \times \begin{bmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{bmatrix} \times \begin{bmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{bmatrix} \times \begin{bmatrix} e^{i\alpha_1/2} & 0 & 0 \\ 0 & e^{i\alpha_2/2} & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

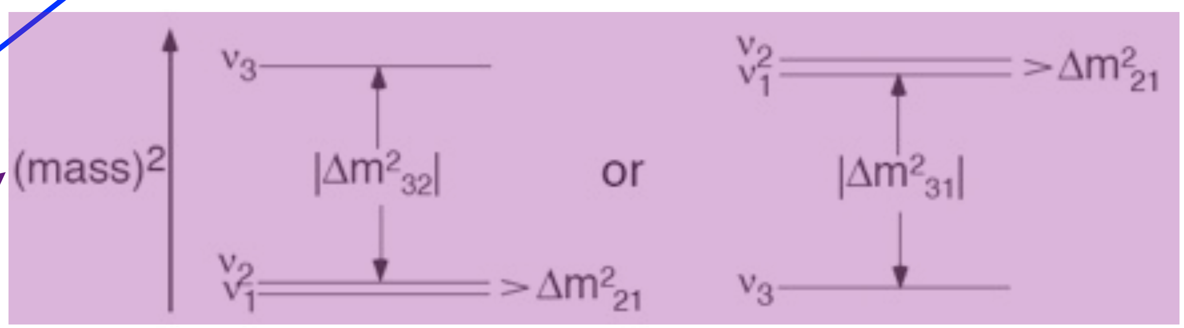
$c_{ij} \equiv \cos\theta_{ij} \quad s_{ij} \equiv \sin\theta_{ij}$

- Despite success of current experiments, many questions remain about oscillations
  - Is the PMNS matrix sufficient to explain oscillations?
  - Are there more neutrinos than the 3 active flavors?
  - What is the size of U_{e3}?
  - Is the CP violating phase non-zero?
  - What is the mass hierarchy?

$\nu_4, \nu_5, \ldots$?

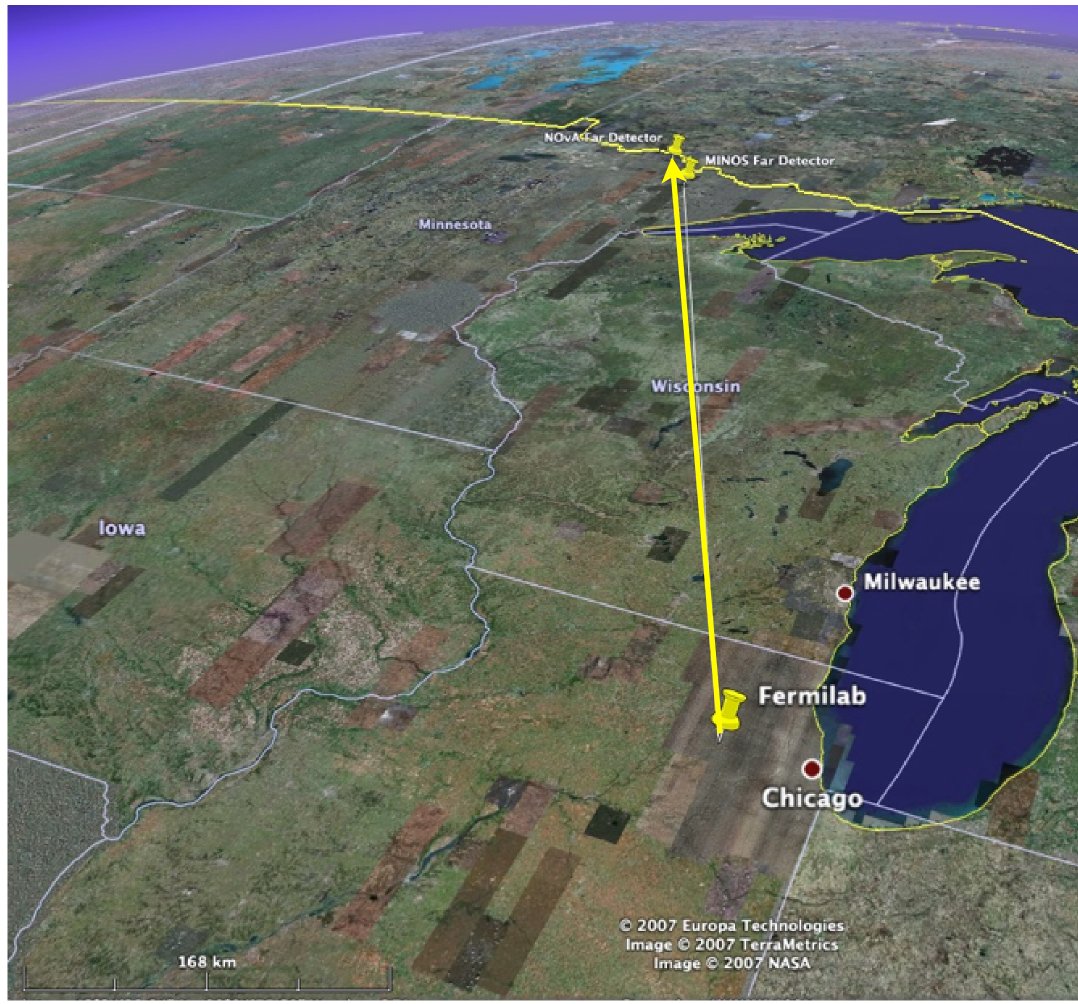
$\theta_{13} \neq 0$?

$P(\nu_\alpha \rightarrow \nu_\beta) \neq P(\bar{\nu}_\alpha \rightarrow \bar{\nu}_\beta)$



NOνA

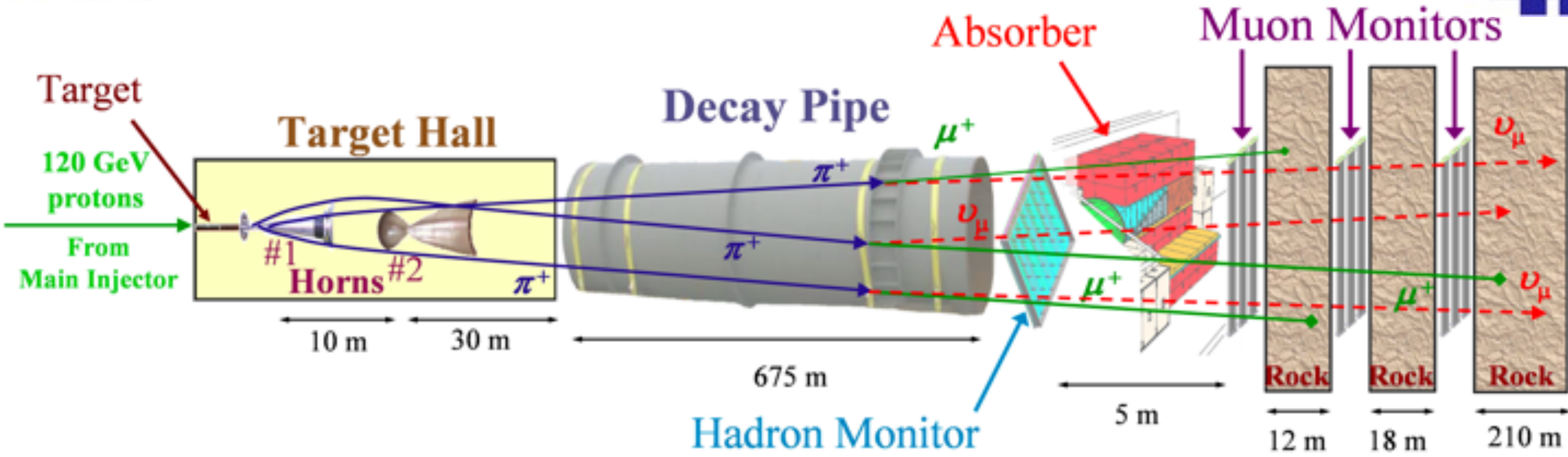
- NOνA is a 810 km baseline neutrino experiment
- Searching for $\nu_\mu \rightarrow \nu_e$ and $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ oscillations
- Use near detector to understand beam at source, far to look for oscillations
- Physics goals include
  - Measurement of θ_{13}
  - Determining the ordering of mass hierarchy
  - Measure δ - CP violating phase
- Use equal exposures for ν and $\bar{\nu}$



NOvA Collaboration

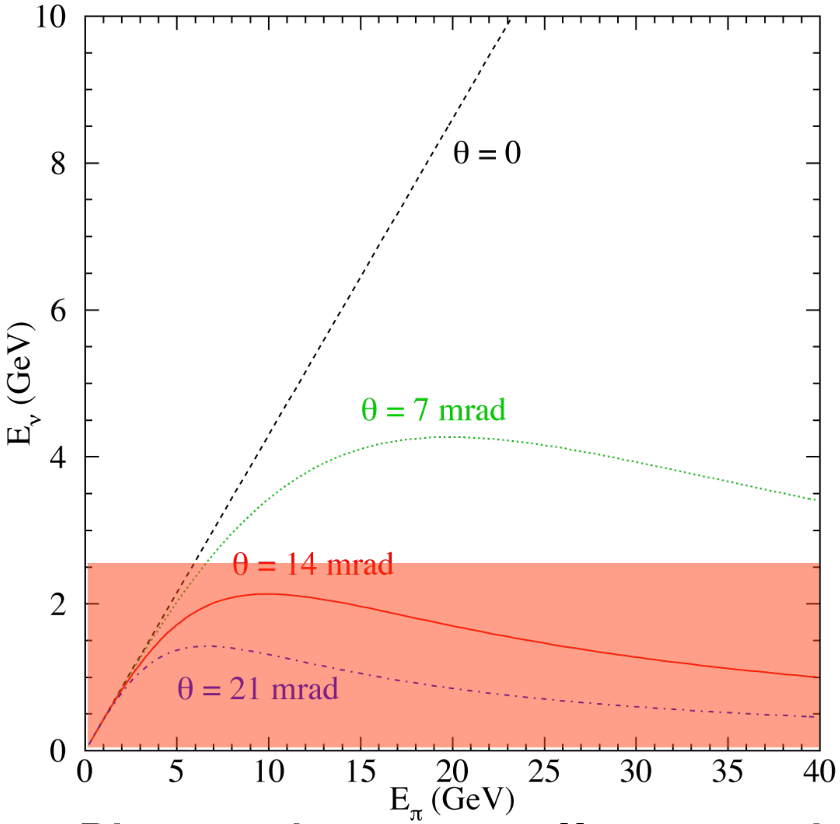
Argonne, Athens, Caltech, College de France, Fermilab, Harvard, Indiana, Lebedev Physical Institute, Michigan State, Minnesota-Twin Cities, Minnesota-Duluth, INR Moscow, T U München, Northern Illinois, Northwestern, Ohio State,P.U.C. Rio de Janeiro, South Carolina, SMU, Stanford, SUNY Stony Brook, Tennessee, Texas-Austin, Texas-Dallas, Texas A&M, Tufts, UCLA, Virginia, William and Mary, Wichita State

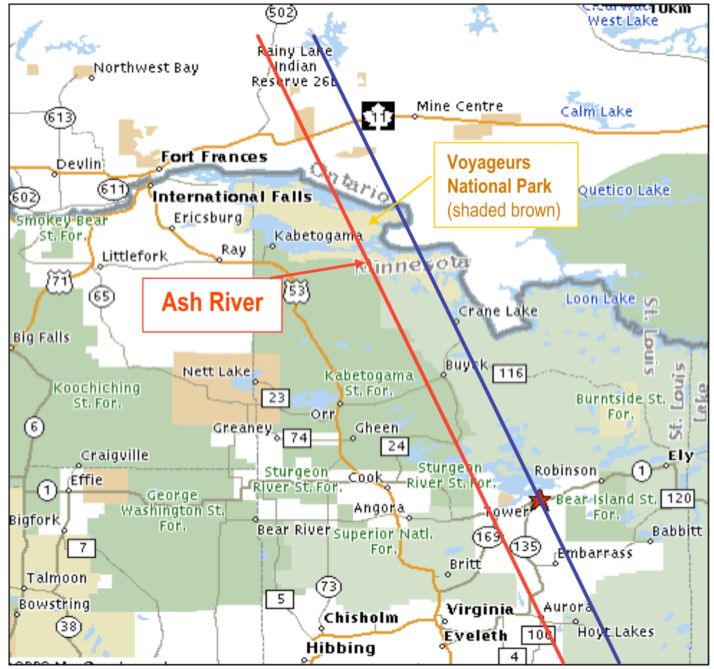
NuMI Beam



- Magnetic horns focus produced pions and kaons, pions and kaons decay into muons and neutrinos - can select neutrinos or anti-neutrinos using horn current
- 10 μs beam spill, every 2.2 seconds
- Operating since 2005, currently delivers 280 - 300 kW
- Recent experiments operating in the beam are MINOS, MINERνA, and ArgoNeuT

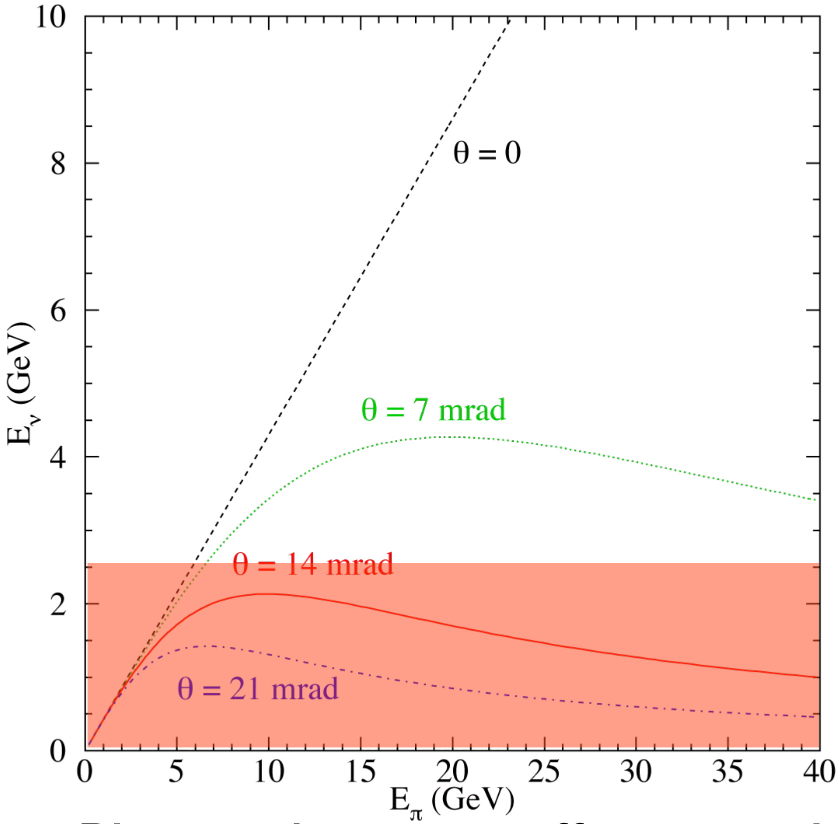
Off-Axis Beam

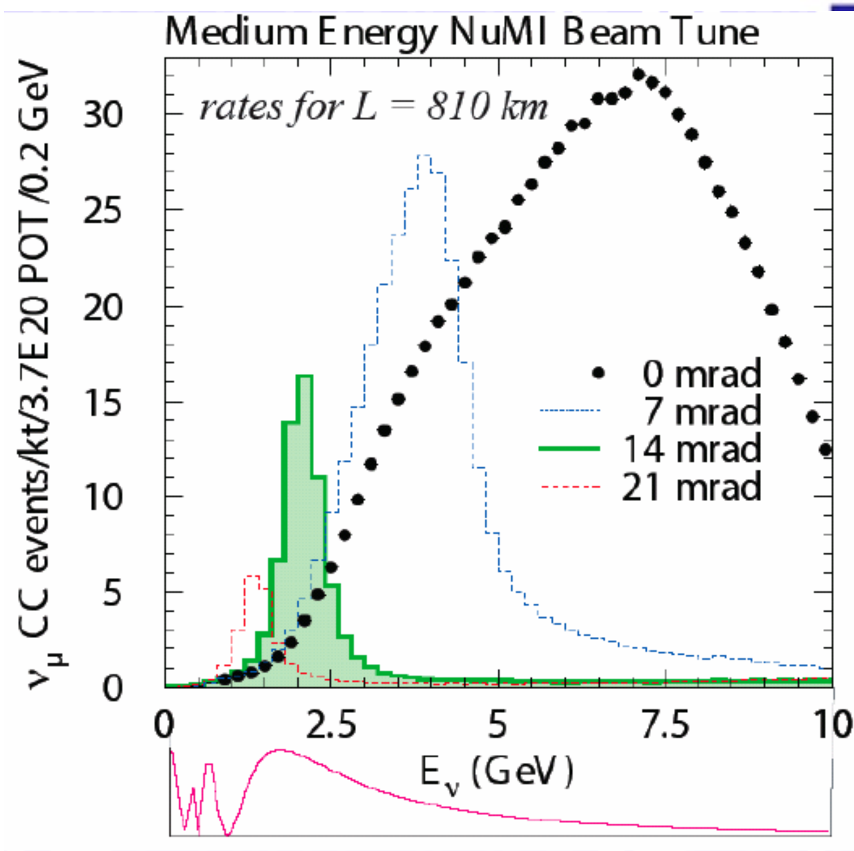




- Placing detector off axis exploits decay kinematics to produce a narrow band beam
- 14 mrad off-axis produces a narrow band beam peaked ~2.2 GeV to maximize oscillation probability
- Almost no high energy tail, reduces feed down from neutral current interactions

Off-Axis Beam





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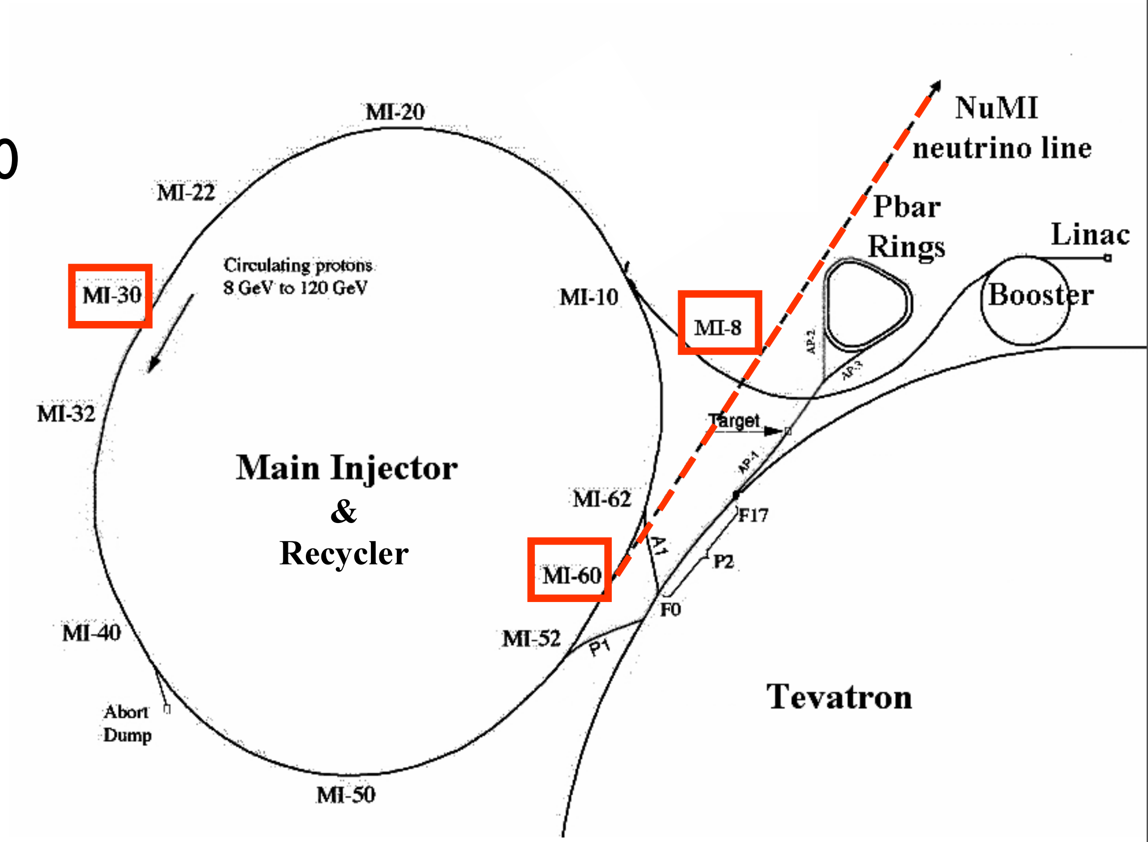
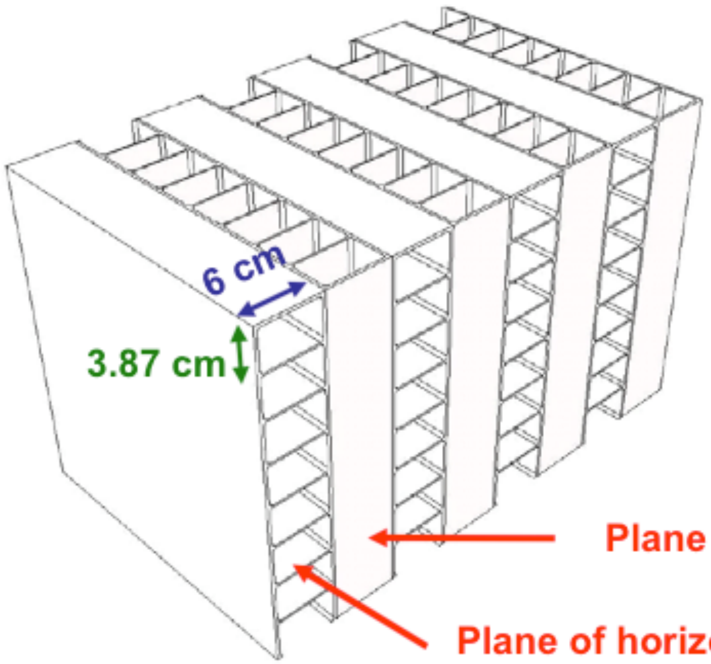
Accelerator Upgrades

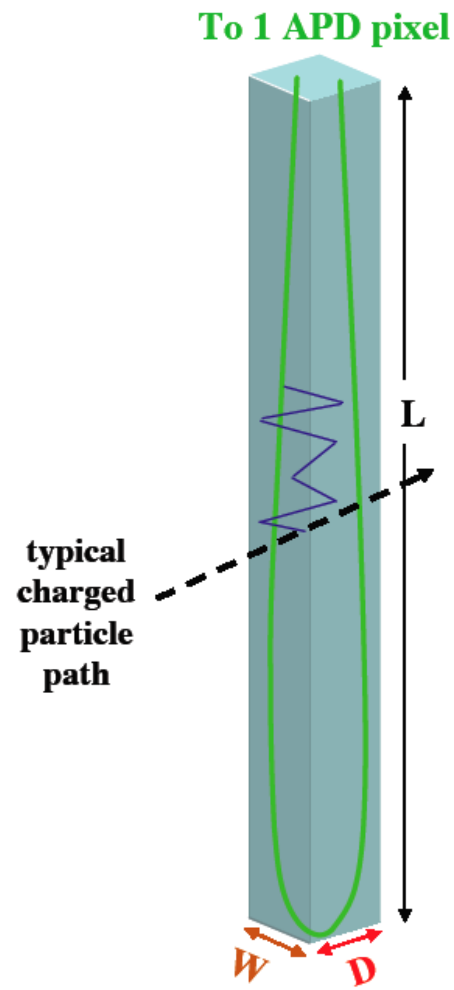
- Plan is to increase beam power to 700 kW using existing complex
- Lower cycle time to 1.33 seconds by slip stacking in the Recycler
- Increase intensity per cycle using new injection kicker to allow 12 Booster instead of 11
- Upgrade target, horn 1, etc



Active Detector Element

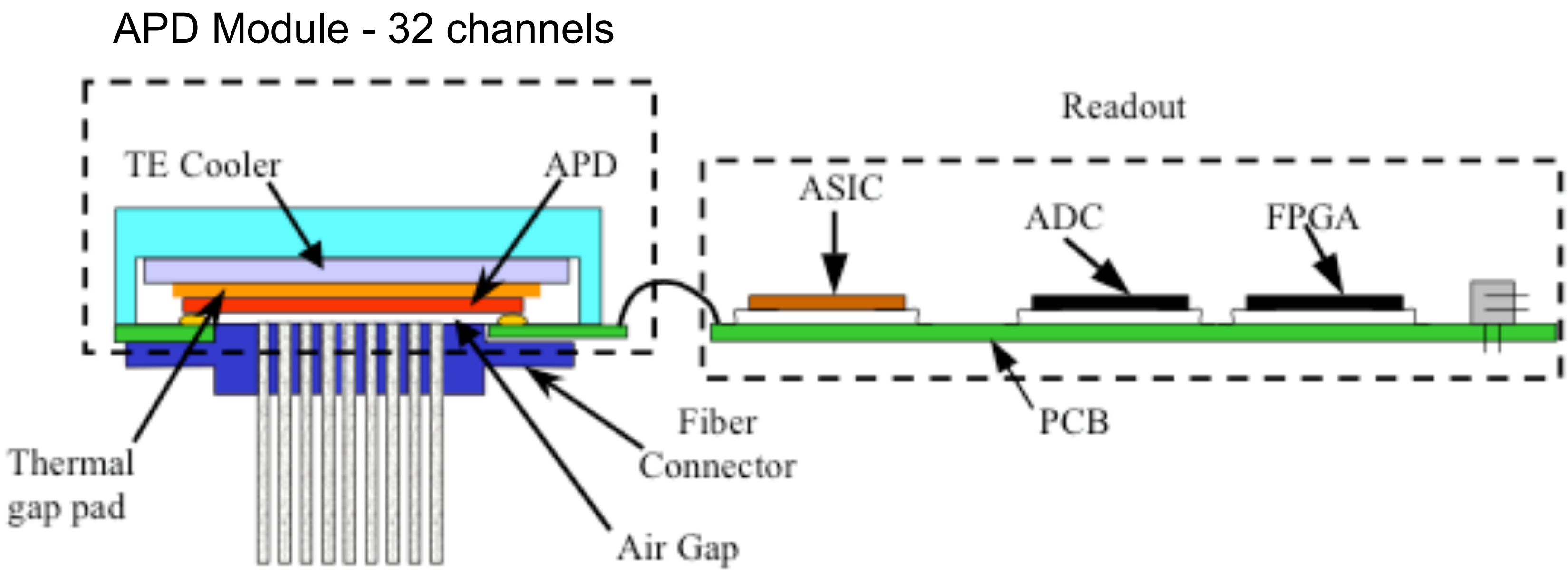


> 357,000 cells in FD
~12,000 km fiber in FD
0.15 X_0 sampling per plane



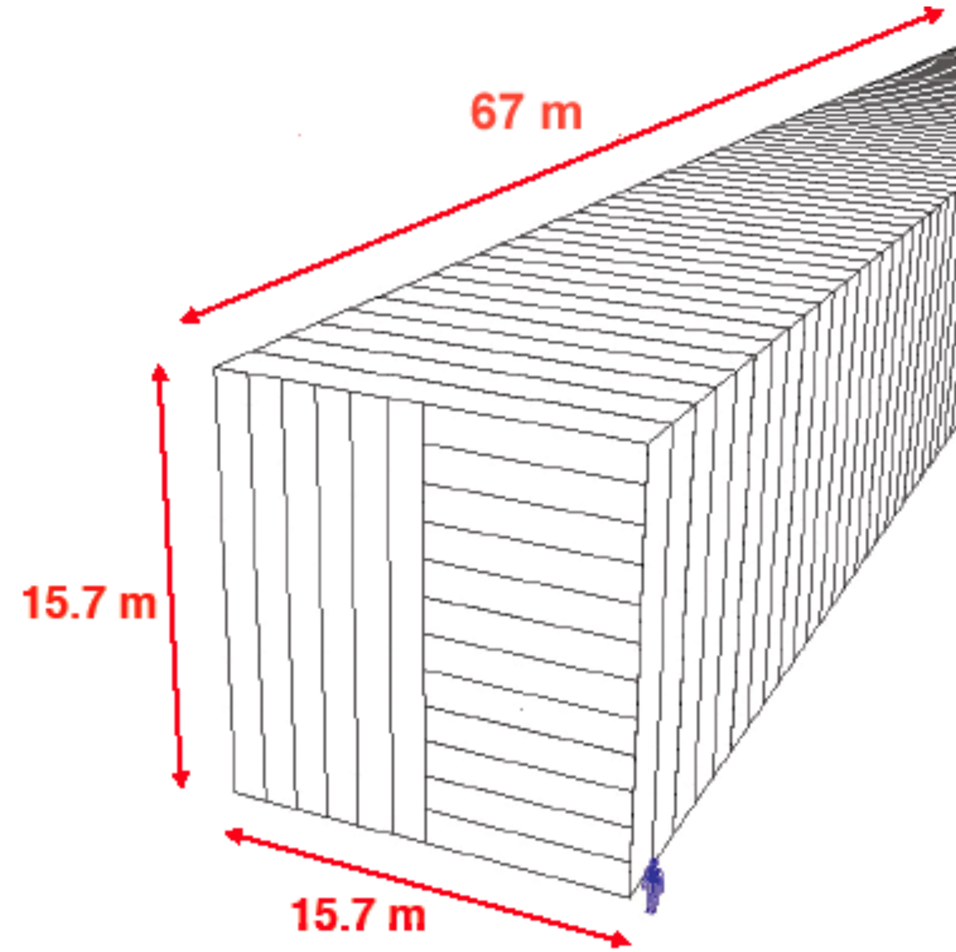
- Basic element is a PVC extrusion with 15% TiO_2 to increase reflectivity
- Extrusions filled with liquid scintillator - mineral oil with 5% pseudocumene and some wave shifters, ~30 PE at far end from scintillator
- Scintillator light delivered to APD using WLS fiber

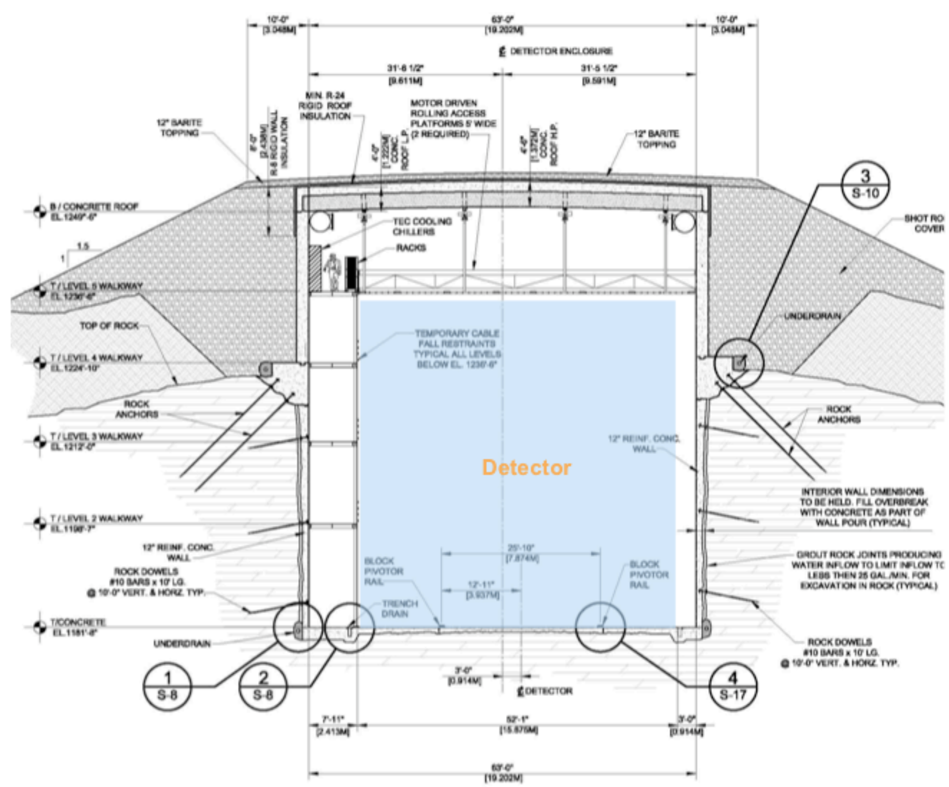
Readout



- Avalanche Photo Diodes used to detect scintillation light
  - 85% Quantum efficiency, 100x Gain
  - Cooled to -15 C to reduce dark noise to 2 PE, 4PE total noise
- ASIC handles amplification, shaping and multiplexing to ADC

Far Detector





14 kt total mass, 70% scintillator
930 Planes
~3 m equivalent earth overburden of barite and concrete

Far Detector Site

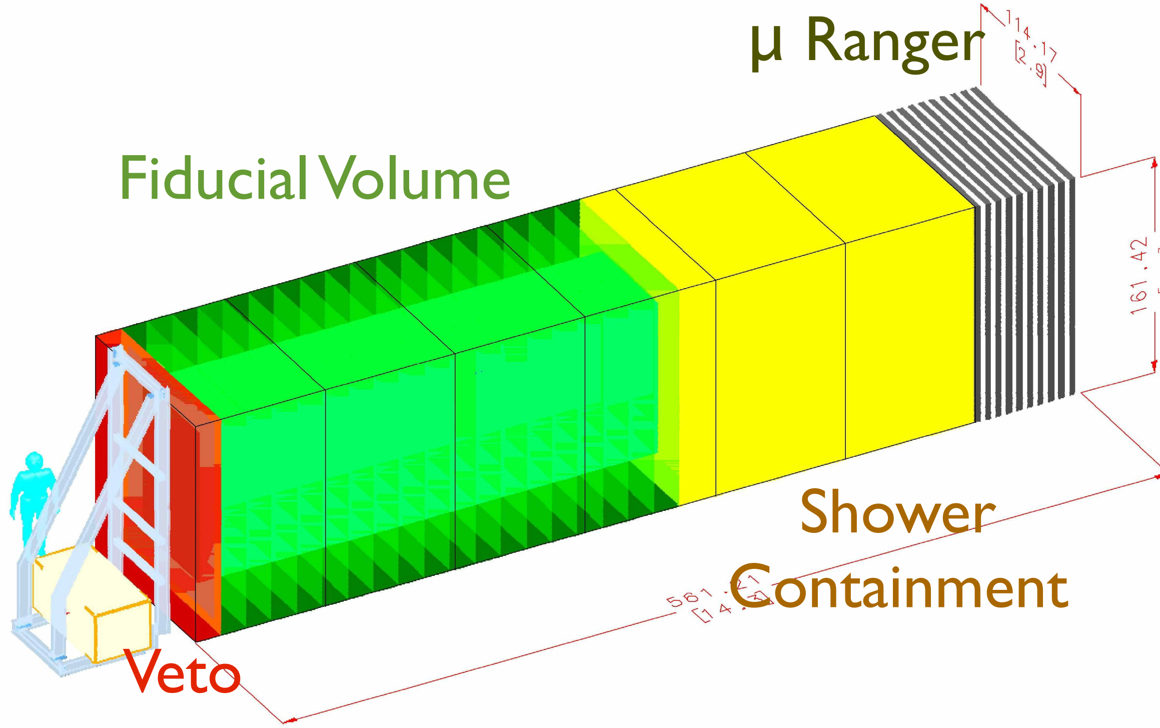
Far Detector Site

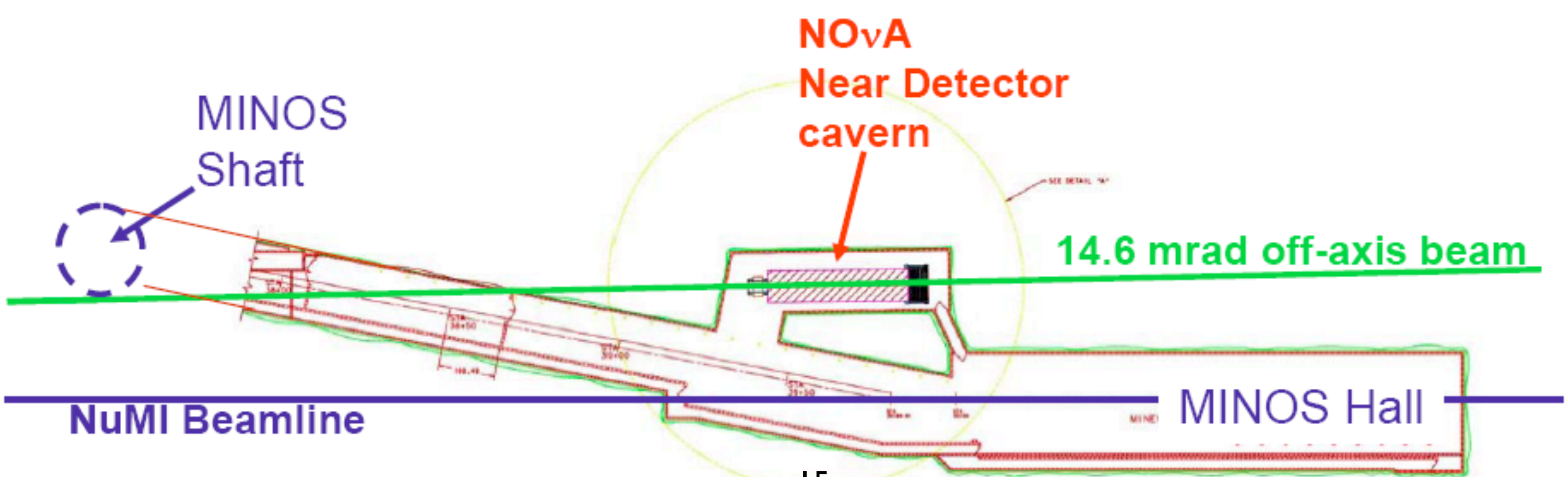
Sense of Scale

Soldier Field in Chicago - Capacity: 61,500

Near Detector

- Same extrusions, scintillator and readout as FD
- Located upstream of MINOS ND, 14 mrad off axis
- 210 t total mass, 20 t fiducial
- Steel muon catcher at back, contains up to 2 GeV muons

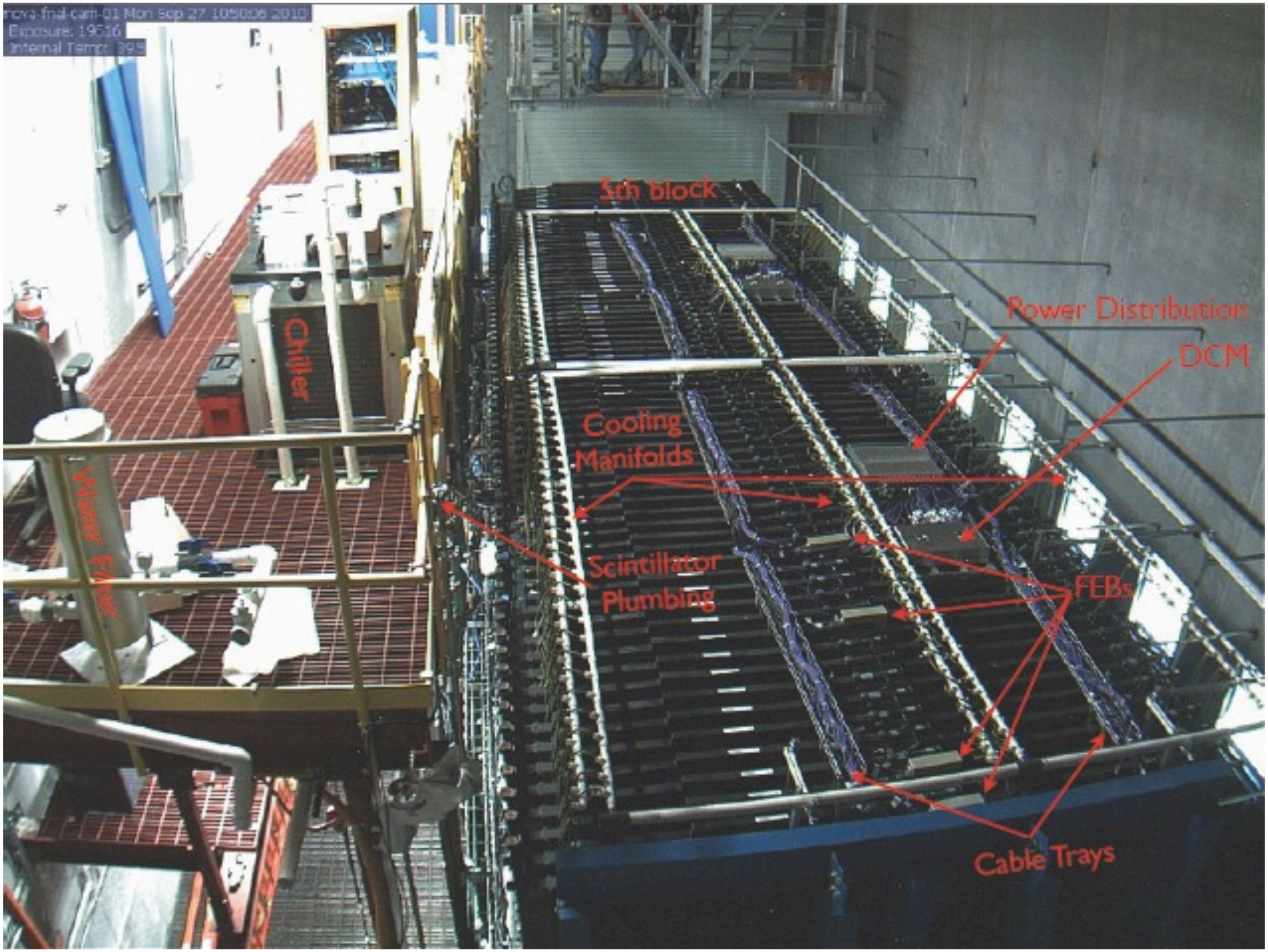




Near Detector - on the Surface (NDOS)

- ND constructed on surface late summer 2010
- Test of construction and integration
- Will see very off-axis NuMI beam (107 mrad) and on axis Booster beam
- Scintillator filling started October 15, 2010
- Take data parasitically during MINOS and MINERνA running

Near Detector - on the Surface



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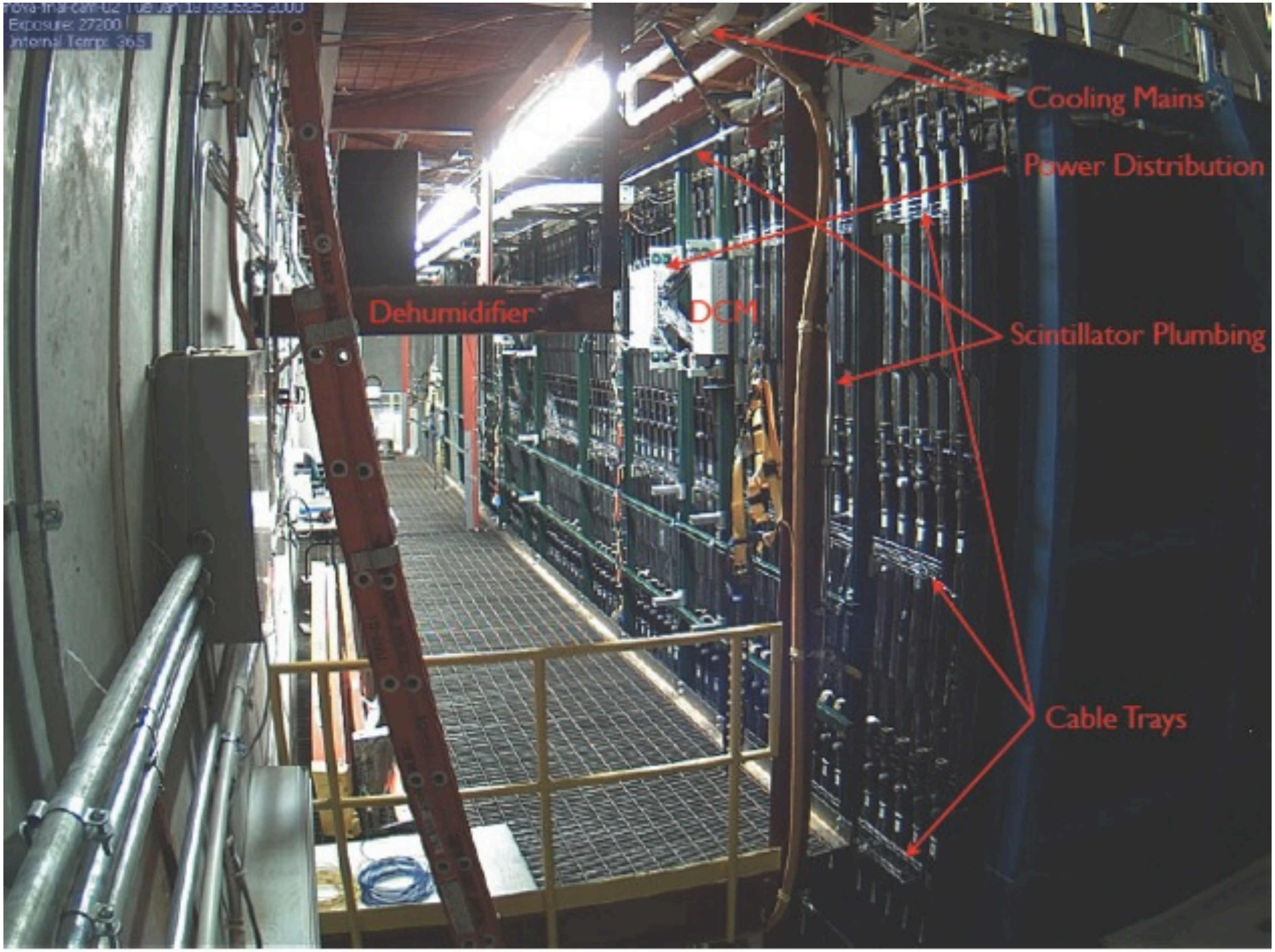
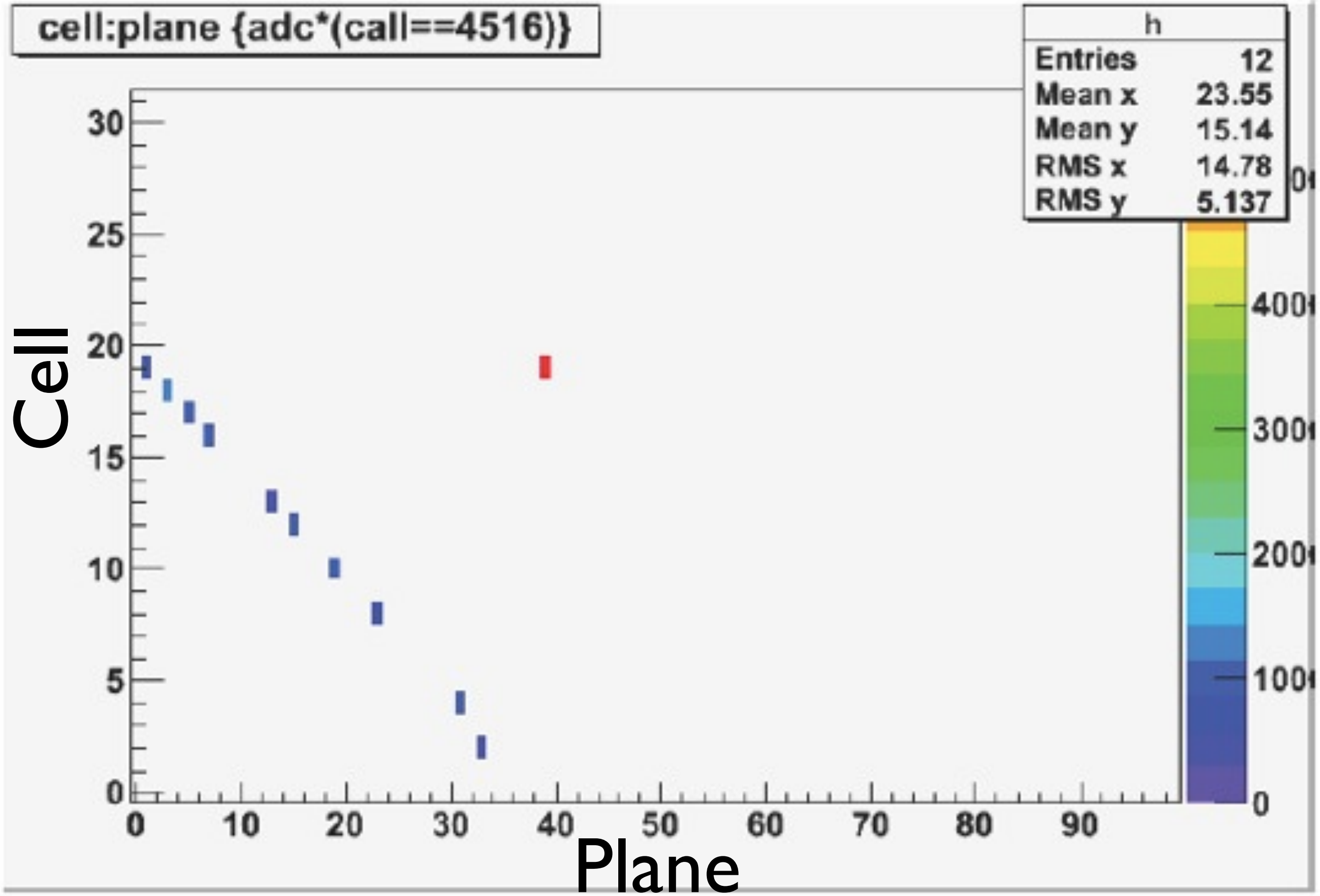


Cosmic Ray in NDOS!

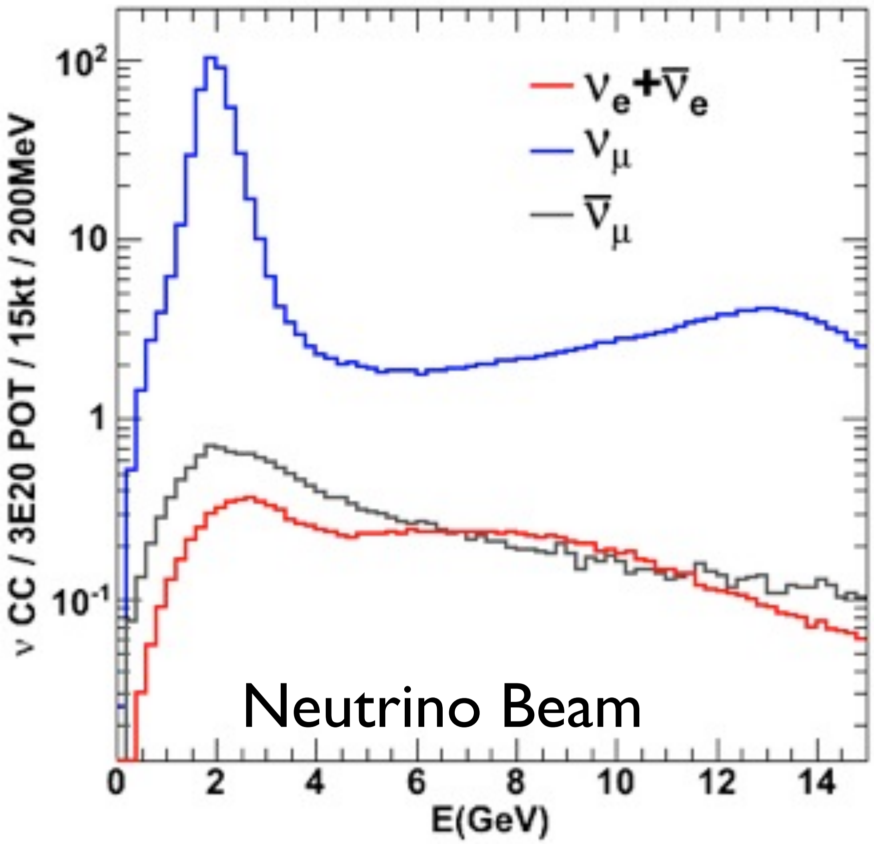


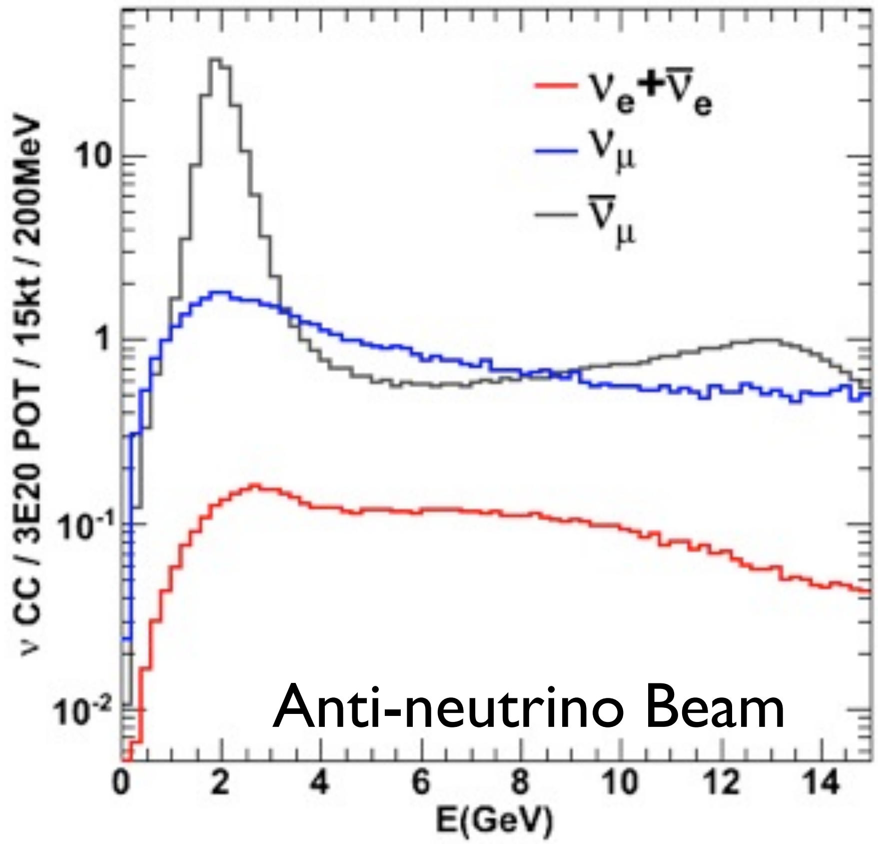
- NDOS just started reading out data last week
- Example cosmic ray muon shown

Schedule

- NDOS running fall 2010
- FD construction at Ash River site begins July 2011
- Accelerator shutdown March 2012
- 700 kW beam turns on February 2013, 2/3 FD built
- FD complete fall 2013
- Schedule actually *accelerated* over the last 1.5 years

Sensitivities

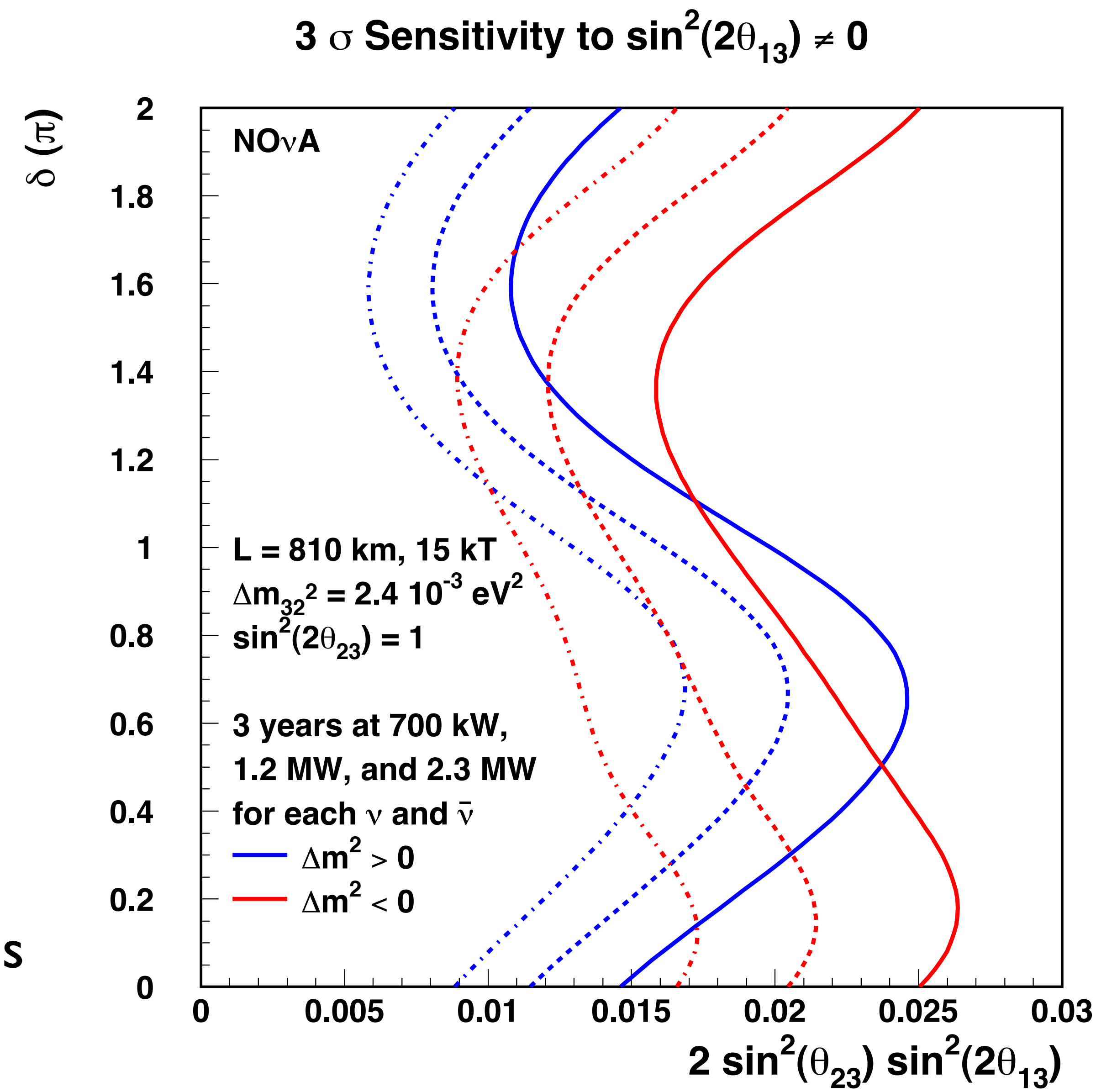




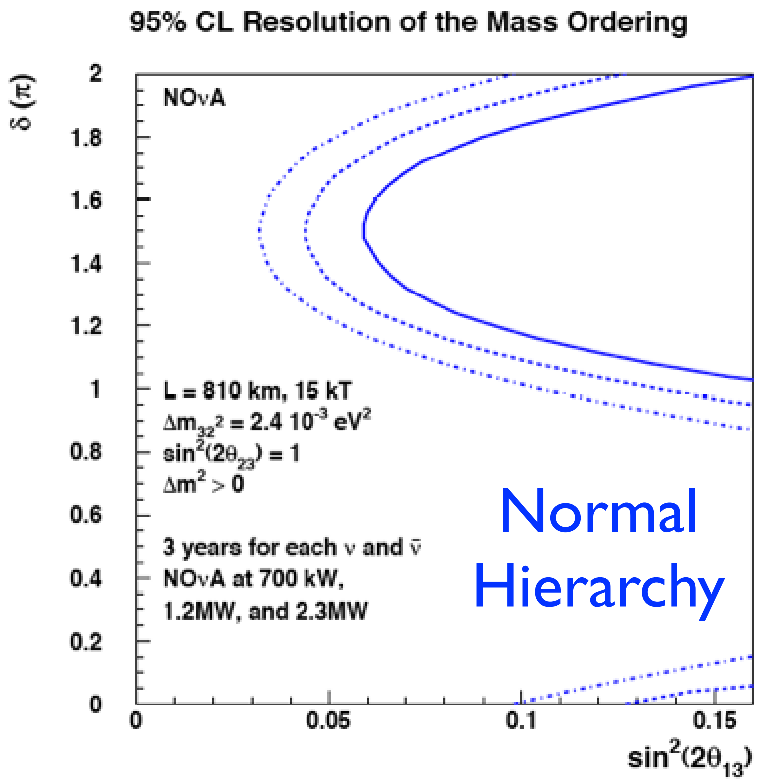
- Following plots are all for 15 kt detector
- 3 years each of neutrino and anti-neutrino beams, 0.7, 1.2, and 2.3 MW powers
- Full simulation of flux, interactions, and detector response
- Reconstruction based event selection

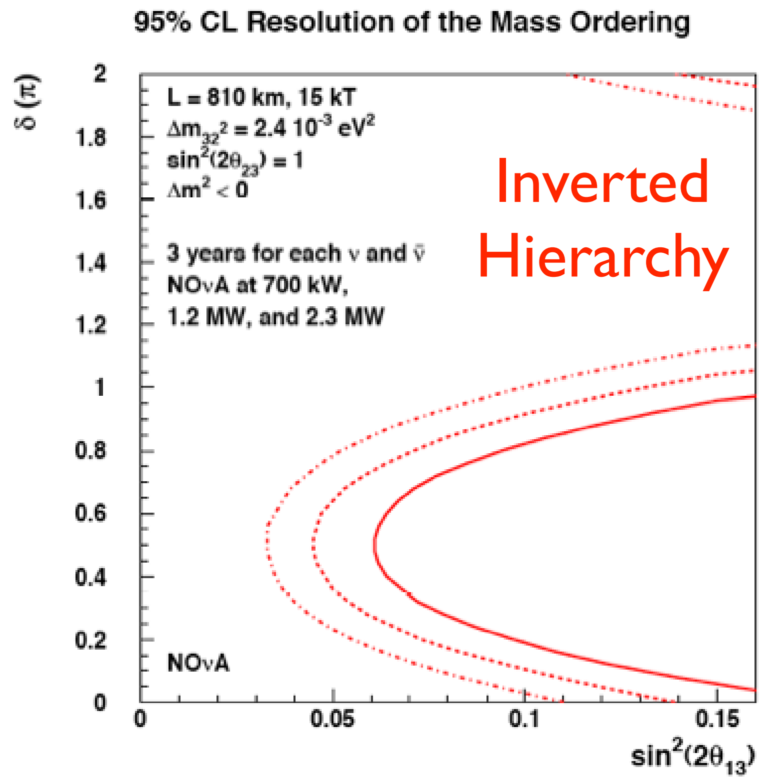
Sensitivity to $\sin^2(2\theta_{13})$

- Plot shows δ vs $\sin^2(2\theta_{13})$ 3σ sensitivity for 3 years each of neutrinos and anti-neutrinos
  - 700 kW - solid lines
  - 1.2 MW - dashed lines
  - 2.3 MW - dash-dot lines
  - Normal hierarchy - blue
  - Inverted hierarchy - red
- Curves are equal oscillation probability curves
- Sensitivity varies based on mass hierarchy



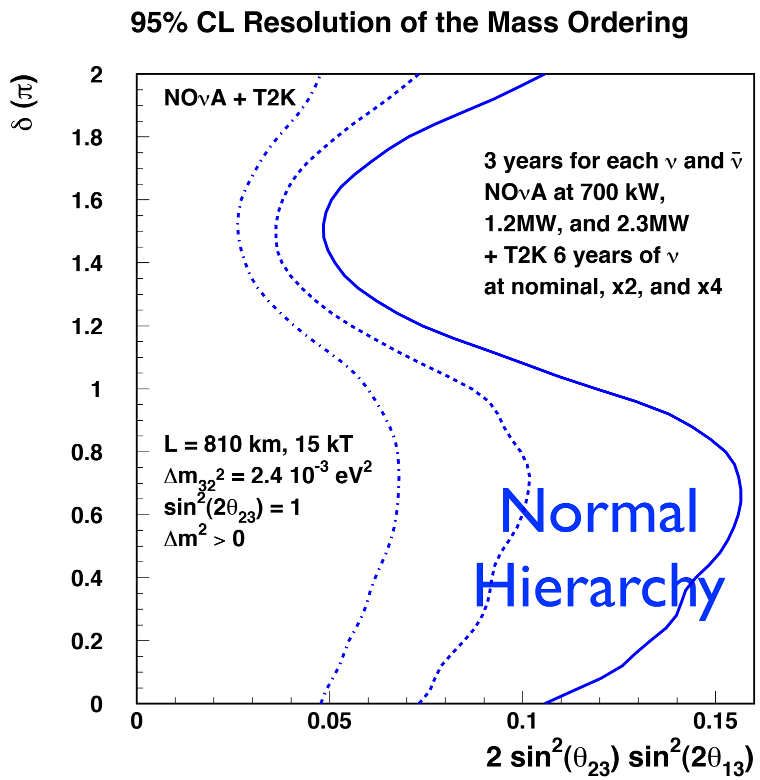
Sensitivity to Mass Ordering

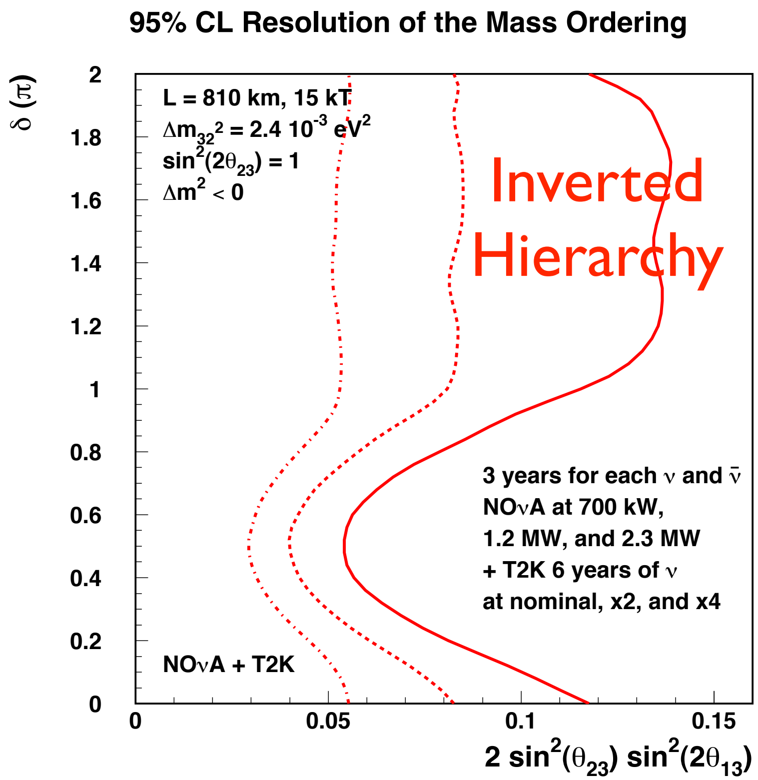




- 95% CL resolution for mass ordering shown for normal and inverted hierarchy, curves represent different beam powers
- Even better resolution with information from another baseline
- Resolve ambiguity for values of $\sin^2(2\theta_{13})$ to the right of the curves

Sensitivity to Mass Ordering





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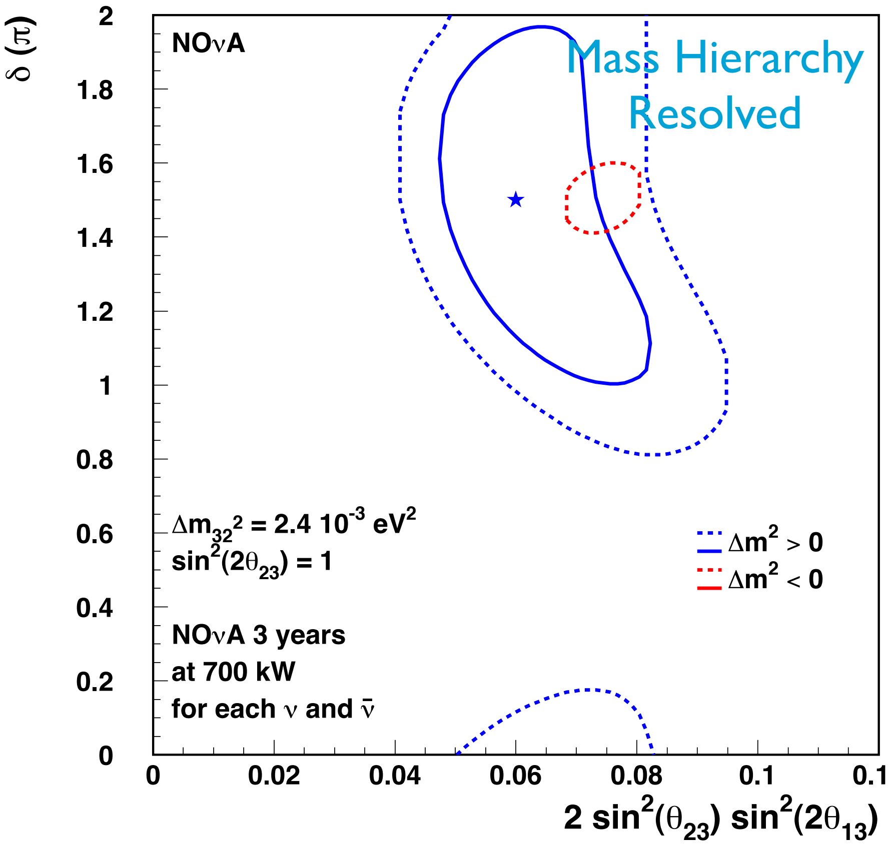
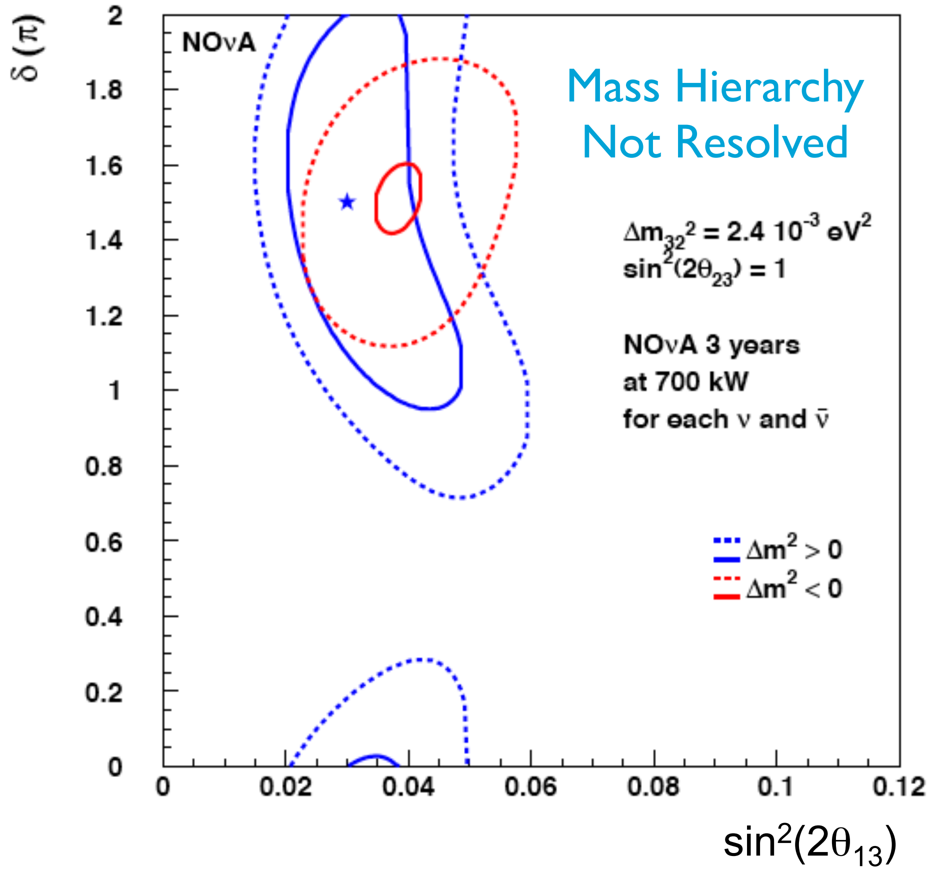
Sensitivity to CP Violating Phase δ

Contours for Starred Point for NOvA

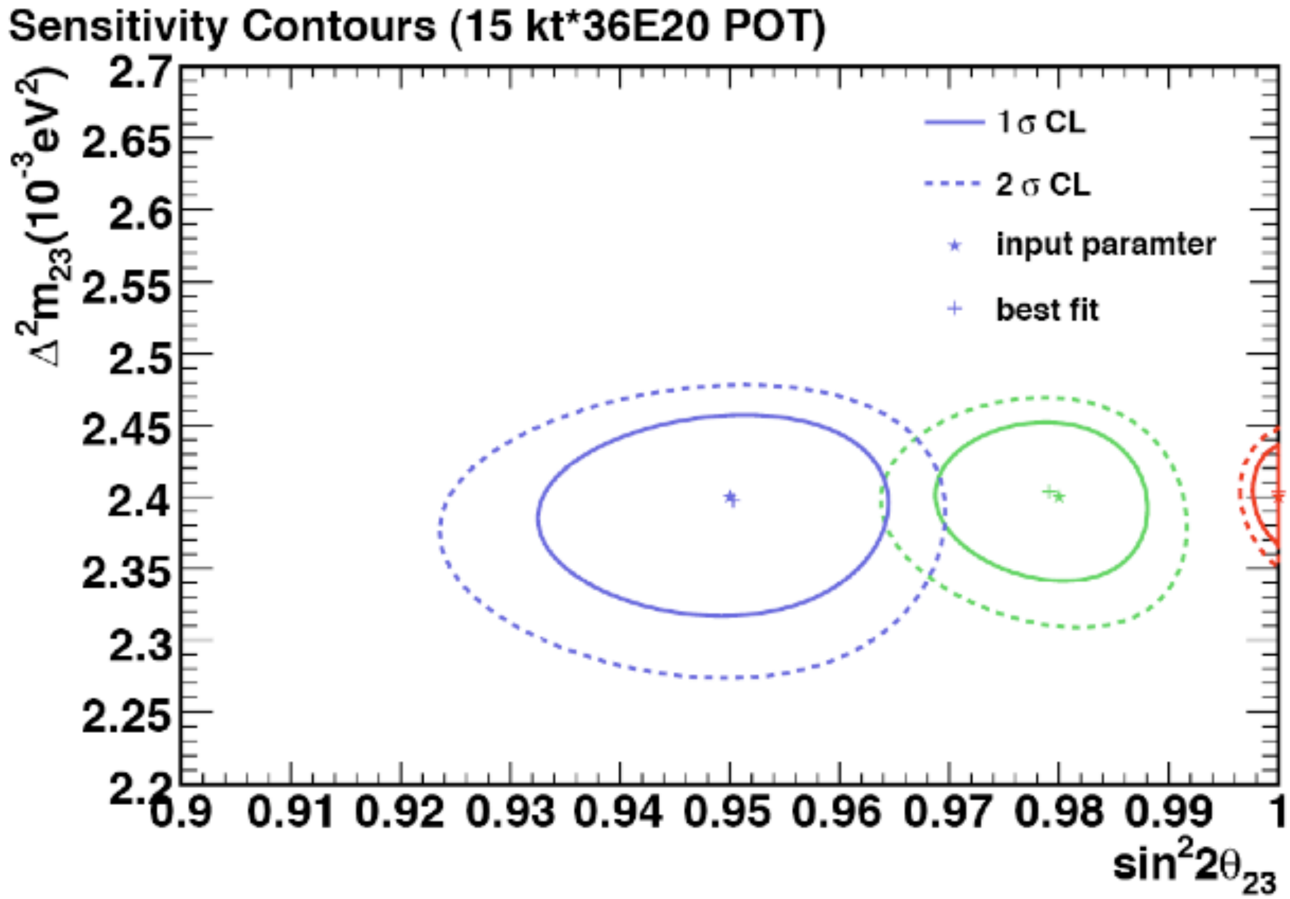


1 and 2 σ Contours for Starred Point for NOvA



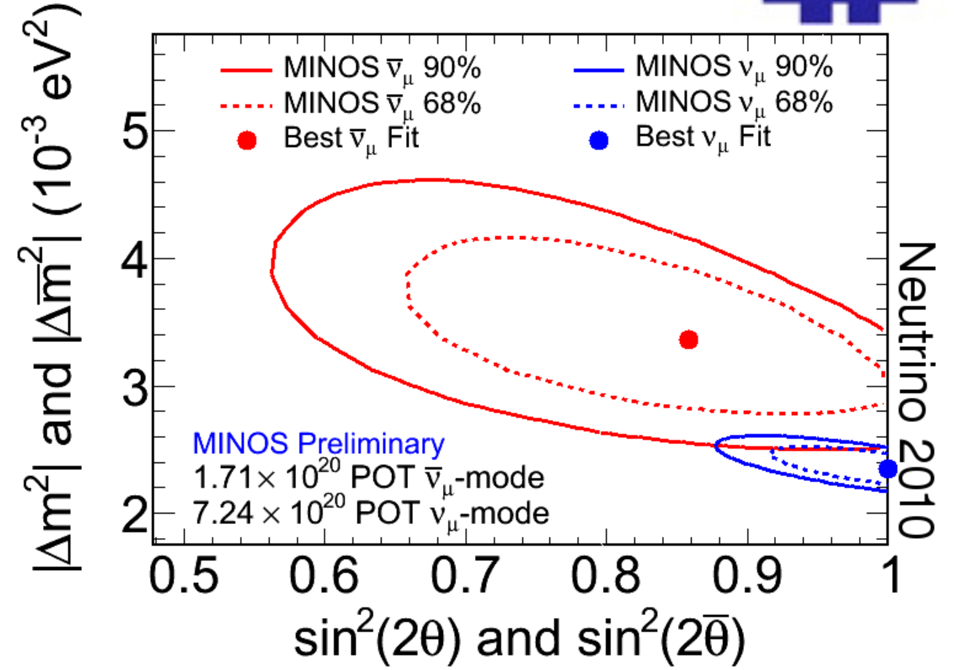
- Plots show 1 and 2σ contours for 700 kW beam with chosen point
- NOνA sensitivity includes $\delta = 0, \pi$ at 2σ
- Can point to which CP phase half plane to target for future measurement

Measurement of $\sin^2(2\theta_{23})$

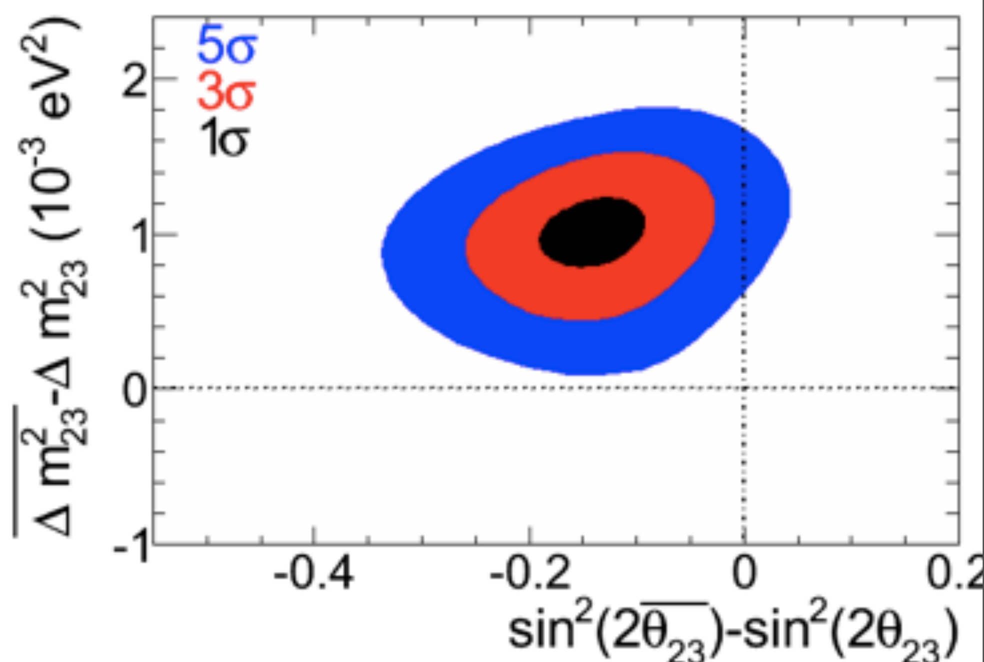


- Quasi-elastic ν_μ charged current interactions provide channel to make high precision measurement
- Possible due to excellent energy resolution, narrow band beam

ν_μ vs $\bar{\nu}_\mu$ Disappearance



- MINOS showed tension between neutrino and anti-neutrino oscillation parameters for $\nu_\mu \rightarrow \nu_\tau$
- NOvA can measure a difference between the two scenarios to 3σ
- Assumes MINOS measured values are correct



Conclusions

- NOνA poised to answer several important questions about neutrino oscillations
  - Search for $\nu_\mu \rightarrow \nu_e$ oscillations, measurement of θ_{13}
  - Determination of mass hierarchy
  - Search for CP violating phase
  - Precision measurement of θ_{23}
  - Clarification of interesting new results from MINOS
- NDOS is in immediate danger of taking data, important prototype for construction of FD
- 14 kt far detector on schedule to be completed in 2013

What We Know About Oscillations

- A variety of experiments (solar, reactor, atmospheric) have shown us
  - Atm→$\Delta m^2 = 2.4 \times 10^{-3}$ eV^2
  - Solar→$\Delta m^2 \approx 8 \times 10^{-5}$ eV^2
- Figure shows the fraction of flavor states in each mass state
- Most mixing angles are large
- Zero point of mass scale currently unknown

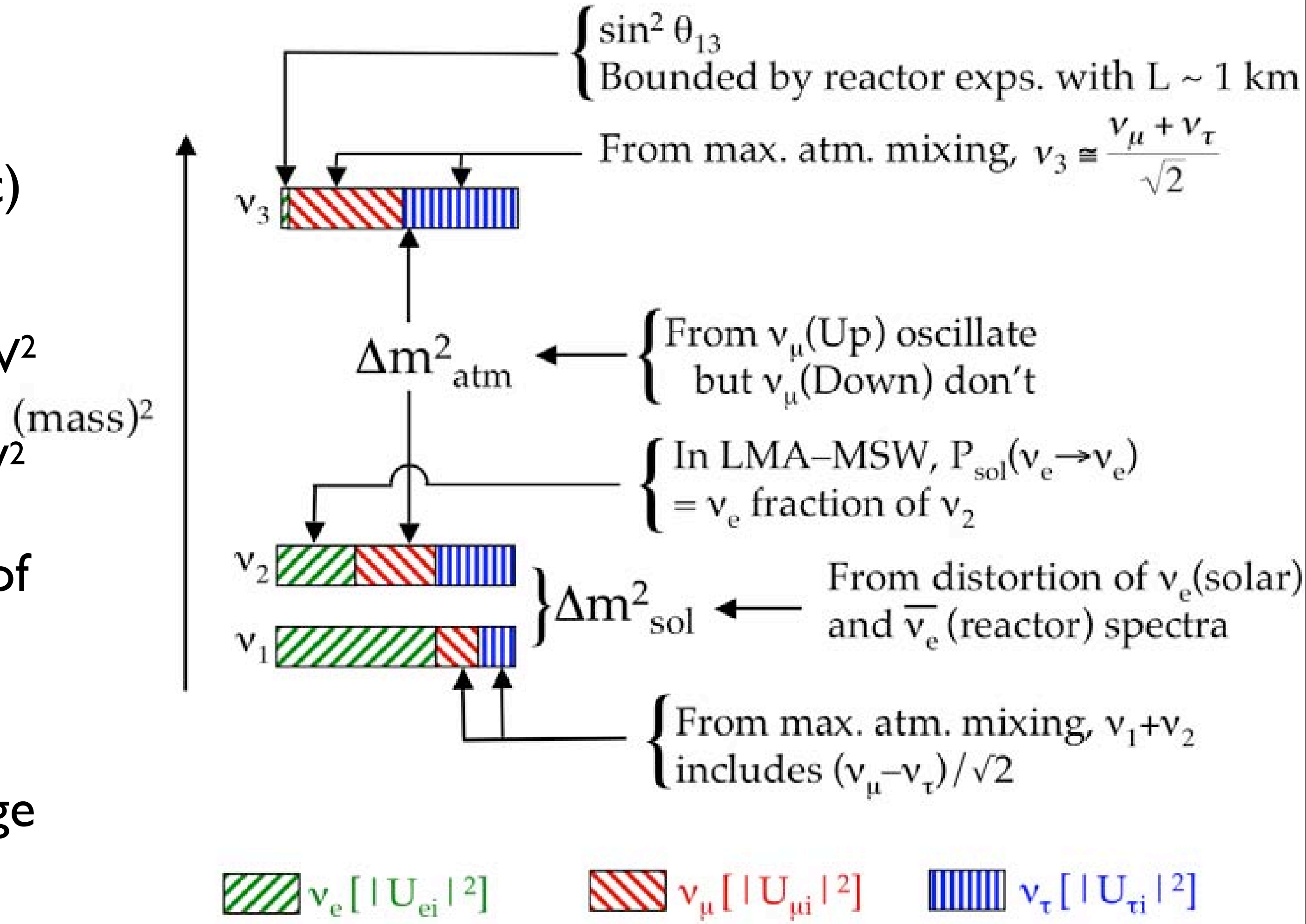
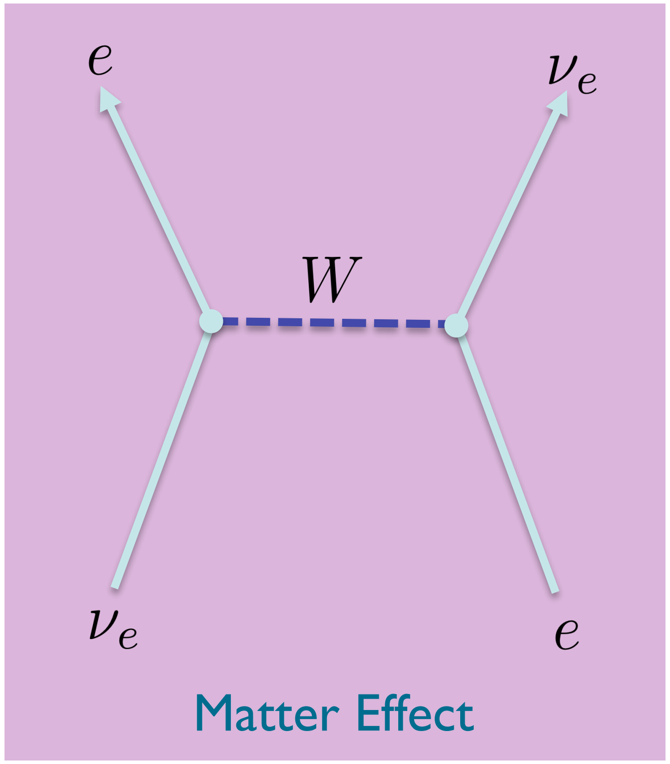
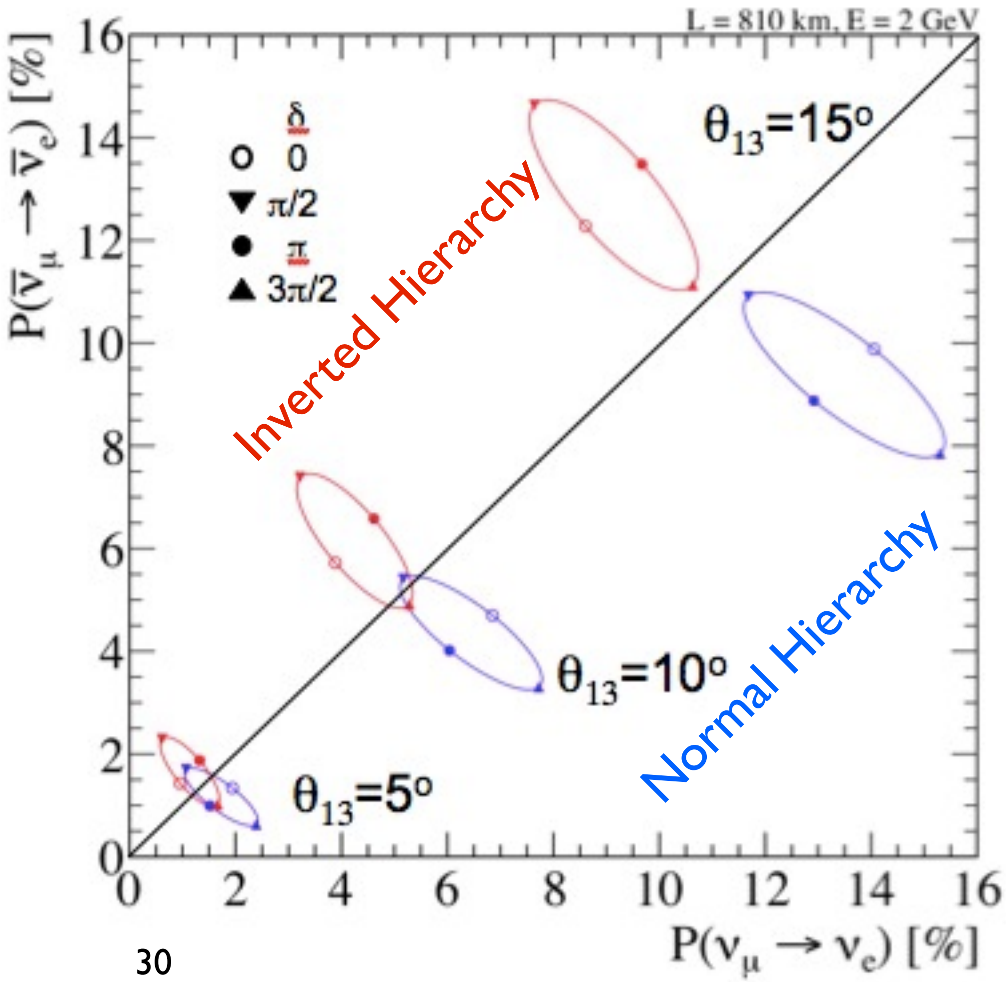


Figure from B. Kayser (2004)

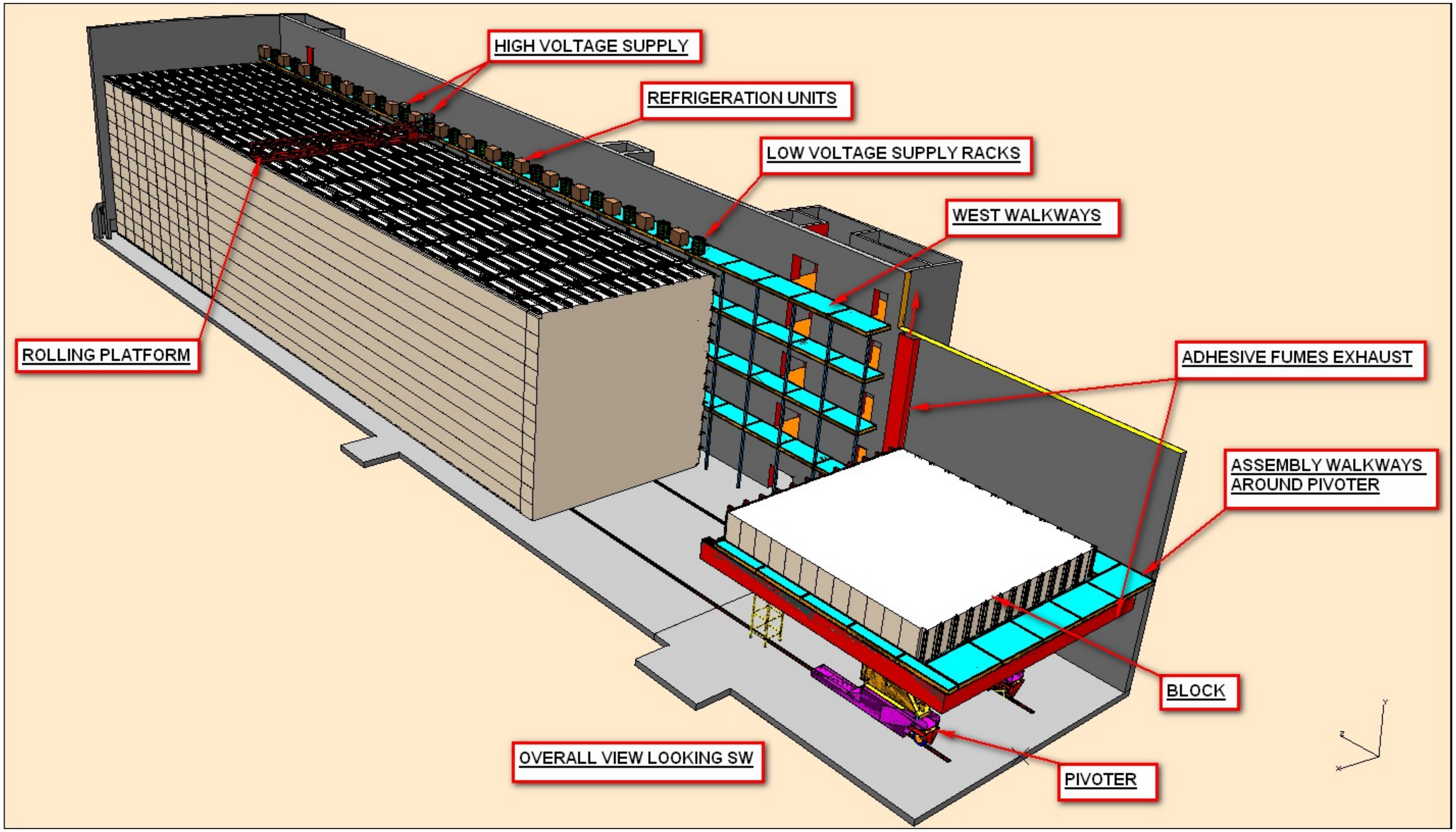
Measuring $\nu_\mu \rightarrow \nu_e$

- It's hard - subdominant oscillation mode so it is a rare process
- Need large detectors and powerful beams to observe it
- Matter effects and CP violation can help clarify some of these questions if θ_{13} is large enough





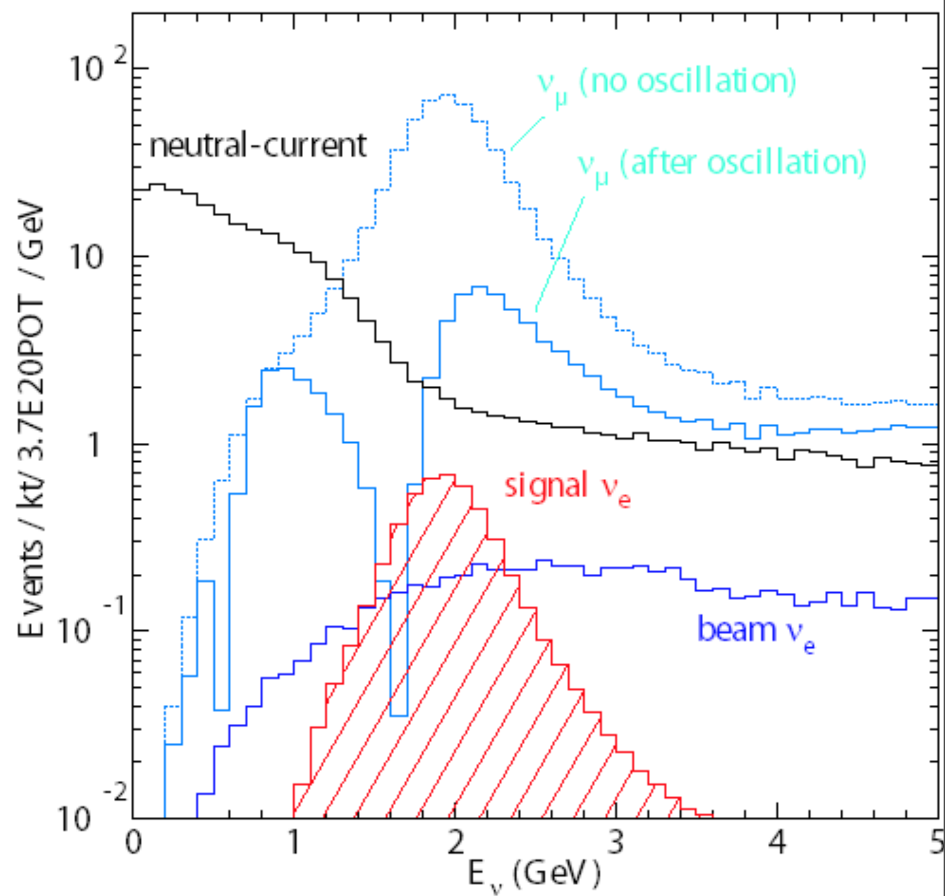
Assembly



- Built in blocks of 31 planes assembled horizontally and then raised to vertical
- Filled in situ

Expected Spectrum at Far Detector

- Spectra assume $|\Delta m^2_{32}| = 2.5 \times 10^{-3}$ eV^2, $\sin^2(2\theta_{13}) = 0.01$
- ν_μ CC background reduced by oscillations, generally easy to distinguish muons from electrons
- NC background harder to reduce, but majority at lower visible energy than the signal
- Beam νe spectrum is more or less flat
- Detector designed to maximize separation of hadronic and EM showers - low Z, fine grained sampling compared to radiation length



Tuesday, October 19, 2010