NOνA Experiment

Resolve ν-mass hierarchy

Resolve θ_{23}-octant ambiguity

Discover CP-violation in leptons

Work of the NOvA Collaboration

next step?

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Neutrino mixing

weak flavor eigenstates $\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix}$ $\begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$ mass (m_1, m_2, m_3) eigenstates

Pontecorvo–Maki–Nakagawa–Sakata Mixing Matrix U

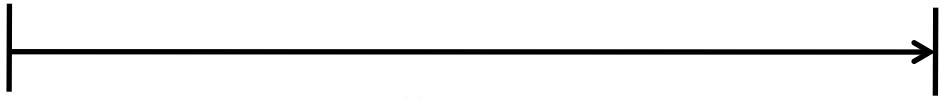
$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{23} & \sin\theta_{23} \\ 0 & -\sin\theta_{23} & \cos\theta_{23} \end{pmatrix} \begin{pmatrix} \cos\theta_{13} & 0 & \sin\theta_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -\sin\theta_{13}e^{-i\delta} & 0 & \cos\theta_{13} \end{pmatrix} \begin{pmatrix} \cos\theta_{12} & \sin\theta_{12} & 0 \\ -\sin\theta_{12} & \cos\theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

mixing angles $\theta_{23}, \theta_{13}, \theta_{12}$

CP-violating phase δ

Oscillation experiments: Beam energy E and baseline L

Known flavor content (& energy) (ν_μ)



Baseline L

Determine energy E and flavor content (ν_e, ν_μ)

Flavor Transition Probabilities

$$P(\nu_\alpha \to \nu_\beta) = \delta_{\alpha\beta} - 4\sum_{i>j} \mathrm{Re}(U^*_{\alpha i} U_{\beta i} U_{\alpha j} U^*_{\beta j}) \sin^2 \frac{\Delta m^2_{ij} L}{4E}$$

$$\mp 2\sum_{i>j} \mathrm{Im}(U^*_{\alpha i} U_{\beta i} U_{\alpha j} U^*_{\beta j}) \sin \frac{\Delta m^2_{ij} L}{2E}$$

$$\Delta m^2_{ij} = m^2_i - m^2_j$$

$-$ for ν; $+$ for $\bar{\nu}$

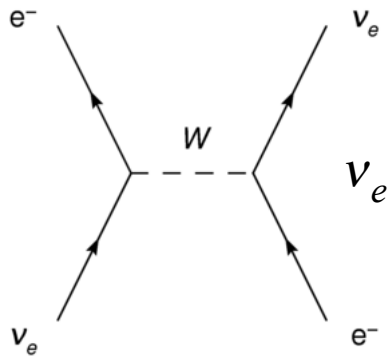
Mikheyev–Smirnov–Wolfenstein

MSW Mass Effects

In the earth's mantle, for interference terms

effect is proportional $\left[1 \pm E/E_R\right]$

$E_R \sim 11\mathrm{GeV}$



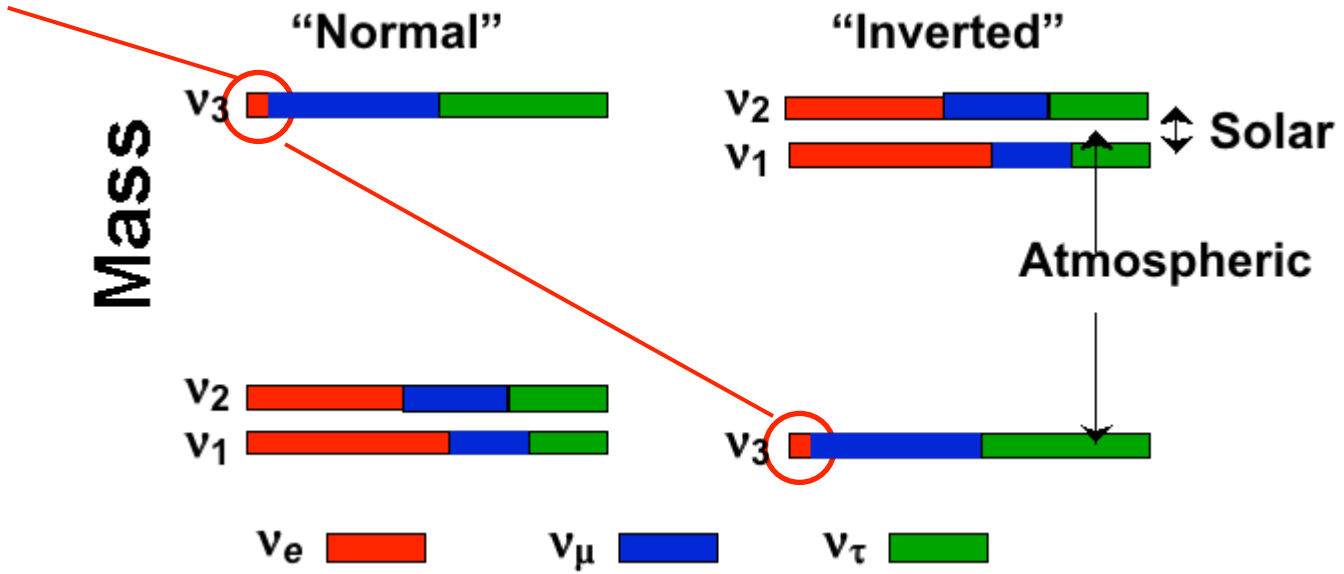
ν_e, not for ν_μ

Learned much about U through oscillation studies

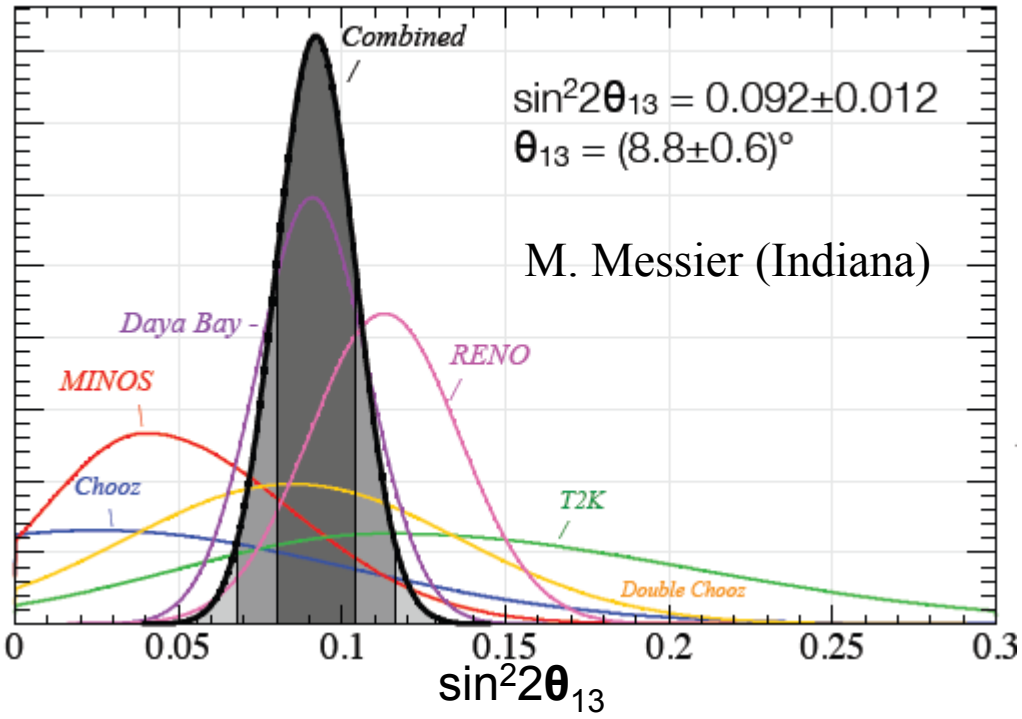
Flavor fractions of mass states given by mixing angles

but Δm^2 Hierarchy is unknown: "Normal" or "Inverted"

New values of θ_{13}



Recent results for Theta-13



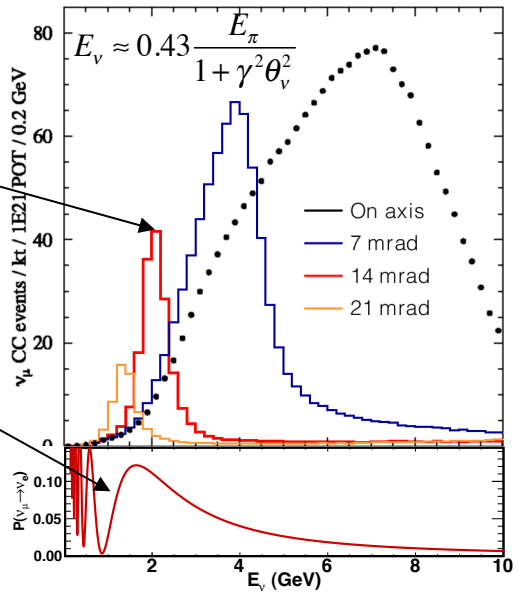
- Daya Bay 0.092 ± 0.017
  - ✓ arXiv:1203.1669v2 [hep-ex]
- RENO 0.113 ± 0.023 (revised)
  - ✓ arXiv:1204.0626v2 [hep-ex]
- Reactor Average
  - ✓ 0.099 ± 0.014
- Combined Average
  - ✓ 0.092 ± 0.012

A value of θ_{13} near 9° provides a windfall for NOνA

NOνA Experiment

150+ Collaborators
25 Institutions
5 Countries

- Nearly monoenergetic beam at 14 mr from axis:
  - Near and Far detector pair.
  - Off-axis ν @ L/E ~ 400 km/GeV, 2 GeV peak
- Goals:
  - measure θ_{13}
  - precision measurements of $|\Delta m^2|$, θ_{23}
  - resolve θ_{23} octant ambiguity
  - compare ν/ν-bar oscillations
  - determine mass hierarchy
  - constrain CP violating phase



NOvA Far Detector Building

Main entrance

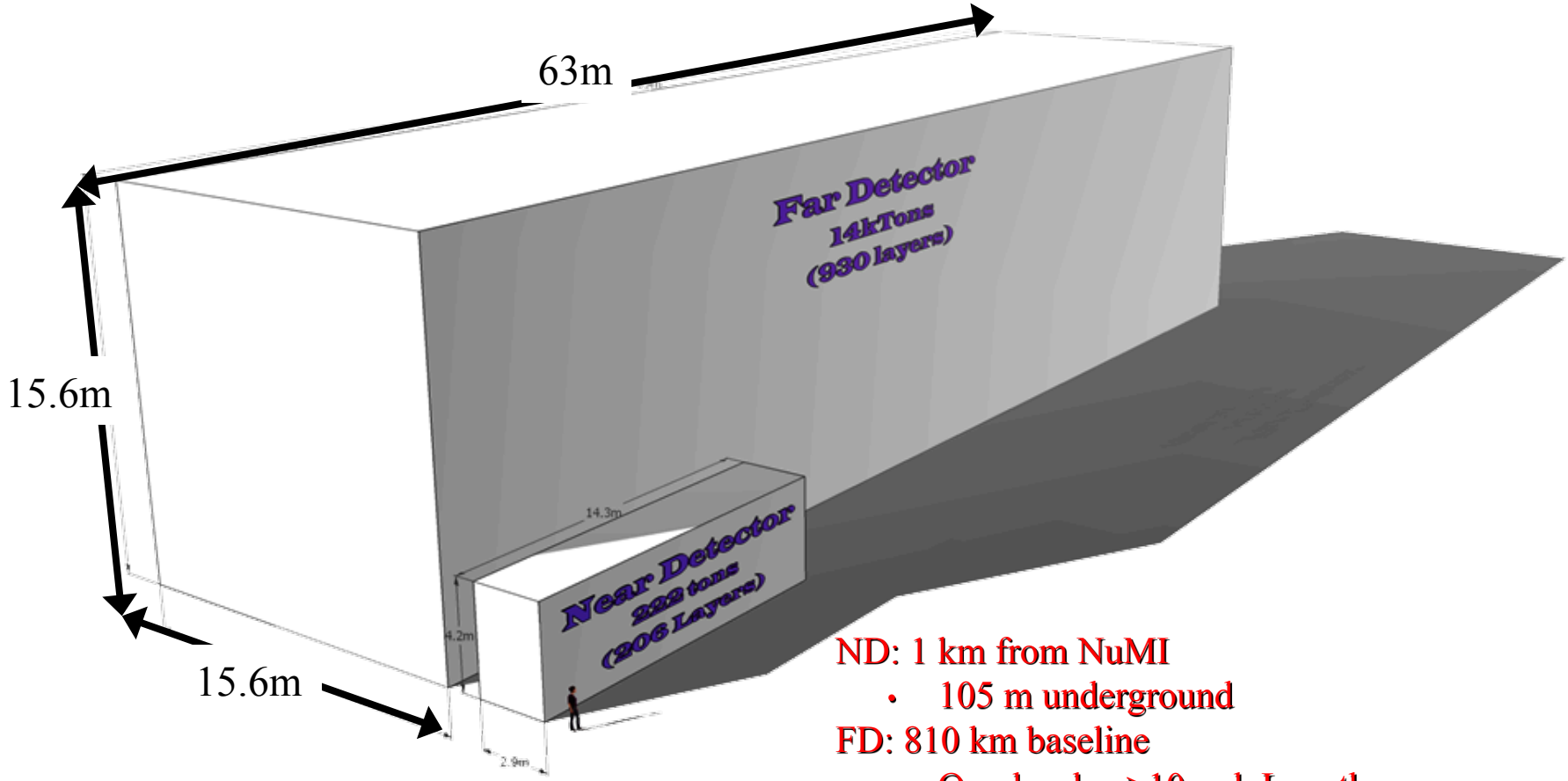
Aerial view

Experiment progress:

Far detector laboratory complete

- Beneficial occupancy of Ash River laboratory on April 13, 2011

NOvA Far Detector Dimensions



ND: 1 km from NuMI
- 105 m underground

FD: 810 km baseline
- Overburden >10 rad. Lengths

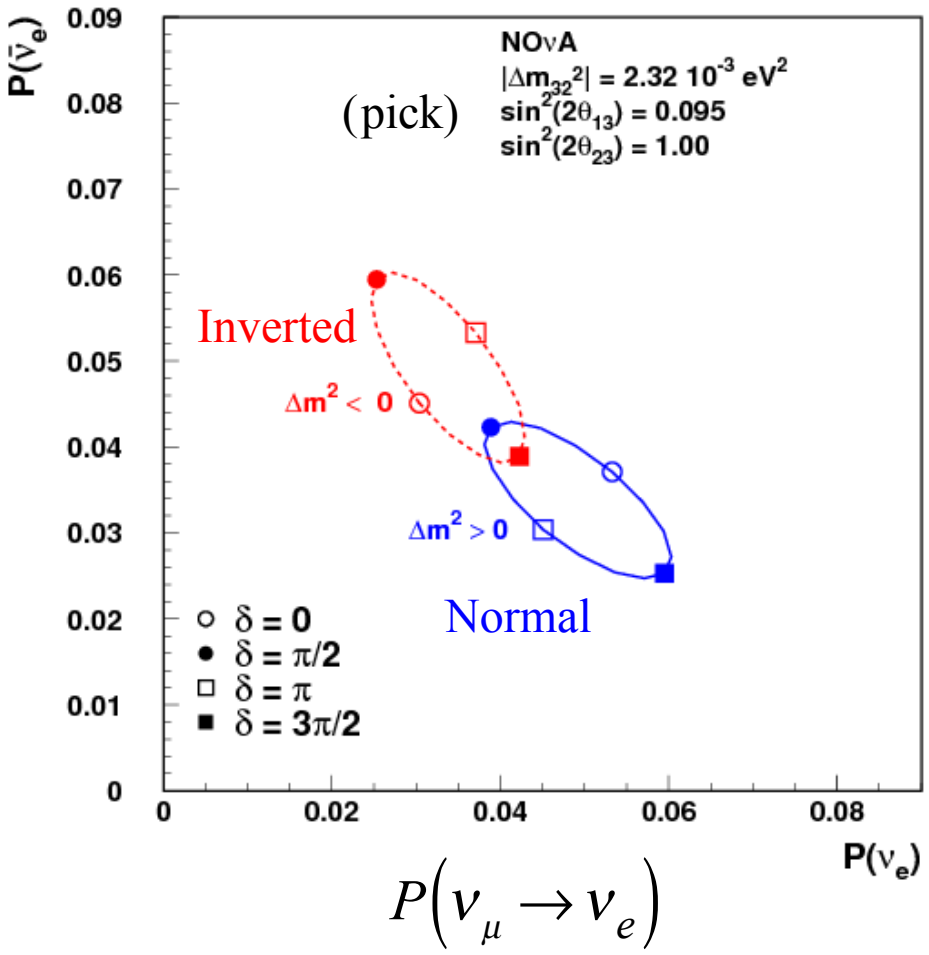
Tracking Calorimeter Technology:
- Highly Segmented (Alternating X/Y)
- Low Z (PVC and Oil; 0.15 radiation length per layer)
- 65% Active Volume

NOvA bi-probability plot

Current run plan: alternate ν_μ and $\bar{\nu}_\mu$ every year, for 6 years

Hierarchy and CP-V results will be shown best in "bi-probability" plot.

$P\left(\bar{\nu}_\mu \rightarrow \bar{\nu}_e\right)$



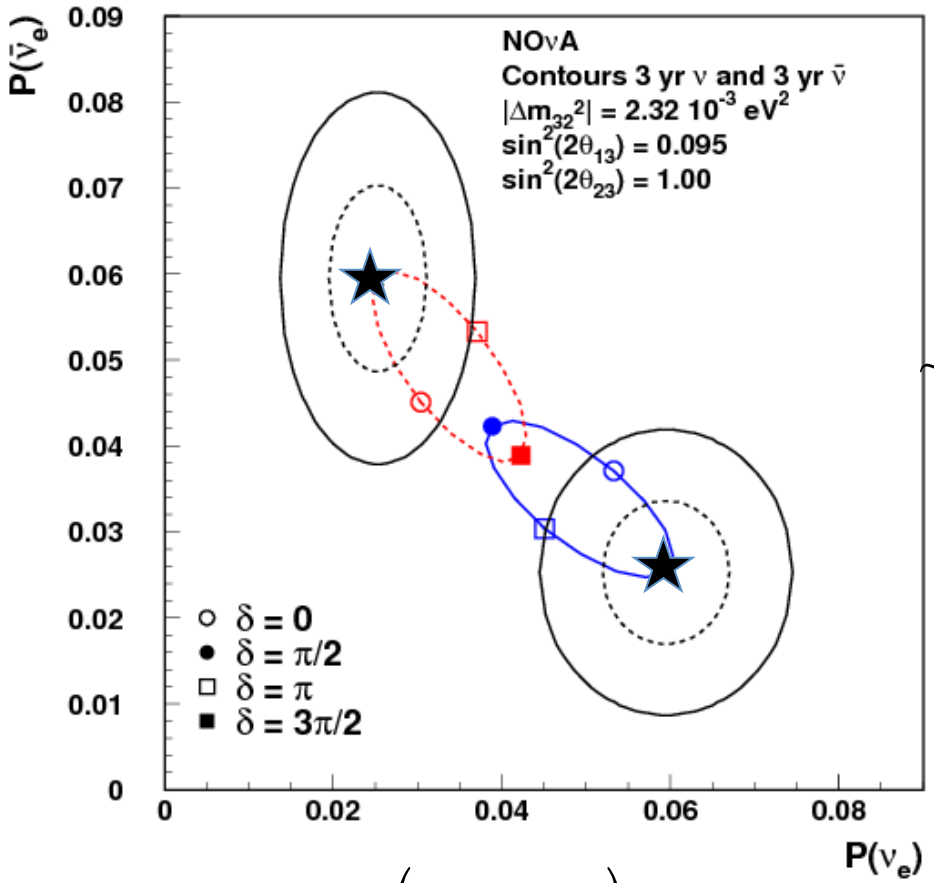
$P\left(\nu_\mu \rightarrow \nu_e\right)$

MSW mass effects depend on hierarchy

Complicates CP-V analysis

NOvA results for ‘lucky” starred points

$P\left(\bar{\nu}_\mu \to \bar{\nu}_e\right)$

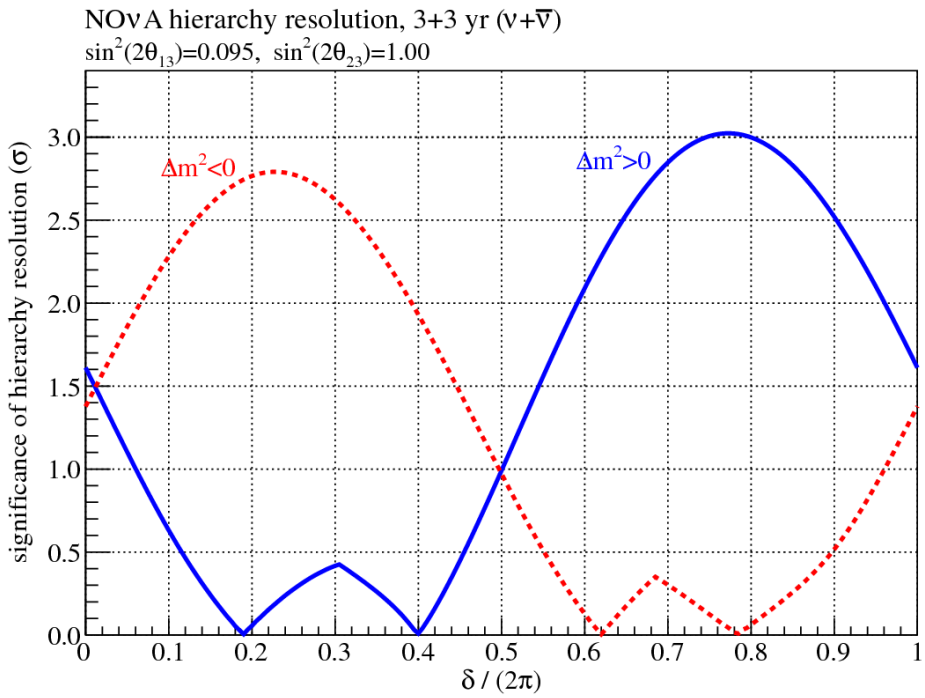


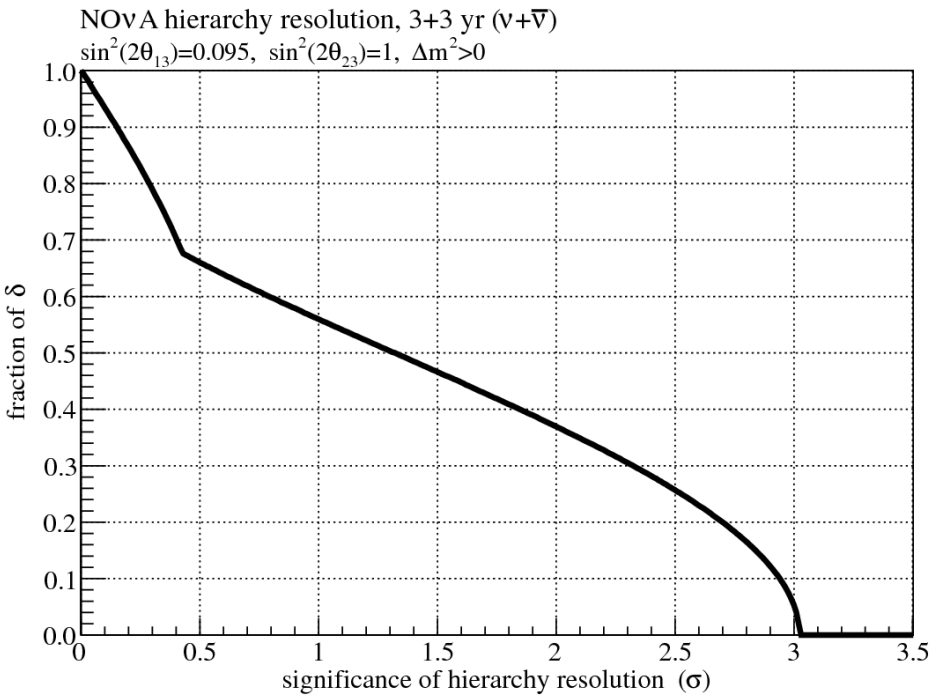
$P\left(\nu_\mu \to \nu_e\right)$

$\sim 3\sigma$ hierarchy resolution

and CP-V $\neq 0$ by $\sim 2\sigma$

General sensitivity to hierarchy & CP-V





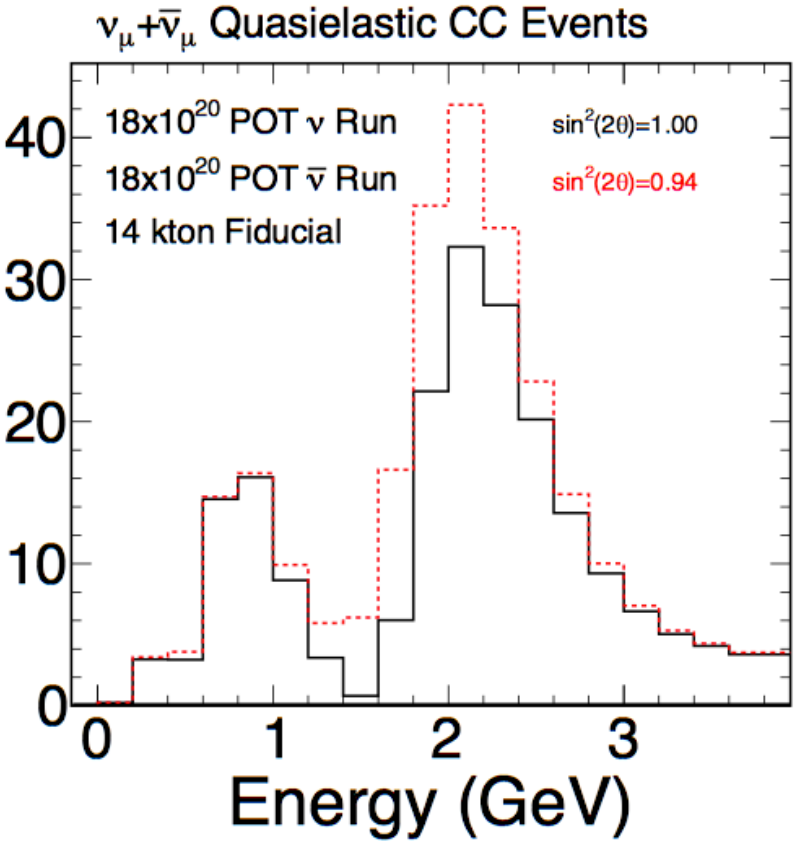
Up to 3σ hierarchy resolution for maximal CP-V ($\delta=\frac{\pi}{2},\frac{3\pi}{2}$)

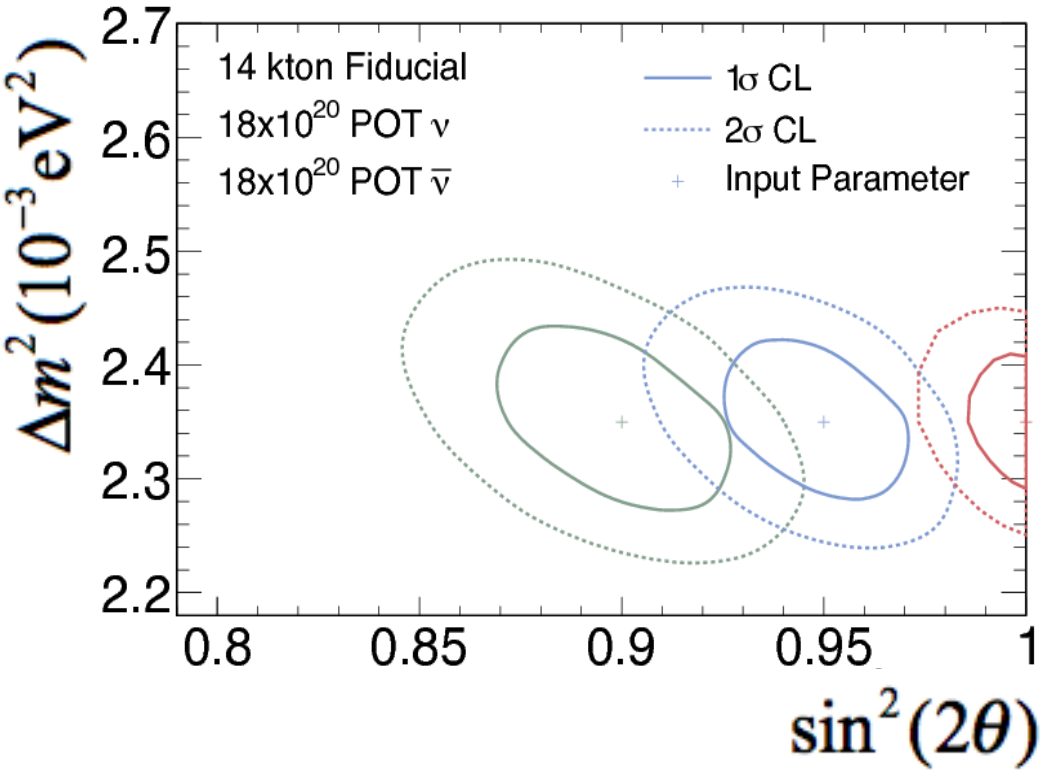
(with T2K results, $0\rightarrow0.5\sigma$)

1σ hierarchy resolution for about 50% of δ range.

ν_μ survival probabilities

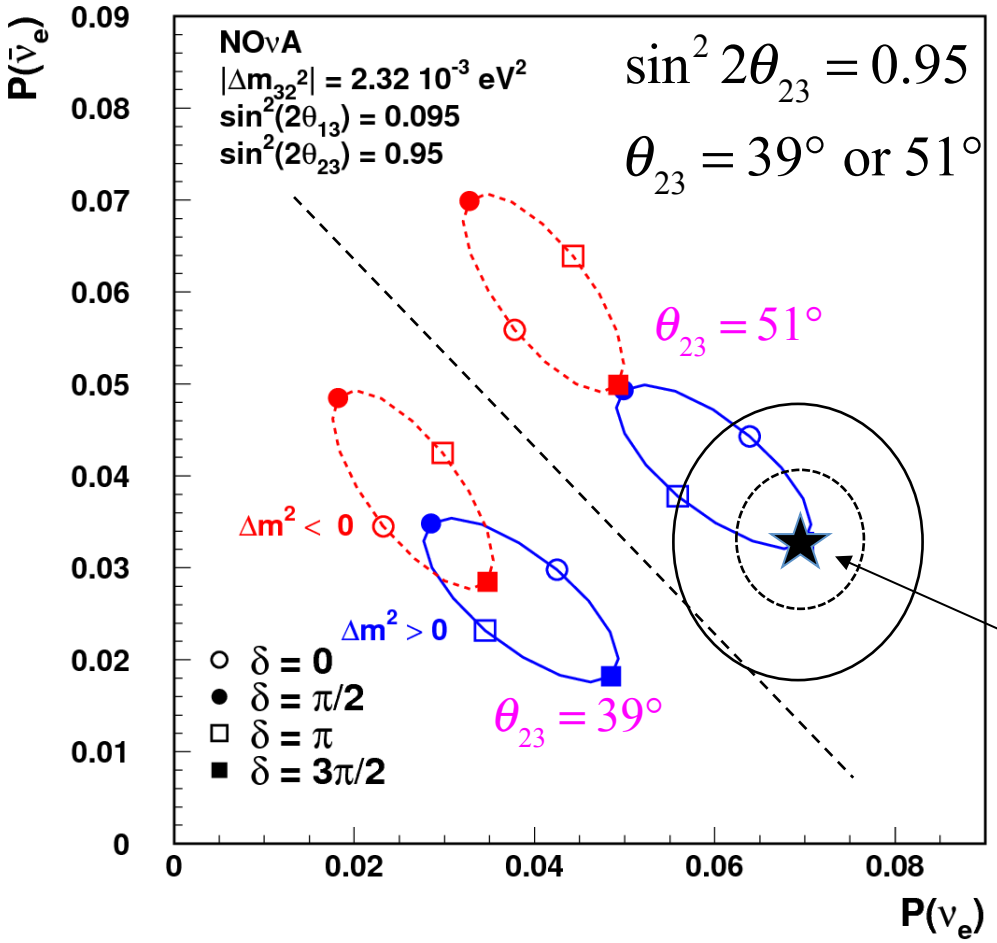
$$P(\nu_\mu \to \nu_\mu) \;\&\; P(\bar{\nu}_\mu \to \bar{\nu}_\mu)$$

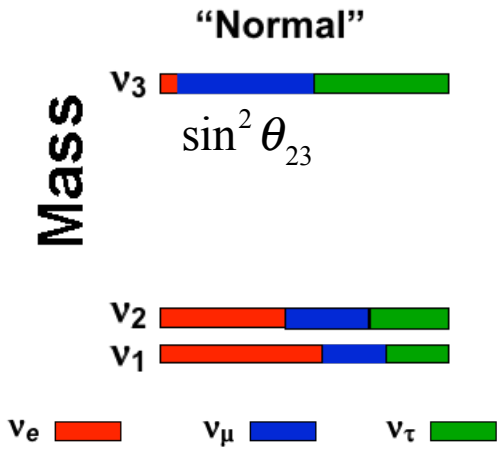




θ_{23} octant ambiguity, ν_e appearance

$$P(\nu_\mu \to \nu_e)\ \&\ P(\bar{\nu}_\mu \to \bar{\nu}_e) \ \propto\ \sin^2\theta_{23}$$





θ_{23} ambiguity resolved by

$$P(\nu_\mu \to \nu_e) + P(\bar{\nu}_\mu \to \bar{\nu}_e)$$

Starred point has

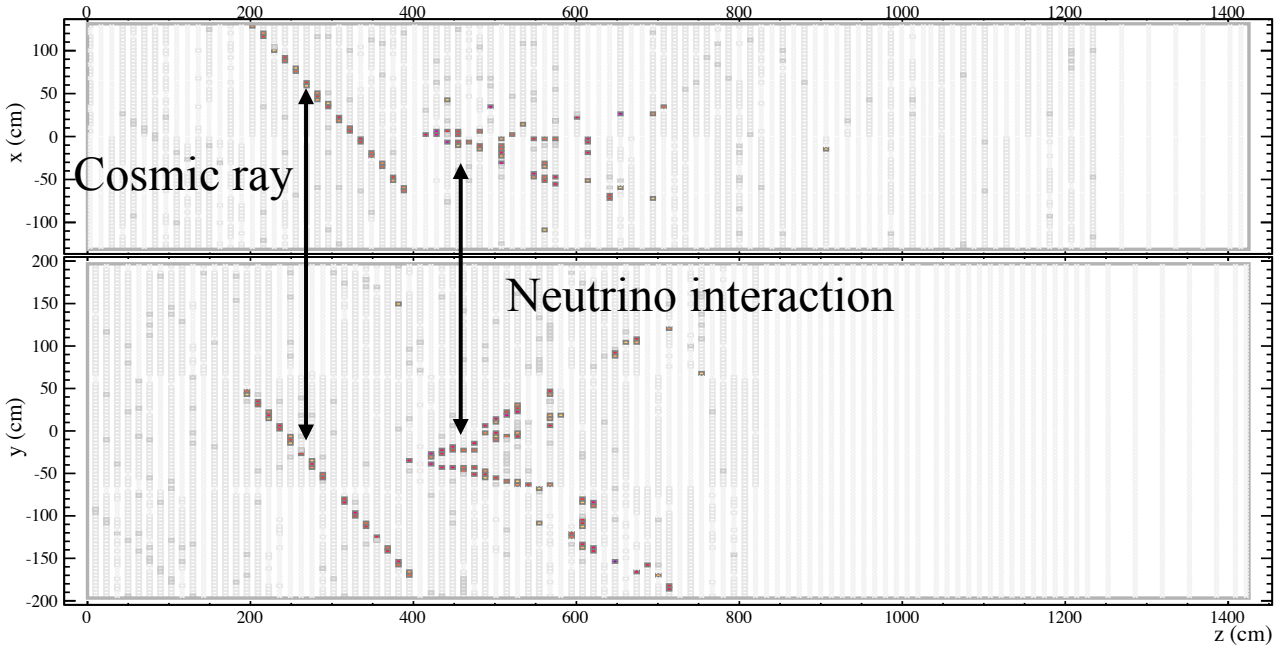
$$P(\nu_\mu \to \nu_e) + P(\bar{\nu}_\mu \to \bar{\nu}_e)$$

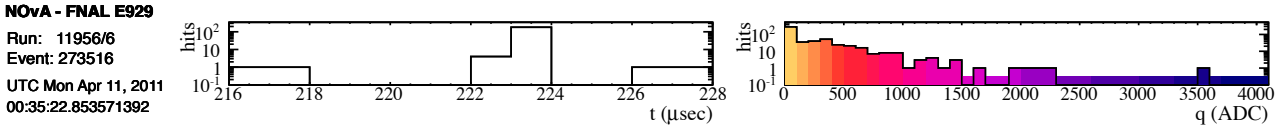
$\sim 2\sigma$ from $\theta_{23} = 45°$

Near Detector On the Surface (NDOS) data

Top View

Side View

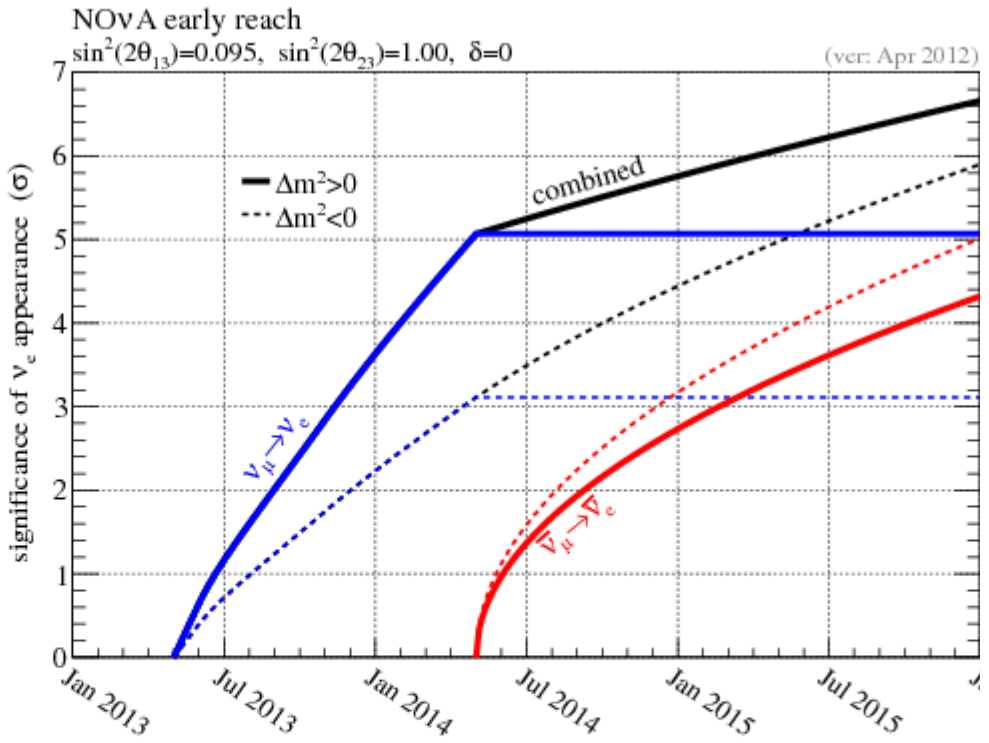




NOνA Run Plan

- Far Detector
  - starting assembly this month
  - reaching 40% by Feb. 2013, beam returns
  - complete by Jan 2014
- Early run plan
  - start with ν
  - can switch to $\bar{\nu}$ at any time
  - reach 5σ for ν_e in NH
- Longer range
  - Hope to improve signal efficiency (45%)
  - Hope to reduce NC fake rate (0.1%)
  - Using recent knowledge of $\sin^2(2\theta_{13}) = 0.095$
  - NOνA example event yields for $\nu_\mu \rightarrow \nu_e$

    but dependent on other oscillation parameters

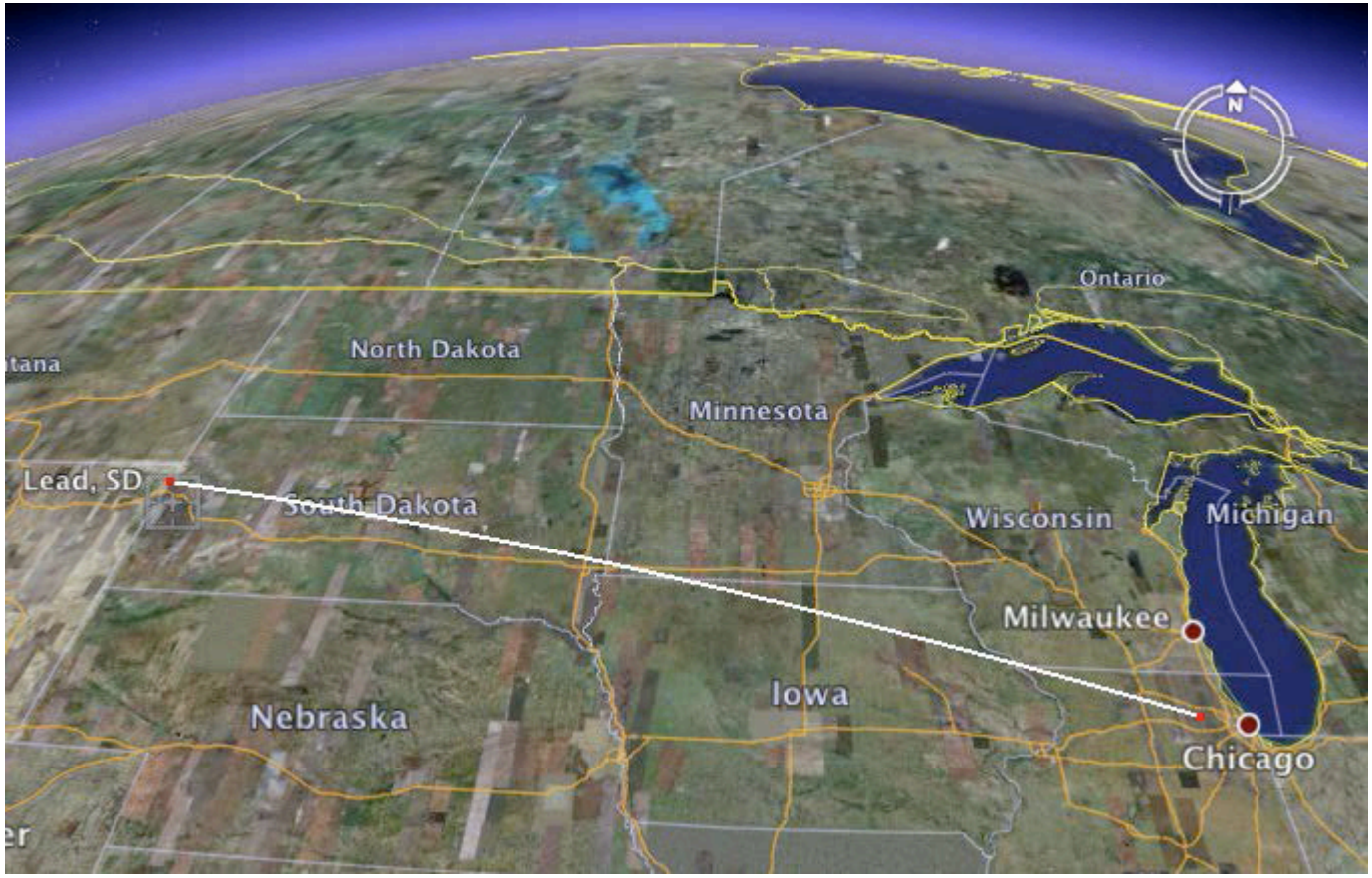


3yr (ν) + 3yr ($\bar{\nu}$)

Background	ν	$\bar{\nu}$
NC	19	10
$\nu_\mu$cc	5	<1
$\nu_e$cc	8	5
tot BG	32	15
$\nu_\mu \rightarrow \nu_e$	68	32

After NOvA is LBNE

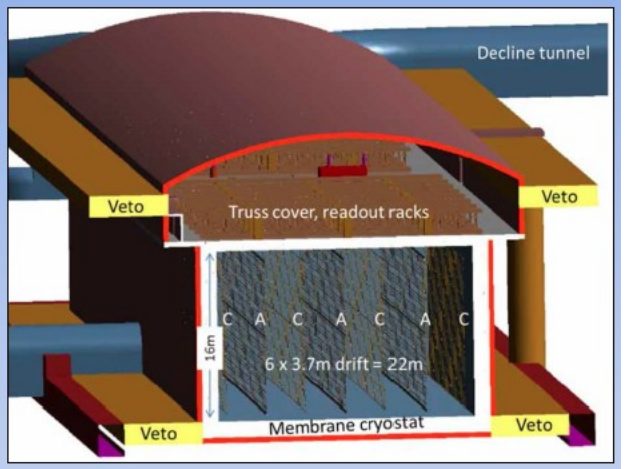
- Better beam & detector for mass hierarchy and CP-V
- Also search for proton decay

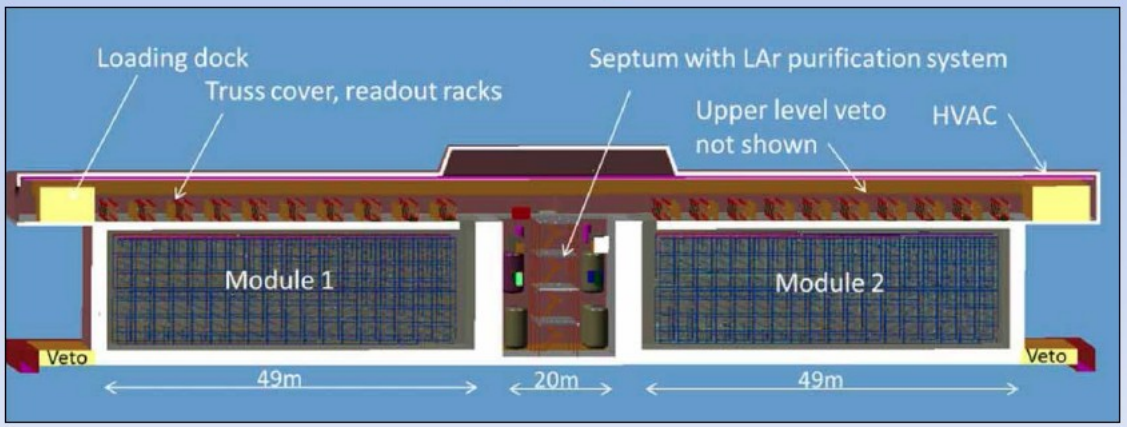


LBNE 40 kton LArTPC

Liquid Argon TPC

- **TPC design**
  - 3.7 m drift length
  - 5 mm wire spacing
  - Three stereo views
- Veto system (800 level)
  - Tag cosmics in adjacent rock





Funding for LBNE

LBNE beam and deep underground detector estimated cost ~ $1.2B. DOE wants the US to have a future in this physics but suggests a cost significantly < than current estimate.

To get the beam and site, “preferred option” is a 10 kT *surface* detector in SD. Cost is OK, but only neutrino physics. Presented to DOE this month with a positive reaction.

The hope is that construction of this beam and facilities at the site will attract foreign contributions to allow a 20-40 kT/underground detector to be built, and perhaps replace current plan.