US Long Baseline Initiatives

Director's Review
Fermilab
9 June 2004

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My Bias

- My bias is that NOνA is the only serious US initiative at present.
- We now have a better picture of an evolving NOνA program.
- I will comment on other directions at the end.

Physics Goals

- **MINOS**
  - Verify the oscillation paradigm
  - Improve measurements of Δm_{23}^2 and $\sin^2(2\theta_{23})$
  - Search for evidence of sterile neutrinos
  - Search for $\nu_\mu \rightarrow \nu_e$ at factor of 2 better sensitivity than CHOOZ
- **NOνA**
  - Extend the $\nu_\mu \rightarrow \nu_e$ search by an order of magnitude
  - Resolve or contribute to the resolution of the mass hierarchy — Unique contribution
  - Start to gather information on CP violation
  - Improve on other MINOS measurements

How Does NOνA Do This?

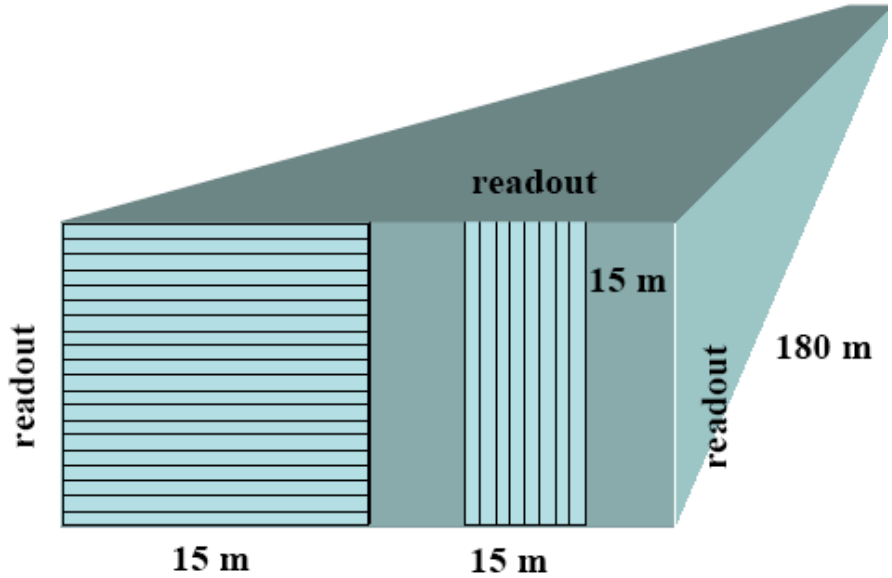
- Use an off-axis, narrow band beam to reduce backgrounds
- Increase the detector mass by a factor of 9 over MINOS (at a cost/kt reduction of 3)
- Build a detector optimized for electron detection
  - Sandwich detector with 0.3 X_0 depth segmentation vs. 1.5 X_0 for MINOS
  - Allows an electron to be seen as a fuzzy track
  - Allows π^0's to be seen as more diffuse objects with conversion gaps

Baseline Detector

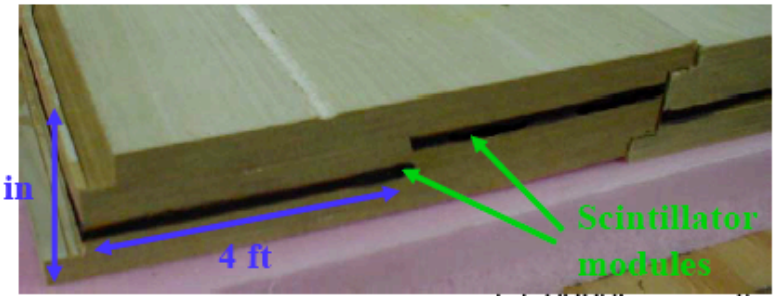
50 kT

Liquid Scintillator:
1.2 m x 3 cm x 14.4 m
30-cell PCV extrusions,
24 extrusions/plane,
750 planes
= 18,000 extrusions
= 540,000 channels
U-shaped WLS fiber into APD readout

Absorber:
20 cm particleboard/ plane (~1/3 X_o)



800 planes X, absorber, Y, absorber, … = detector

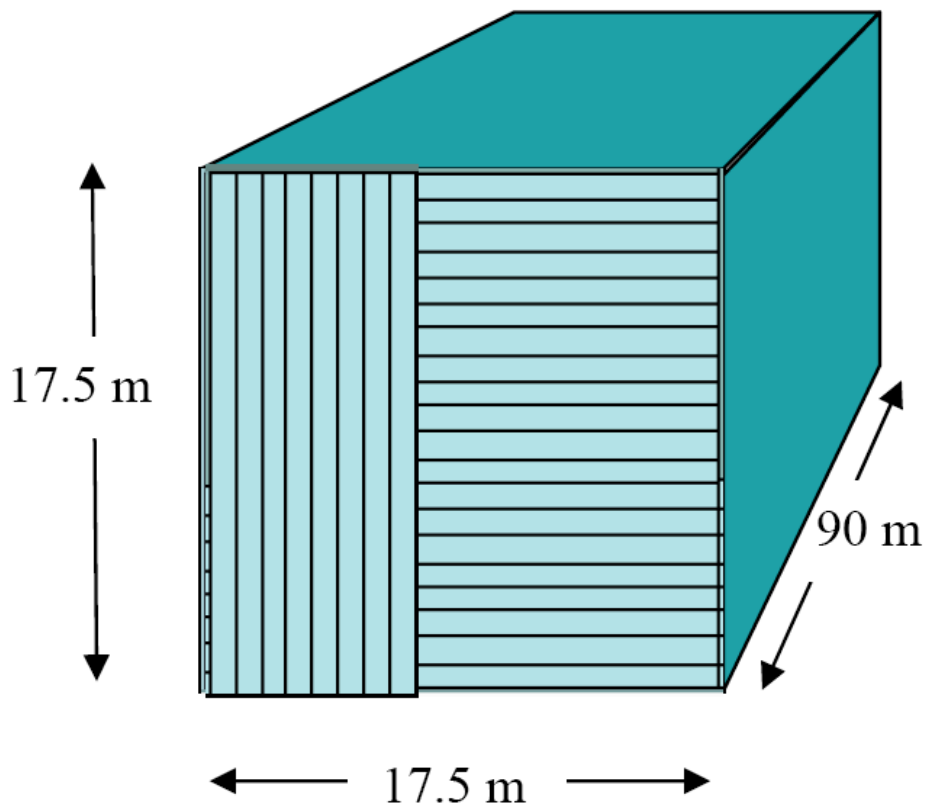


Alternative Under Study: Totally Active Scintillator Detector (TASD)

25 kT

Liquid Scintillator:
1.28 m x 4.9 cm x 17.5 m
32-cell PCV extrusions,
14 extrusions/plane,
1845 planes
= 25,830 extrusions
= 826,560 channels
U-shaped WLS fiber into APD readout

Absorber: None

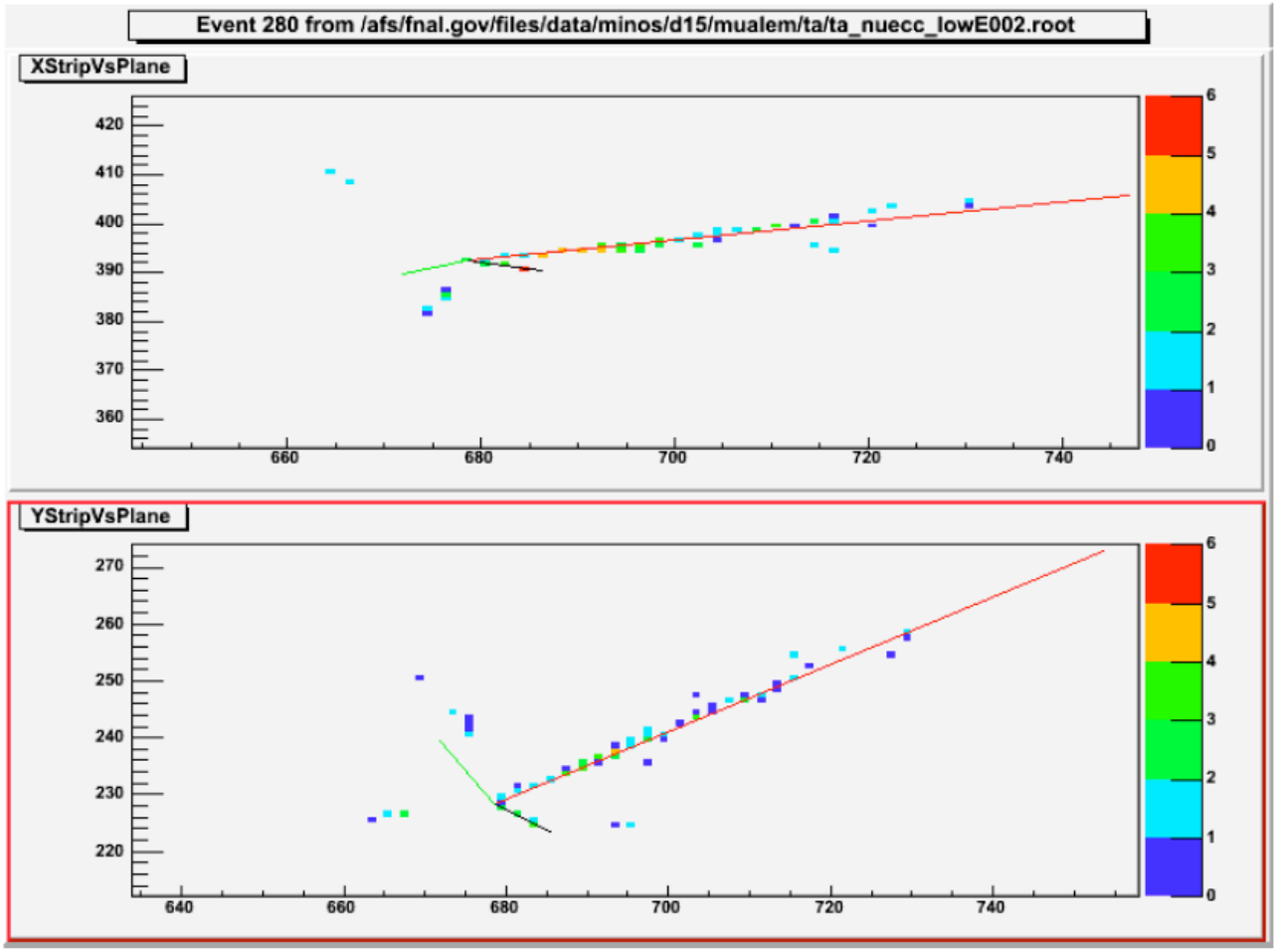


Comparisons

	Baseline	TASD
Mass	50 kT	25 kT
Optimized ν_e efficiency	18%	32%
Optimized s/b	4.8	7.7
FoM	24.5	~26
Cost	$147M	$159M

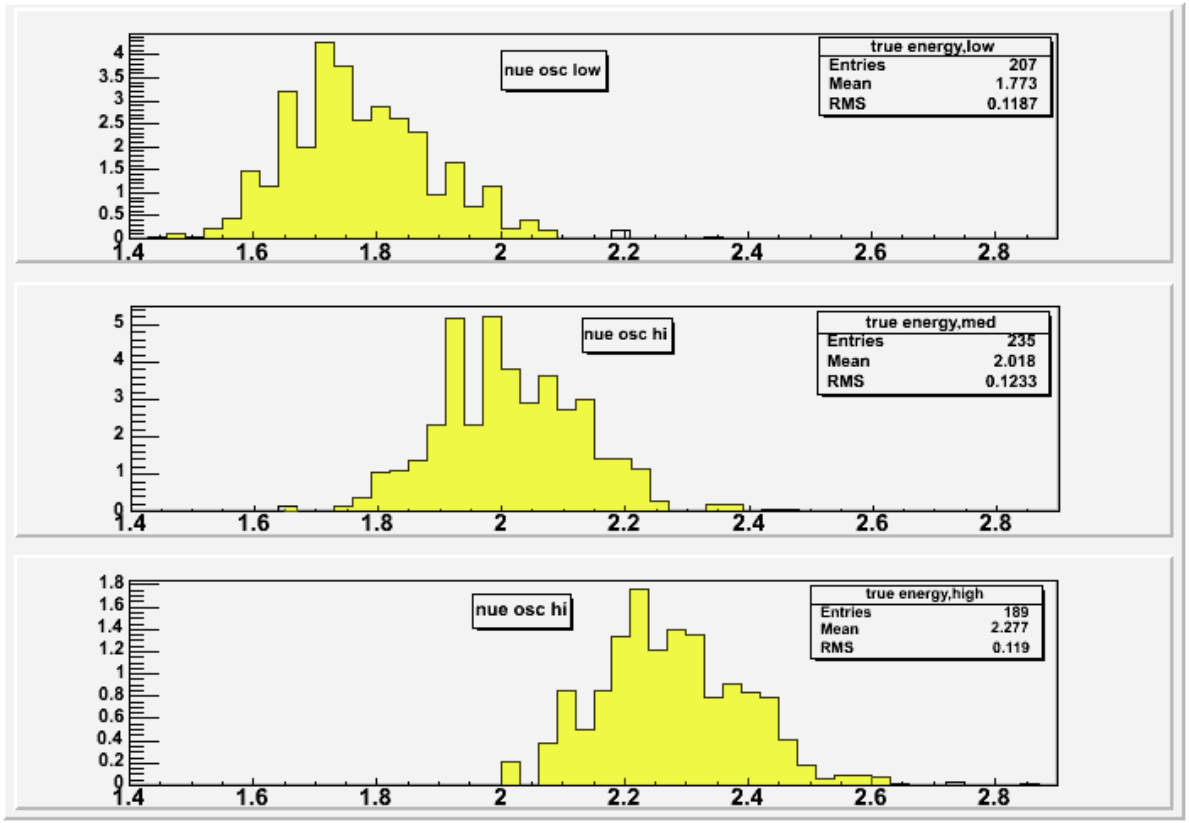
No obvious drawbacks to TASD so far.

Typical TASD Event: $\nu_e A \rightarrow p\, e^- \pi^0$, $E_\nu = 1.65$ GeV



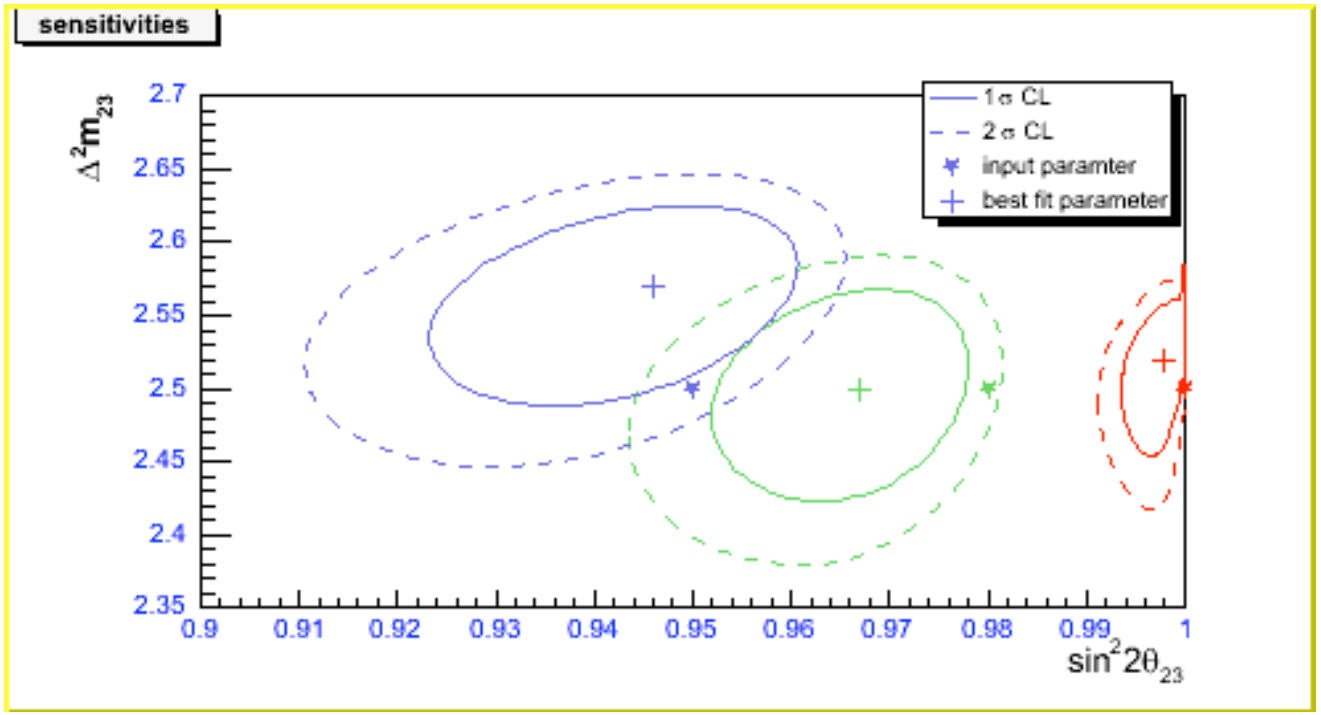
TASD Energy Resolution

- **Excellent electron energy resolution**



Bonus Physics with TASD

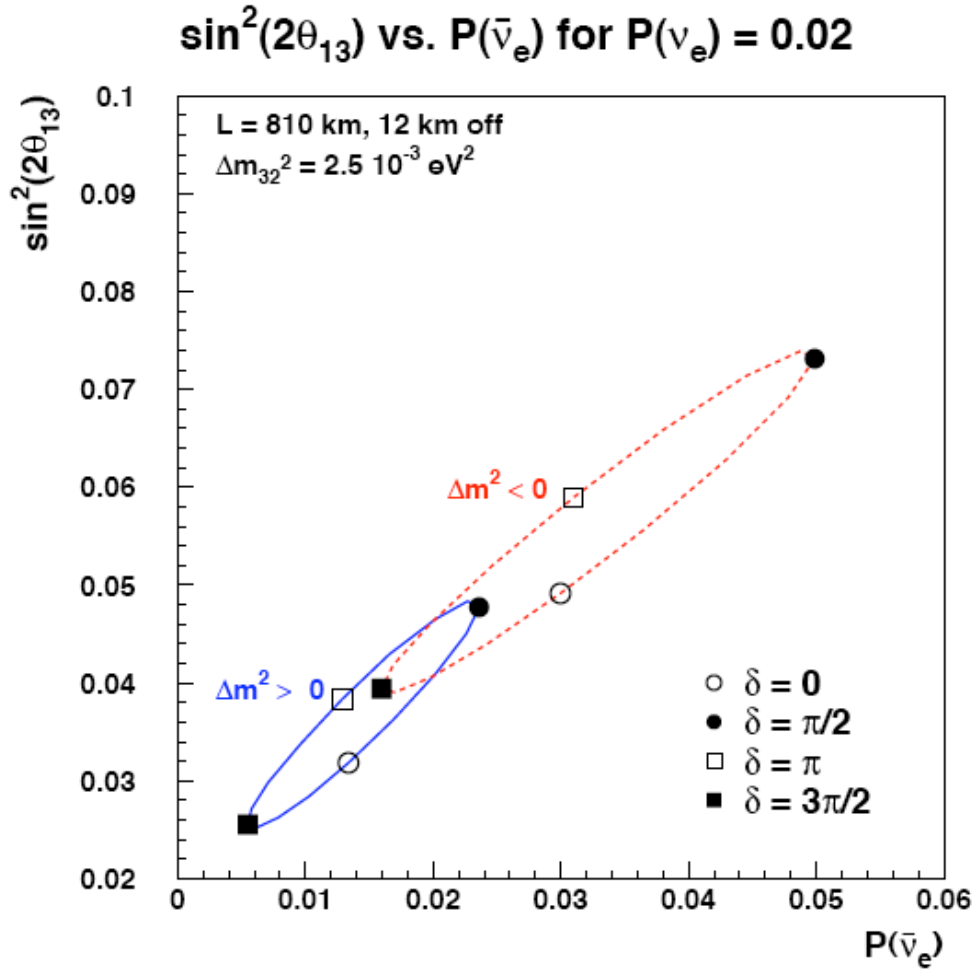
- **Better resolution gives many bonuses**
  - **Excellent measurement of $\sin^2(2\theta_{23})$**



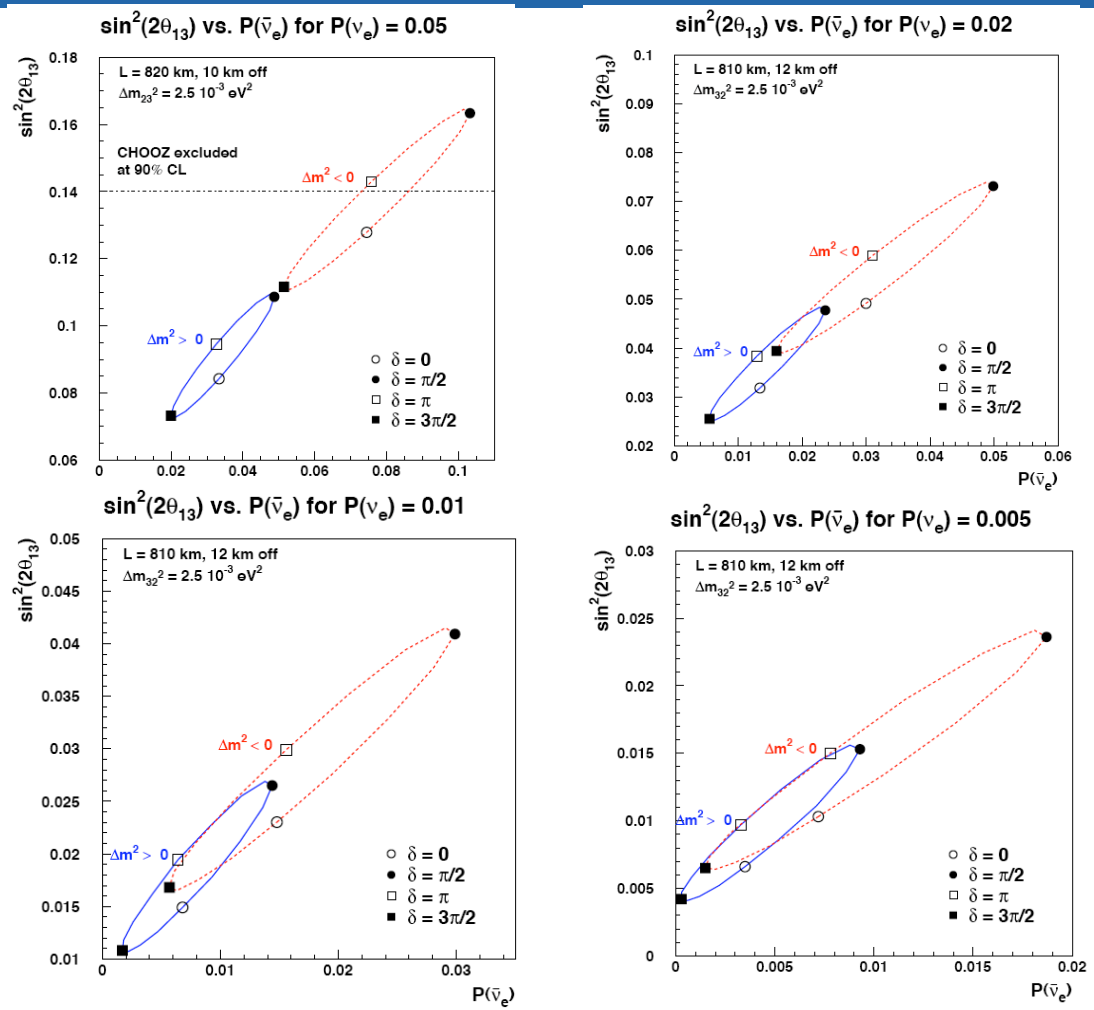
New Simulations

- We now have revised and extended simulations
  - Correct an error in the fiducial containment
  - Correct a miscommunication on the assumed flux
  - Optimized for neutrinos and antineutrinos at
    - 6, 8, 10, 12, 14, and 16 km off-axis for $\Delta m^2 = 0.0025\ eV^2$
    - 8, 10, 12, and 14 km off-axis for $\Delta m^2 = 0.0020\ eV^2$

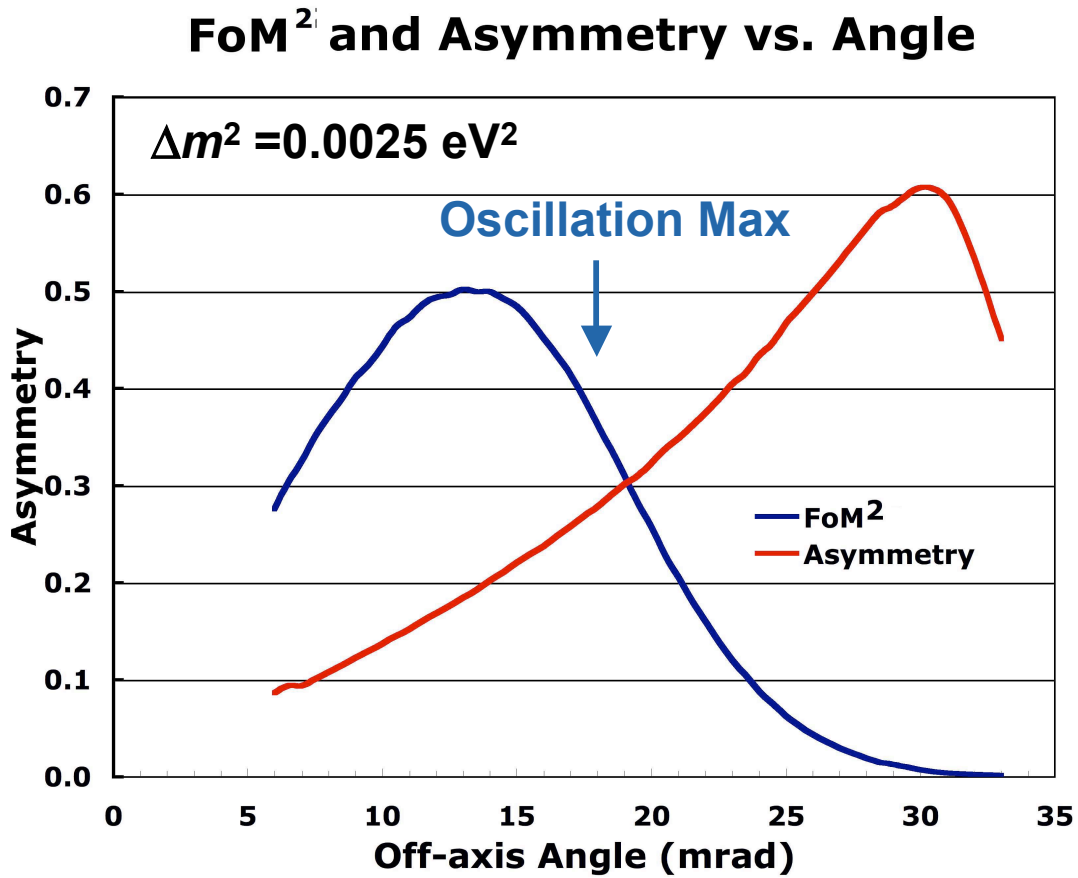
Reminder of the Problem Part 1



Reminder of the Problem Part 1



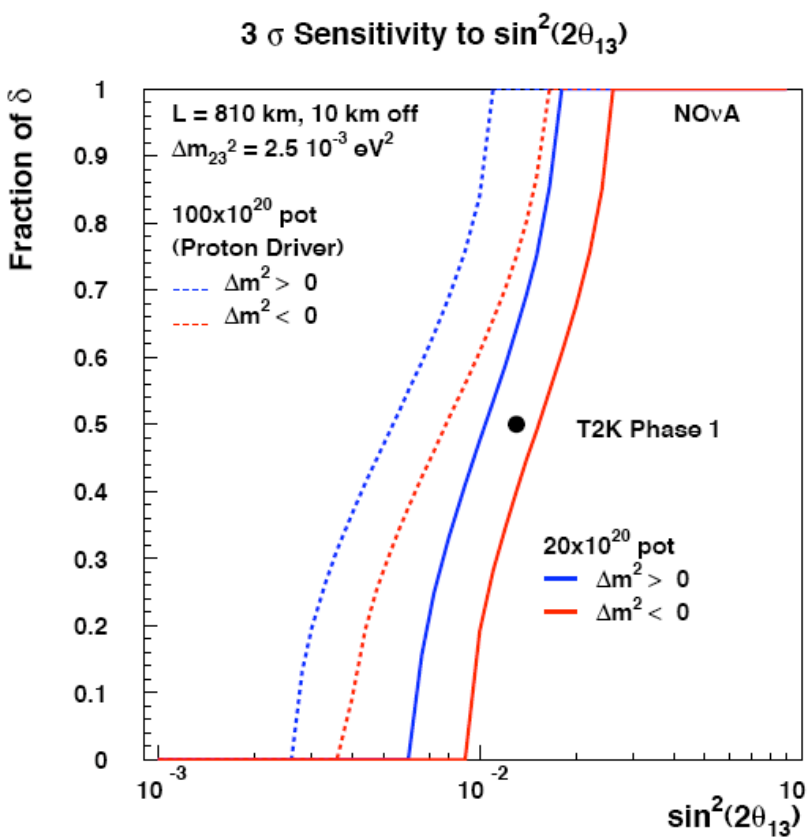
Reminder of the Problem Part 2

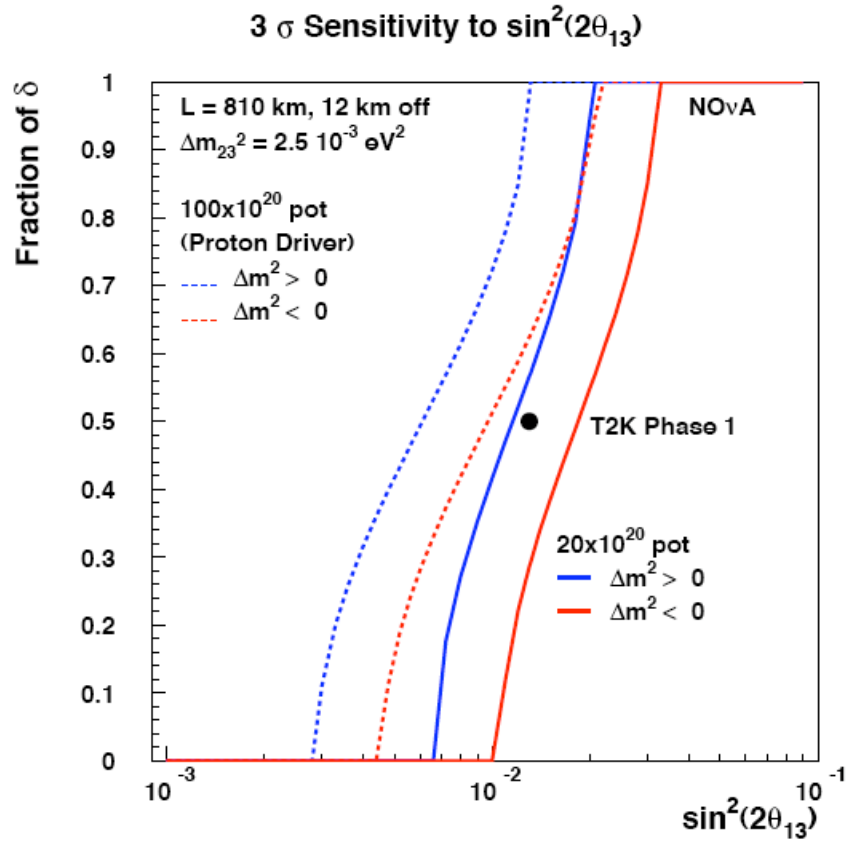


$$\text{FoM} = \frac{\text{signal}}{\sqrt{\text{background}}}$$

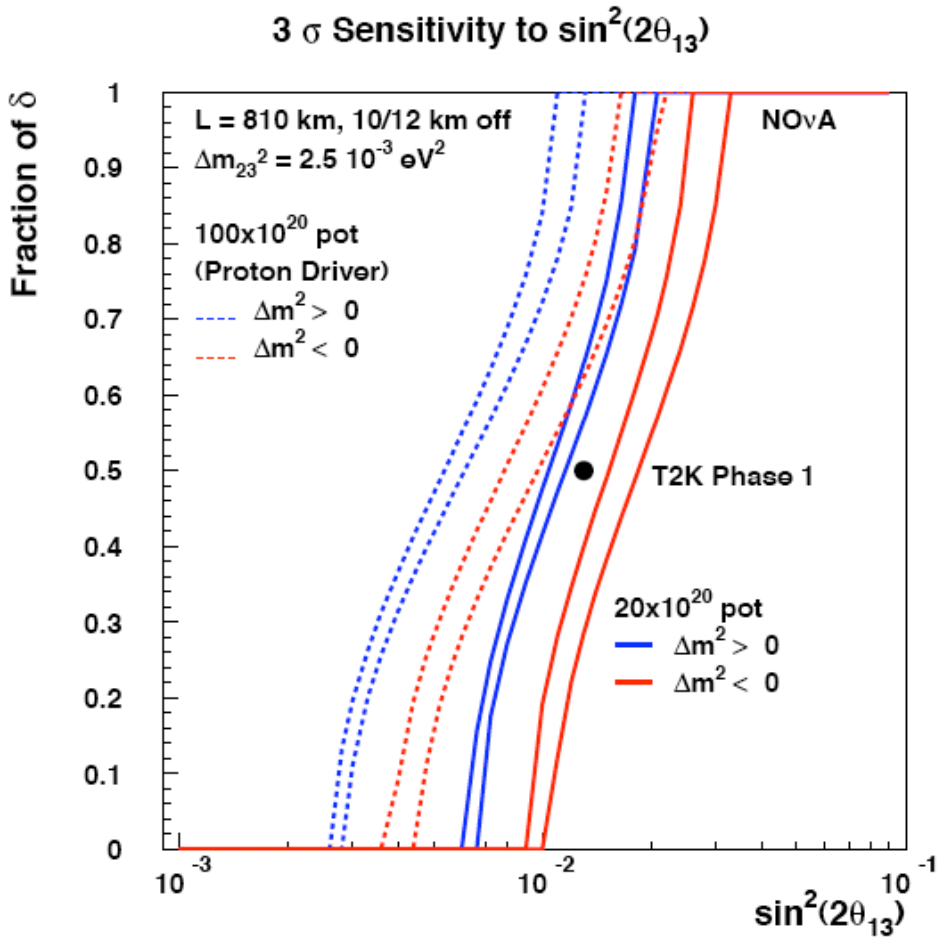
$$\text{Asymmetry} = \left(\frac{\sigma_\nu - \sigma_{\bar{\nu}}}{\sigma_\nu + \sigma_{\bar{\nu}}} \right)$$

3 σ Discovery Potential for $\nu_\mu \rightarrow \nu_e$

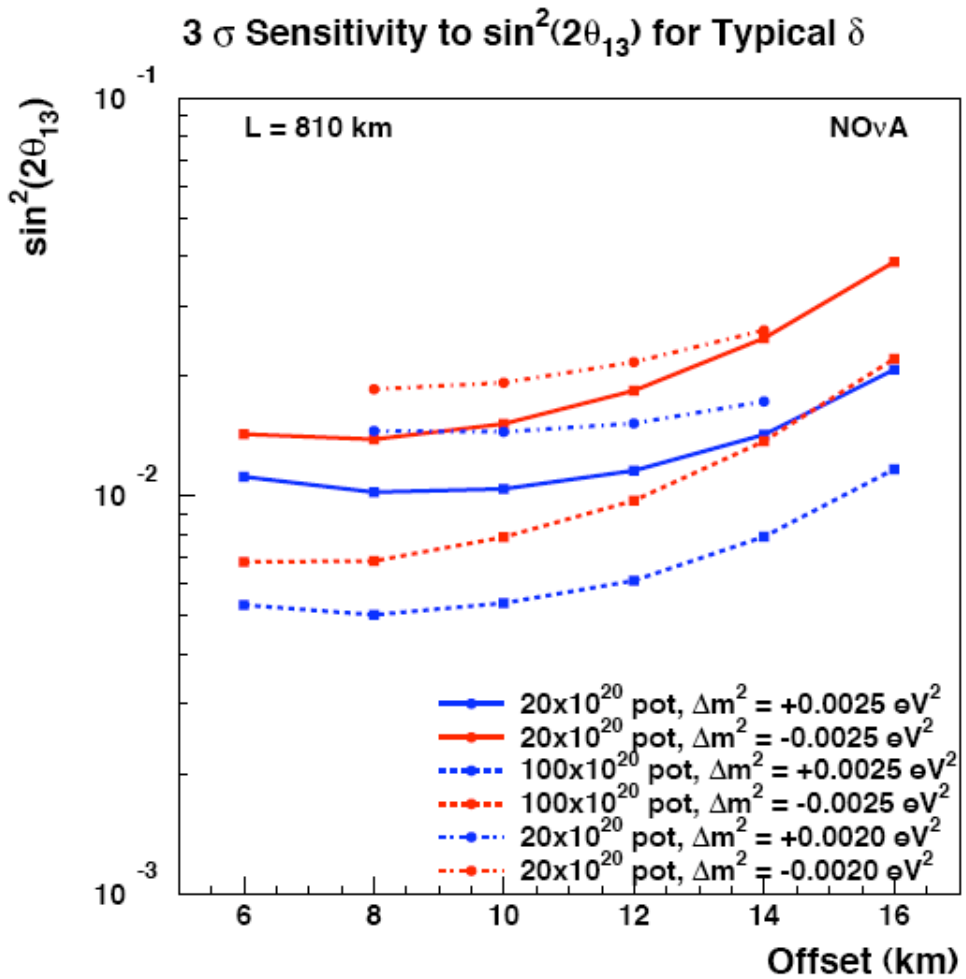




Comparison of 10 and 12 km

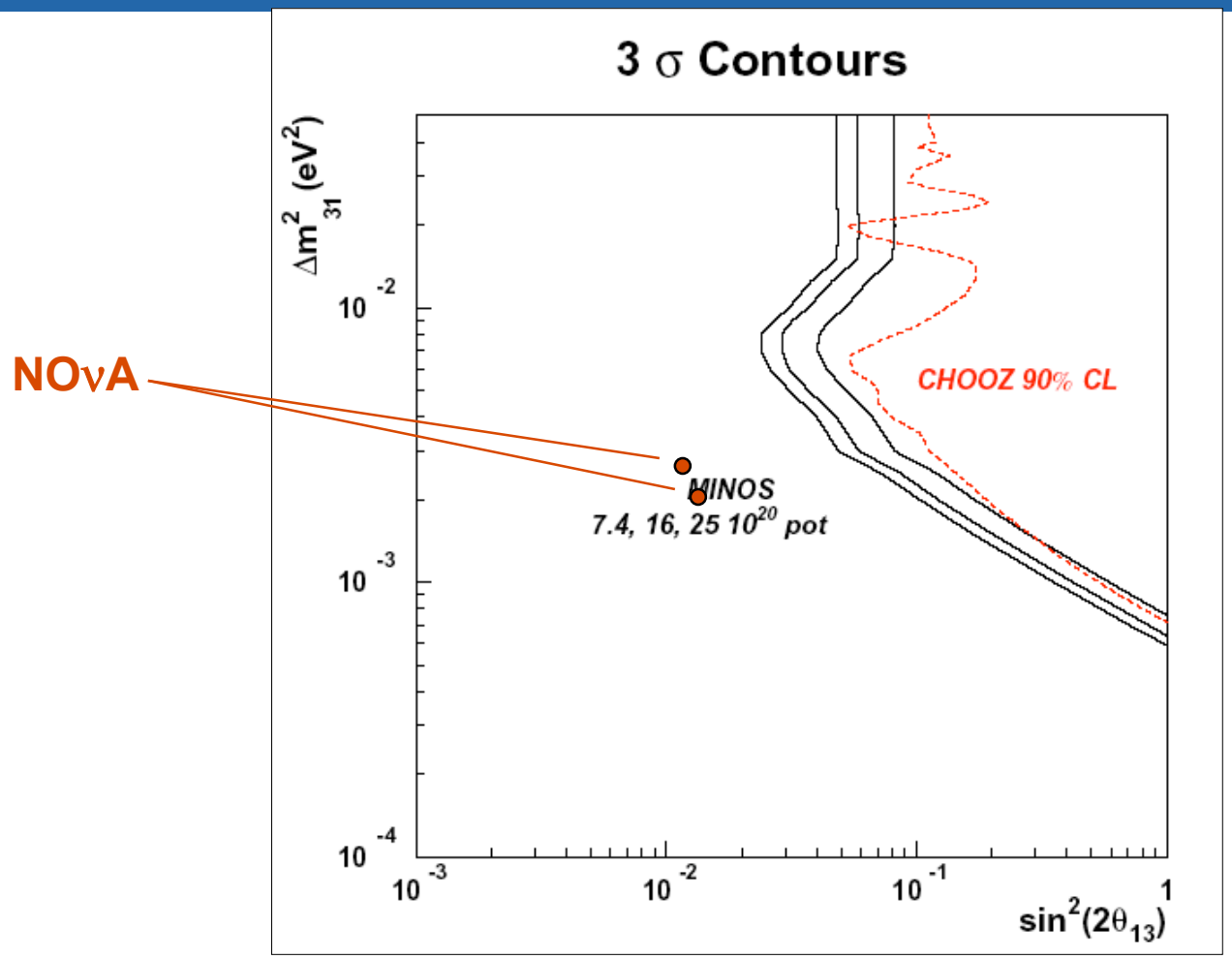


3 σ Discovery Potential for $\nu_\mu \rightarrow \nu_e$ vs. Off-Axis Distance

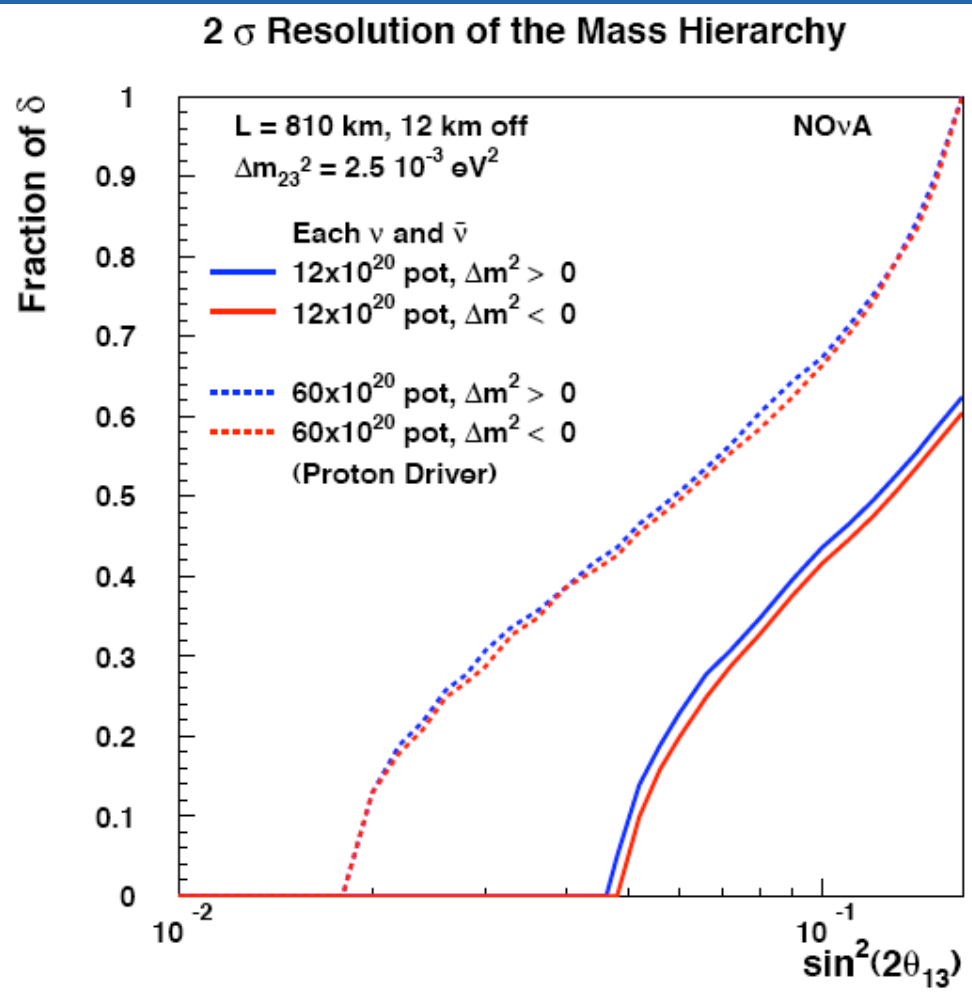


Note: There is a loss of sensitivity for $\Delta m^2 = 0.002\ eV^2$, but not a loss of range, since the CHOOZ limit is correspondingly weaker there.

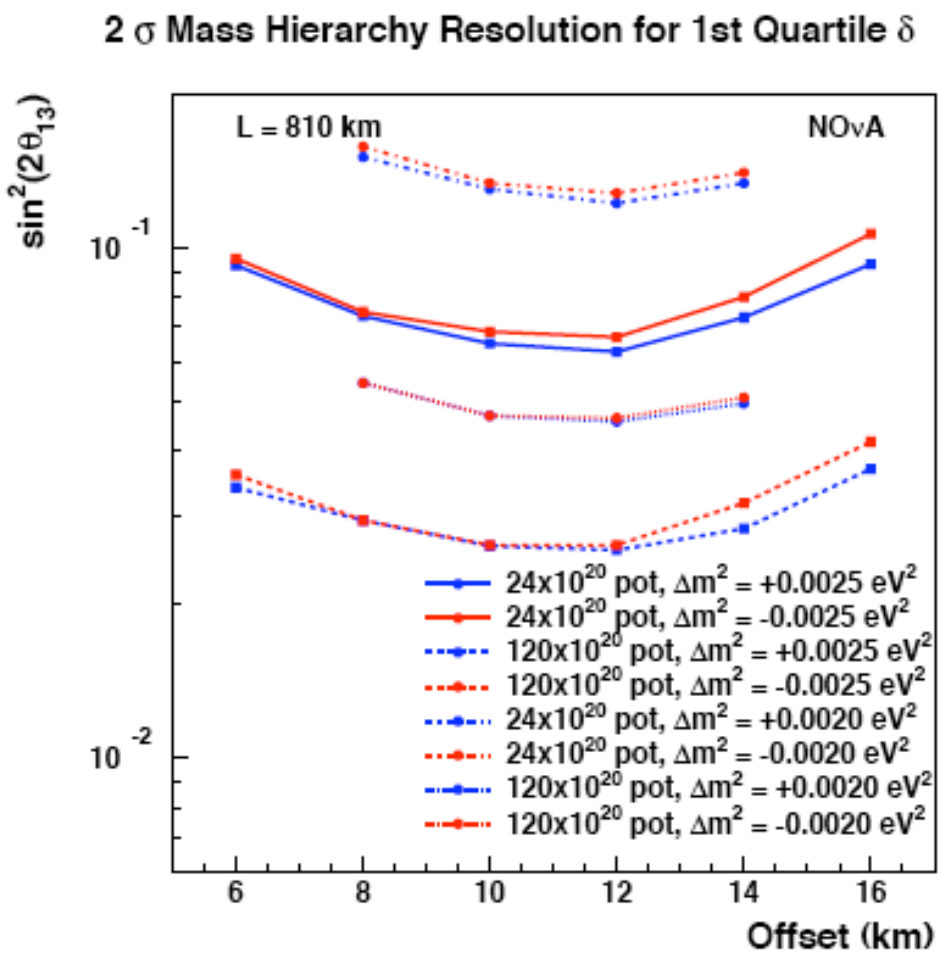
Comparison to MINOS



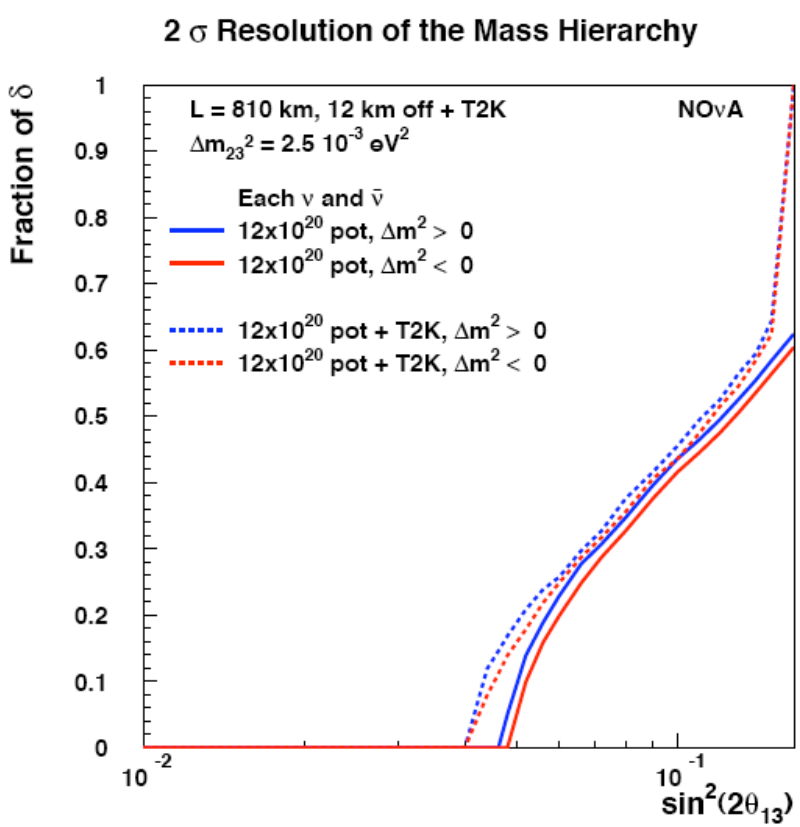
95% CL Resolution of the Mass Hierarchy

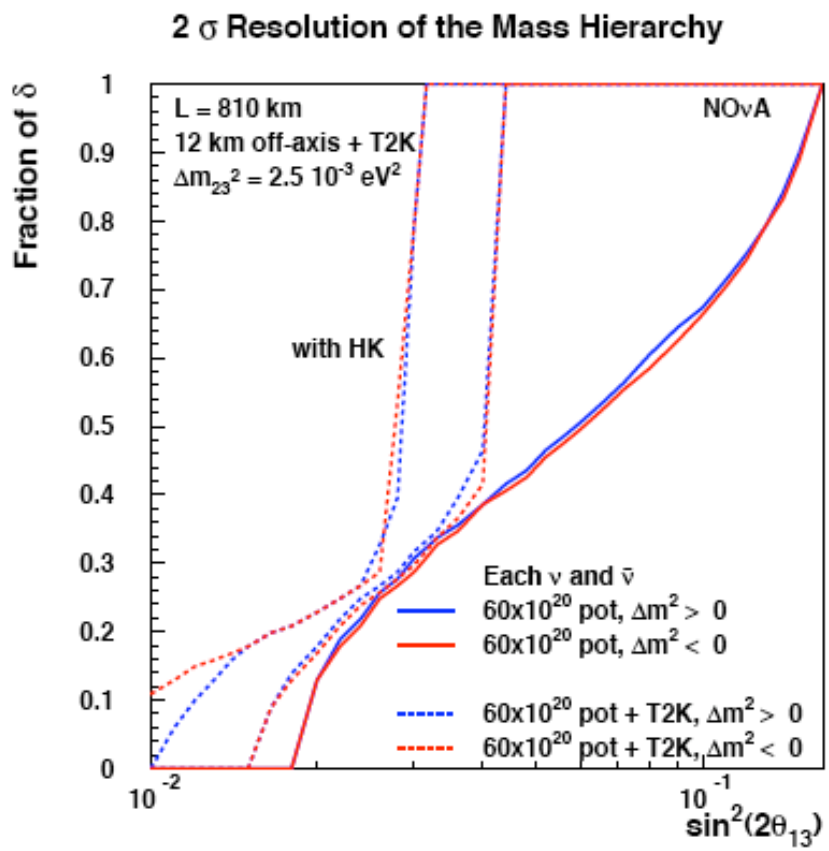


Mass Hierarchy Resolution vs. Off-Axis Distance

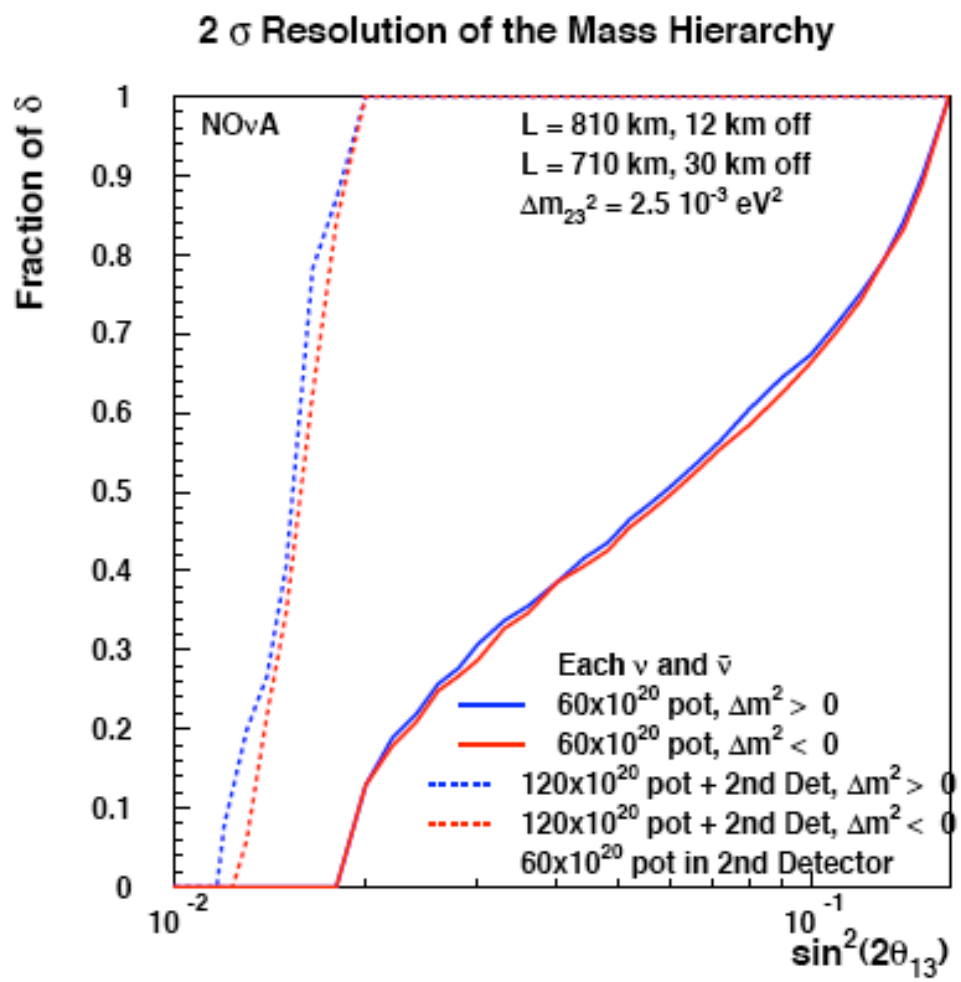


Combination with T2K

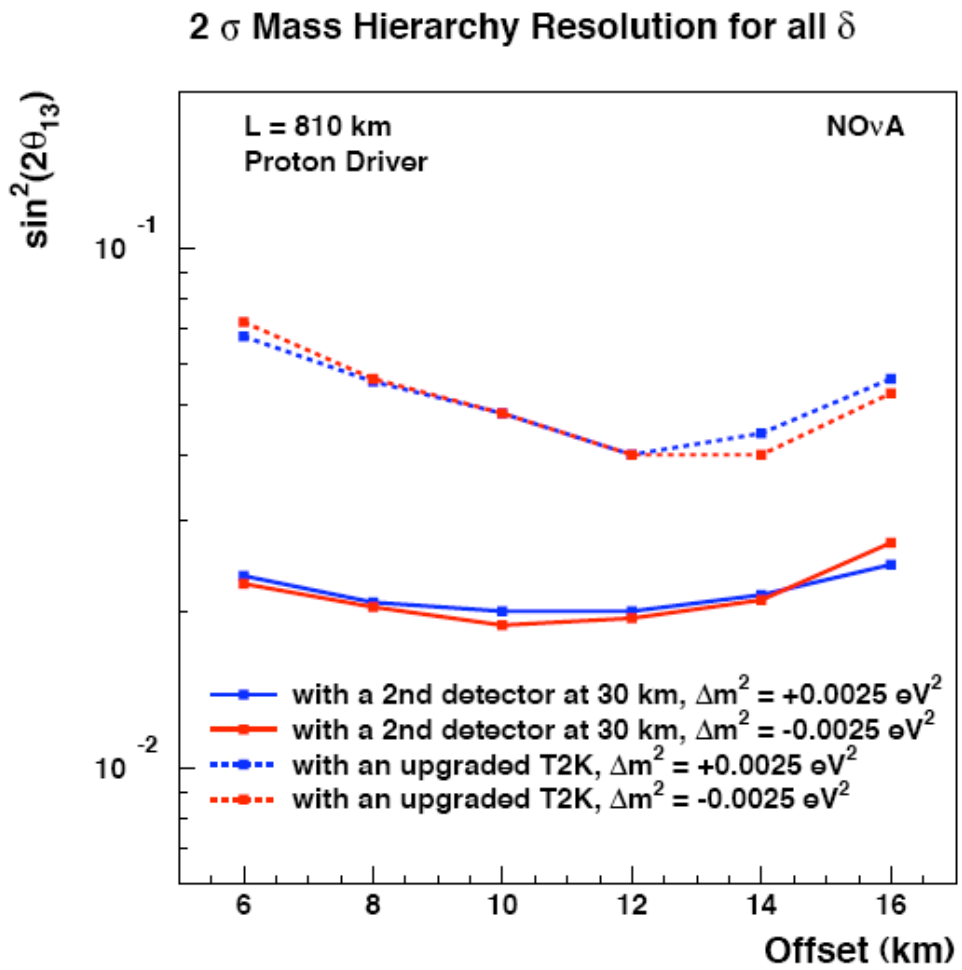




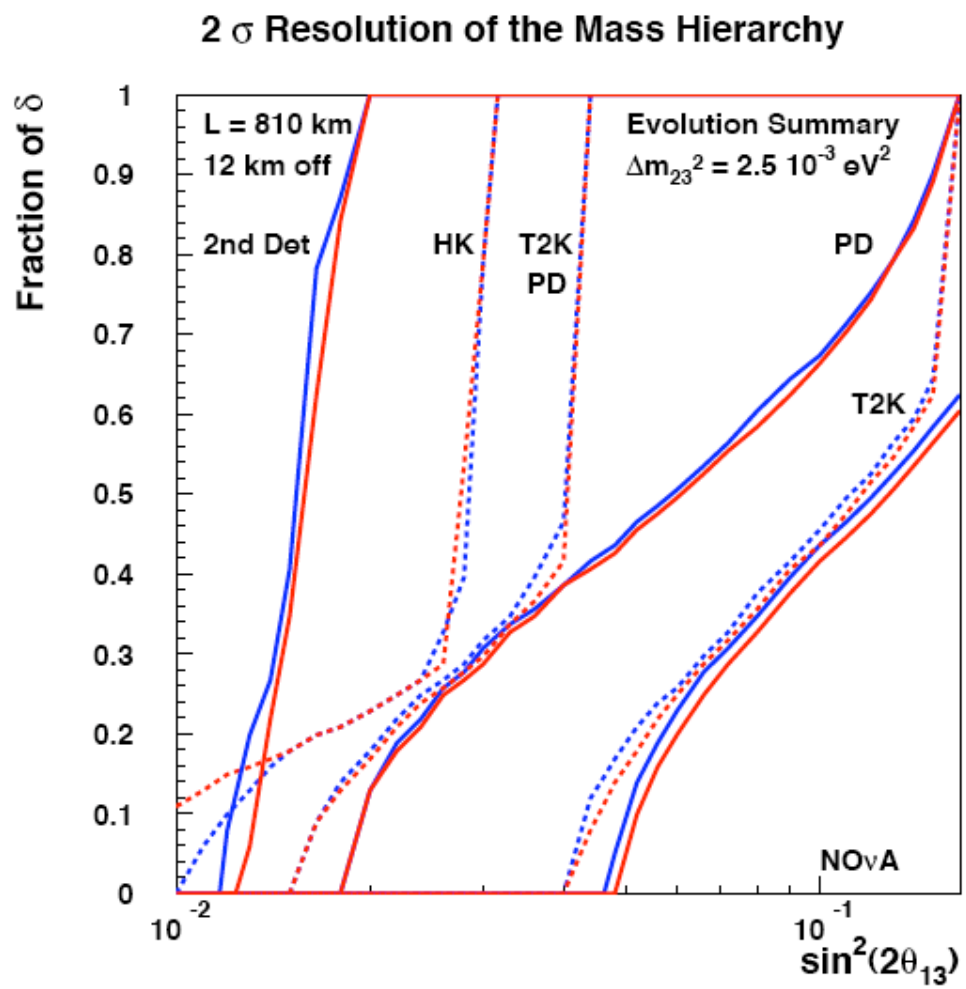
Combination with a 2nd NuMI Detector at the 2nd Maximum



Mass Hierarchy Resolution vs. Off-Axis Distance



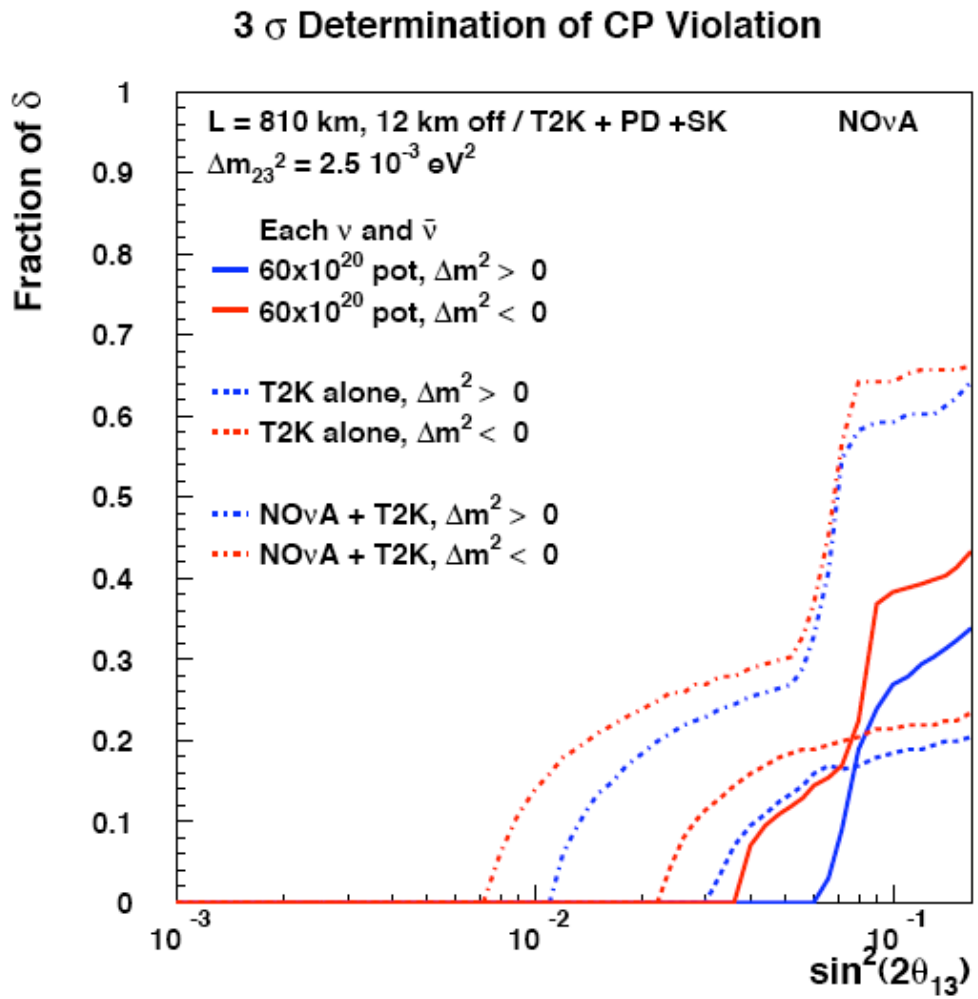
Mass Hierarchy Resolution Summary



Notes on CP Violation

- **Relationship to the mass hierarchy will be different for different experiments.**
  - **Mass hierarchy unimportant for very short baseline experiments, but crucial for long baseline experiments**
- **CP violation is first order in θ_{13}, non-CP violating terms are mostly second order.**
  - **Regions where CP violation is flat in θ_{13} and regions with dips and peaks.**
- **I will use the criterion of fraction of δ for which there is a 3-σ demonstration of CP violation, i.e., $\delta = 0$ or π.**

3 σ Demonstration of CP Violation



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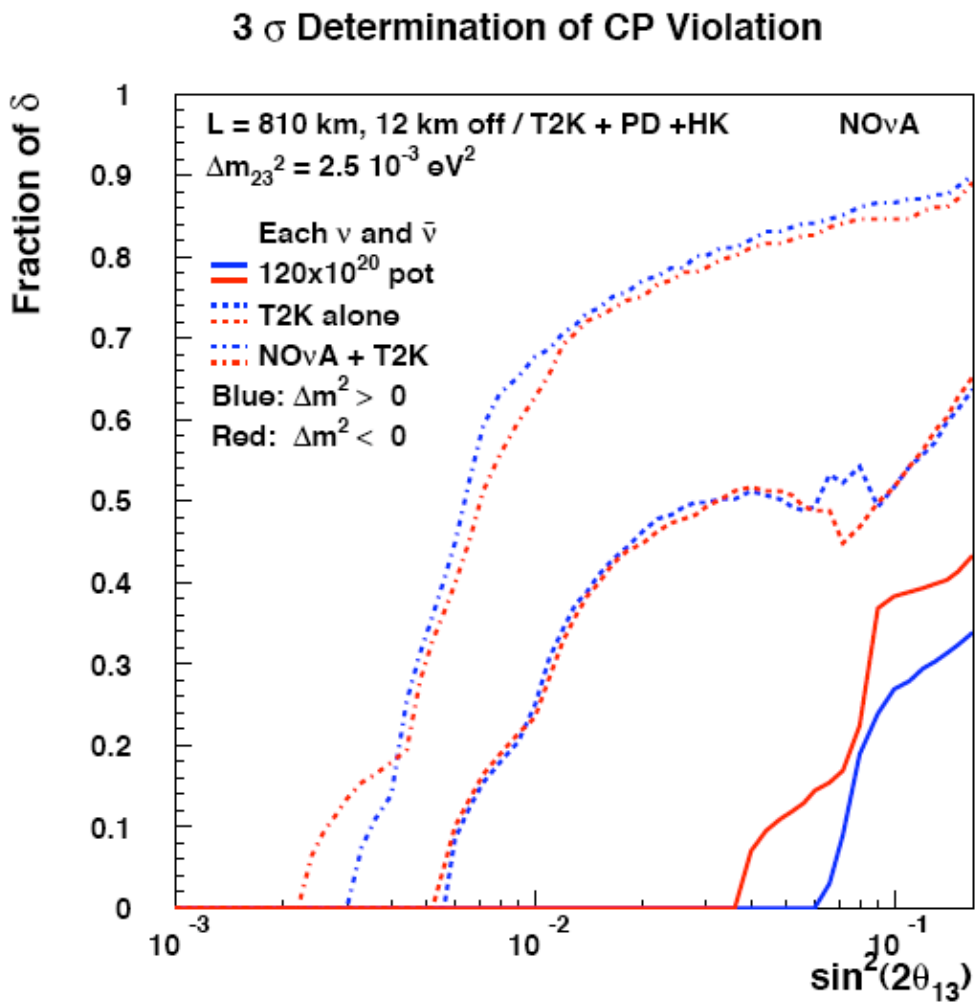

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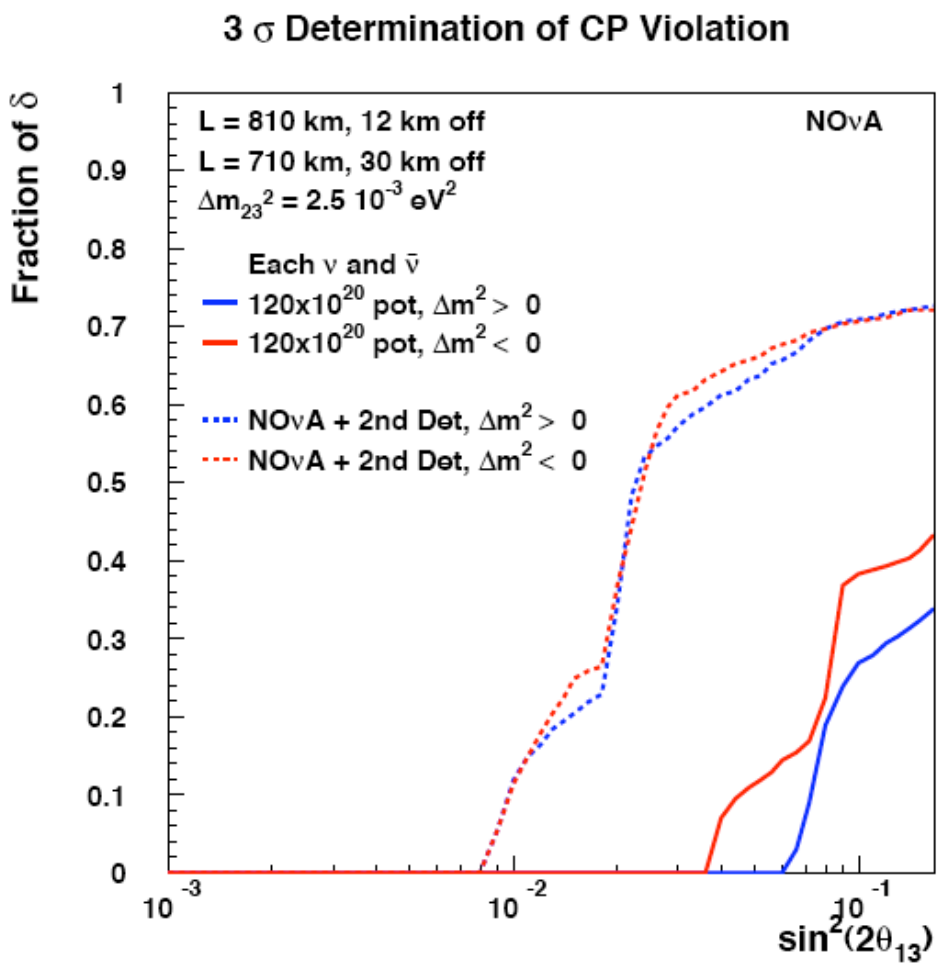
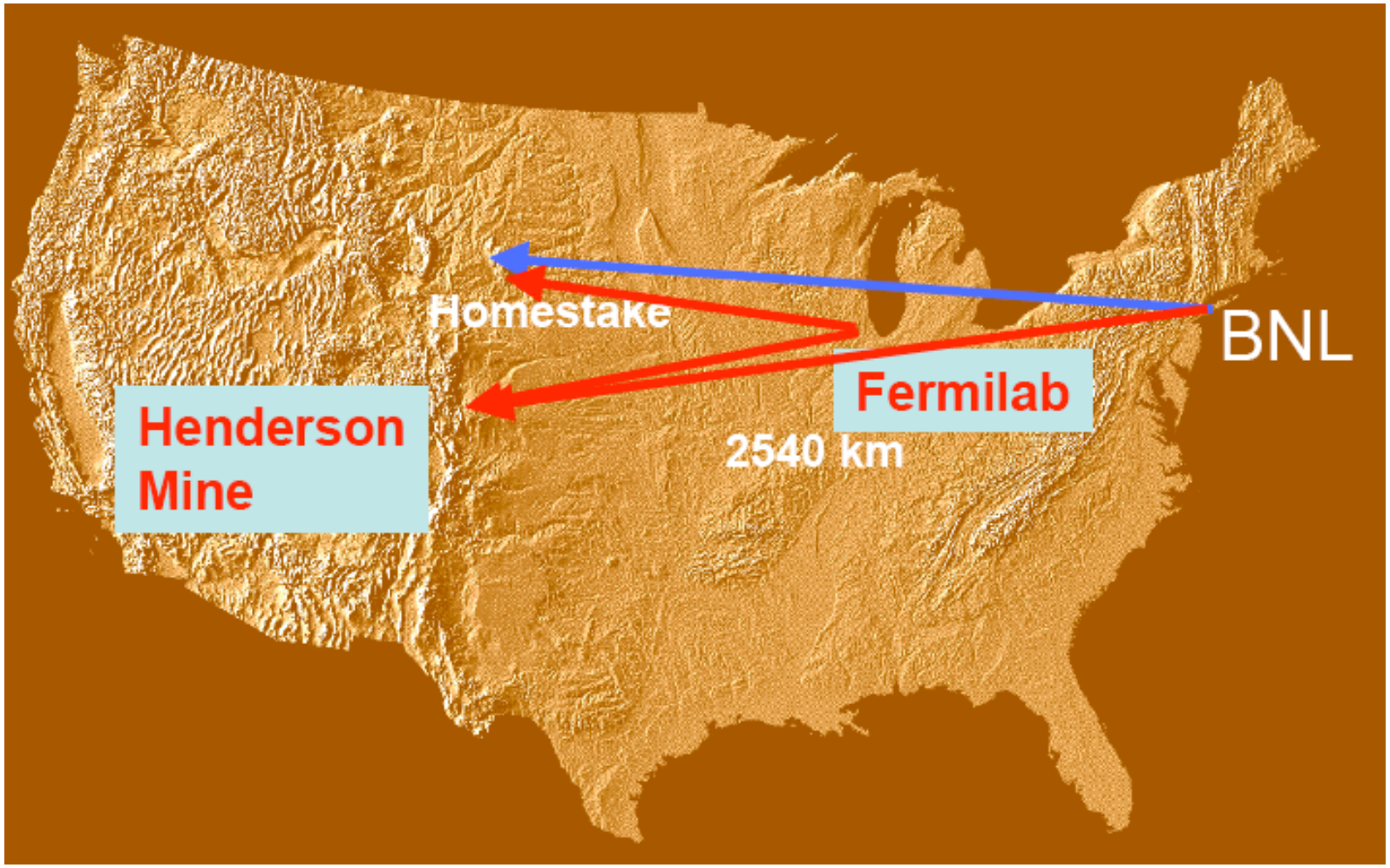


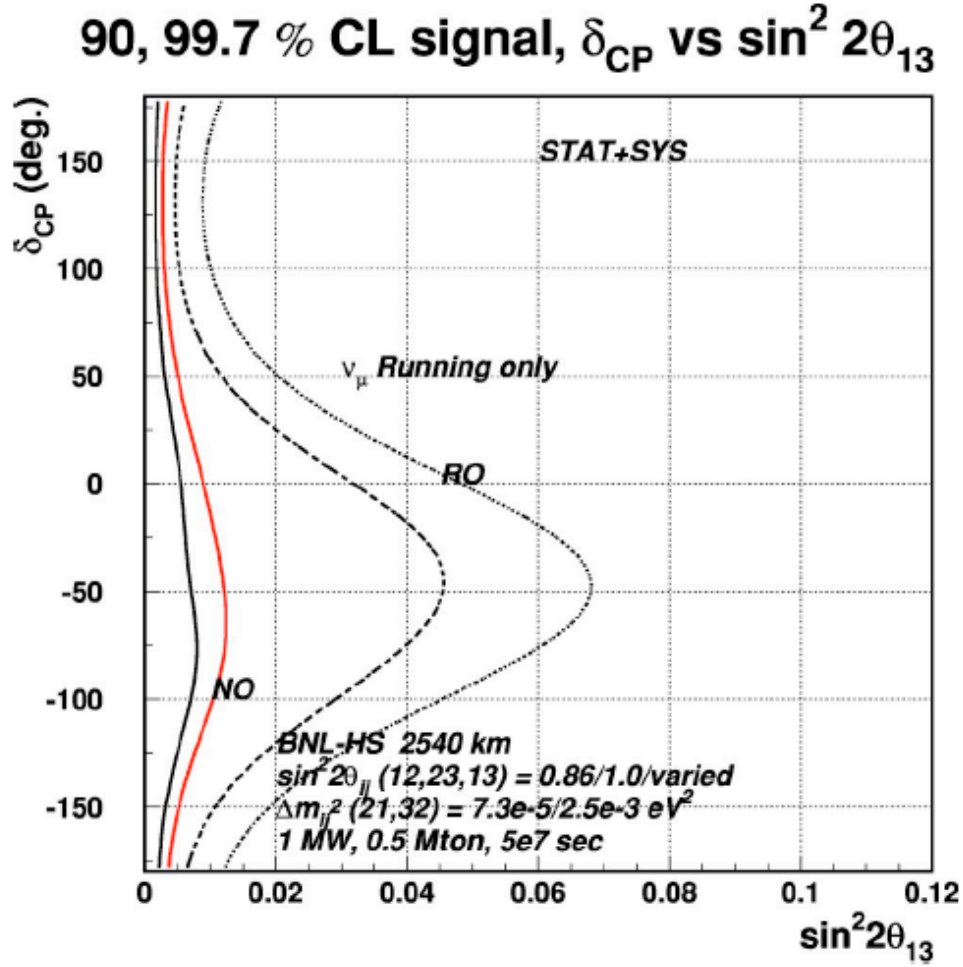
Other US Initiatives



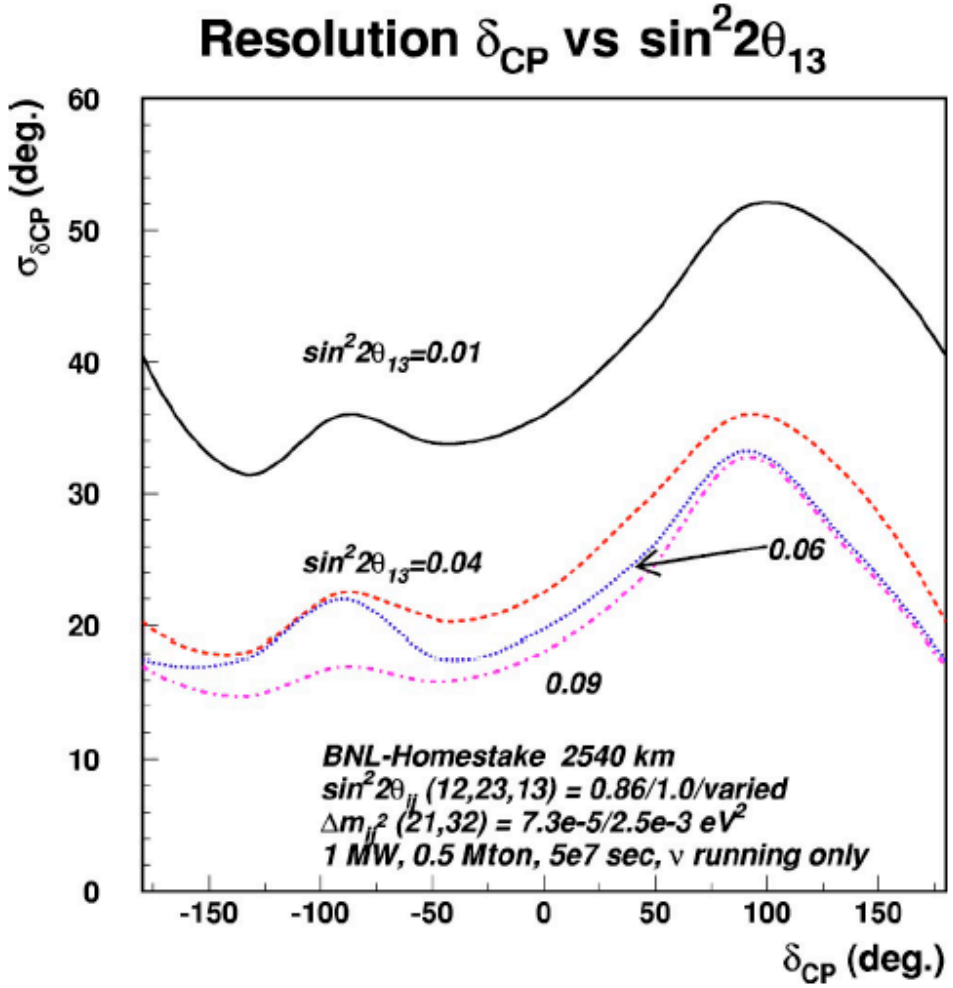
Brookhaven White Paper

- Brookhaven has proposed an intense proton source to an on-axis massive detector (500 kT) over a very long baseline (>2000 km).
  - Idea is to measure all three parameters simultaneously by measuring 3 oscillation maxima.
  - Water Cerenkov does not provide good electron/π^0 separation above 1 GeV – a factor of 5 better rejection than SuperK is needed. (Liquid argon or TASD?)
  - Range appears to be comparable to the NOνA program, although not explicitly calculated in the same way.
  - Very expensive; could not be done anytime soon, if ever.

Brookhaven Sensitivity to $\nu_\mu \rightarrow \nu_e$ Signal



Brookhaven Sensitivity to CP Violation



Correspondence to my 3σ fraction of δ plot:

← **0**

← **0.25**

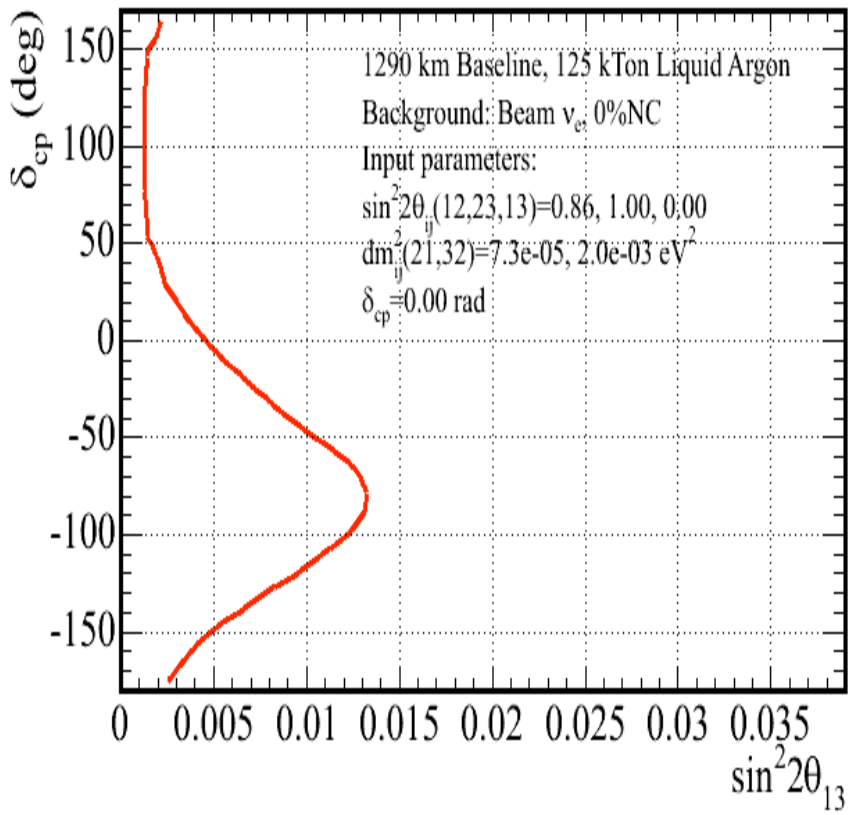
← **0.5**

Doug Michael's FeHo Proposal

- Use 4 MW of power from Fermilab, 2 MW from the Proton Driver as an 8 GeV on-axis beam and 2 MW from the Main Injector as a tunable off-axis beam.
- 16 times the flux of Brookhaven proposal (4 from beam x 4 from distance, 1290 km)
- 100-125 kT liquid argon or TASD (4-5 x NOνA)
- Sensitivities not well calculated yet.
- Same comment as Brookhaven on cost and schedule.

FeHo Sensitivity to $\nu_\mu \rightarrow \nu_e$ Signal

90% CL for Excluding Oscillation Parameters



Note: only 90% CL and only for the normal mass ordering

Only QE events
No NC background
(but all intrinsic ν_e included)

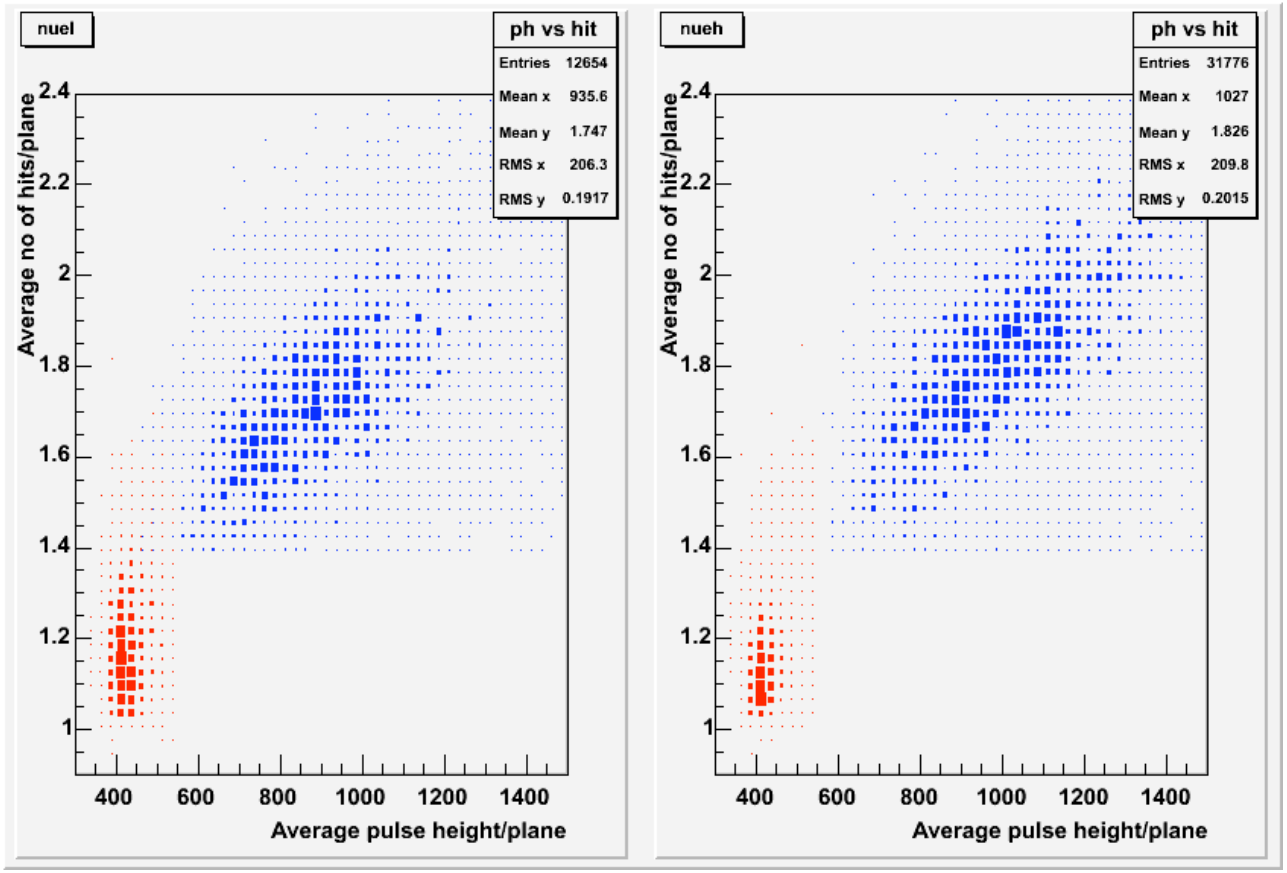
My Conclusion

- **NOνA provides a flexible approach to studying all of the parameters of neutrino oscillations**
  - **A long baseline approach is crucial in the context of the world program.**
  - **NOνA is the first stage of a flexible program where each stage can be planned according to what has been learned in previous stages.**
  - **The range of the NOνA program is comparable to that of other conventional approaches.**
  - **NOνA can be started now (same scale as NuMI/MINOS).**

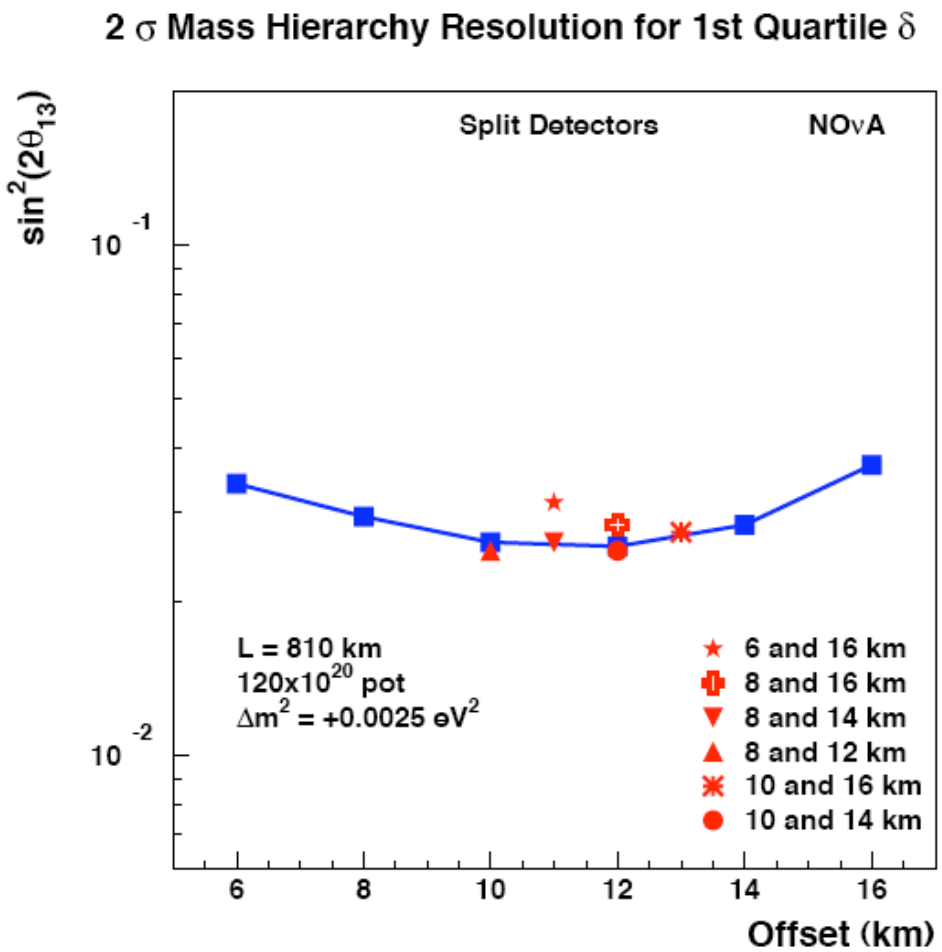
Backup Slides

Quick TASD Update

- **Excellent *e*/μ discrimination**

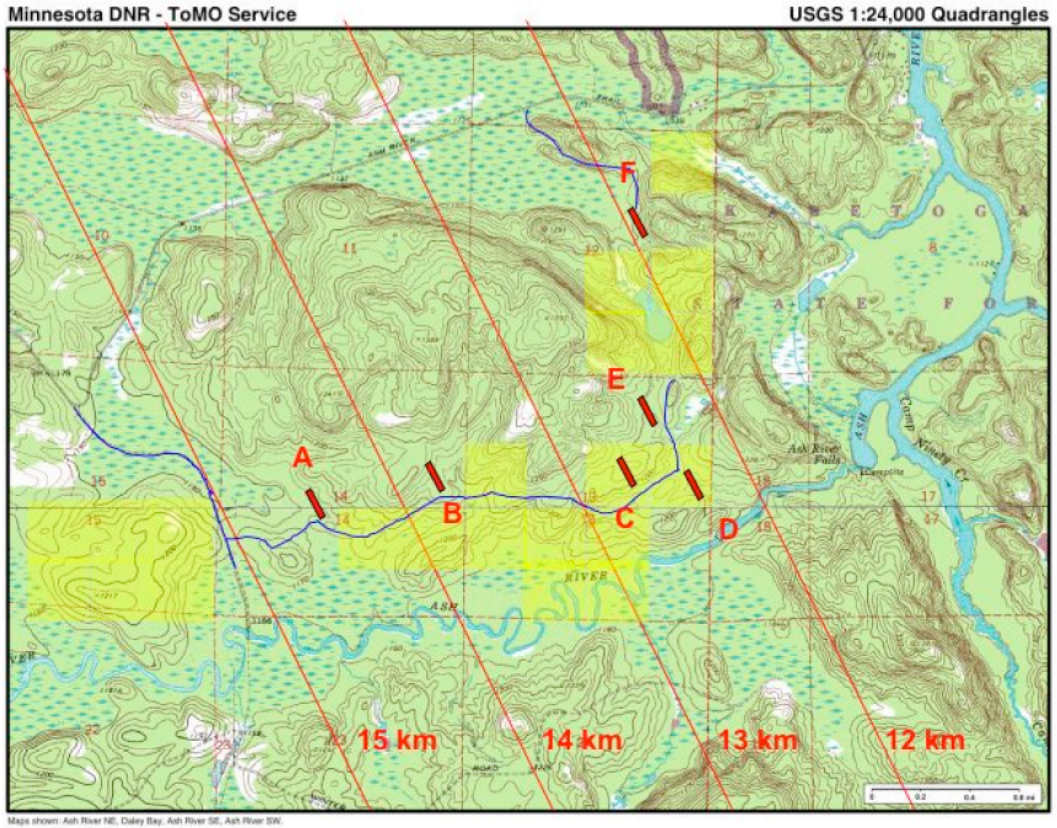


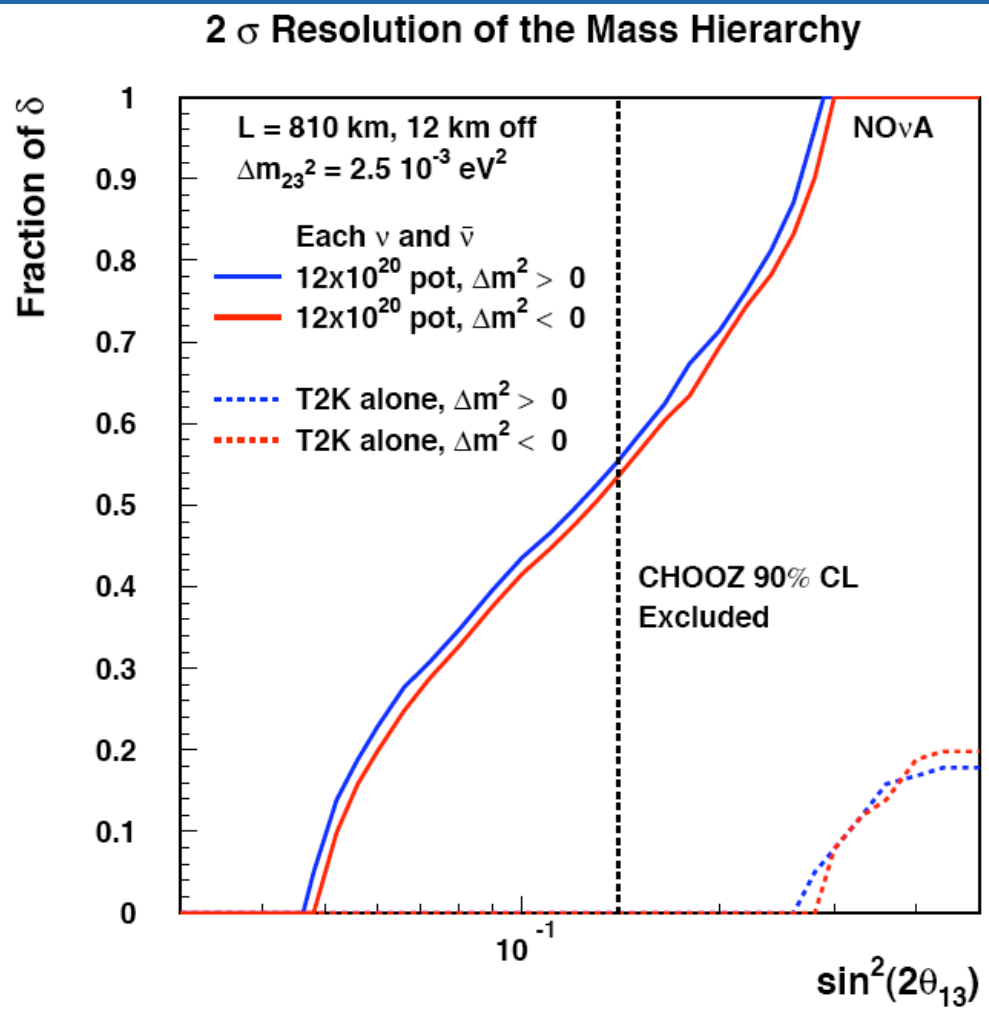
PAC Question: Are two (1/2) Detectors Better than One?



Answer: Yes, but not by enough to overcome the fiducial and infra-structure costs.

Locations at Ash River



At Ash River, we Are limited to Distances > 11 km Because "a river Runs through it."

Mass Hierarchy Resolution Comparison of NOνA and T2K