$\Delta m^2_{23}(\Delta m^2_{13})$ and θ_{23} Current Status, Future Prospects

Stanley Wojcicki

SLAC Neutrino Workshop 2013
Part of Snowmass 2013 Process
March 6, 2013

Why Precision (High Intensity) Measurements?

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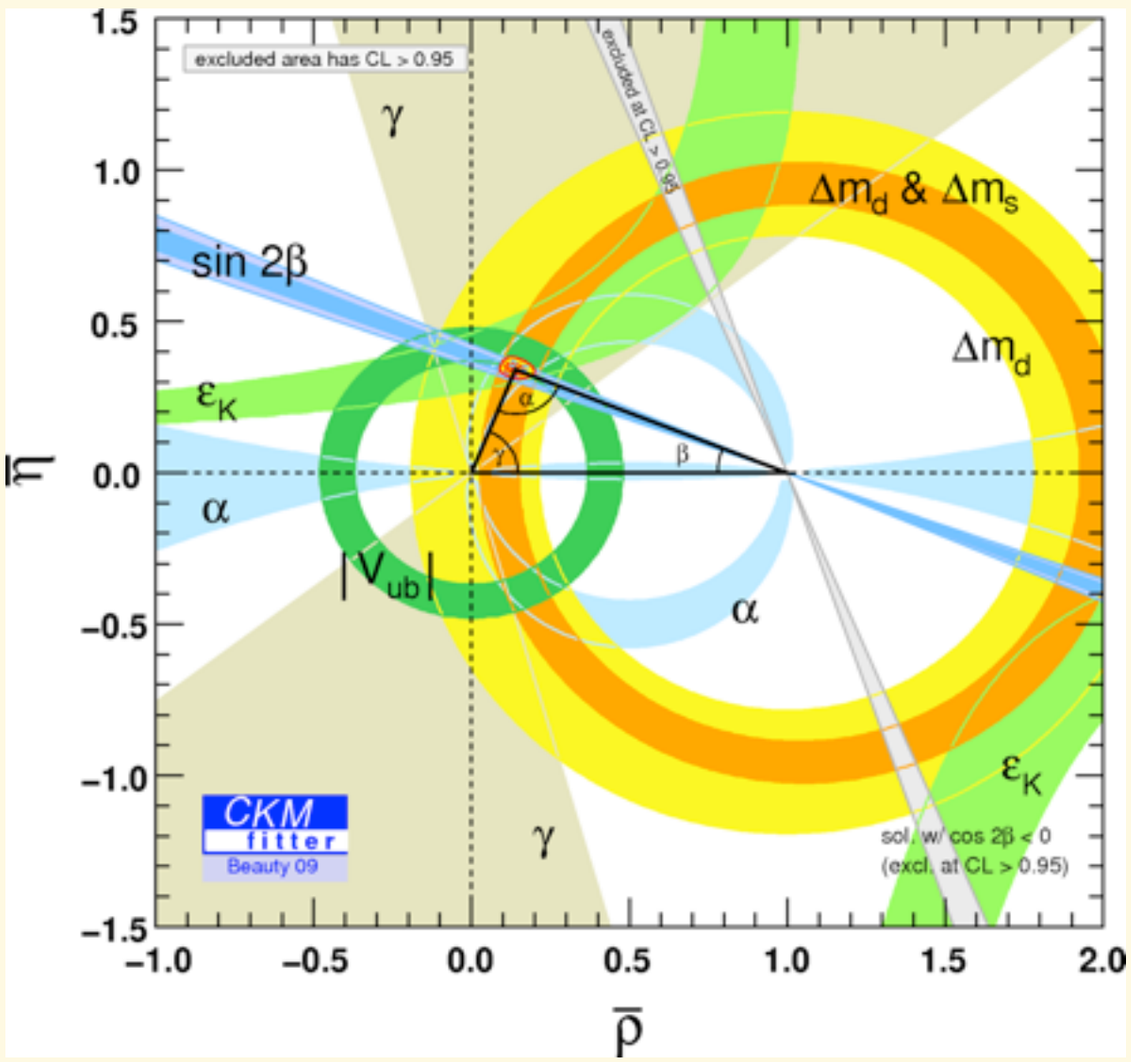

Quark Sector

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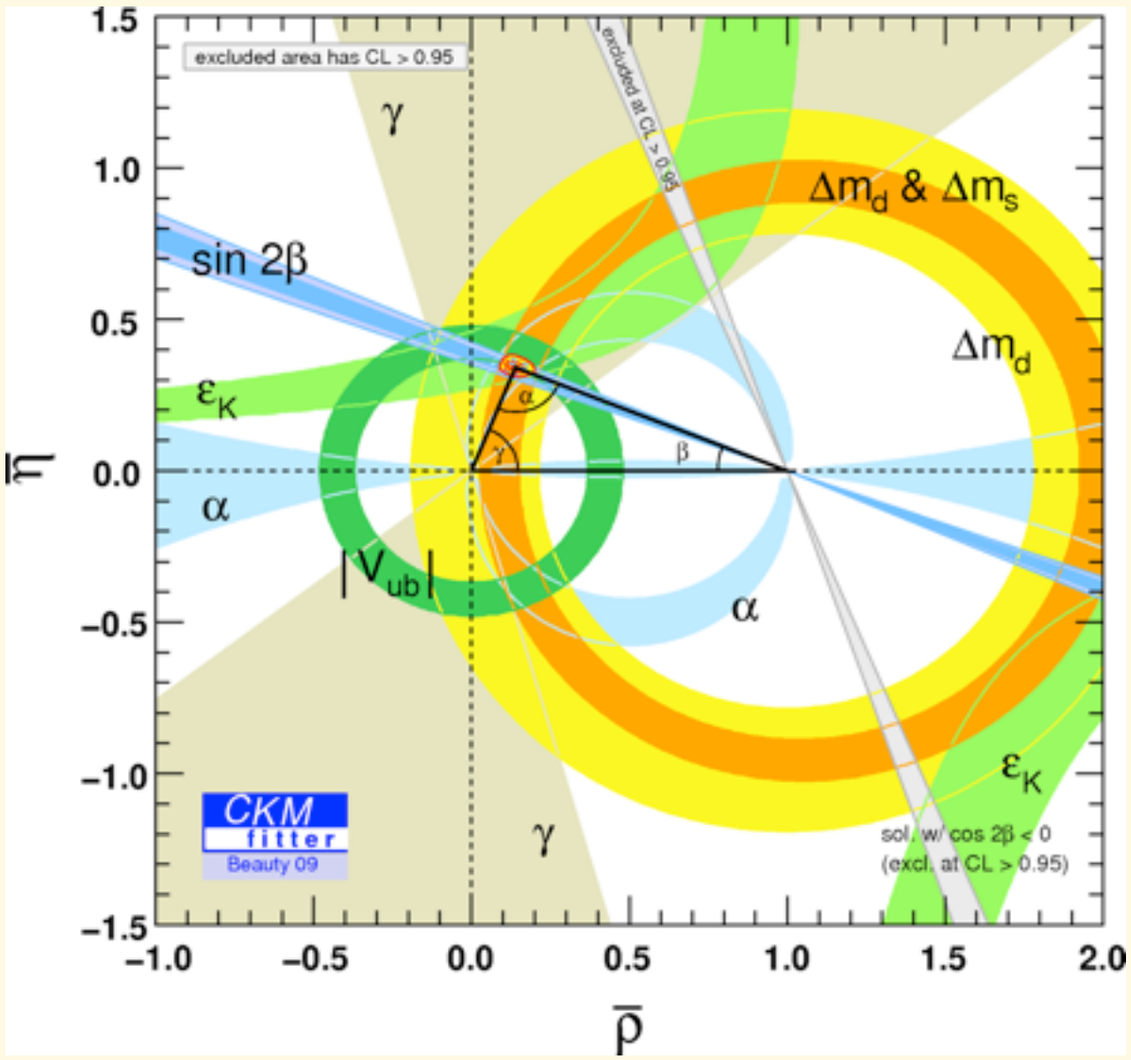

Quark Sector

Some parameters (eg δ) still unknown. Need high fluxes.

By comparison with the quark sector, the lepton sector is very much unconstrained

Disagreements between multiple measurements of the same parameter can indicate possible new physics

Outline

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"people often overestimate what will happen in the next two years and underestimate what will happen in ten" - Bill Gates

Relevant White Papers

- J. Thomas et al., "CHerenkov detectors In mine PitS (CHIPS): A White Paper"

- M. Messier for the NOvA collaboration, "Extending the NOvA Physics Program"

→ - R. Plunkett, J. Thomas, "MINOS+: Using the NuMI Beam as a Precision Tool for Neutrino Physics"

- P. Adamson et al., "A Case for the Further Exploitation of NuMI"

→ - K. Heeger for the Daya Bay collaboration, "The Daya Bay Measurement of Delta_m^2_ee"

- T. Nakaya for the Hyper-K collaboration, "Hyper-Kamiokande Physics Opportunities: Exploring Neutrino Properties with Atmospheric Neutrinos

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- But generally most of the information is contained in one kind of measurements
- Looking at those measurements, even in 2v approximation, can tell us about systematic limits

Δm^2_{ee} and $\Delta m^2_{\mu\mu}$

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- Have different dependence on Δm^2_{31} and Δm^2_{32}
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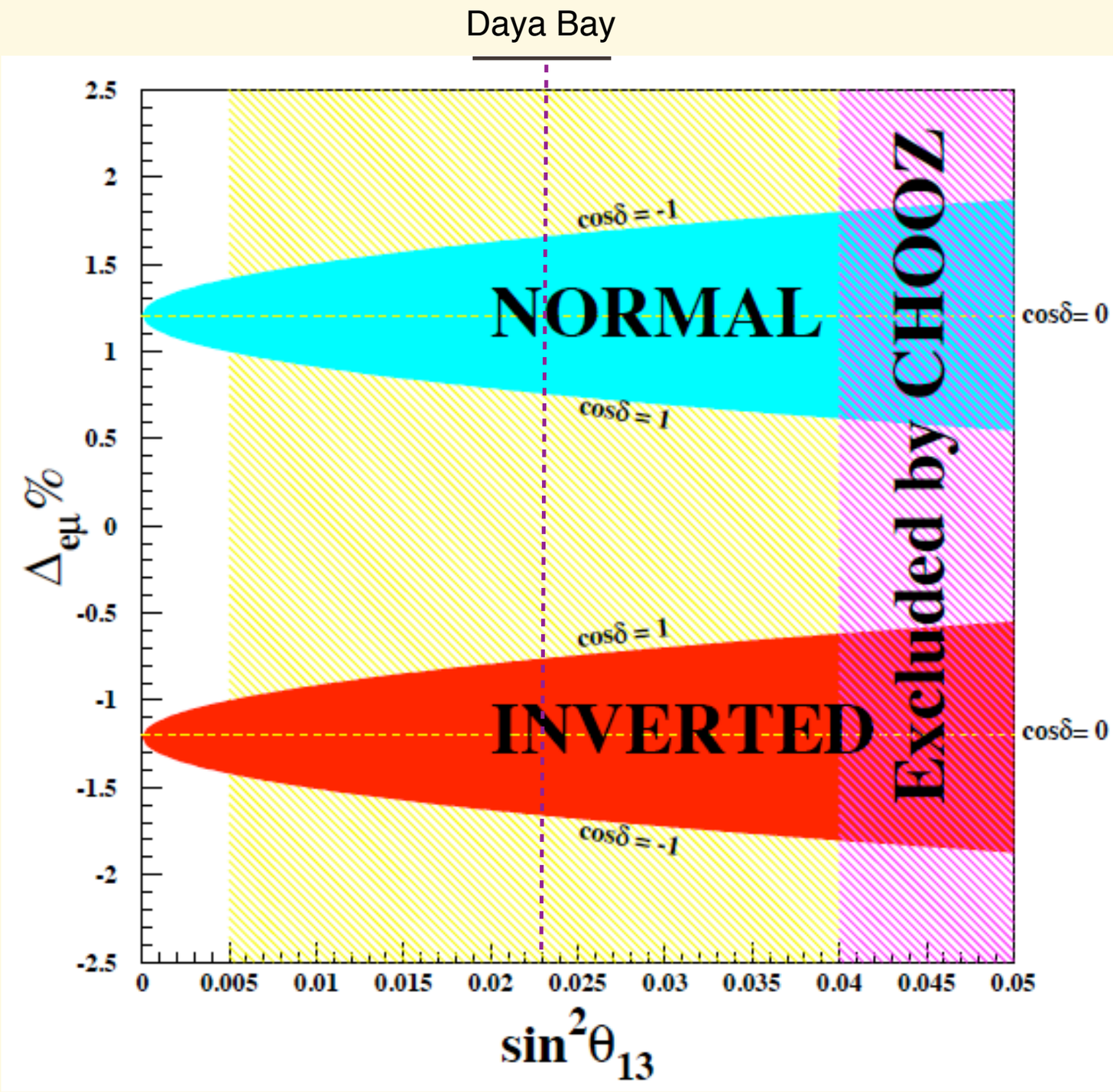

H.Nunokawa, S.Parke and R.Zukanovich-Zunchal
Phys.Rev.D72:013009,2005

Reactor Spectra -> Δm^2_{ee}

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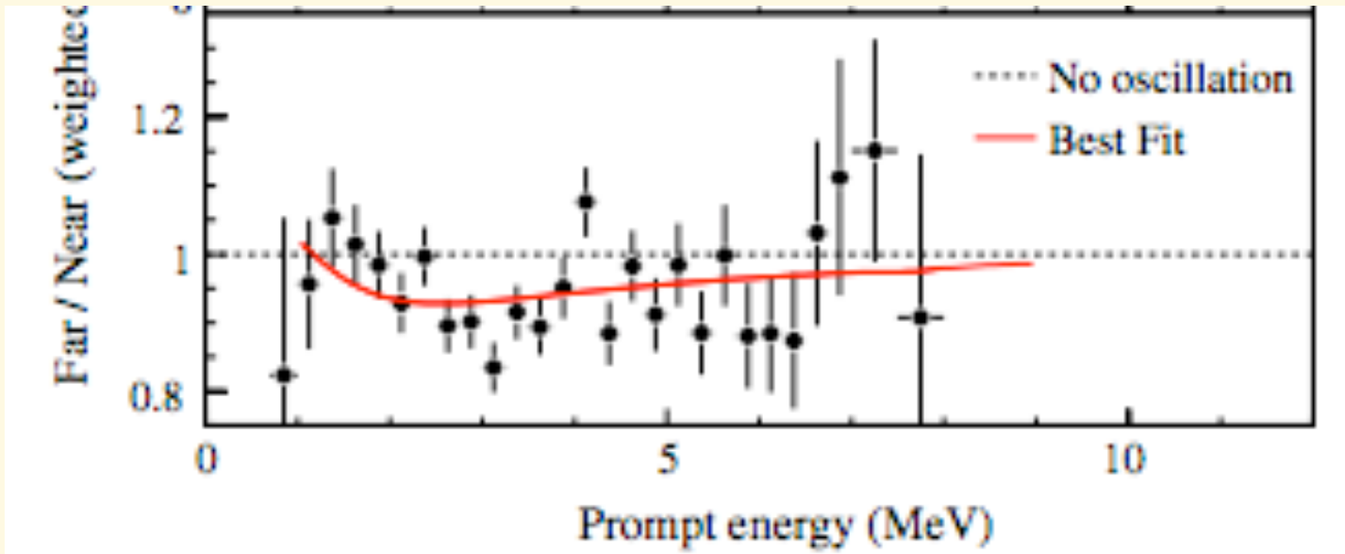
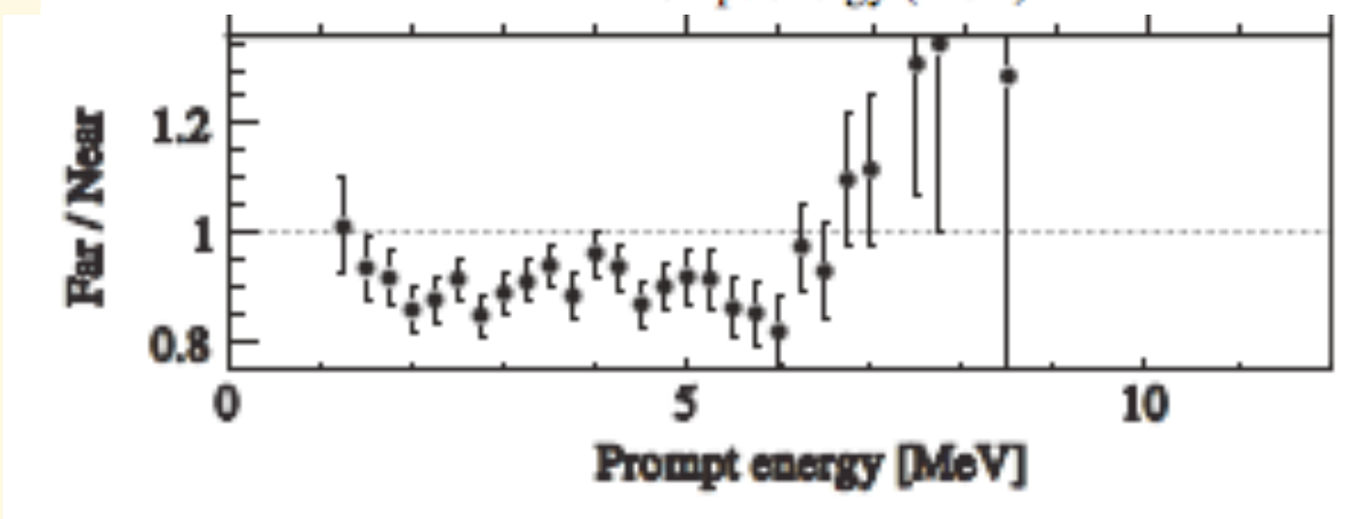
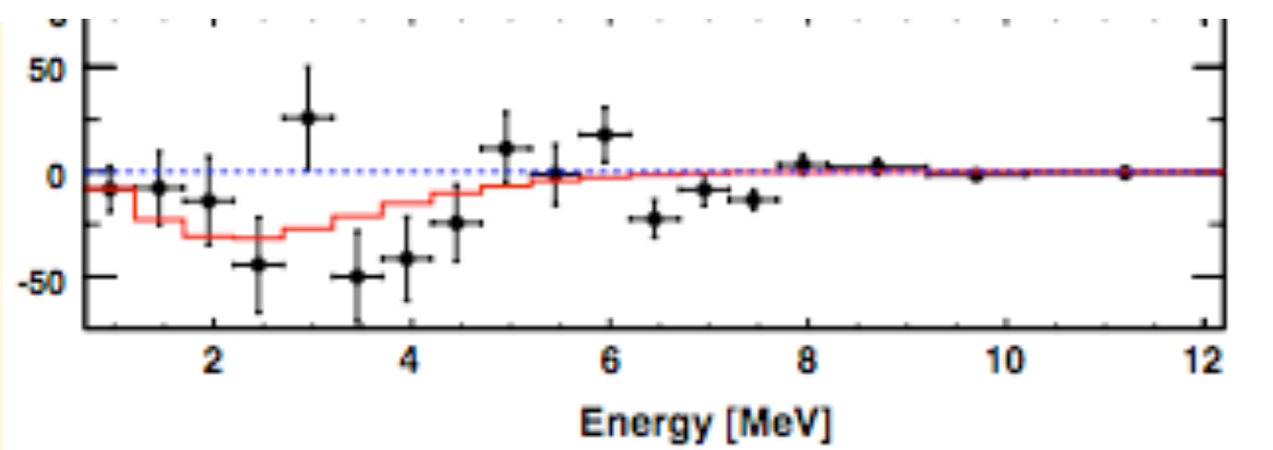


Daya Bay



RENO



Double CHOOZ
23.7/17

Daya Bay Projection

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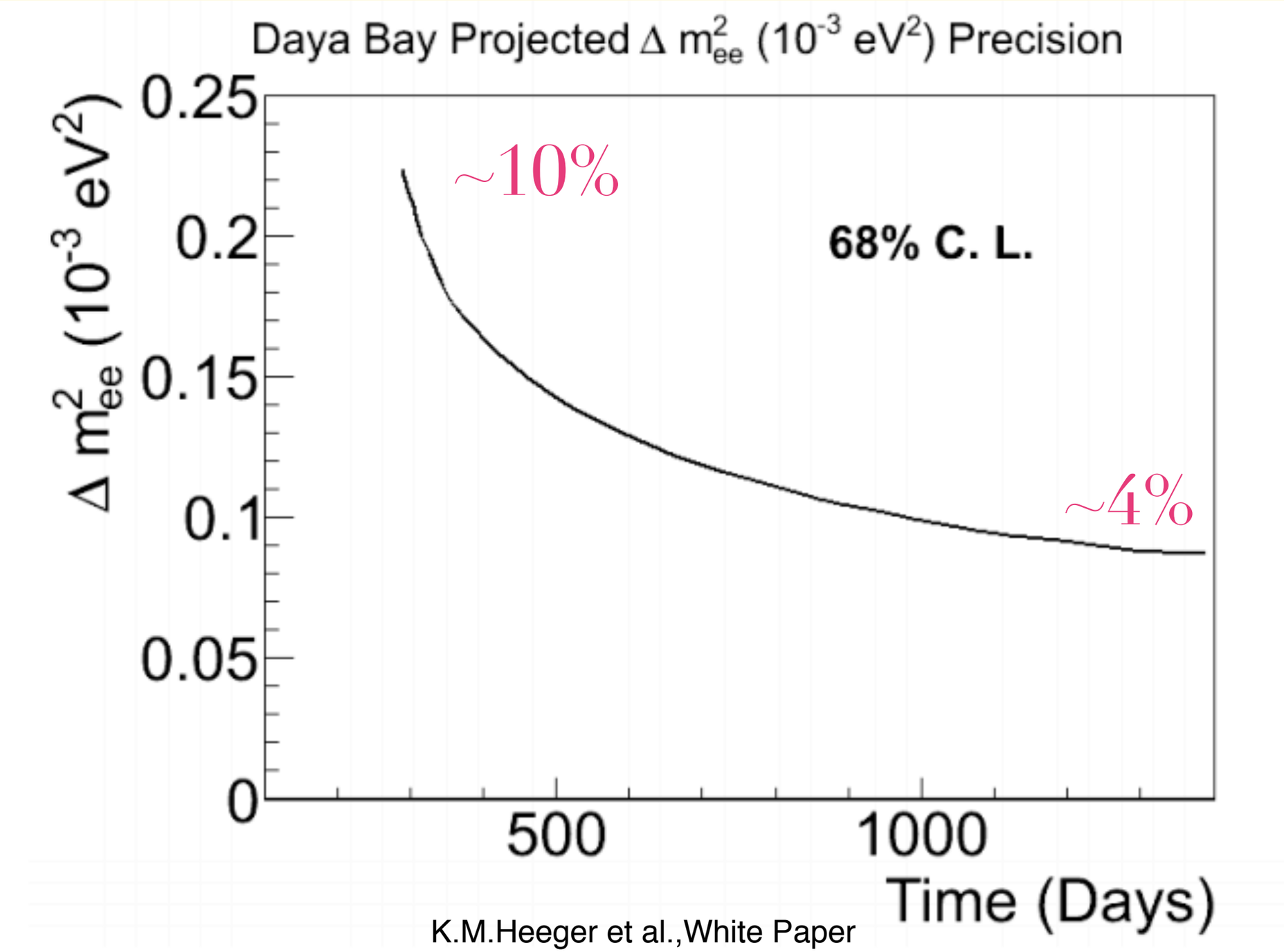

K.M.Heeger et al.,White Paper

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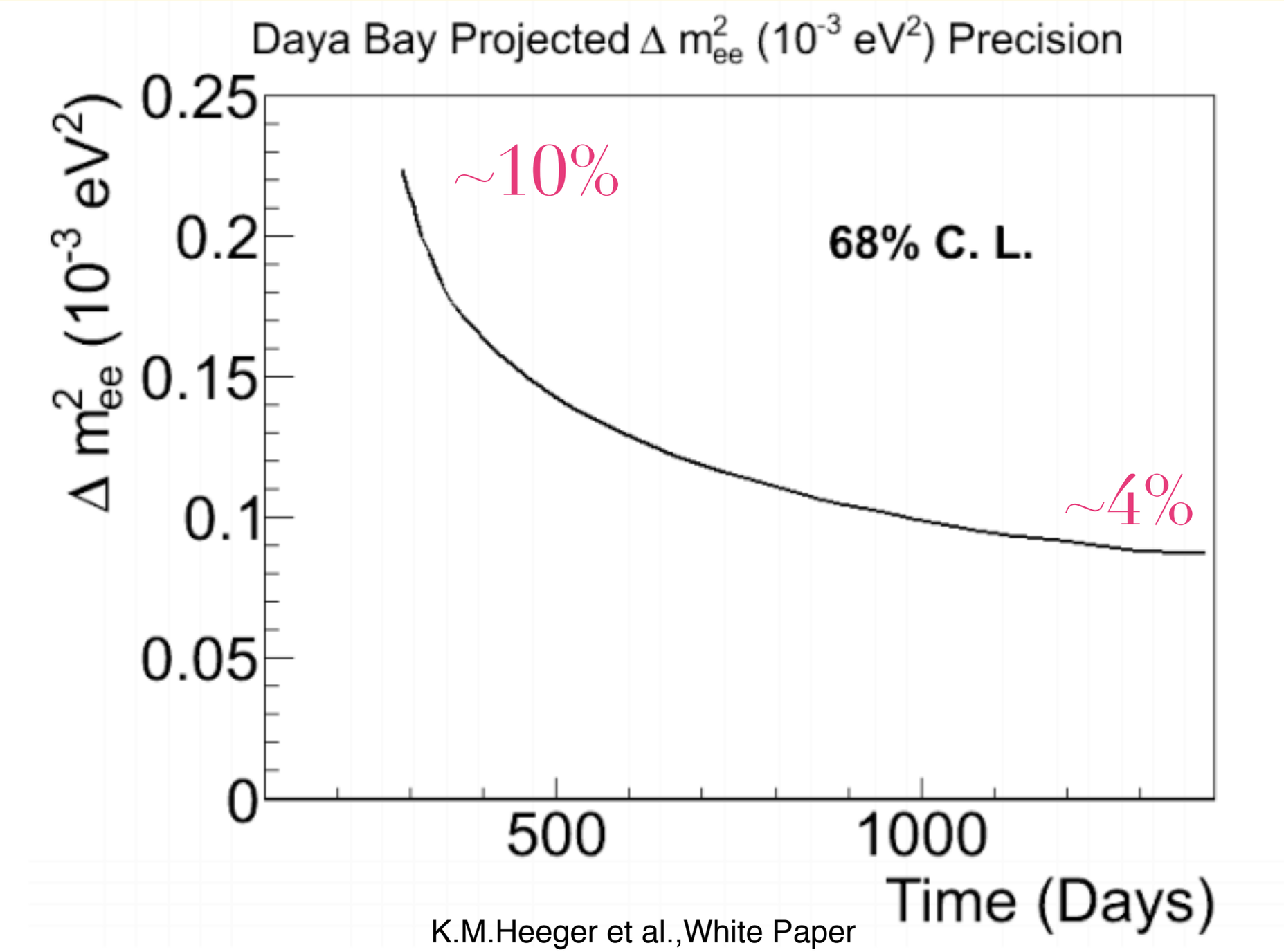

Daya Bay II projects +-0.6% measurement of Δm^2_{32}

Techniques for $\Delta m^2_{\mu\mu}$

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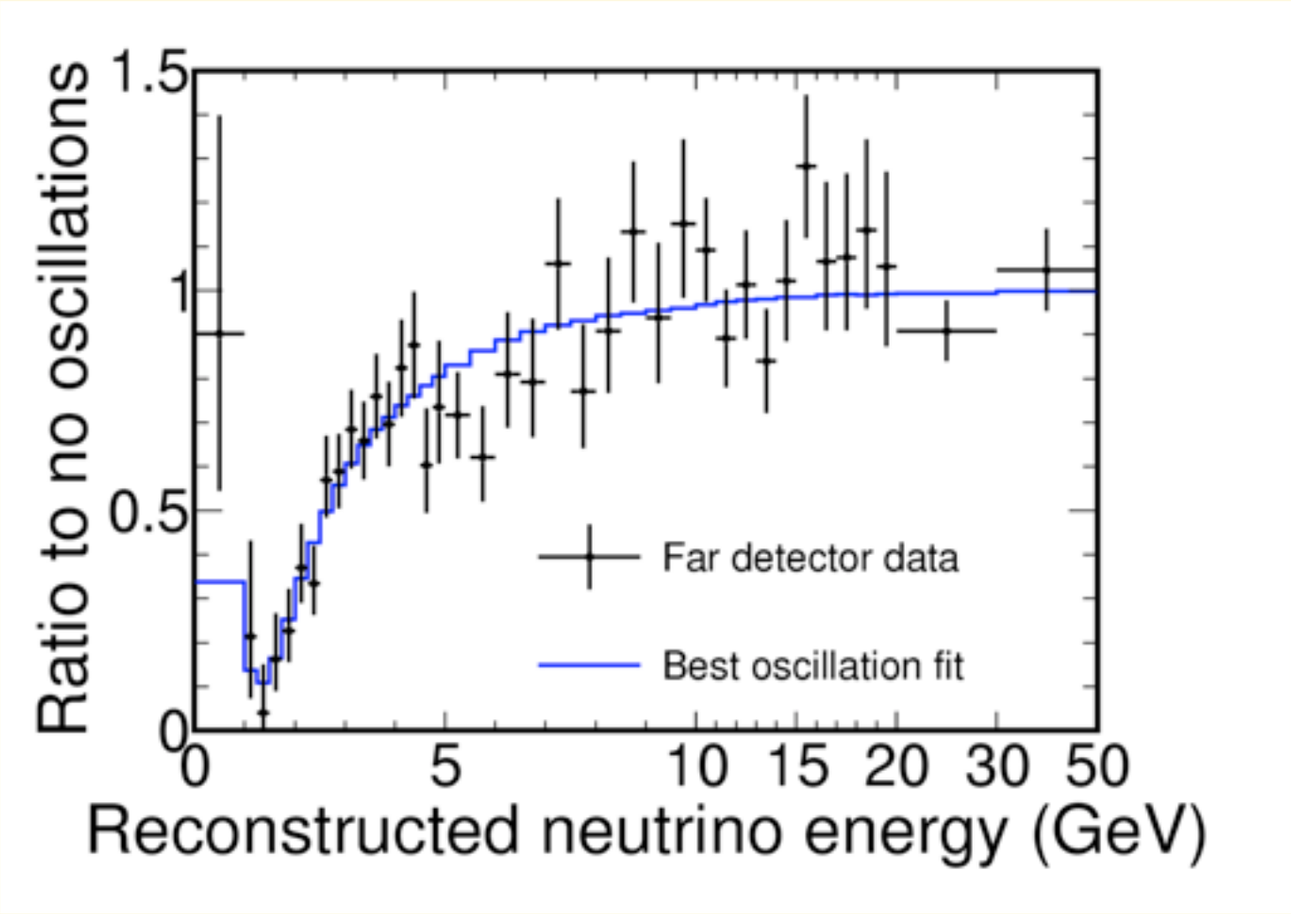

MINOS - energy

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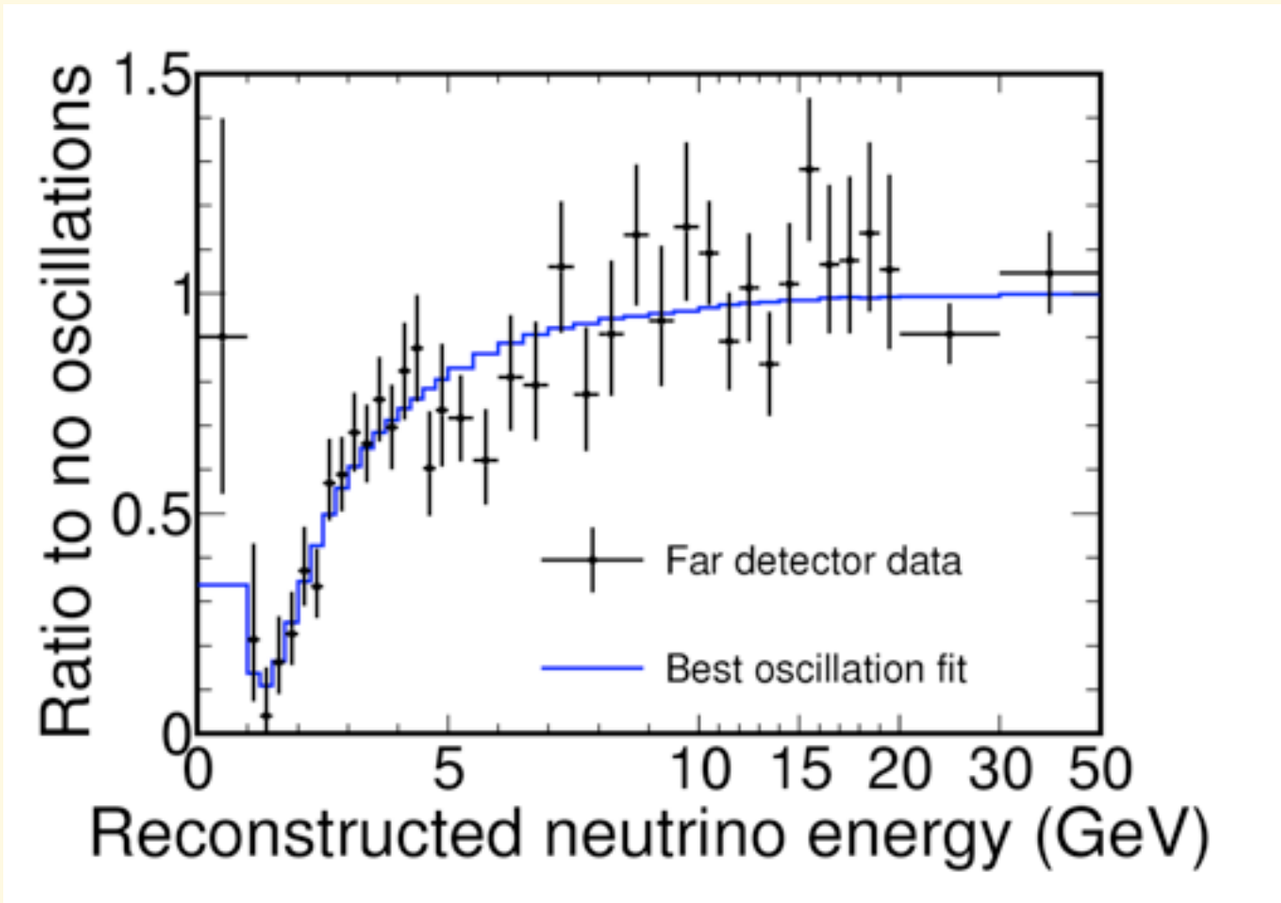

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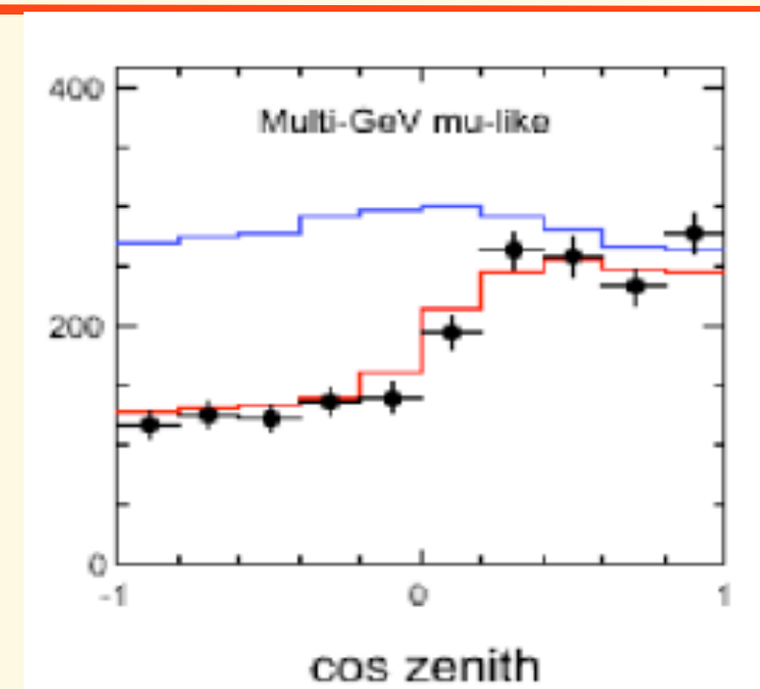

SuperK - zenith angle

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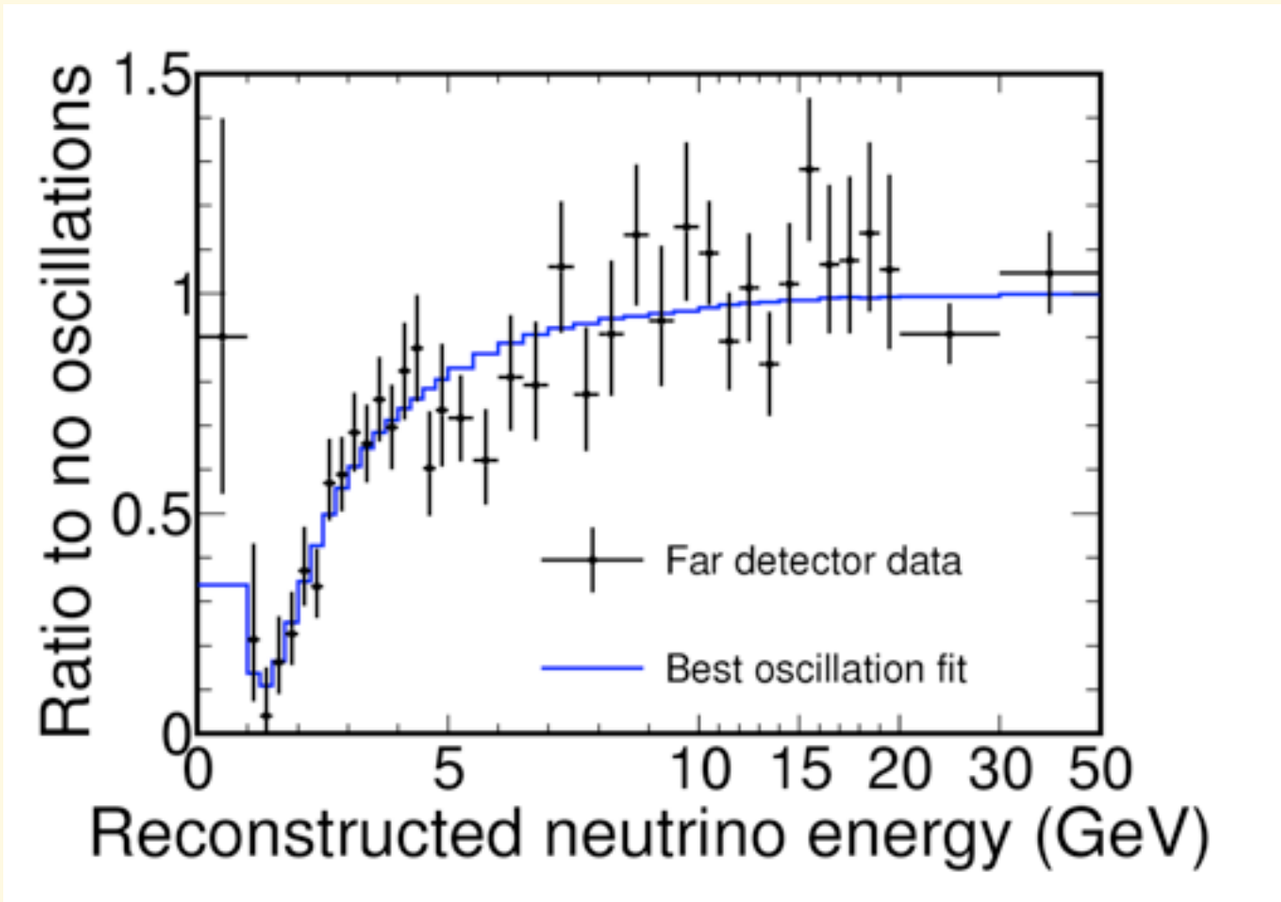

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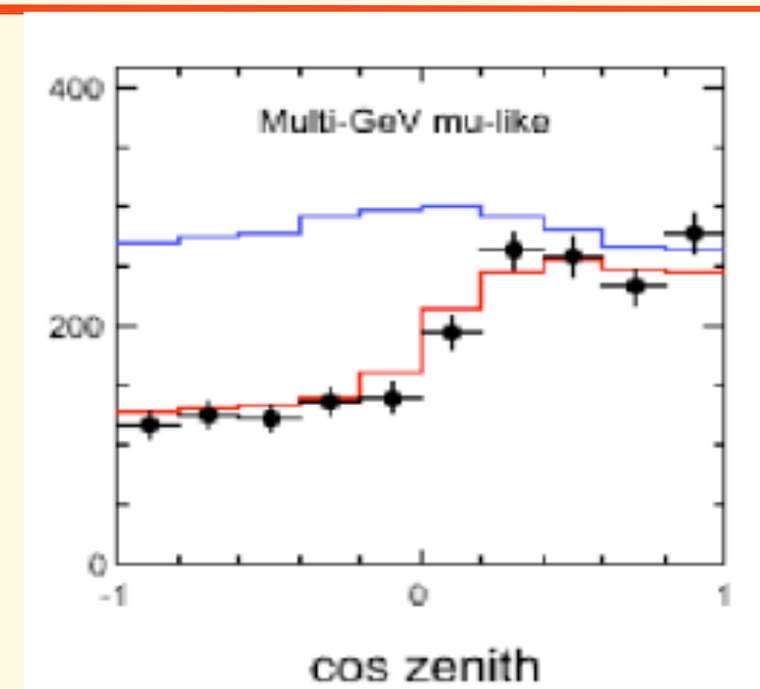

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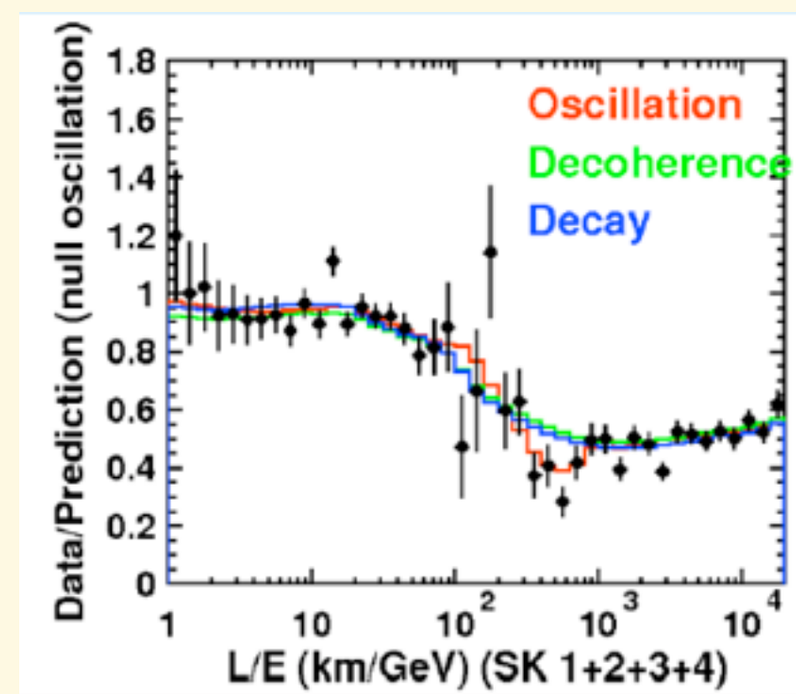

SuperK - L/E

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  - information from the dip in ν_μ disappearance
  - up/down ratio for $|\cos\theta_{zen}|$ ~1 in atmospherics
  - global 3-flavor fit
- If $\sin^2(2\theta_{23})$ NE 1, which octant is $\sin^2\theta_{23}$ in? What is the dominant component of ν_3?
  - global fit: $P_{\nu e} \sim \sin^2\theta_{13} \times \sin^2\theta_{23} + f(..MH,\delta,E)$

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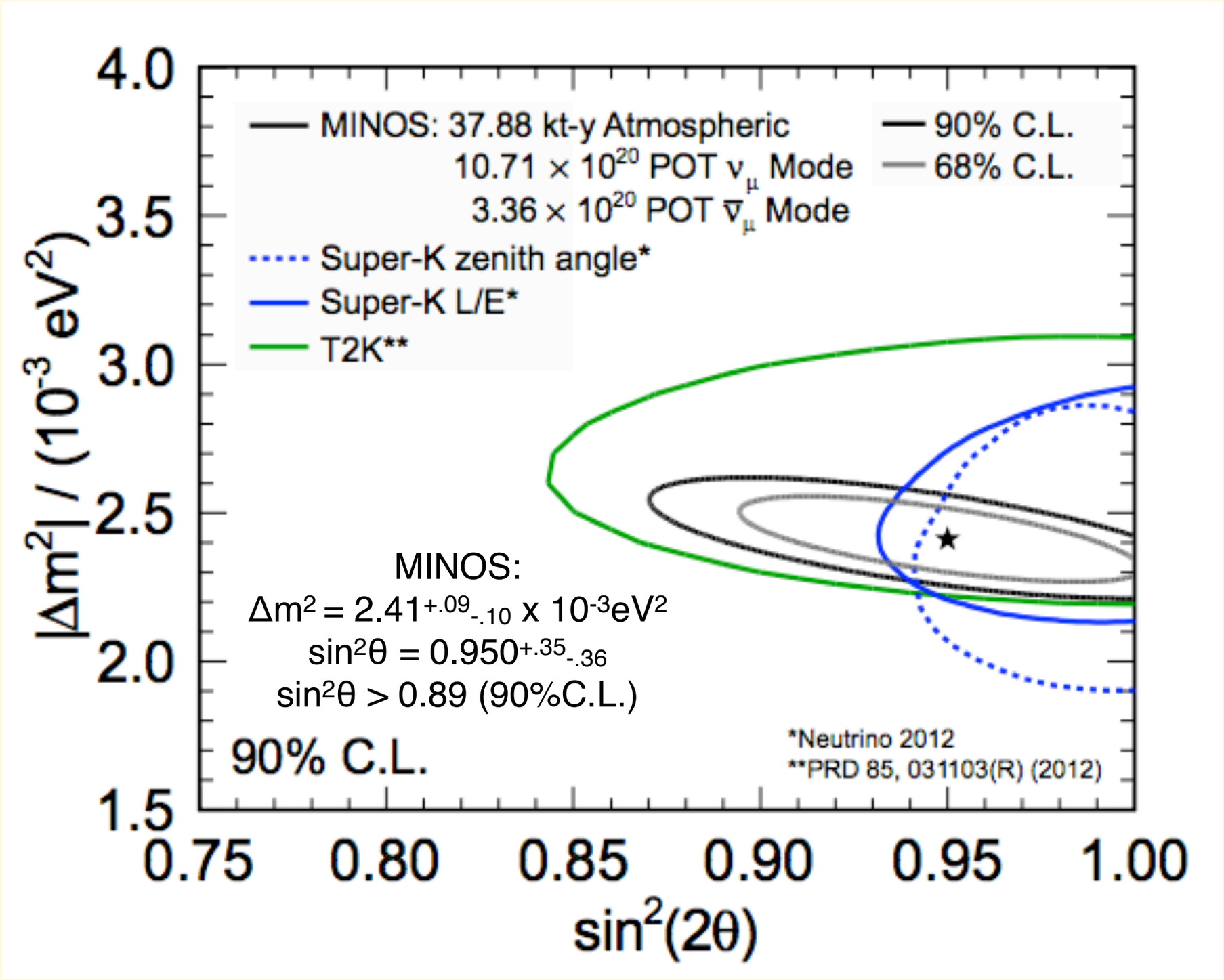

SuperK Atmospheric

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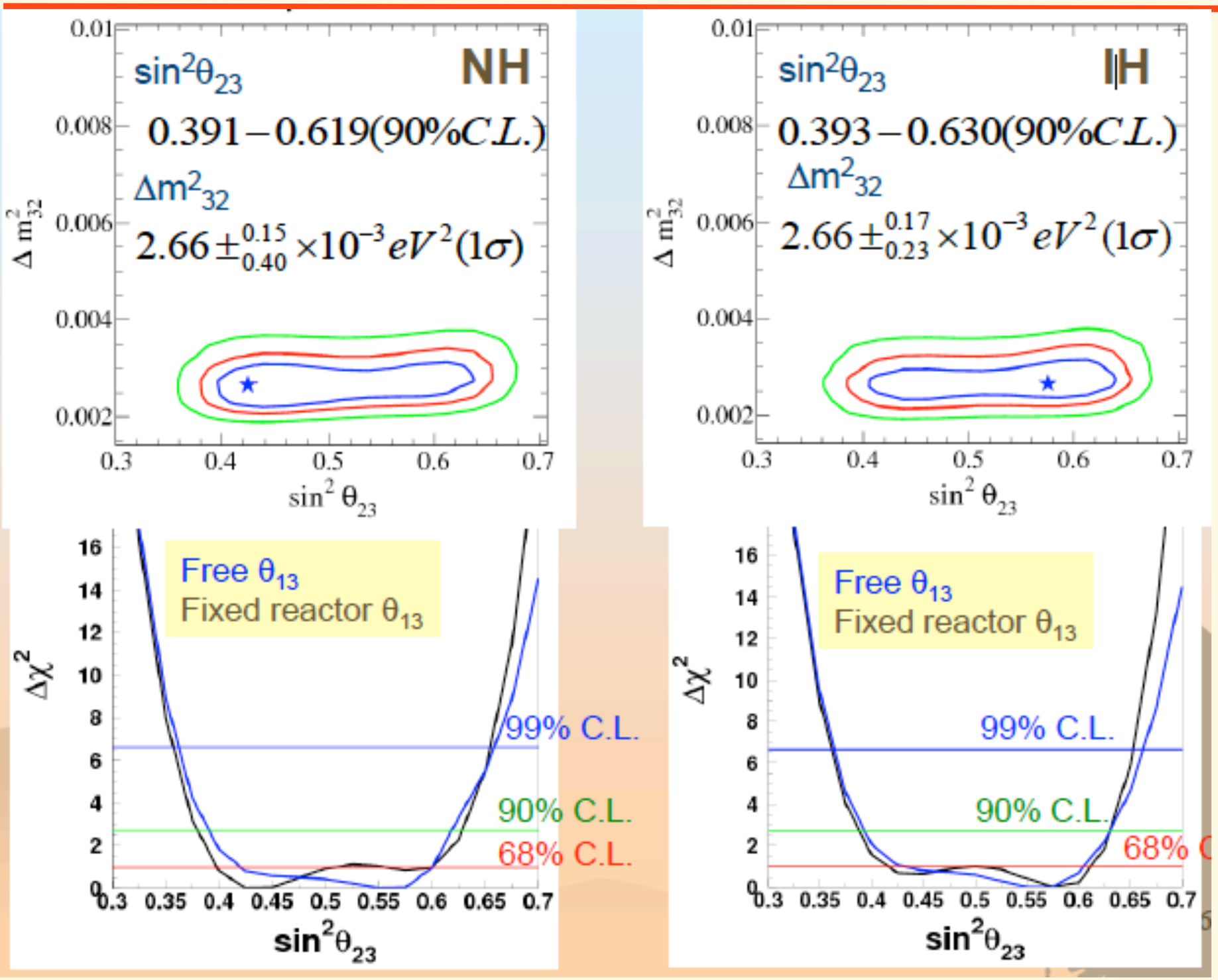

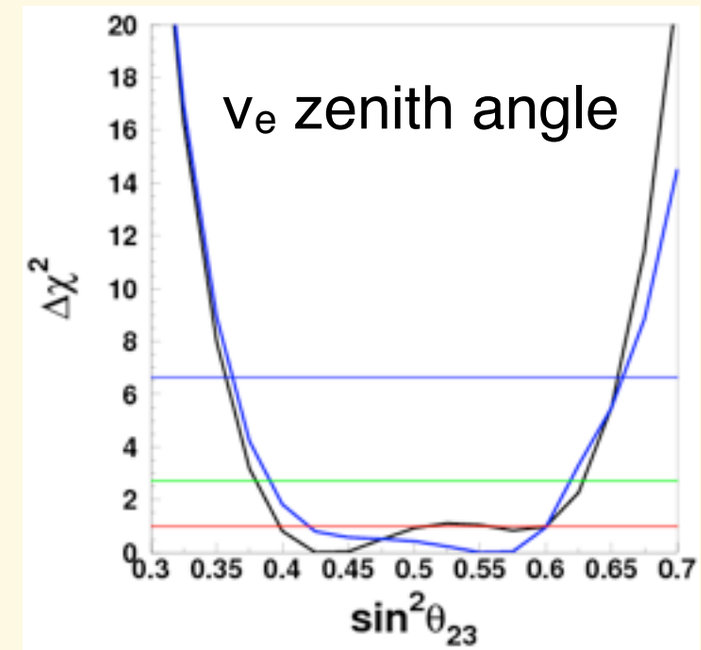

from Y.Itow, Nutrino2012

3-flavor analysis with reactor constraints

MINOS ν_e appearance

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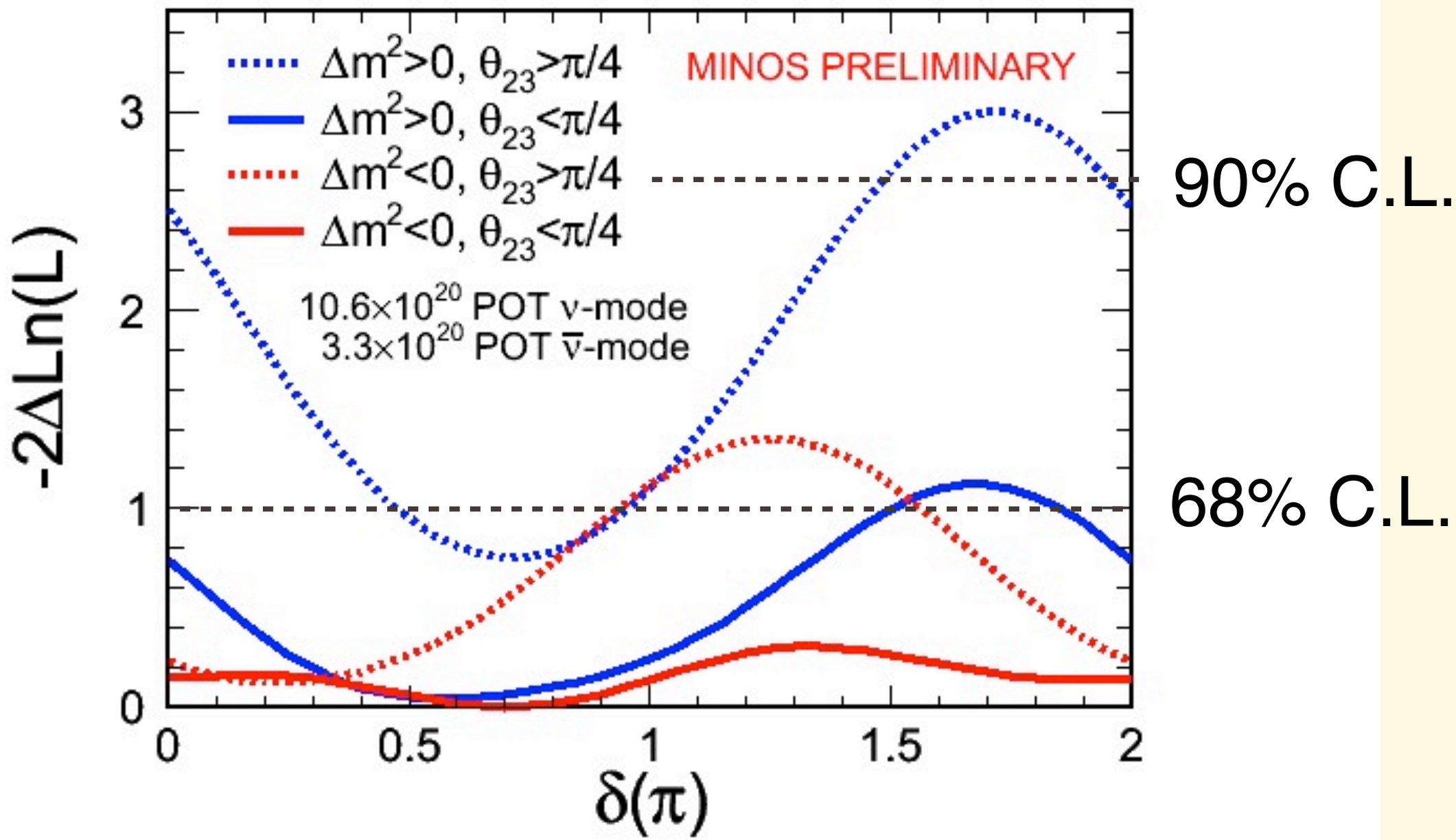

MINOS+ Sensitivities

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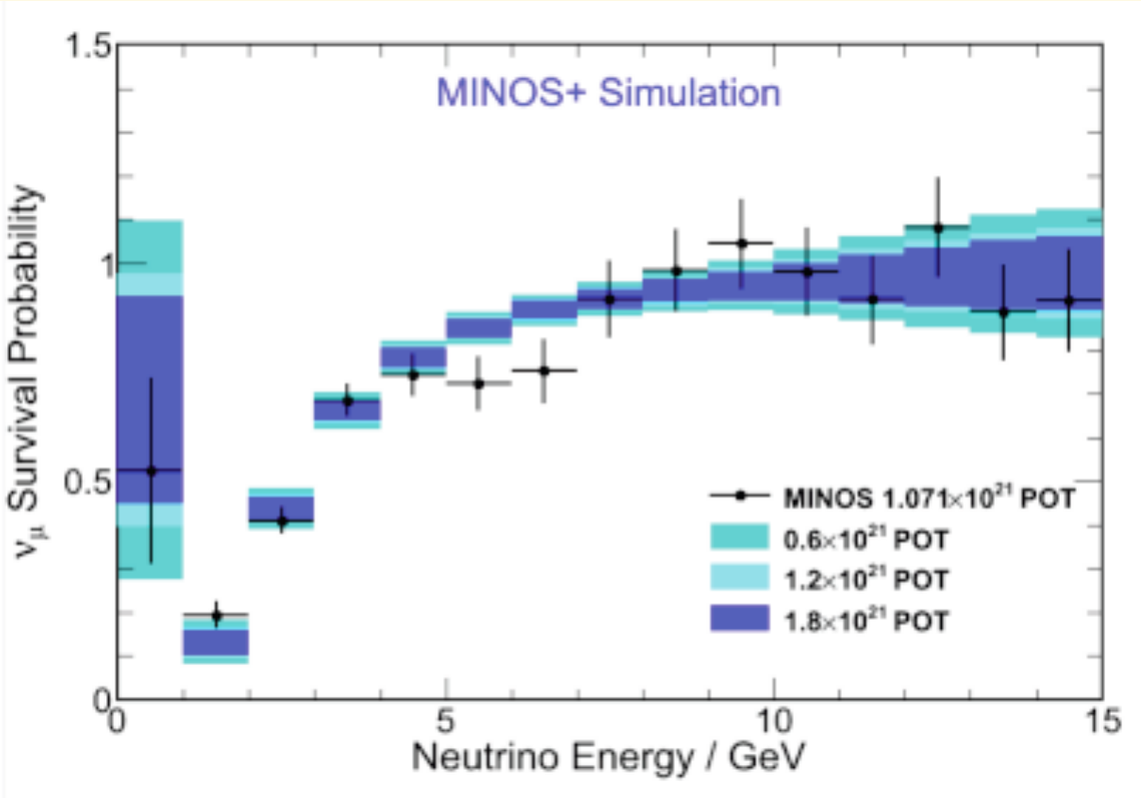

Improved Energy Spectra
Test current paradigm
Improves Δm^2 resolution

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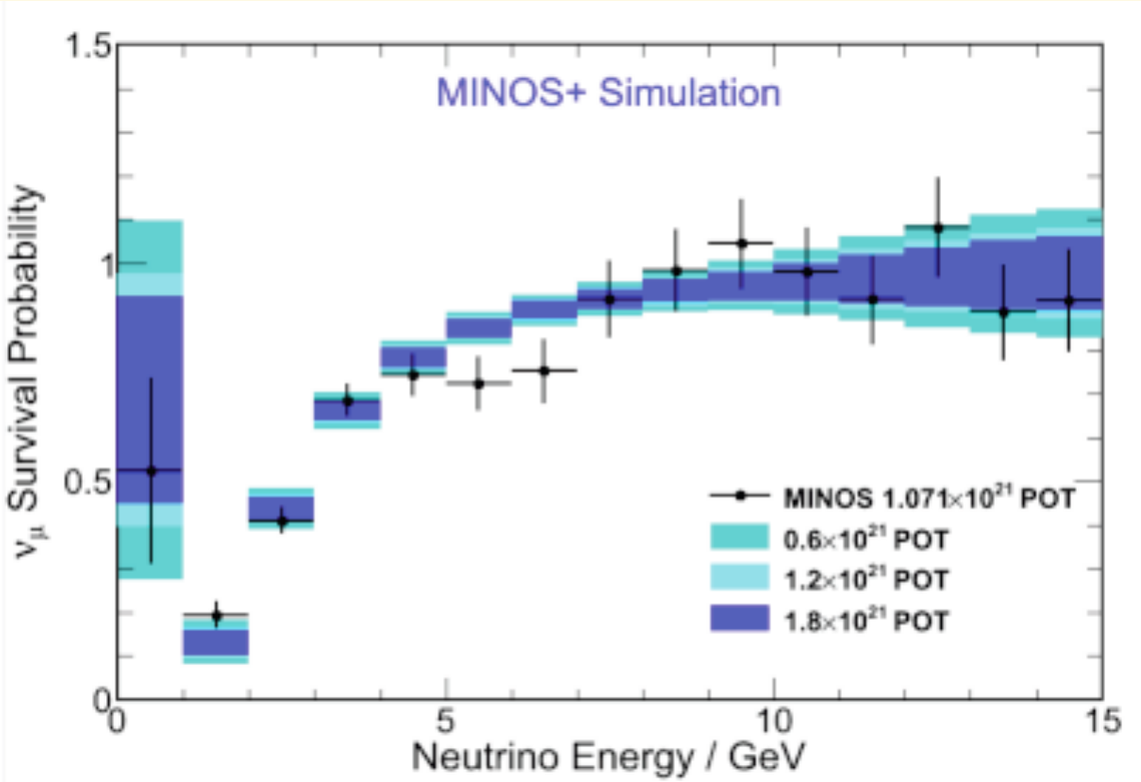

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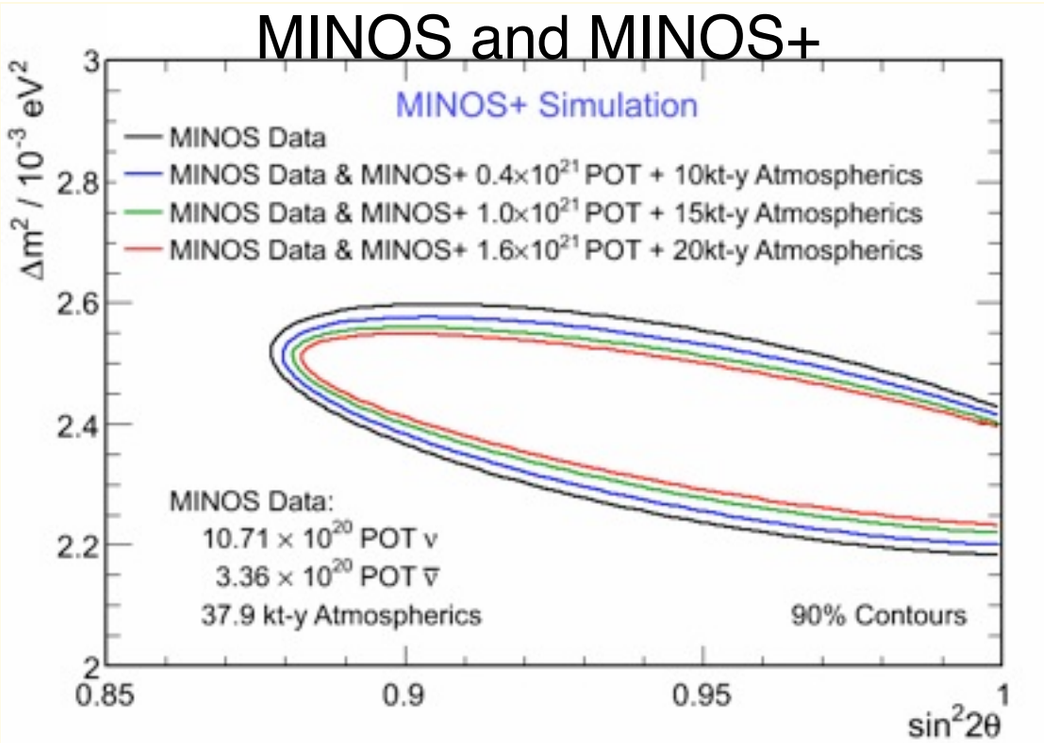

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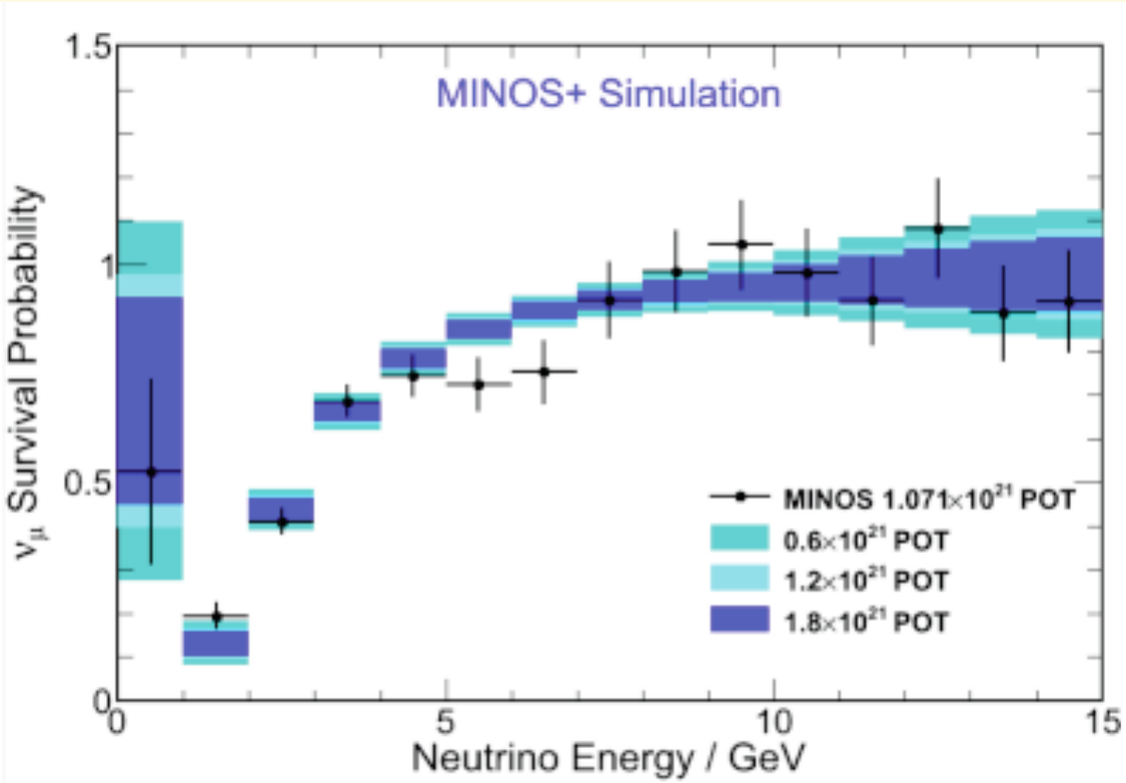

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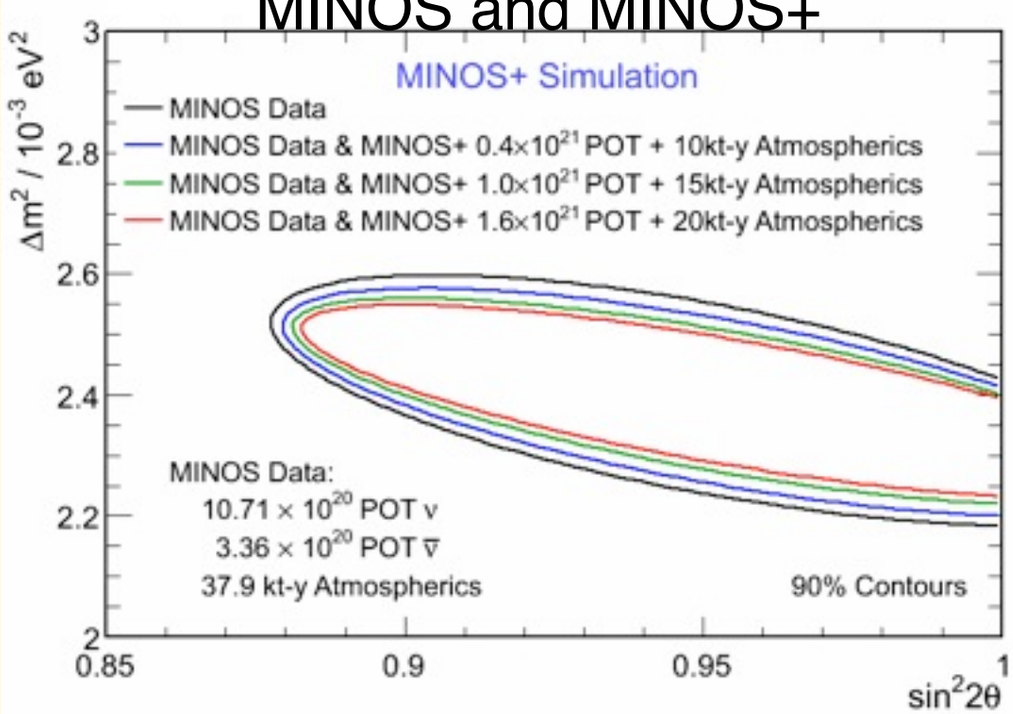

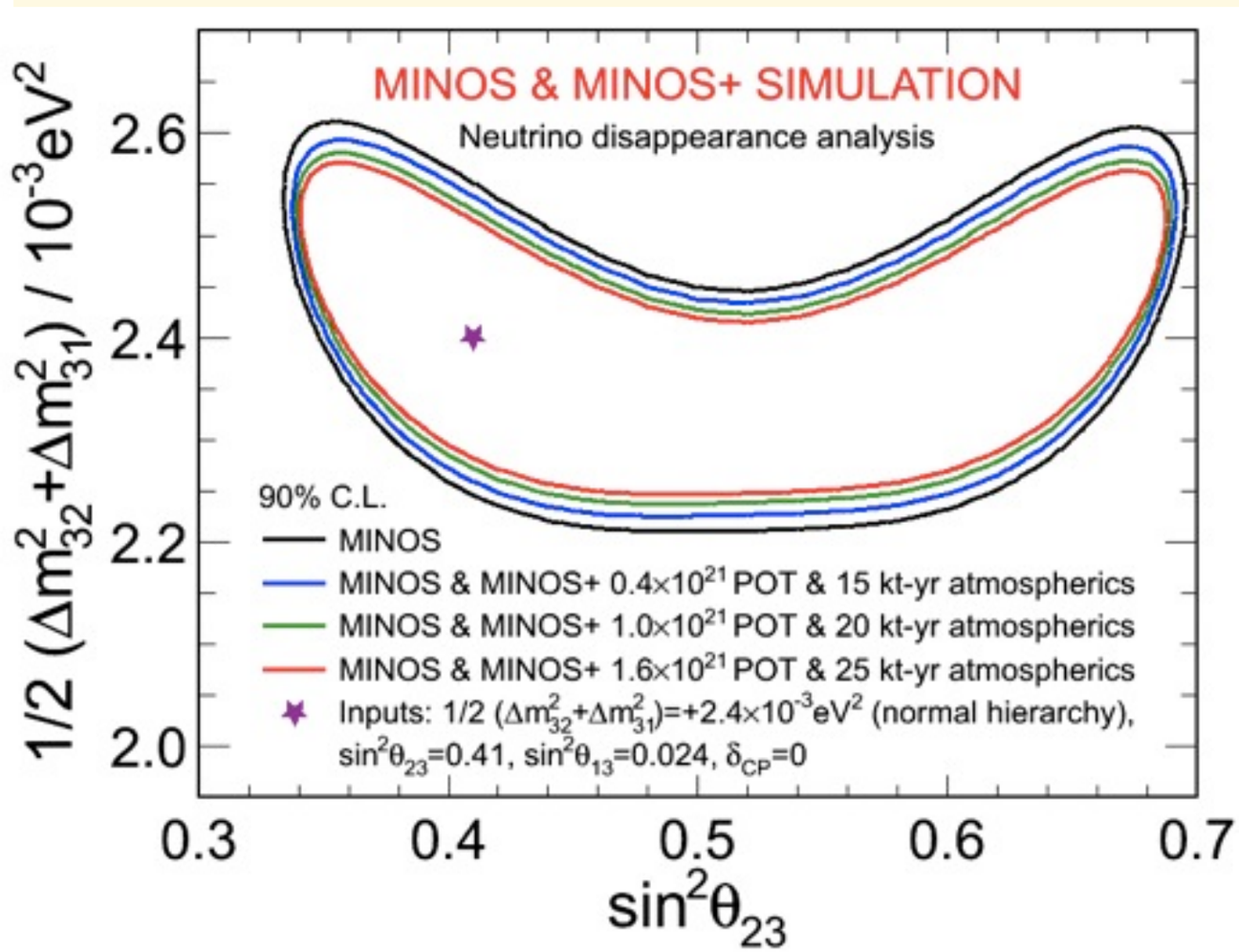

NOvA projections

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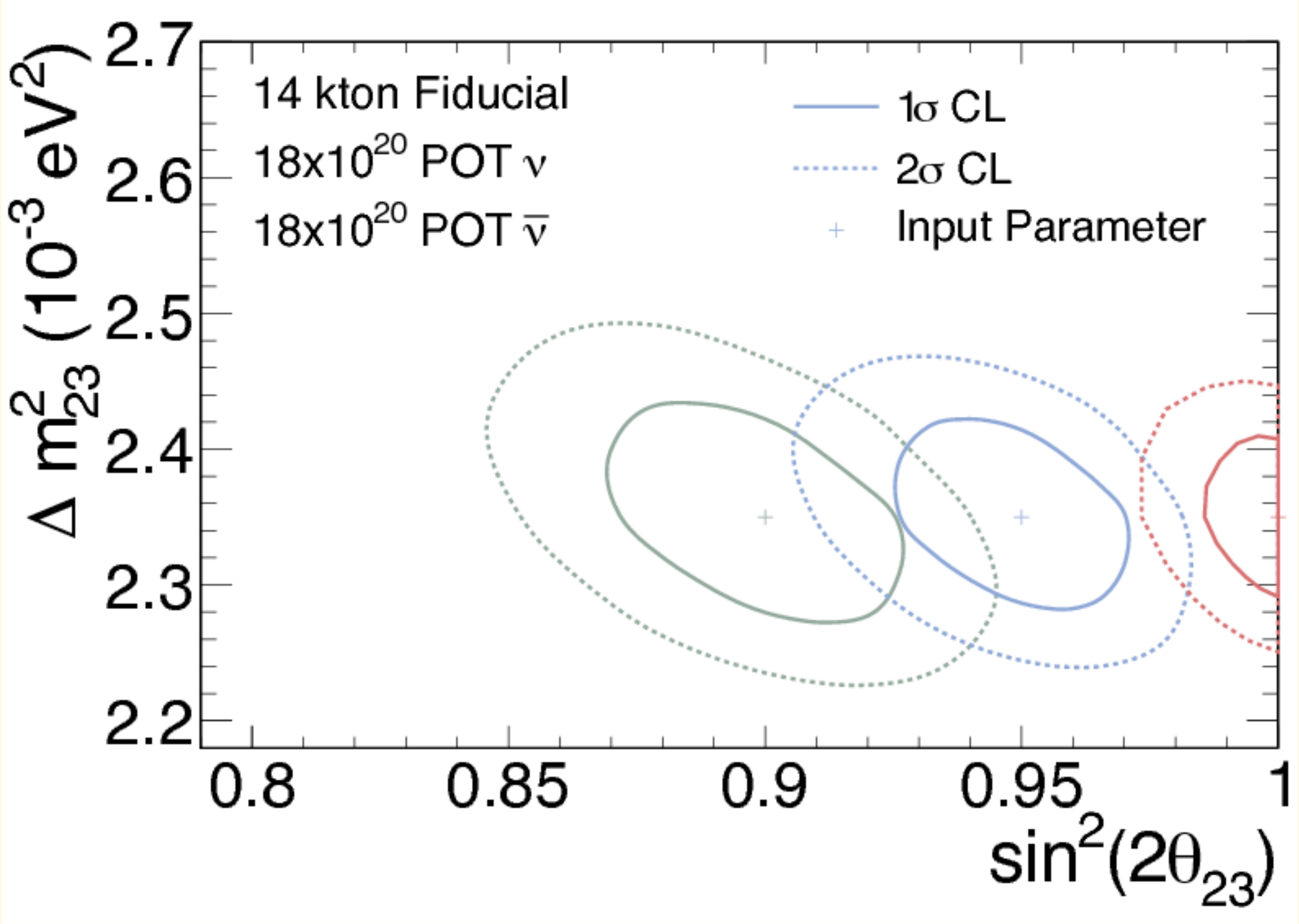

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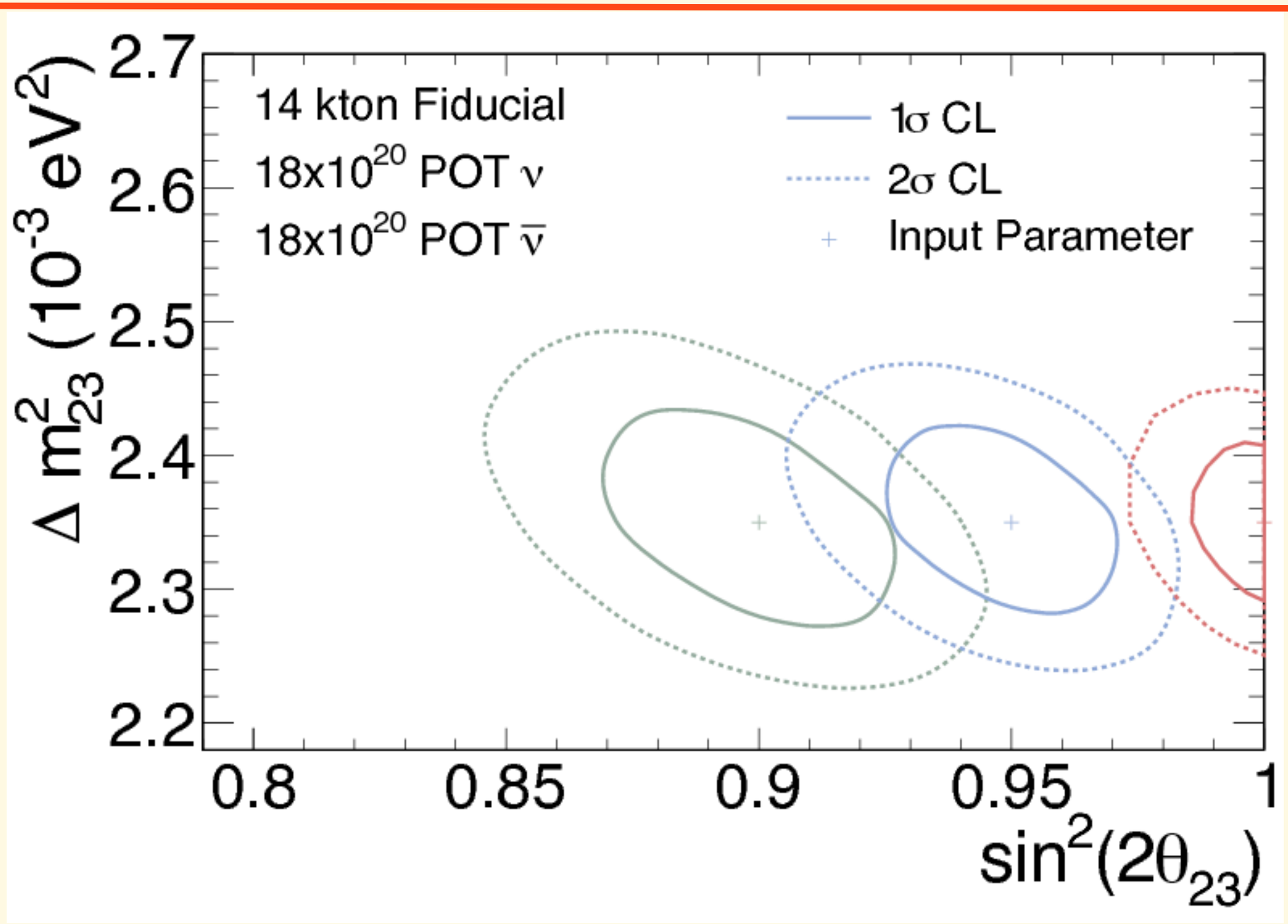

T2K Goal @ 3.75MWx10^7 s: $\delta(\Delta M^2_{23})<10^{-4}eV^2$ $\delta(\sin^2 2\theta_{23}) \sim 1\%$

Accelerator ν_e Appearance

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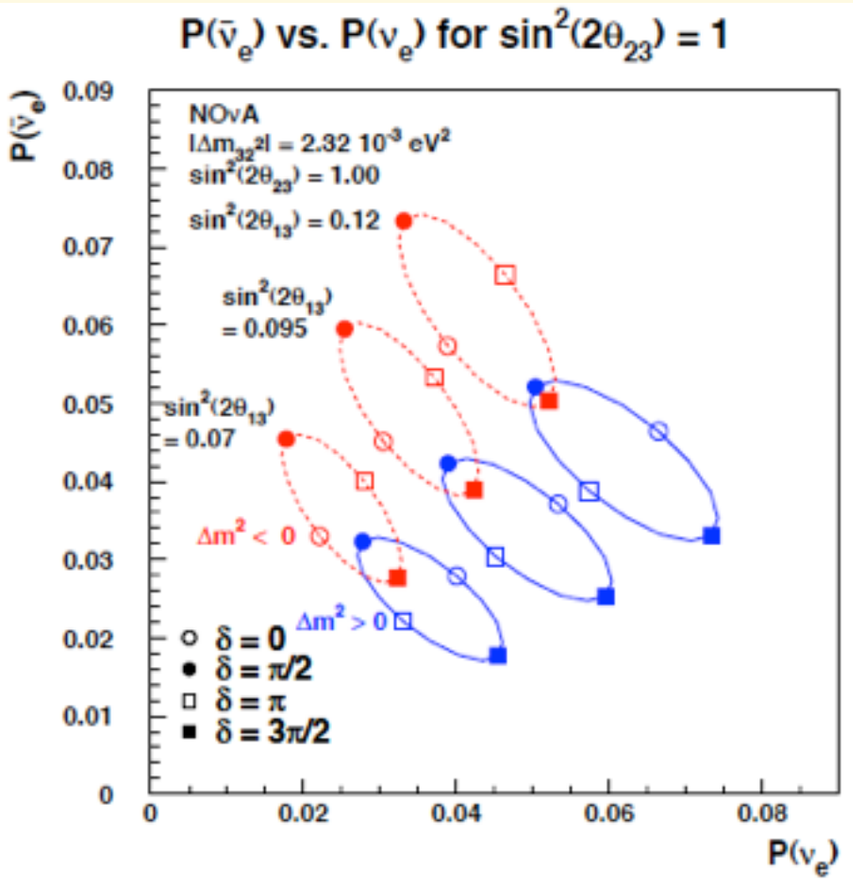
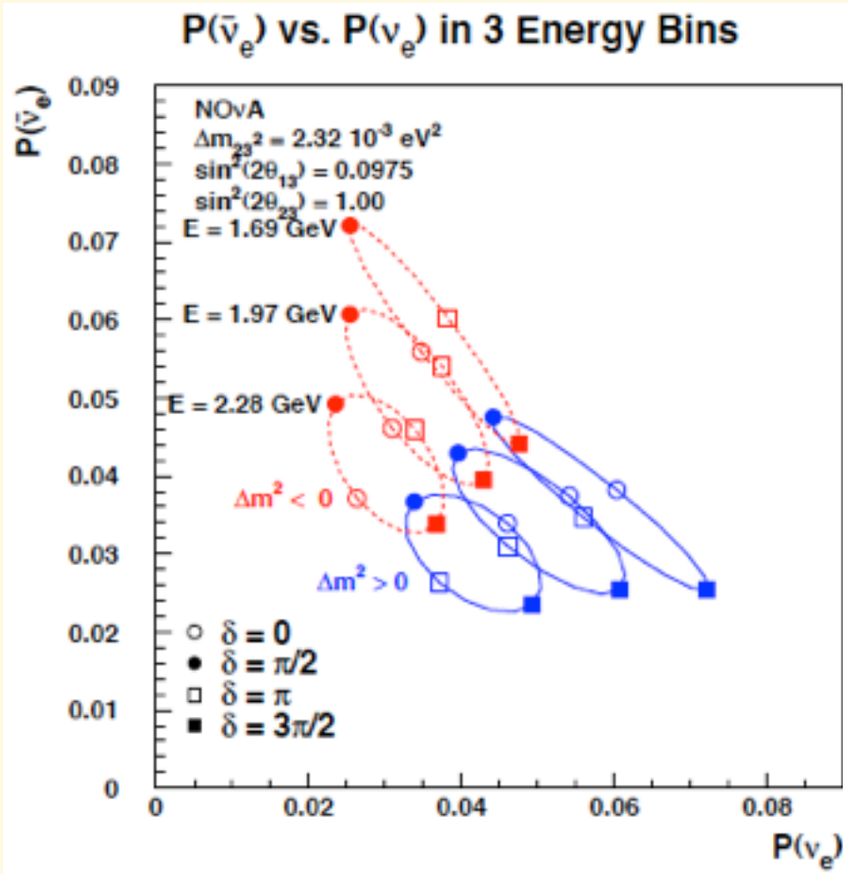
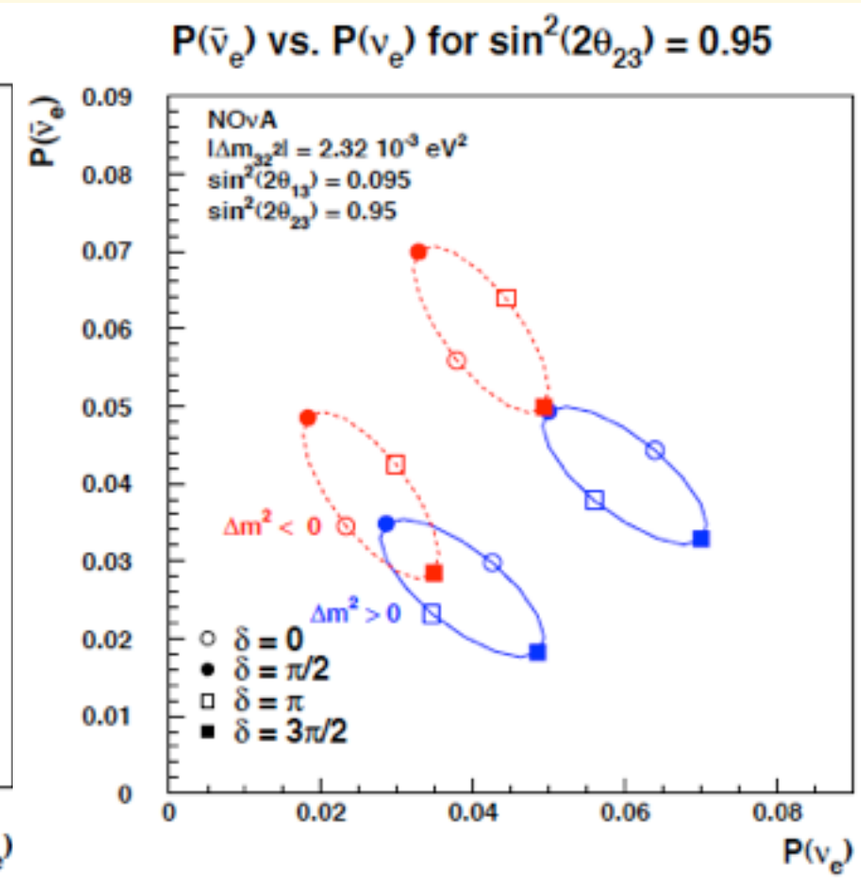


Theta13 - should be known very well in 5-8 years



Energy resolution



Octant ambiguity

Octant - MH Ambiguity

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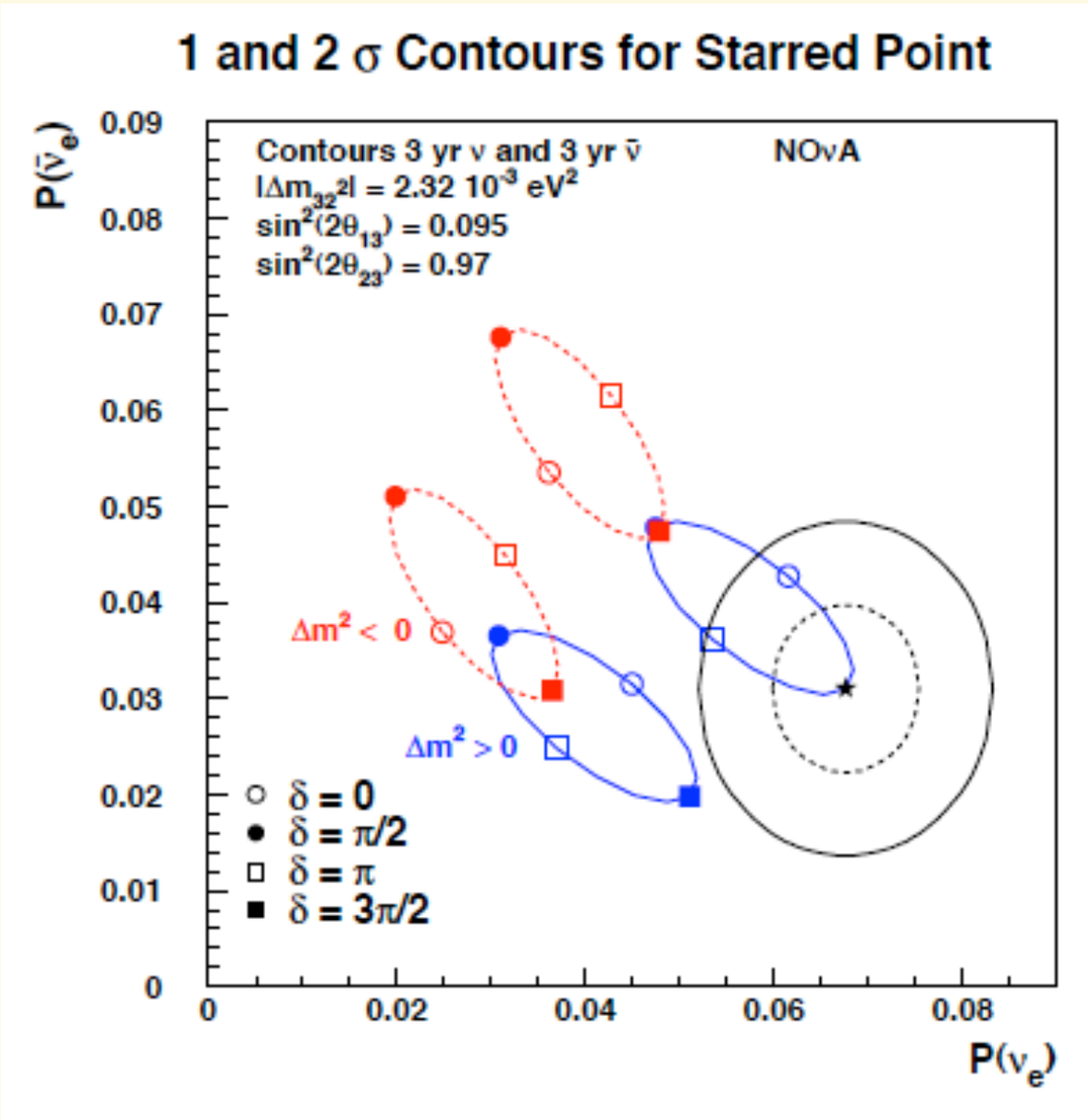
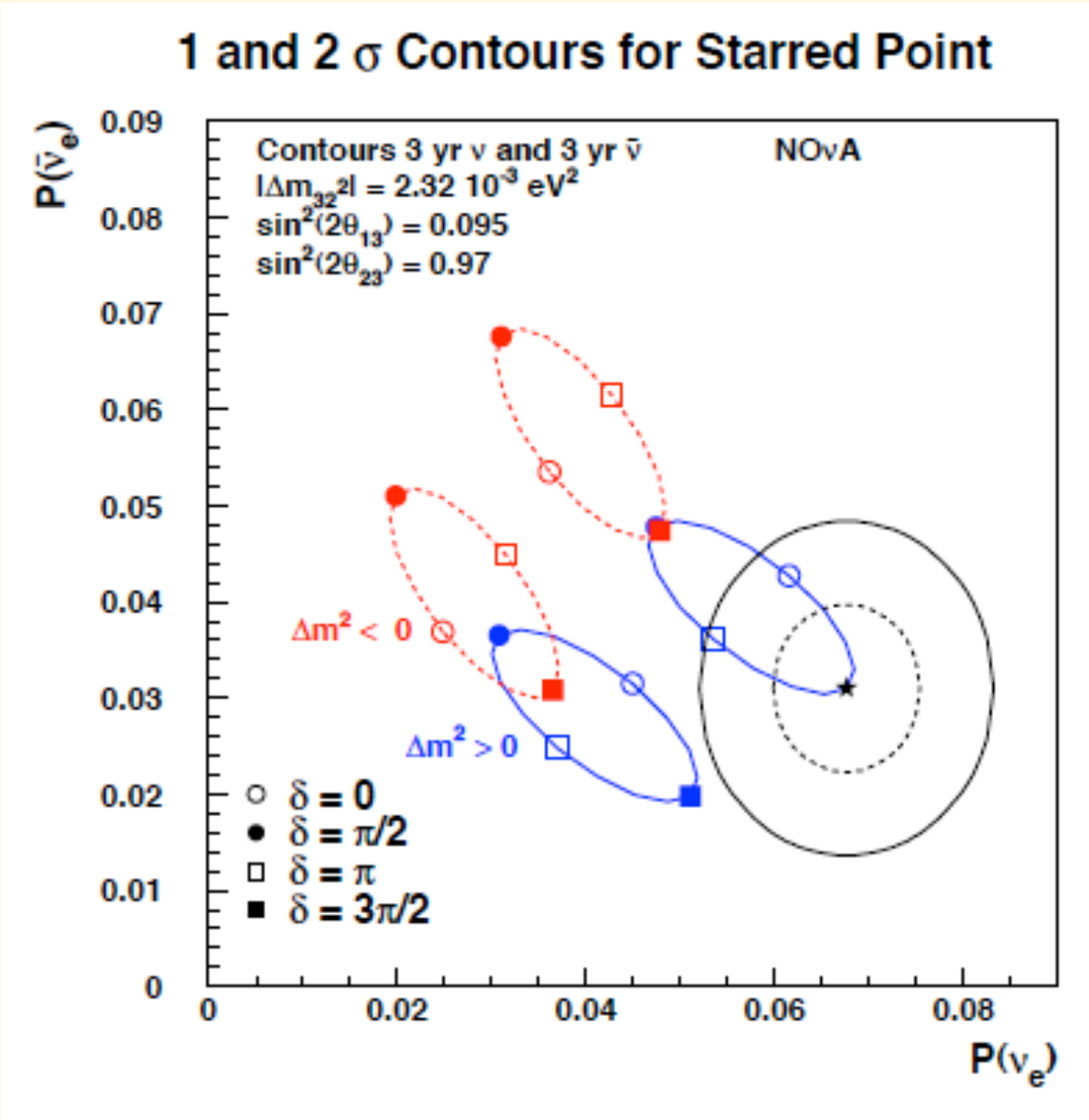


Both Mass Hierarchy and
Octant Ambiguity Resolved

Octant - MH Ambiguity



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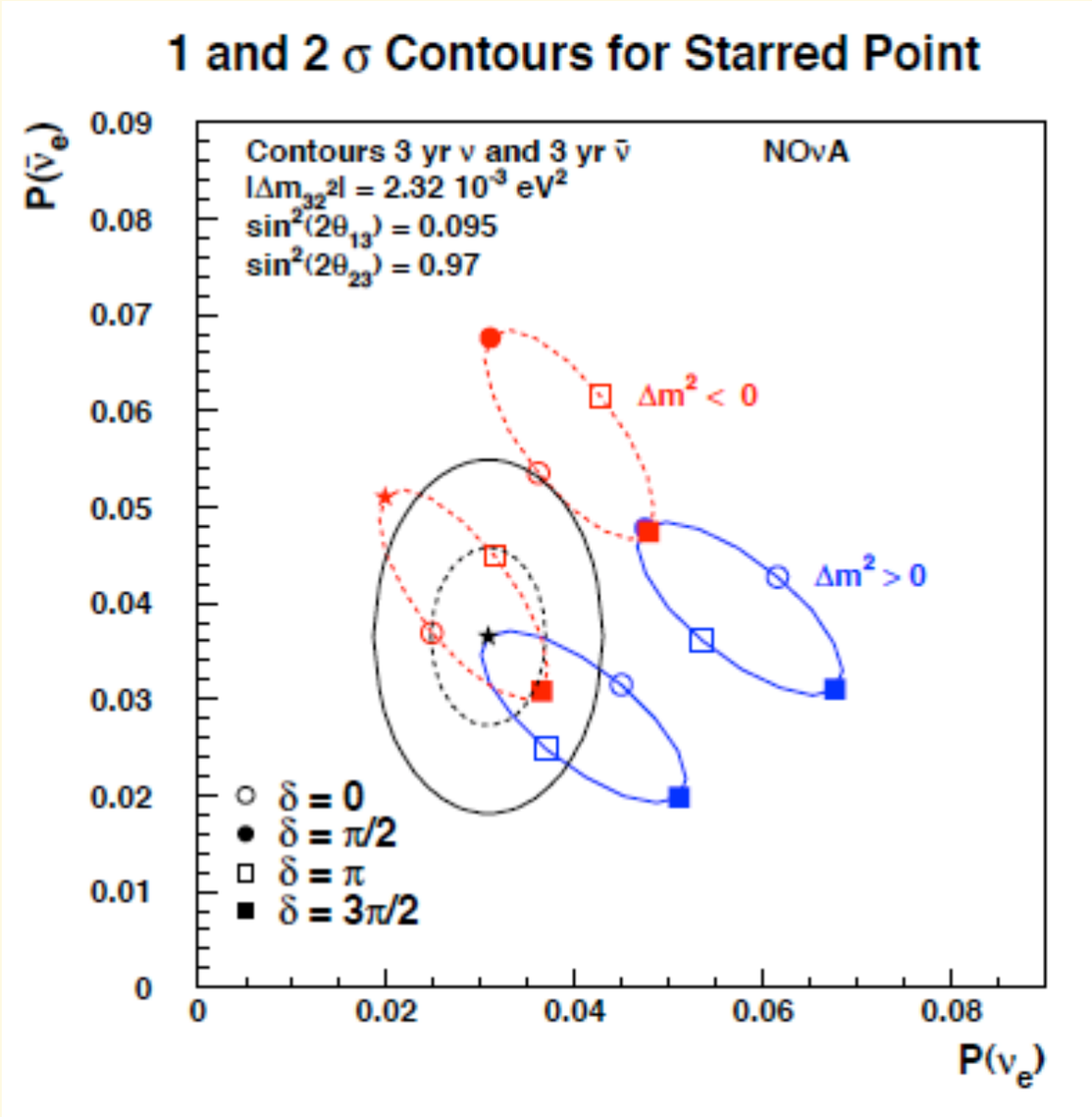

Mass Hierarchy not resolved
Octant ambiguity at 2σ

NOvA Octant Sensitivity

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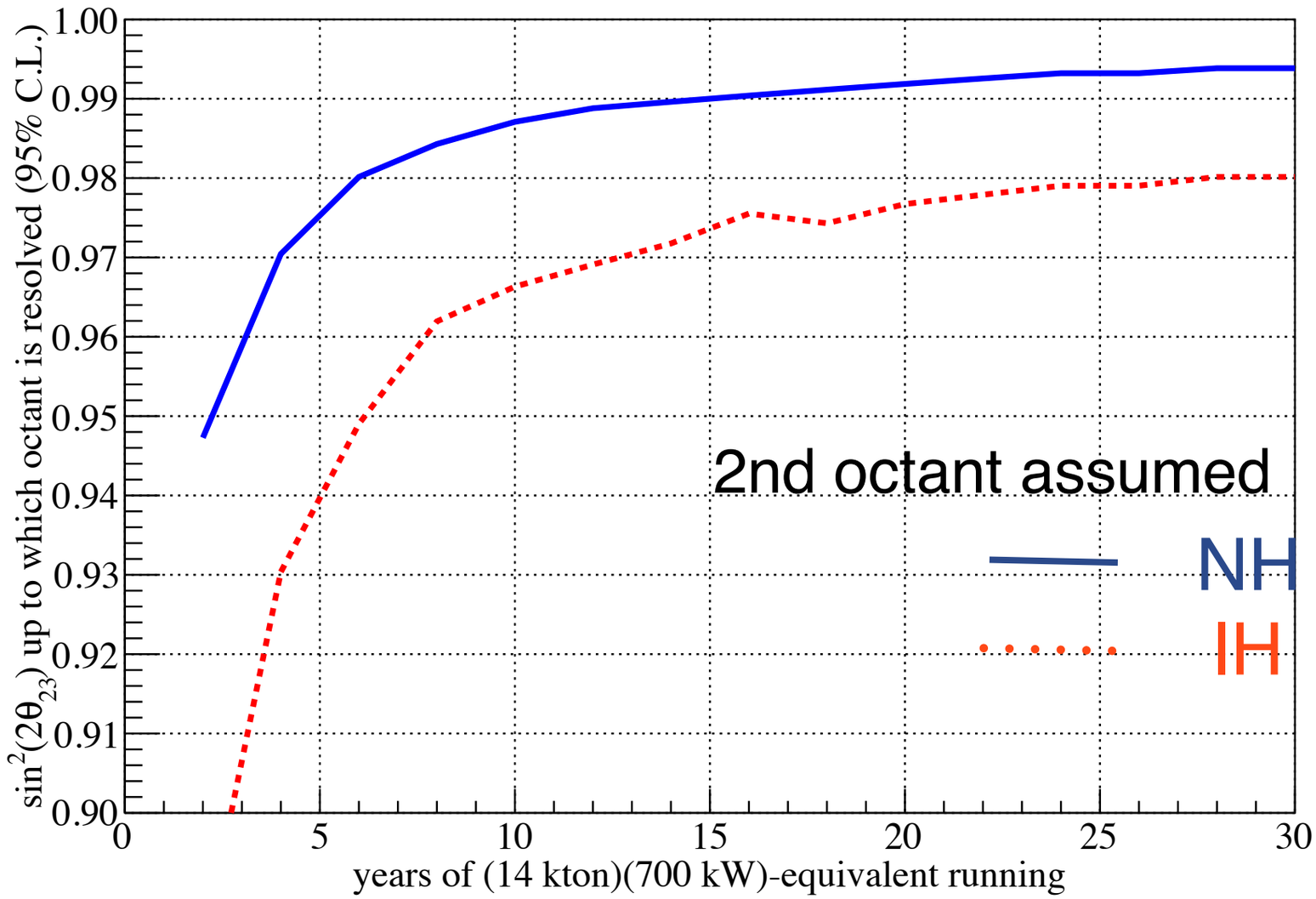

from Ryan Patterson, Cal Tech

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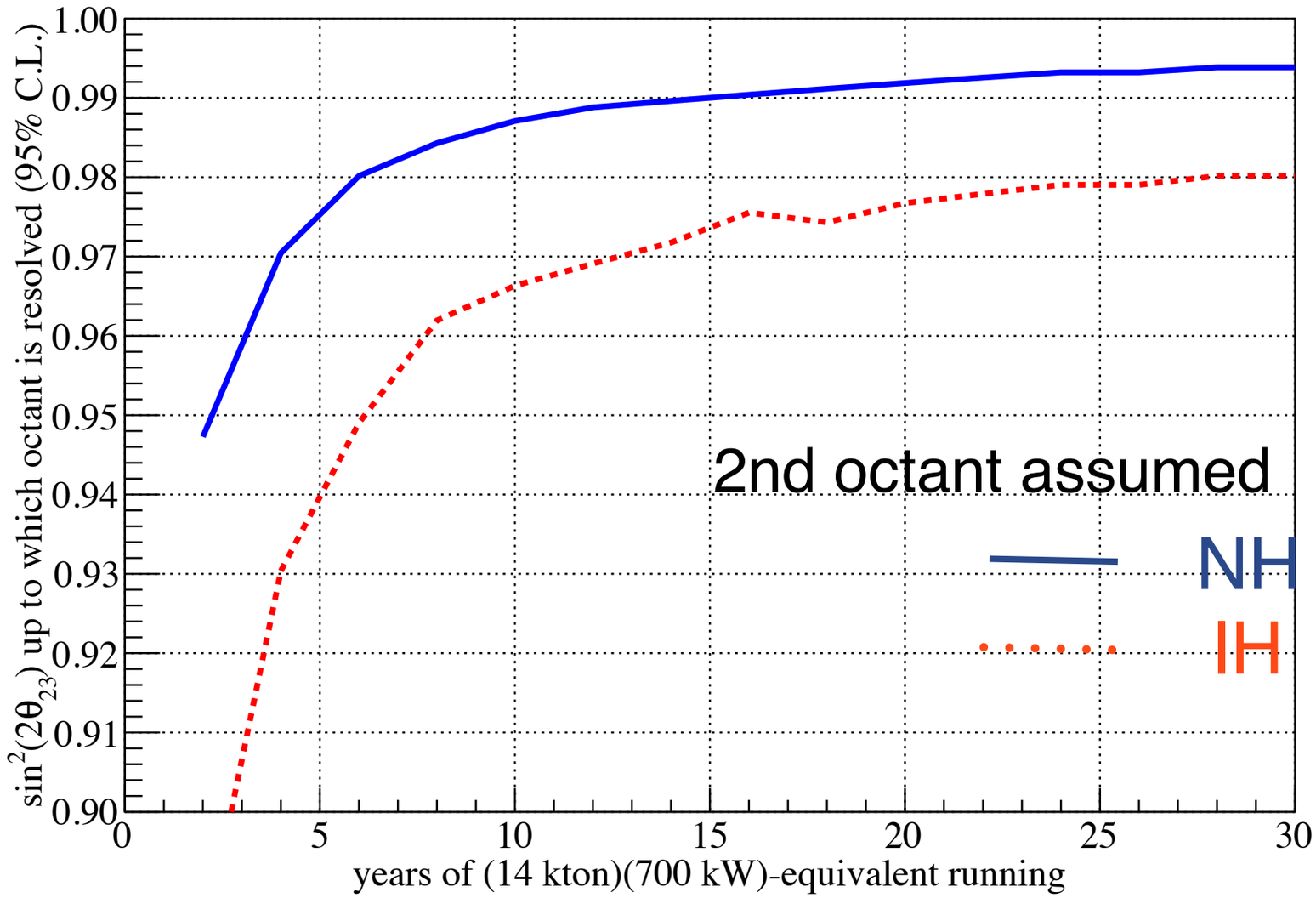

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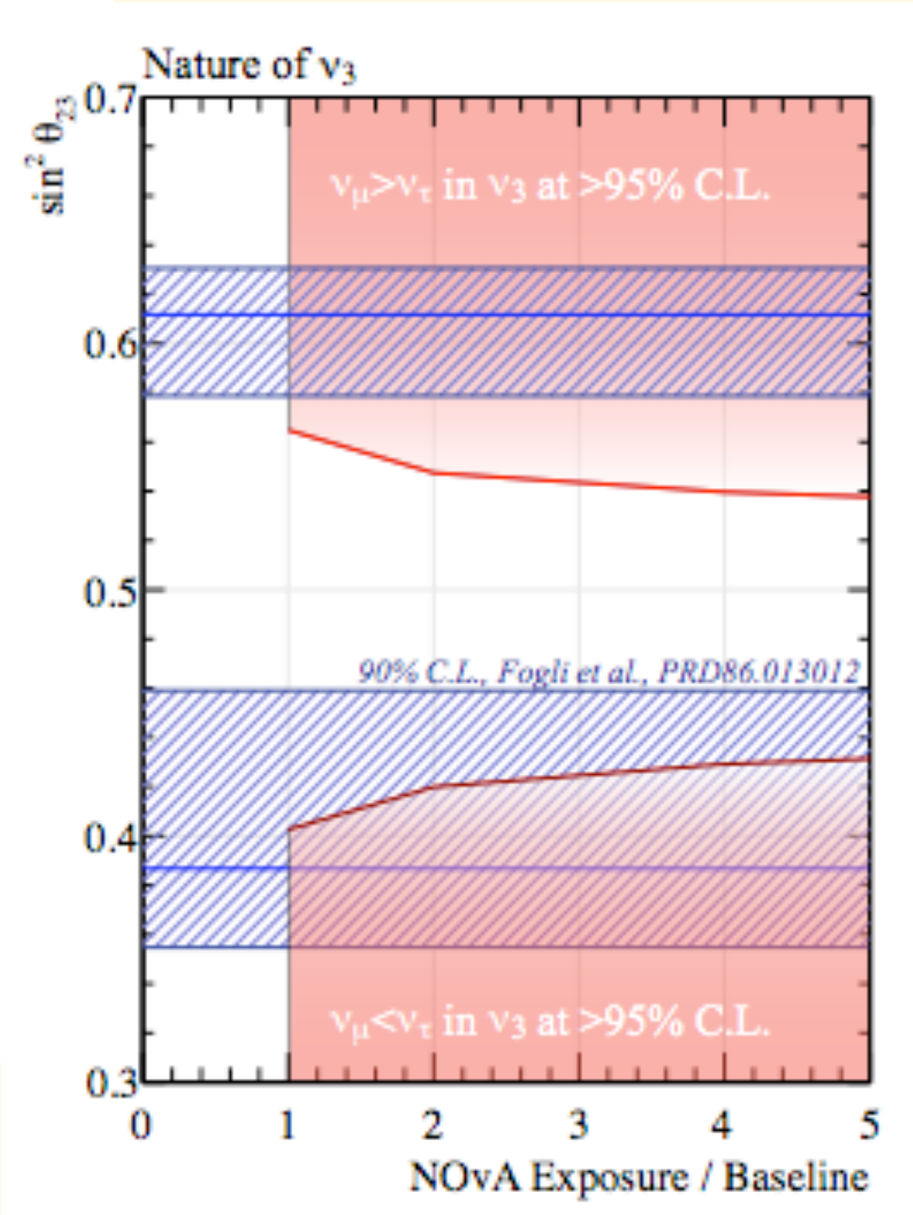

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Broadening NUMI scope

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- New initiatives
  - CHIPS (preliminary ideas at this time)
    - Water Cherenkov 50-100kt
    - In flooded former mine pit (several exist)
    - Rather shallow - 30m of H_2O overburden

NOvA Octant Sensitivity

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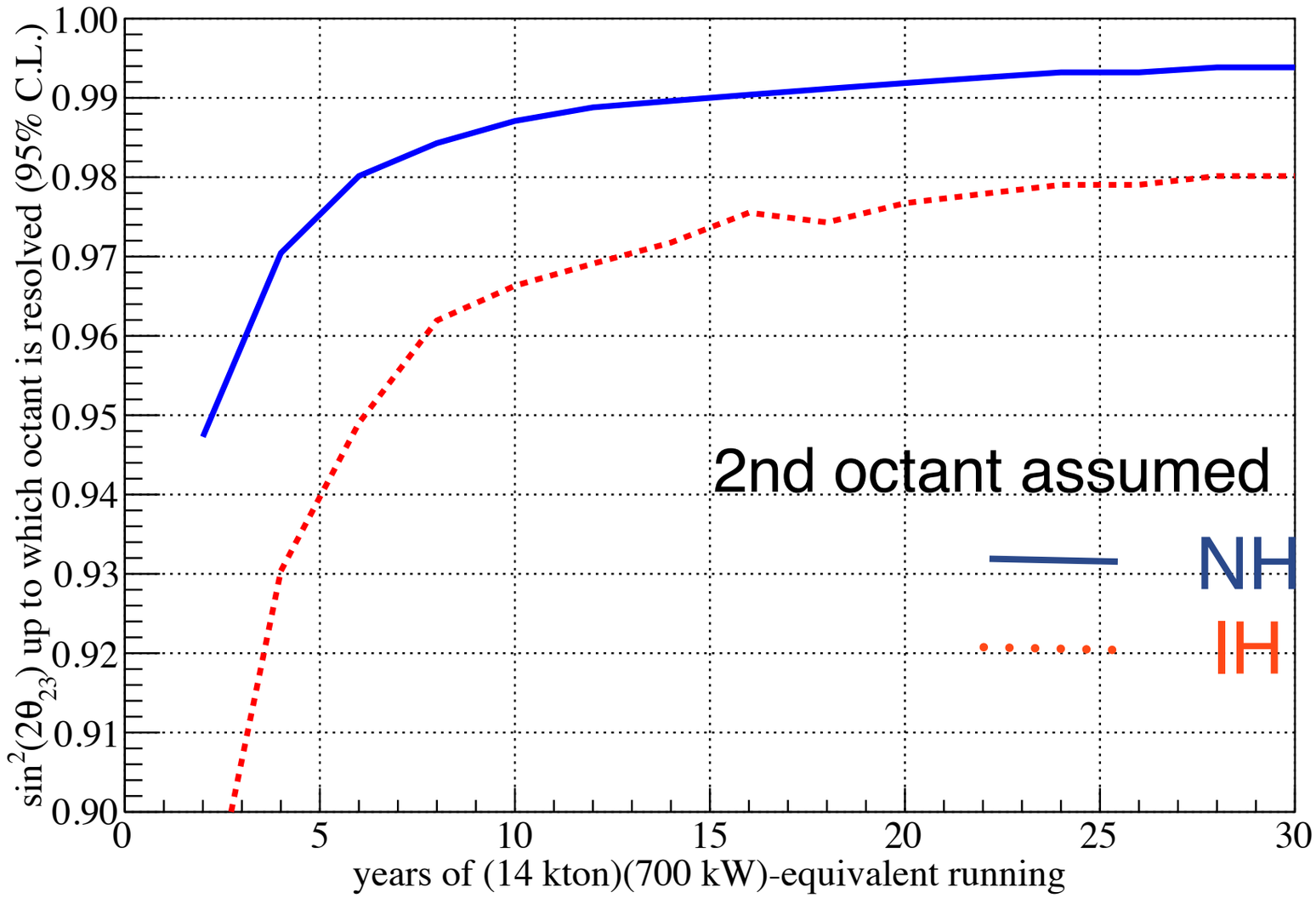

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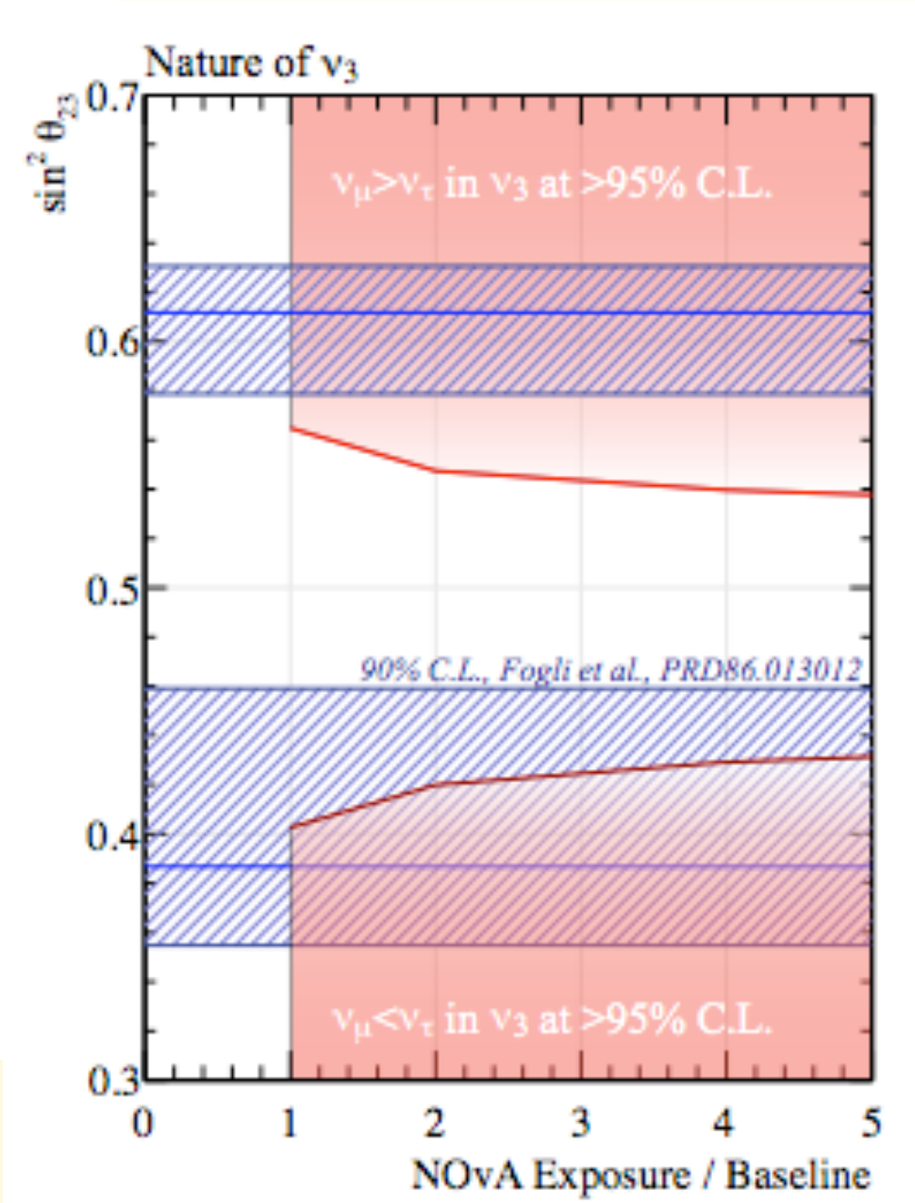

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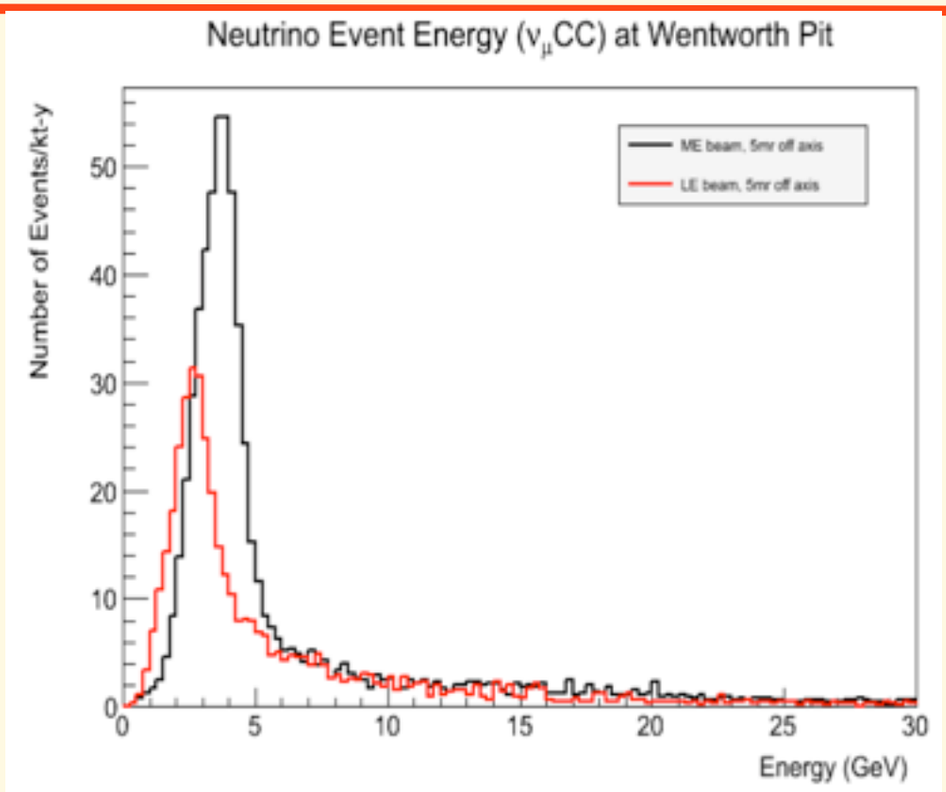

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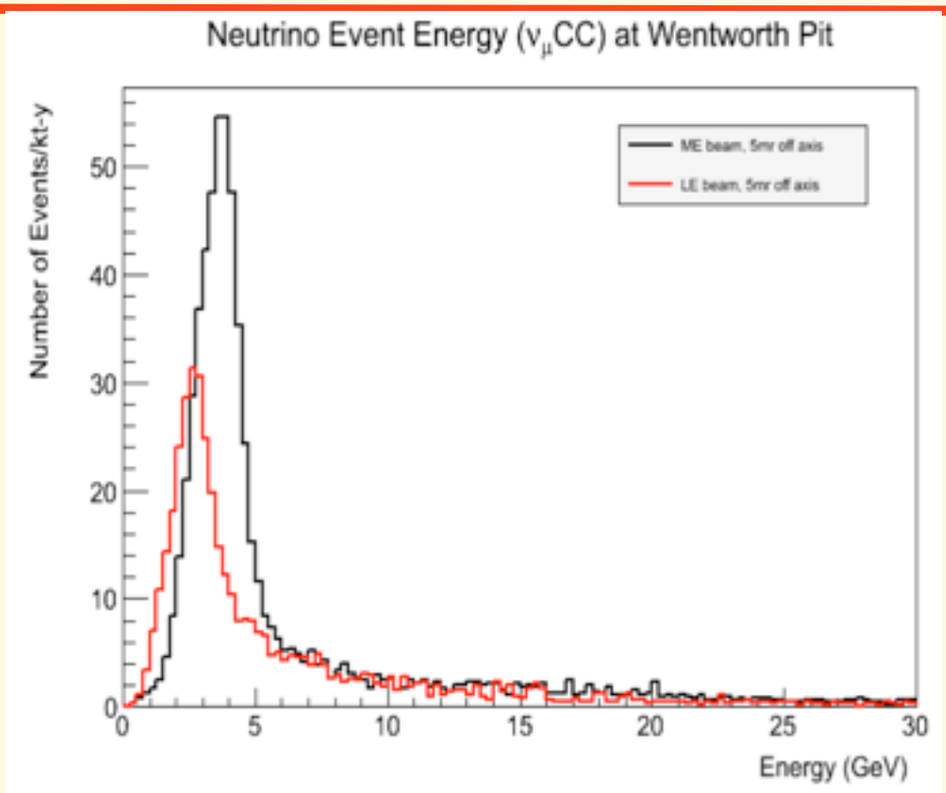

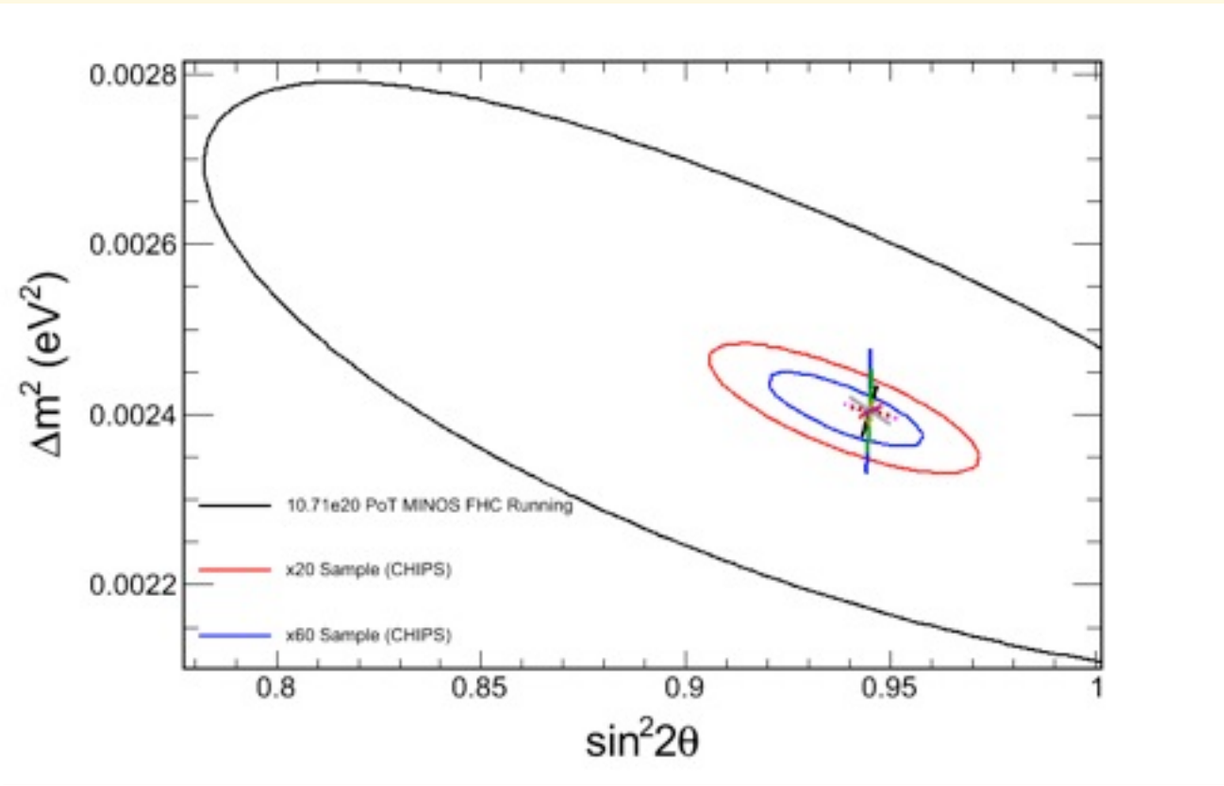

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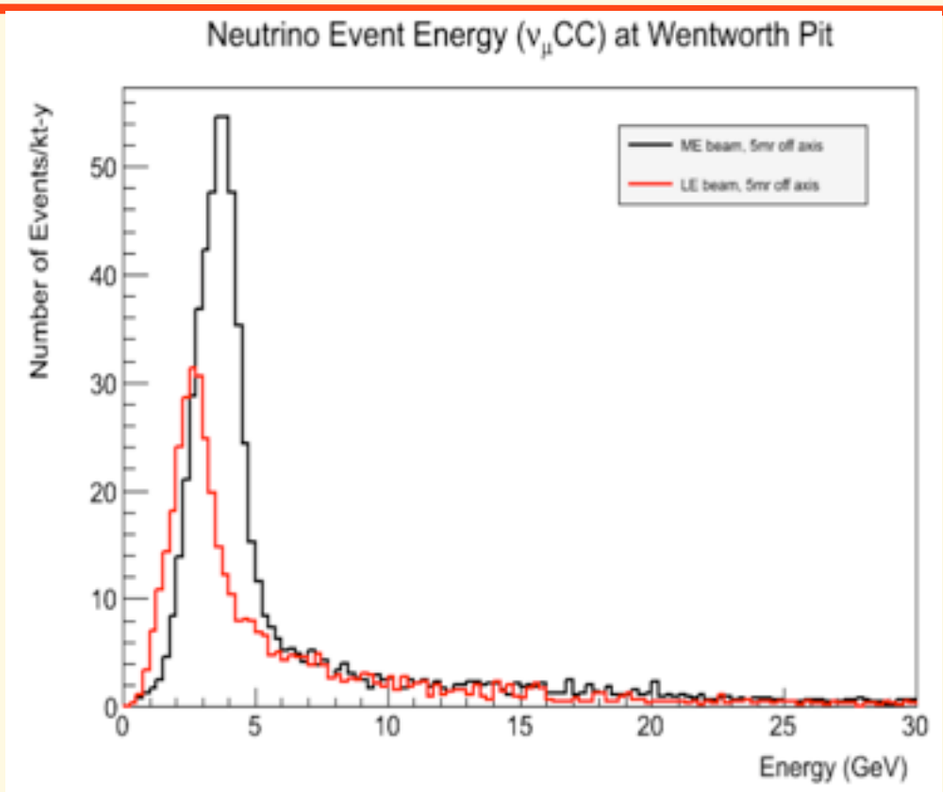

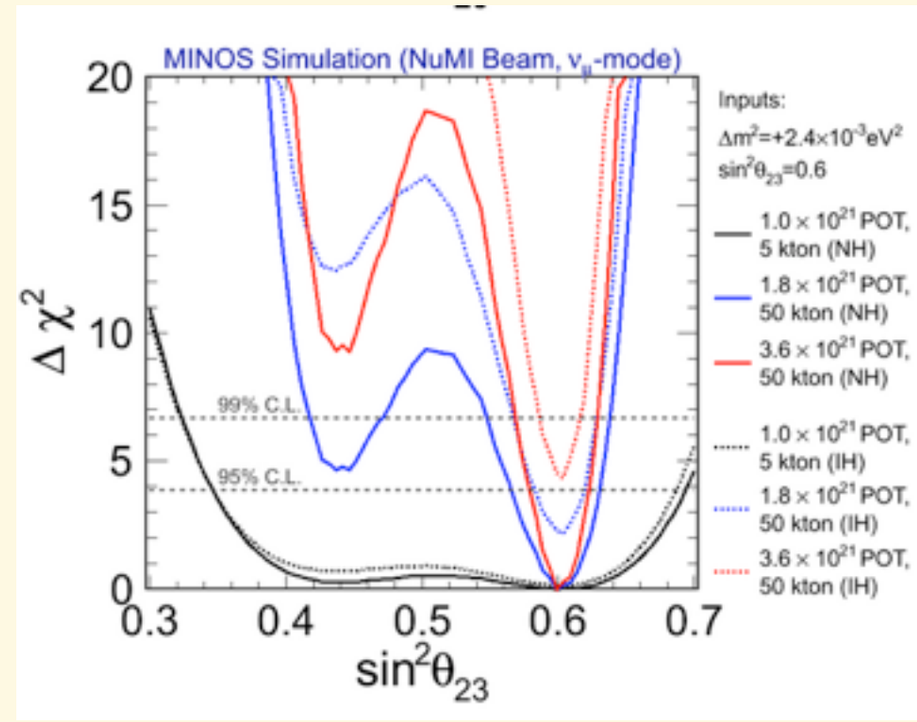

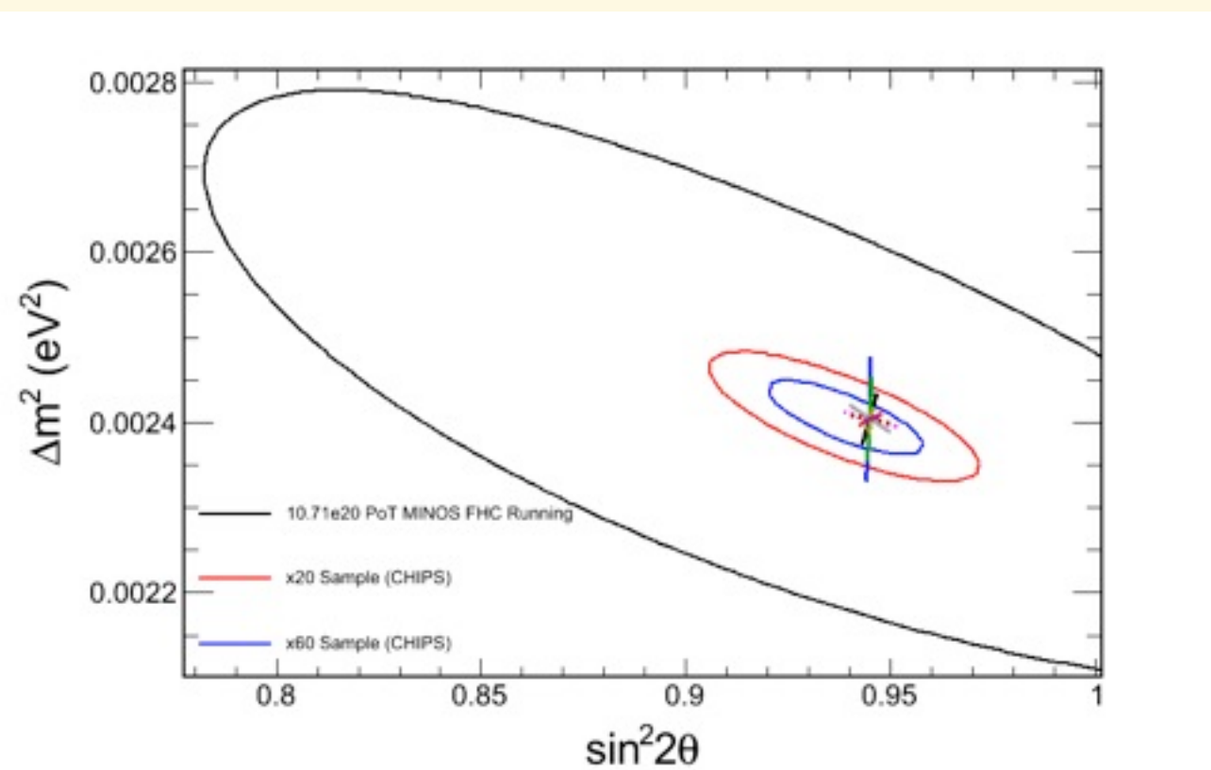

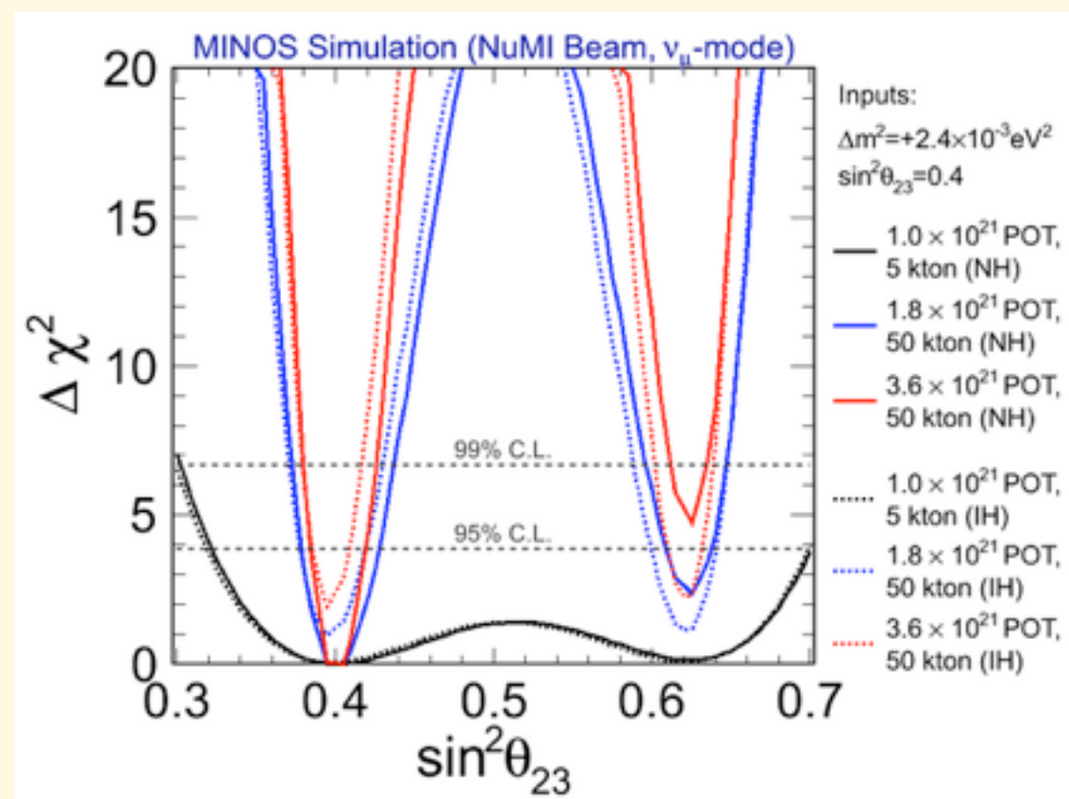

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- There are strong hints that θ_{23} differs from 45°
- The experiments in progress have a good chance of resolving the octant degeneracy and mass hierarchy
- If not, the next generation, designed to probe CP violation, should be able to do it