Abstract

Within the realm of oscillation physics, DUNE and T2HK will either agree or disagree. If they agree then the choice of fourth detector is not too vital for oscillations: nailing down the precision is the main focus. If they disagree then we want to be well positioned to understand why. A fourth detector with a more well understood material may simplify some systematics, although the effect of the near detector choice may be crucial here. In addition, targeting lower energies with the opportunity to measure solar neutrinos could allow DUNE to single-handedly measure all six of the oscillation parameters providing a key check that we understand the lepton sector. Finally, in the context of astrophysics and other secondary physics goals, LAr provides the largest benefit since other designs won't be competitive with JUNO or HK.

Realizing the physics goals at DUNE

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MOOD

November 4, 2019

BROOKHAVEN NATIONAL LABORATORY

Brookhaven NDI Neutrino Discovery Initiative

Framing the Question

What fourth detector maximizes our physics return?

Detector considerations

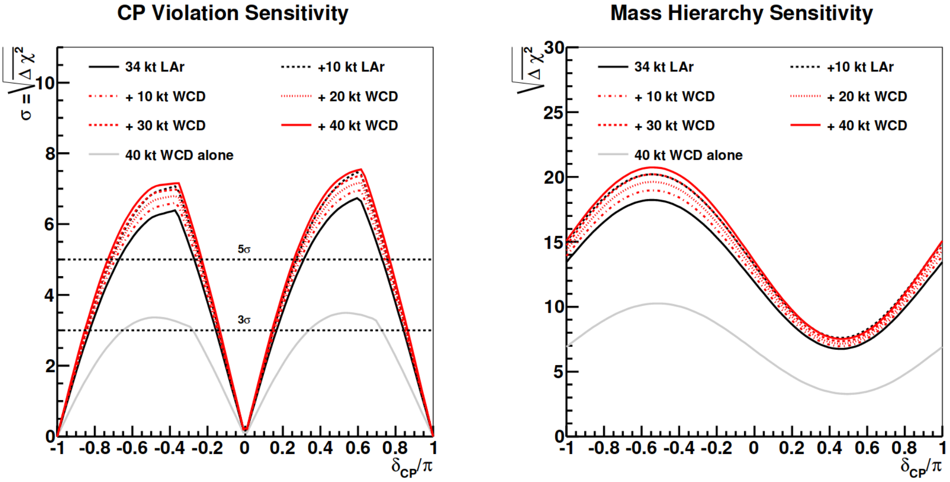
1. LArTPC
2. WbLS (Theia)
3. Water-Cherenkov (Gd?)
4. Oil

Desired outputs

1. Oscillation goals (LBL)
2. Secondary goals (SN, atm, solar, nucleon decay, . . .)

I'm a theorist so pardon me

LAr versus Water



J. Alonso, et al. 1409.5864

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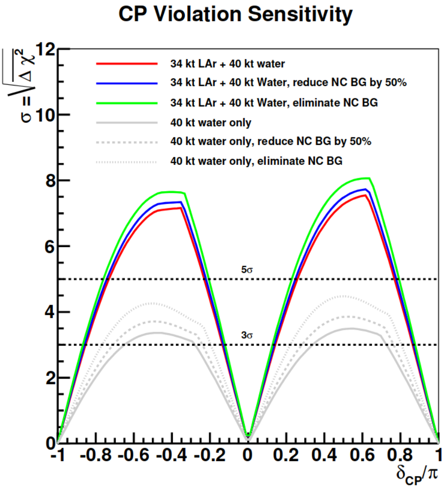

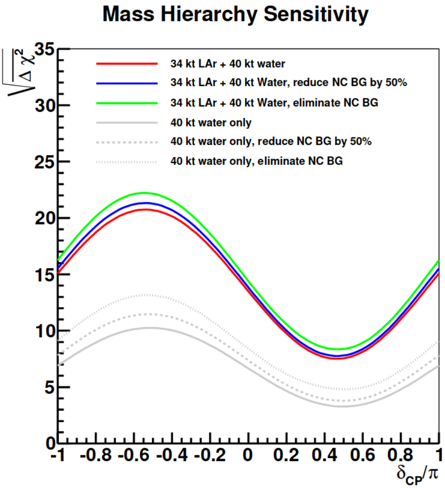

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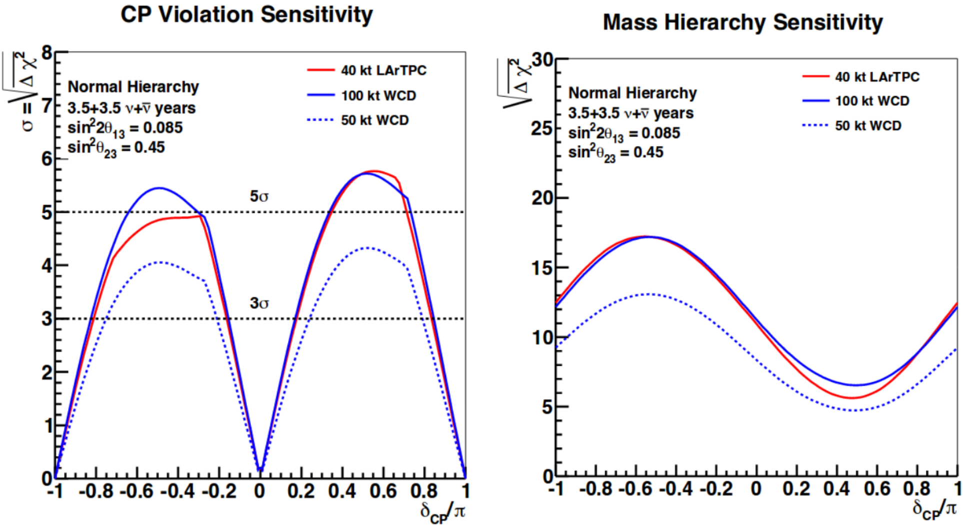
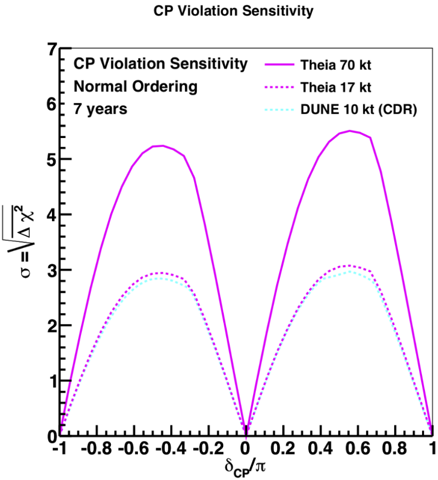
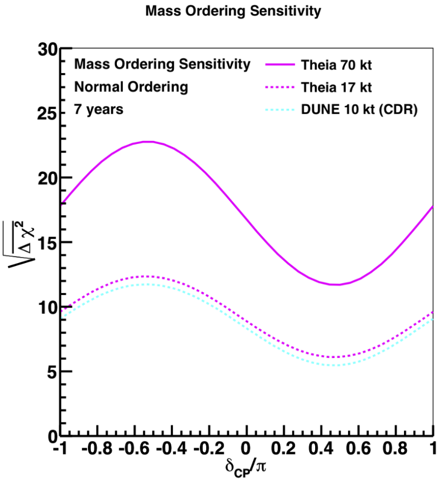


Vincent Fischer, THEIA 1809.05987

Theia





Theia 1911.03501

Oscillation Comparison

The most interesting comparison isn't:

- MO
- $\delta \neq 0, \pi$
- $\Delta\delta$
- θ_{23} Octant
- $\Delta\theta_{23}$
- BSM

as a function of:

- 40 kt LAr vs. 100 kt WBD
- 40 kt LAr vs. 30 kt LAr + 25 kt WBD
- 40 kt LAr vs. 30 kt LAr + 25 kt WbLS
- 40 kt LAr vs. 30 kt LAr + 25 kt Oil

Will DUNE and T2HK Agree?

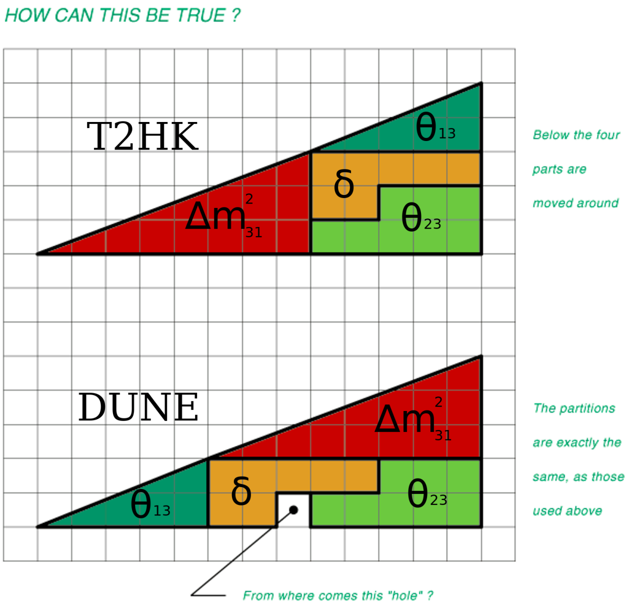
Combining oscillation experiments, often in slight tension

1. Solar + KamLand (Δm^2_{21}) $\to$ tension
2. Reactor + T2K (θ_{13}) $\to$ tension
3. T2K + NOvA (θ_{23}) $\to$ tension (sometimes)

Currently have at most one good measurement of each parameter

We should be prepared if/when more tensions appear

Putting the puzzle pieces together



Long Baseline Consistency

DUNE and T2HK will need to be consistent with:

1. Each other on disappearance for $\sin 2\theta_{23}$ and $|\Delta m^2_{32}|$
2. Atmospheric on disappearance for $\sin 2\theta_{23}$ and $|\Delta m^2_{32}|$
3. Each other on appearance for MO, δ, and θ_{23}
4. Reactors for θ_{13}

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Many checks, if they disagree:

Systematics?

- Flux (norm, shape)
- Cross section (QE, Res, DIS, FSI, ...)
- Detector response, PID
- ...

or

New physics?

- NSI (NC, CC)
- Sterile (3+N)
- Decay (inv, vis)
- Decoherence
- ...

Interesting oscillation comparison

What if DUNE and T2HK don't agree?

40 kt LAr + T2HK + systematic shift
compared to
40 kt LAr + T2HK + new physics

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Secondary Physics Cases

Atmospheric neutrinos — K. Kelly, et al. 1904.02751

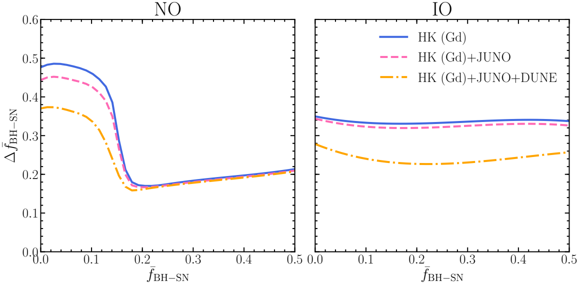
Solar neutrinos — Capozzi, et al. 1808.08232

Nucleon decay: Kaon channel?

Galactic supernova: MO, many BSM constraints, astro

DSNB: SN properties

Diffuse Supernova Neutrino Background can constrain $R_{\rm SN}$ and $f_{\rm BH}$



K. Møller, A. Suliga, I. Tamborra, PBD 1804.03157

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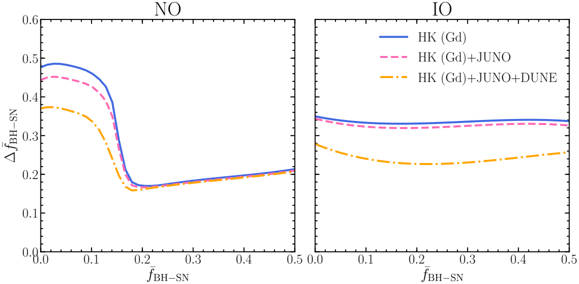

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All benefit from more LAr

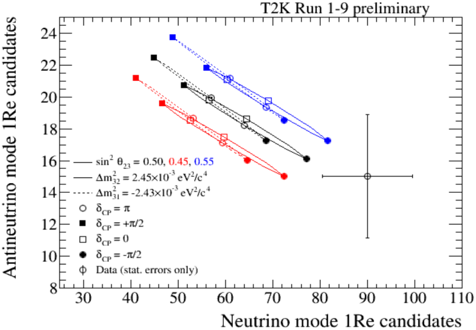
Summary Table

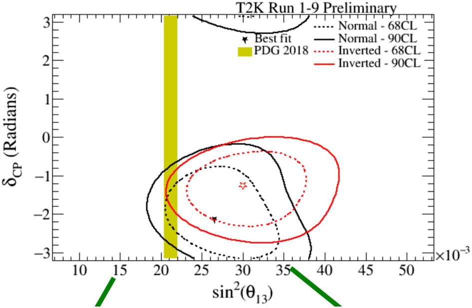
Detector	Pros	Cons
LAr	Near detector All secondaries	No cross check at 1300 km
Water	Cross check with HK for far Different systematics	Near detector Secondaries (SK,HK)
WbLS	Different systematics	Near detector Secondaries (SK,HK,JUNO)
Oil	Different systematics	Near detector Secondaries (JUNO)

Thanks!

Backups

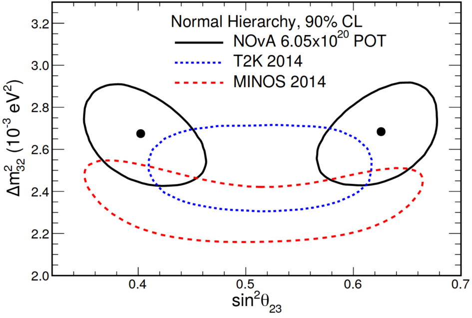
θ_{13} Tension at T2K



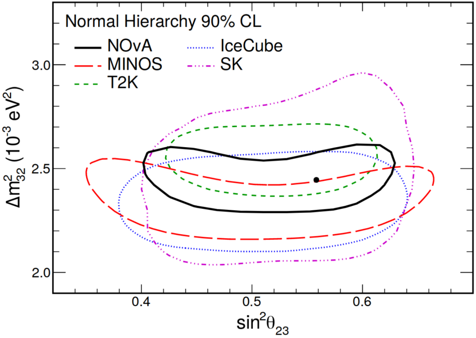


$$J = c_{12}s_{12}c_{13}^2 s_{13}c_{23}s_{23}\sin\delta$$

Old θ_{23} tension at NOvA

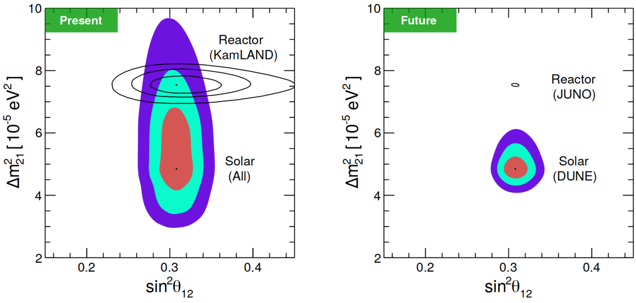


NOVA 1701.05891



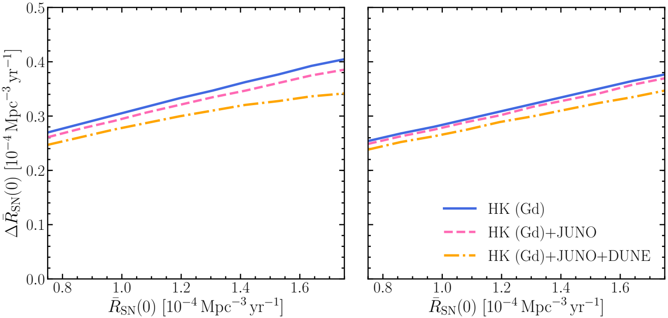
NOVA 1806.00096

Solar Parameters with DUNE and JUNO



F. Capozzi, et al. 1808.08232

Supernova Neutrinos



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