# An Overview of Current Neutrino Experiments and Their Prospects

Byeongsu Yang
Chonnam National University

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# OUTLINE

- Precision oscillation program
- Absolute-mass and rare-event searches
- Beyond the three-flavor framework
- Astrophysical neutrinos

# From Oscillation Discovery to Precision Neutrino Physics

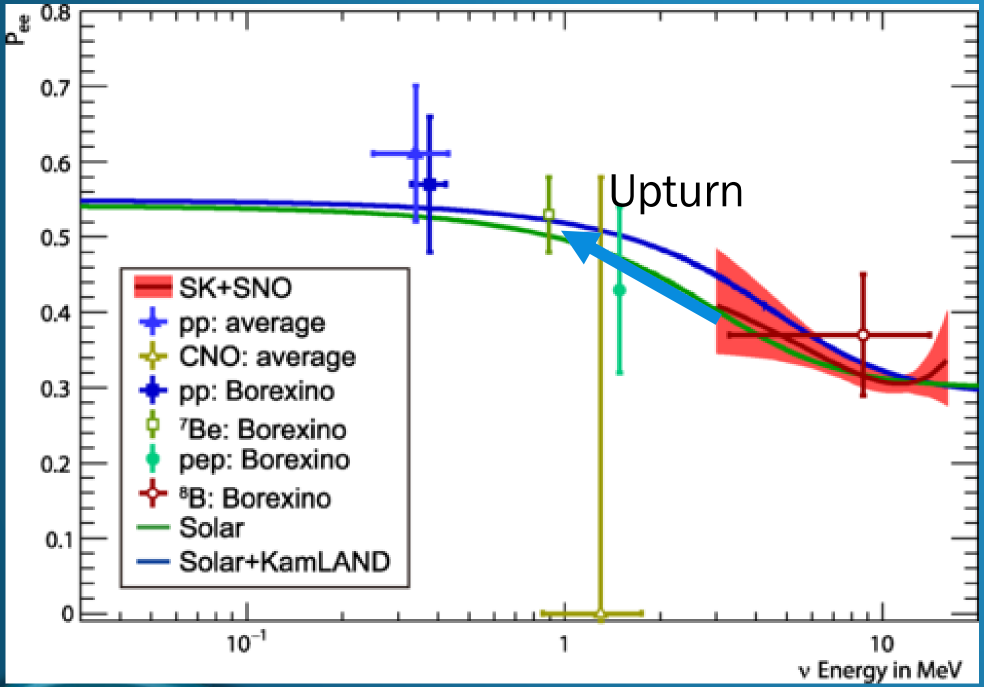
- Neutrino oscillations are established
- Precision measurements are the next frontier
- Leptonic CP violation and the mass ordering remain unresolved
- The absolute mass scale and lepton-number violation remain unknown
- Complementary experiments will define the next decade

# Current Status of Three-Flavor Oscillations

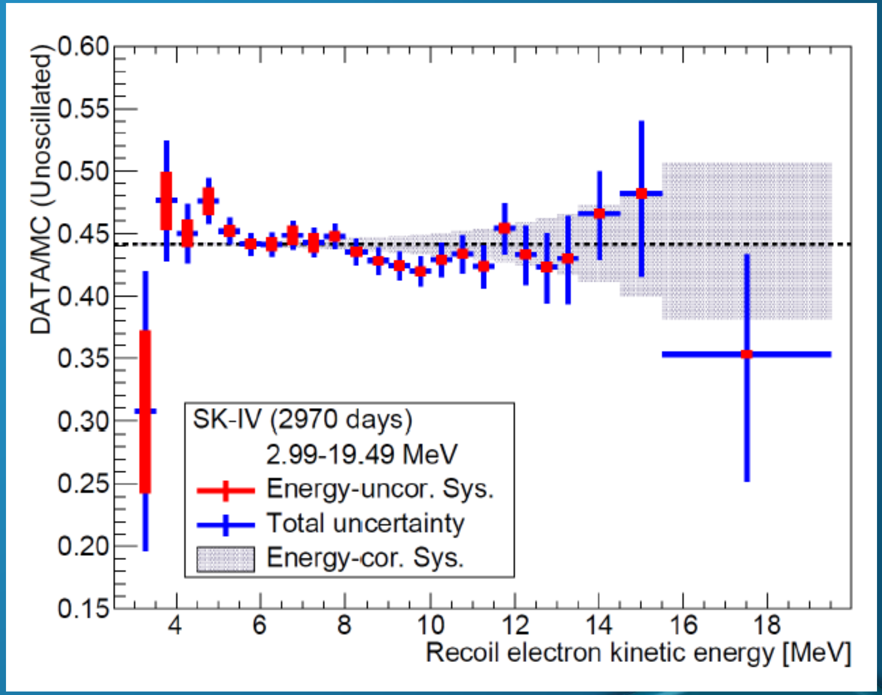
| Quantity | Key Experiments | Status |
|---|---|---|
| $\theta_{12}, \Delta m_{21}^2$ | Solar, KamLAND/JUNO | Precisely measured |
| $\theta_{13}$ | Short-baseline reactors | Precisely measured |
| $\lvert\Delta m_{atm}^2\rvert$ | Atmospheric, accelerators | Precisely measured. |
| $\theta_{23}$ | Atmospheric, accelerators | Octant open |
| $\delta_{CP}$ | Accelerators | CP violation open |
| mass ordering | Atmospheric, accelerator, JUNO | Independent confirmation needed |

# Solar Neutrinos Across the Energy Spectrum

- Solar neutrinos probe oscillation over a broad energy range
- Current data are consistent with the MSW-LMA prediction
- The MSW transition region remains a key precision test



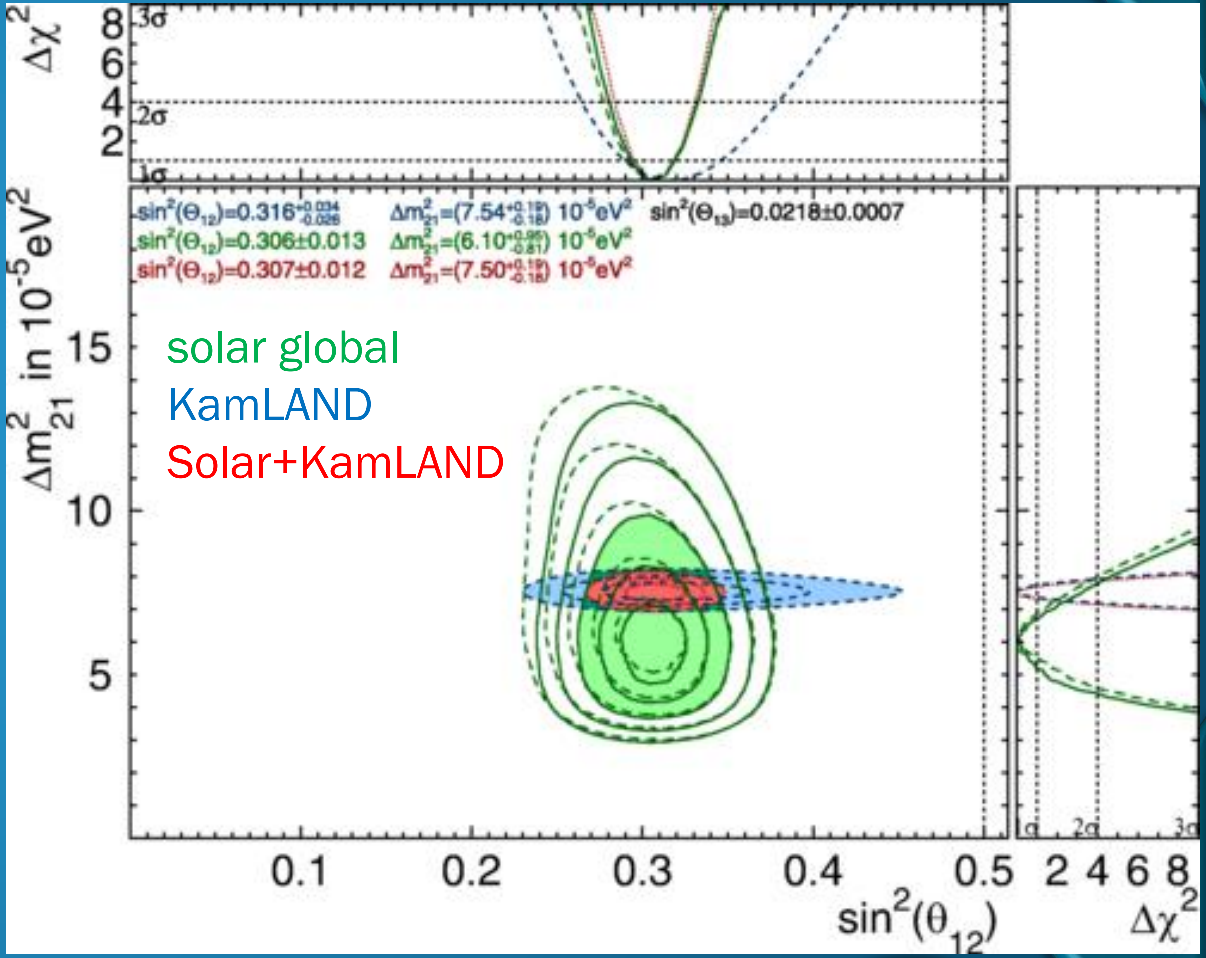

Phys. Rev. D 109, 092001 (2024)




Phys. Rev. D 113, 112001 (2026)

# Solar + KamLAND: Complementary Constraints

- Solar and reactor data constrain the same parameters differently
- Their combination established the LMA-MSW solution
- A mild (~1.4σ) solar–KamLAND tension remains

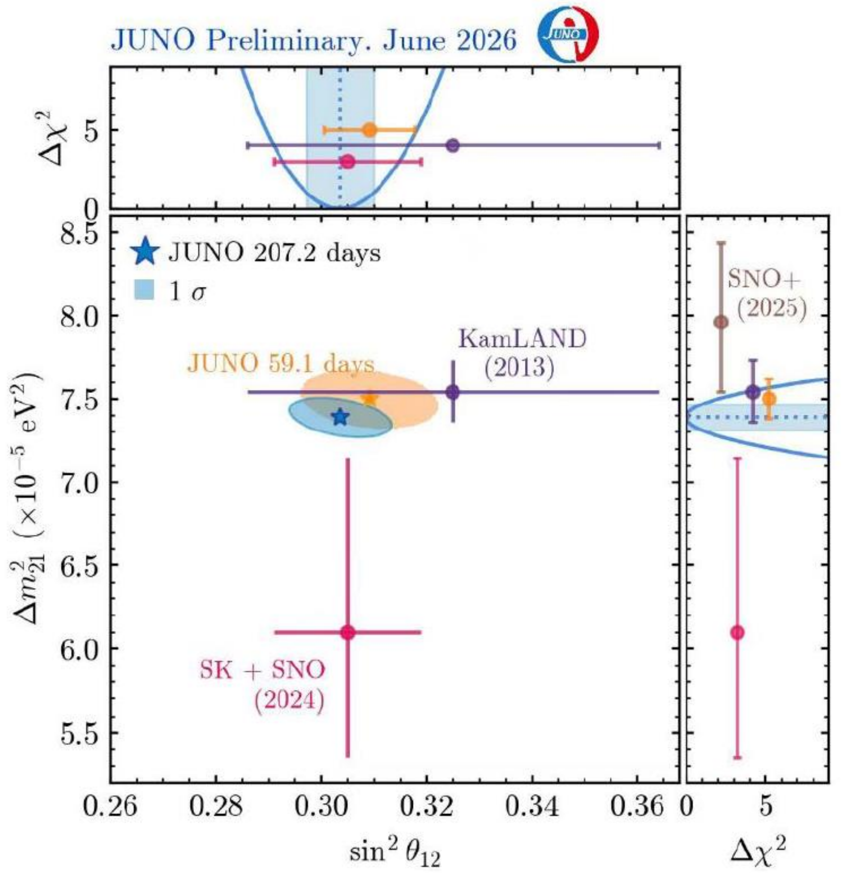



Phys. Rev. D 109, 092001 (2024)

# JUNO: A New Precision Reactor Experiment

- 20-kton liquid scintillator at a 53-km reactor baseline
- Fine spectral structure enables precision oscillation measurements
- Early data already improve solar-sector precision

*JUNO has entered the precision-oscillation era.*

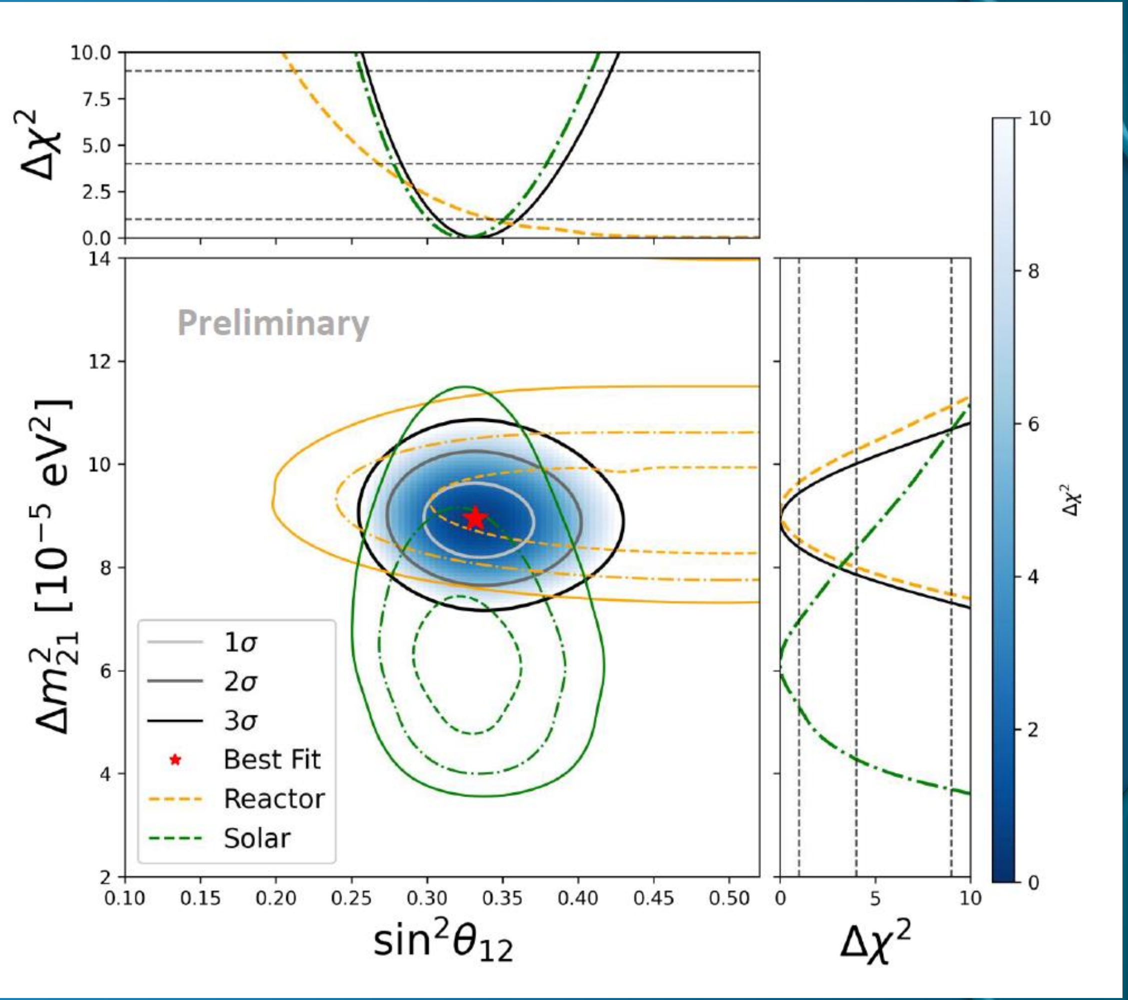



| | |
|---|---|
| $\Delta m^2_{21}$ | 7.388 ± 0.078 (1.60% → 1.06%) |
| $\sin^2\theta_{12}$ | 0.3036 ± 0.0064 (2.8% → 2.1%) |

Y. Wang @ Neutrino 2026

# Solar–Reactor Consistency Test with Super-Kamiokande

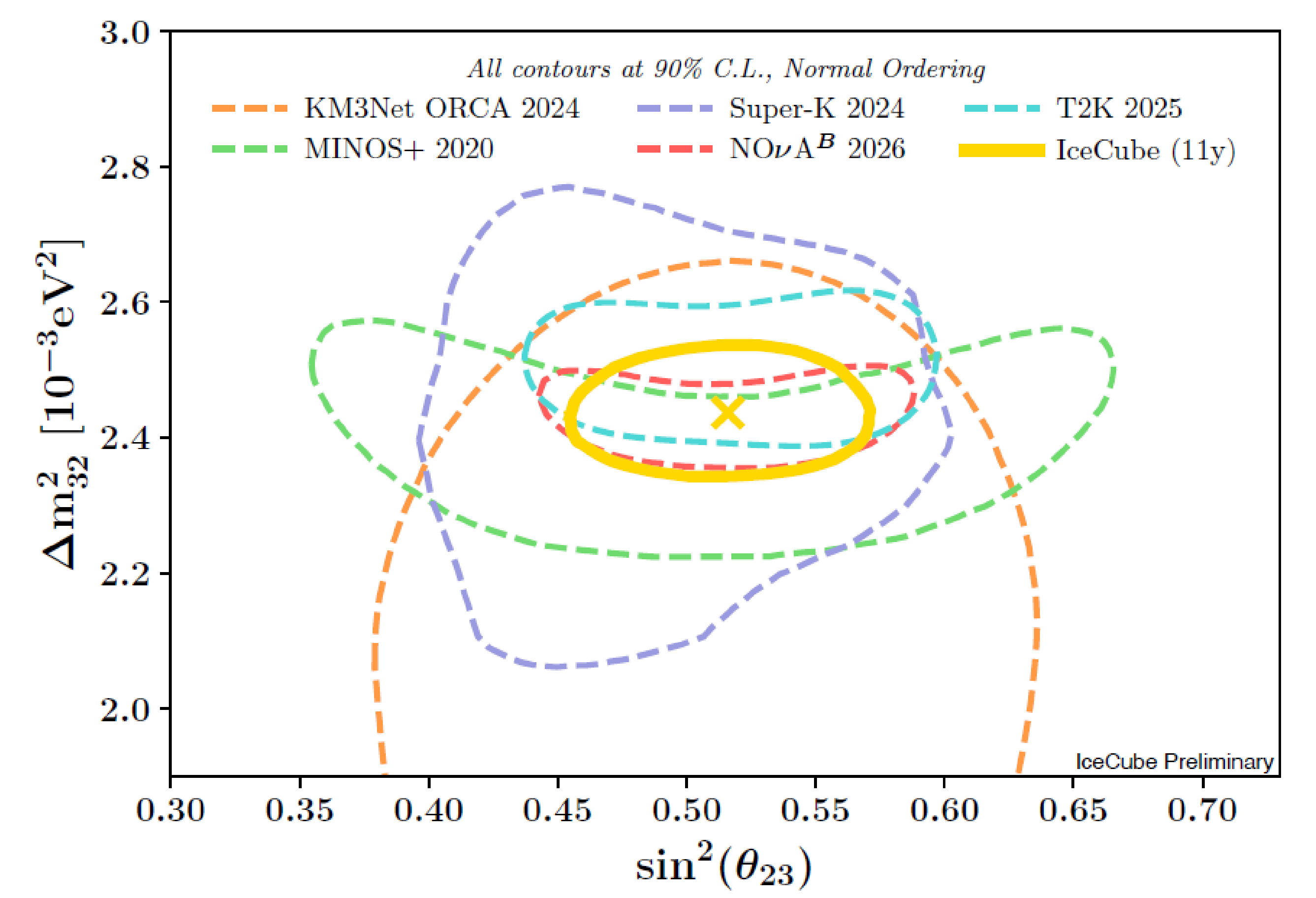
- SK solar (I–IV) vs. reactor (VI–VII): 1.94σ tension in $\Delta m^2_{21}$
- A common detector provides a valuable consistency cross-check




Z. Hu @ Neutrino 2026

# The Atmospheric Sector: Precision and Remaining Ambiguities

- $|\Delta m^2_{atm}|$ is precisely measured in multiple channels
- Precision continues to improve across beam and atmospheric programs
- $\theta_{23}$ is consistent with near-maximal mixing; the octant remains unresolved



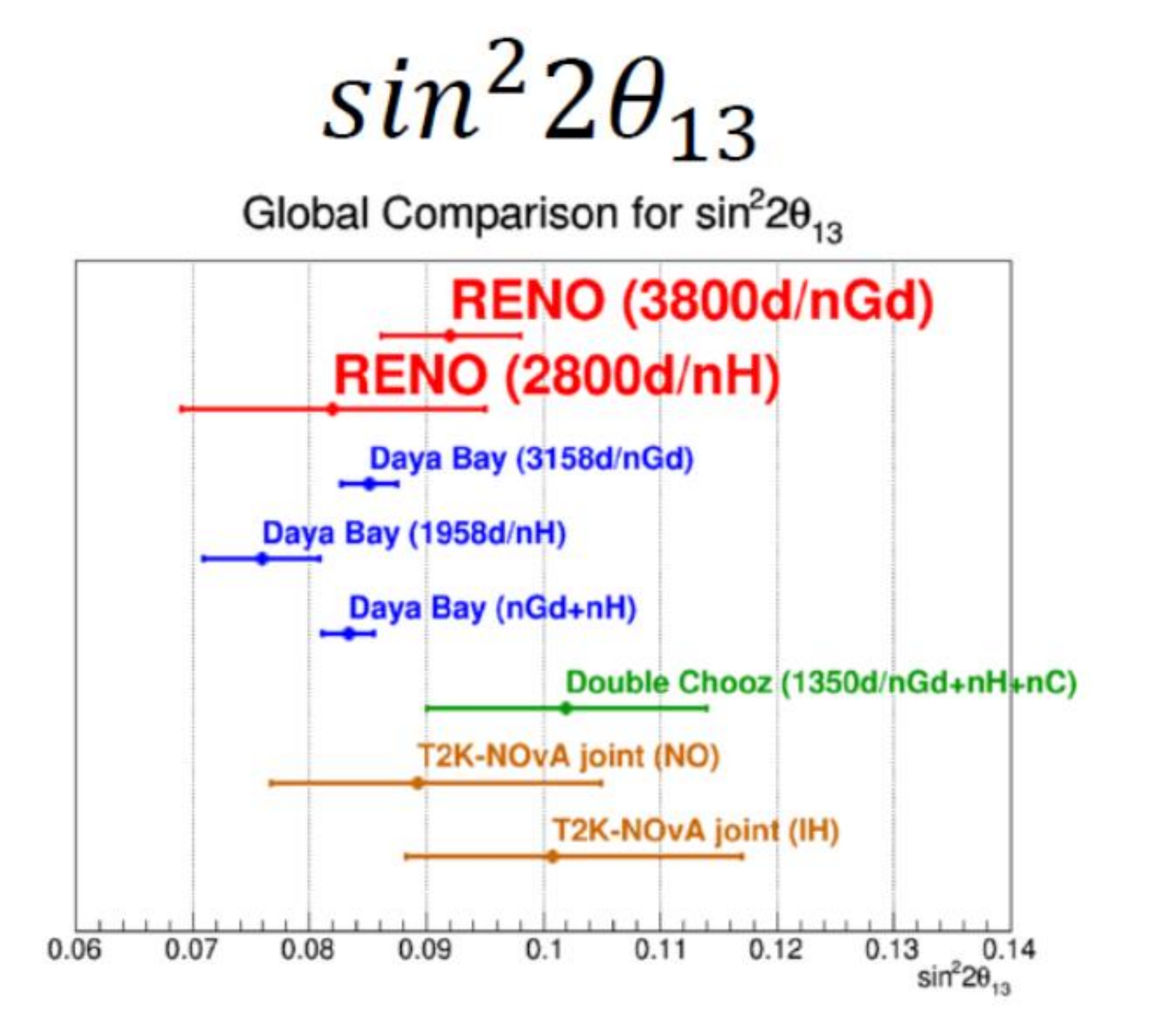

S. N. Axani@ Neutrino 2026

All Neutrino 2026 updates are shown in the backup: T2K, NOvA, MINOS+, Super-K, IceCube, and KM3NeT.

# $\theta_{13}$: Reactor Precision and Accelerator Consistency

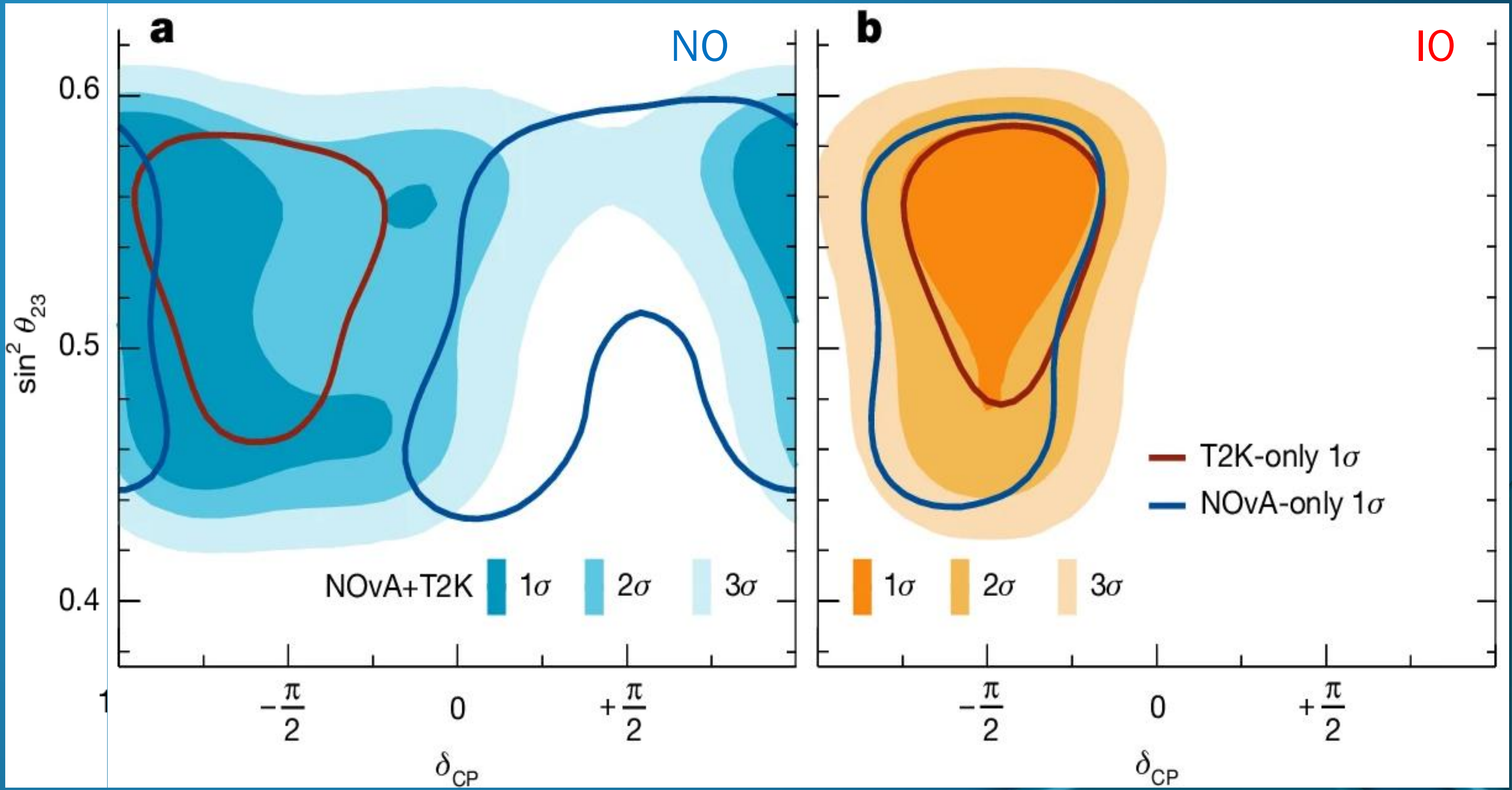
- Daya Bay provides the most precise $\theta_{13}$ measurement
- Reactor and accelerator appearance results are consistent
- A nonzero $\theta_{13}$ enables long-baseline CP-violation searches

*Precision reactor data are a key input to accelerator analyses.*



# Leptonic CP Violation: Current Constraints

- T2K + NOvA joint analysis provides the current beam reference
- CP violation is not yet established

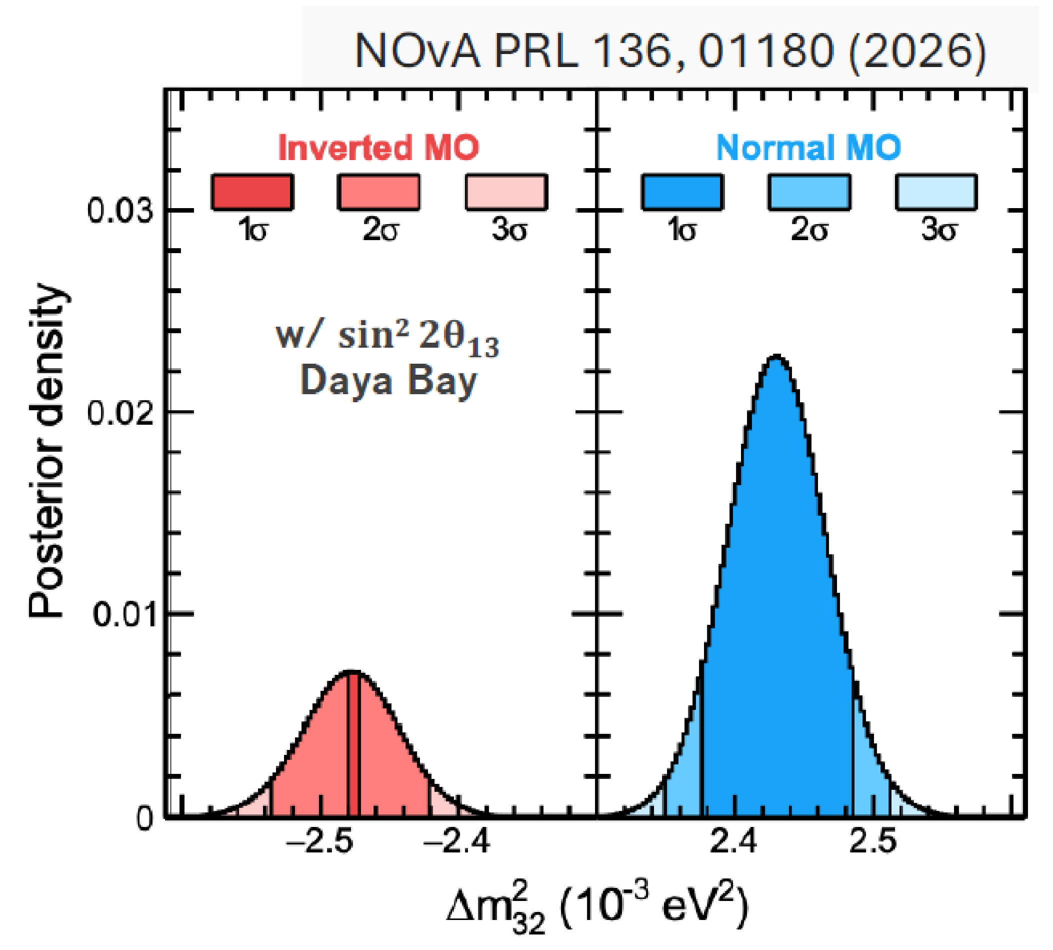



Neutrino 2026 updates: T2K, NOvA, and Super-K,

Nature 646, 818–824 (2025)

# Neutrino Mass Ordering: Complementary Tests

- Beam and atmospheric neutrinos probe ordering through matter effects
- JUNO probes ordering through reactor-spectrum interference
- A robust determination requires agreement across methods




Neutrino 2026 updates: T2K, NOvA, Super-K, KM3NeT, and JUNO

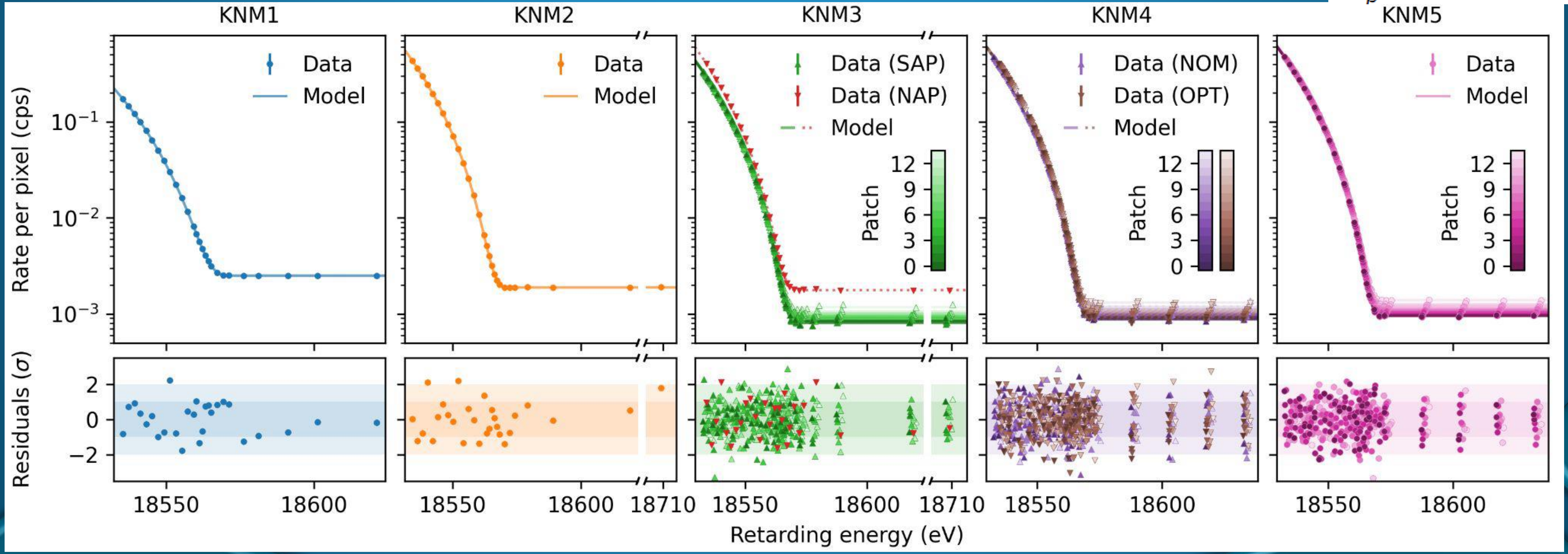
# Near-Future Oscillation Programs

| | Hyper-K | DUNE | KNO |
|---|---|---|---|
| Beam / technology | J-PARC beam / water Cherenkov | Fermilab / LArTPC | J-PARC beam / water Cherenkov |
| Baseline | ~ 295 km | ~1300 km | ~ 1000 km |
| Status | Physics data: 2028 | Far data: early 2030; MW beam: 2031 | ~2× Hyper-K target; funding effort ongoing |

# Absolute Neutrino Mass: Direct Searches and Cosmology

- KATRIN directly constrains the kinematic mass $m_\beta$.
- Cosmology reaches lower masses but depends on the cosmological model and data combination.

$m_\beta$ **< 0.45 eV** (90% CL)

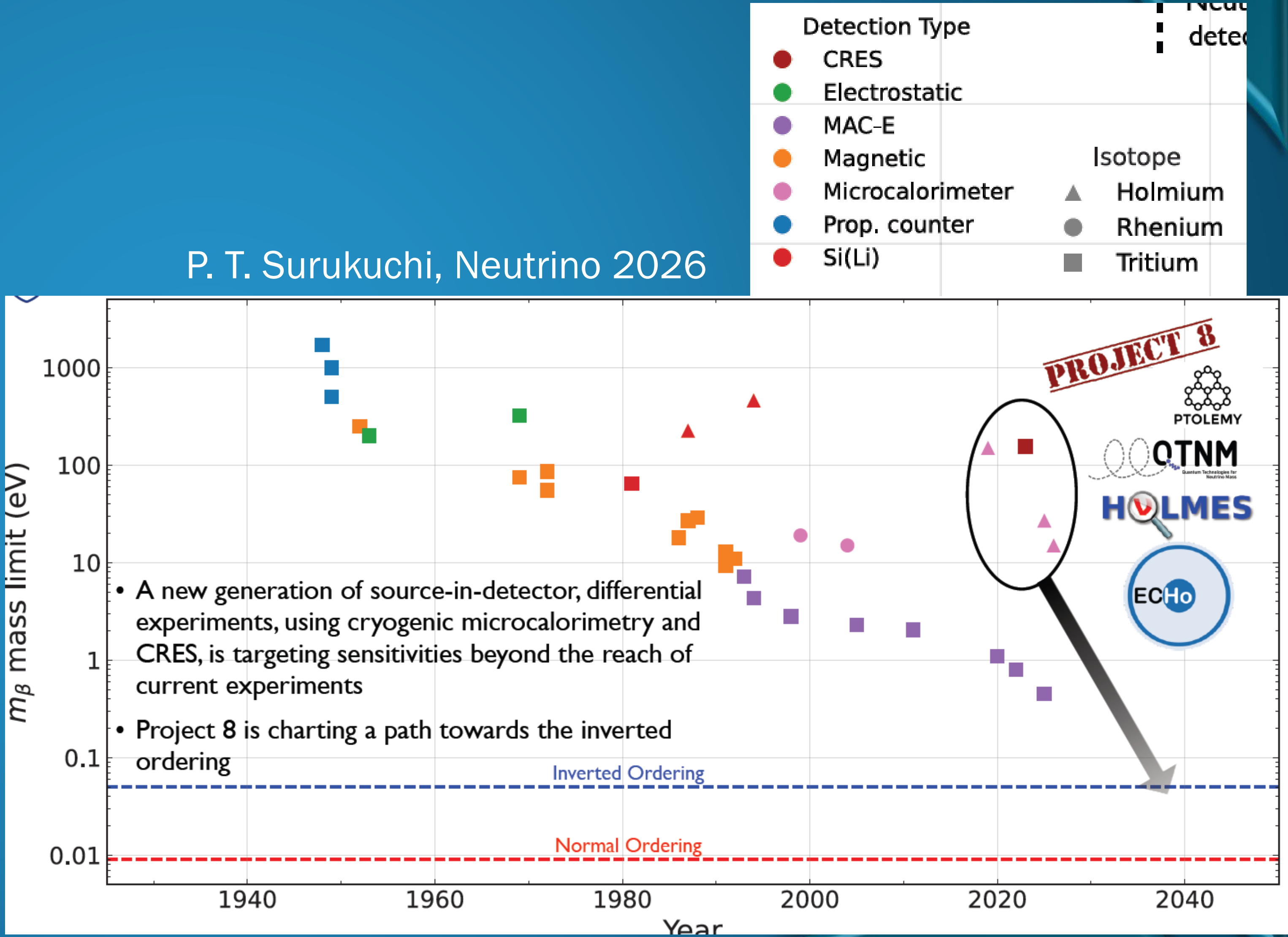



Science 388 (2025) 6743]

# Direct Mass Measurements: Multiple Routes Forward

- KATRIN
  - MAC-E-filter β spectroscopy
  - Current leading direct limit
- Project 8
  - Cyclotron-radiation spectroscopy
  - Atomic-tritium route toward ~40 meV
- ECHo / HOLMES
  - Ho-163 calorimetric electron-capture spectroscopy
  - Independent low-Q approach

P. T. Surukuchi, Neutrino 2026



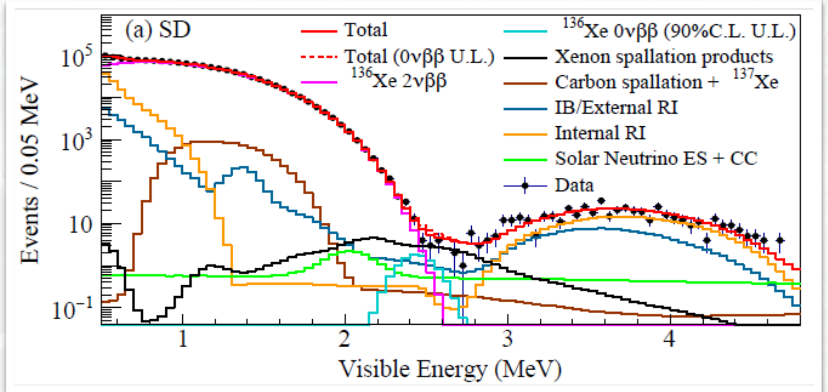
# 0νββ: Current Experimental Landscape

- Present searches set isotope-specific half-life limits
- No signal has been established; backgrounds near $Q_{\beta\beta}$ remain central.

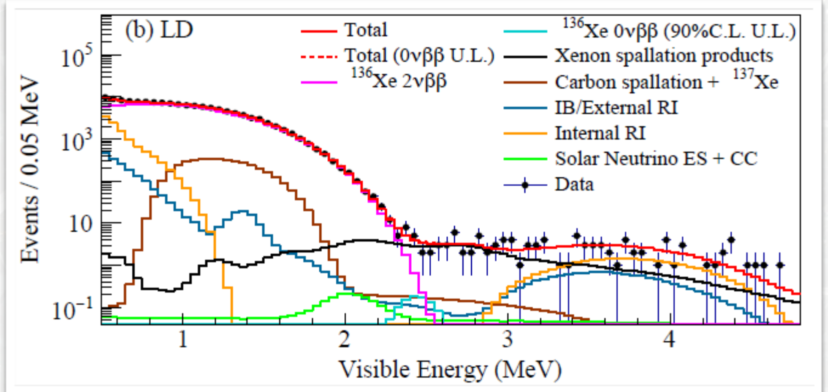
| |
|---|
| Current leading programs |
| Xe: KamLAND-Zen |
| Ge: GERDA / Majorana legacy |
| Te: CUORE |
| Mo: AMoRE |

*Current limits are driven by complementary isotope and detector choices.*

Singles Data (SD) $E \sim 90\,\% \sim 1131$ days




Long-Lived Data (LD) $E \sim 10\,\% \sim 111$ days



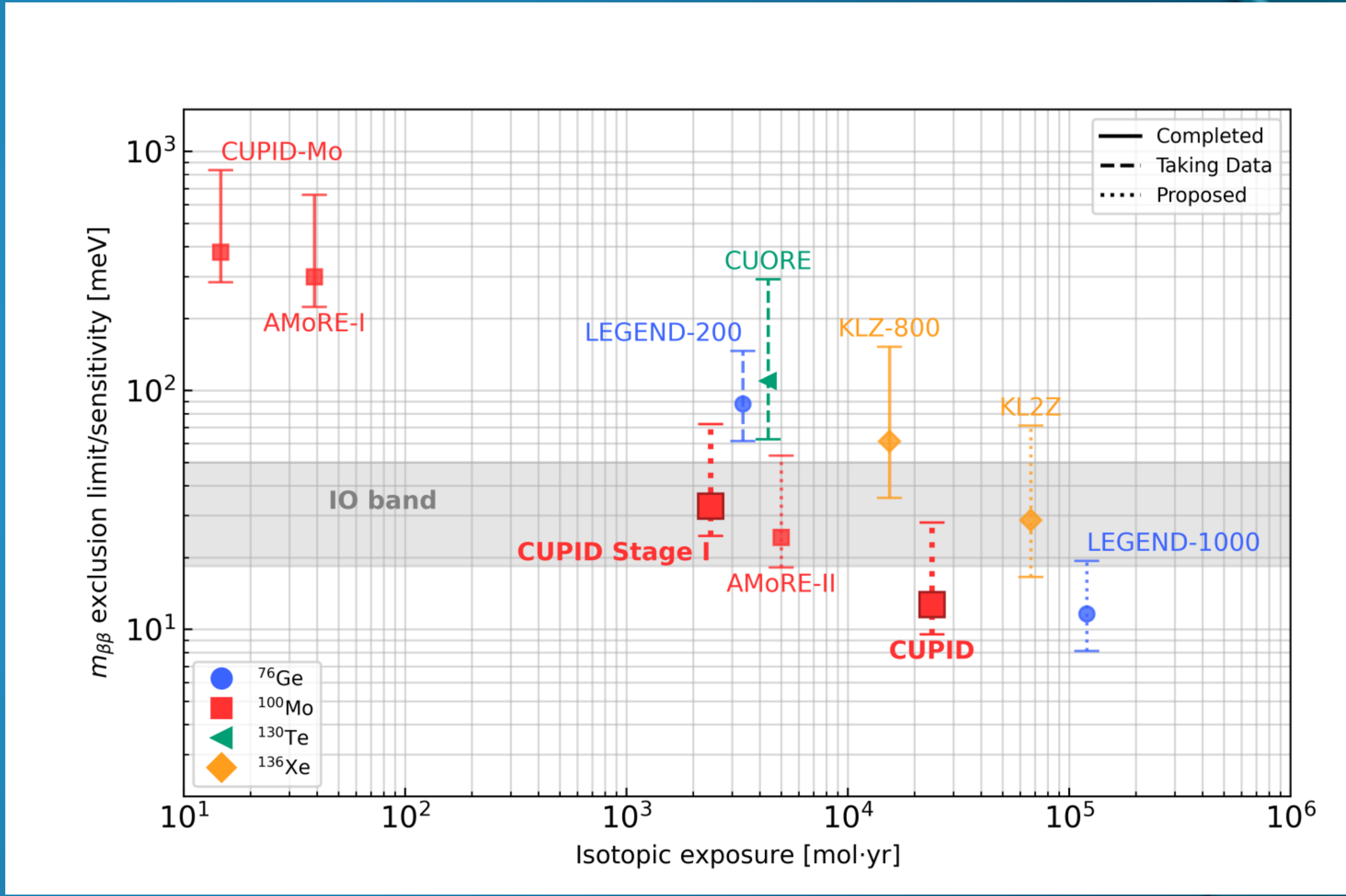

$$T_{1/2}^{0\nu\beta\beta} > 3.8 \times 10^{26} \text{ years}$$



O. Penek, Neutrino 2026

# 0νββ: Next-Generation Discovery Programs

- Larger isotope masses and lower backgrounds extend half-life reach.
- Resolution, topology, and particle ID offer complementary paths to background rejection.
- A discovery requires independent confirmation across isotopes and technologies.



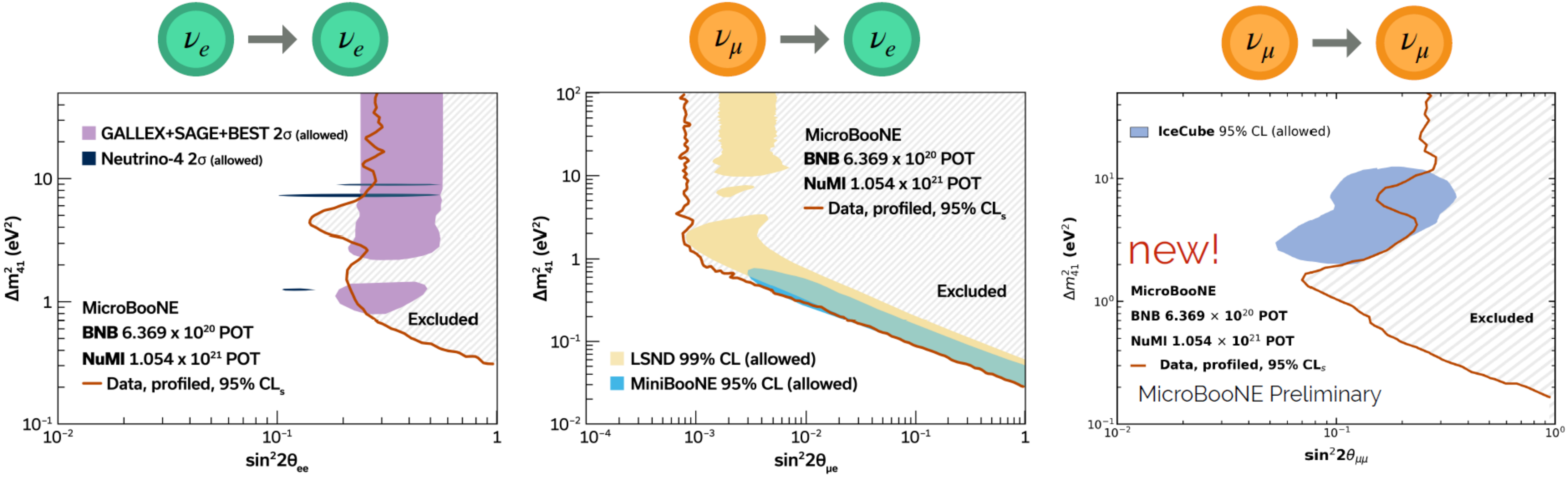

Me Sisti, Neutrino 2026 (CUORE and CUPID)

*The next goal is background-controlled tonne-scale exposure.*

# Sterile Neutrinos: MicroBooNE Constraints

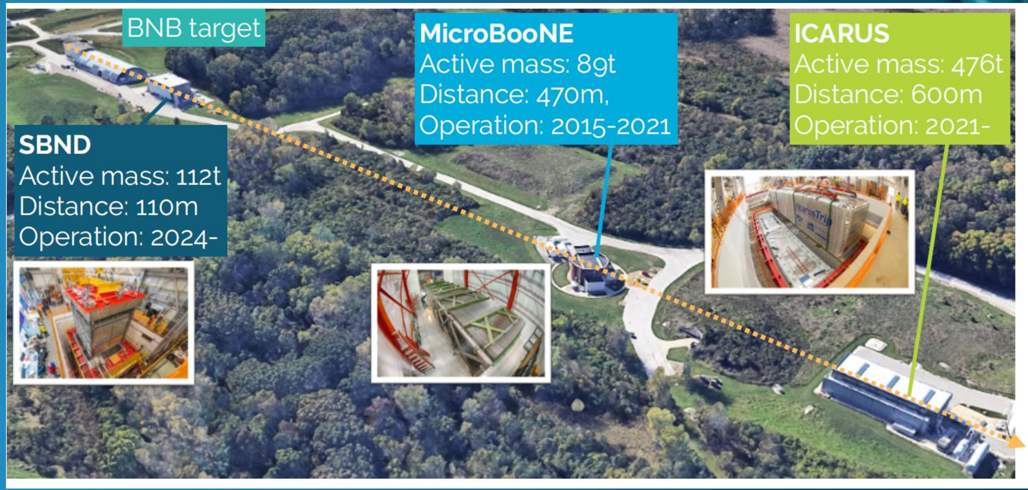
- MicroBooNE tests eV-scale sterile-neutrino parameter space through complementary channels.

J. H. Jo, Neutrino 2026



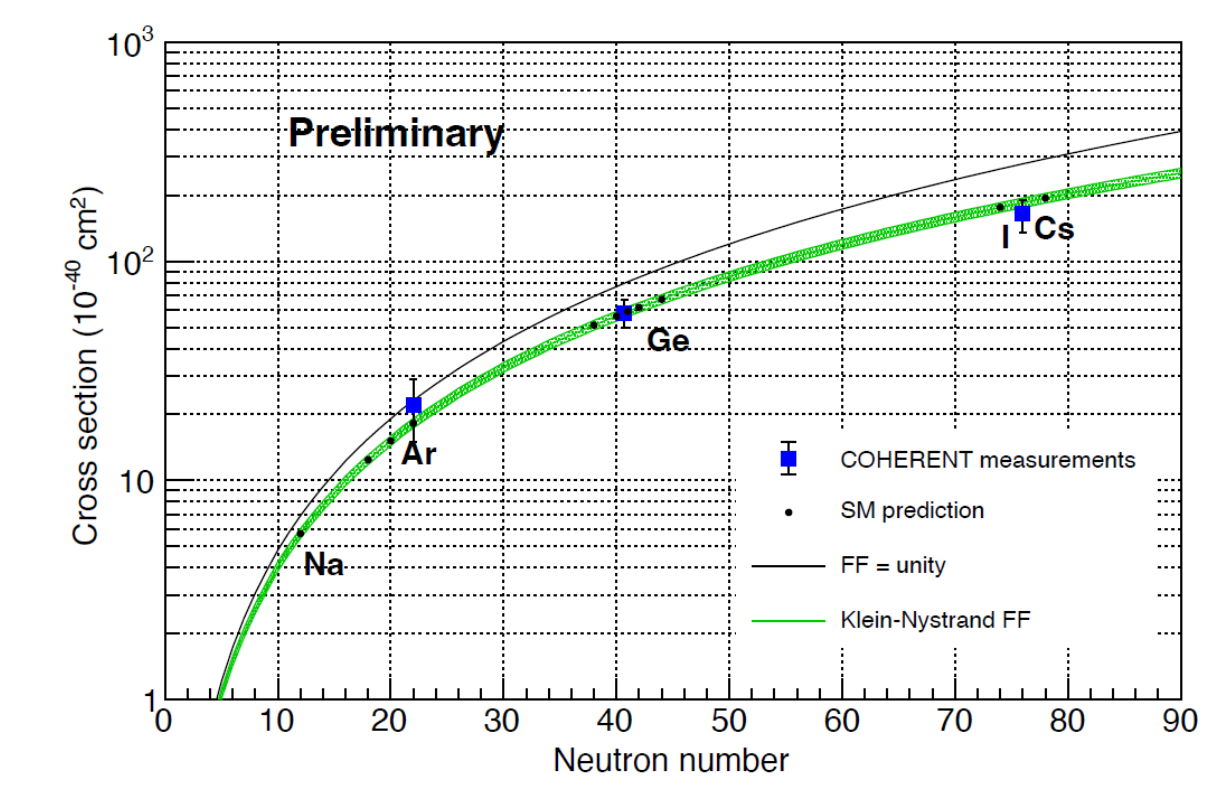
# Sterile-Neutrino Searches with Diverse Neutrino Sources

- Different sources and baselines test complementary sterile-neutrino parameter space.
- Representative ongoing:
  - SBN, JSNS², PROSPECT, STEREO, DANSS, NEOS, SoLid, BEST, IceCube, etc
- Proposed opportunities
  - RENE, IsoDAR@Yemilab, etc



# CEvNS: A Rapidly Developing Frontier

- CEvNS is now experimentally established
- COHERENT tests coherence across multiple nuclear targets
- Low-threshold detectors extend sensitivity to low-energy neutrinos
- New reach: NSI, light mediators, and neutrino electromagnetic properties

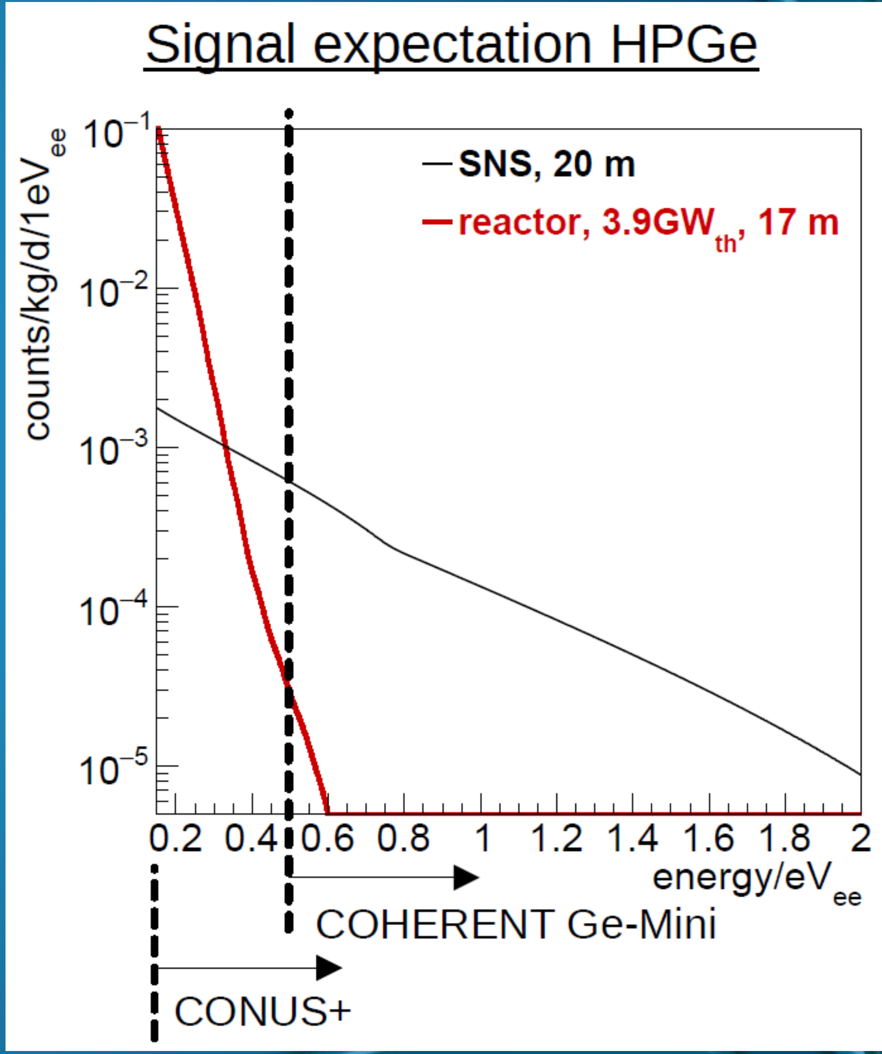



S. Hedges, Neutrino 2026

CEvNS turns low-energy neutrinos into a precision and discovery probe.

# CEvNS: Near-Future Opportunities

- Lower thresholds unlock the reactor CEvNS signal
- Multiple targets separate nuclear and new-physics effects
- Reactor and stopped-pion sources provide complementary energy regimes
- Detector R&D overlaps strongly with dark-matter technology




Threshold and background control define the next CEvNS discoveries.

J. Hakenmuler, Neutrino 2026

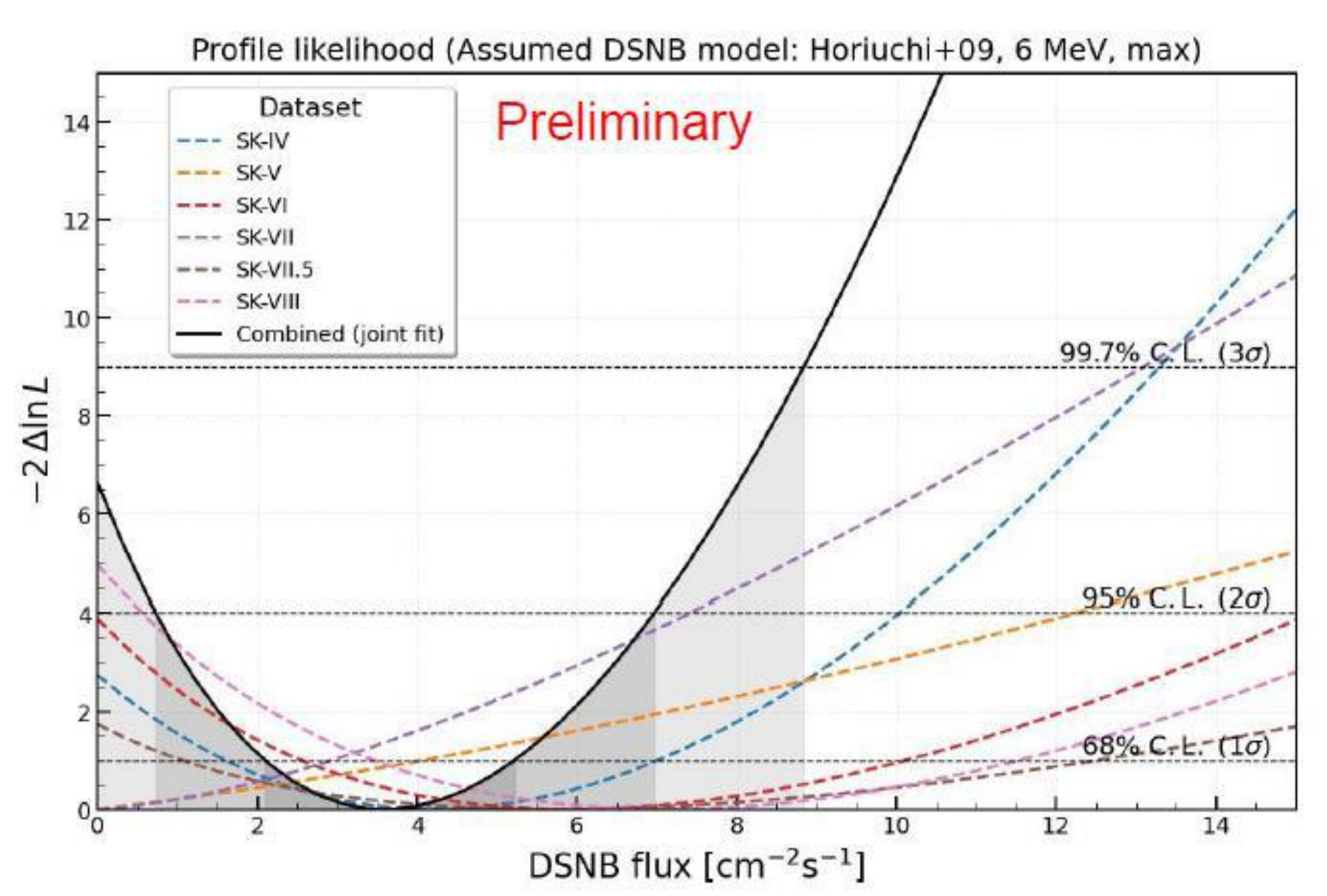
# Supernova Burst Neutrinos: Detector Complementarity

- Operating detectors continuously monitor the next Galactic burst
  - Super-K, IceCube, KamLAND, SNO+, JUNO, etc.: current network

- Future large detectors will greatly extend sensitivity
  - Hyper-K, DUNE, KNO (funding effort ongoing)

# DSNB: The Next Diffuse Neutrino Signal

- Relic $\bar{\nu}_e$ flux from all past core-collapse supernovae
- Super-K-Gd reports a 2.6σ preference for a DSNB component
- Neutron tagging is central to background suppression
- JUNO and Hyper-K will provide decisive tests



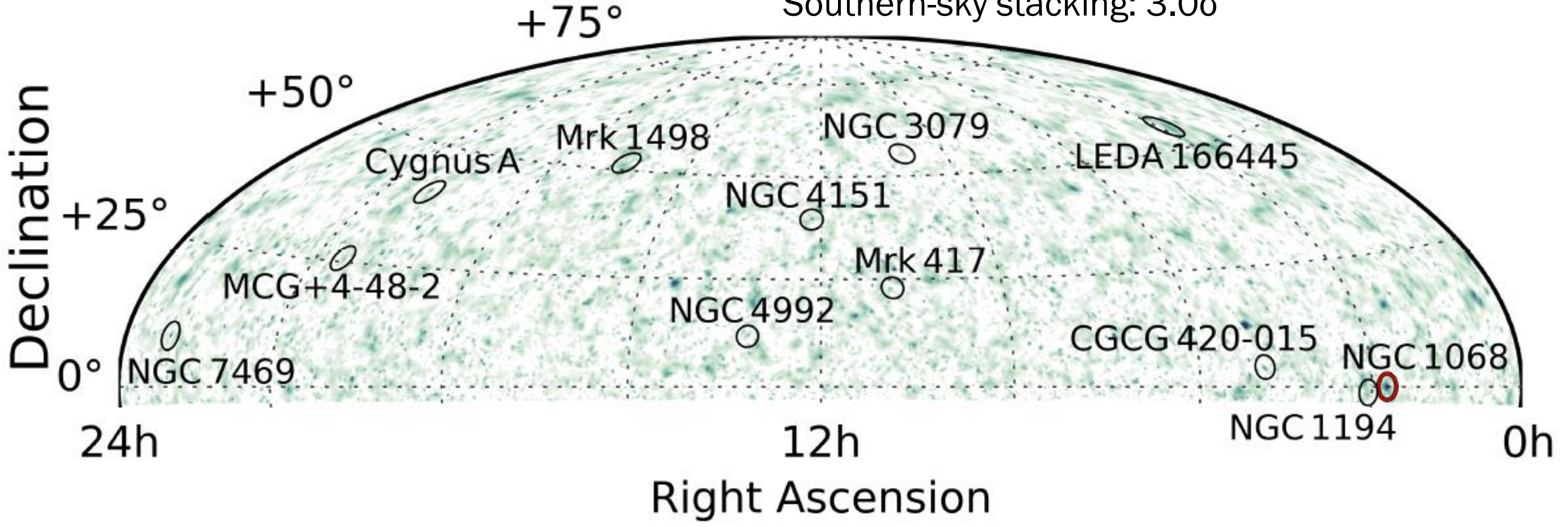

H. Sekiya, Neutrino 2026

# High-Energy Neutrinos: From Flux Discovery to Source Identification

- The diffuse astrophysical neutrino flux is established
- Population studies point to γ-ray-obscured AGN as candidate sources
- IceCube-Gen2 and KM3NeT will test these emerging associations

IceCube: accumulating evidence for neutrinos from γ-ray-obscured AGN

Northern-sky ensemble (11 sources): 3.3σ
NGC 4151: 2.9σ
Southern-sky stacking: 3.0σ

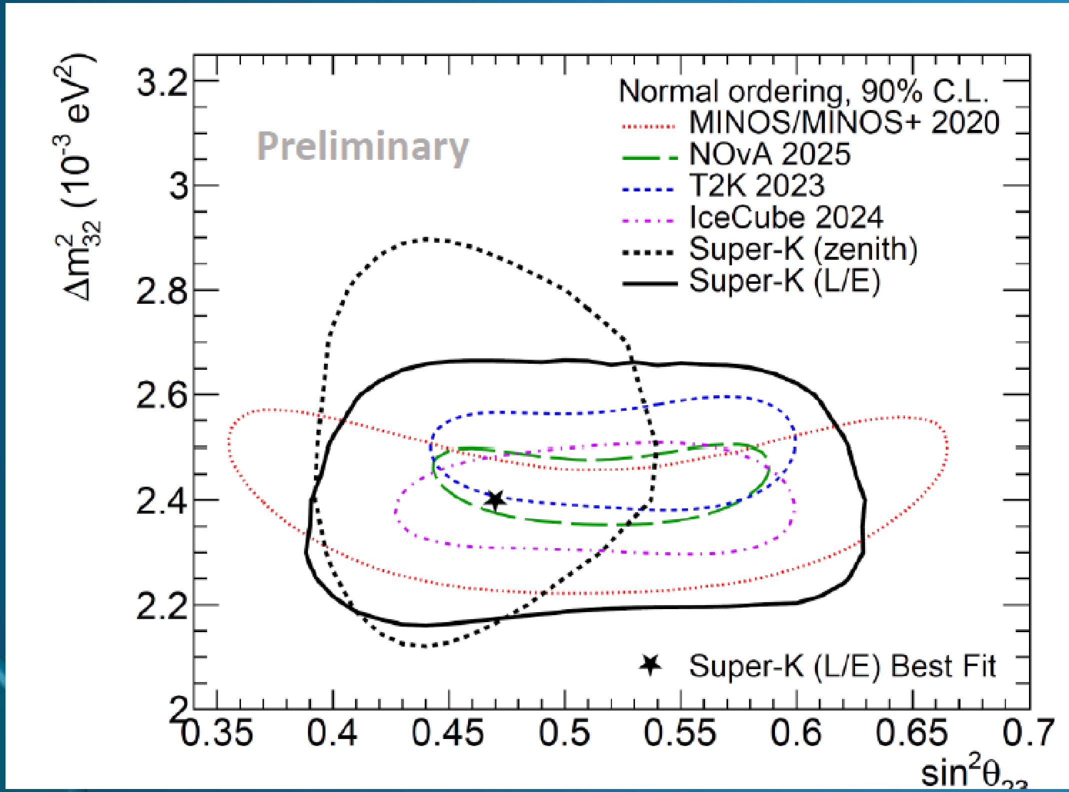


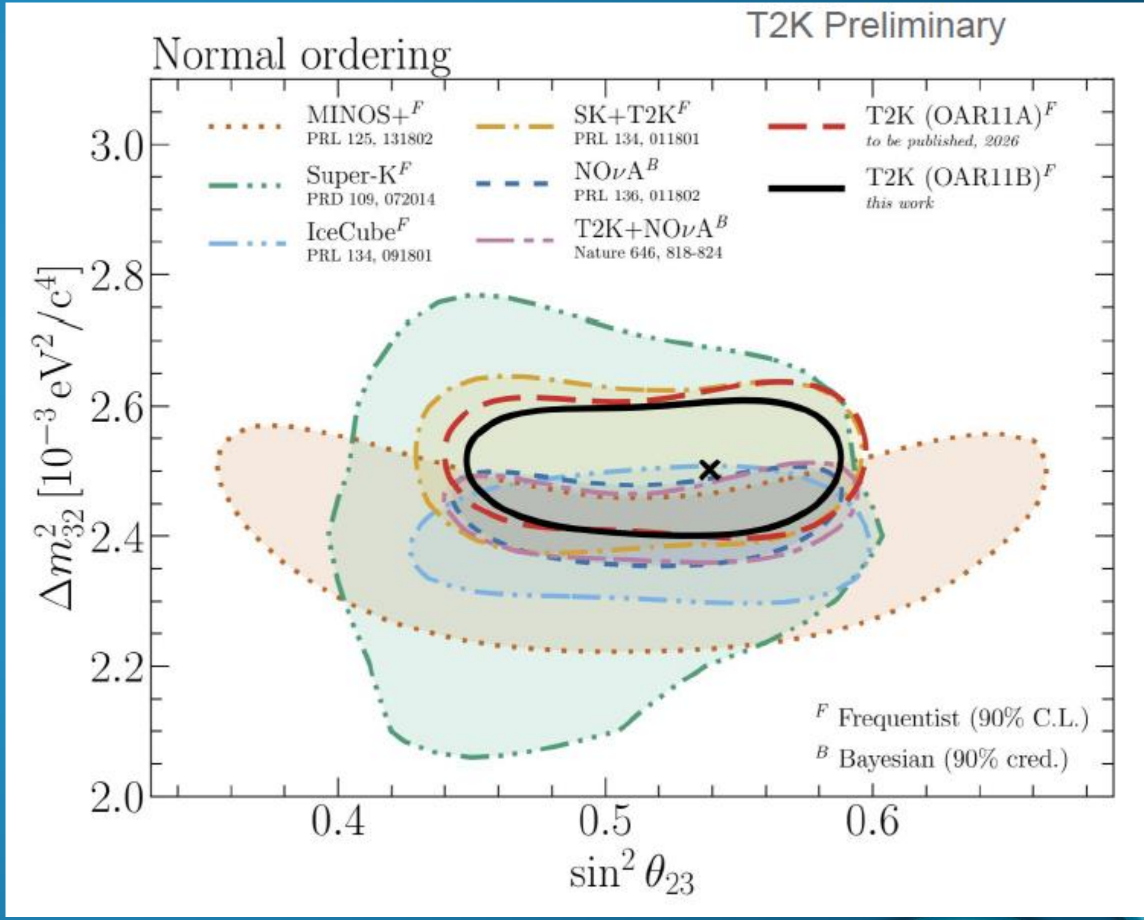

A. Kheirandish, Neutrino 2026

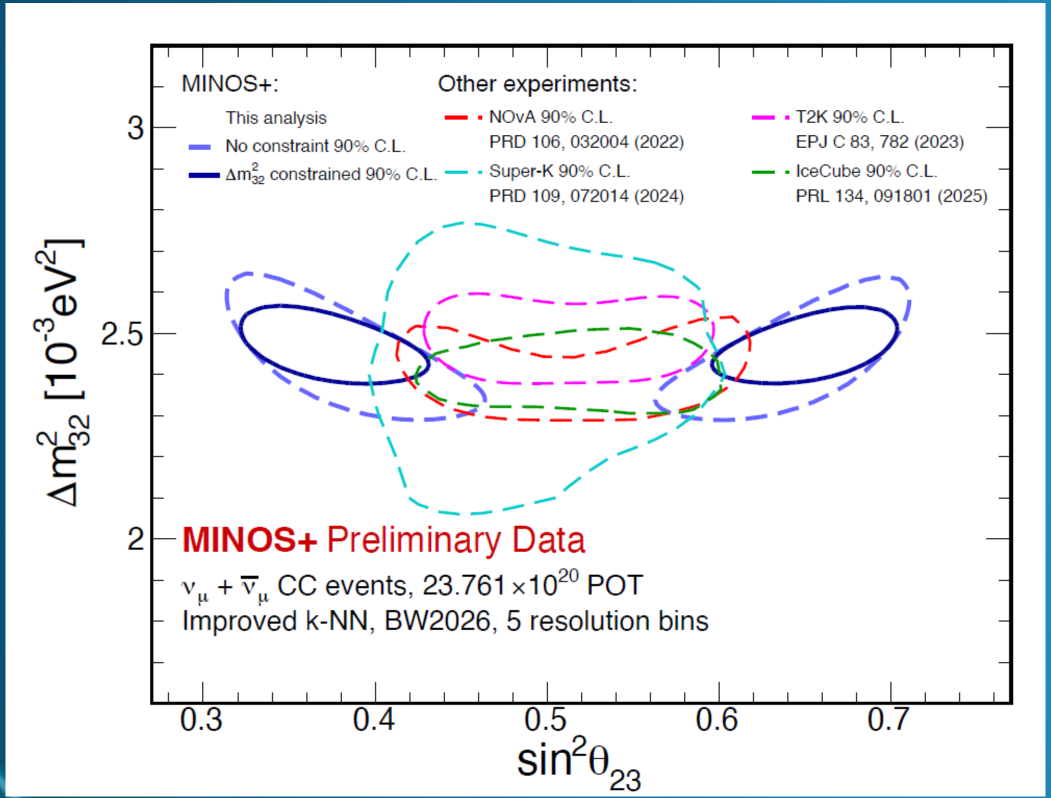
# Take-Home Messages

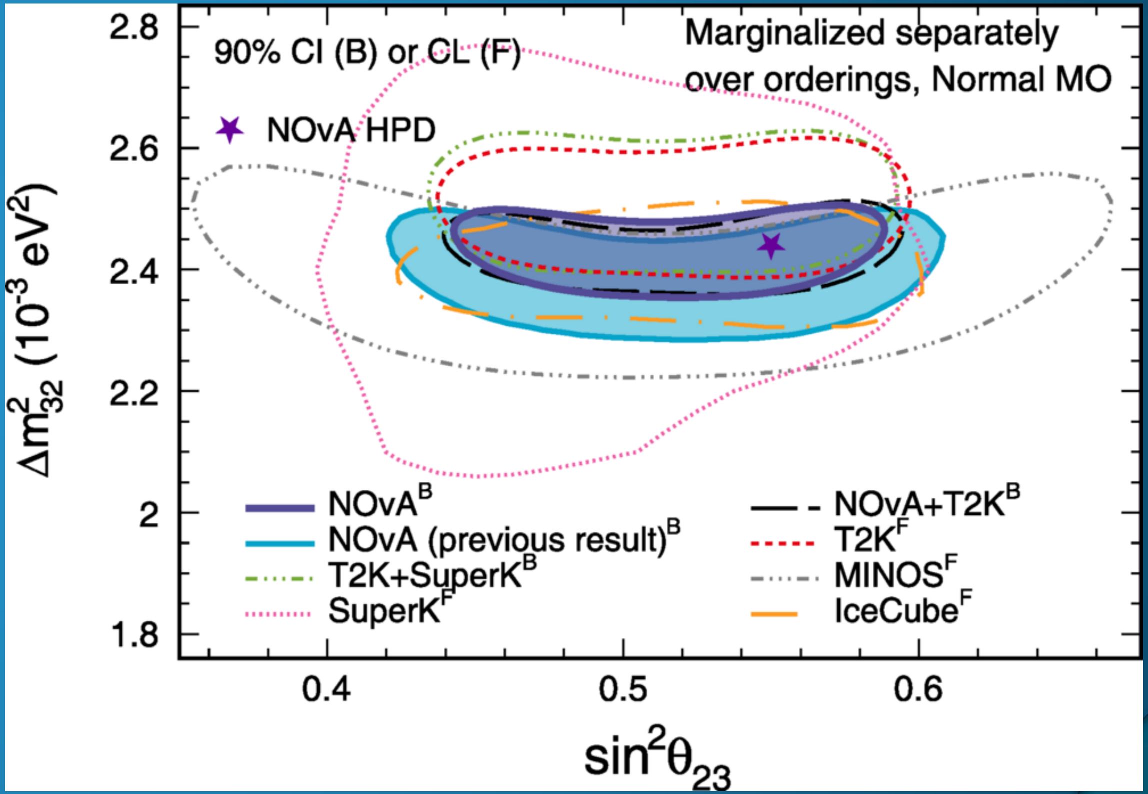
- Oscillations are established; precision questions remain
- CP violation and ordering are near-term targets
- JUNO, Hyper-K, and DUNE are complementary
- 0νββ, CEνNS, and DSNB broaden discovery potential

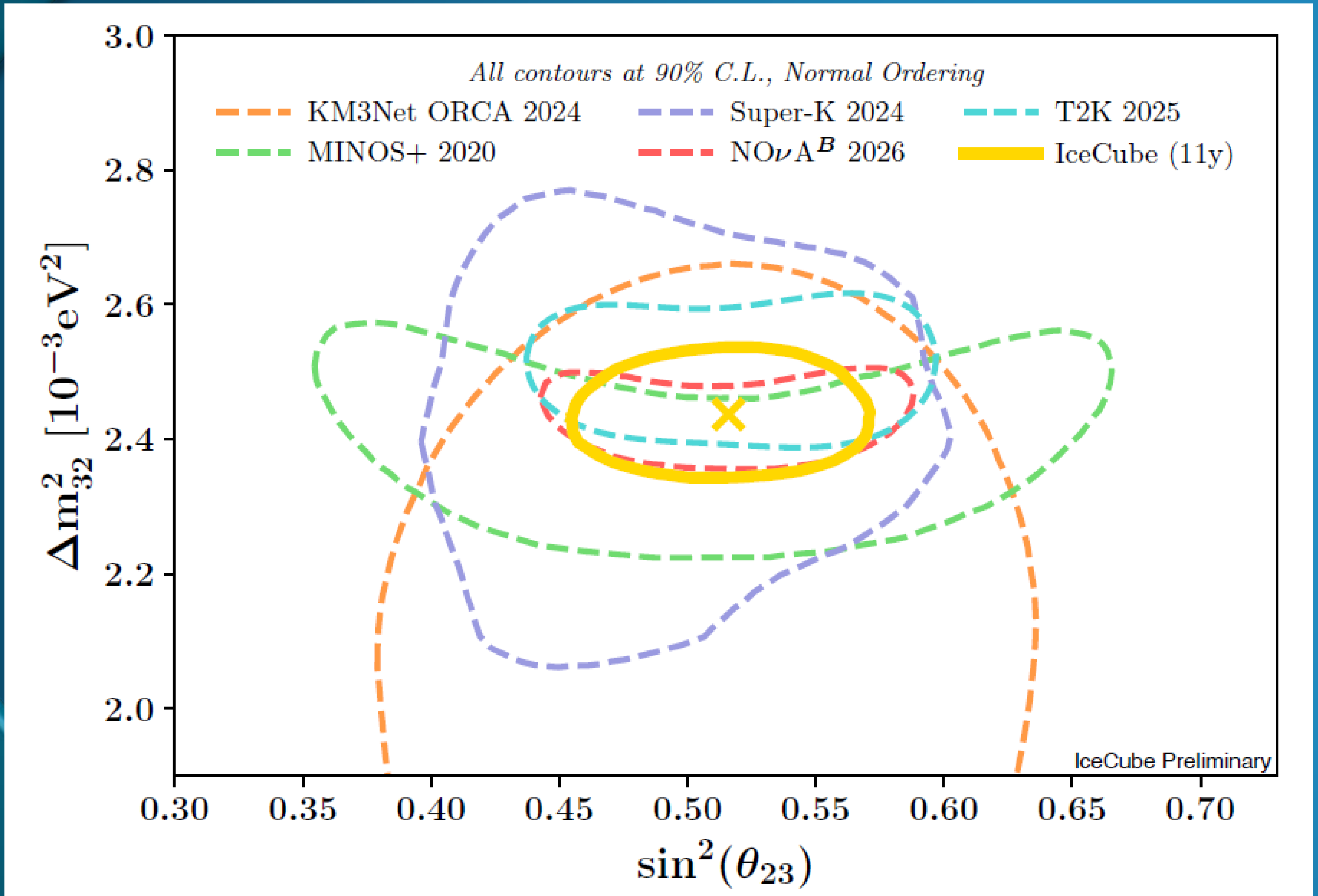
# Backup


Normal ordering, 90% C.L.
MINOS/MINOS+ 2020
NOvA 2025
T2K 2023
IceCube 2024
Super-K (zenith)
Super-K (L/E)
Preliminary
Super-K (L/E) Best Fit
$\Delta m^2_{32}$ ($10^{-3}$ eV$^2$)
$\sin^2\theta_{23}$

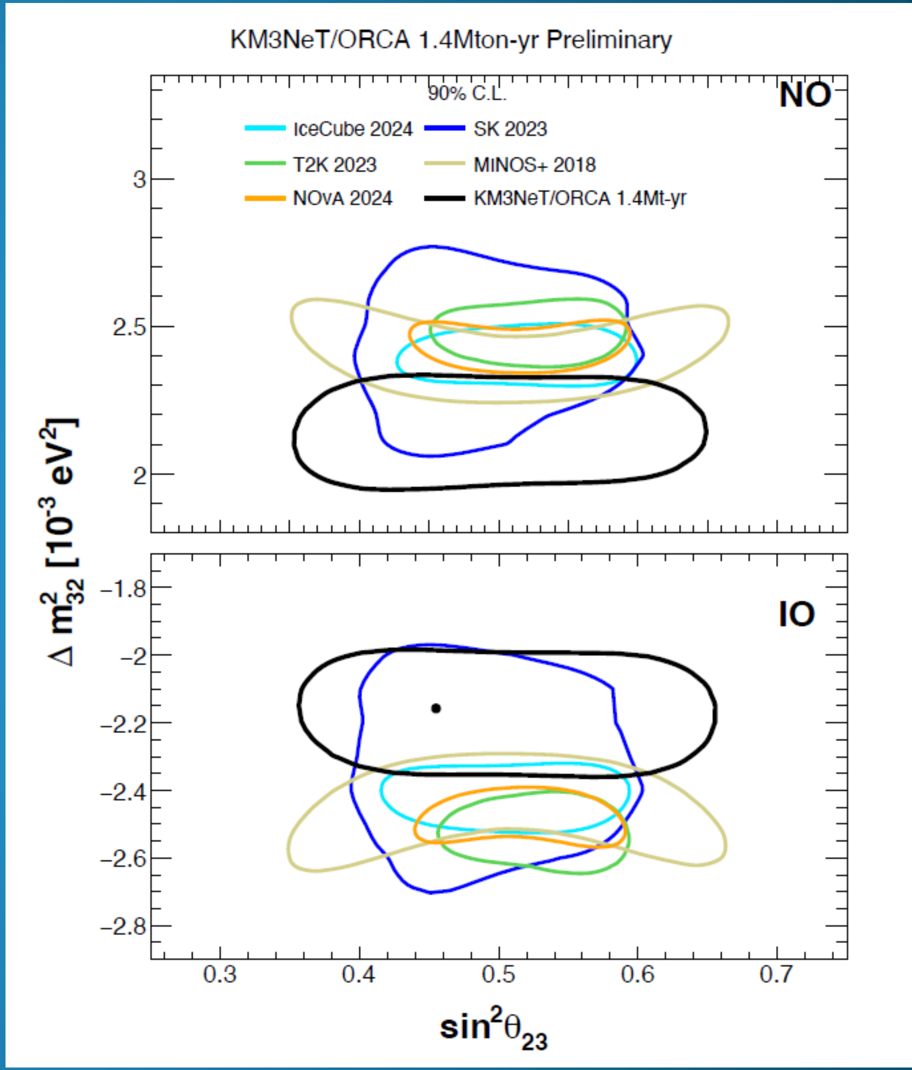

T2K Preliminary
Normal ordering
MINOS+$^F$
PRL 125, 131802
SK+T2K$^F$
PRL 134, 011801
T2K (OAR11A)$^F$
to be published, 2026
Super-K$^F$
PRD 109, 072014
NO$\nu$A$^B$
PRL 136, 011802
T2K (OAR11B)$^F$
this work
IceCube$^F$
PRL 134, 091801
T2K+NO$\nu$A$^B$
Nature 646, 818-824
$^F$ Frequentist (90% C.L.)
$^B$ Bayesian (90% cred.)
$\Delta m^2_{32}$ [$10^{-3}$ eV$^2$/c$^4$]
$\sin^2\theta_{23}$


MINOS+:
This analysis
No constraint 90% C.L.
$\Delta m^2_{32}$ constrained 90% C.L.
Other experiments:
NOvA 90% C.L. PRD 106, 032004 (2022)
Super-K 90% C.L. PRD 109, 072014 (2024)
T2K 90% C.L. EPJ C 83, 782 (2023)
IceCube 90% C.L. PRL 134, 091801 (2025)
MINOS+ Preliminary Data
$\nu_\mu + \bar{\nu}_\mu$ CC events, $23.761 \times 10^{20}$ POT
Improved k-NN, BW2026, 5 resolution bins
$\Delta m^2_{32}$ [$10^{-3}$eV$^2$]
$\sin^2\theta_{23}$

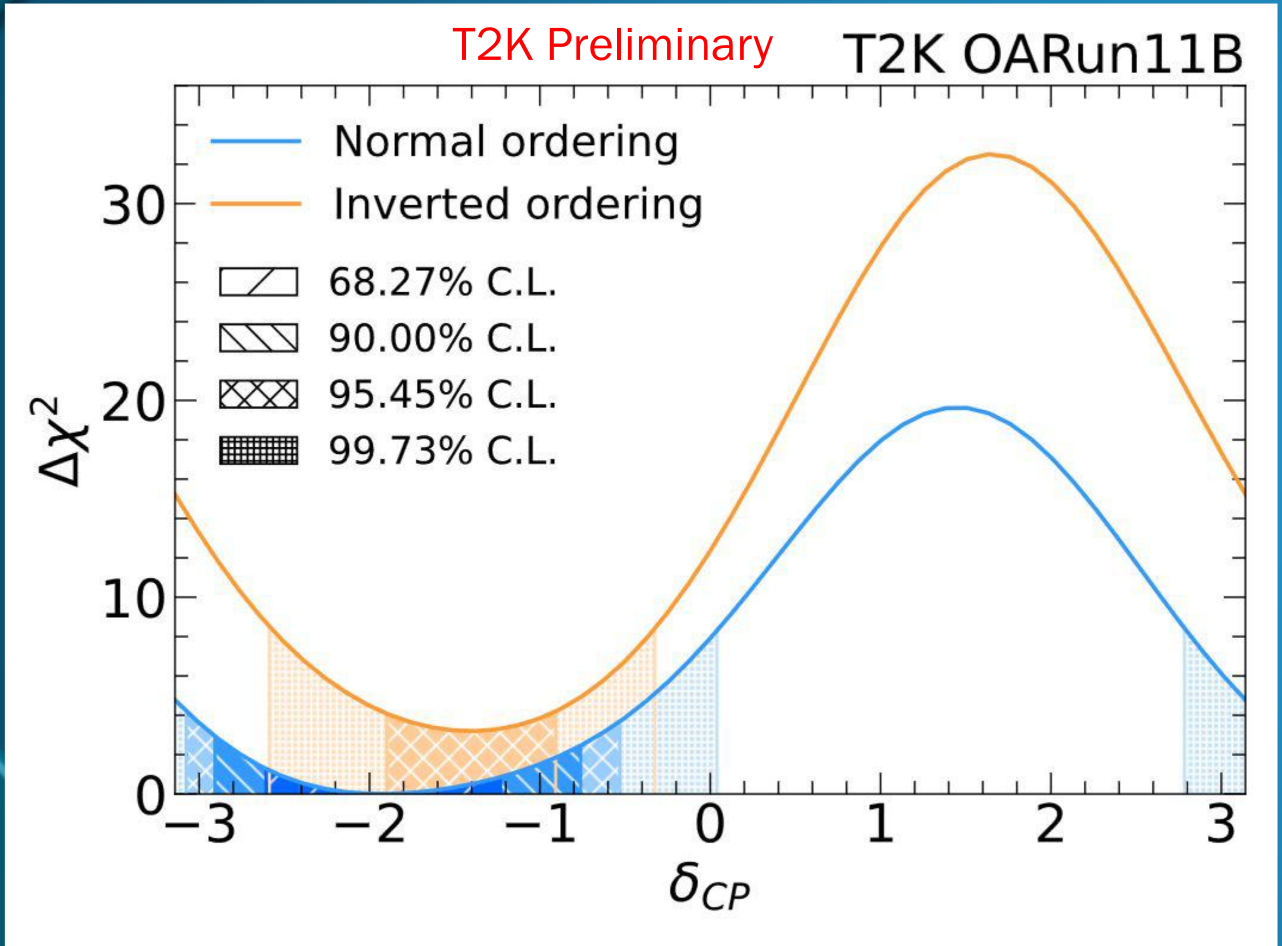

90% CI (B) or CL (F)
Marginalized separately over orderings, Normal MO
NOvA HPD
NOvA$^B$
NOvA (previous result)$^B$
T2K+SuperK$^B$
SuperK$^F$
NOvA+T2K$^B$
T2K$^F$
MINOS$^F$
IceCube$^F$
$\Delta m^2_{32}$ ($10^{-3}$ eV$^2$)
$\sin^2\theta_{23}$

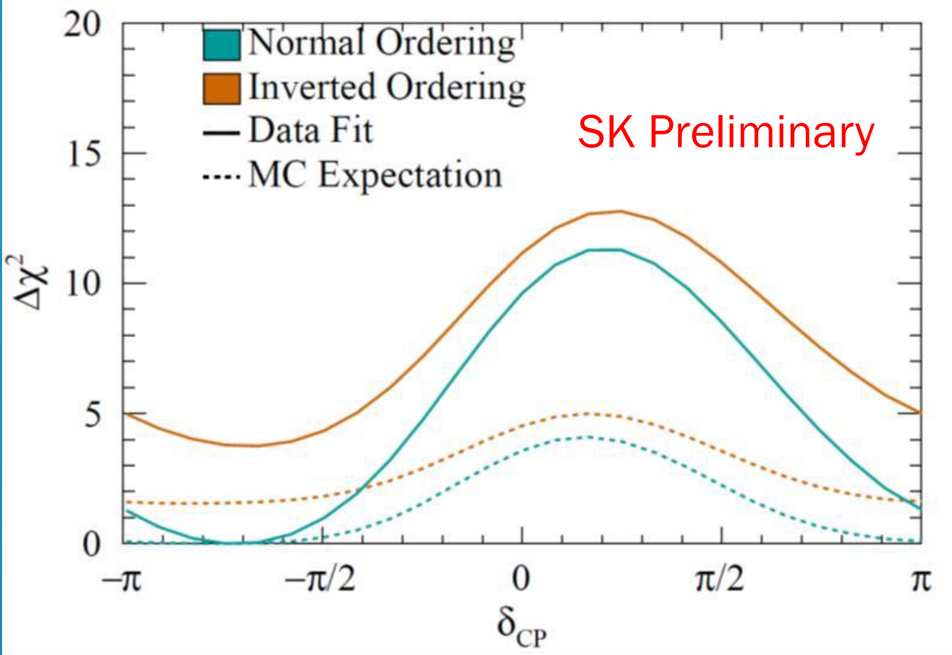


All contours at 90% C.L., Normal Ordering
KM3Net ORCA 2024
Super-K 2024
T2K 2025
MINOS+ 2020
NO$\nu$A$^B$ 2026
IceCube (11y)
IceCube Preliminary
$\Delta m^2_{32}$ $[10^{-3}\mathrm{eV}^2]$
$\sin^2(\theta_{23})$

KM3NeT/ORCA 1.4Mton-yr Preliminary
90% C.L.
NO
IceCube 2024
SK 2023
T2K 2023
MINOS+ 2018
NOvA 2024
KM3NeT/ORCA 1.4Mt-yr
IO
$\Delta m^2_{32}$ $[10^{-3}\ \mathrm{eV}^2]$
$\sin^2\theta_{23}$


T2K Preliminary
T2K OARun11B
Normal ordering
Inverted ordering
68.27% C.L.
90.00% C.L.
95.45% C.L.
99.73% C.L.
$\Delta\chi^2$
$\delta_{CP}$

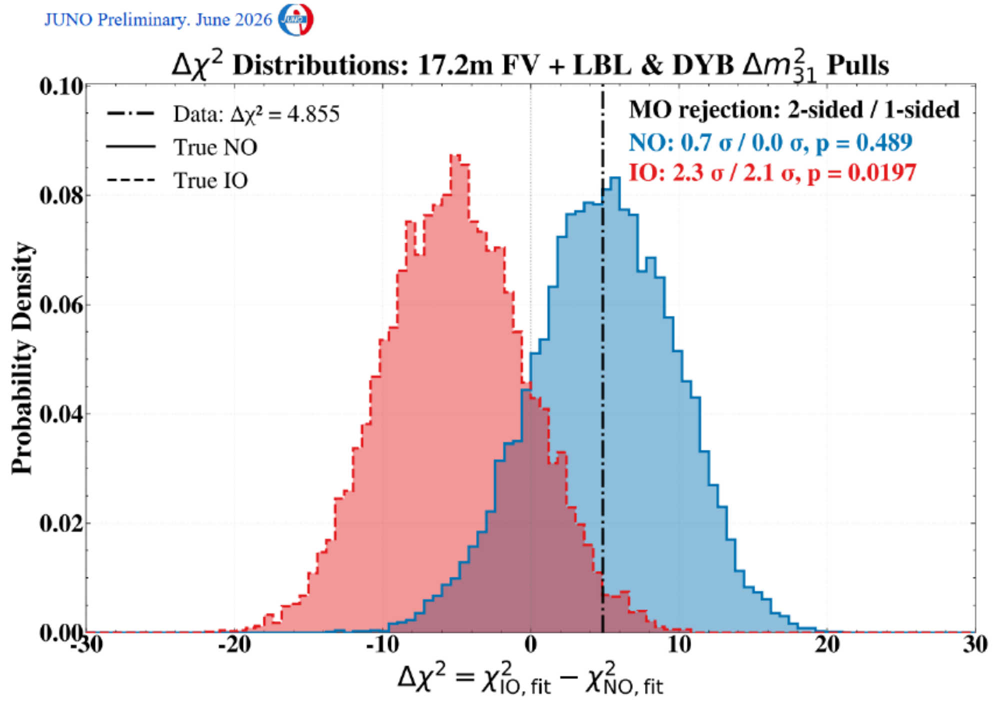

Normal Ordering
Inverted Ordering
Data Fit
MC Expectation
SK Preliminary
$\Delta\chi^2$
$\delta_{CP}$

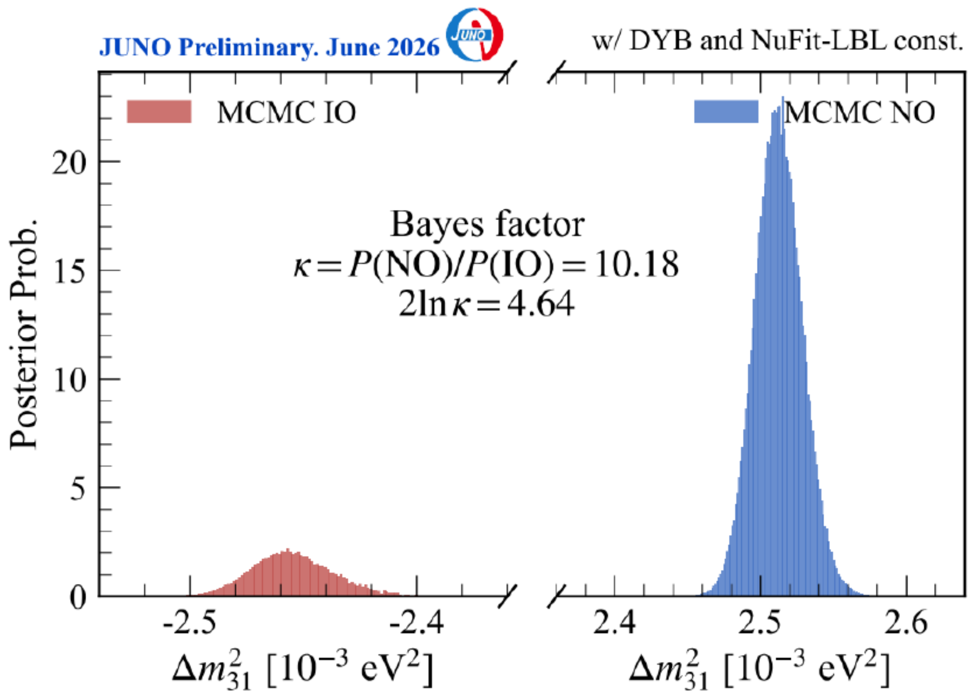
# Neutrino Mass Ordering Significance

Posters: 252, 205

- Frequentist approach using pseudo exp. to convert $\Delta\chi^2$ to significance
- Influence of $\delta_{CP}$ considered (scanned)
- Normal Ordering is favored at **2.3σ**

- Bayesian approach using Markov Chain Monte Carlo(MCMC) method
- Normal Ordering is favored with a Bayes factor of **10.18** ➔ 2ln κ= 4.64
  - ⇨ Consistent with the frequentist $\Delta\chi^2$

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