Annual MAPS Meeting

Existing Solutions to the NOvA–T2K Tension

A Comprehensive Literature Review & Status Update

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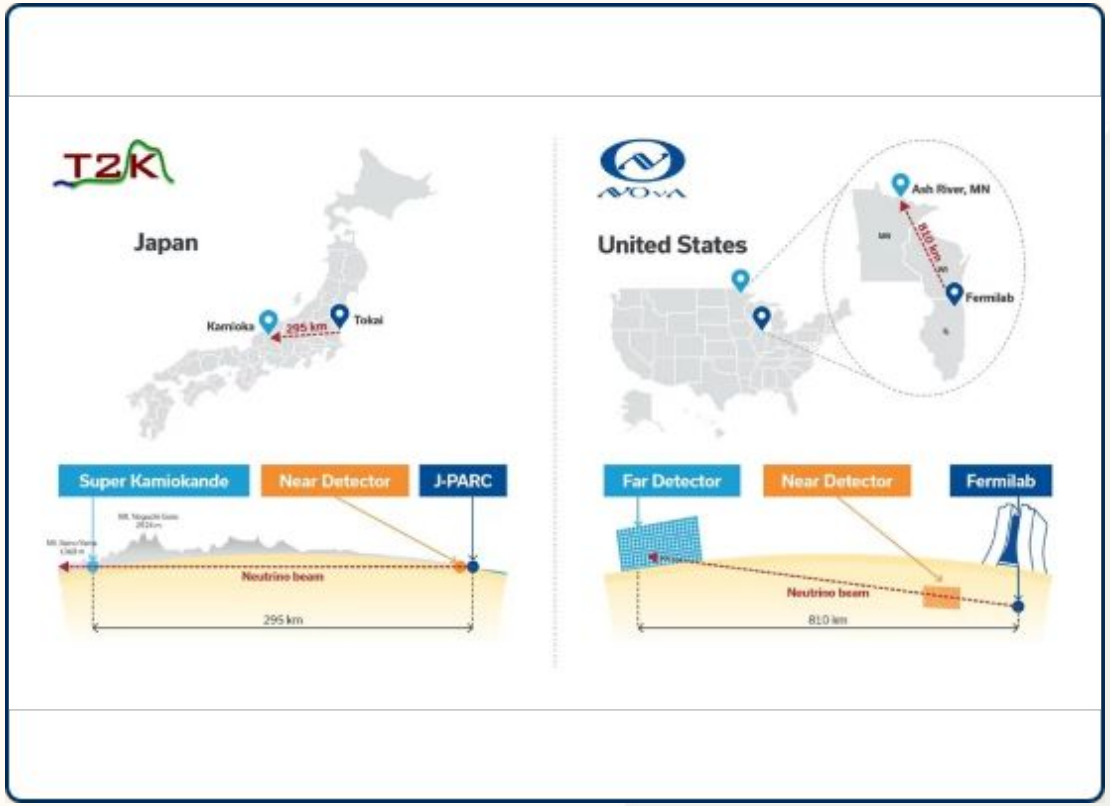
COMPLEMENTARY ARCHITECTURES

- **T2K (Japan):** 295 km baseline, 0.6 GeV peak energy. Narrow-band beam focused on the 1st oscillation maximum.
- **NOvA (USA):** 810 km baseline, 2.0 GeV peak energy. Large matter effects due to longer Earth propagation.
- **The Tension:** A mismatch in observed ν_e appearance rates leads to divergent preferred values for δ_{CP}.

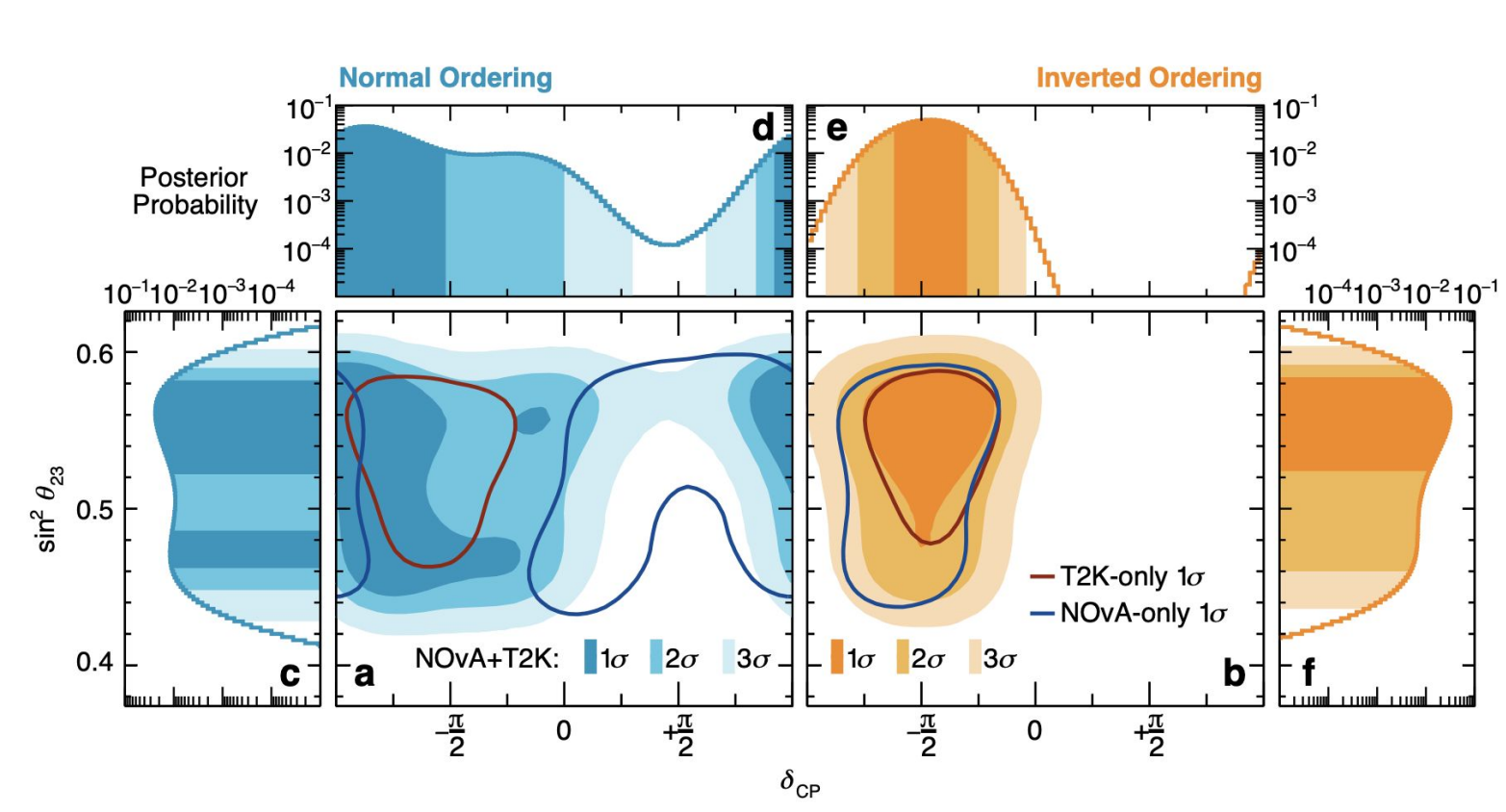


Ref: Rahaman et al., 2022

The Core Discrepancy

T2K: Massive ν_e appearance Excess
Strong demand for maximal CP violation:
$\delta_{CP} \approx 1.5\,\pi$

NOvA: Moderate ν_e appearance Excess
Pulling towards distinct parameter region:
$\delta_{CP} \approx 0.9\,\pi$

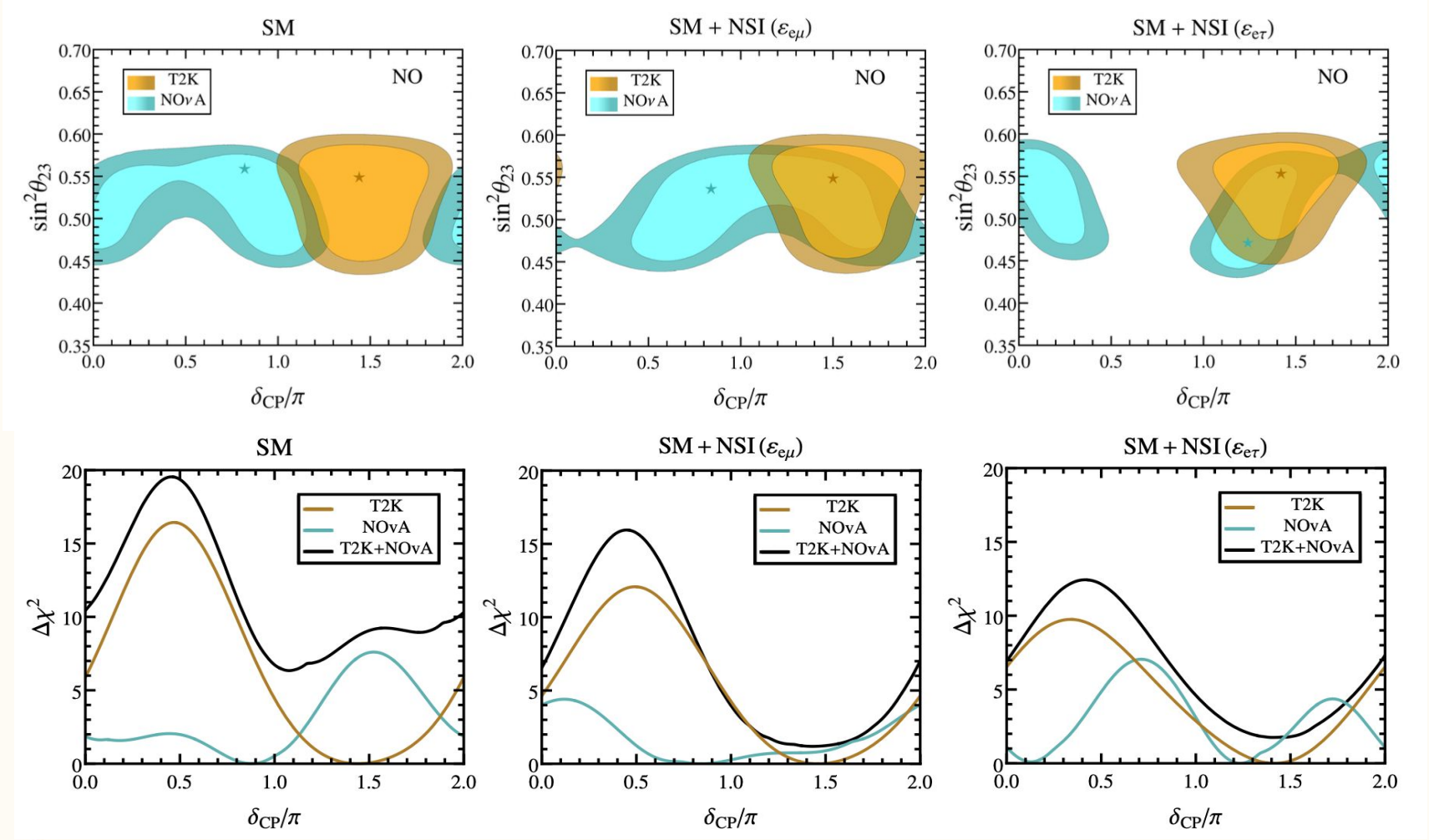


Ref: NOvA & T2K Collaborations (Nature, 2025)

NC NSI (Propagation)

$$H = U \begin{bmatrix} 0 & 0 & 0 \\ 0 & k_{21} & 0 \\ 0 & 0 & k_{31} \end{bmatrix} U^{\dagger} + V_{\mathrm{CC}} \begin{bmatrix} 1+\varepsilon_{ee} & \varepsilon_{e\mu} & \varepsilon_{e\tau} \\ \varepsilon^{*}_{e\mu} & \varepsilon_{\mu\mu} & \varepsilon_{\mu\tau} \\ \varepsilon^{*}_{e\tau} & \varepsilon^{*}_{\mu\tau} & \varepsilon_{\tau\tau} \end{bmatrix}$$

Best fit: $|\varepsilon_{e\mu}| = 0.125$, $\phi_{e\mu} = 1.35\pi$, $|\varepsilon_{e\tau}| = 0.22$, $\phi_{e\tau} = 1.70\pi$

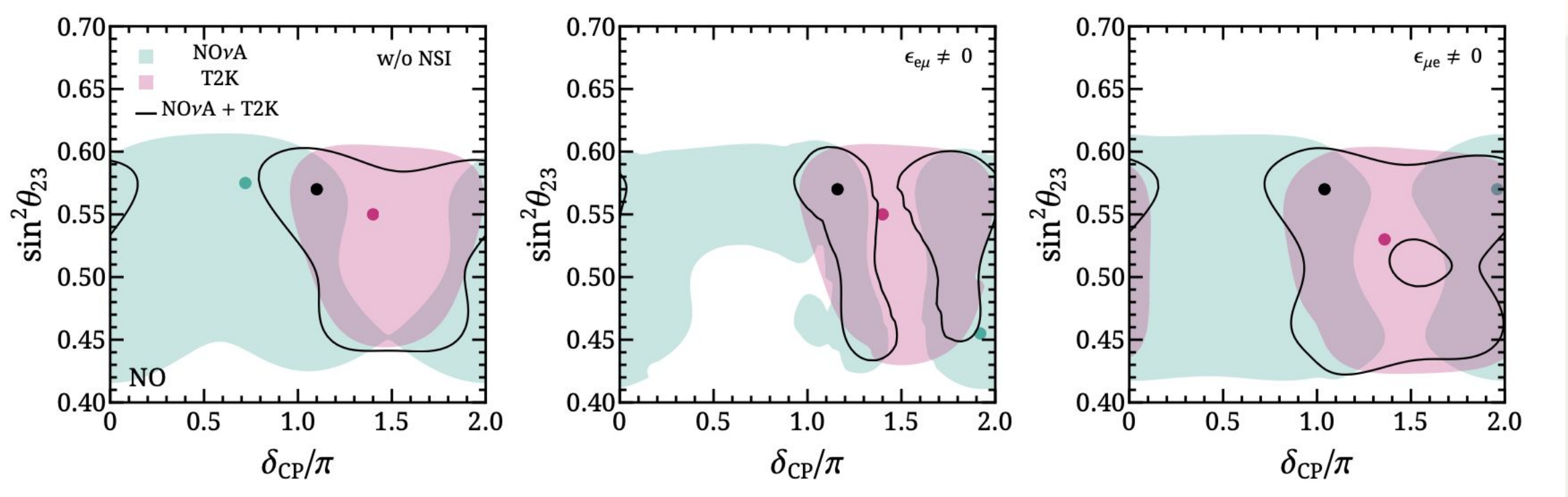


- NSI introduces new flavor-changing couplings during propagation:
- **The Fix:** Adding NSI reconciles both experiments onto a common value of $\delta_{CP} \approx 1.5\,\pi$
- **Current Status:** 2024 reassessment shows hint significance at **~ 1.8 σ**

Ref: Chatterjee & Palazzo (PRL, 2020; PRD, 2024), Denton (PRL, 2021)

CC NSI (Production)

- ➔ **Occurs during ν production from pion decay**
- ➔ **$\varepsilon_{e\mu}$, $\varepsilon_{\mu e} \sim 10^{-3}$**
- ➔ **$1.8\,\sigma \rightarrow 1\sigma$**
- ➔ **degeneracy of the form $\delta_{CP} \pm \Phi \approx 1.5\pi$**



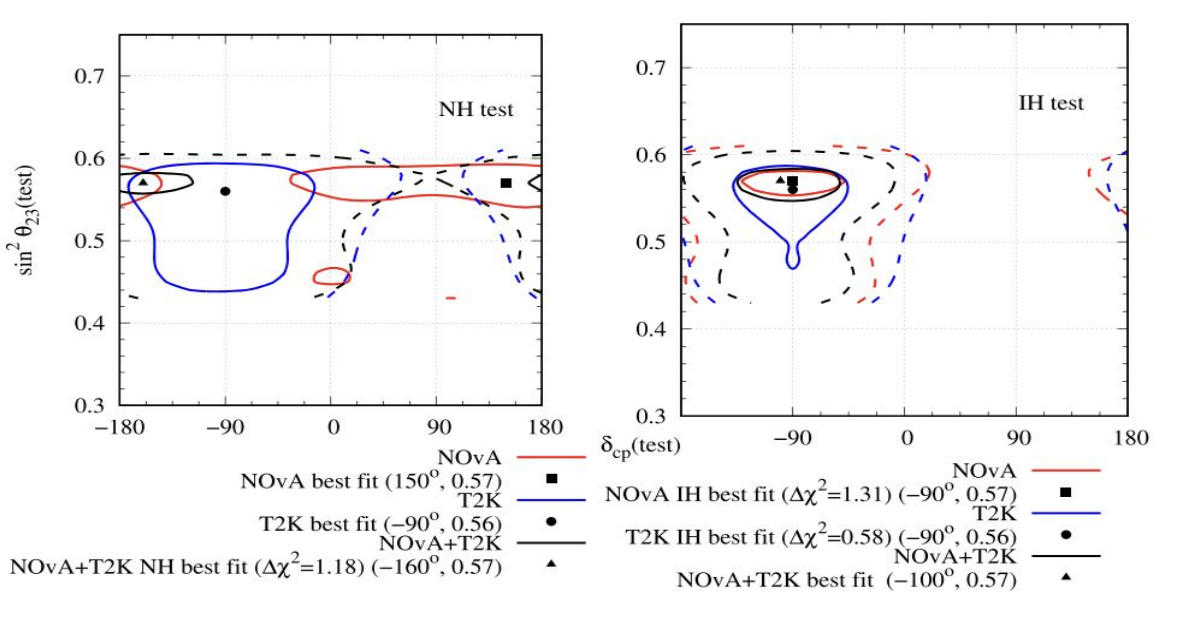
Ref: Cherchiglia et al. (PRD, 2025)

Non-Unitary mixing

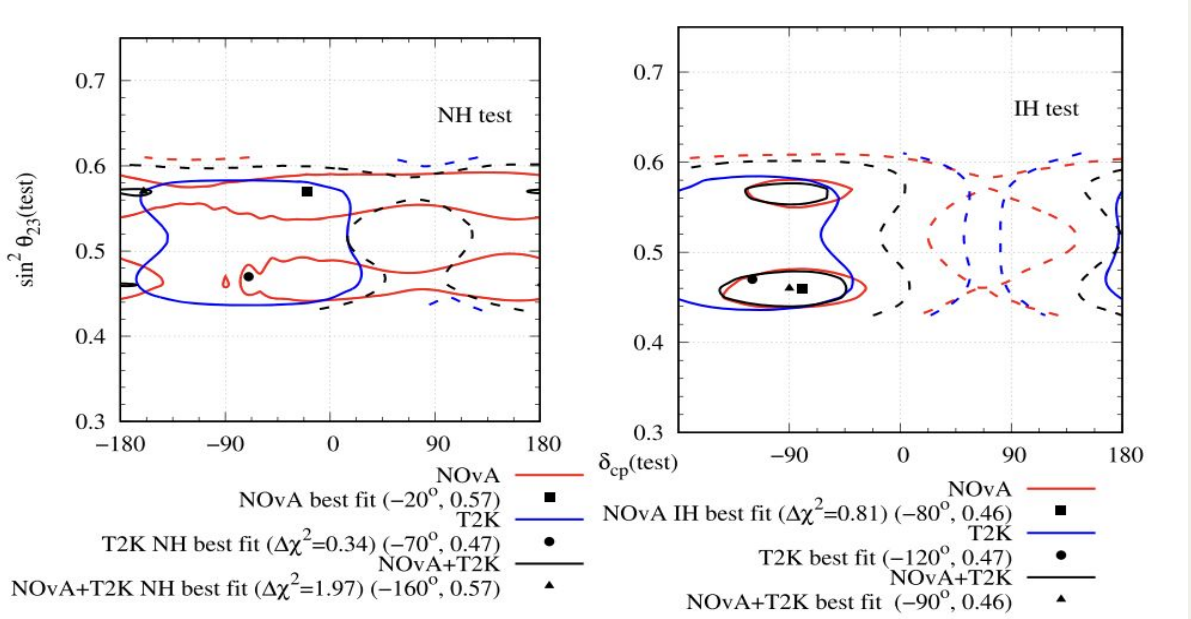
$$N = N_{NP} U_{3\times3} = \begin{bmatrix} \alpha_{00} & 0 & 0 \\ \alpha_{10} & \alpha_{11} & 0 \\ \alpha_{20} & \alpha_{21} & \alpha_{22} \end{bmatrix} U_{\text{PMNS}}$$

- ➔ For α_{10} : NOvA loses it δ_{CP} sensitivity for NH
- ➔ Degenerate best fit for T2K
- ➔ IH-HO ($\Delta\chi^2 = 0.72$), NH-HO ($\Delta\chi^2 = 0.72$), NH-LO ($\Delta\chi^2 = 0.72$)
- ➔ $|\alpha_{10}| = 0.06$ (Best fit for both)

α_{00}



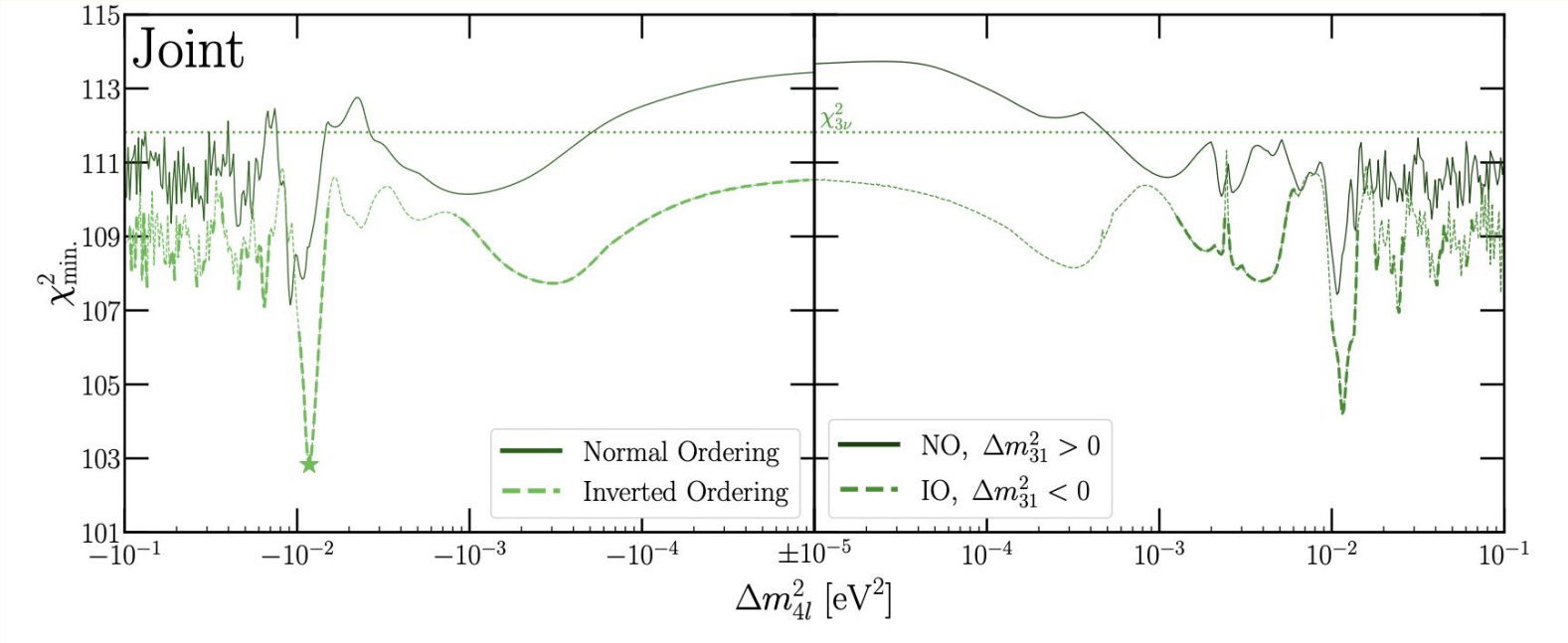
α_{10}



Ref: Miranda et al. (EPJC,2021), Yu et al. (NPB, 2026)

Very light sterile neutrino

- ➔ $|\Delta m^2_{4l}| \sim 10^{-2}$ eV^2 have pronounced oscillation at NOvA and T2K
- ➔ 4-flavor is preferred over 3-flavor by $\Delta\chi^2 \approx 9$
- ➔ NC matter effect is pronounced for NOvA



Ref: de Gouvea et al. (PRD, 2022)

Pseudo-Sterile States (3+1)

$$H = U K U^{\dagger} + V ,$$

$$V = \mathrm{diag}\,(V_{CC}, 0, 0, V_S - V_{NC}) ,$$

$$V_{CC} = \sqrt{2} G_F N_e ,$$

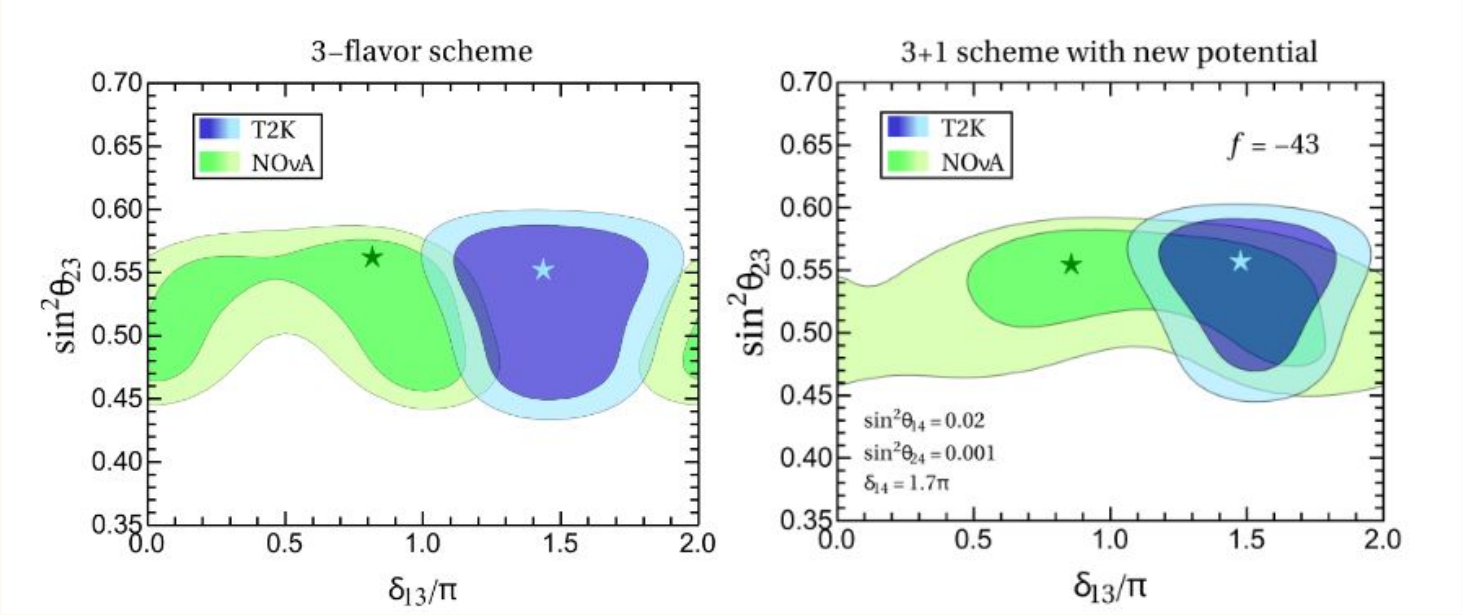
$$V_{NC} = -\frac{1}{2}\sqrt{2} G_F N_n ,$$

$$V_S = -f \times V_{NC}$$

$$\bar{H}^{\mathrm{mat}}_{3\nu} \approx V_{CC} \begin{bmatrix} 1+\bar{f}_{\oplus} s^2_{14} & \bar{f}_{\oplus} \tilde{s}_{14} s_{24} & \bar{f}_{\oplus} \tilde{s}_{14} \tilde{s}^*_{34} \\ \dagger & \bar{f}_{\oplus} s^2_{24} & \bar{f}_{\oplus} s_{24} \tilde{s}^*_{34} \\ \dagger & \dagger & \bar{f}_{\oplus} s^2_{34} \end{bmatrix} ,$$

$$\bar{H}^{\mathrm{NSI}}_{3\nu} \approx V_{CC} \begin{bmatrix} \varepsilon^{\oplus}_{ee} & \varepsilon^{\oplus}_{e\mu} & \varepsilon^{\oplus}_{e\tau} \\ \dagger & \varepsilon^{\oplus}_{\mu\mu} & \varepsilon^{\oplus}_{\mu\tau} \\ \dagger & \dagger & \varepsilon^{\oplus}_{\tau\tau} \end{bmatrix} .$$

- ➔ **At Low Energies: E ≤ 1 TeV**
- ➔ **3 + 1 (Pseudo-Sterile) → Effective 3 flavor NSI type interaction**
- ➔ **At High Energies: E ≥ 1 TeV**
- ➔ **3 + 1 dominates: 10 TeV resonance**

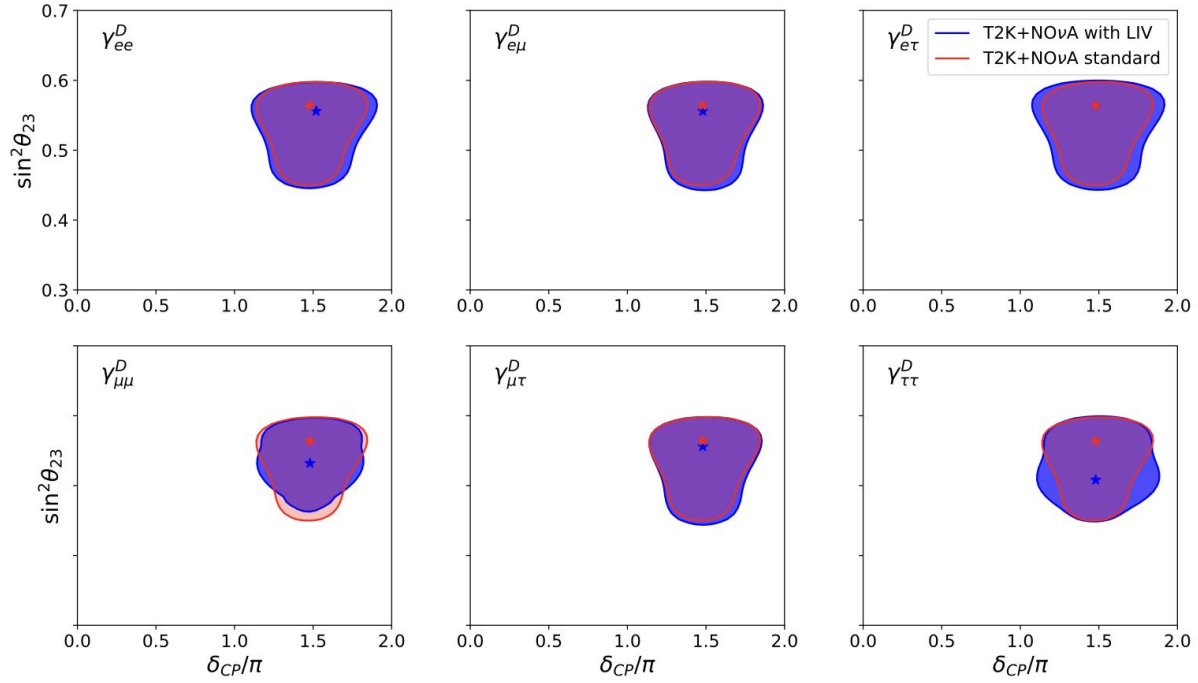


Ref: Chatterjee:2026ctb

LIV

Isotropic violation

$$H_{\rm LIV} = \begin{pmatrix} \gamma_{ee}^{(D)} & \gamma_{e\mu}^{(D)} & \gamma_{e\tau}^{(D)} \\ \gamma_{e\mu}^{(D)*} & \gamma_{\mu\mu}^{(D)} & \gamma_{\mu\tau}^{(D)} \\ \gamma_{e\tau}^{(D)*} & \gamma_{\mu\tau}^{(D)*} & \gamma_{\tau\tau}^{(D)} \end{pmatrix} E^{D-3},$$



- ➔ Modifies the Hamiltonian with matter density independent terms.
- ➔ D= 4, 5 and 6 can alleviate the tension (**0.4–2.4σ CL significance**)
- ➔ Bestfit: $\gamma^{(5)}_{\tau\tau} = 3.58\times10^{-32}\,\mathrm{GeV}^{-1}$
- ➔ D odd: CPT-odd
- ➔ D even: CPT-even

Ref: Lin et al. (PRD, 2022), Rahaman, 2021; Barenboim & Masud, 2020

STANDARD PHYSICS ALTERNATIVES

Vacuum Oscillations

Dropping matter effects fits the current data just as well as standard matter-modified fits, while reducing the inter-experiment tension.

Statistical Fluctuation

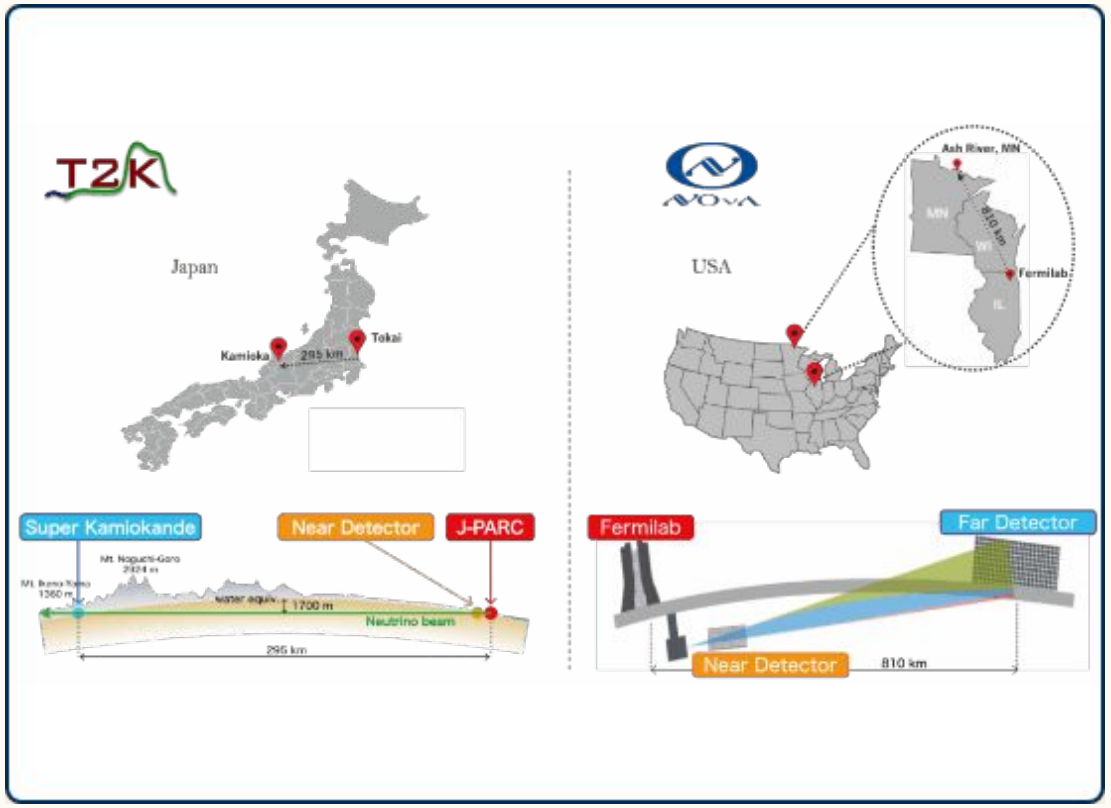
The 2σ level is common in high-energy physics. It may simply be a fluctuation that vanishes with more integrated luminosity.

Systematic Bias

Potential shared systematics in NuMI/J-PARC flux modeling haven't been fully explored in BSM solution papers.

Ref: Rahaman et al., 2021; Bharti et al., 2020

2025: THE JOINT ANALYSIS MILESTONE



The landmark Nature 2025 publication sidesteps BSM by combining raw datasets:

Precision: Mass-squared difference Δm^2_{31} measured to ≤ 2σ uncertainty.

CPV Result: 3σ interval for δ is $[-1.38\pi, 0.30\pi]$.

Key takeaway: No strong preference for mass ordering yet, but if IO is true, CPV is confirmed.

Ref: NOvA & T2K Collaborations (Nature, 2025)

Work in progress

- ➔ Trying to reproduce the NOvA and T2K data using GLoBES
- ➔ Nest Step: Check Superscaling variable impact on NOvA-T2K tension

Thank You