GLOBAL ANALYSIS OF NEUTRINO OSCILLATIONS

Concha Gonzalez-Garcia
(YITP-Stony Brook& ICREA-University of Barcelona)

NEUTRINO '26
International Conference on Neutrino Physics and Astrophysics
June 22nd - 26th, 2026
UCI Department of Physics & Astronomy

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Outline

Status of the 3ν global description

What we know and what we do not know (yet?)

Implications & Explorations

The ν evidence & path to BSM

- In the SM only $\nu_{L,\alpha}$, $\alpha = e, \mu, \tau$:

  Gauge Invariance $\Rightarrow$ Each Lepton Flavour α conserved $\Rightarrow$ Total Lepton # Conserved

  $\Leftrightarrow$ ν strictly massless

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- We have observed with high (or good) precision:

  $*$ Atmospheric ν_μ & $\bar{\nu}_\mu$ disappear likely to ν_τ (SK, MINOS, IceCube, KM3NeT)

  $*$ Accel. ν_μ & $\bar{\nu}_\mu$ disappear at $L \sim 300/800$ Km (K2K, T2K, MINOS, NOνA)

  $*$ Some accel ν_μ & $\bar{\nu}_\mu$ appear as ν_e & $\bar{\nu}_e$ at $L \sim 300/800$ Km (T2K, MINOS, NOνA)

  $*$ Solar ν_e convert to ν_μ/ν_τ (Cl, Ga, SK, SNO, Borexino)

  $*$ Reactor $\overline{\nu}_e$ disappear at $L \sim 200/60$ Km (KamLAND. JUNO (12/2025))

  $*$ Reactor $\overline{\nu}_e$ disappear at $L \sim 1$ Km (D-Chooz, Daya Bay, Reno)

  $\Rightarrow$ L_α are violated $\Rightarrow$ There is BSM Physics

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  $\Rightarrow L_\alpha$ are violated $\Rightarrow$ There is BSM Physics

- The *important* question: What BSM? Talks by S Rabi, K Babu, M Schmidt

- The global analysis path:

  Precise consistent determination of the low energy effective Lagrangian of such BSM

The New Minimal Standard Model

- Minimal Extension to allow for LFV ⇒ give Mass to the Neutrino

  - With SM fields: Use ν_L^c is right-handed

$$\mathcal{L}-\mathcal{L}_{SM} = -\frac{1}{2}M_\nu \overline{\nu_L}\nu_L^C + h.c. \Rightarrow \begin{cases} L \text{ is violated} \ \Rightarrow \ \text{Majorana } \nu = \nu^c \\ SU(2)_L \text{ is violated} \ \Rightarrow \ \text{Effective LE} \end{cases}$$

  - Introduce ν_R AND <u>impose L conservation</u>

$$\mathcal{L}-\mathcal{L}_{SM} = -M_D\overline{\nu_L}\nu_R - \frac{1}{2}M_R\xcancel{\overline{\nu_R}}\nu_R^C + h.c. \quad \Rightarrow \text{Dirac } \nu \neq \nu^c:$$

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- Either way ⇒ Charged current interactions of massive leptons are not diagonal

$$\frac{g}{\sqrt{2}}W_\mu^+\sum_{ij}\left(U_{\text{LEP}}^{ij}\,\overline{\ell^i}\,\gamma^\mu\,L\,\nu^j \;+\; U_{\text{CKM}}^{ij}\,\overline{U^i}\,\gamma^\mu\,L\,D^j\right) \;+\; h.c.$$

For $N = 3 + s$ $\nu' s$: $U_{\text{LEP}} = 3 \times N$ $\quad U_{\text{LEP}}U_{\text{LEP}}^\dagger = I_{3\times 3}$ $\quad U_{\text{LEP}}^\dagger U_{\text{LEP}} \neq I_{N\times N}$

- Either way ⇒ Lepton flavours not conserved in ν propagation

The New Minimal Standard Model: ν flavour oscillations

- In vacuum:

$$P_{\alpha\beta} = \delta_{\alpha\beta} - 4\sum_{j\neq i}^{n} \mathrm{Re}[U^\star_{\alpha i} U_{\beta i} U_{\alpha j} U^\star_{\beta j}] \sin^2\left(\frac{\Delta_{ij}}{2}\right) + 2\sum_{j\neq i} \mathrm{Im}[U^\star_{\alpha i} U_{\beta i} U_{\alpha j} U^\star_{\beta j}] \sin\left(\Delta_{ij}\right)$$

$\Delta_{ij} = (m_i^2 - m_j^2)\frac{L}{4E}$ ⇒ No information on ν mass scale nor Majorana/Dirac

- When osc between 2-ν dominates: $P_{\alpha\neq\beta} = \sin^2(2\theta)\ \sin^2\left(\Delta m^2 \frac{L}{4E}\right)$

⇒ No information on Mass Ordering ($\equiv$ sign(Δm^2)) nor octant of θ nor CPV

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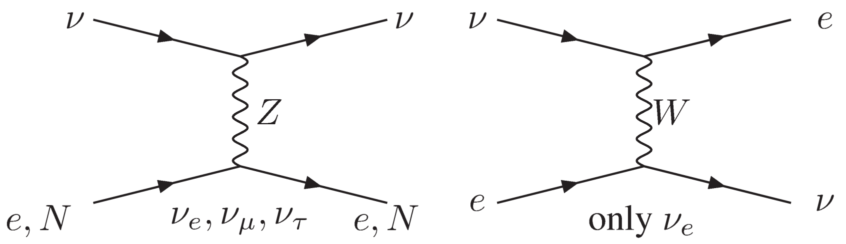
- If ν cross matter regions (Sun, Earth...)

  it interacts *coherently*

  Different flavours have different interactio



⇒ Effective potential in ν_e evolution: $V_e \neq V_{\mu,\tau} \Rightarrow \Delta V^{\nu_e} = -\Delta V^{\bar\nu_e} = \sqrt{2} G_F N_e$

⇒ Modification of mixing angle and oscillation wavelength (MSW)

⇒ Solar $\nu_e' s$: 2ν-dominant dependence on θ octant

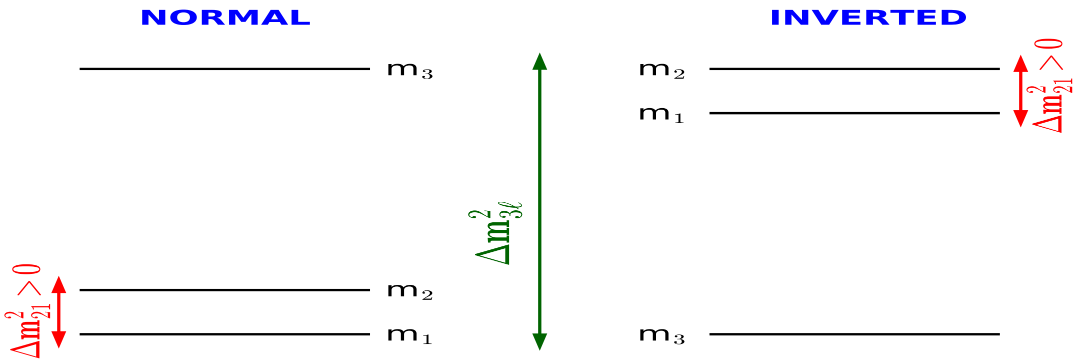
⇒ LBL & ATM $\nu_{\mu(e)}, \overline{\nu}_{\mu(e)}$: Dependence on sign($\Delta m^2$)

3 ν Flavour Parameters

- For **for 3 ν's** : 3 Mixing angles + 1 Dirac Phase + 2 Majorana Phases

$$U_{\rm LEP} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta_{\rm cp}} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta_{\rm cp}} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \xcancel{\begin{pmatrix} e^{i\eta_1} & 0 & 0 \\ 0 & e^{i\eta_2} & 0 \\ 0 & 0 & 1 \end{pmatrix}}$$

- Convention: $0 \leq \theta_{ij} \leq 90°$ $0 \leq \delta \leq 360°$ $\Rightarrow$ 2 Mass Orderings (MO)



$$\Delta m^2_{21} > 0 \text{ by convention}$$

$$\Delta m^2_{3\ell} = \begin{cases} \Delta m^2_{31} > 0 \text{ for NO} \\ \Delta m^2_{32} < 0 \text{ for IO} \end{cases}$$

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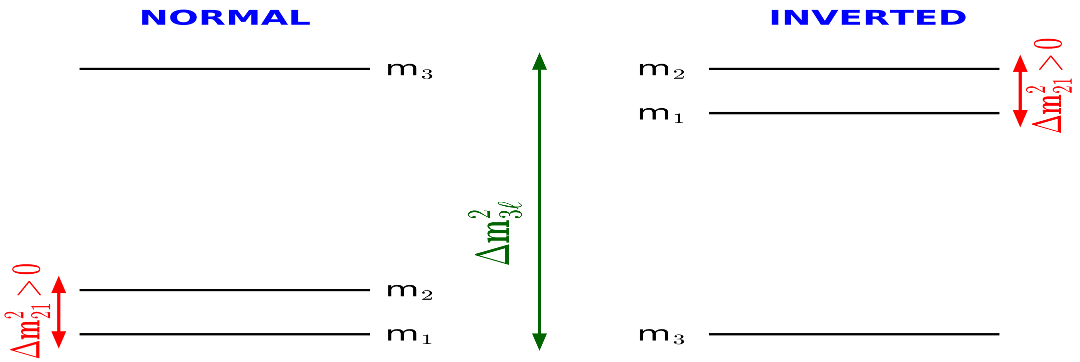

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Experiment	2ν dominant	3ν effects	3ν synergies
Solar Experiments	θ_{12}, Δm^2_{21}	θ_{13}	
Reactor LBL (KamLAND/JUNO)	θ_{12}, Δm^2_{21}	θ_{13}, MO	
Reactor MBL (Daya Bay, Reno, D-Chooz)	θ_{13}, $\lvert\Delta m^2_{3\ell}\rvert$	θ_{12}, Δm^2_{21}	MO
Atmospheric Experiments (SK,IC)	θ_{23}, $\lvert\Delta m^2_{3\ell}\rvert$	θ_{13}, $\delta_{\rm cp}$, MO	
Acc LBL ν_μ Disapp (Minos,T2K,NOvA)	θ_{23} , $\lvert\Delta m^2_{3\ell}\rvert$	θ_{12}, Δm^2_{21}	
Acc LBL ν_e App (Minos,T2K,NOvA)	θ_{13}, $\lvert\Delta m^2_{3\ell}\rvert$	$\delta_{\rm cp}$, MO, θ_{23}	

3 ν Global Analysis

Bari

PHYSICAL REVIEW D **111,** 093006 (2025)

Neutrino masses and mixing: Entering the era of subpercent precision

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We perform an updated global analysis of the known and unknown parameters of the standard three-neutrino (3ν) framework, using data available at the beginning of 2025. The known oscillation parameters include three mixing angles $(\theta_{12}, \theta_{23}, \theta_{13})$ and two squared mass gaps, chosen as $\delta m^2 = m_2^2 - m_1^2 > 0$ and $\Delta m^2 = m_3^2 - \frac{1}{2}(m_1^2 + m_2^2)$, where the discrete parameter $\alpha = \mathrm{sign}(\Delta m^2)$ distinguishes normal ordering (NO, $\alpha = +1$) from inverted ordering (IO, $\alpha = -1$). With respect to our previous 2021 update, the combination of accelerator, reactor, and atmospheric neutrino data leads to appreciably reduced uncertainties for θ_{23}, θ_{13}, and $|\Delta m^2|$. In particular, $|\Delta m^2|$ is the first 3ν parameter to enter the domain of subpercent precision (0.8% at 1σ). We underline some issues about common systematics in combined fits that might affect (and possibly weaken) this error estimate. Concerning oscillation unknowns, we find a relatively weak preference for NO versus IO (at 2.2σ), for *CP* violation versus conservation in NO (1.3σ), and for the first θ_{23} octant versus the second in NO (1.1σ). We discuss the current status and qualitative prospects of the mass ordering hint in the plane charted by the mass parameters $(\delta m^2, \Delta m^2_{ee})$, where $\Delta m^2_{ee} = |\Delta m^2| + \frac{1}{2}\alpha(\cos^2\theta_{12} - \sin^2\theta_{12})\delta m^2$, to be jointly measured by the JUNO experiment with subpercent precision. We also discuss upper bounds on nonoscillation observables, including the effective ν_e mass m_β in β decay, the effective Majorana mass $m_{\beta\beta}$ in $0\nu\beta\beta$ decay, and the sum of neutrino masses Σ in cosmology. We adopt $m_\beta < 0.50$ eV (2σ) from current ^{3}H data and report $m_{\beta\beta} < 0.086$ eV (2σ) from a combined ^{76}Ge, ^{130}Te, and ^{136}Xe data analysis, accounting for parametrized nuclear matrix element covariances. Concerning Σ, current results show tensions within the standard Λ cold dark matter (ΛCDM) cosmological model, pulling Σ toward unphysical values and suggesting possible model extensions. We discuss representative combinations of data, with or without augmenting the ΛCDM model with extra parameters accounting for possible systematics (lensing anomaly) or new physics (dynamical dark energy). The resulting 2σ upper limits are roughly spread around the bound $\Sigma < 0.2$ eV within a factor of 3 (both up- and downward), with different implications for NO and IO scenarios. Bounds from oscillation and nonoscillation data are also discussed in the planes charted by pairs of $(m_\beta, m_{\beta\beta}, \Sigma)$ parameters.

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I. INTRODUCTION

Results from solar, atmospheric, accelerator, and reactor neutrino oscillation experiments have established the standard three-neutrino (3ν) framework, where the neutrino states $(\nu_e, \nu_\mu, \nu_\tau)$ with definite flavor are mixed with neutrino states (ν_1, ν_2, ν_3) with definite masses (m_1, m_2, m_3) via a unitary mixing matrix $U_{\alpha i}$ [1,2]. The current pillars of the 3ν framework are represented by multiple measurements of five parameters: three mixing angles θ_{ij} $(\theta_{12}, \theta_{13}, \theta_{23})$ governing oscillation amplitudes and two independent squared mass differences governing oscillation frequencies, which we choose as $\delta m^2 = m_2^2 - m_1^2 > 0$ and $\Delta m^2 = m_3^2 - \frac{1}{2}(m_1^2 + m_2^2)$. Each of these

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2020 global reassessment of the neutrino oscillation picture

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Abstract: We present an updated global fit of neutrino oscillation data in the simplest three-neutrino framework. In the present study we include up-to-date analyses from a number of experiments. Concerning the atmospheric and solar sectors, besides the data considered previously, we give updated analyses of IceCube DeepCore and Sudbury Neutrino Observatory data, respectively. We have also included the latest electron antineutrino data collected by the Daya Bay and RENO reactor experiments, and the long-baseline T2K and NOνA measurements, as reported in the Neutrino 2020 conference. All in all, these new analyses result in more accurate measurements of θ_{13}, θ_{12}, Δm^2_{21} and $|\Delta m^2_{31}|$. The best fit value for the atmospheric angle θ_{23} lies in the second octant, but first octant solutions remain allowed at $\sim 2.4\sigma$. Regarding CP violation measurements, the preferred value of δ we obtain is 1.08π (1.58π) for normal (inverted) neutrino mass ordering. The global analysis still prefers normal neutrino mass ordering with 2.5σ statistical significance. This preference is milder than the one found in previous global analyses. These new results should be regarded as robust due to the agreement found between our Bayesian and frequentist approaches. Taking into account only oscillation data, there is a weak/moderate

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NuFit-6.0: updated global analysis of three-flavor neutrino oscillations

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Abstract: We present an updated global analysis of neutrino oscillation data as of September 2024. The parameters θ_{12}, θ_{13}, Δm^2_{21}, and $|\Delta m^2_{3\ell}|$ ($\ell = 1, 2$) are well-determined with relative precision at 3σ of about 13%, 8%, 15%, and 6%, respectively. The third mixing angle θ_{23} still suffers from the octant ambiguity, with no clear indication of whether it is larger or smaller than 45°. The determination of the leptonic CP phase δ_{CP} depends on the neutrino mass ordering: for normal ordering the global fit is consistent with CP conservation within 1σ, whereas for inverted ordering CP-violating values of δ_{CP} around 270° are favored against CP conservation at more than 3.6σ. While the present data has in principle 2.5–3σ sensitivity to the neutrino mass ordering, there are different tendencies in the global data that reduce the discrimination power: T2K and NOvA appearance data individually favor normal ordering, but they are more consistent with each other for inverted ordering. Conversely, the joint determination of $|\Delta m^2_{3\ell}|$ from global disappearance data prefers normal ordering. Altogether,

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2020 global reassessment of the neutrino oscillation picture

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Abstract: We present an updated global fit of neutrino oscillation data in the simplest three-neutrino framework. In the present study we include up-to-date analyses from a number of experiments. Concerning the atmospheric and solar sectors, besides the data considered previously, we give updated analyses of IceCube DeepCore and Sudbury Neutrino Observatory data, respectively. We have also included the latest electron antineutrino data collected by the Daya Bay and RENO reactor experiments, and the long-baseline T2K and NOνA measurements, as reported in the Neutrino 2020 conference. All in all, these new analyses result in more accurate measurements of θ_{13}, θ_{12}, Δm^2_{21} and $|\Delta m^2_{31}|$. The best fit value for the atmospheric angle θ_{23} lies in the second octant, but first octant solutions remain allowed at $\sim 2.4\sigma$. Regarding CP violation measurements, the preferred value of δ we obtain is 1.08π (1.58π) for normal (inverted) neutrino mass ordering. The global analysis still prefers normal neutrino mass ordering with 2.5σ statistical significance. This preference is milder than the one found in previous global analyses. These new results should be regarded as robust due to the agreement found between our Bayesian and frequentist approaches. Taking into account only oscillation data, there is a weak/moderate

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NuFIT (www.nu-fit.org)

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NuFit-6.0: updated global analysis of three-flavor neutrino oscillations

JHEP12(2024)216

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Abstract: We present an updated global analysis of neutrino oscillation data as of September 2024. The parameters θ_{12}, θ_{13}, Δm^2_{21}, and $|\Delta m^2_{3\ell}|$ ($\ell = 1, 2$) are well-determined with relative precision at 3σ of about 13%, 8%, 15%, and 6%, respectively. The third mixing angle θ_{23} still suffers from the octant ambiguity, with no clear indication of whether it is larger or smaller than 45°. The determination of the leptonic CP phase δ_{CP} depends on the neutrino mass ordering: for normal ordering the global fit is consistent with CP conservation within 1σ, whereas for inverted ordering CP-violating values of δ_{CP} around 270° are favored against CP conservation at more than 3.6σ. While the present data has in principle 2.5–3σ sensitivity to the neutrino mass ordering, there are different tendencies in the global data that reduce the discrimination power: T2K and NOvA appearance data individually favor normal ordering, but they are more consistent with each other for inverted ordering. Conversely, the joint determination of $|\Delta m^2_{3\ell}|$ from global disappearance data prefers normal ordering. Altogether,

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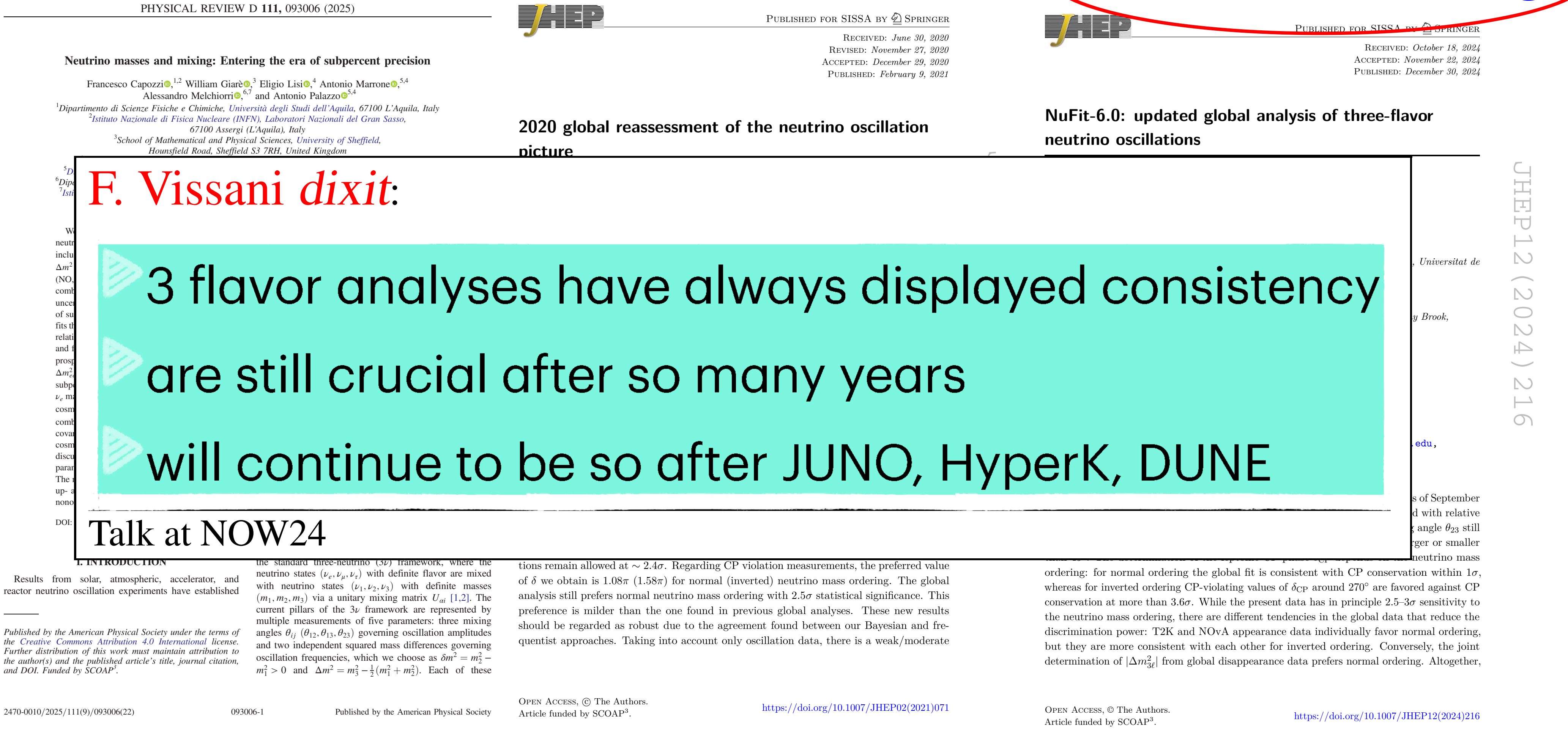
3 ν Global Analysis

Bari

Valencia

NuFIT (www.nu-fit.org)



PHYSICAL REVIEW D **111,** 093006 (2025)

Neutrino masses and mixing: Entering the era of subpercent precision

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Alessandro Melchiorri,[6,7] and Antonio Palazzo[5,4]
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I. INTRODUCTION

Results from solar, atmospheric, accelerator, and reactor neutrino oscillation experiments have established

the standard three-neutrino (3ν) framework, where the neutrino states $(\nu_e, \nu_\mu, \nu_\tau)$ with definite flavor are mixed with neutrino states (ν_1, ν_2, ν_3) with definite masses (m_1, m_2, m_3) via a unitary mixing matrix $U_{\alpha i}$ [1,2]. The current pillars of the 3ν framework are represented by multiple measurements of five parameters: three mixing angles θ_{ij} $(\theta_{12}, \theta_{13}, \theta_{23})$ governing oscillation amplitudes and two independent squared mass differences governing oscillation frequencies, which we choose as $\delta m^2 = m_2^2 - m_1^2 > 0$ and $\Delta m^2 = m_3^2 - \frac{1}{2}(m_1^2 + m_2^2)$. Each of these

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2020 global reassessment of the neutrino oscillation picture

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NuFit-6.0: updated global analysis of three-flavor neutrino oscillations

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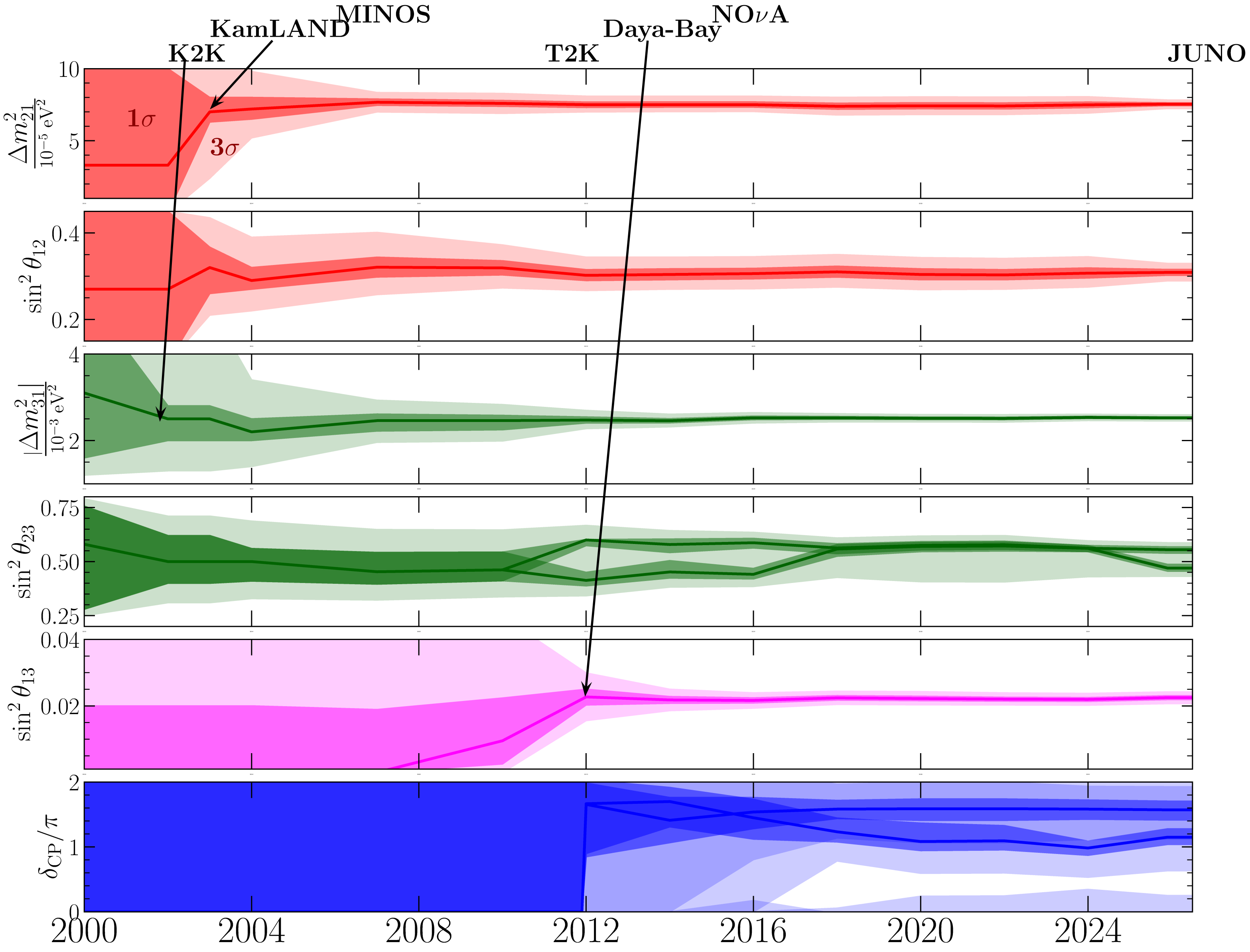
F. Vissani *dixit*:

- 3 flavor analyses have always displayed consistency
- are still crucial after so many years
- will continue to be so after JUNO, HyperK, DUNE

Talk at NOW24

3 ν Flavour Parameters: Time Perspective



Data to be Described

Solar experiments

- Chlorine total rate, 1 data point.
- Gallex & GNO total rates, 2 points.
- SAGE total rate, 1 data point.
- SK1 E and zenith spect, 44 poins.
- SK2 E and D/N spect, 33 points.
- SK3 E and D/N spect, 42 points.
- SK4 2970-day E spectrum and D/N asym, 46 points.
- SNO combined analysis, 7 points.
- Borexino Ph-I 740.7-day low-E spect 33 points.
- Borexino Ph-I 246-day high-E spect ,6 points.
- Borexino Ph-II 1292-day low-E spect, 192 points.
- Borexino Ph-III 1433-day low-E spect, 120 points.

Reactor experiments

- KamLAND DS1,DS2&DS3 spectra with Daya-Bay fluxes 69 points
- DChooz FD/ND ratios with 1276-day (FD) and 587-day (ND) exposures , 26 points.
- Daya-Bay 3158-day EH1,2,3 spectra ,78 points.
- Reno 300-day FD/ND ratios 45 points.
- SNO+ 1.45 Kt-ur spectrum DSI & II, 46 points
- JUNO 59.1-day spectrum, 66 data points

Atmospheric experiments

- IceCube/DeepCore 2023 8-years,200 points.
- IceCube/DeepCore 2024 9.3-years (χ^2 map provided).
- SK I-V 484 kton-years(χ^2 map provided).
- NOT INCLUDED: { IceCube/DeepCore 11.2-years
  KM3NeT/ORCA 510 days

Accelerator experiments

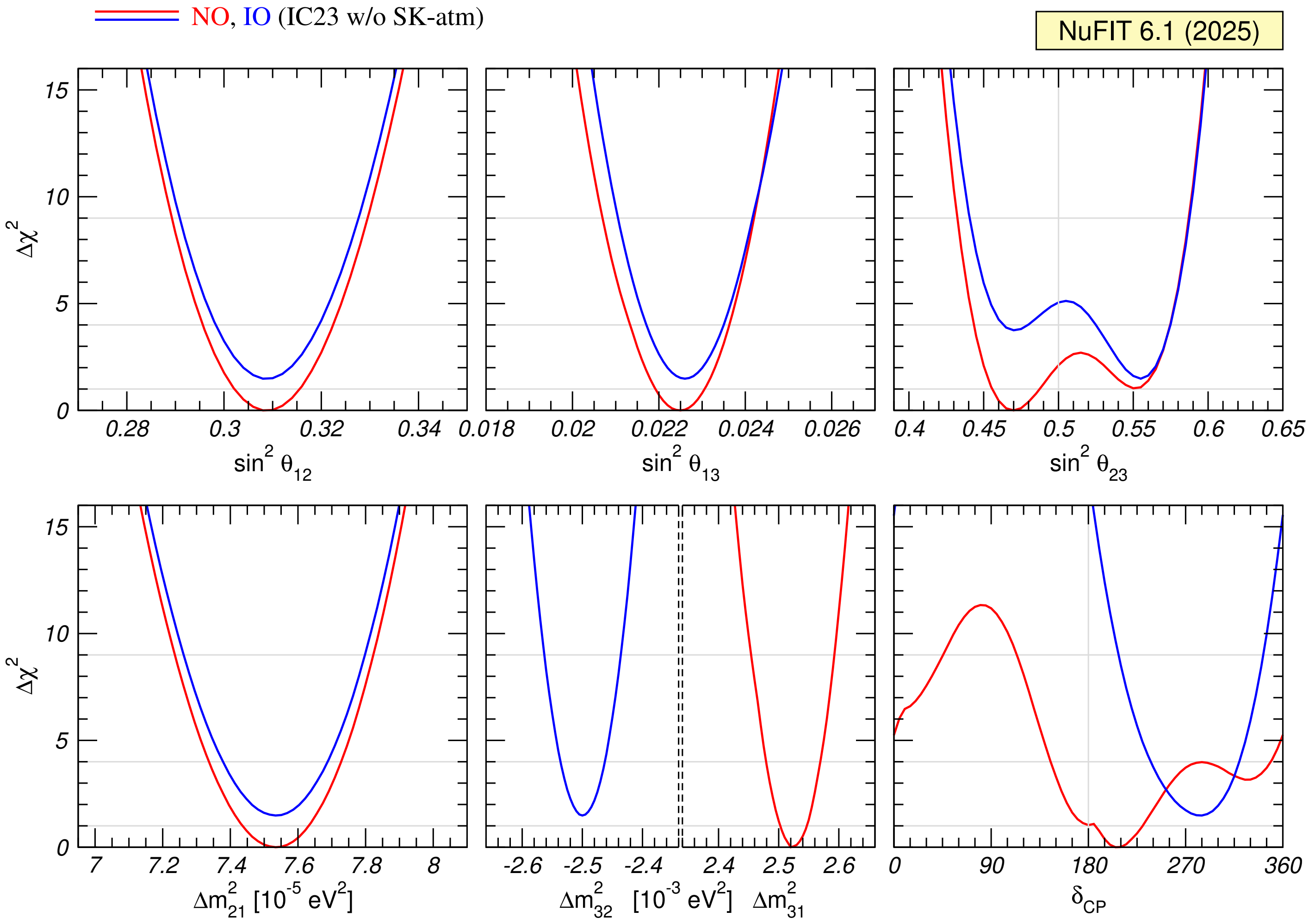
- MINOS 10.71 × 10^{20} pot ν_μ-disapp data, 39 poins.
- MINOS 3.36 × 10^{20} pot $\bar{\nu}_\mu$-disapp data , 14 points.
- MINOS 10.6 × 10^{20} pot ν_e-app data , 5 points.
- MINOS 3.3 × 10^{20} pot $\bar{\nu}_e$-app data , 5 points.
- T2K 21.4 × 10^{20} pot ν_μ-disapp data, 28 points.
- T2K 21.4 × 10^{20} pot ν_e-app data, 9 points CCQE and 7 points CC1π.
- T2K 16.3 × 10^{20} pot $\bar{\nu}_\mu$-disapp, 19 points.
- T2K 16.3 × 10^{20} pot $\bar{\nu}_e$-app, 9 points.
- NOνA 26.6 × 10^{20} pot ν_μ-disapp data , 21 points.
- NOνA 26.6 × 10^{20} pot ν_e-app data , 15 points.
- NOνA 12.5 × 10^{20} pot $\bar{\nu}_\mu$-disapp, 18 points.
- NOνA 12.5 × 10^{20} pot $\bar{\nu}_e$-app, 13 points.

Global 3 ν Flavour Parameters: Spring 2026

Global 6-parameter fit http://www.nu-fit.org

Esteban, MCGG, Maltoni, Martinez, Pinheiro,Schwetz, 2410.05480,2601.09791

(In last years good agreement with results from Bari and Valencia groups)



IC23 $\equiv$ Our analysis of Icecube data from 2304.12236

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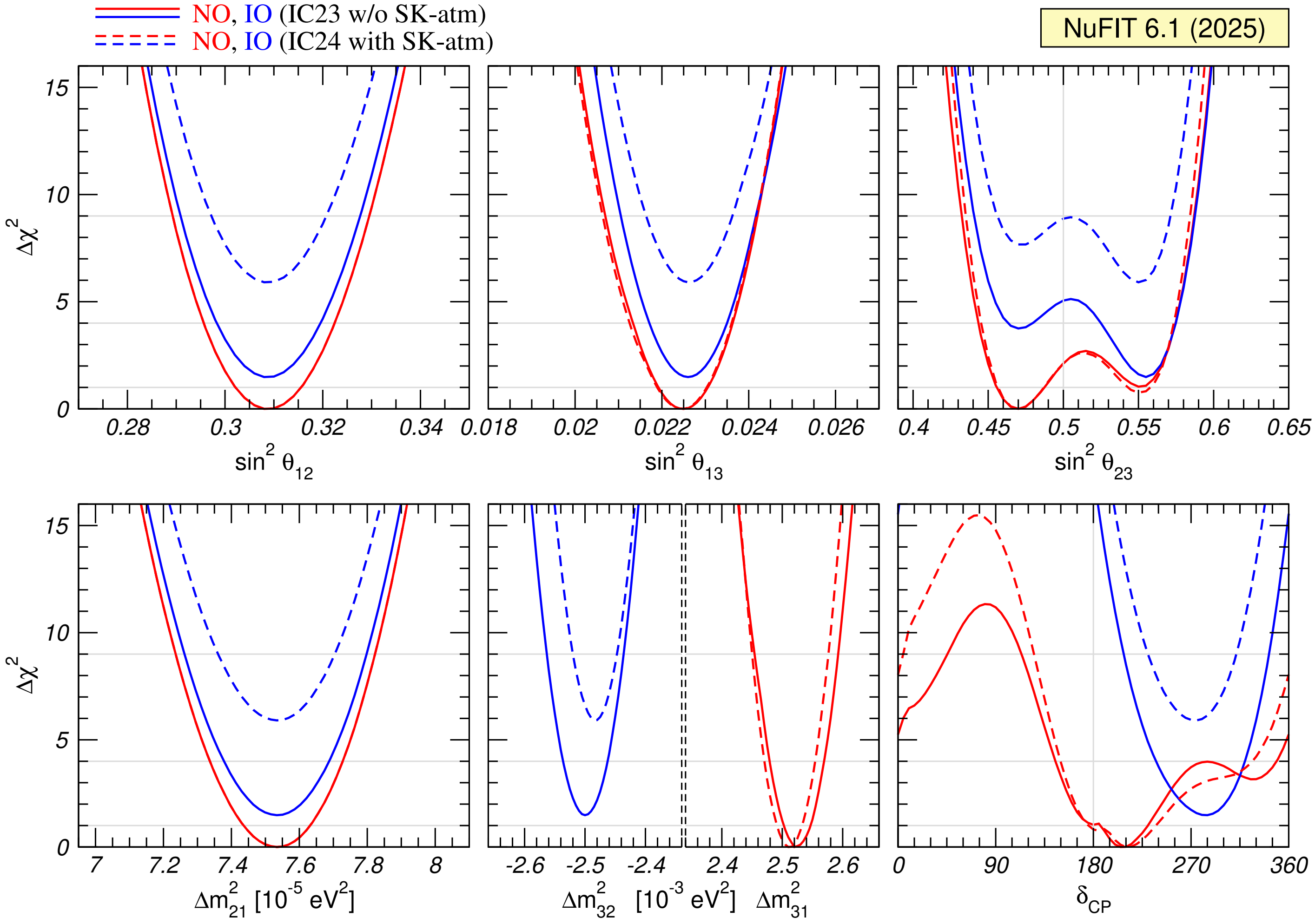


IC23 $\equiv$ Our analysis of Icecube data from 2304.12236

SK-atm $\equiv$ χ^2 table from SK1-5

IC24 $\equiv$ χ^2 table from Icecube data from 2405.02163

Global 3 ν Flavour Parameters: Spring 2026

Global 6-parameter fit http://www.nu-fit.org

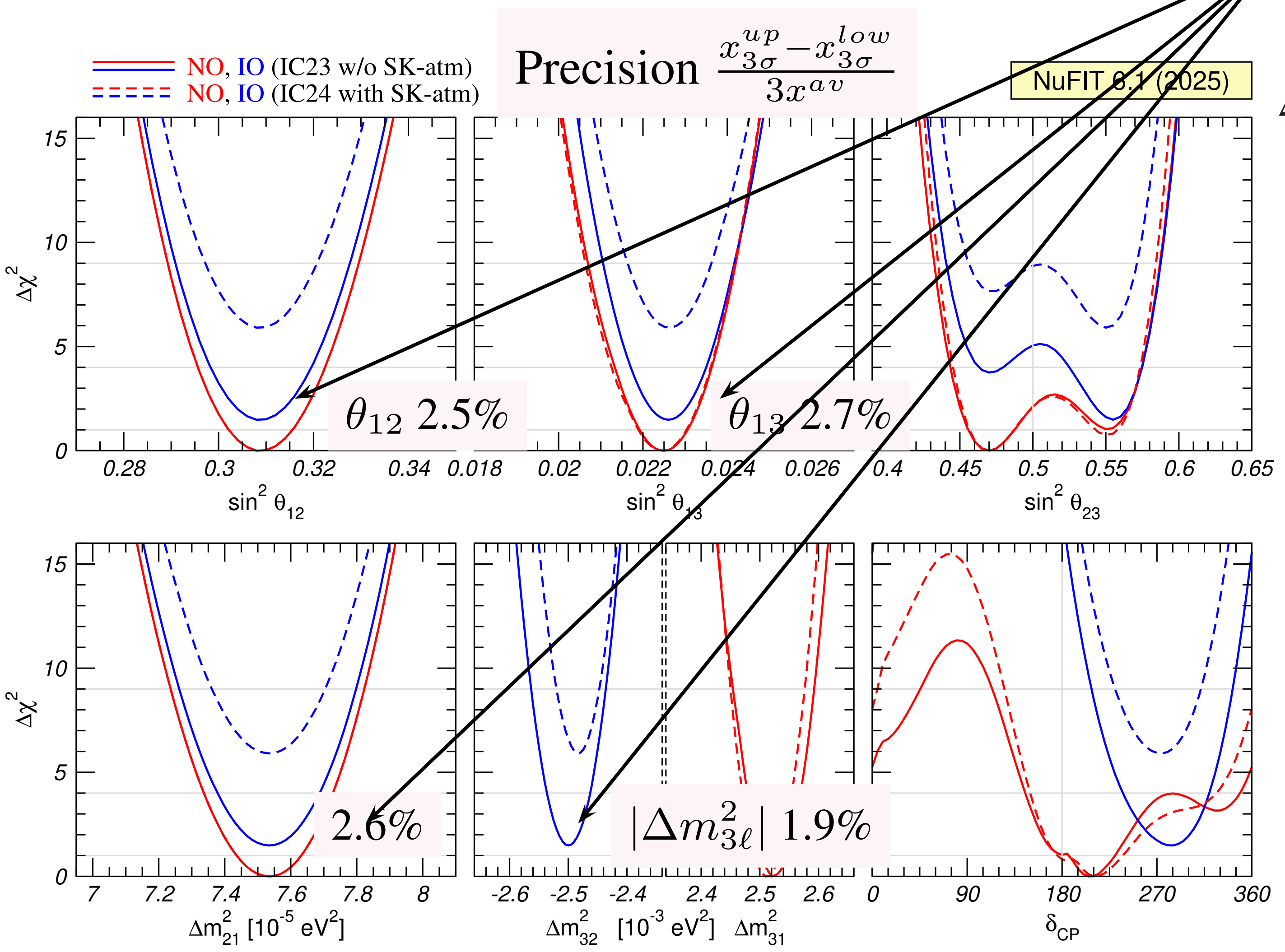
Esteban, MCGG, Maltoni, Martinez, Pinheiro,Schwetz, 2410.05480,2601.09791

- 4 well-known parameters:

$\theta_{12}, \theta_{13}, \Delta m^2_{21}, |\Delta m^2_{3\ell}|$

Δm^2_{21} Solar vs Reactors

Time varing Tension



Precision $\frac{x^{up}_{3\sigma}-x^{low}_{3\sigma}}{3x^{av}}$

θ_{12} 2.5%

θ_{13} 2.7%

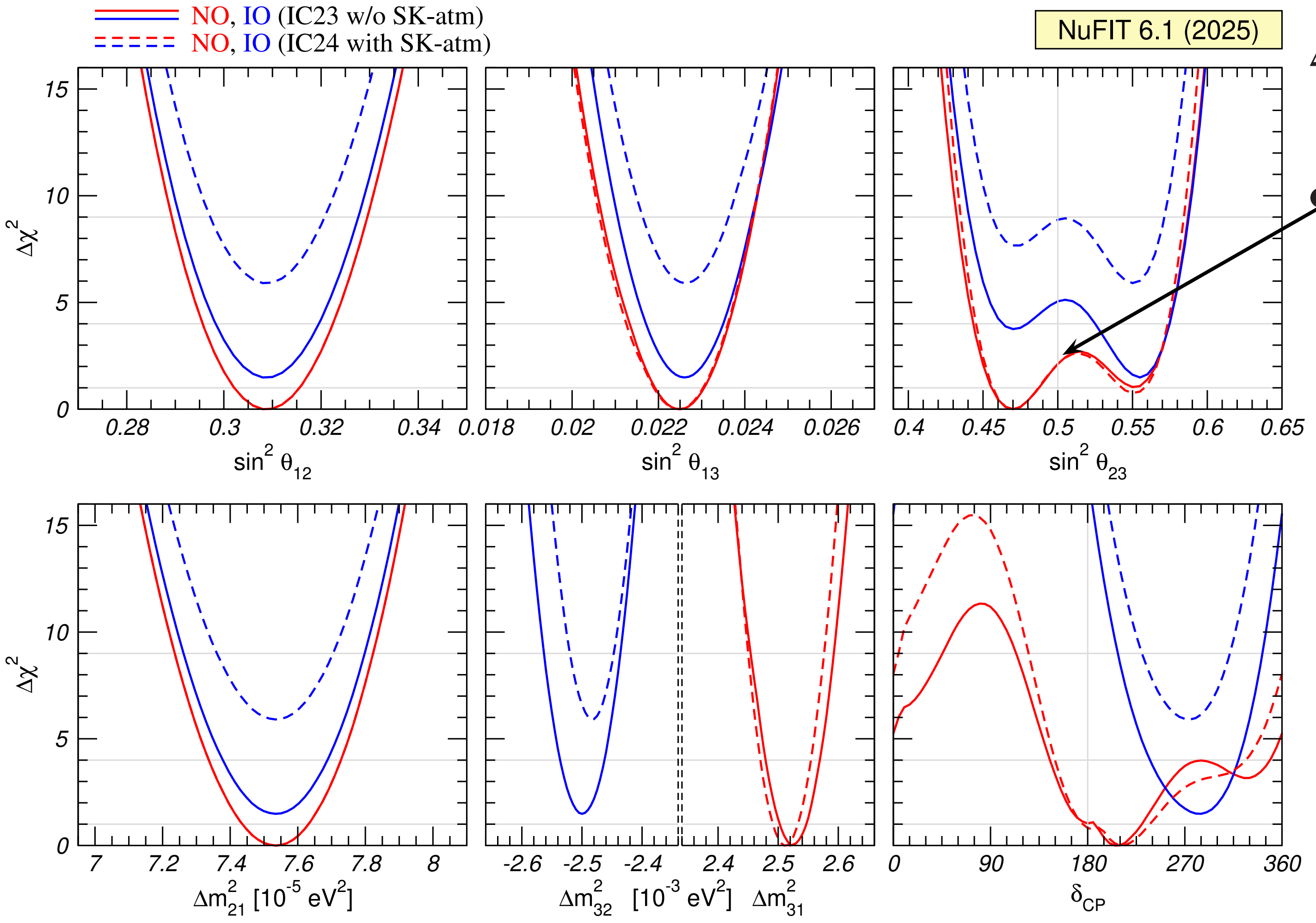
2.6%

$|\Delta m^2_{3\ell}|$ 1.9%

Global 3 ν Flavour Parameters: Spring 2026

Global 6-parameter fit http://www.nu-fit.org

Esteban, MCGG, Maltoni, Martinez, Pinheiro,Schwetz, 2410.05480,2601.09791



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  Δm^2_{21} Solar vs Reactors

  Time varing Tension

- θ_{23}: Least known angle

  Maximal? Octant?

  non-robust yet

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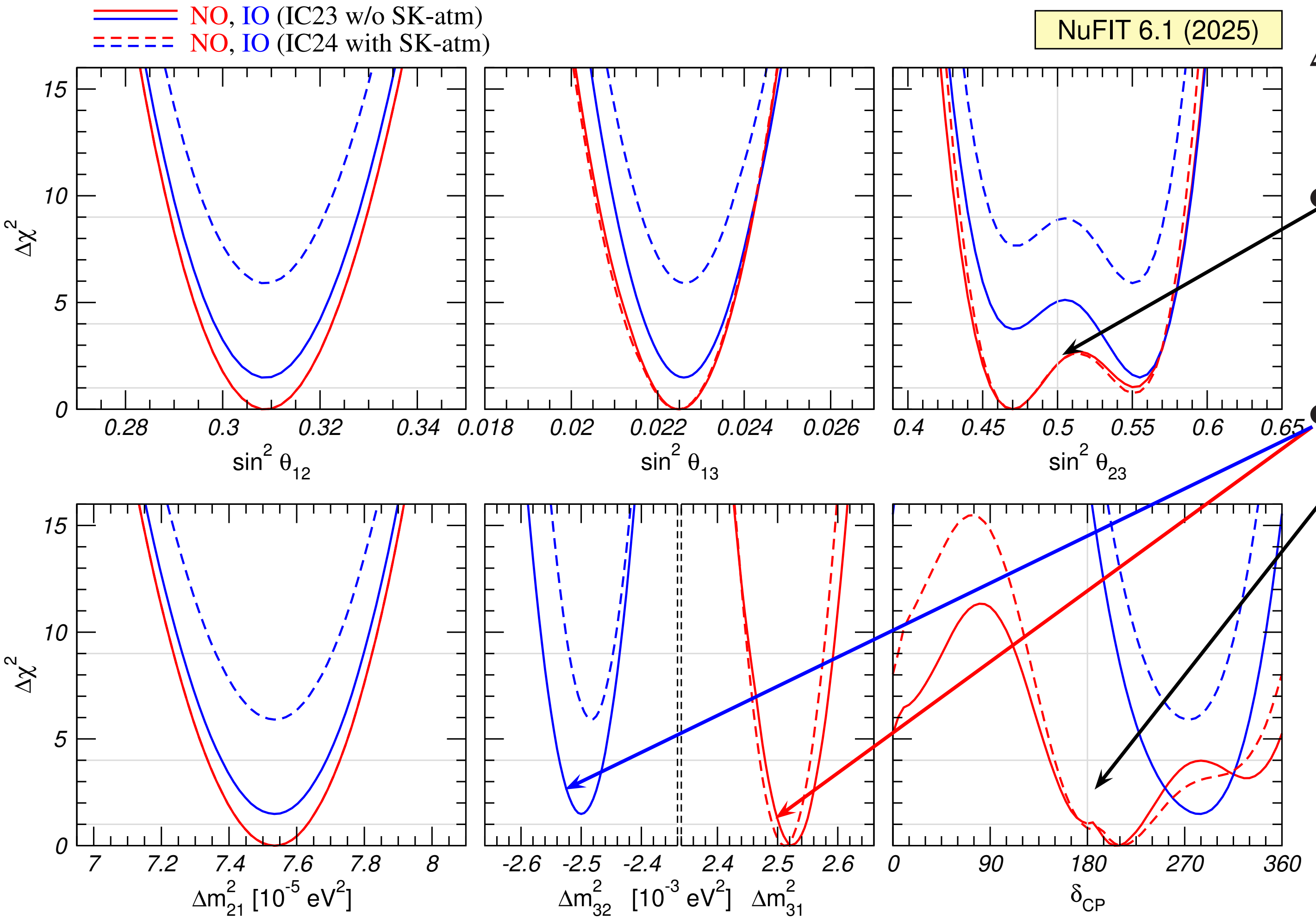

- 4 well-known parameters:

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  Δm^2_{21} Solar vs Reactors

  Time varing Tension

- θ_{23}: Least known angle

  Maximal? Octant?

  non-robust yet

- Ordering NO or IO?

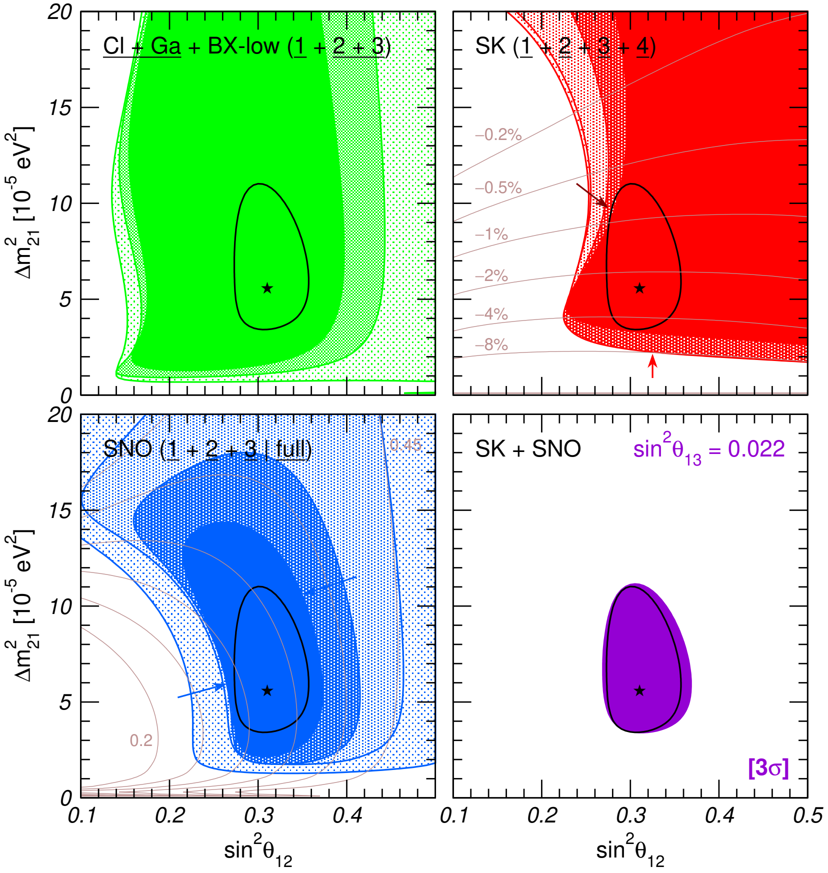
  CPV?:

3 ν Analysis: “12” Sector

Solar

- From average vac. osc. ($E \lesssim 1$ MeV) to adiabatic matter transitions ($E \gtrsim 4$ MeV)

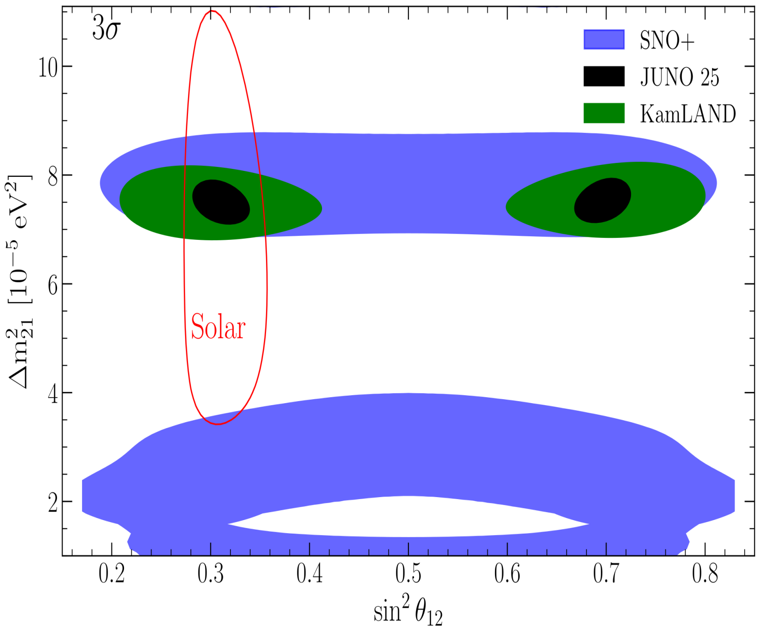
  $\Rightarrow \theta_{12} \leq 45^\circ$



- Solar region determined by SK and SNO

Reactors LBL

- Effectively vacuum oscillations



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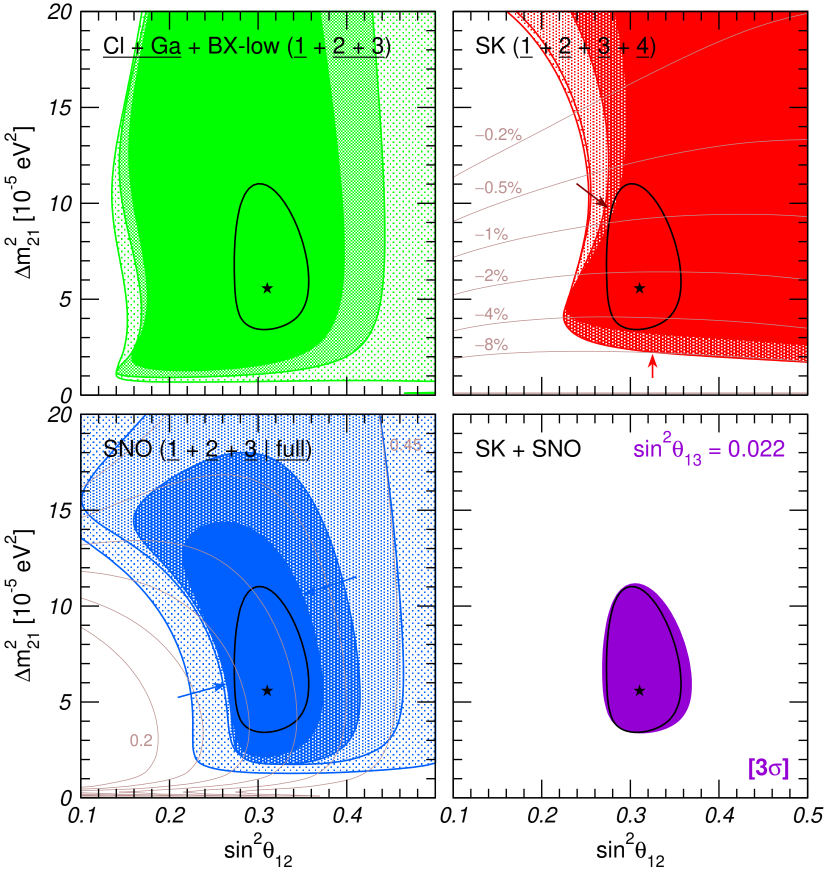
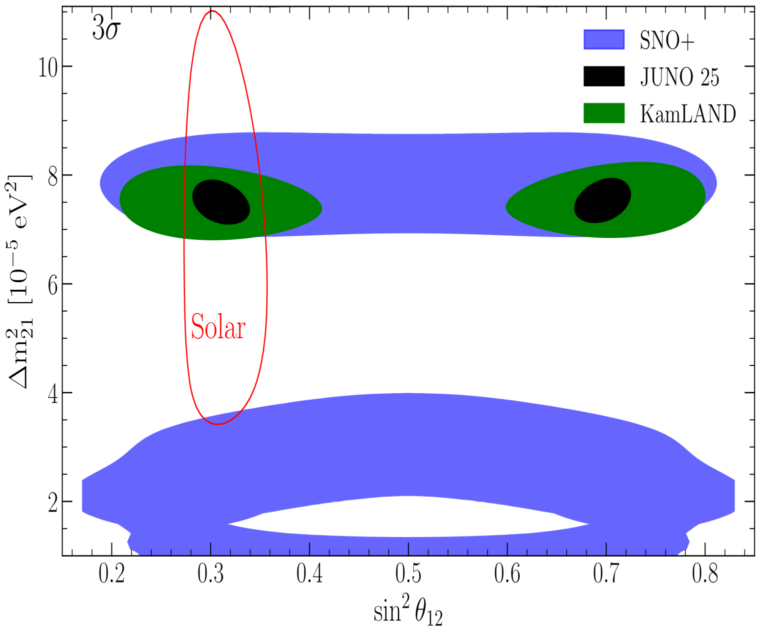


- Solar region determined by SK and SNO
- Till Dec. 2025 dominant θ_{12} precision

Reactors LBL

- Effectively vacuum oscillations



- 2003-2015:

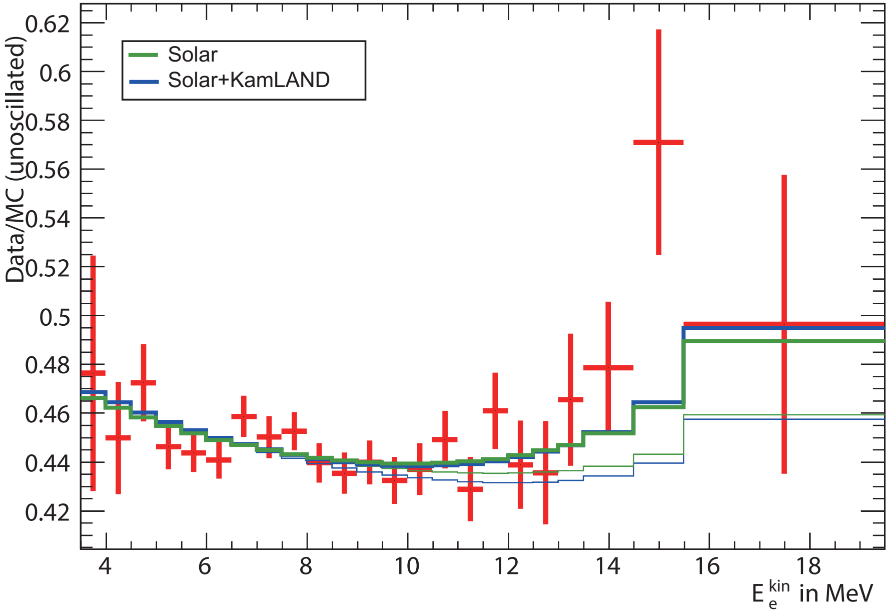
  KamLAND dominant Δm^2_{12} precision

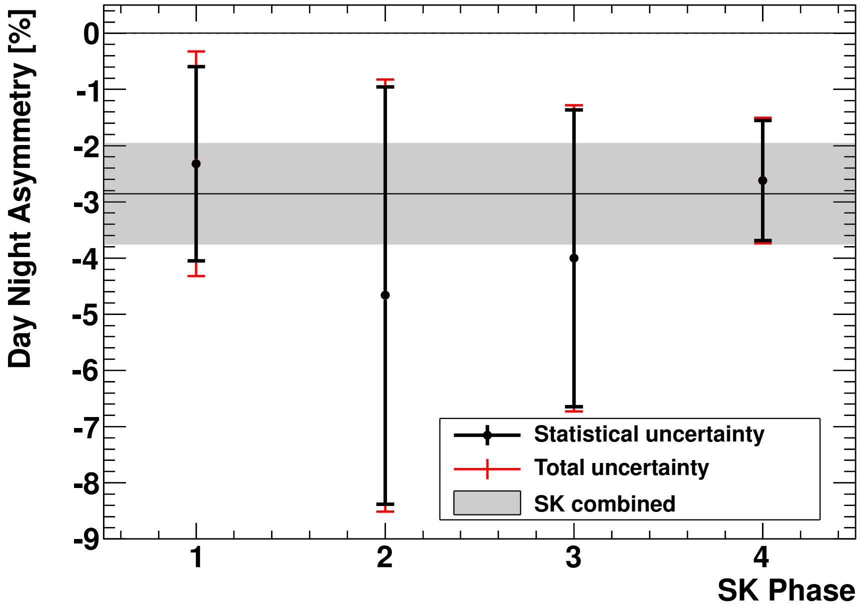
- After Dec 2025:

  JUNO leads Δm^2_{12} and θ_{12} precision (with solar prior $\theta_{12} \leq 45°$)

3 ν Analysis: status of Δm^2_{21} tension

- Long-standing weak tension on preferred Δm^2_{21} from solar and reactor LBL
- Choice of the assumed solar model (GS, AGSS, MB22,. . .) has little impact
- Cause $\left\{ \begin{array}{l} \text{– Too much Day-Night asymmetry (D/N) in SK} \\ \text{– No indication of low-E MSW turn-up} \end{array} \right.$
- With SK IV $\left\{ \begin{array}{l} \text{– D/N: 3.6\% → 2.6\%} \\ \text{– “Hints” of turn-up} \end{array} \right. \Rightarrow$ Tension reduced





SK Collab. 2312.12907

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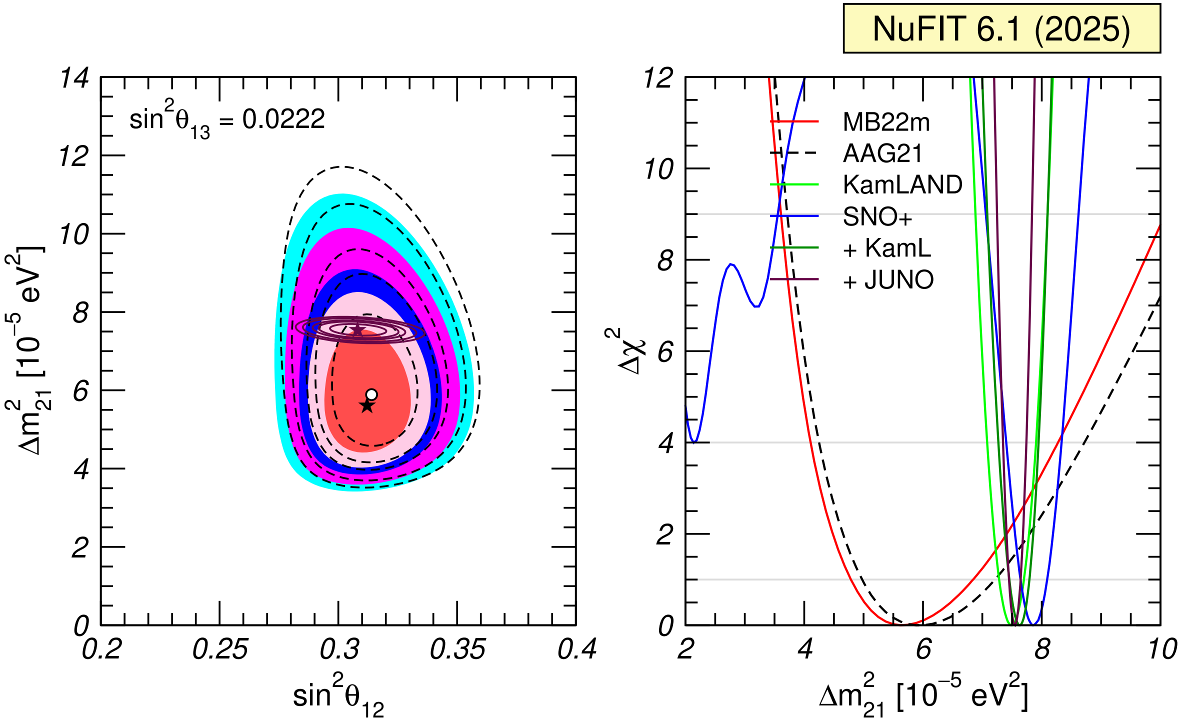
  - – "Hints" of turn-up

  $\Rightarrow$ Tension reduced :$\chi^2_{\rm PG,Sol\,reac}/n = 2.3/2$ (#σ=1)



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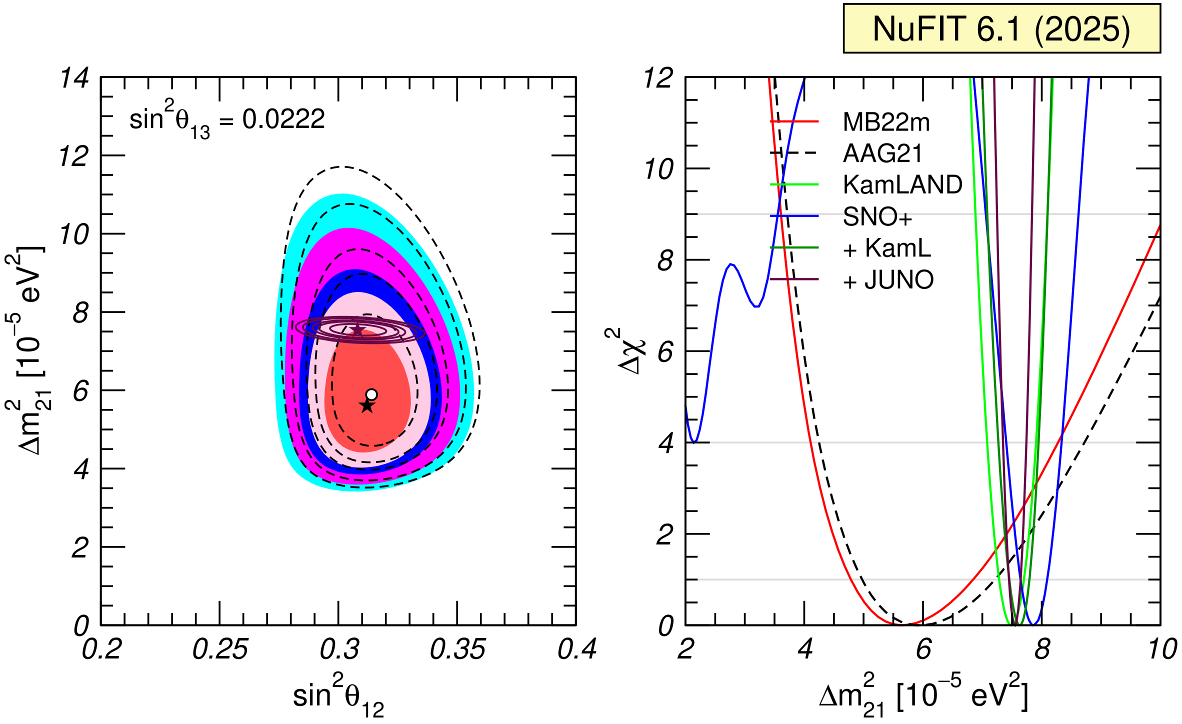
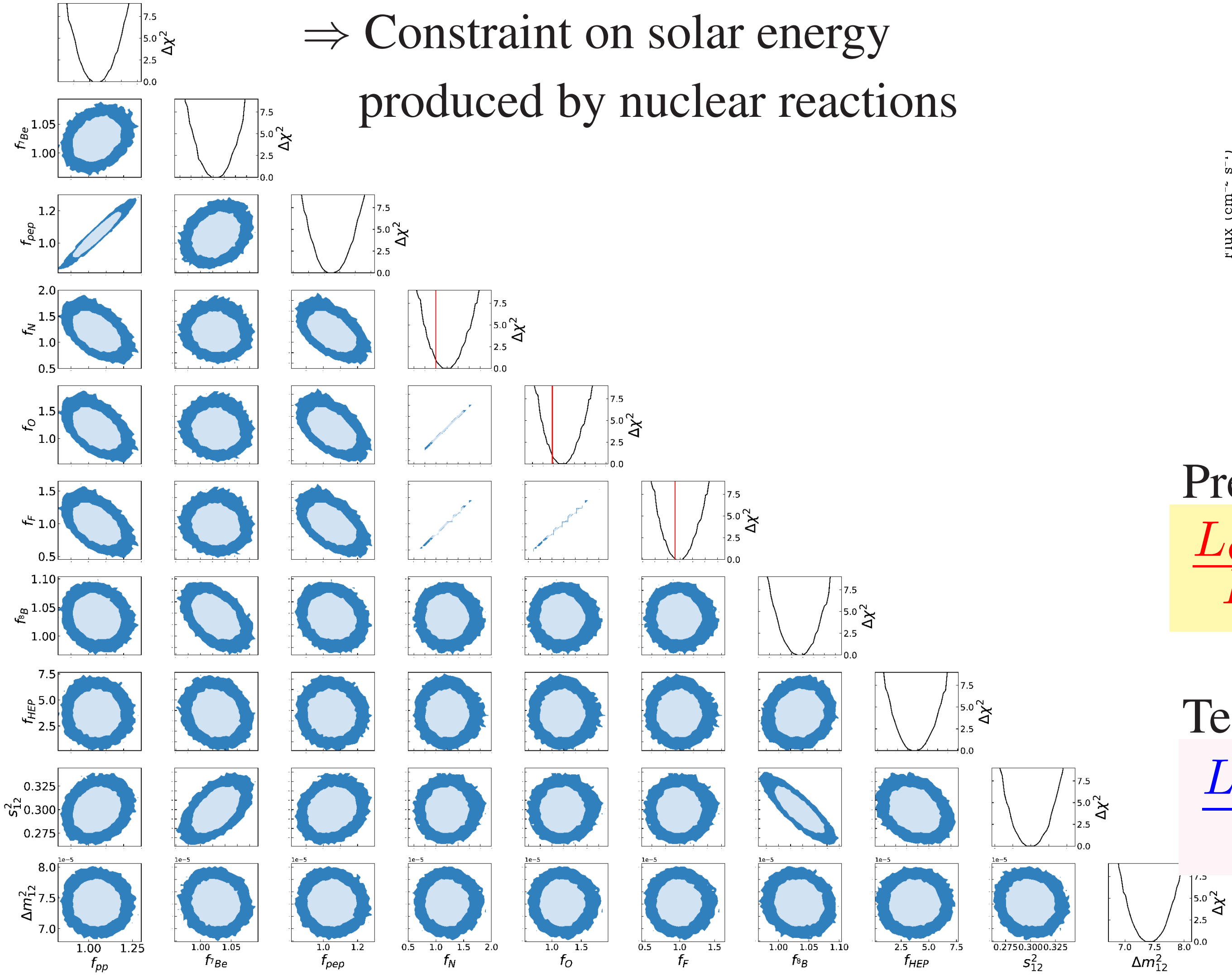


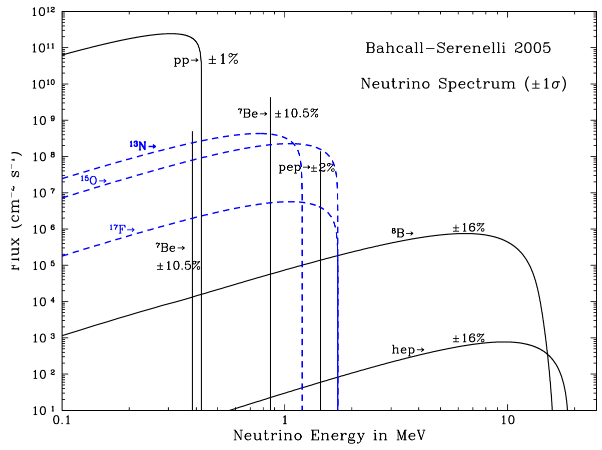
Talks by Li (JUNO/TAO), Wang (JUNO), Hu (SK), Kaptanoglu (SNO+)

Spin-off: Testing How the Sun Shines with $\nu's$

Fitting together oscillations and normalization of ν-producing reactions: $f_i = \frac{\Phi_i}{\Phi_i^{SSM}}$

$\Rightarrow$ Constraint on solar energy produced by nuclear reactions





Present limit on CNO:

$$\frac{L_{\rm CNO}}{L_\odot} < (0.75 \pm 0.3)\,\%\ (3\sigma)$$

Test of Lum Constraint:

$$\frac{L_\odot(\nu - \text{inferred})}{L_\odot} = 1.04 \pm 0.06$$

MCGG, Maltoni, Pinheiro, Serenelli 2311.16226

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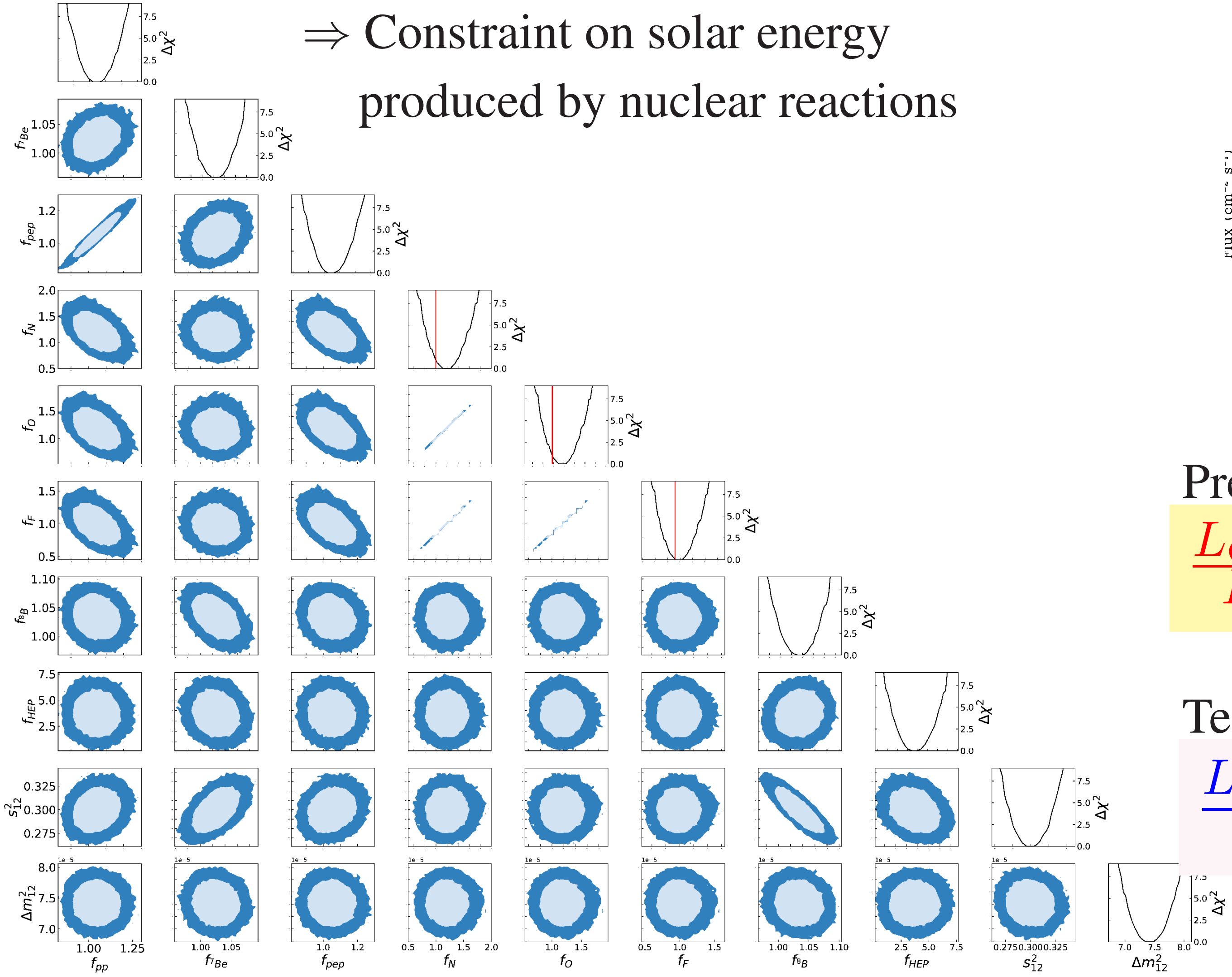
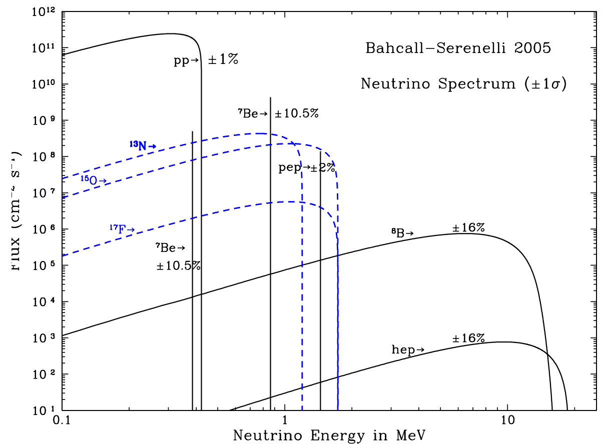


⇒ Constraint on solar energy produced by nuclear reactions



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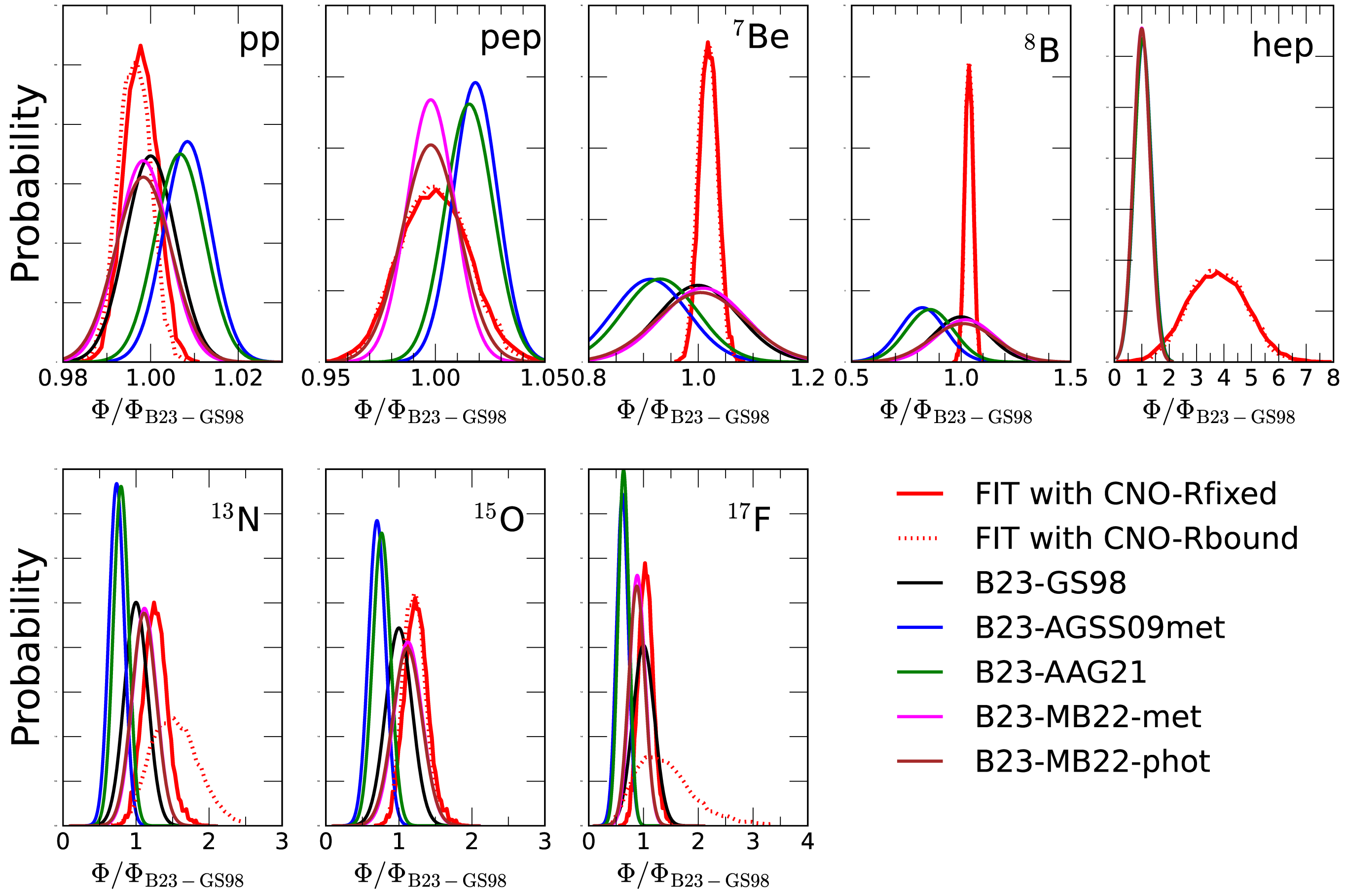
MCGG, Maltoni, Pinheiro, Serenelli 2311.16226

Talk by Han (PandaX)

Posters: Xu,Wu (90); Hebert (147); Ma (198);Xu (302); Russell (316); Huang (421)

Spin-off: Testing How the Sun Shines with $\nu's$

Some SSM independently determined fluxes more or as precise the SSM predictions

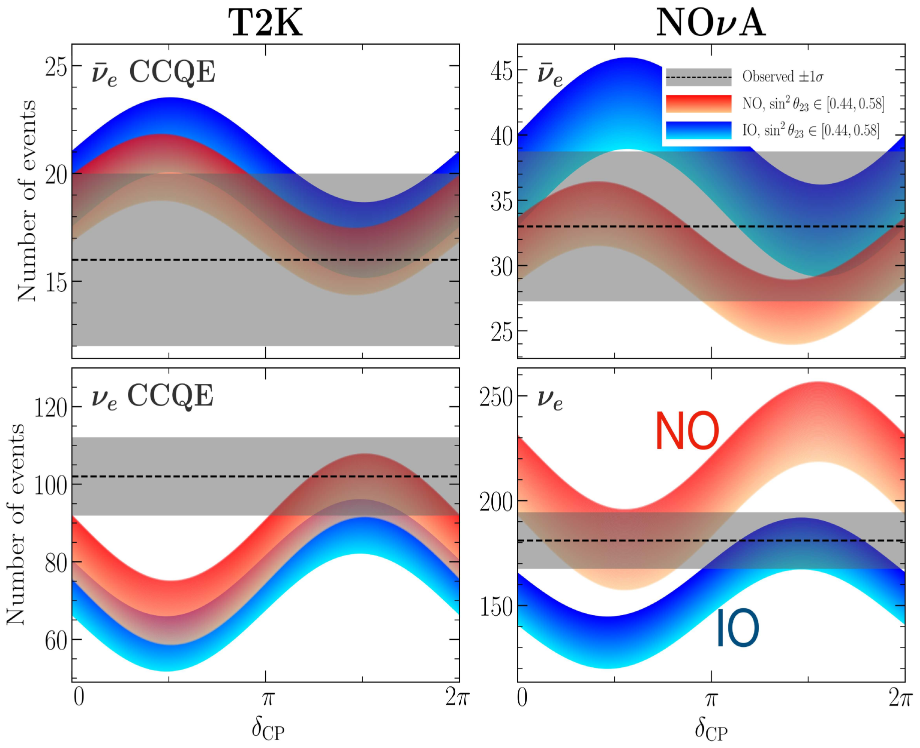


MCGG, Maltoni, Pinheiro, Serenelli 2311.16226

⇒ They could (and should) be be used to improve SSM's

MO, CPV, Octant θ_{23}: $\nu_\mu \to \nu_e$ at LBL

- Dominant info from ν_e vs $\overline{\nu}_e$ appearance in LBL T2K (285 km) and NOνA (810) Km



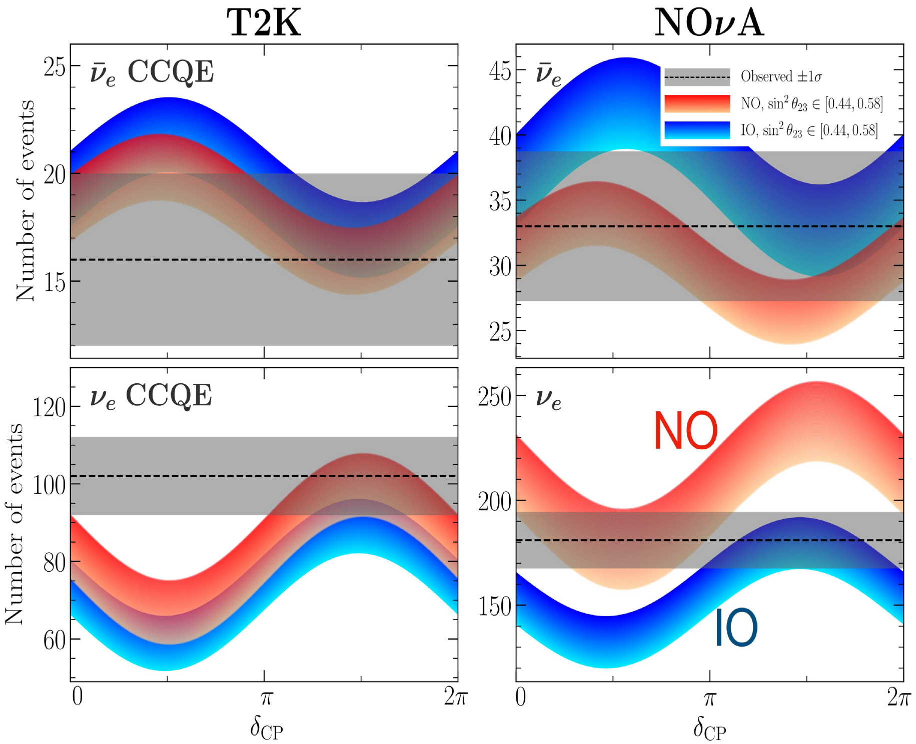
Each T2K and NOνA favour NO

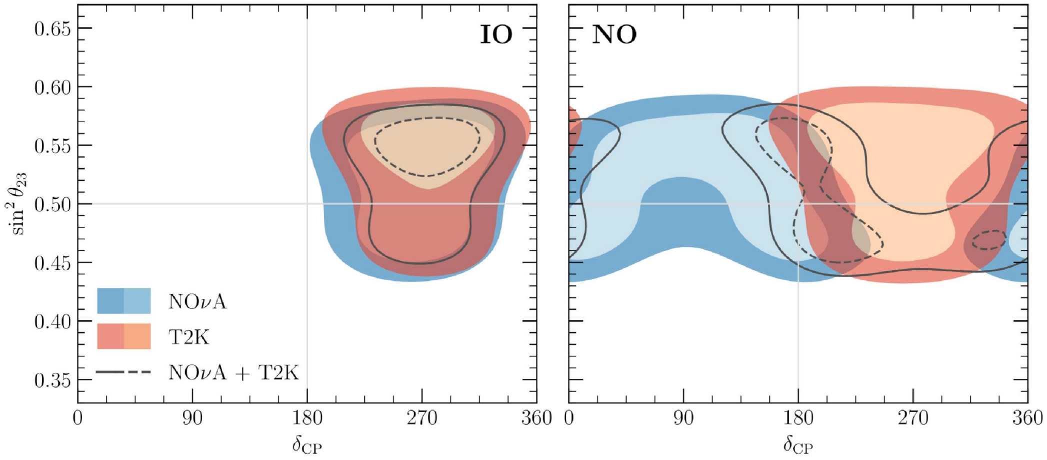
But tension ($\sim 2\ \sigma$) in δ_{CP} in NO

	normal ordering			inverted ordering		
	$\chi^2_{\rm PG}/n$	p-value	$\#\sigma$	$\chi^2_{\rm PG}/n$	p-value	$\#\sigma$
T2K vs NOvA	7.9/3	0.047	2.0σ	1.8/3	0.61	0.5σ

MO, CPV, Octant θ_{23}: $\nu_\mu \rightarrow \nu_e$ at LBL

- Dominant info from ν_e vs $\overline{\nu}_e$ appearance in LBL T2K (285 km) and NOνA (810) Km





IO
- b.f. $\delta_{\rm CP}$ close to 270° ≡ Max CPV
- CPC excluded at $\gtrsim 3\ \sigma$
- $\theta_{23} > 45^\circ$ favoured

NO
- b.f. $\delta_{\rm CP}$ close to 180° ≡ CPC
- both θ_{23} octant at $1\ \sigma$

Each T2K and NOνA favour NO

But tension ($\sim 2\ \sigma$) in δ_{CP} in NO

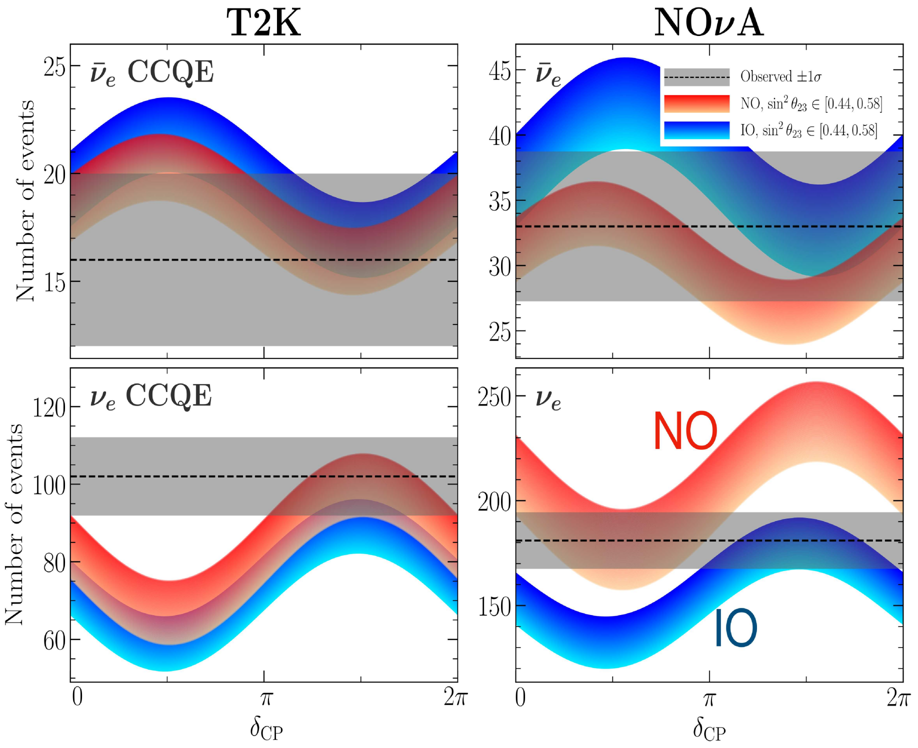
	normal ordering			inverted ordering		
	$\chi^2_{\rm PG}/n$	p-value	#σ	$\chi^2_{\rm PG}/n$	p-value	#σ
T2K vs NOvA	7.9/3	0.047	2.0σ	1.8/3	0.61	0.5σ

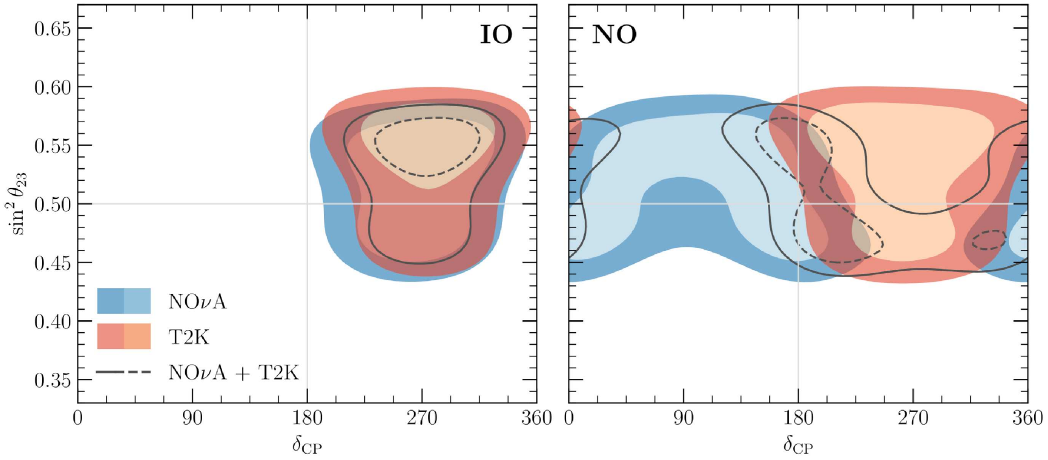
- IO best fit in LBL combination

$$\chi^2_{\rm IO} - \chi^2_{\rm NO} = -3.3$$

MO, CPV, Octant θ_{23}: $\nu_\mu \to \nu_e$ at LBL

- Dominant info from ν_e vs $\overline{\nu}_e$ appearance in LBL T2K (285 km) and NOνA (810) Km





IO
- b.f. δ_{CP} close to 270° $\equiv$ Max CPV
- CPC excluded at $\gtrsim 3\ \sigma$
- $\theta_{23} > 45°$ favoured

NO
- b.f. δ_{CP} close to 180° $\equiv$ CPC
- both θ_{23} octant at 1 σ

Each T2K and NOνA favour NO

But tension ($\sim 2\ \sigma$) in δ_{CP} in NO

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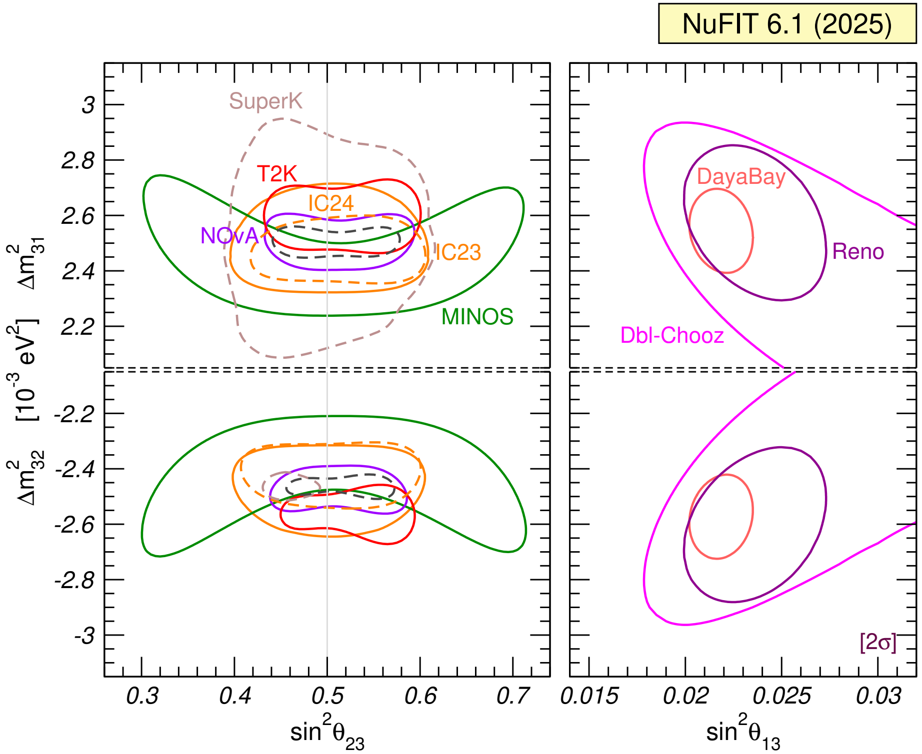
Talks by Vallari (NOνA), King (T2K)

Posters: Mikola Prais (420); Schefke (459,471); Hua (499); Tong (62); Rajaolisoa (215); Murthy,Chen (237); Zhao (247);Sullivan (397); Marathe (434); Vallari (451)

MO: MBL reactors vs LBL/ATM

- Complementarity between varius data sets in the determination of $\Delta m^2_{3\ell}$



- Non-trivial consistency check of 3ν-osc

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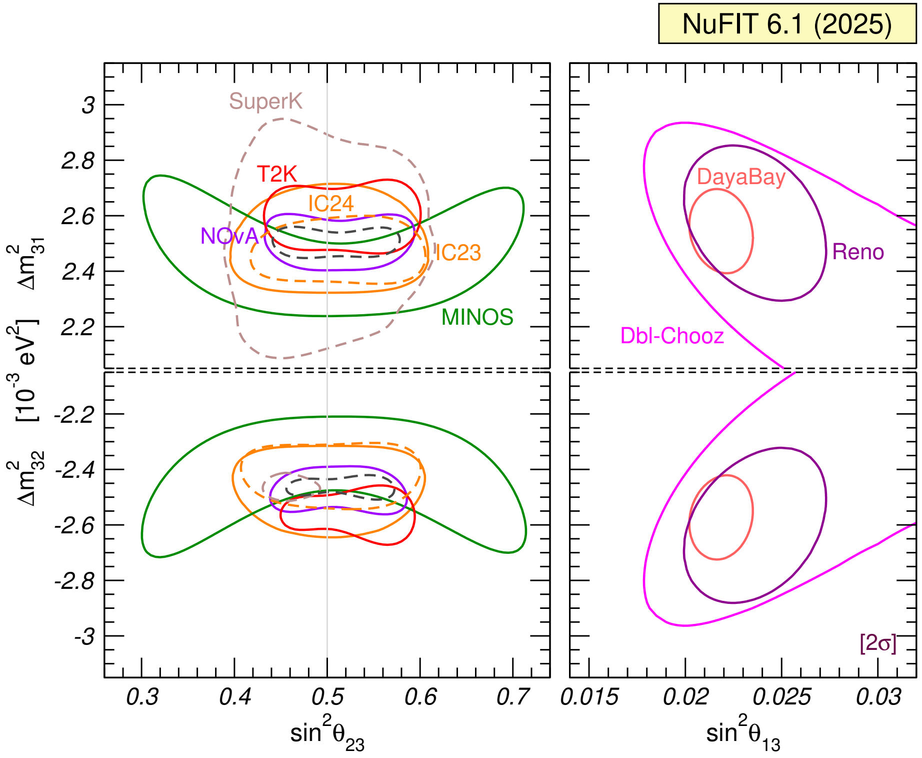


- Non-trivial consistency check of 3ν-osc

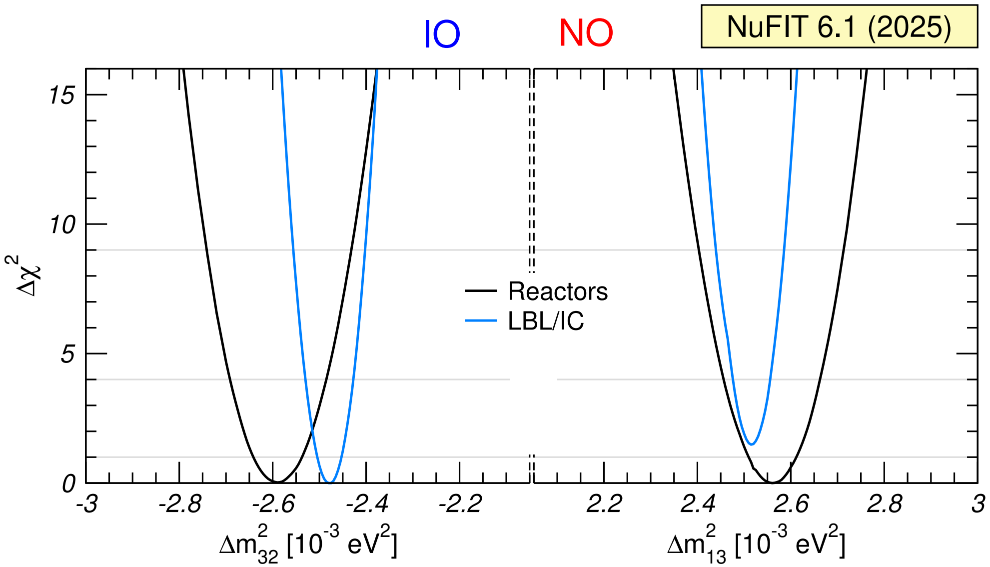
- MO info from ν_μ disapp (LBL/ATM)

$$\Delta m^2_{\mu\mu} \simeq \Delta m^2_{3l} + \begin{matrix} c^2_{12}\Delta m^2_{21} & \text{NO} \\ s^2_{12}\Delta m^2_{21} & \text{IO} \end{matrix} + \dots$$

vs ν_e disapp (MBL React):

$$\Delta m^2_{ee} = \Delta m^2_{3l} + \begin{matrix} s^2_{12}\Delta m^2_{21} & \text{NO} \\ c^2_{12}\Delta m^2_{21} & \text{IO} \end{matrix}$$

Nunokawa,Parke,Zukanovich hep-ph/0503283



- Better agreement in NO

⇒ NO best fit in Reactor + ν_μ-disapp

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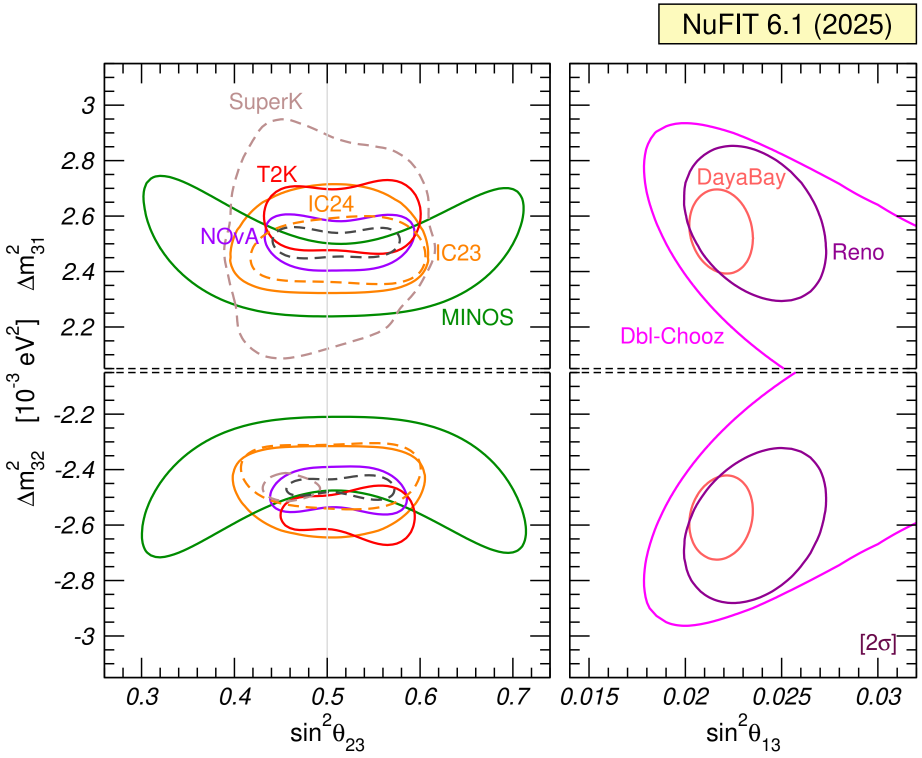

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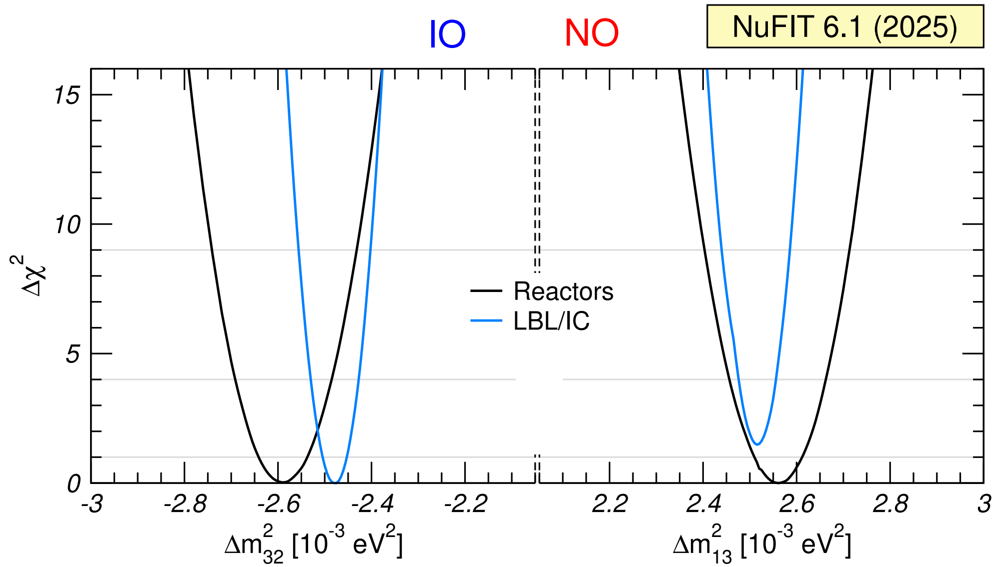


- Better agreement in NO

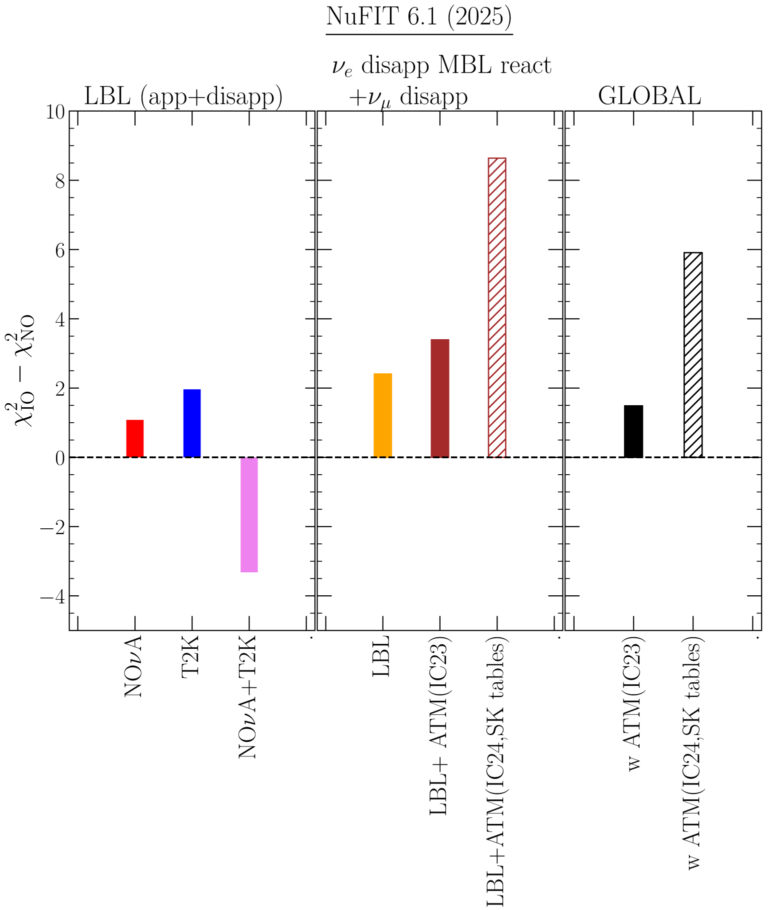
$\Rightarrow$ NO best fit in Reactor + ν_μ-disapp

Talks by Zhang (MBL Reactors), Axani (IceCube), De Jong (KM3Net)

Posters: Kueviakoe (97); Jargowsky (225); Girgus (230); Meighen-Berger (277)

MO, CPV, θ_{23}: Global Status

- In addition to synergies with reactors via ν_μ disappearance, ATM ν_e's provide further sensitivity to MO (IC23, SK) and CPV (SK)



$$\chi^2_{\rm IO}-\chi^2_{\rm NO} = \begin{cases} 1.5 & \text{w IC23 w/o SK} - \text{ATM} \\ 5.9 & \text{w IC24 w SK} - \text{ATM} \end{cases}$$

MO, CPV, θ_{23}: Global Status

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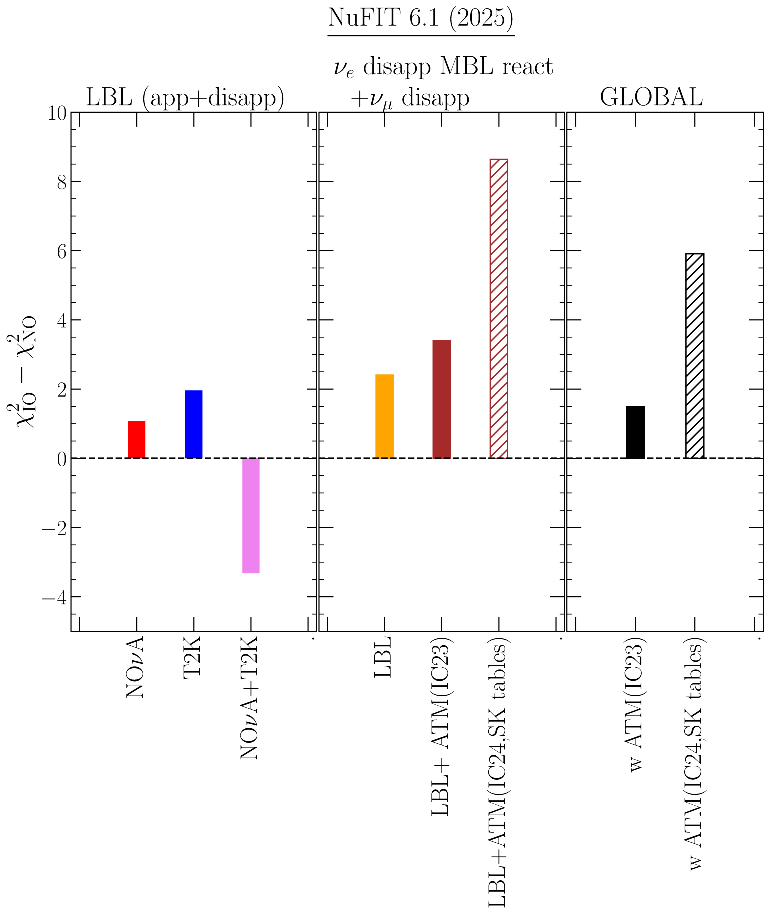
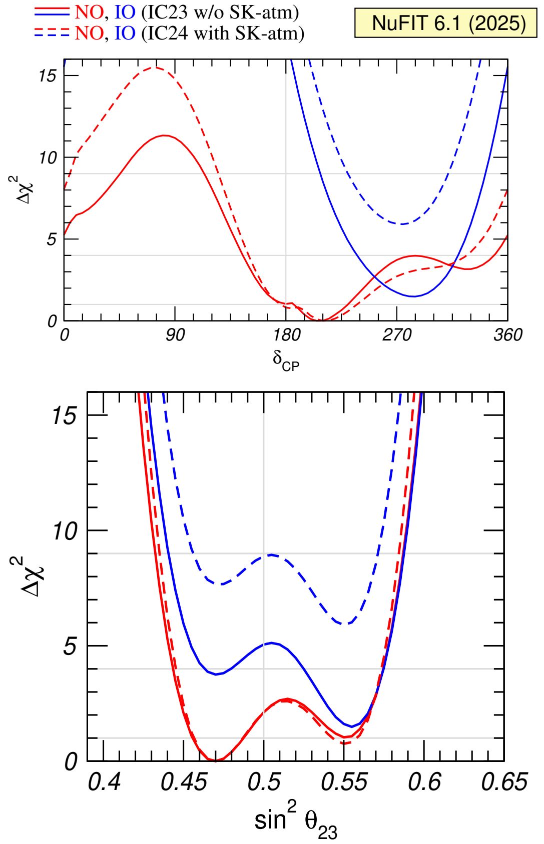




NO:

- CPC ($\delta_{CP} = 180^\circ$) at 1 σ
- Excluded at 3σ

$47^\circ < \delta_{CP} < 112^\circ$ w/o SK-ATM
($5^\circ < \delta_{CP} < 125^\circ$)(w SK-ATM)

- θ_{23}: b.f. 1st octant but both at 1 σ

IO:

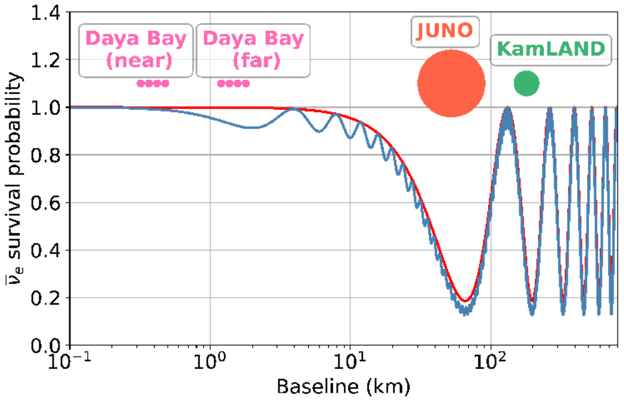
- b.f. $\delta_{CP} \sim 270^\circ \equiv$ Max CPV
- CPC excluded at 4 (4.7) σ
- θ_{23}: b.f. 2nd octant

$$\chi^2_{\min,\theta_{23}<45^\circ} - \chi^2_{\min,\theta_{23}>45^\circ} = 2.3\ (1.8)$$

$$\chi^2_{IO} - \chi^2_{NO} = \begin{cases} 1.5 & \text{w IC23 w/o SK} - \text{ATM} \\ 5.9 & \text{w IC24 w SK} - \text{ATM} \end{cases}$$

Mass Ordering: First lesson from JUNO

$$P_{\nu_e,\nu_e} = 1 - c_{13}^4 \sin^2 2\theta_{12} \sin^2\left(\frac{\Delta m^2_{21} L}{4E}\right) - \sin^2 2\theta_{13}\left[c_{12}^2 \sin^2\left(\frac{\Delta m^2_{31} L}{4E}\right) + s_{12}^2 \sin^2\left(\frac{\Delta m^2_{32} L}{4E}\right)\right]$$

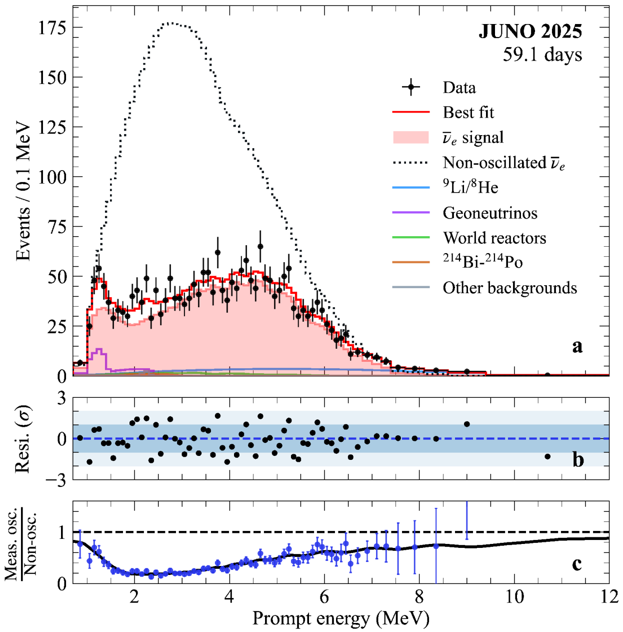


In First data release JUNO focus on Δm^2_{21}, θ_{12} and no analysis results on $\Delta m^2_{3\ell}$/MO

This is what we reproduced and included in NuFIT 6.1

But the data points are there.... so we carefully checked

59 Day data :



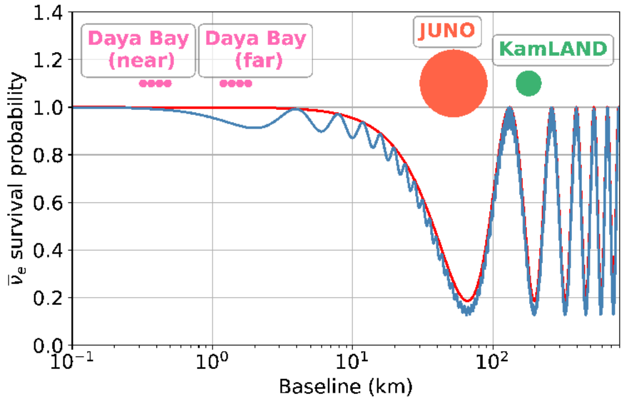
JUNO coll. 2511.14593

Mass Ordering: First lesson from JUNO

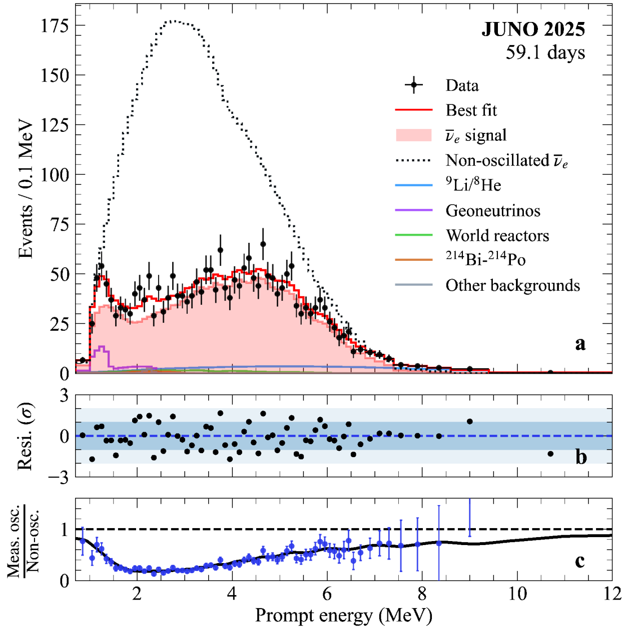
$$P_{\nu_e,\nu_e} = 1 - c_{13}^4 \sin^2 2\theta_{12} \sin^2\left(\frac{\Delta m^2_{21} L}{4E}\right) - \sin^2 2\theta_{13}\left[c_{12}^2 \sin^2\left(\frac{\Delta m^2_{31} L}{4E}\right) + s_{12}^2 \sin^2\left(\frac{\Delta m^2_{32} L}{4E}\right)\right]$$

$$\simeq 1 - c_{13}^4 \sin^2 2\theta_{12} \sin^2\left(\frac{\Delta m^2_{21} L}{4E}\right) - \sin^2 2\theta_{13}\left(\frac{\Delta m^2_{ee} L}{4E}\right)$$

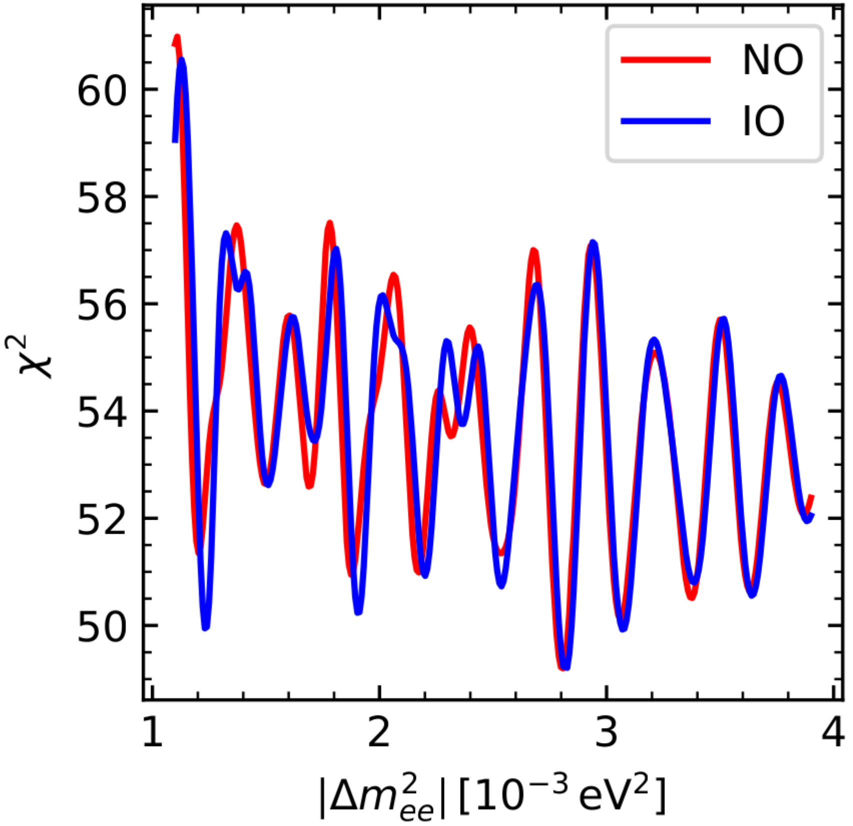
$$\Delta m^2_{ee} = \Delta m^2_{3l} + \begin{matrix} s_{12}^2 \Delta m^2_{21} & \text{NO} \\ c_{12}^2 \Delta m^2_{21} & \text{IO} \end{matrix}$$



59 Day data :



JUNO coll. 2511.14593



Esteban,MCGG,Maltoni,Martinez-Soler,Pinheiro, Schwetz 2601.09791

Mass Ordering: First lesson from JUNO

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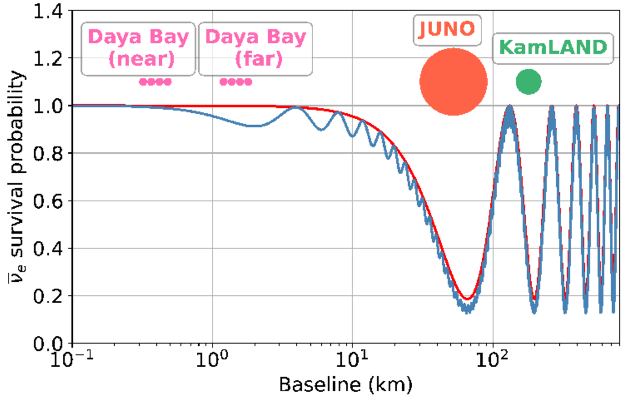
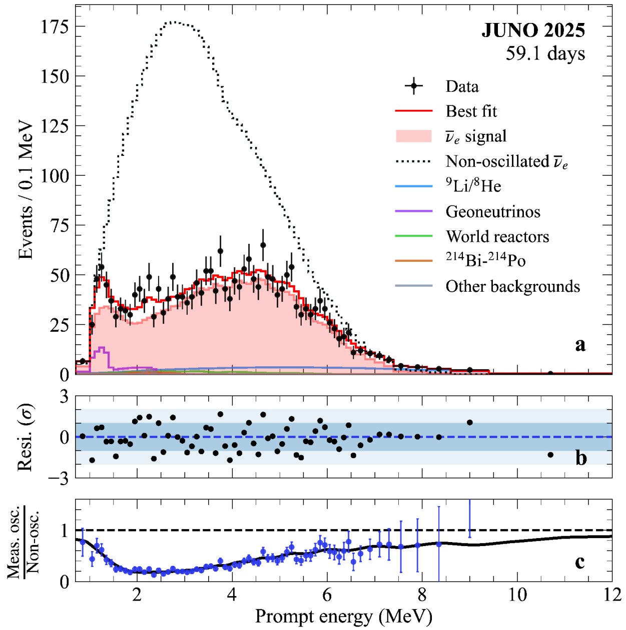


59 Day data :



JUNO Coll. 2511.14593

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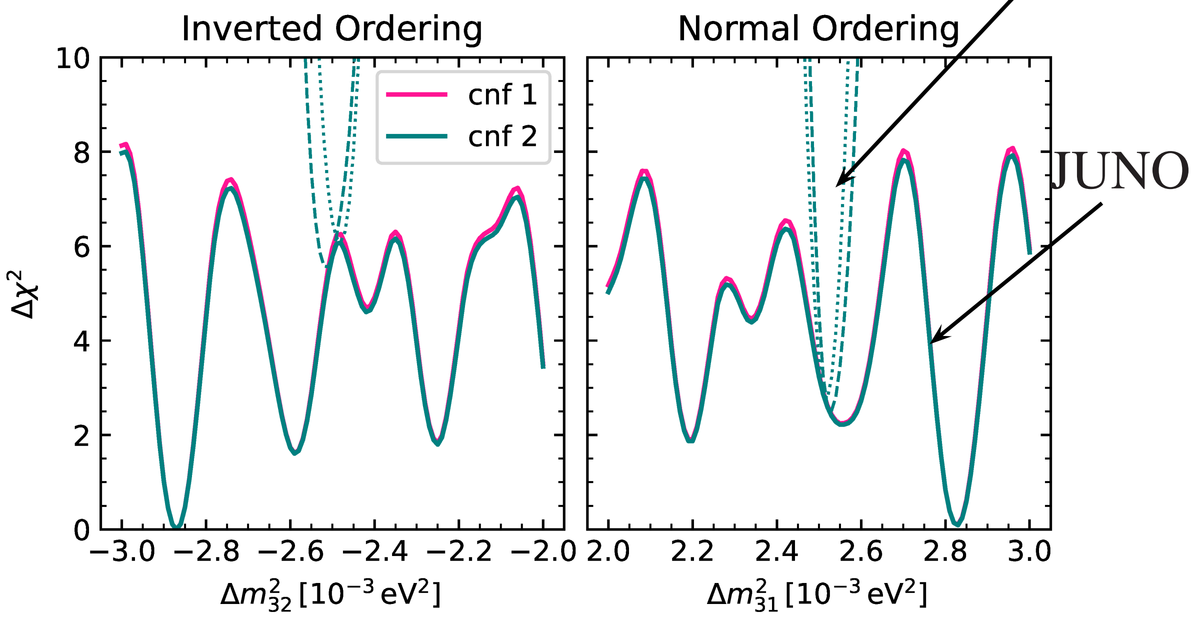
NuFIT 6.1



JUNO

Esteban,MCGG,Maltoni,Martinez-Soler,Pinheiro, Schwetz 2601.09791

With 1st 59 days:

$$\chi^2_{\rm IO} - \chi^2_{\rm NO} = \begin{cases} 1.5 \to 4.5 & \text{w IC23 w/o SK} - \text{ATM} \\ 5.9 \to 9.4 & \text{w IC24 w SK} - \text{ATM} \end{cases}$$

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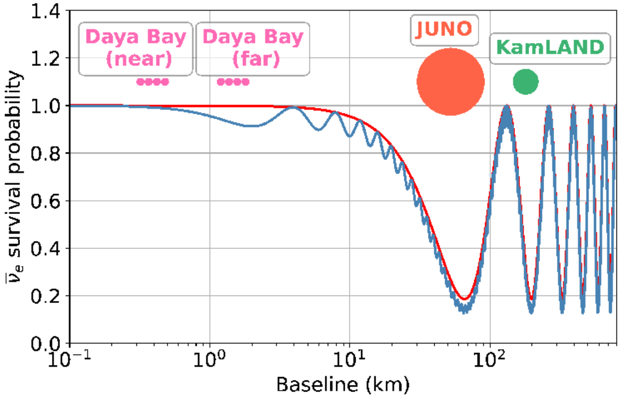

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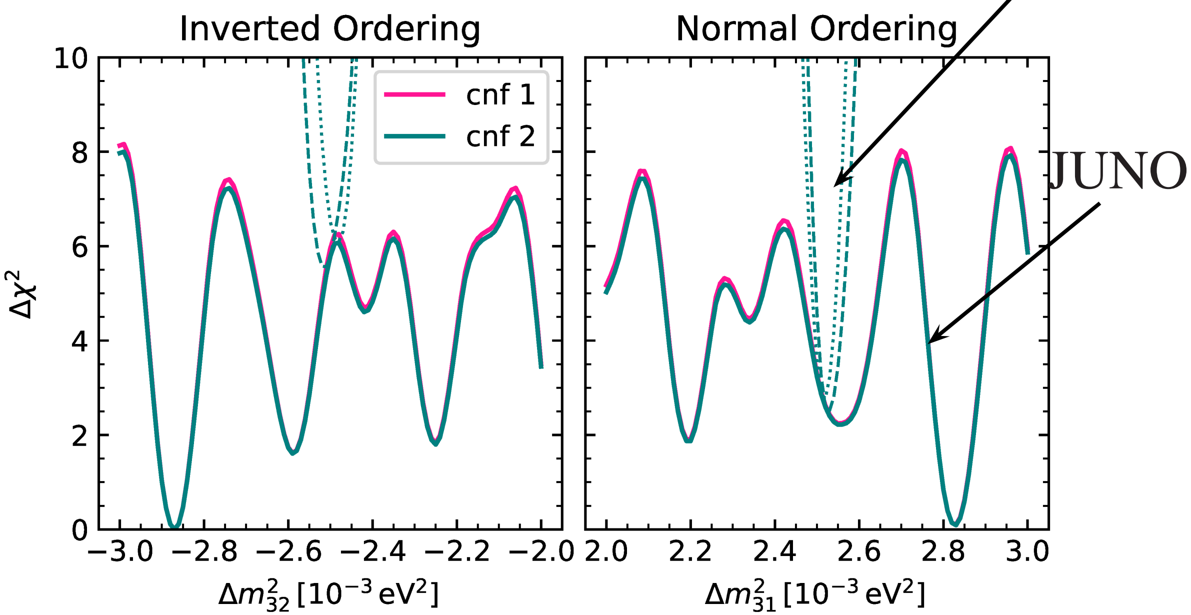
NuFIT 6.1



Esteban,MCGG,Maltoni,Martinez-Soler,Pinheiro, Schwetz 2601.09791

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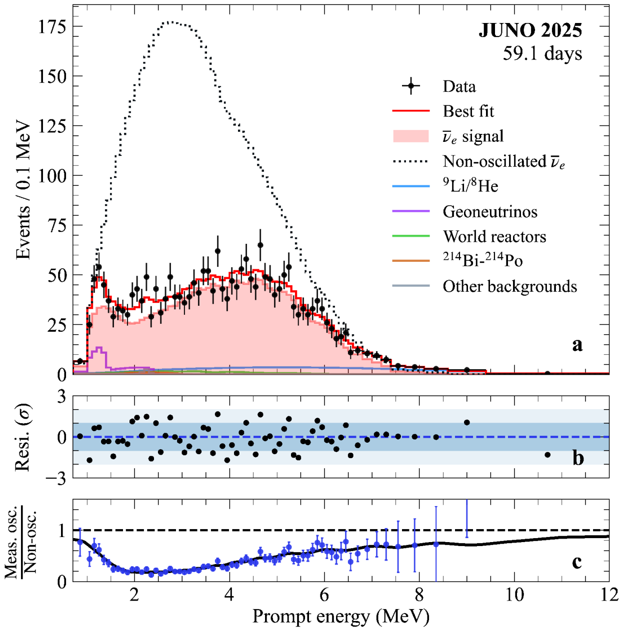

JUNO Coll. 2511.14593

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With ~ 250 Days? Let's see after coffee!!

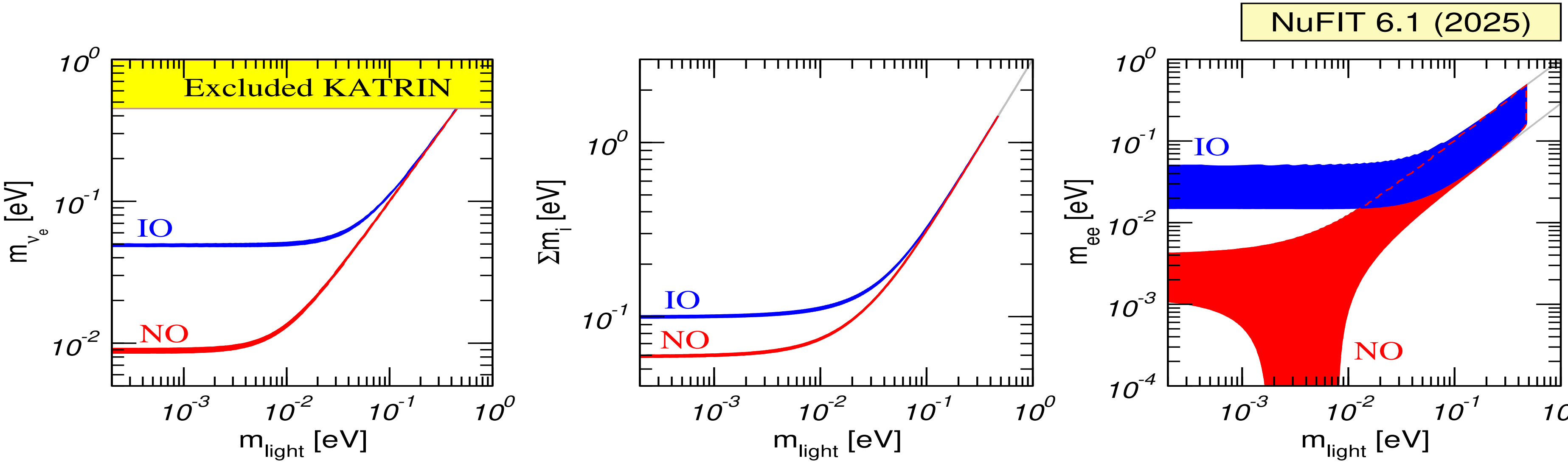
Talks by Li (JUNO/TAU), Wang (JUNO)

Mass Scale & Dirac vs Majorana in 3ν-mixing

β decay: Dirac or Majorana $$m^2_{\nu_e} = \sum m_j^2 |U_{ej}|^2 = \begin{cases} \text{NO}: & m_\ell^2 + \Delta m^2_{21} c^2_{13} s^2_{12} + \Delta m^2_{31} s^2_{13} \\ \text{IO}: & m_\ell^2 + \Delta m^2_{21} c^2_{13} s^2_{12} - \Delta m^2_{31} c^2_{13} \end{cases}$$

ν-less β-β decay: $\Leftrightarrow$ Majorana $$m_{ee} = \left|\sum U^2_{ej} m_j\right| = f(m_\ell, \text{osc param, maj phases})$$

Cosmology: Dirac or Majorana $$\sum m_i = \begin{cases} \text{NO}: & \sqrt{m_\ell^2} + \sqrt{\Delta m^2_{21} + m_\ell^2} + \sqrt{\Delta m^2_{31} + m_\ell^2} \\ \text{IO} & \sqrt{m_\ell^2} + \sqrt{-\Delta m^2_{31} - \Delta m^2_{21} - m_\ell^2} + \sqrt{-\Delta m^2_{31} - m_\ell^2} \end{cases}$$



95% CL

NO :	$0.0085\ \text{eV} \le m_{\nu_e} \le 0.4\ \text{eV}$	$0.058\ \text{eV} \le \sum m_\nu \le 1.2\ \text{eV}$	$0 \le m_{ee} \le 0.41\ \text{eV}$
IO :	$0.048\ \text{eV} \le m_{\nu_e} \le 0.4\ \text{eV}$	$0.098\ \text{eV} \le \sum m_\nu \le 1.2\ \text{eV}$	$0.015\ \text{eV} \le m_{ee} \le 0.41\ \text{eV}$

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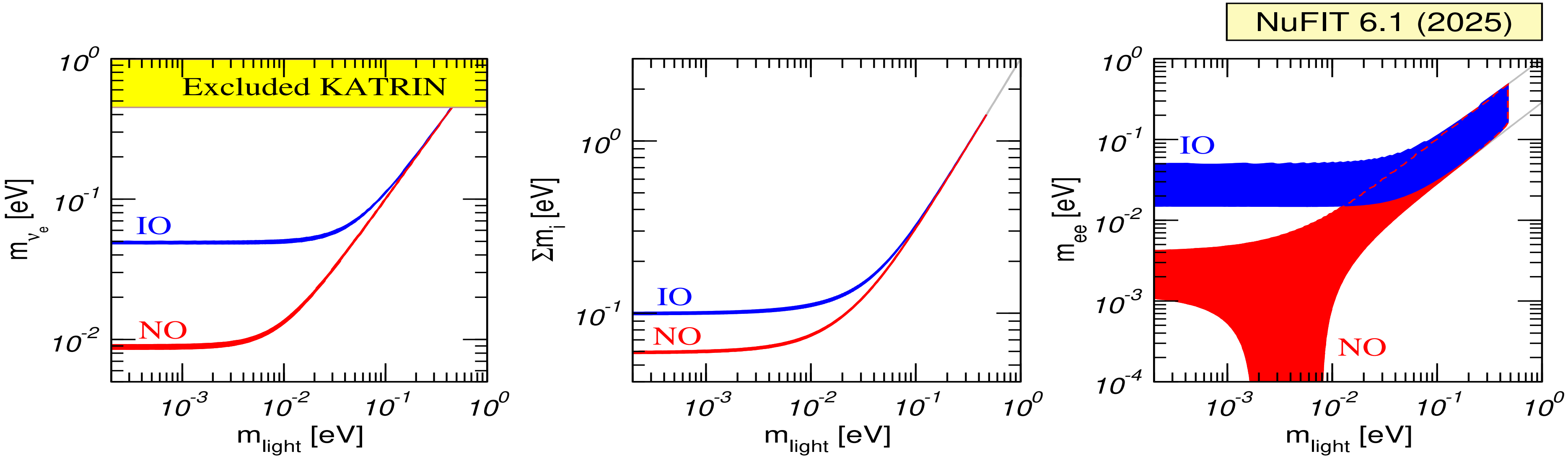

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Talks by Wiesinger (KATRIN)
and Surukuchi (Project 8)

Talk by Knox

Talks by Sisti (CUORE)
Penek (Kland-ZEN);
Romo Luque (LEGEND); Gann

ν OSC and New Physics w/o new states in OSC

If SM is an effective low energy theory, for $E \ll \Lambda_{\rm NP}$

– The same particle content as the SM and same pattern of symmetry breaking

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \sum_n \frac{1}{\Lambda_{\rm NP}^{n-4}} \mathcal{O}_n$$

– At dim=5 only 1 operator:

$O_5 = \frac{\lambda^\nu_{ij}}{\Lambda_{\rm NP}} \left(\overline{L_{L,i}}\tilde{\phi}\right)\left(\tilde{\phi}^T L^C_{L,j}\right) \Rightarrow \frac{1}{2}\overline{\nu}_L M_\nu \nu^C_L \equiv$ Majorana Mass $\Rightarrow$ ν-less $\beta\beta$ decay

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– At dim=6 $\mathcal{O}_6 \sim \bar{L}\bar{L}LL$, $\bar{Q}Q\bar{L}L$ are LN conserving but can be LFV so in general

$$\mathcal{L} = \mathcal{L}_{SM} + \frac{c_{5\alpha\beta}}{\Lambda_{LN}} \left(\overline{L_\alpha}\tilde{\phi}\right)\left(\tilde{\phi}^T L^C_\beta\right) + \sum_i \frac{c_{6,i}}{\Lambda^2_{LF}} \mathcal{O}_{6,i}$$

⇒ possible to *decouple* :

New Physics scale Λ_{LN} responsible for the small m_ν from

New Physics scale Λ_{LF} ($\ll \Lambda_{LN}$) controlling signals at Lab experiments.

⇒ possible signals in ν experiments: Non-standard ν int. (NSI), non-unitarity …

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Talk by B. Dev

Posters: Acero (27); Sousa,Prais (77); Lister (194); Chaudhary (195); Davies, Huang (309); Sun (361); Das (408); Marathe (434); Souza (462)

NSI in ν Oscillations : Degeneracies

- Effective parametrization: $\mathcal{L}_{\rm NSI}^{\rm NC} = -2\sqrt{2}G_F\varepsilon_{\alpha\beta}^{fP}(\bar\nu_\alpha\gamma^\mu L\nu_\beta)(\bar f\gamma_\mu P f)\,, \qquad P = L, R$

- In matter with NSI: $\varepsilon_{\alpha\beta}(r) \equiv \sum_{f=p,n,e}\frac{N_f(r)}{N_e(r)}\varepsilon_{\alpha\beta}^f$

$$H^\nu = U_{\rm vac}\begin{pmatrix} 0 & 0 & 0 \\ 0 & \frac{\Delta m_{21}^2}{2E_\nu} & 0 \\ 0 & 0 & \frac{\Delta m_{31}^2}{2E_\nu}\end{pmatrix}U_{\rm vac}^\dagger + \sqrt{2}G_F N_e(r)\begin{pmatrix} 1+\varepsilon_{ee}-\varepsilon_{\mu\mu} & \varepsilon_{e\mu} & \varepsilon_{e\tau} \\ \varepsilon_{e\mu}^* & 0 & \varepsilon_{\mu\tau} \\ \varepsilon_{e\tau}^* & \varepsilon_{\mu\tau}^* & \varepsilon_{\tau\tau}-\varepsilon_{\mu\mu}\end{pmatrix}$$

- So $H \to -H^*$ ($\equiv$ Probabilities are Invariant) if simultaneously:

$\theta_{12} \to \frac{\pi}{2} - \theta_{12}$ $\quad$ $(\varepsilon_{ee}-\varepsilon_{\mu\mu}) \to -(\varepsilon_{ee}-\varepsilon_{\mu\mu}) - 2$ $\quad$ New "Dark" ($\theta_{12} > \frac{\pi}{4}$) region (solar)

$\Delta m_{31}^2 \to -\Delta m_{32}^2$ and $\quad$ $(\varepsilon_{\tau\tau}-\varepsilon_{\mu\mu}) \to -(\varepsilon_{\tau\tau}-\varepsilon_{\mu\mu})$ $\quad$ Lost order info (ATM&LBL)

$\delta \to \pi - \delta$ $\quad$ $\varepsilon_{\alpha\beta} \to -\varepsilon_{\alpha\beta}^* \qquad (\alpha \neq \beta)$ $\quad$ CPV confusion (ATM&LBL)

Miranda,Tortola, Valle, hep-ph/0406280
MCGG,Maltoni,Salvado 1103.4265
Coloma, Schwetz, 1604.05772

for $N_f(r)/N_e(r) \neq$ constant $\Rightarrow$ $\varepsilon_{\alpha\beta}$ are not constant $\Rightarrow$ degeneracy only approximate

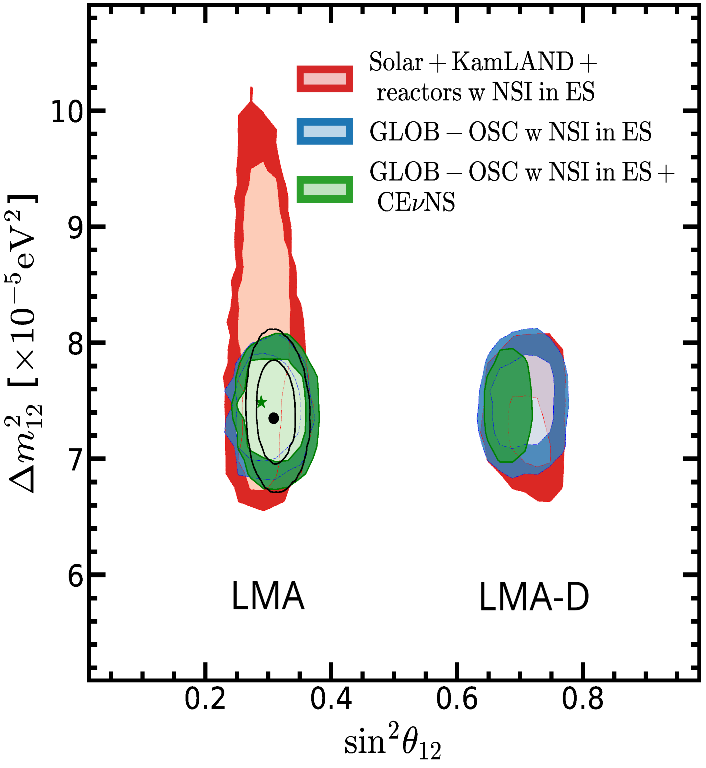
NSI in ν OSC (and CEνNs): Global Analysis

With NSI with up,down and/or e: Coloma, MCGG, Maltoni, Pinheiro, Urrea 2305.07698

LMA-D allowed by oscillations

Adding CEνNs ($M_{\rm med} \gtrsim 50$ MeV)

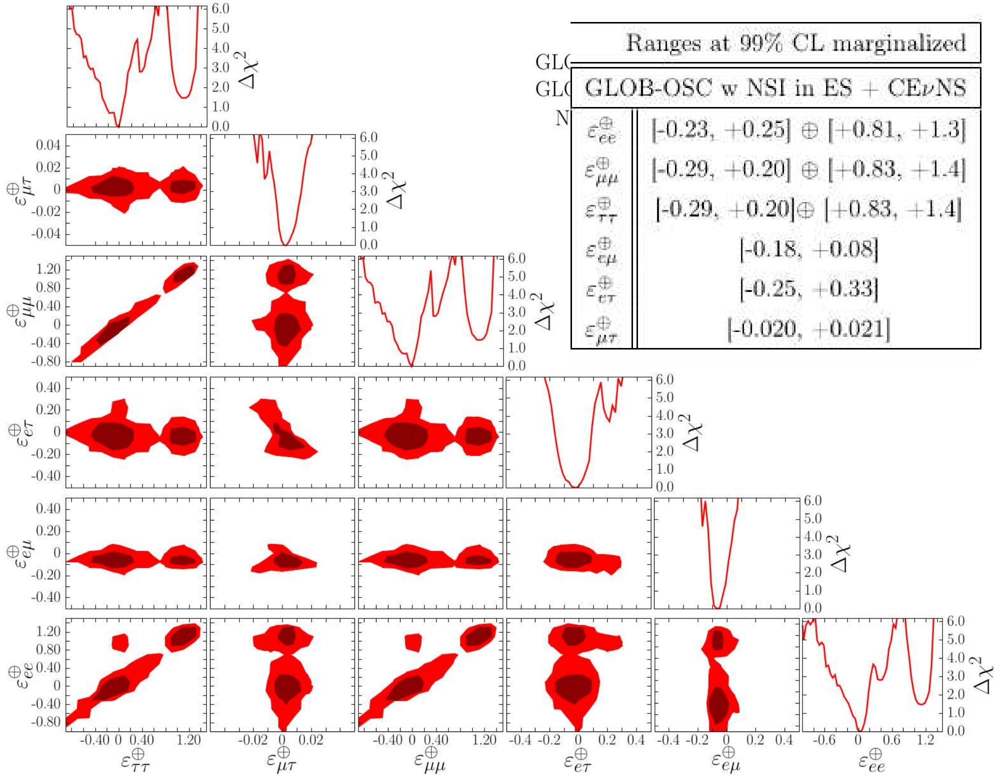
$\Rightarrow$ LMA-D only above 2σ



No evidence of CP conserving NSI's

$\Rightarrow$ Maximum effect at future LBL experiments

$$\varepsilon^{\oplus}_{\alpha\beta} = \varepsilon^{e}_{\alpha\beta} + \left(2 + Y^{\oplus}_{n}\right)\varepsilon^{u}_{\alpha\beta} + \left(1 + 2Y^{\oplus}_{n}\right)\varepsilon^{d}_{\alpha\beta}$$



Ranges at 99% CL marginalized	
	GLOB-OSC w NSI in ES + CEνNS
$\varepsilon^{\oplus}_{ee}$	[-0.23, +0.25] $\oplus$ [+0.81, +1.3]
$\varepsilon^{\oplus}_{\mu\mu}$	[-0.29, +0.20] $\oplus$ [+0.83, +1.4]
$\varepsilon^{\oplus}_{\tau\tau}$	[-0.29, +0.20]$\oplus$ [+0.83, +1.4]
$\varepsilon^{\oplus}_{e\mu}$	[-0.18, +0.08]
$\varepsilon^{\oplus}_{e\tau}$	[-0.25, +0.33]
$\varepsilon^{\oplus}_{\mu\tau}$	[-0.020, +0.021]

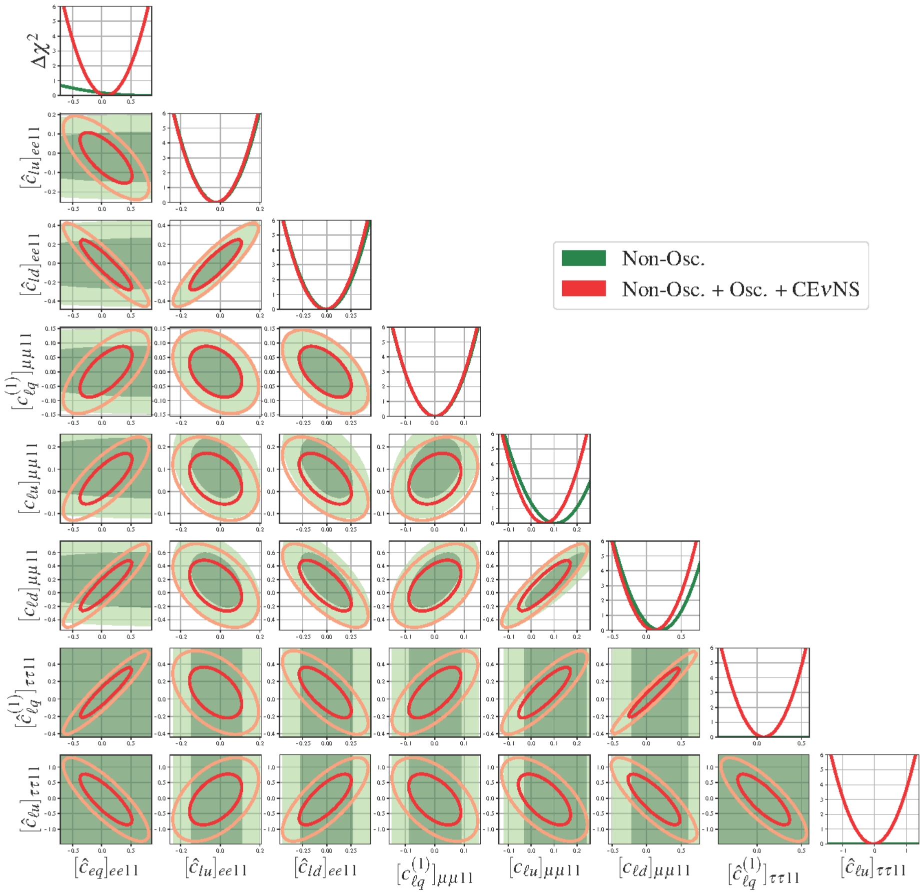
$\Rightarrow$ Restricts NSI solution to T2K/NOνA tension

Blanco,Coloma, Esteban,MCGG, Maltoni, Martinez, Pinheiro, 26XX.XXXX

ν OSC bounds in SMEFT

SMEFT $\Rightarrow$ NC-NSI for ν_ℓ and ℓ & CC-NSI all related. Are ν-osc bounds still relevant?

Recent efforts on consistently embedding NSI constraints in SMEFT framework show the relevance of the constraints from oscillations



Coloma *etal* 2411.00090

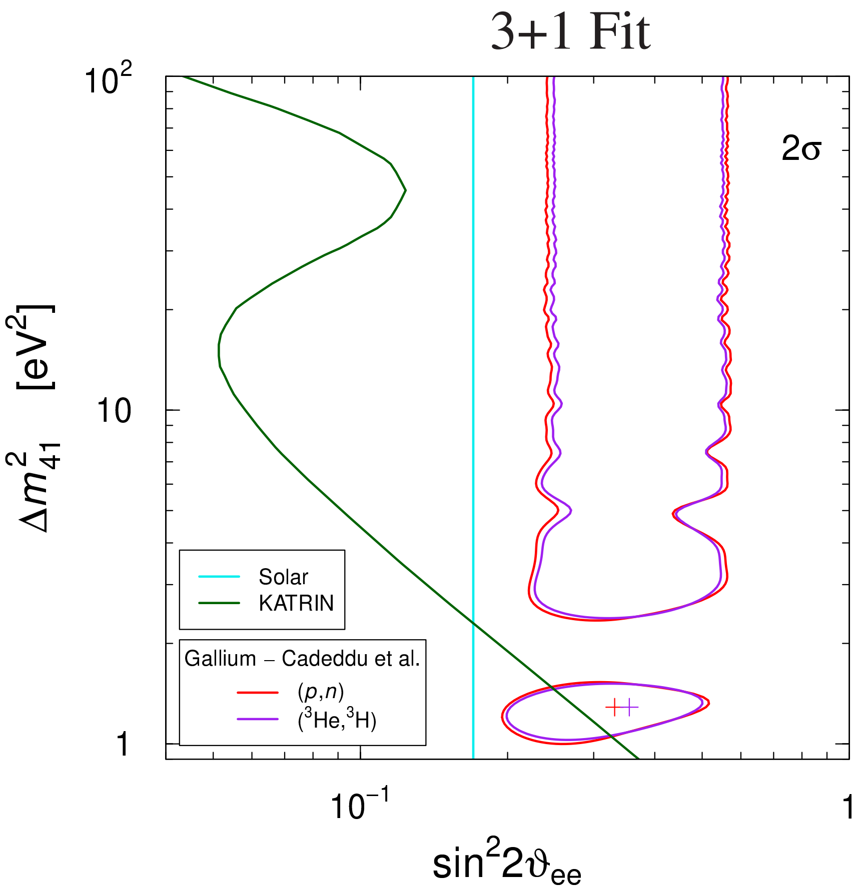
Operators	1σ interval	
	Non-Osc.	Non-Osc. + Osc. + CEνNS
$[\hat{c}_{eq}]_{ee11}$	0.76 ± 1.80	0.07 ± 0.30
$[c_{\ell u}]_{\mu\mu 11}$	0.110 ± 0.091	0.058 ± 0.076
$[c_{\ell d}]_{\mu\mu 11}$	0.19 ± 0.27	0.11 ± 0.25
$[\hat{c}^{(1)}_{\ell q}]_{\tau\tau 11}$	Unconstrained	0.07 ± 0.19
$[\hat{c}_{\ell u}]_{\tau\tau 11}$	Unconstrained	-0.04 ± 0.54

$$[O_{\ell q}]_{IIJJ} = (\bar{\ell}_I \bar{\sigma}_\mu \ell_I)(\bar{q}_J \bar{\sigma}^\mu q_J)$$
$$[O^{(3)}_{\ell q}]_{IIJJ} = (\bar{\ell}_I \bar{\sigma}_\mu \sigma^i \ell_I)(\bar{q}_J \bar{\sigma}^\mu \sigma^i q_J)$$
$$[O_{\ell u}]_{IIJJ} = (\bar{\ell}_I \bar{\sigma}_\mu \ell_I)(u^c_J \sigma^\mu \bar{u}^c_J)$$
$$[O_{\ell d}]_{IIJJ} = (\bar{\ell}_I \bar{\sigma}_\mu \ell_I)(d^c_J \sigma^\mu \bar{d}^c_J)$$
$$[O_{eq}]_{IIJJ} = (e^c_I \sigma_\mu \bar{e}^c_I)(\bar{q}_J \bar{\sigma}^\mu q_J)$$
$$[O_{eu}]_{IIJJ} = (e^c_I \sigma_\mu \bar{e}^c_I)(u^c_J \sigma^\mu \bar{u}^c_J)$$
$$[O_{ed}]_{IIJJ} = (e^c_I \sigma_\mu \bar{e}^c_I)(d^c_J \sigma^\mu \bar{d}^c_J)$$

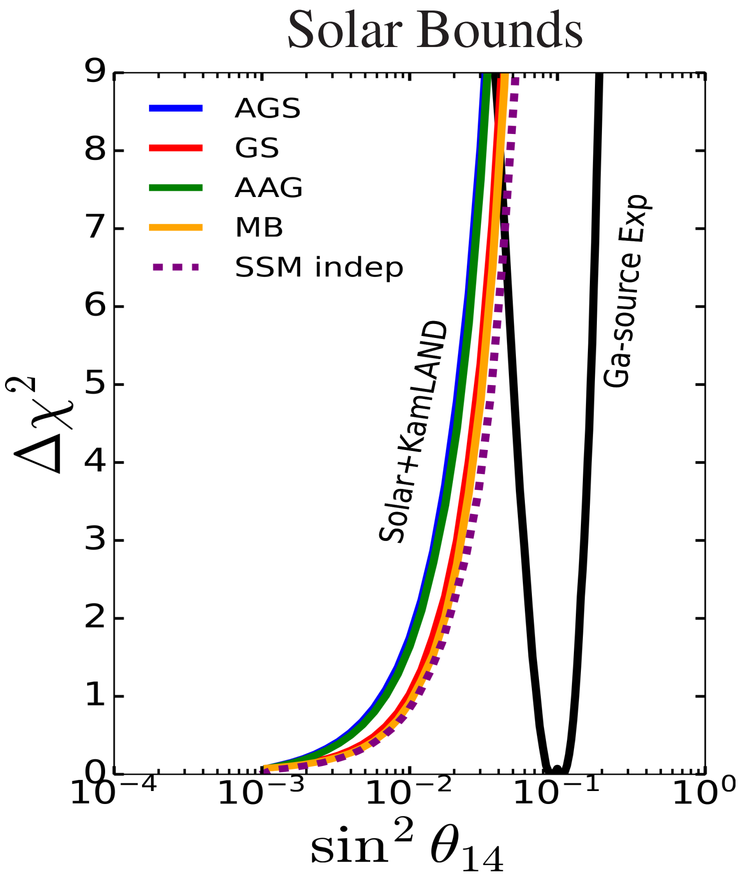
A difficult case: eV sterile neutrino oscillations

- 30 years (Gomez-Cadenas, MCGG hep-ph/9604246 , Goswami hep-ph/9507212) of global analysis with a 4th (or more) O(eV) neutrino to explain the SBL anomalies as they came
  - LSND ($\nu_\mu \to \nu_e$, 3.8 σ) & MiniBOONE (4.8 σ) anomaly:
    sterile neutrino explanation robustely disfavoured from global fits (Dentler *et al* 1803.10661) and not confirmed by MicroBOONE (2512.07159) $\Rightarrow$ unexplained
    Talks by J.H.Jo (MicroBOONE), Lee (JSNS2), Wan (SBND), Mooney (ICARUS)
  - Reactor anomaly ($\nu_e \to \nu_e$, $\sim 2\,\sigma$):
    came with new flux calc (Huber 1106.0687; Mention *et al* 1101.2755) and left with newer fluxes (Kopeikin *et al* 2103.01486; Giunti *etal*, 2110.06820; Perisse *et al* 2304.14992…) or may be *revived* with alternative fluxes (Giunti *et al* 2605.10353) Talks by Zang (SBL reactors), Li (TAO)
  - Gallium anomaly ($\nu_e \to \nu_e$, $\sim 5\sigma$): found & baptized in solar Ga exp test data (Acero *et al* 0711.4222,1006.3244) and confirmed BEST (2109.11482, 2201.07364)
    Increasing tension with Solar, reactor and KATRIN (Giunti *et al* 2209.00916; Berryman *et al* 2111.12530; Goldhagen *et al* 2109.14898; Brdar *et al* 2303.05528; MCGG,Maltoni,Pinheiro *et al* 2411.16840 …)
    $\Rightarrow$ unexplained Poster by Caddedu (53)

Solar modeling and the Gallium anomaly



Caddedu etal, 2507.13013



In all cases $\chi^2_{\rm PG}/n > 13.5$ ($\#\sigma > 3.7$)

$\Rightarrow$ Incompatiblity is SSM independent

MCGG, M.Maltoni, J. Pinheiro, 2411.16840

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    ⇒ unexplained Poster by Caddedu (53)
- Intense theory and experimental effort: Posters: Acharya (21); Sonzgni (26);Jung (46); Sousa (77); Clark (112); Lee (133); Park (168); Aurisano (206); Ryu (219); Mendez (239); Putnam(287); Xia,(298); Pallat (301); Garcia (313); Yoshioka (355); Pons (375); Yadav (382); Venegas Vargas (409)

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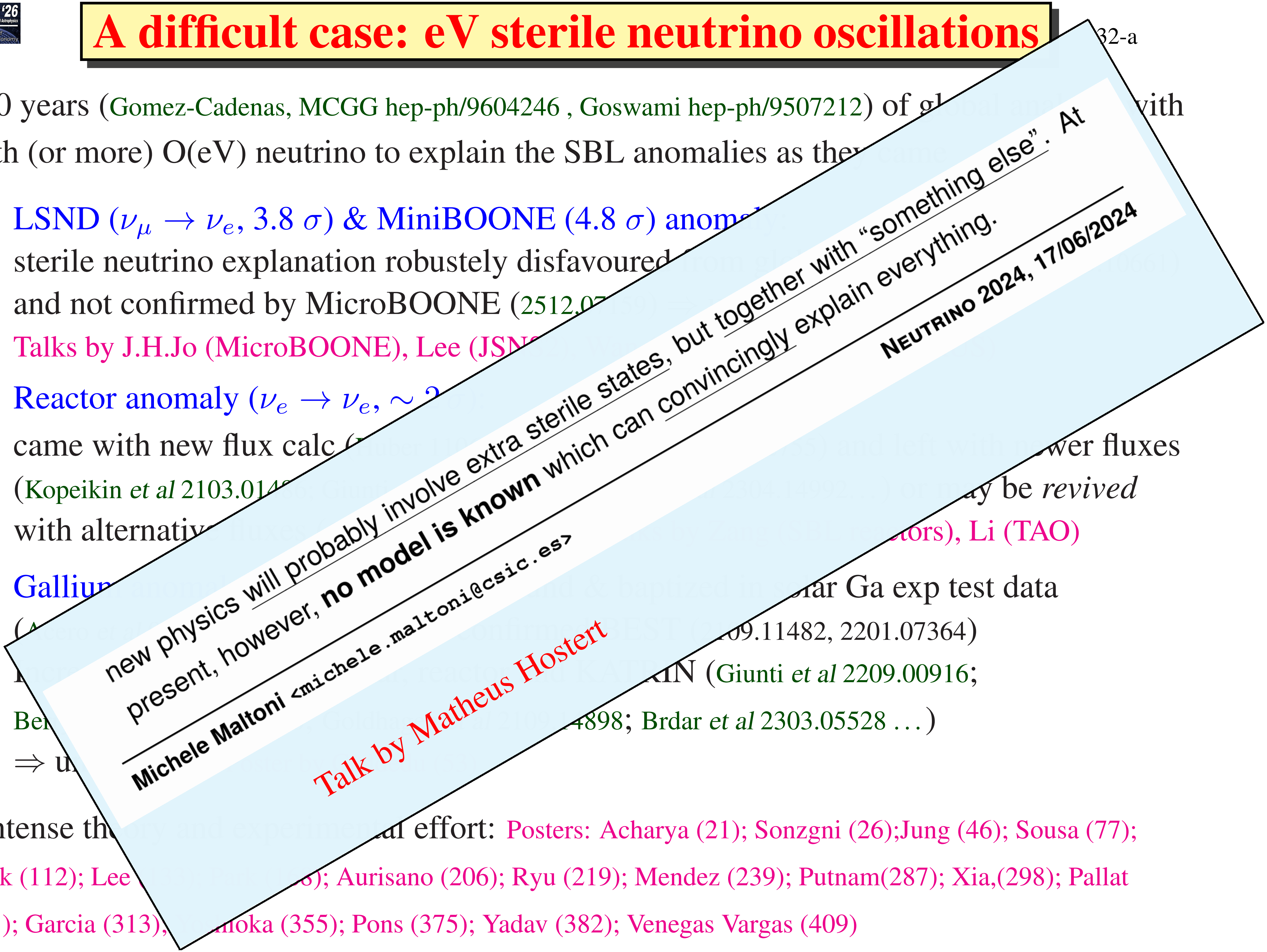

new physics will probably involve extra sterile states, but together with "something else". At present, however, **no model is known** which can convincingly explain everything.

Michele Maltoni `<michele.maltoni@csic.es>`

NEUTRINO 2024, 17/06/2024

Talk by Matheus Hostert

Summary

- 3ν paradigm is robustly established:
  - Flavour parameters before Neutrino 26

		best fit $\pm 1\sigma$		3σ rel prec
		IC23 w/o SK-ATM	w IC24 & SK-ATM	
$\frac{\Delta m^2_{21}}{10^{-5}\ \text{eV}^2}$		$7.537^{+0.094}_{-0.10}$	$7.537^{+0.094}_{-0.10}$	**7.8%**
$\sin^2\theta_{12}$		$0.3088^{+0.0067}_{-0.0066}$	$0.3088^{+0.0067}_{-0.0066}$	**13 %**
$\frac{\Delta m^2_{3\ell}}{10^{-3}\ \text{eV}^2}$	(NO)	$+2.521^{+0.026}_{-0.018}$	$+2.511^{+0.021}_{-0.010}$	**5.5–5%**
	(IO)	$-2.500^{+0.024}_{-0.023}$	$-2.483^{+0.020}_{-0.020}$	**5.6–5%**
$\sin^2\theta_{23}$	(NO)	$0.470^{+0.017}_{-0.014}$	$0.470^{+0.017}_{-0.014}$	30–29%
	(IO)	$0.555^{+0.013}_{-0.016}$	$0.550^{+0.013}_{-0.016}$	29–28%
$\sin^2\theta_{13}$	(NO)	$0.02249^{+0.00057}_{-0.00057}$	$0.02248^{+0.00055}_{-0.00059}$	**15%**
	(IO)	$0.02261^{+0.00056}_{-0.00056}$	$0.02262^{+0.00057}_{-0.00056}$	
$\delta_{\rm CP}/^\circ$	(NO)	207^{+23}_{-20}	212^{+26}_{-36}	100–98%
	(IO)	283^{+24}_{-28}	274^{+22}_{-25}	54–55%
$\chi^2_{\rm IO} - \chi^2_{\rm NO}$		1.5	5.9	

  - Status of **MO**, CPV, and θ_{23} octant correlated & obscured by the slight tension in ν_e appearance between T2K and NOνA in NO
  - Complementarity in $|\Delta m^2_{3\ell}|$ determination with ν_μ disappearance at LBL & ATM and ν_e disappearance at reactors becoming more relevant in **MO** determination
- Robustness of the 3ν-osc picture ⇒ relevant constraints in extended scenarios
  - ∗ Constraints on NSI relevant to future LBL and present tensions
  - ∗ Relevant information in the context of the SMEFT
  - ∗ Constraints on sterile mixing relevant to SBL anomalies

Thank you!!

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Ivan Esteban, Michele Maltoni, Ivan Martinez-Solar,
Joao P Pinheiro, Thomas Schwetz
Pilar Coloma, Pablo Blanco-Mas, Salvador Urrea