

Neutrinos: oscillations and beyond

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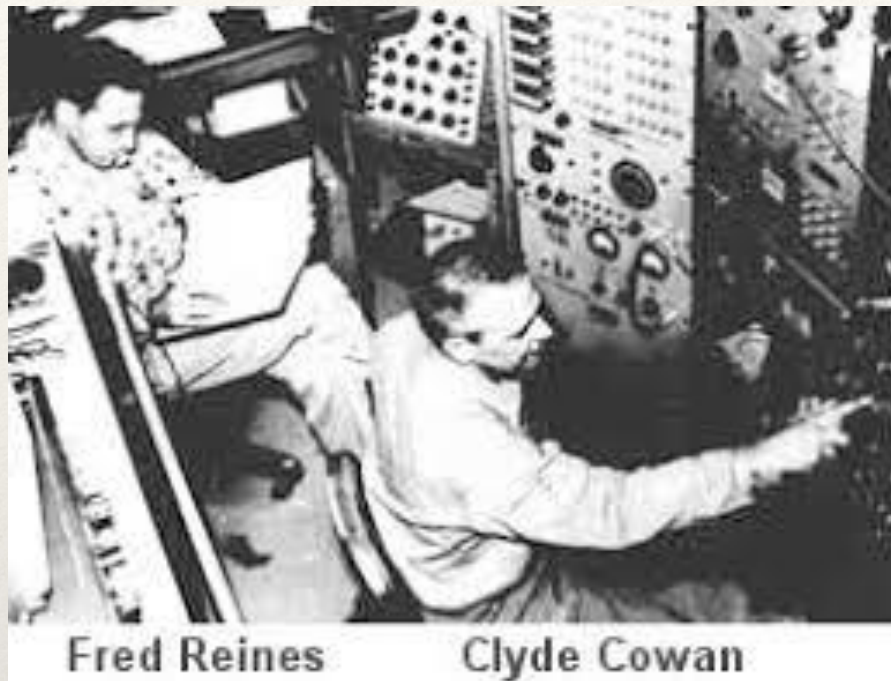
PPC 2026



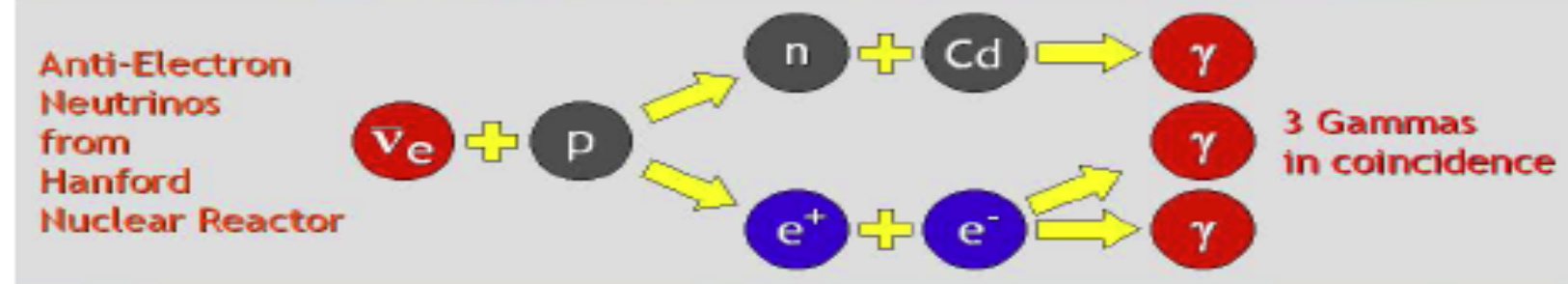
70th anniversary of neutrino discovery

- ❖ Postulated by Pauli in 1930 to explain conservation of energy in beta decay
- ❖ “one can conclude that there is no practically possible way of observing the neutrino.” : Bethe and Peierls (1934)
- ❖ Inverse beta decay process to detect neutrinos, possibility of a Cl based experiment : Pontecorvo (1946)
- ❖ Cl based detector for reactor antineutrinos : Alvarez (1947)
- ❖ Detecting neutrinos from nuclear explosions : Reines and Cowan (1951)

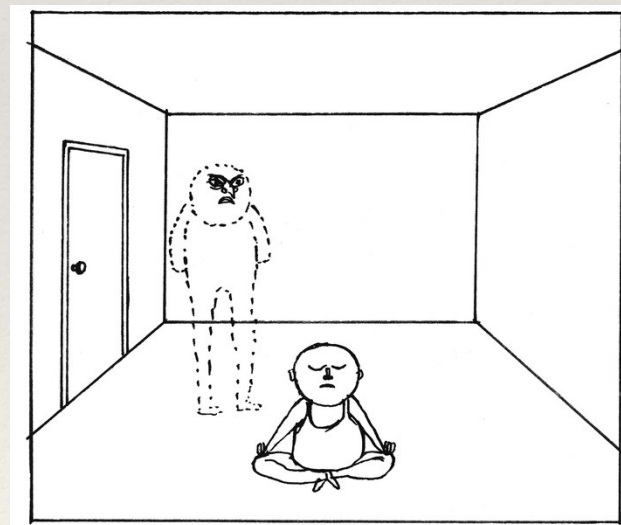
Neutrinos: from poltergeist to particle



In 1956, 25 years after neutrinos were proposed
Using antineutrinos produced in nuclear reactors



- Clyde Cowan (1919-1974)
- Fred Reines (1918 - 1998)
- Nobel Prize to F. Reines in 1995



Three neutrino flavours are experimentally detected

The neutrino mass matrix

- ❖ The neutrino mass matrix at low energy

$$m_\nu = U_{PMNS}^* \text{Diag}(m_1, m_2, m_3) U_{PMNS}^\dagger$$

- ❖ Mixing matrix relating the flavour and mass states

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu1} & U_{\mu2} & U_{\mu3} \\ U_{\tau1} & U_{e\tau2} & U_{\tau3} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

$$U_{PMNS} = R_{23}(\theta_{23}) R_{13}(\theta_{13}, \delta) R_{12}(\theta_{12}) P(\sigma, \rho) -$$

Parameters of the neutrino mass matrix

- ❖ **9 unknown parameters for three neutrino flavours**

3 masses m_1, m_2, m_3
3 mixing angles $\theta_{12}, \theta_{13}, \theta_{23}$
3 phases δ, α, β

- ❖ **Oscillation experiments sensitive to**

2 mass squared differences $\Delta m_{21}^2 = m_2^2 - m_1^2, \Delta m_{31}^2 = m_3^2 - m_1^2$
3 mixing angles $\theta_{12}, \theta_{13}, \theta_{23}$
1 Dirac phase δ

- ❖ **Absolute neutrino mass comes from**

Tritium Beta-decay

Neutrino-less double beta decay

Cosmology

- ❖ **Majorana CP phases from lepton number violating processes**

Oscillation probability (vacuum)

If neutrinos have mass:

$$\nu_\alpha = \sum_i U_{\alpha i} \nu_i$$

$$P_{\alpha\beta} = \delta_{\alpha\beta} - 4 \sum_{i < j} \text{Re}(U_{\alpha i}^* U_{\beta j}^* U_{\alpha j} U_{\beta i}) \sin^2 \Delta_{ij} + 2 \sum_{i > j} \text{Im}(U_{\alpha i}^* U_{\beta j}^* U_{\alpha j} U_{\beta i}) \sin 2\Delta_{ij}$$

$$\begin{pmatrix} \nu_e \\ \nu_\mu \end{pmatrix} = \begin{pmatrix} \cos \theta & \sin \theta \\ -\sin \theta & \cos \theta \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \end{pmatrix}$$

$$\Delta_{ij} = \Delta m_{ij}^2 L / 4E$$

$$\Delta m_{ij}^2 = m_i^2 - m_j^2$$

$$P(\nu_e \rightarrow \nu_\mu) = \sin^2 2\theta \sin^2(\Delta m^2 L / 4E)$$

Neutrino Oscillation requires

Non-zero neutrino masses

Non-zero mixing angles

Oscillation effect $\Delta m^2 \sim E/L$

$$\bar{\nu} : U \rightarrow U^*$$

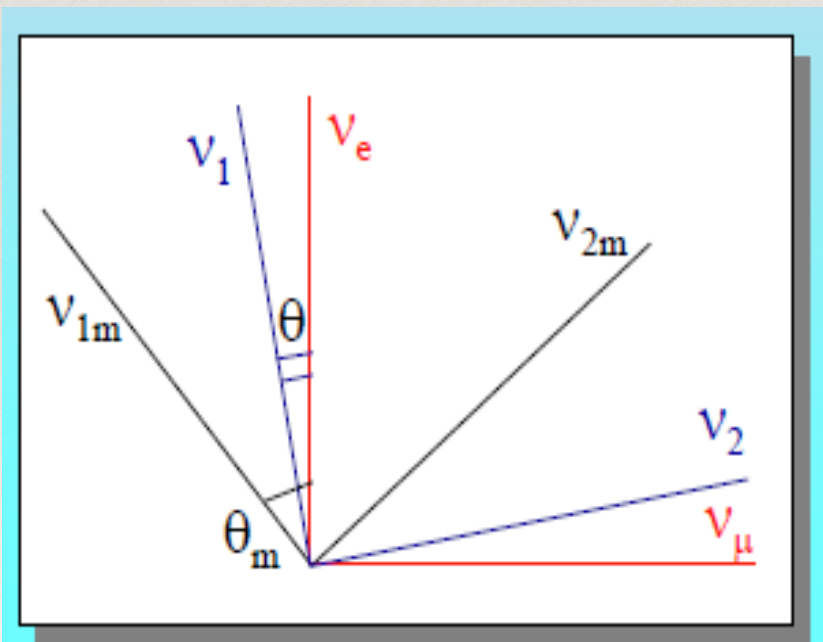
Not sensitive to the sign of Δm^2

Not sensitive to the octant of θ

Matter effect

	<i>in vacuum:</i>		<i>in matter:</i>	
■ Effective Hamiltonian	H_0	→	$H = H_0 + V$	$V = V_e - V_\mu$
■ Eigenstates	ν_1, ν_2	→	ν_{1m}, ν_{2m}	depend on n_e, E
■ Eigenvalues	m_1, m_2 $m_1^2/2E, m_2^2/2E$	→	m_{1m}, m_{2m} H_{1m}, H_{2m}	

Courtesy: A. Yu. Smirnov



Mixing angle in matter is defined with respect to the matter eigenstates

The eigenvalues and the mixing angle are determined by diagonalizing the effective Hamiltonian in matter

Matter effect

- In matter, only ν_e 's undergoes Charged current interaction $\rightarrow$ an effective potential of $\sqrt{2}G_F N_e$

Effective mixing angle θ_M in matter

$$\tan 2\theta_M = \frac{\Delta m^2 \sin 2\theta}{\Delta m^2 \cos 2\theta - 2\sqrt{2}G_F n_e E}$$

$$\Delta m^2 \cos 2\theta = 2\sqrt{2}G_F n_e E, \theta_M \rightarrow \pi/4 \quad \text{MSW Resonance}$$

L. Wolfenstein, PRD 17, 1978 S.P. Mikheyev, A.Yu. Smirnov, SJNP 42, 1985

$$\Delta m_m^2 = [(\Delta m^2 \cos 2\theta - 2\sqrt{2}G_F n_e E)^2 + \Delta m^2 \sin^2 2\theta]^{1/2}$$

For antineutrinos potential changes sign

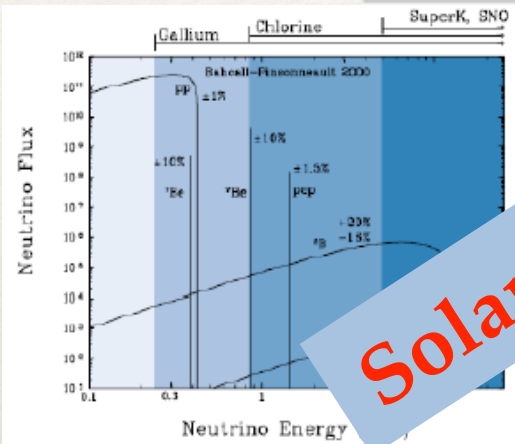
Resonance for $\Delta m^2 < 0$

Matter effect is sensitive to the ordering of the mass states

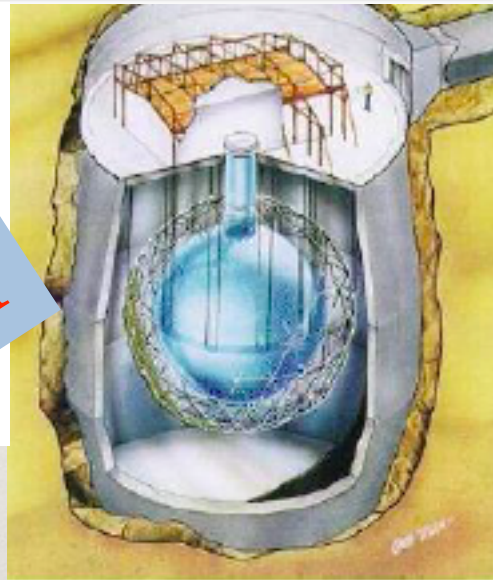
- Probabilities are obtained by solving propagation equation in matter
- Depends on density profile of matter

Neutrino oscillation: evidences

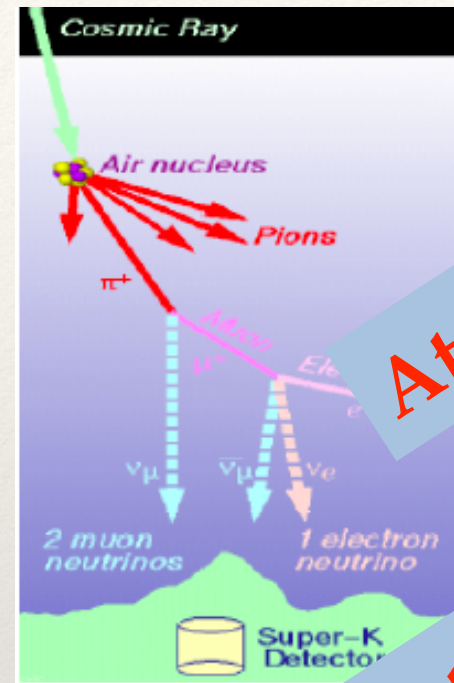
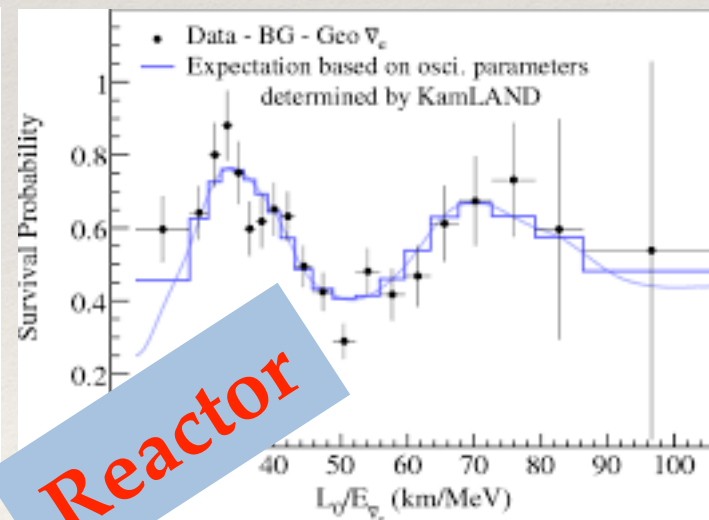
$$\frac{CC}{NC} = \frac{\nu_e}{\nu_e + \nu_\mu + \nu_\tau} < 1$$



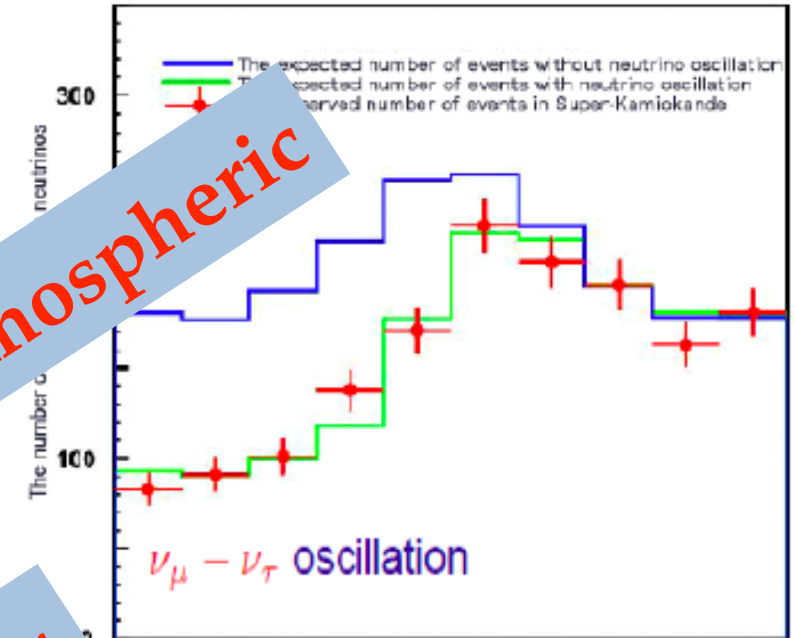
Solar



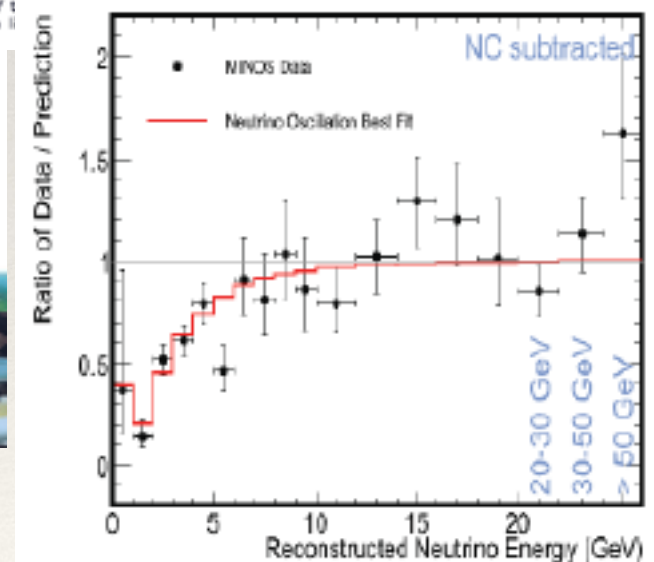
Reactor



Atmospheric



Accelerator



Three neutrino oscillation paradigm

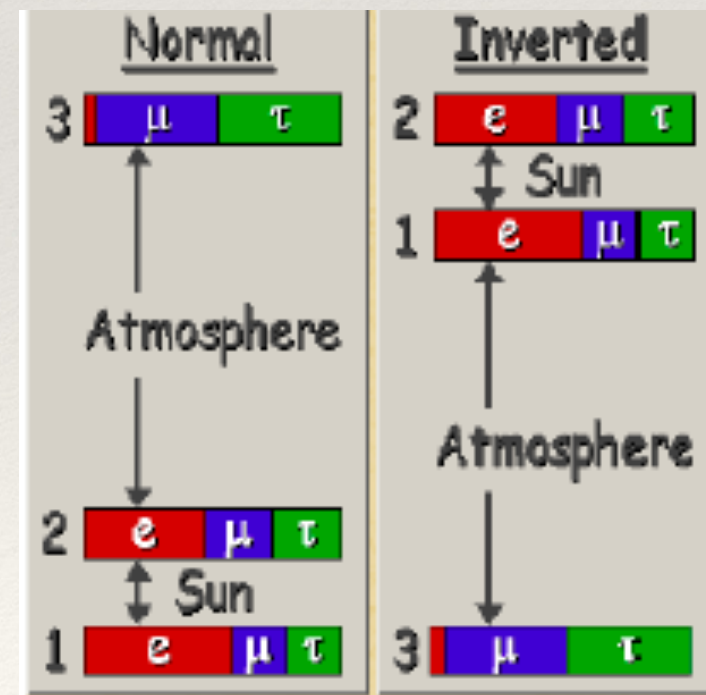
- ❖ Measurement of non-zero θ_{13} in reactor experiments $\longrightarrow$ three neutrino picture

$$\begin{array}{c}
 \text{Atm +LBL} \qquad \qquad \qquad \text{Sol+KL} \\
 \begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} 1 & & \\ & c_{23} & s_{23} \\ & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & & e^{-i\delta} s_{13} \\ & 1 & \\ -e^{i\delta} s_{13} & & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} \\ -s_{12} & c_{12} \\ & & 1 \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix} \\
 c_{12} = \cos \theta_{12} \text{ etc.}, \quad \delta \text{ CP-violating phase}
 \end{array}$$

- $\Delta m_{21}^2, \theta_{12}, \theta_{13}$ Solar + KamLAND
- $\Delta m_{31}^2, \theta_{13}$ Reactor
- $\Delta m_{31}^2, \theta_{23}, \theta_{13}, \delta_{CP}$ Atm + LBL



Interplay among different sectors
because of θ_{13}

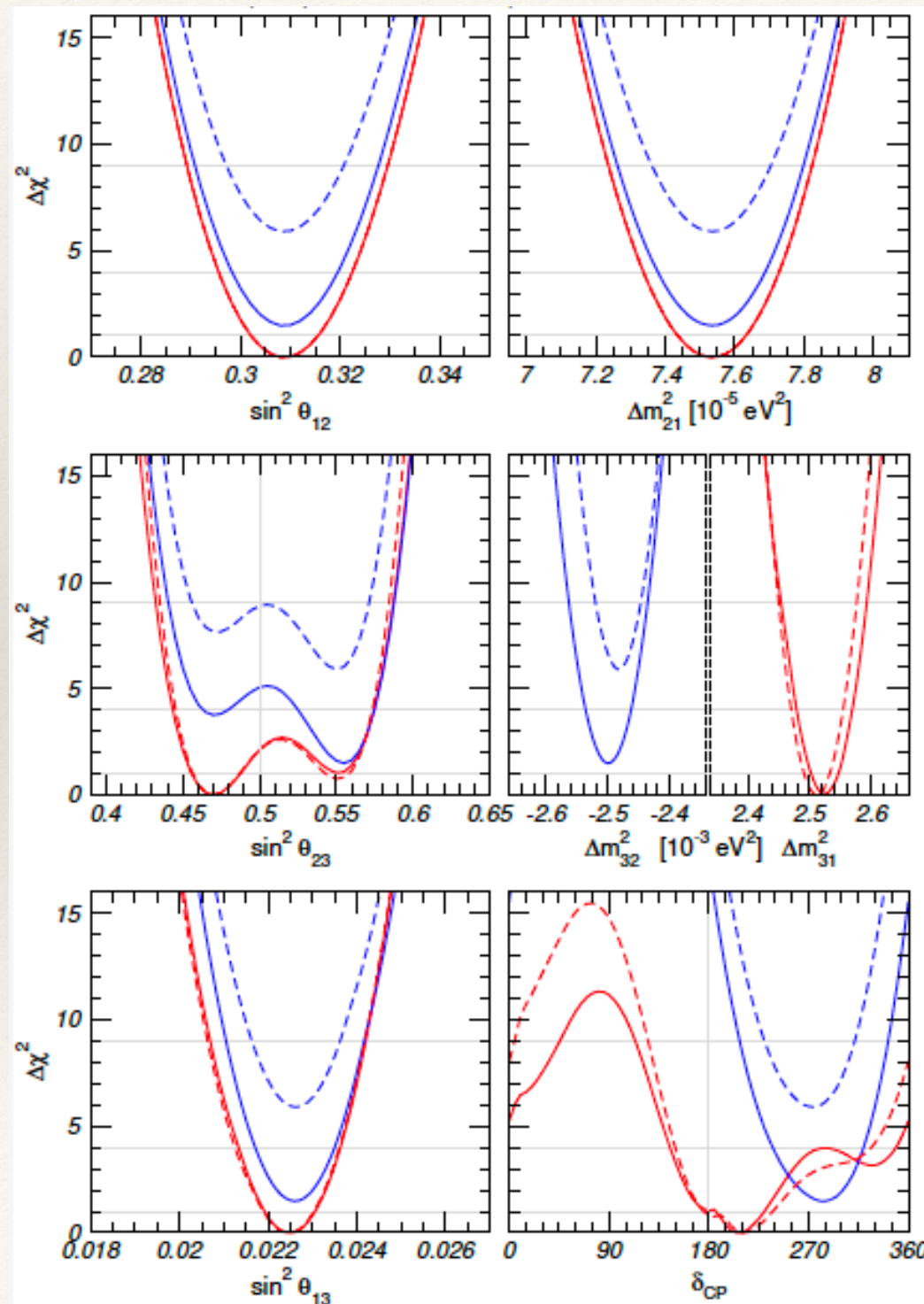


Global analysis

- ❖ Combined analysis of data of all the experiments
- ❖ Theoretical inputs : flux, cross-section, probability, detector parameters
- ❖ Frequentist and Bayesian approach
- ❖ Captures tensions in the data
- ❖ Complementarity and synergy
- ❖ Three groups : Bari, Valencia, NuFit

Neutrino oscillation parameters

— NO, IO (IC23 w/o SK-atm)
 - - NO, IO (IC24 with SK-atm)



NuFIT 6.1 (2025)

Solar parameters : $\Delta m_{21}^2, \sin^2 \theta_{12}$

Solar + KamLAND + **JUNO**
 SNO+ reactor, SK reactor

Atmospheric Parameters : $\Delta m_{3l}^2, \sin^2 \theta_{23}$

Δm_{3k}^2 : SK+ICECUBE +KM3NeT /ORCA
 +MINOS +T2K+NOvA
 +Daya-bay+**JUNO**

$\sin^2 \theta_{23}$: SK+IC +KM3NeT/ORCA
 +MINOS+ T2K+NOvA

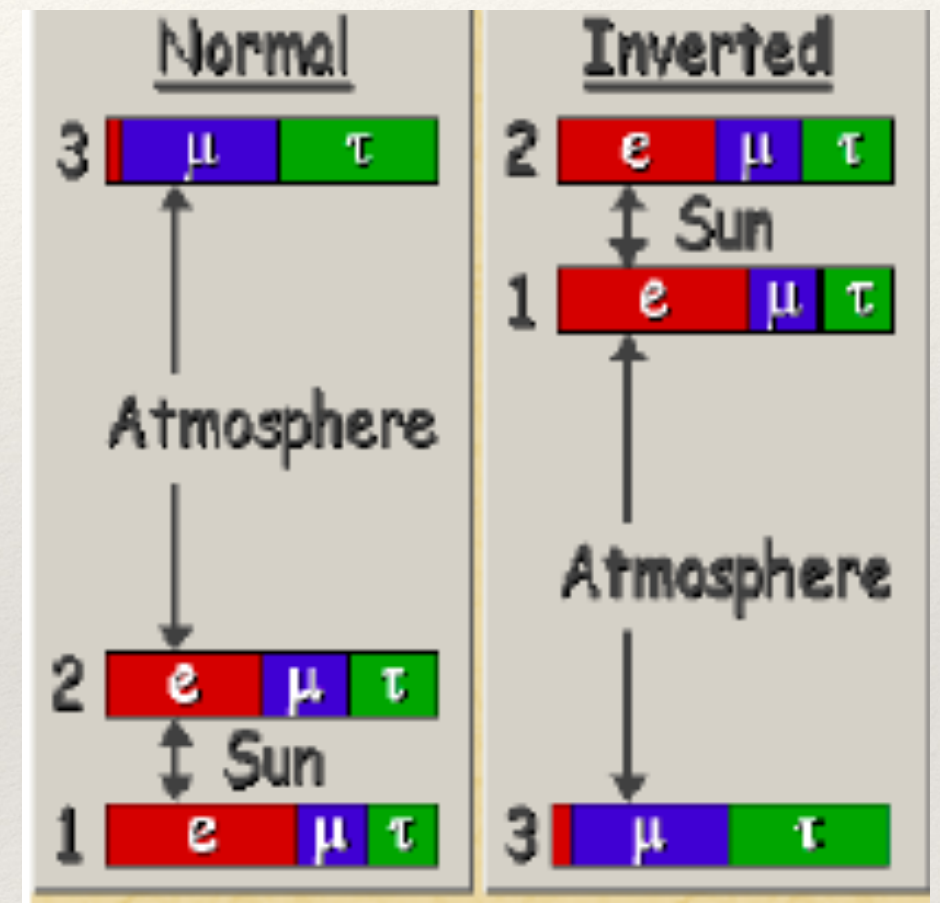
Reactor Angle : $\sin^2 \theta_{13}$

Daya-Bay + RENO+Double CHOOZ

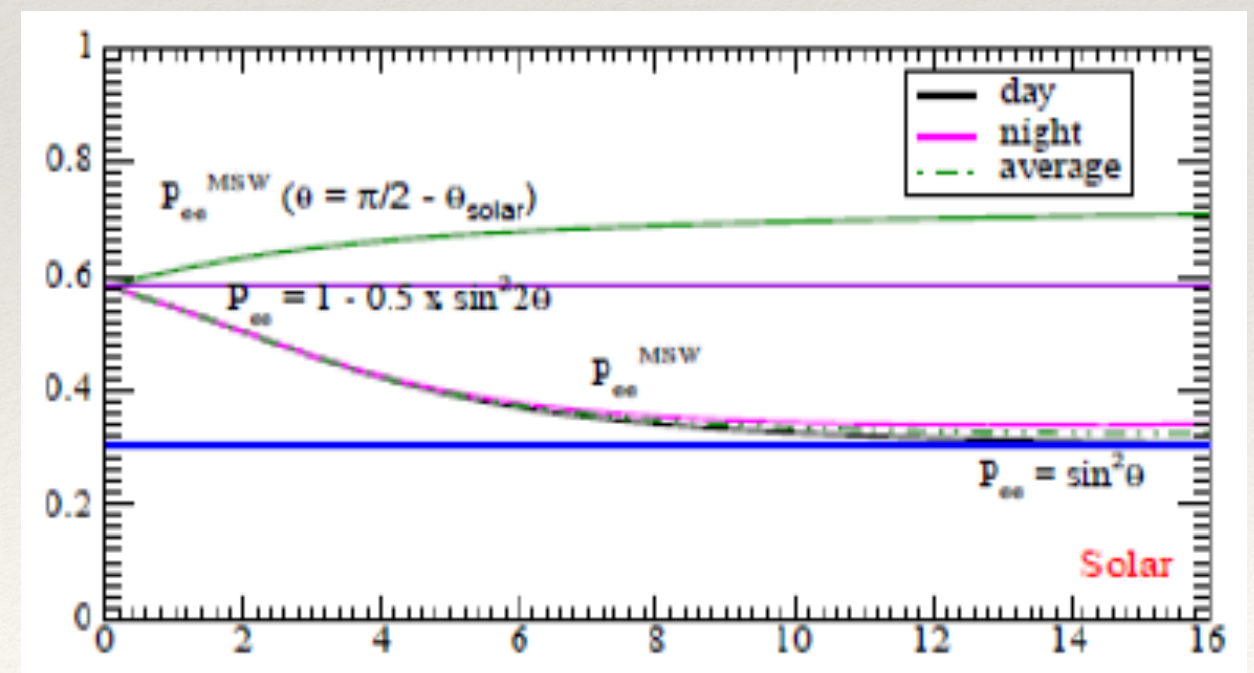
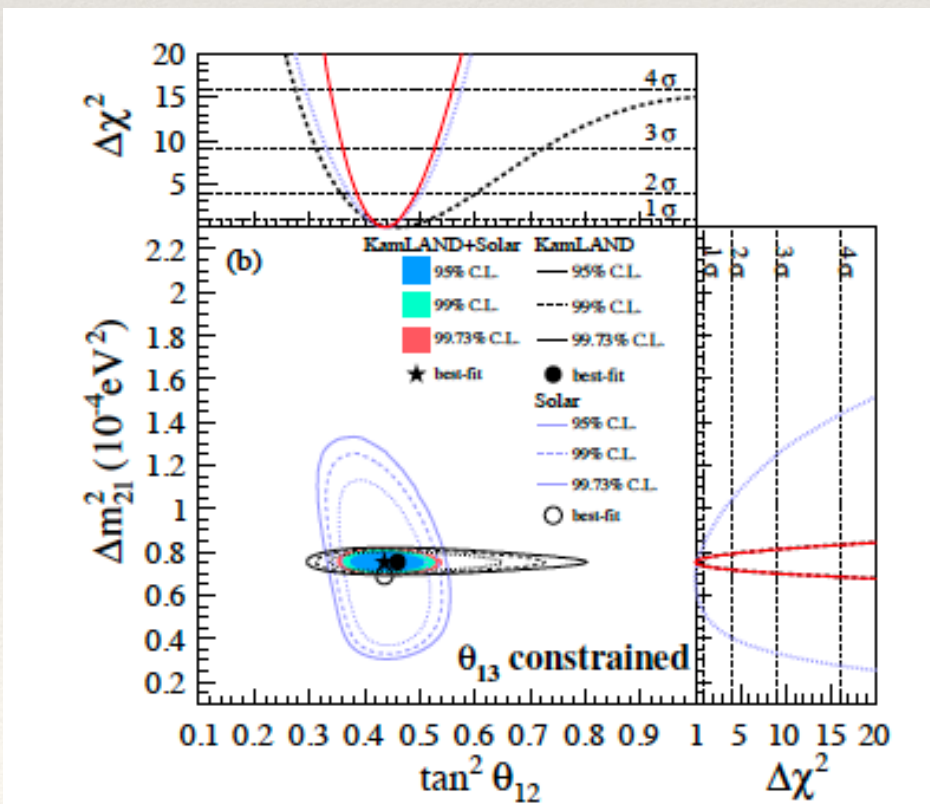
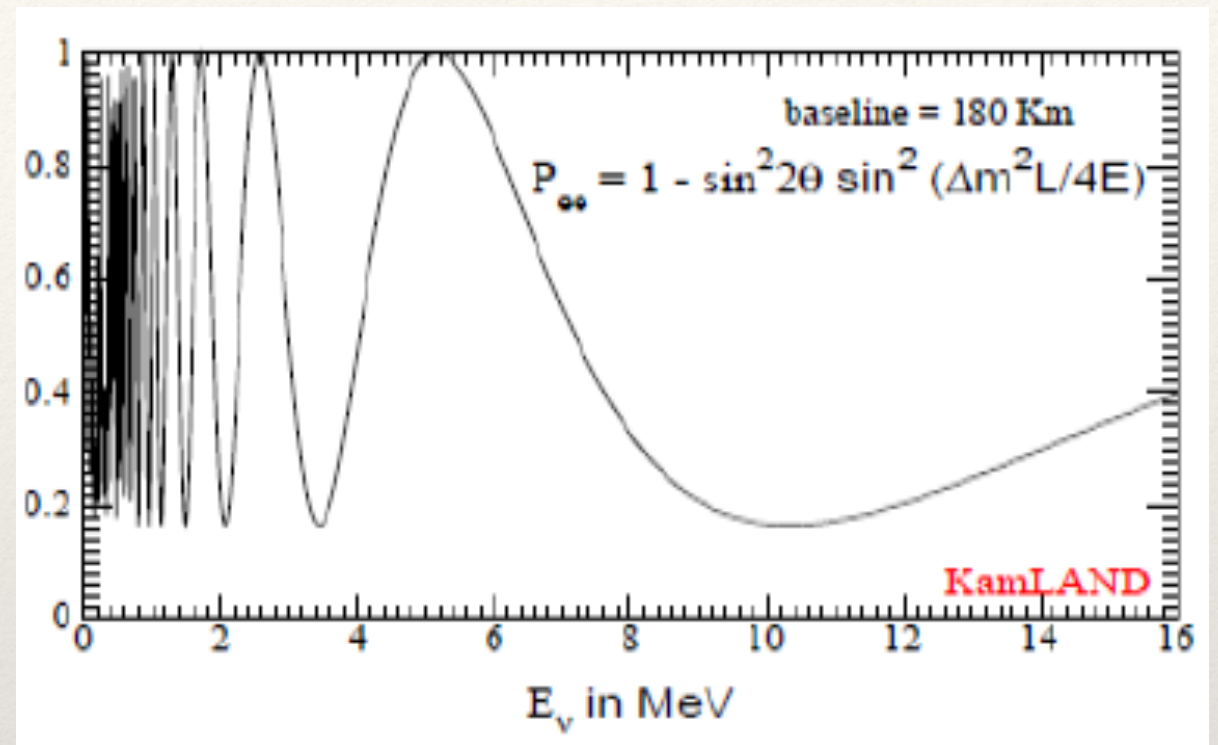
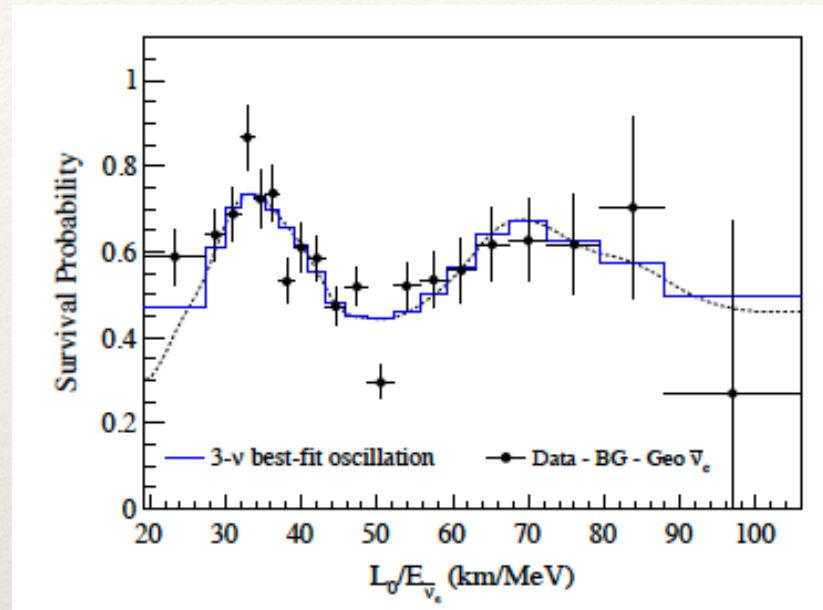
δ_{CP} : T2K/NOvA, Atmospheric (talk by N. Bell)

Oscillation parameters we do not know

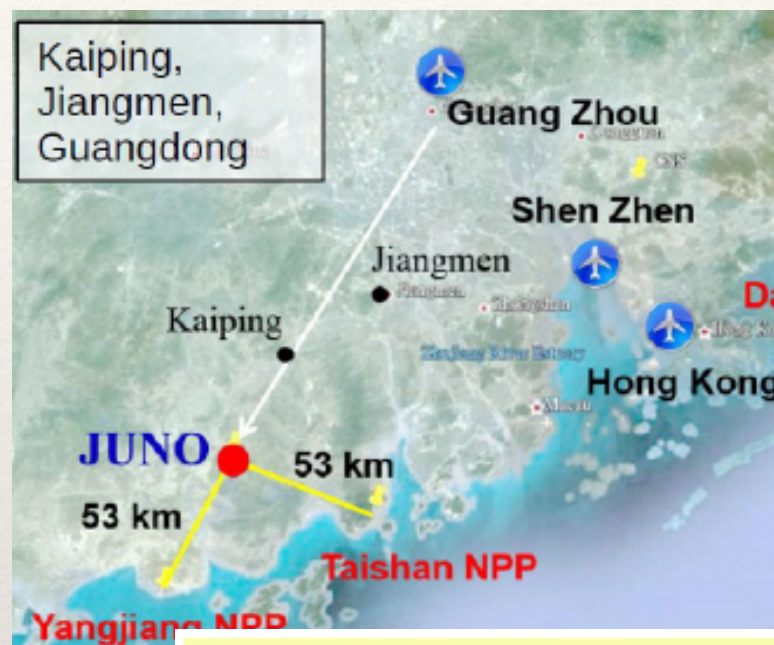
- ❖ The neutrino mass ordering i.e. if the third state is above or below the first two states
- ❖ The octant of the 2-3 mixing angle i.e. if $\theta_{23} > 45^\circ$ or $< 45^\circ$
- ❖ The value of the CP phase



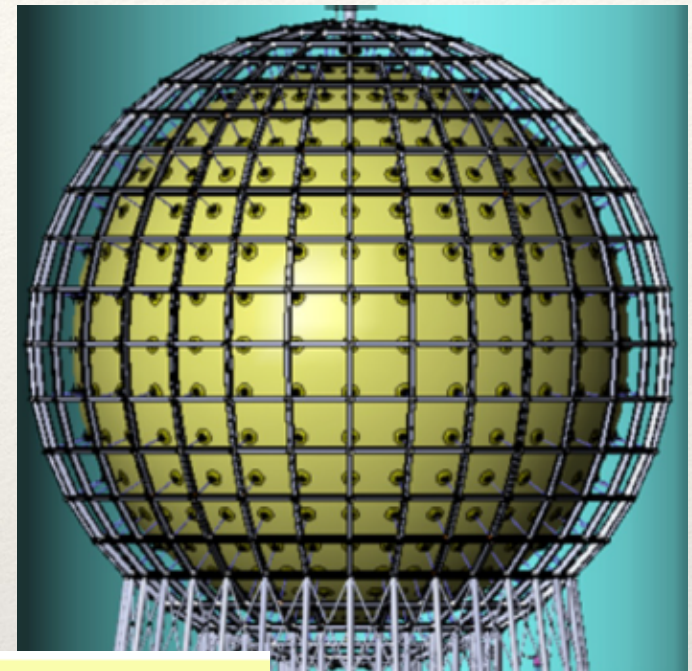
Solar parameters



JUNO: Jiangmen Underground Neutrino Observatory



- ❖ Reactor Antineutrino Experiment
- ❖ 20 kt Liquid Scintillator detector at 53 km



$$P_R(\bar{\nu}_e \rightarrow \bar{\nu}_e) = 1 - \left\{ \cos^4 \theta_{13} \sin^2 2\theta_{12} \sin^2 \Delta_{21} + \sin^2 2\theta_{13} \sin^2 \theta_{12} \left(\cos 2\Delta_{31} \sin^2 \Delta_{21} - \frac{1}{2} \sin 2\Delta_{31} \sin 2\Delta_{21} \right) \right\}$$

Determination of mass ordering

Precision of solar parameters

Petcov & Piai, PLB 2002
Choubey, Petcov, Piai, PRD 2003

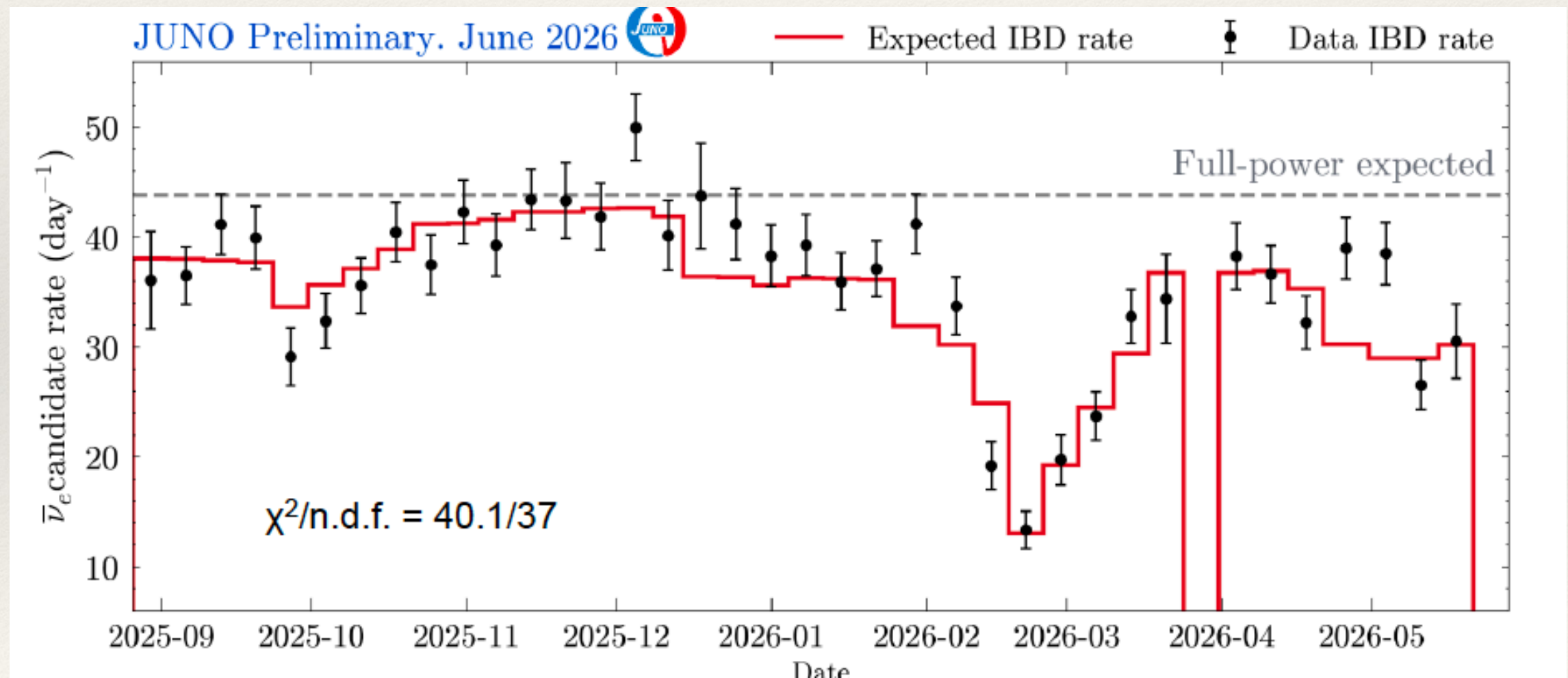
For a ~ 60 km baseline

Bandyopadhyay, Choubey, Goswami PRD, 2003

First results from JUNO

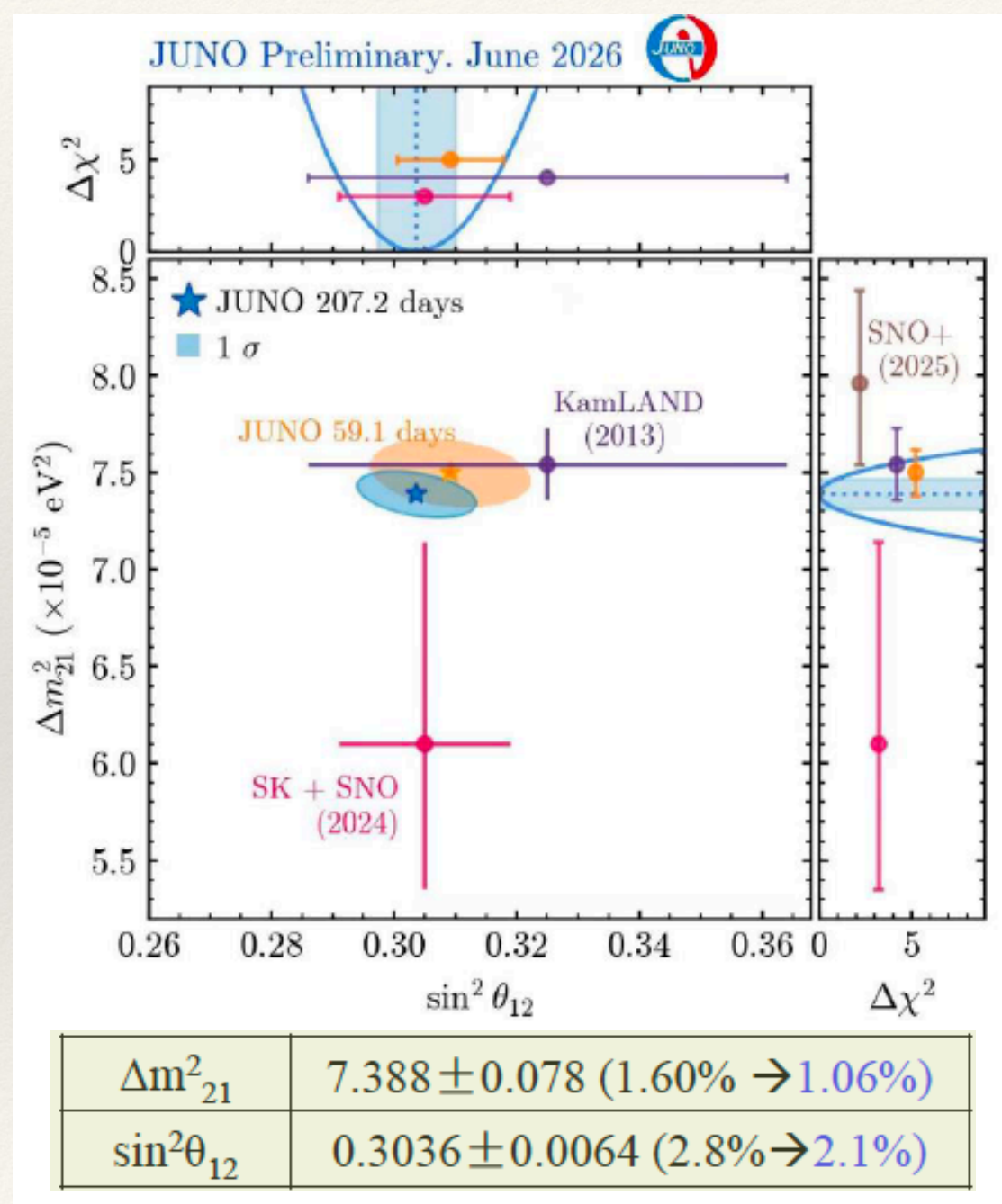
First results using 59 days data published [JUNO Collaboration Nature 654 2026](#)

207 days data announced in Neutrino 2026

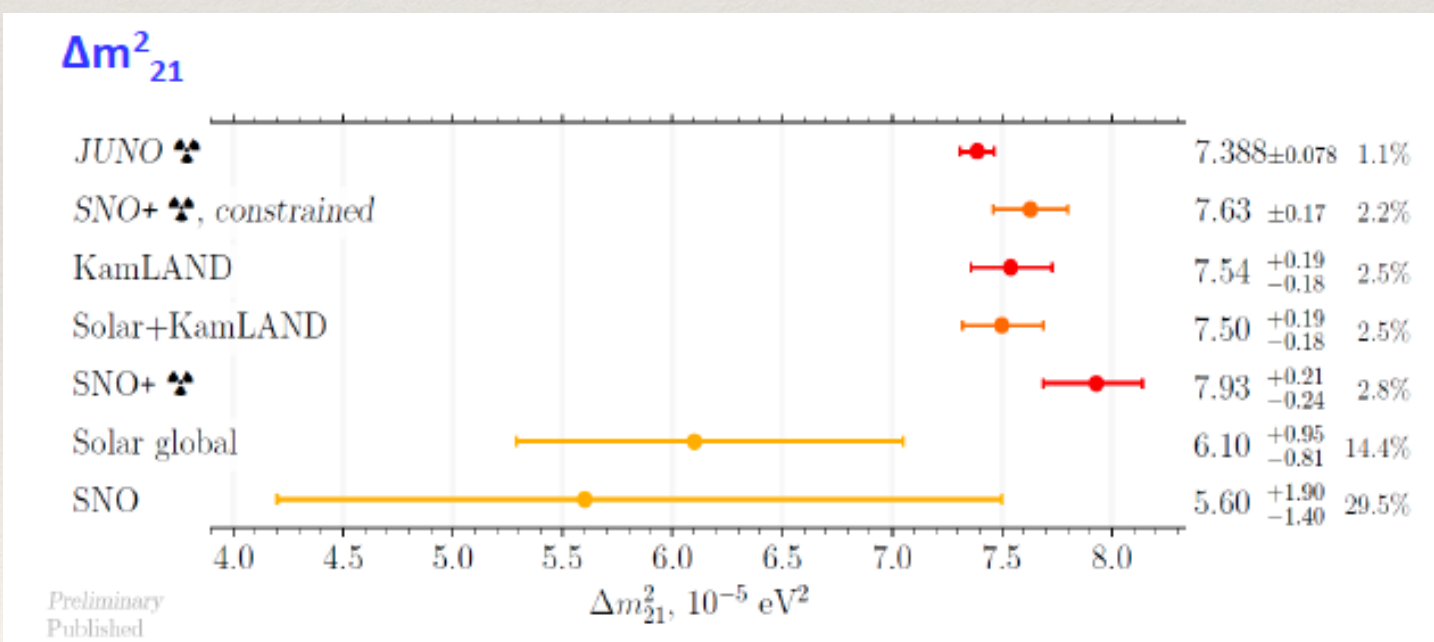
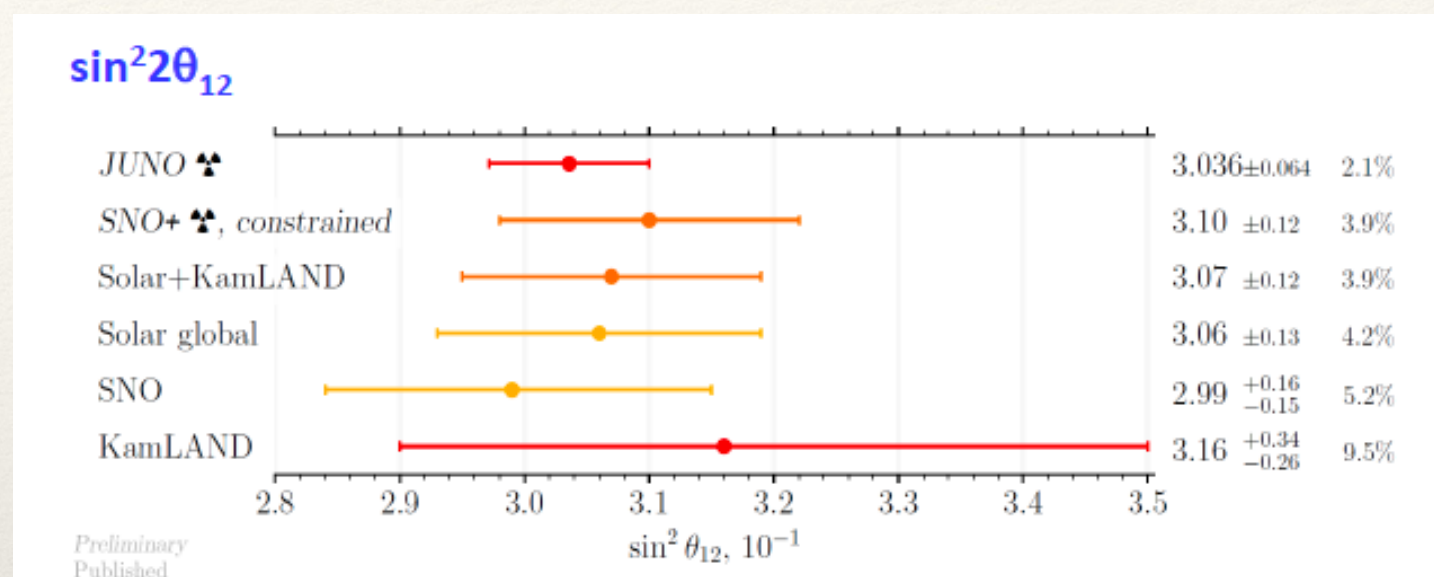


Y. Wang Neutrino 2026

New results on solar parameters

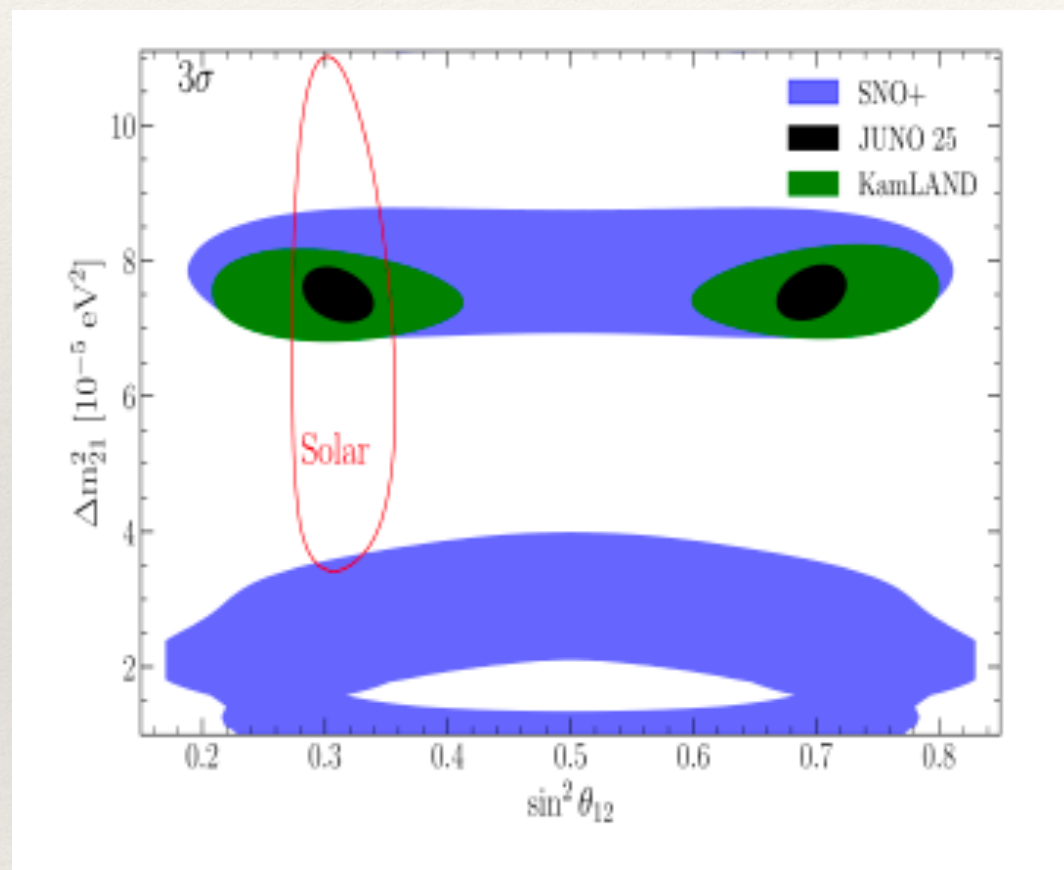


(Solar prior : $\theta_{12} < 45^\circ$)



Y. Wang Neutrino 2026

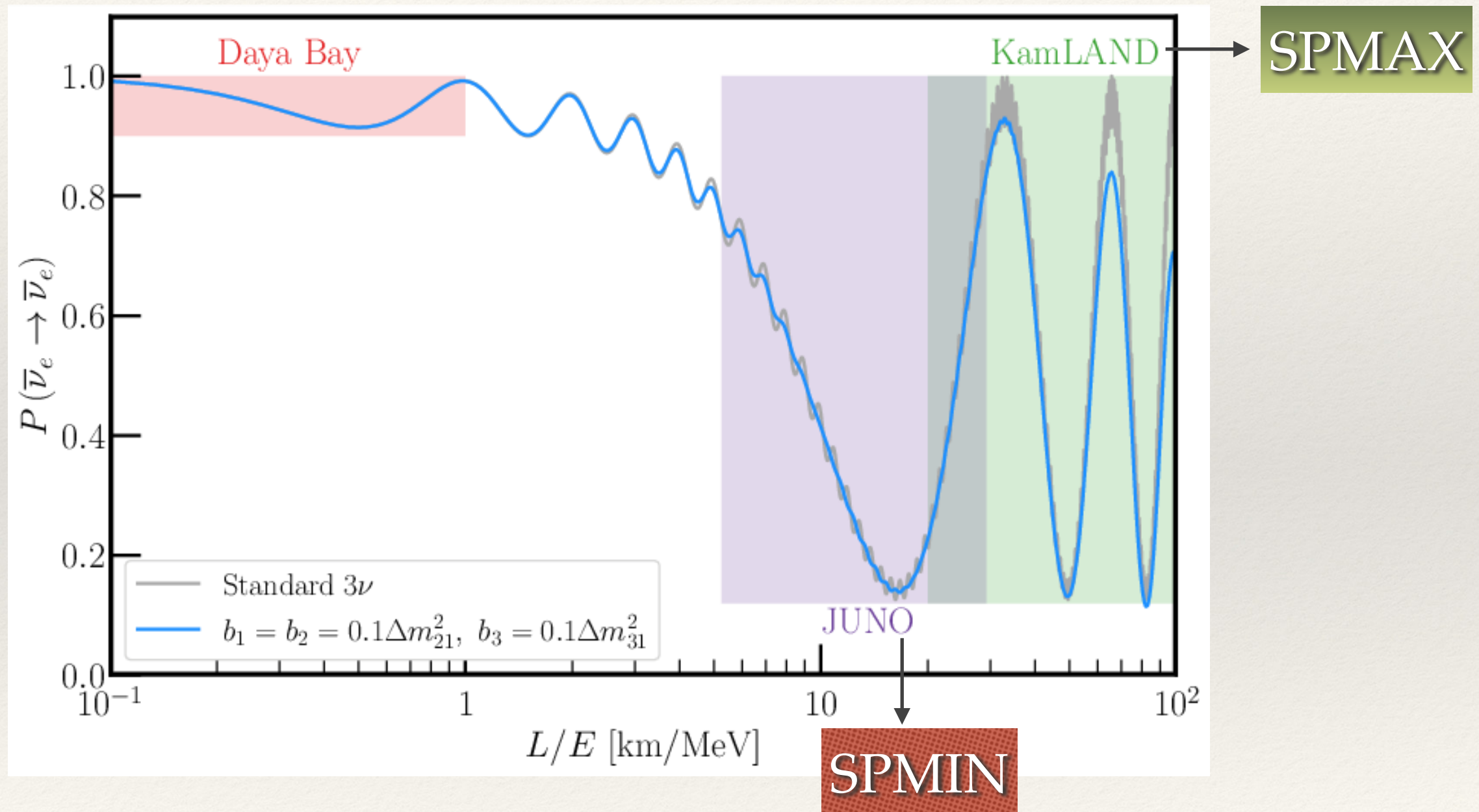
Why JUNO gives better sensitivity?



M.C. Gonzalez-Garcia , Neutrino 2026

- ❖ Optimal baseline to measure solar oscillations
- ❖ Larger statistics than KamLAND (20 kt vs 1 kt)
- ❖ Better energy resolution
- ❖ KamLAND had reactors spread over wider range of baselines leading to more averaging

Different reactor experiments



Precision of θ_{12}

$$P_{\bar{e}\bar{e}} = 1 - \sin^2 2\theta_{12} \sin^2 \Delta m_{21}^2 L/4E$$

SPMAX :

$$\sin^2 \Delta m_{21}^2 L/4E = 0$$

$$P_{\bar{e}\bar{e}} = 1$$

No dependence on θ_{12}

SPMIN :

$$\sin^2 \pi L/\lambda = 1$$

$$P_{\bar{e}\bar{e}} = 1 - \sin^2 2\theta$$

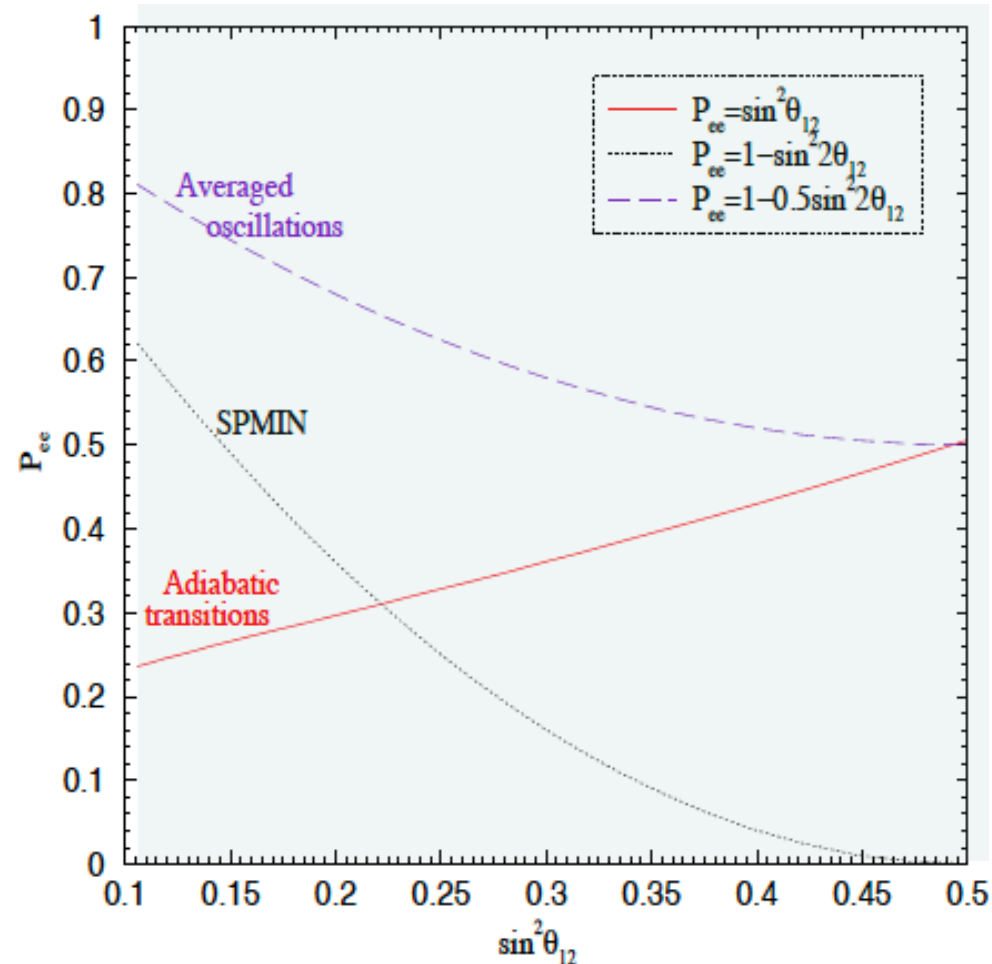
Dependence on θ_{12}

$$0.14 < \cos 2\theta_{12} < 0.57$$

SPMIN best

$L \sim 60$ km

Bandyopadhyay,
Choubey, Goswami
PRD , 2003



$$(\Delta \sin^2 \theta_{12})_{AD} \sim \Delta P_{ee}$$

$$(\Delta \sin^2 \theta_{12})_{AV} \sim \frac{\Delta P_{ee}}{-2 \cos 2\theta_{12}}$$

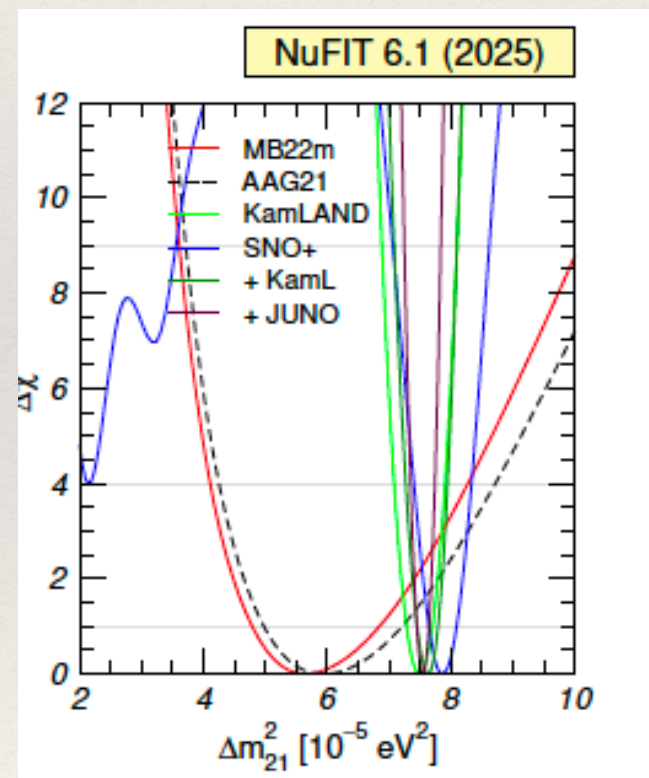
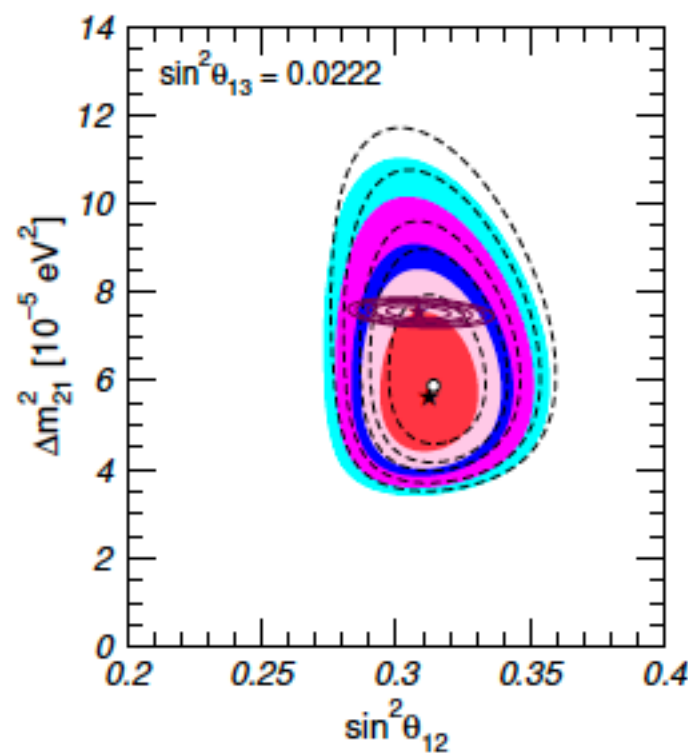
$$(\Delta \sin^2 \theta_{12})_{SPMIN} \sim \frac{\Delta P_{ee}}{-4 \cos 2\theta_{12}}$$

Tension in Δm_{21}^2

Tension in the best-fit value of Δm_{21}^2 from solar and reactor measurements

SK observes more day/night asymmetry

The absence of spectral upturn at low energy as predicted by MSW effect

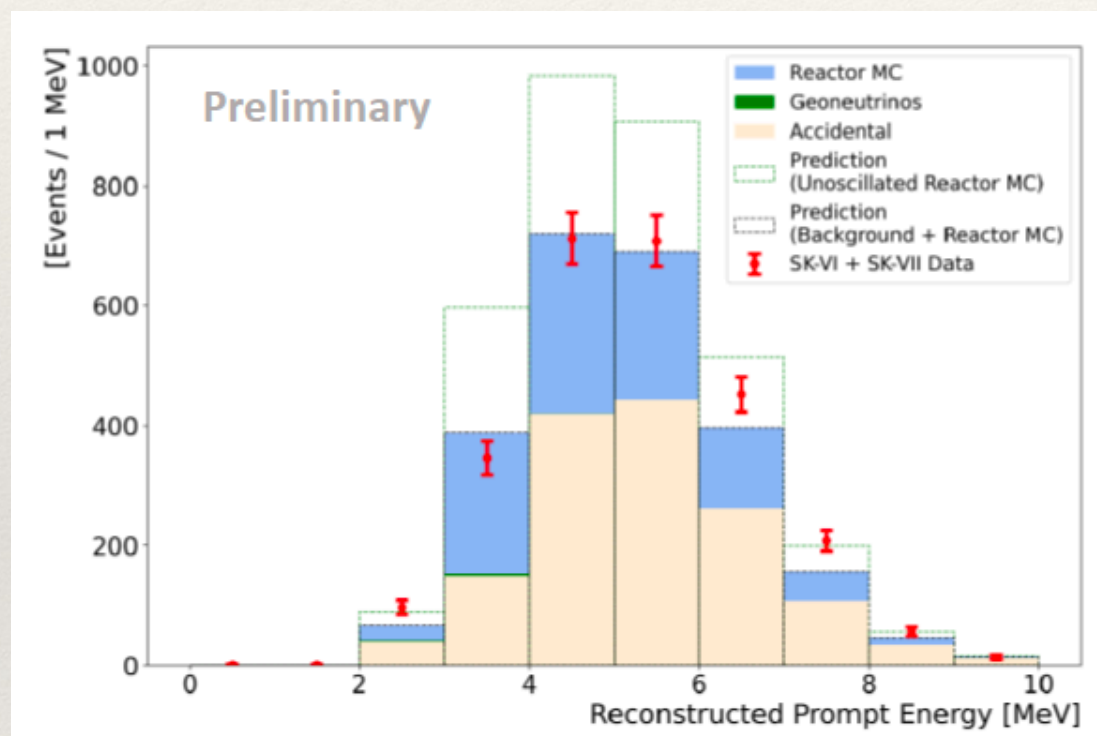


Adding JUNO improves precision but the best-fit remains similar to KamLAND

M.C. Gonzalez-Garcia , Neutrino 2026

SK solar + reactor

Addition of Gd makes it possible to observe reactor antineutrinos in SK



	$\sin^2 \theta_{12}$	$\Delta m_{21}^2 [10^{-5} \text{ eV}^2]$
SK Solar	$0.324^{+0.027}_{-0.023}$	$6.10^{+1.26}_{-0.86}$
SK Reactor	$0.50^{+0.16}_{-0.16}$	$9.08^{+0.55}_{-0.54}$
SK Reactor + Solar	$0.33^{+0.028}_{-0.026}$	$8.94^{+0.46}_{-0.47}$

Analyzed **SK VI-VII data** (~400 live days)

- reactor $\bar{\nu}_e$ in SK for the 1st time (6σ)
- solar ν_e & reactor $\bar{\nu}_e$ in one detector

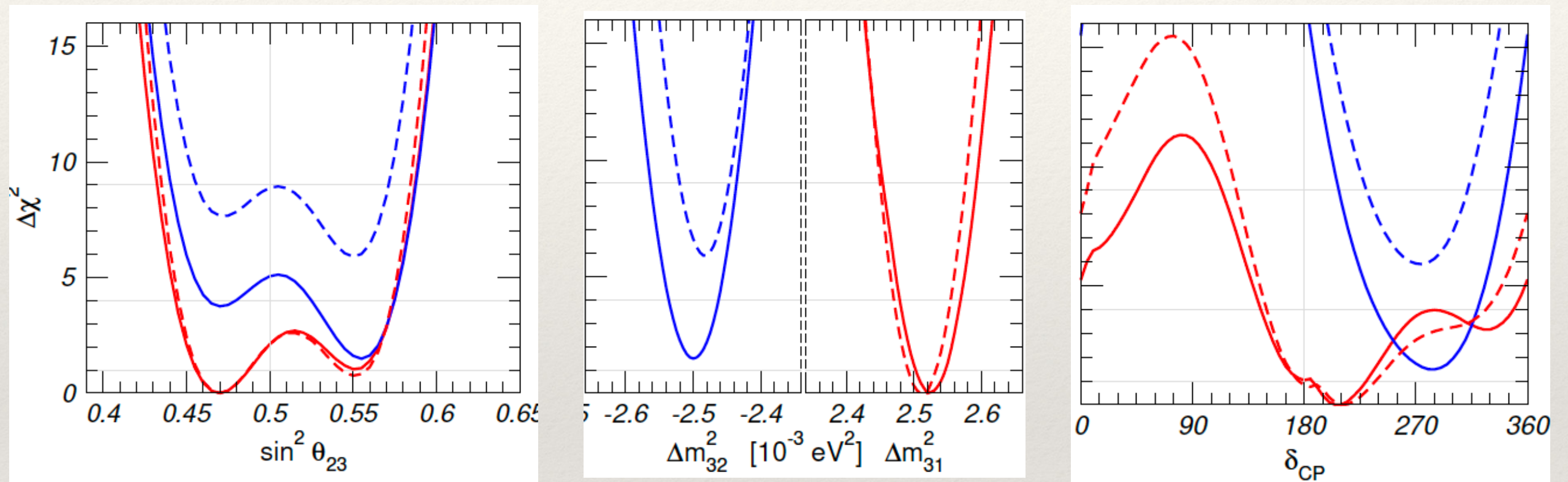
Tension persists at 1.94 sigma

Z. Hu, Neutrino 2026

Mass ordering, octant, δ_{CP}

— — NO, IO (IC23 w/o SK-atm)
- - - - - - NO, IO (IC24 with SK-atm)

NuFIT 6.1 (2025)



Lower octant and Normal Ordering preferred by global fit

Value of δ_{CP} close to 180° for NO and 270° for IO

Why these parameters are particularly difficult to determine ?

Degeneracy problem

- ❖ The main problem in determination of hierarchy, octant and δ_{CP} in LBL experiments is due to presence of degeneracies
- ❖ Degeneracy $\rightarrow$ different set of parameters giving the same probability $\rightarrow$ equally good fit to the data
- ❖

Hierarchy - δ_{CP} degeneracy

$$P_{\mu e}(\Delta, \delta_{CP}) = P_{\mu e}(-\Delta, \delta'_{CP})$$

Minakata, NunoKawa, 2001

Intrinsic octant degeneracy

$$P_{\mu\mu}(\theta_{23}) = P_{\mu\mu}(\theta_{23} - \pi/2 - \theta_{23})$$

Fogli and Lisi, 1996

Octant - δ_{CP} degeneracy

$$P_{\mu e}(\theta_{23}, \delta_{CP}) = P_{\mu e}(\theta'_{23}, \delta'_{CP})$$

Gandhi, Ghosal, Goswami, Shankar 2005

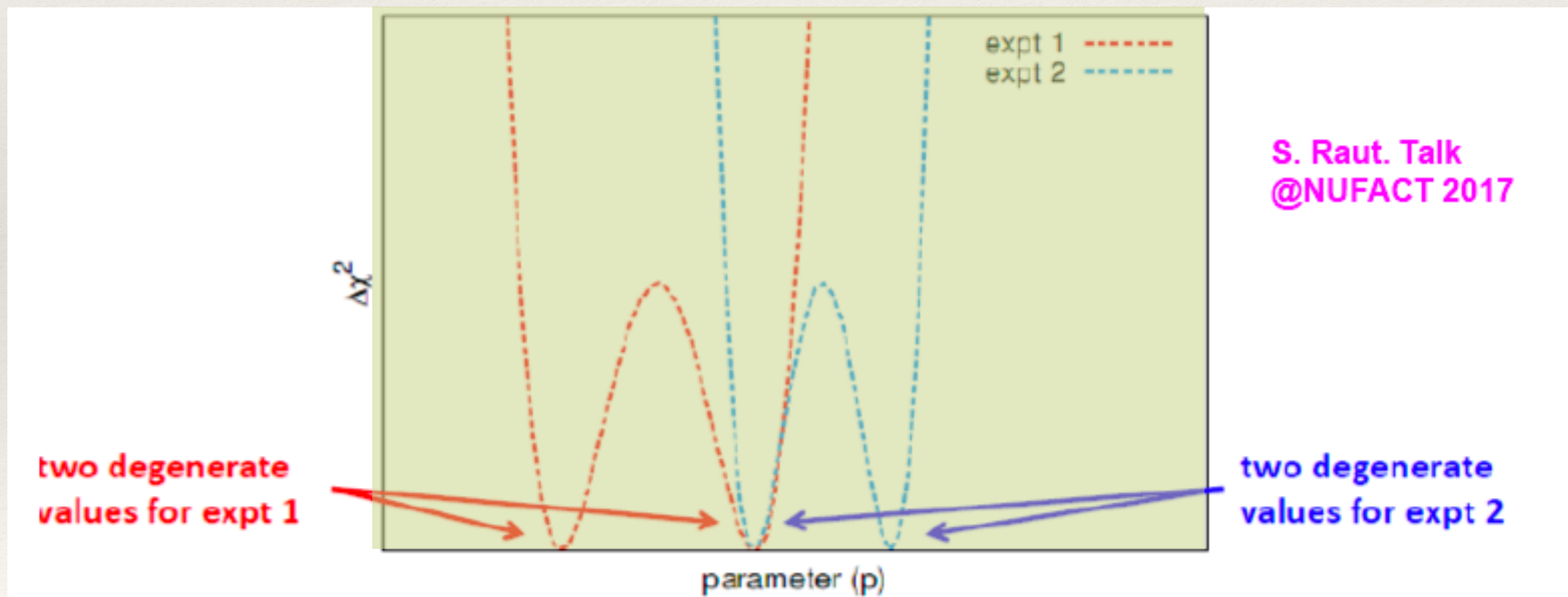
Comprehensive Approach

$$P_{\mu e}(\theta_{23}, \Delta, \delta_{CP}) = P_{\mu e}(\theta'_{23}, -\Delta', \delta'_{CP}) \Rightarrow \text{generalized (hierarchy - } \theta_{23} - \delta_{CP}) \text{ degeneracy.}$$

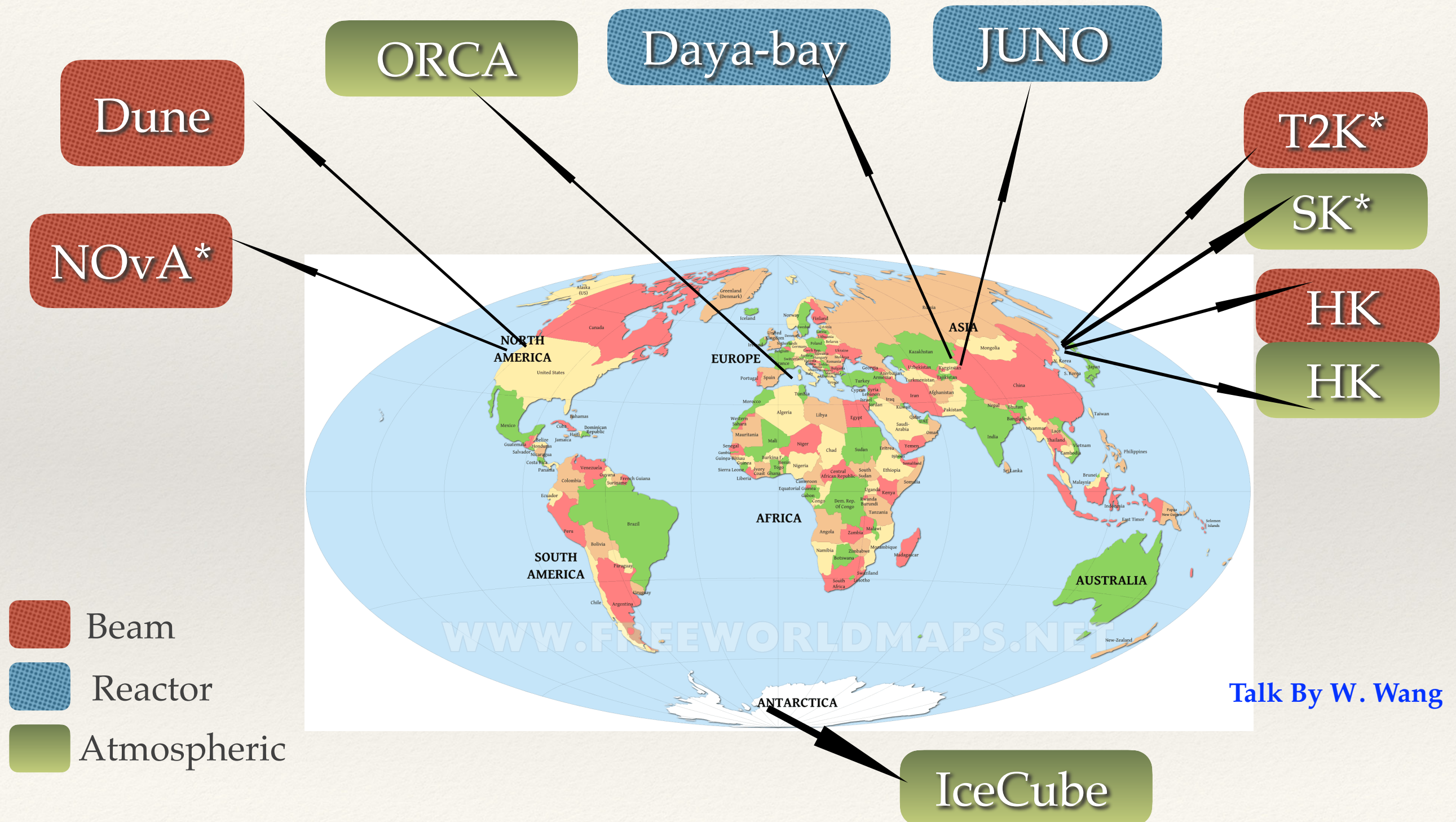
Ghosh, Ghoshal, Goswami, Nath, Raut, 2015

Synergy between experiments

- ❖ Different experiments have different L, E dependence and therefore the dependence on the oscillation probability on a given parameter can be different



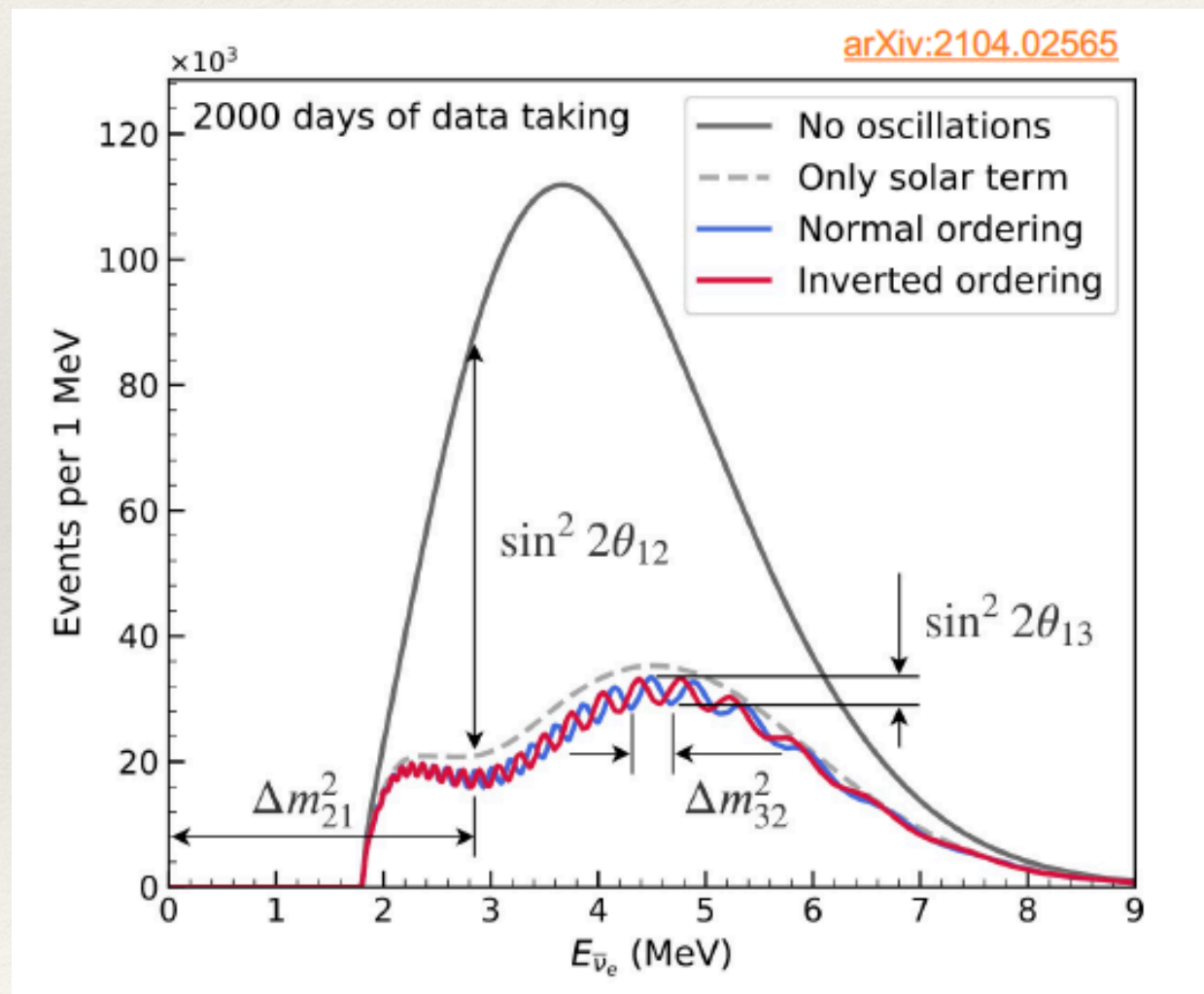
Current and future oscillation experiments



Talk By W. Wang

Mass ordering with JUNO

$$P_R(\bar{\nu}_e \rightarrow \bar{\nu}_e) = 1 - \left\{ \cos^4 \theta_{13} \sin^2 2\theta_{12} \sin^2 \Delta_{21} + \sin^2 2\theta_{13} \sin^2 \theta_{12} \left(\cos 2\Delta_{31} \sin^2 \Delta_{21} - \frac{1}{2} \sin 2\Delta_{31} \sin 2\Delta_{21} \right) \right\}$$



From interference between solar and atmospheric frequencies

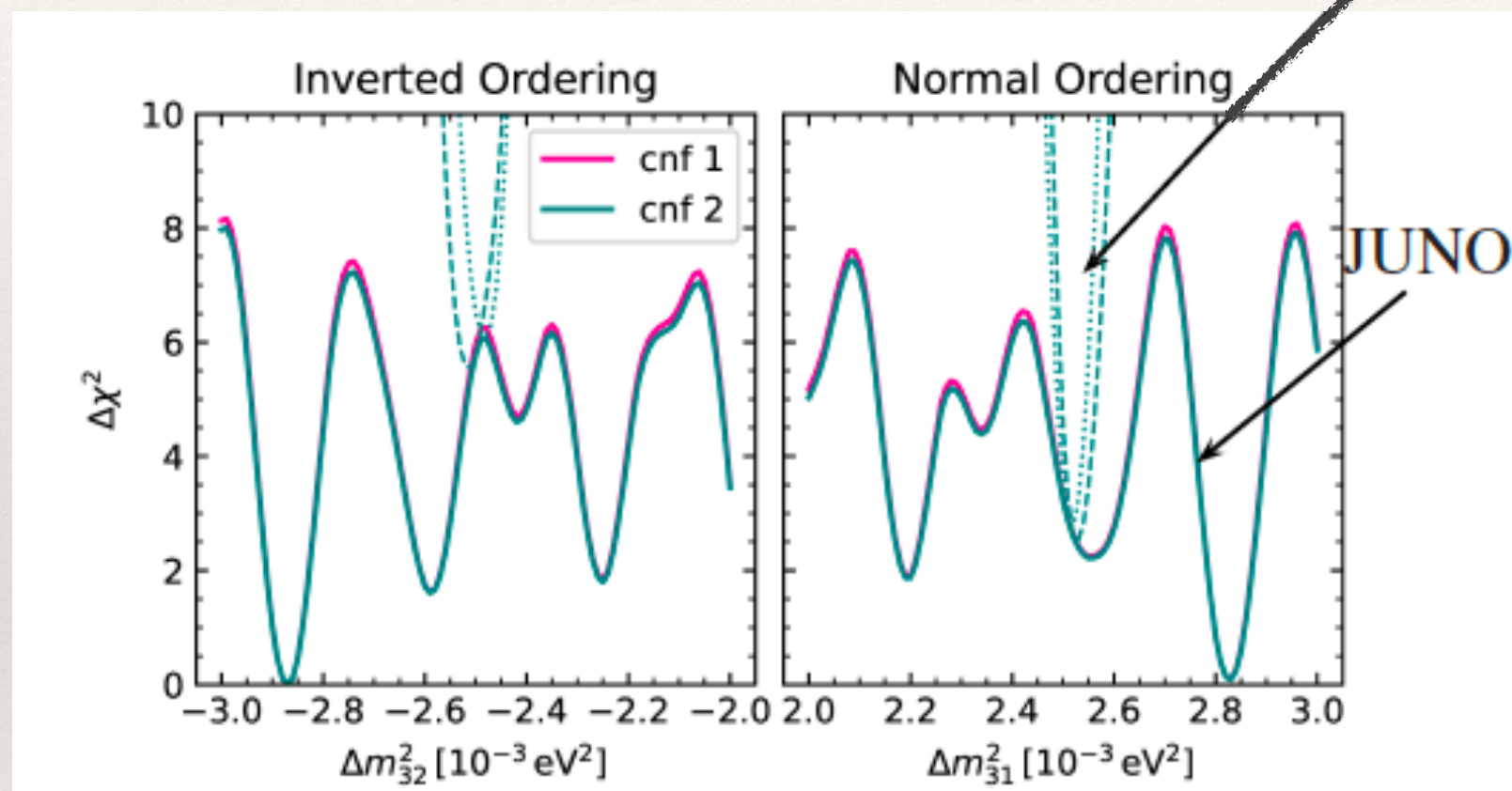
Distortions in the energy spectrum

Better than 3% energy resolution reqd.

No hierarchy-CP degeneracy

Impact of 1st JUNO results

NuFit 6.1

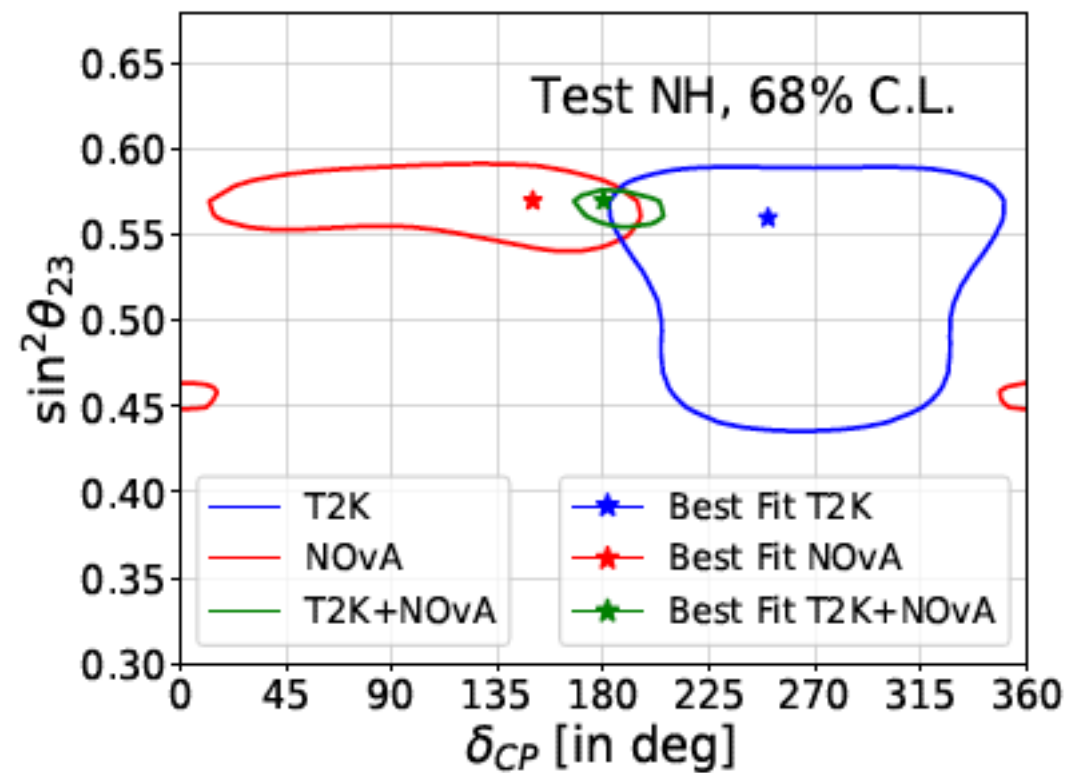


$$\chi_{\text{IO}}^2 - \chi_{\text{NO}}^2 = \begin{cases} 1.5 \rightarrow 4.5 & \text{w IC23 w/o SK - ATM} \\ 5.9 \rightarrow 9.4 & \text{w IC24 w SK - ATM} \end{cases}$$

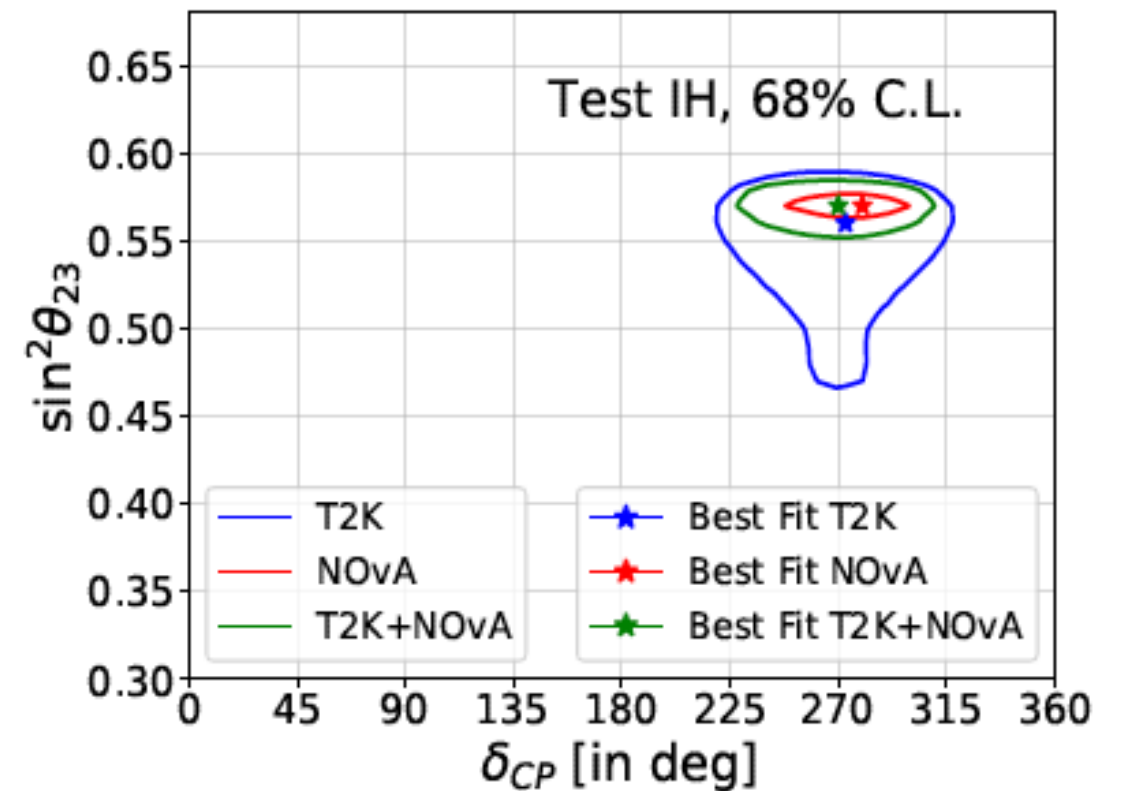
59 days

M.C. Gonzalez-Garcia , Neutrino 2026

T2K-NOvA tension



Present for NO

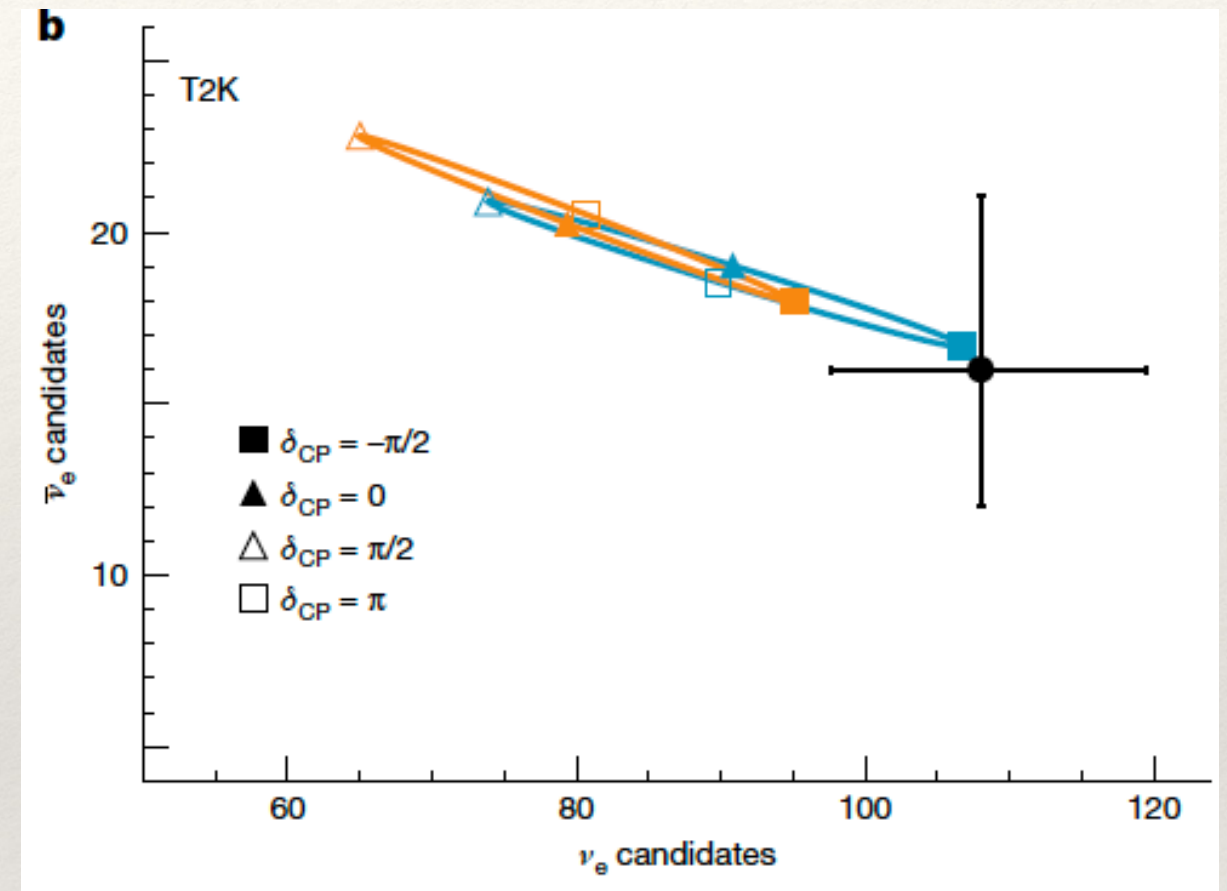
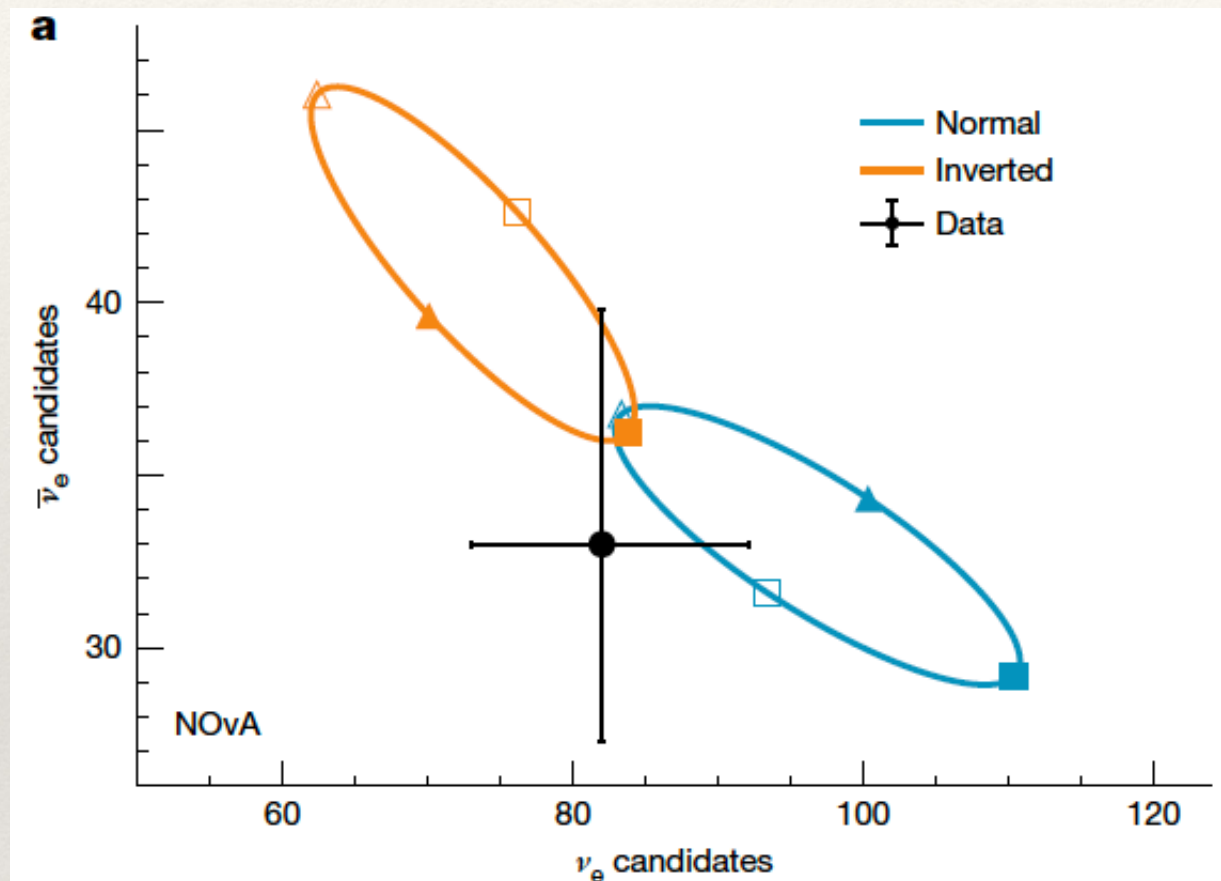


But not for IO

Goswami, Gupta, Rahaman, Raut, JHEP 2026

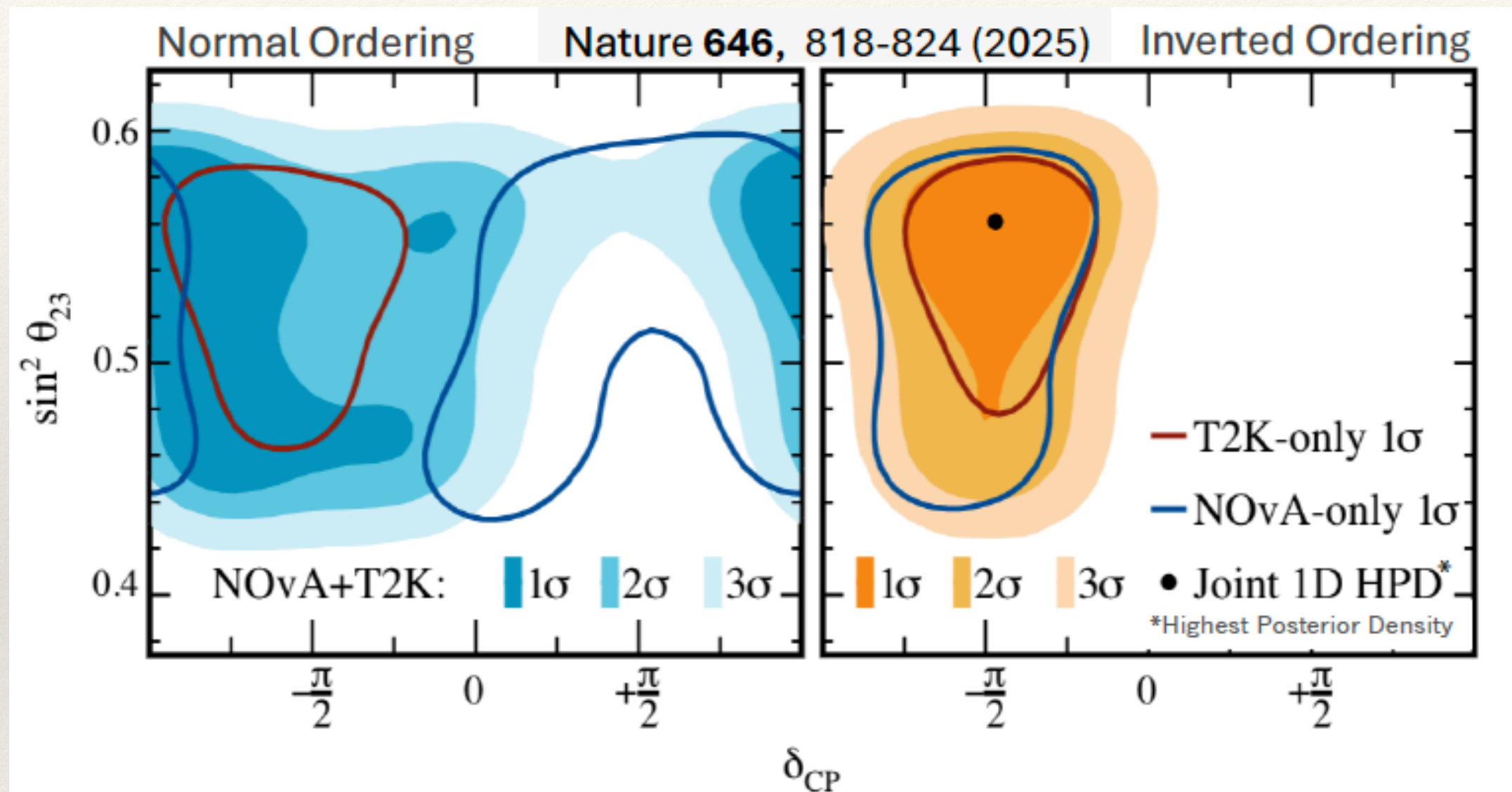
T2K/NOvA joint analysis : *Nature* 646, 818–824 (2025)

Electron events in T2K and NOvA



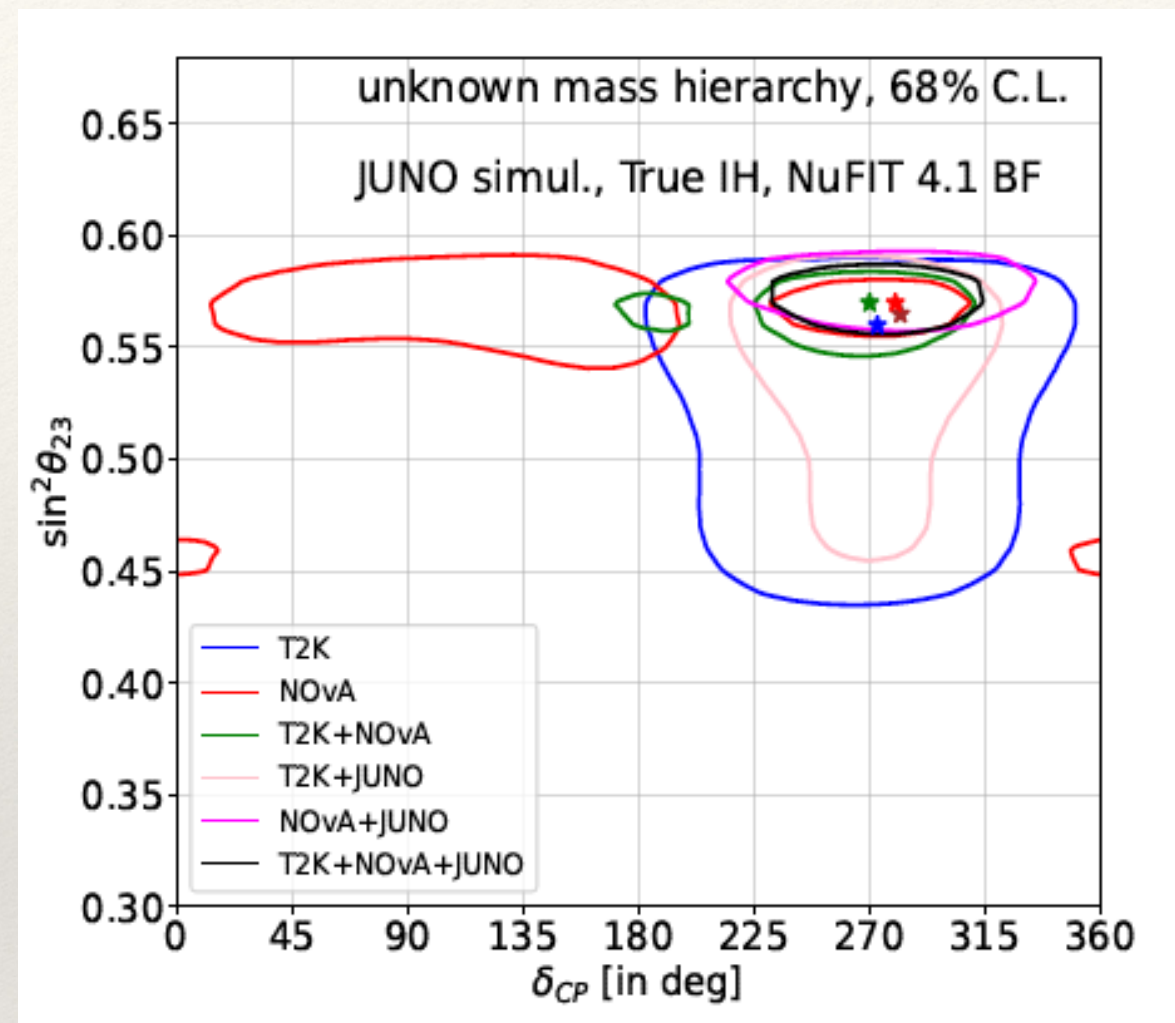
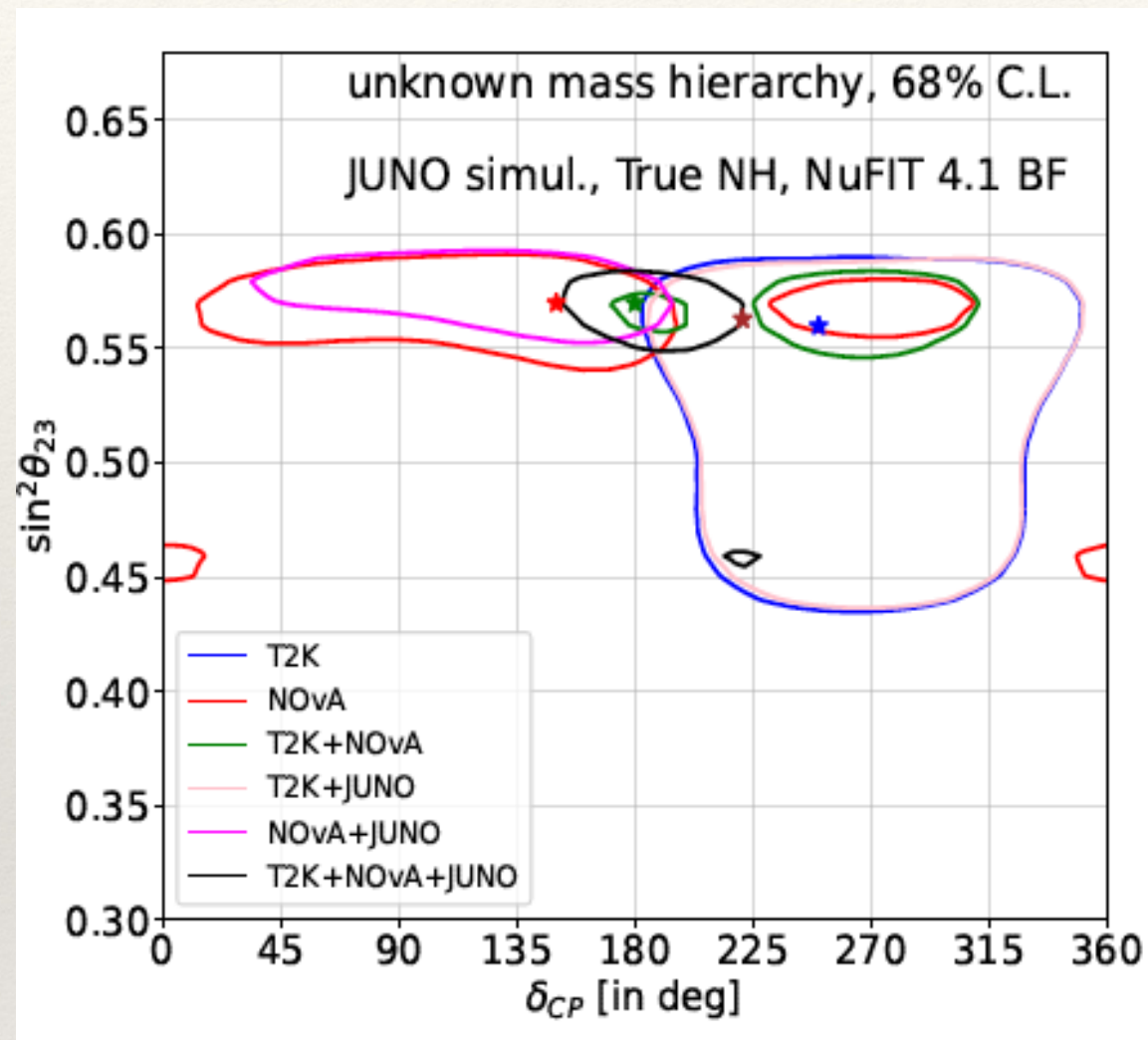
The electron excess observed fixes the value of $\delta_{CP} \sim 270^\circ$ for T2K

Impact on mass ordering



T2K + NOvA weak preference for IO, because of overlap in δ_{CP}

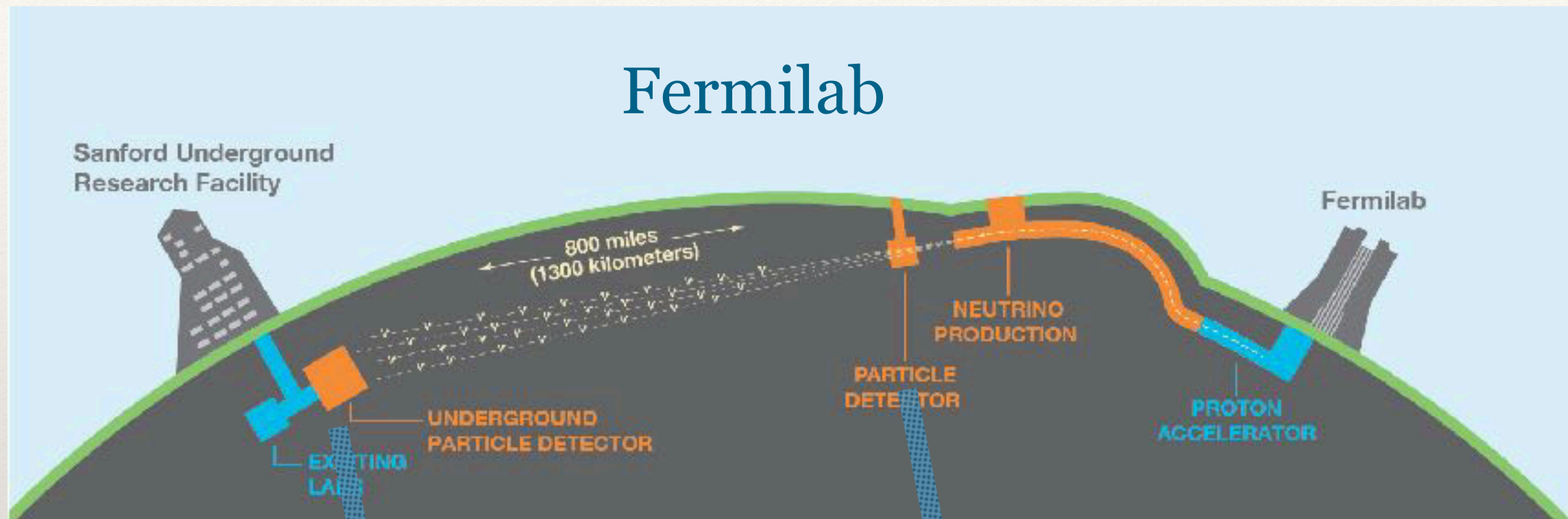
T2K+NOvA +JUNO (simulations)



Adding JUNO (6 years) with NOvA removes the wrong-hierarchy solution

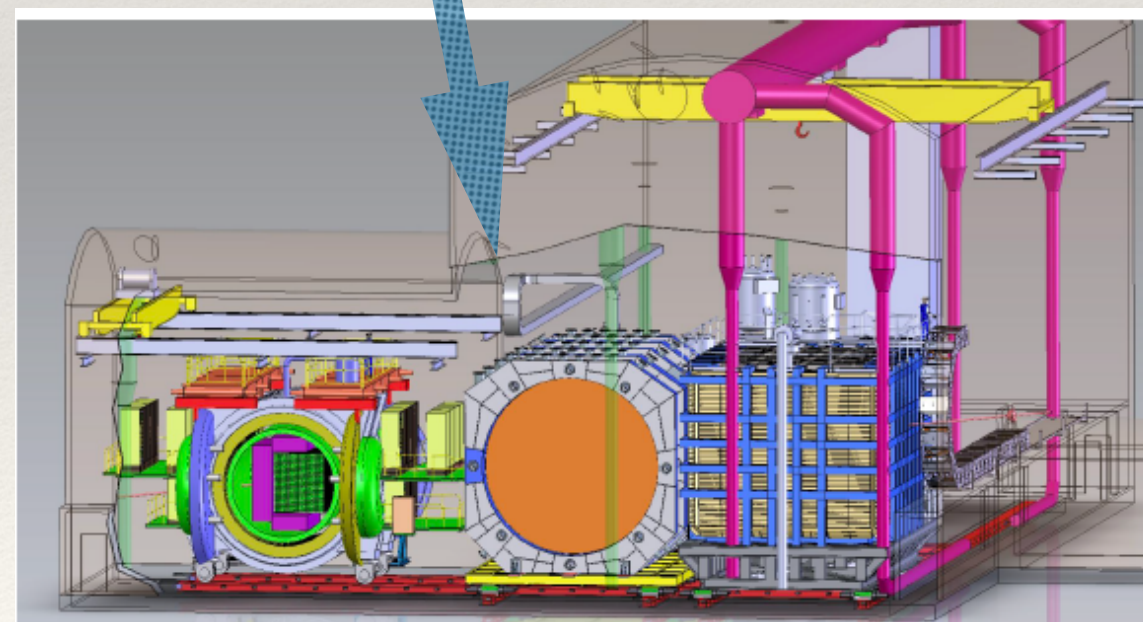


DUNE



Far Detector

Liquid Argon Time
Projection Chamber



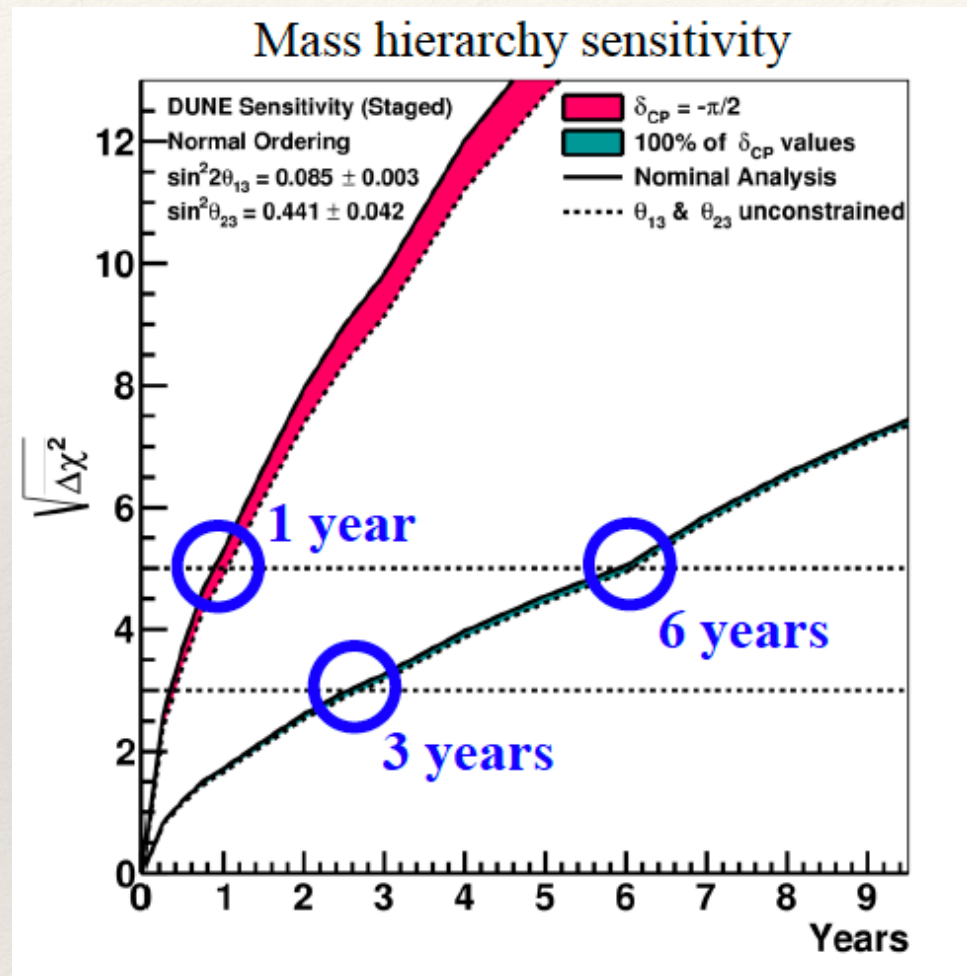
SAND

ND-GAr

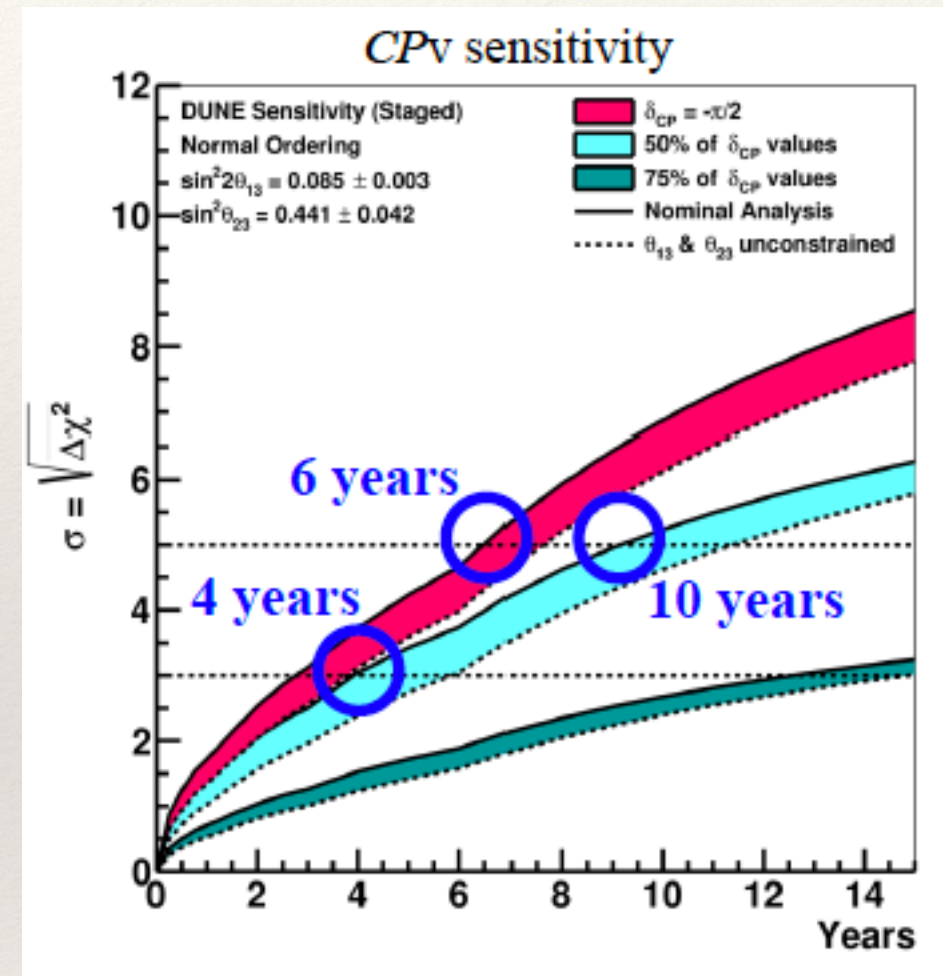
ND-LAr

DUNE PRISM

Mass hierarchy and CP with DUNE



Hierarchy sensitivity due
to enhanced matter effects at 1300
km baseline



Matter effects help in removing
wrong hierarchy-wrong CP solutions

Beyond vanilla oscillations

- ❖ Possibility of probing new physics beyond the SM in neutrino oscillation experiments [talk by M. Dolan](#)
- ❖ Sterile neutrinos, non-standard interactions, non-unitarity of neutrino mixing matrices, CPT violation, long range force, unstable neutrinos
- ❖ Sub-leading effect [see however, talk by M. Sen](#)
- ❖ **Changes the oscillation probability**
- ❖ [Impact on the 3-neutrino picture — extra parameters and degeneracies](#)
- ❖ [Constraining new physics parameters](#)
- ❖ [Unique signatures of BSM physics in neutrino experiments ?](#)



Is there any hint of new physics in data ?

Non-standard interactions

Standard-NC interaction

$$\nu_\alpha + f \rightarrow \nu_\alpha + f$$

Non-Standard NC interaction

$$\nu_\alpha + f \rightarrow \nu_\beta + f$$

$$\mathcal{L} = -G^{\alpha\beta} \epsilon_{\alpha\beta}^f \bar{\nu}_\alpha \gamma^\mu \nu_\beta \bar{f} \gamma_\mu f$$

$$\epsilon_{\alpha\beta} = \sum_{f=e,u,d} \frac{N_f}{N_e} \epsilon_{\alpha\beta}^f$$

$$H = \frac{1}{2E} \left[U \text{diag}(0, \Delta m_{21}^2, \Delta m_{31}^2) U^\dagger + V \right]$$

For earth's matter

$$N_u \approx N_d \approx 3N_e$$

$$\epsilon_{\alpha\beta} \approx \epsilon_{\alpha\beta}^e + 3\epsilon_{\alpha\beta}^u + 3\epsilon_{\alpha\beta}^d$$

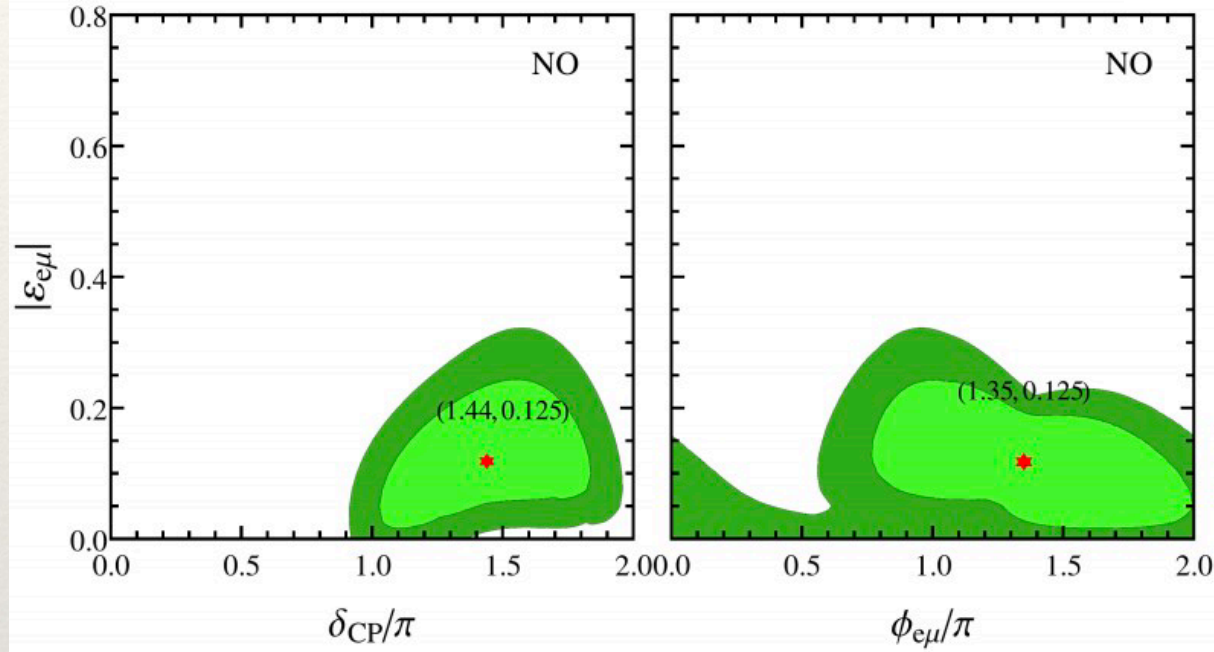
$V \Rightarrow$ matter potential in presence of NSI,

$$V = A \begin{pmatrix} 1 + \epsilon_{ee} & \epsilon_{e\mu} e^{i\phi_{e\mu}} & \epsilon_{e\tau} e^{i\phi_{e\tau}} \\ \epsilon_{e\mu} e^{-i\phi_{e\mu}} & \epsilon_{\mu\mu} & \epsilon_{\mu\tau} e^{i\phi_{\mu\tau}} \\ \epsilon_{e\tau} e^{-i\phi_{e\tau}} & \epsilon_{\mu\tau} e^{-i\phi_{\mu\tau}} & \epsilon_{\tau\tau} \end{pmatrix}.$$

Here, $A \equiv 2\sqrt{2}G_F N_e E$ and $\epsilon_{\alpha\beta} e^{i\phi_{\alpha\beta}} \equiv \sum_{f,C} \epsilon_{\alpha\beta}^{fC} \frac{N_f}{N_e}$

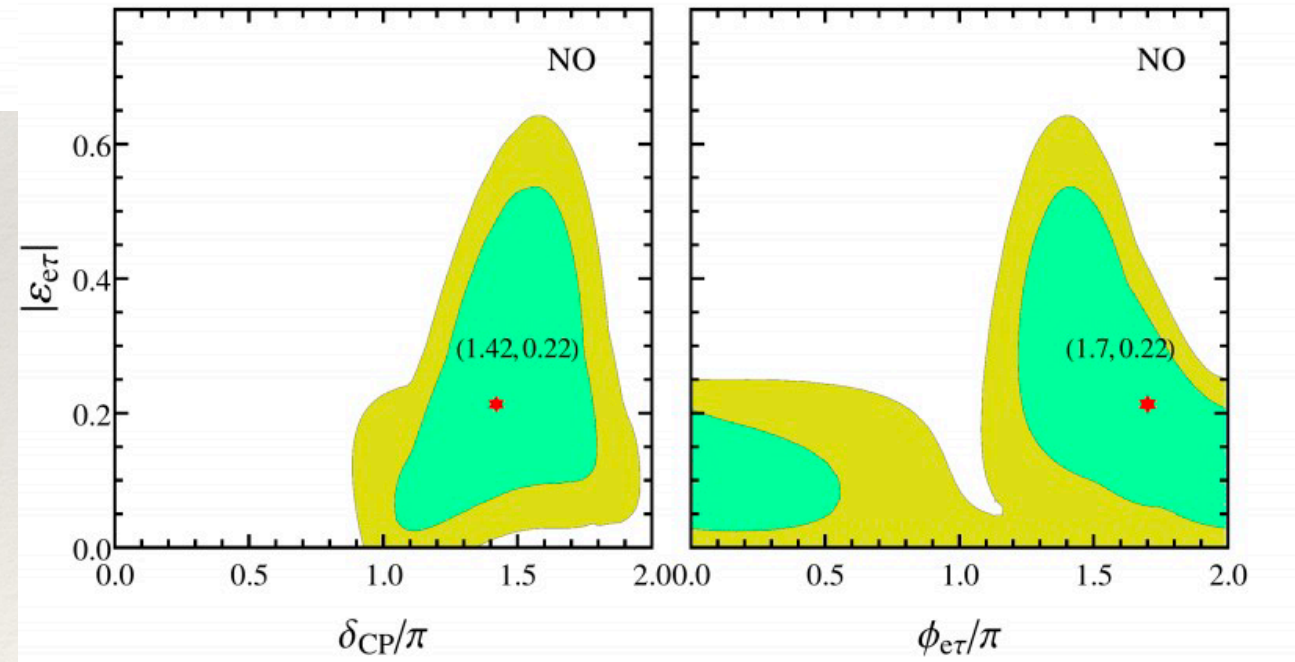
Hint for non-zero NSI in T2K+NOvA ?

$$\Delta\chi^2 = \chi_{\text{SM}}^2 - \chi_{\text{SM+NSI}}^2$$



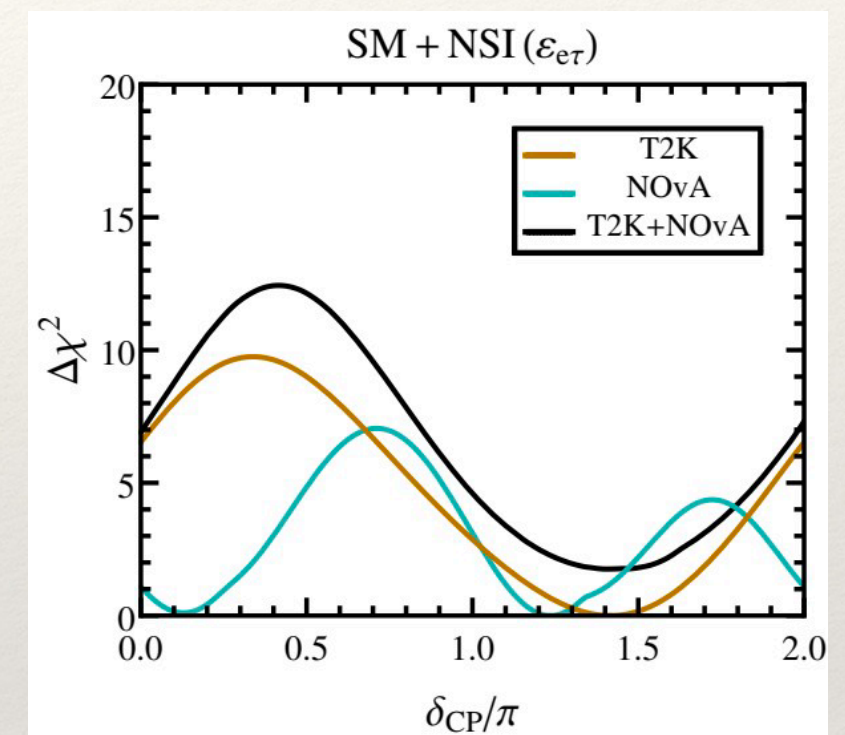
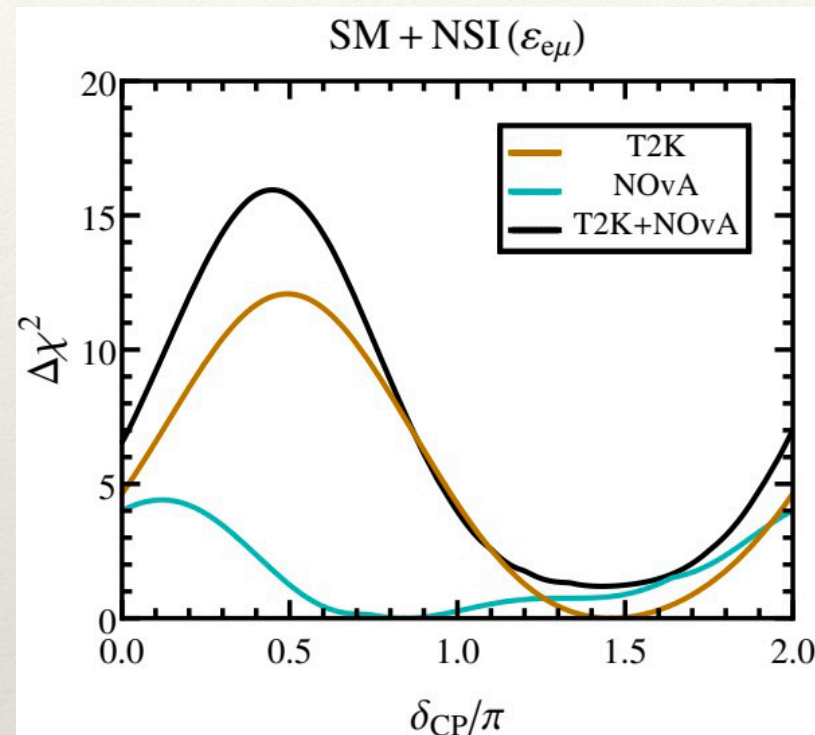
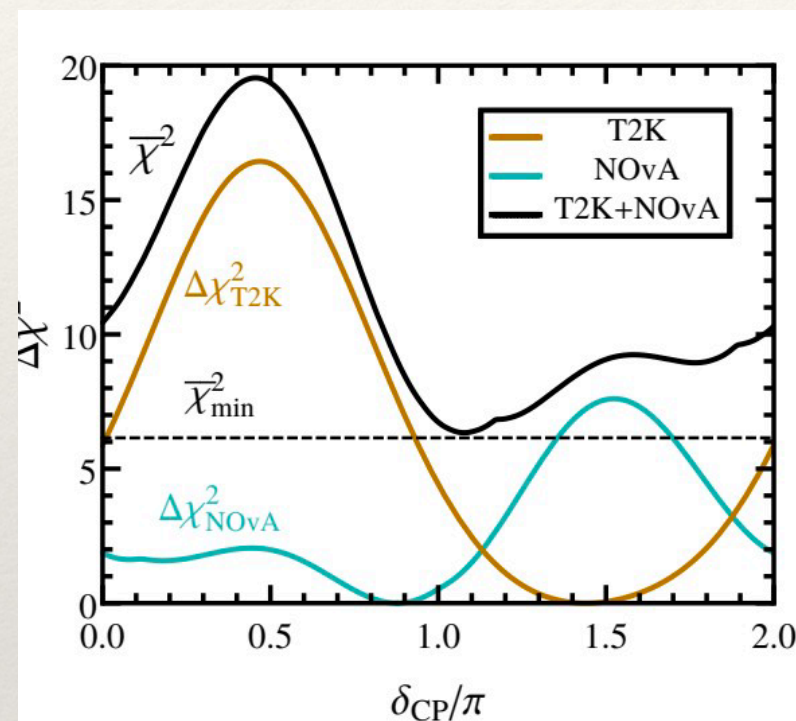
NMO	NSI	$ \epsilon_{\alpha\beta} $	$\phi_{\alpha\beta}/\pi$	δ_{CP}/π	$\Delta\chi^2$
NO	$\epsilon_{e\mu}$	0.13	1.35	1.44	3.1
	$\epsilon_{e\tau}$	0.22	1.70	1.42	3.2
IO	$\epsilon_{e\mu}$	0.05	1.44	1.50	0.94
	$\epsilon_{e\tau}$	0.23	1.54	1.54	2.9

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S.S. Chatterjee, A. Palazo, PRD 110, 113002 (2024)

T2K/NOvA tension and non-standard interactions



Tension reduces in presence of NSI

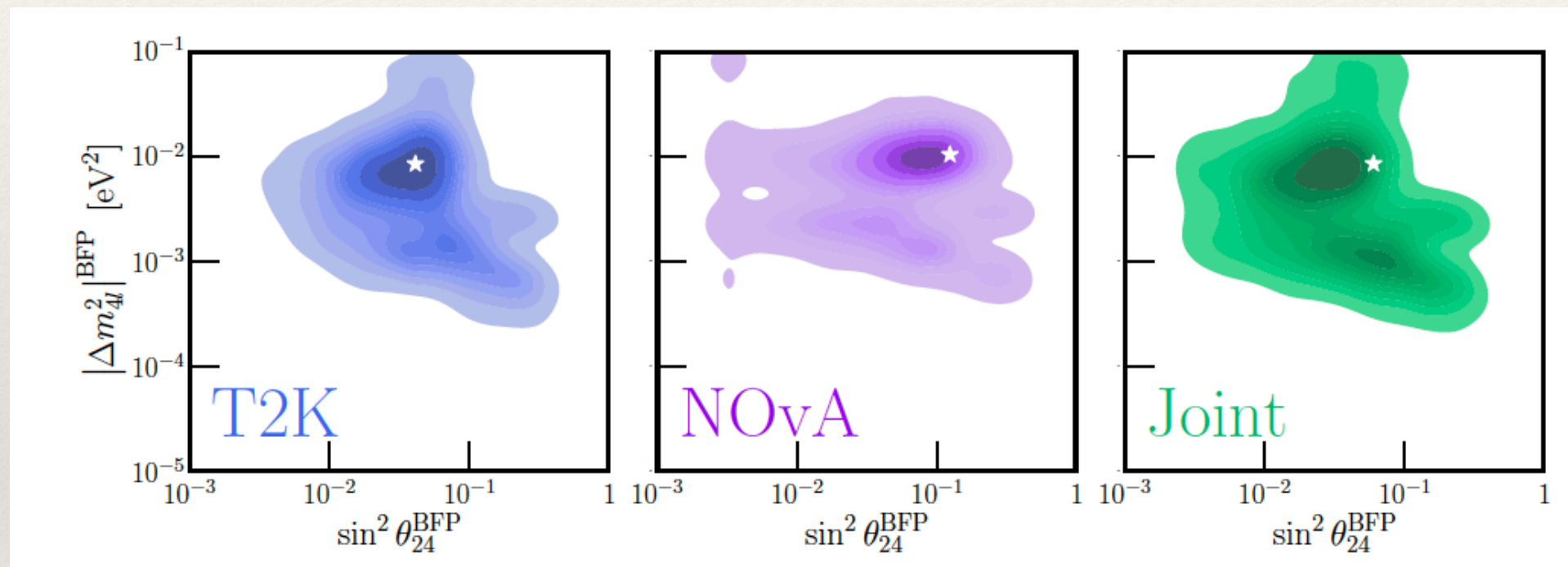
Chatterjee, Palazo, PRD 110, 113002 (2024). PRL 126 051802 (2021)

Denton, Gherkin, Pestes, PRL 126 051801 (2021)

Rahaman, Razzaque, Uma Sankar Universe 8, 109 (2022)

Very light sterile neutrinos

Sterile neutrinos with $\Delta m^2 \sim 10^{-3} - 10^{-2} \text{ eV}^2$ invoked to explain T2K/NOvA tension

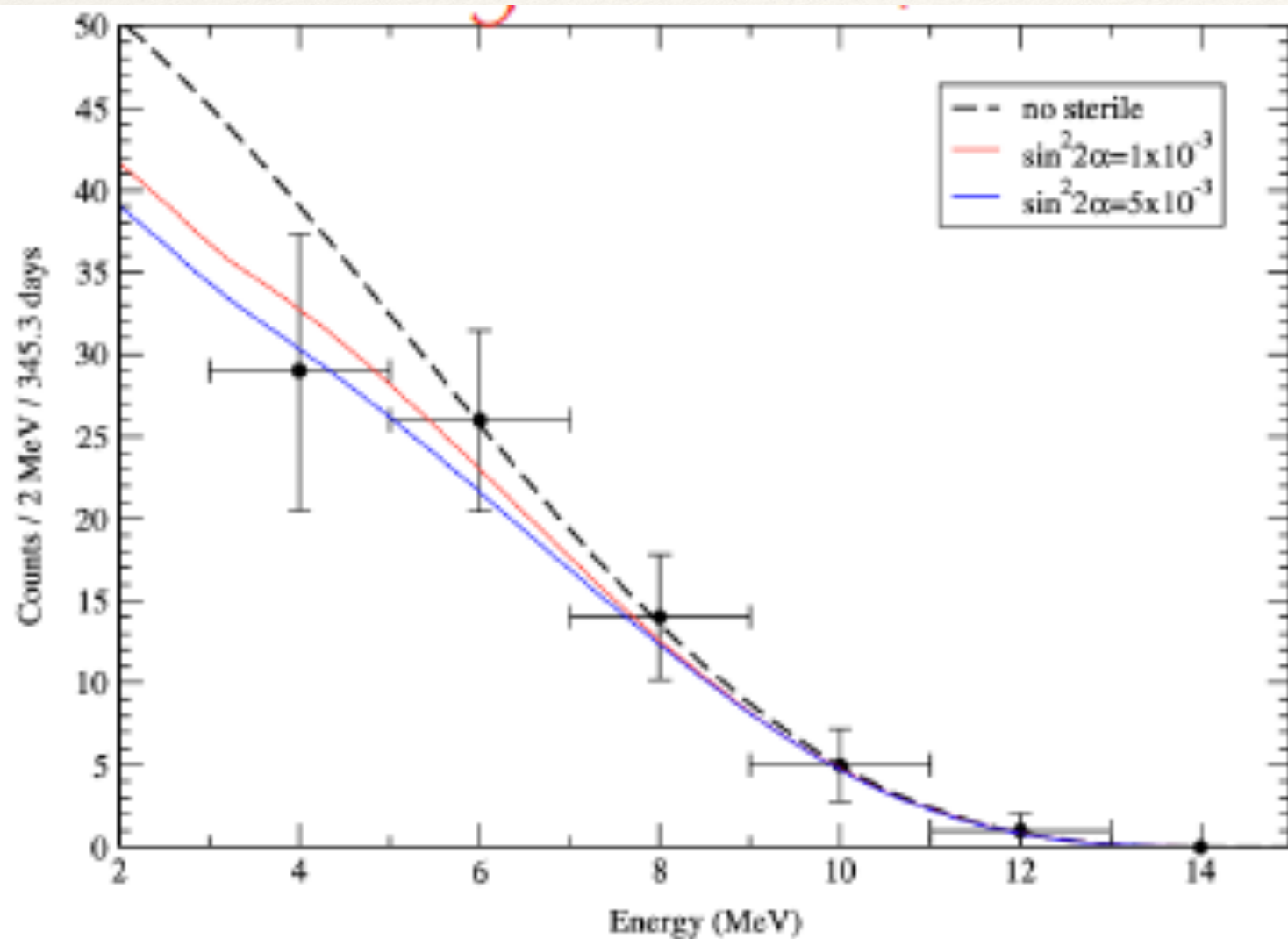


$$U_s = \tilde{R}_{34}(\theta_{34}, \delta_{34}) R_{24}(\theta_{24}) \tilde{R}_{14}(\theta_{14}, \delta_{14}) R_{23}(\theta_{23}) \tilde{R}_{13}(\theta_{13}, \delta_{13}) R_{12}(\theta_{12})$$

Additional parameters give improved fit

De Gouvea, Sanchez, Kelly, PRD106, 5,055025 (2022)

Spectral upturn in solar neutrino data



The predicted spectral
upturn from
MSW effect not seen in data

Ultra light sterile neutrinos with

$$\Delta_s \sim 10^{-5} - 10^{-4} \text{ eV}^2,$$

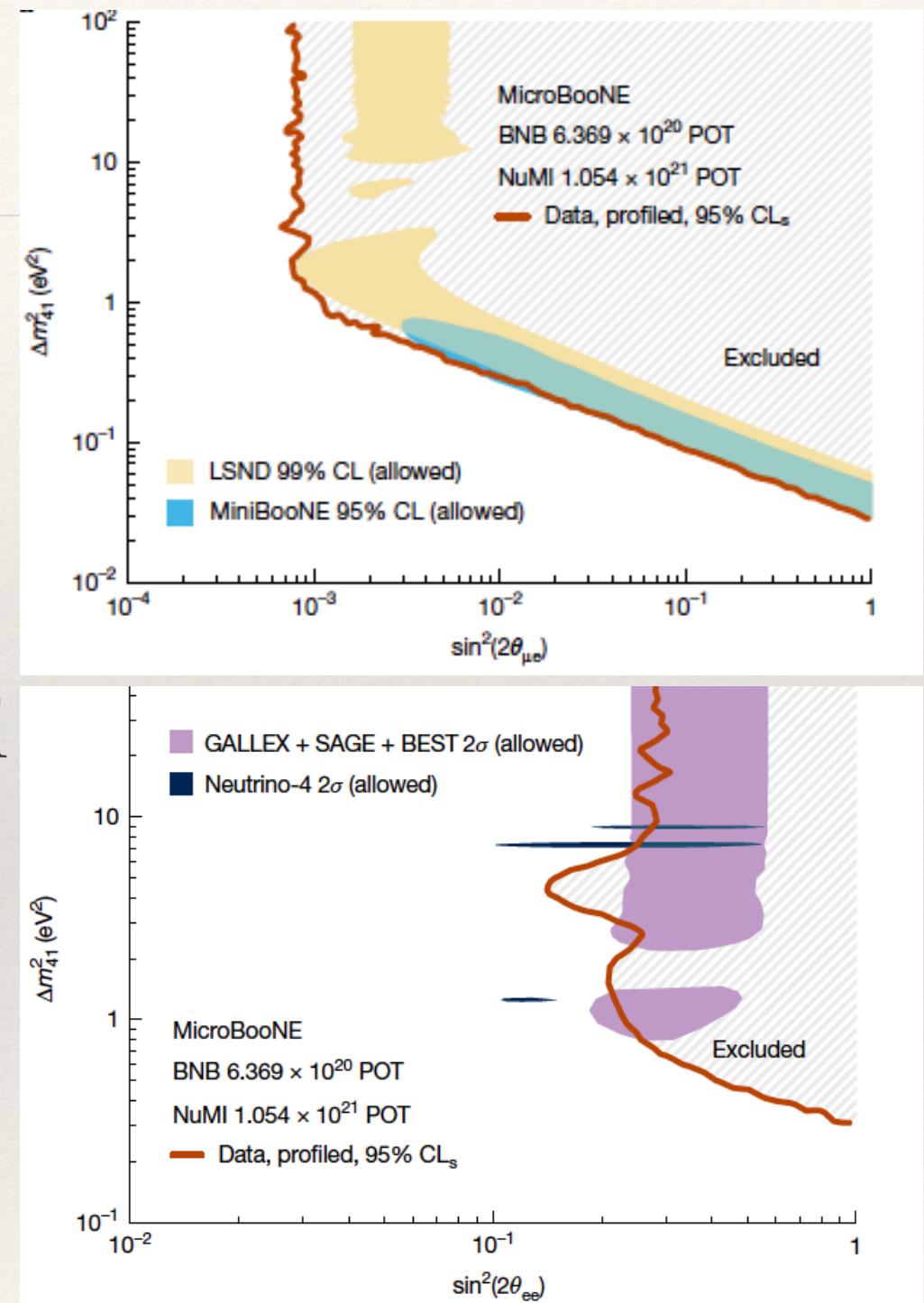
$$\sin^2 2\alpha \sim 10^{-5} - 10^{-3}$$

can explain this

Light sterile neutrinos



- ❖ Hints of eV scale sterile neutrino : LSND, MiniBoone, Ga Source anomaly
- ❖ 3+1 picture minimal scenario
- ❖ Strong tension in disappearance and appearance experiments
- ❖ MicroBooNE disfavour eV scale sterile from appearance mode
- ❖ Results from SBND awaited



Conclusions

- ❖ Three flavour oscillation paradigm well established
- ❖ Precision era in measurement of oscillation parameters
- ❖ Initial JUNO data already gives best precision to Δm_{21}^2 , $\sin^2 \theta_{12}$
- ❖ Preference for NO from global analysis, initial JUNO results
- ❖ T2K / NOvA tension for δ_{CP}
- ❖ Synergy between experiments can help in removing the degeneracies
- ❖ Ongoing and upcoming experiments makes the field very vibrant
- ❖ Existence of eV scale sterile neutrino oscillations unsolved for 30 years
- ❖ No other strong hint for beyond oscillation physics
- ❖ Future high-statistics high-intensity expts have potential to probe this

Sydney Marathon, 30th August 2026



Neutrinos running a marathon for 70 years

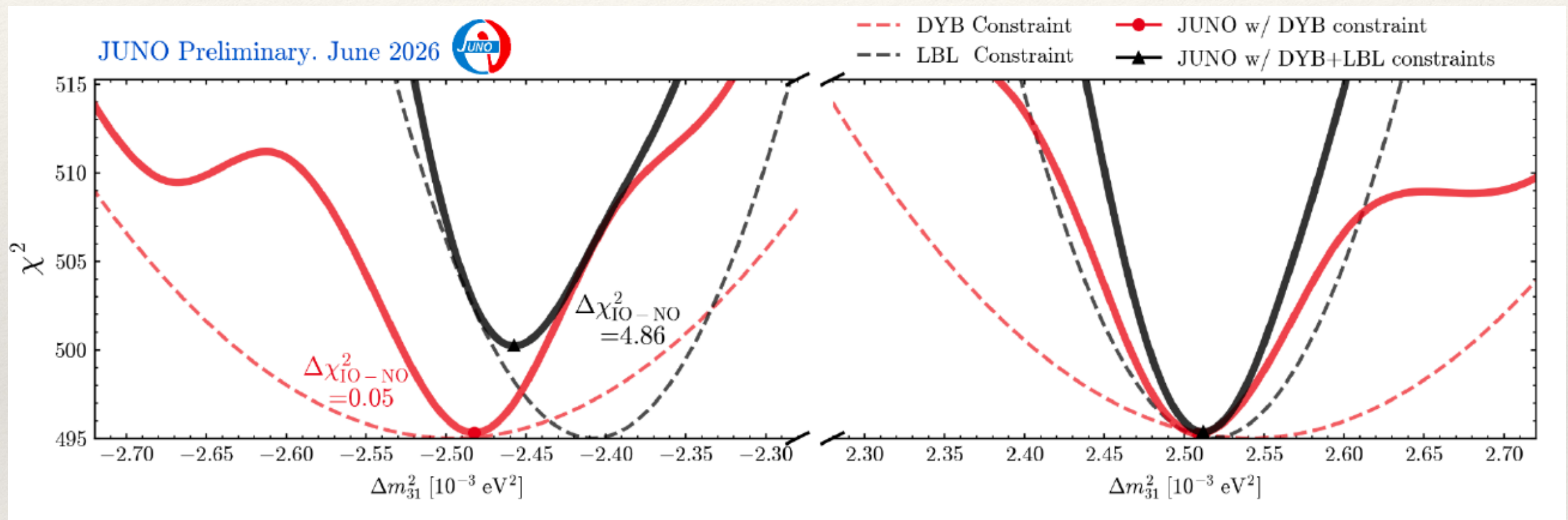
Many more exciting results in the coming years



Acknowledge the Gordon Godfrey visitor programme and the hospitality of Physics department of UNSW

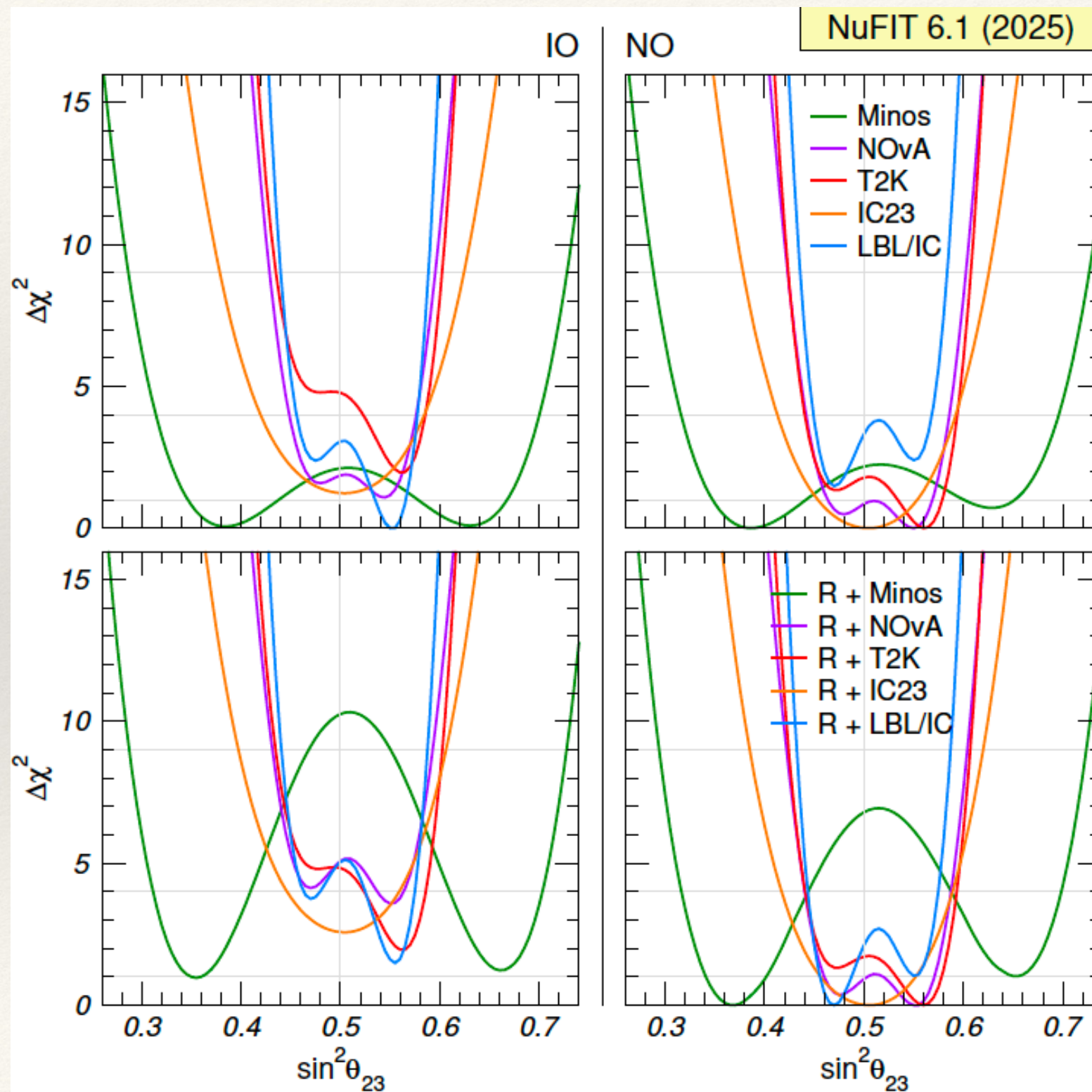


Constraint on Δm_{31}^2

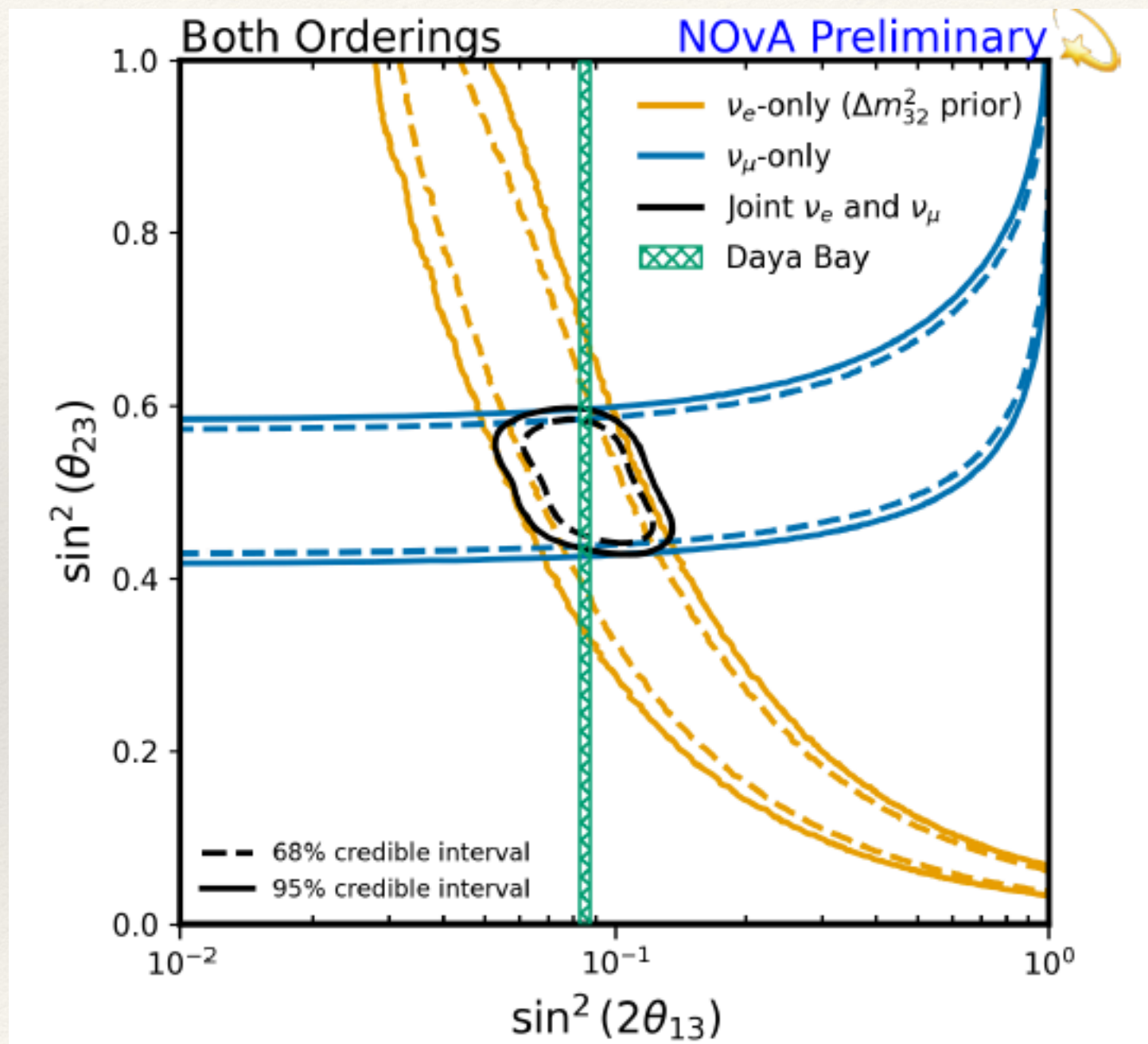


Y. Wang, Neutrino 2026

Determination of θ_{23}



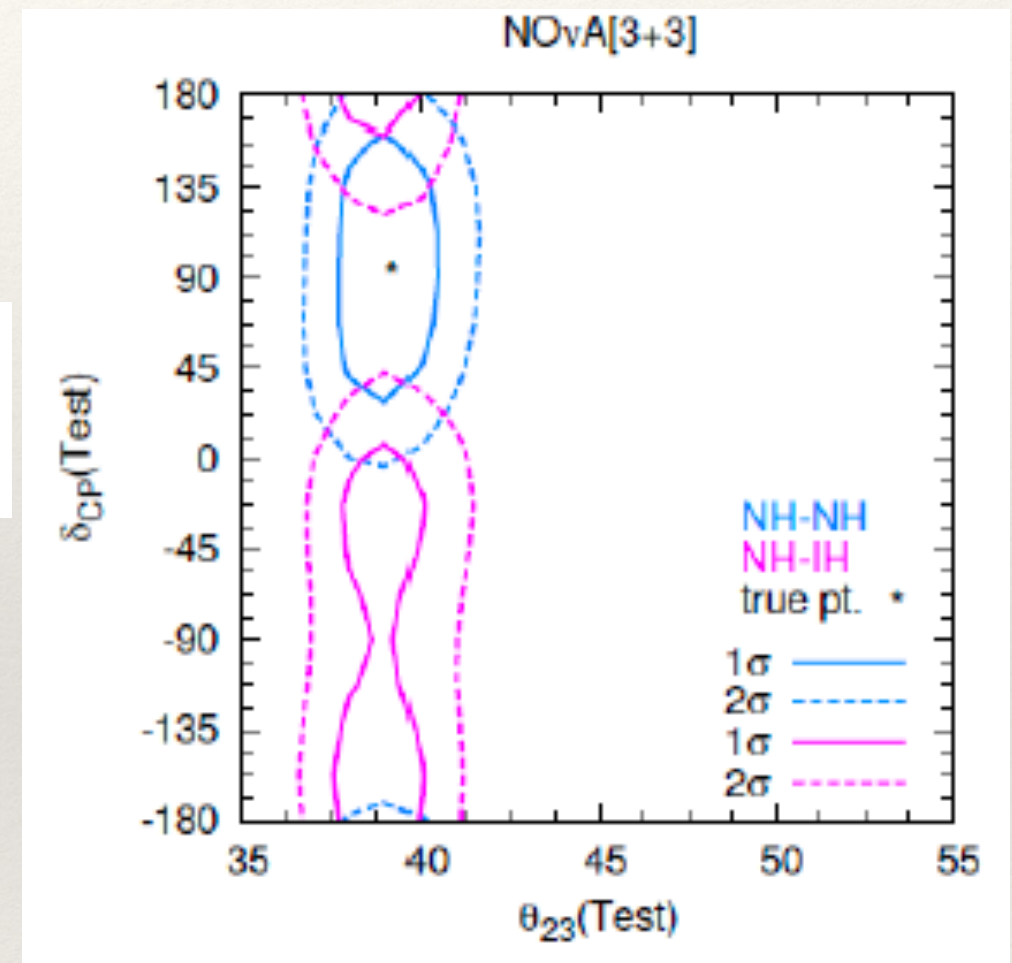
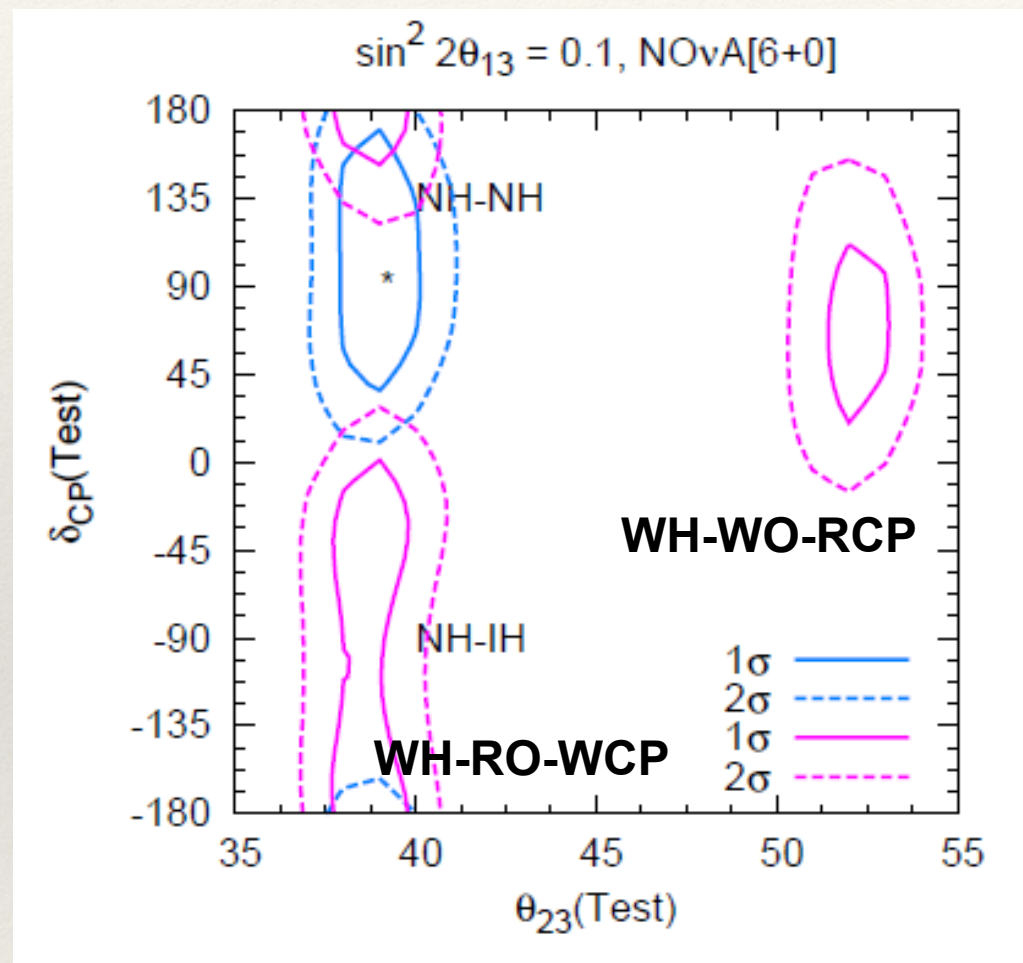
Determination of θ_{23}



Interplay of θ_{13} and θ_{23}

Interplay of appearance
and disappearance

Synergy between neutrinos and antineutrinos

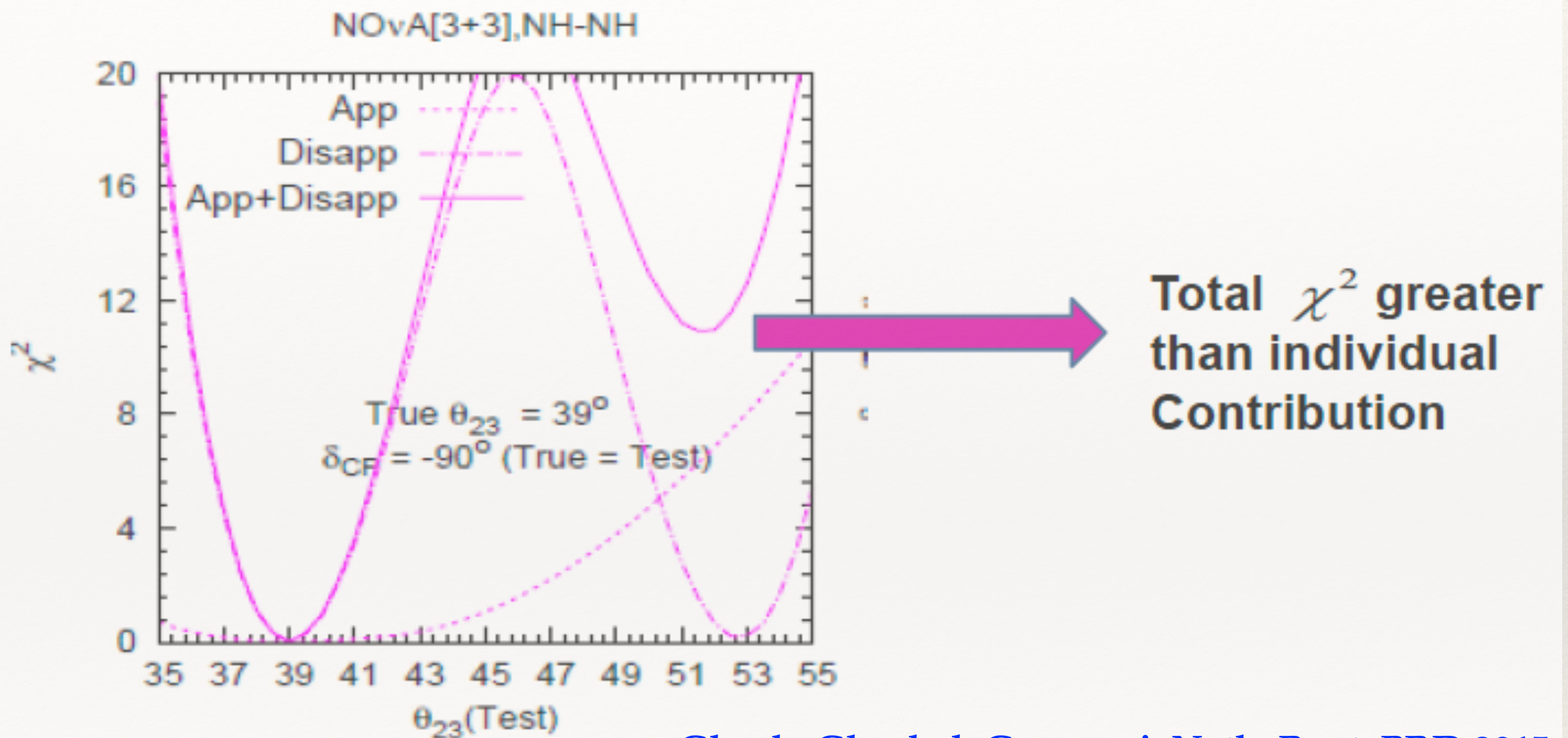


Ghosh, Ghoshal, Goswami, Nath, Raut, PRD 2015

Agarwala, Prakash, Uma sankar, JHEP 2013

Combination of neutrino and antineutrino run removes wrong octant solutions

Synergy between channels



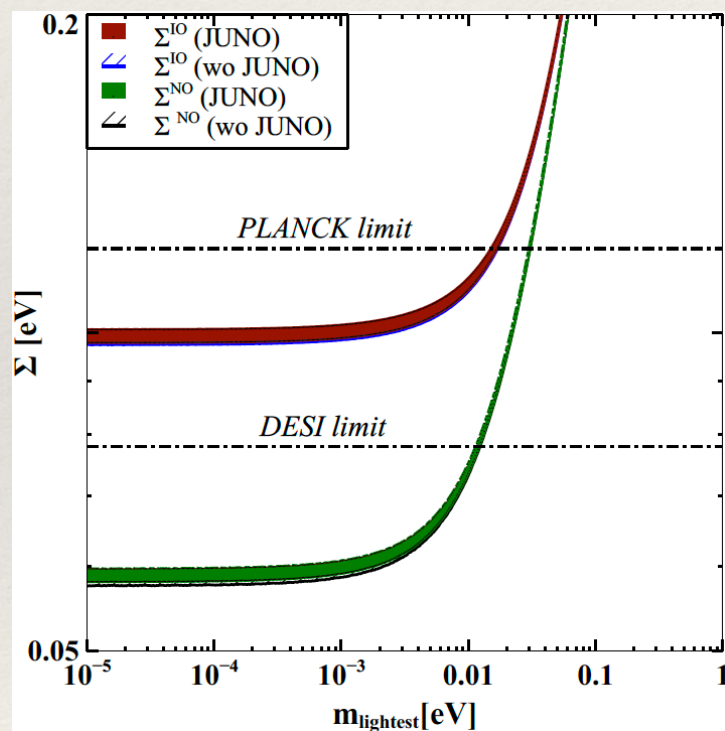
Ghosh, Ghoshal, Goswami, Nath, Raut, PRD 2015

Combination of disappearance and appearance channels can give octant sensitivity

Absolute neutrino mass

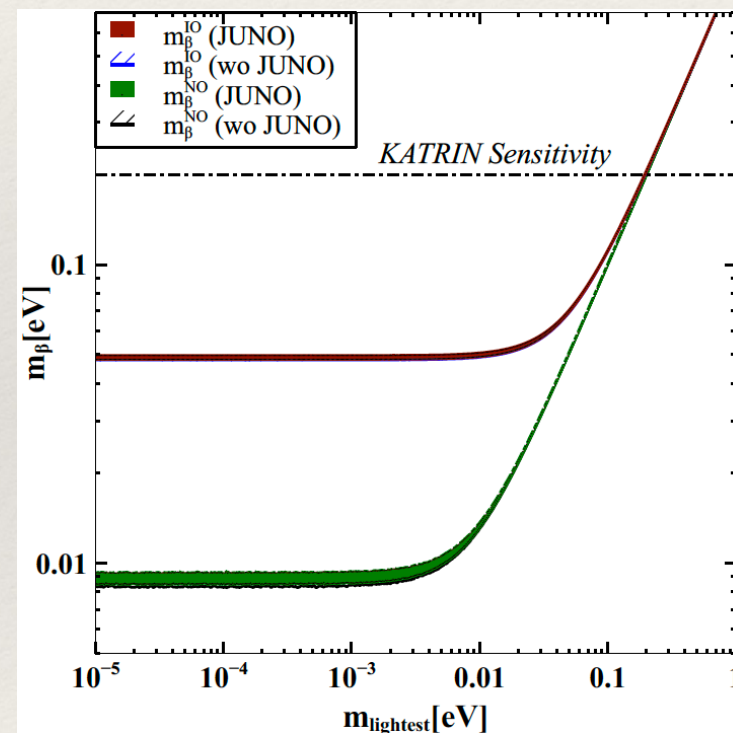
Cosmology

$$\Sigma = m_1 + m_2 + m_3$$



β - Decay

$$m_\beta^2 = \Sigma U_{ei}^2 m_i^2$$



Neutrino less double beta decay

$$m_{\beta\beta} = \Sigma |U_{ei}^2 m_i^2|$$

