

Overview of neutrino mixing

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Erice: INTERNATIONAL SCHOOL OF NUCLEAR PHYSICS, 47th COURSE



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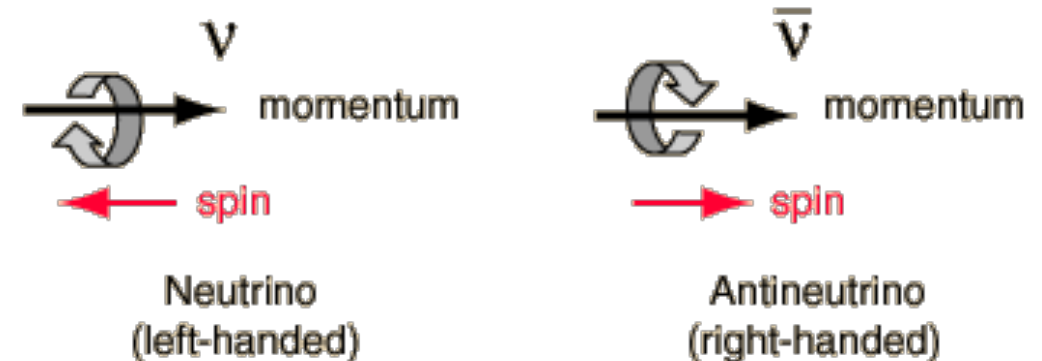
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Neutrinos in the Standard Model

- ♦ The SM only contains **LH neutrinos** (and RH antineutrinos): no $SU(2)_L$ RH neutrinos



- ♦ Only neutral fundamental fermion: **Dirac** or **Majorana** nature?
- ♦ No mass term for neutrinos can be built with the content of the SM:

Dirac mass term

$$m\bar{\nu}_R\nu_L$$



Majorana mass term

$$\frac{1}{2}m\nu_L^T\mathcal{C}^\dagger\nu_L$$



Lowest dim mass term

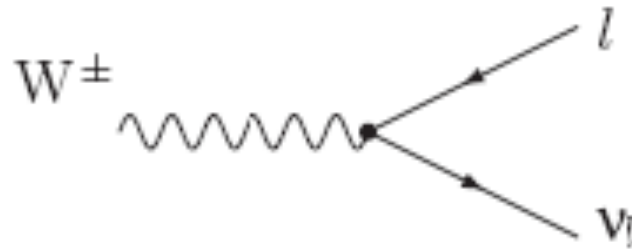
$$\frac{g}{\Lambda}(L_L^T\sigma_2\phi)\mathcal{C}^\dagger(\phi^T\sigma_2L_L)$$



Neutrinos are strictly massless in the Standard Model!

Neutrino interactions in the SM

Charged Current (CC):



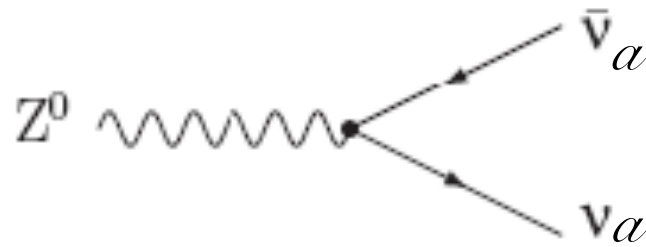
$$W^- \rightarrow l_{\alpha}^{-} + \bar{\nu}_{\alpha}$$

$$W^+ \rightarrow l_{\alpha}^{+} + \nu_{\alpha}$$

$$(\alpha = e, \mu, \tau)$$

$$\mathcal{L}_{\text{CC}} = -\frac{g}{\sqrt{2}} \sum_{\alpha} \bar{\nu}_{\alpha L} \gamma^{\mu} l_{\alpha L} W_{\mu} + \text{h.c.}$$

Neutral Current (NC):



$$Z^0 \rightarrow \nu_{\alpha} \bar{\nu}_{\alpha}$$

$$\mathcal{L}_{\text{NC}} = -\frac{g}{2 \cos \theta_W} \sum_{\alpha} \bar{\nu}_{\alpha L} \gamma^{\mu} \nu_{\alpha L} Z_{\mu}^0$$

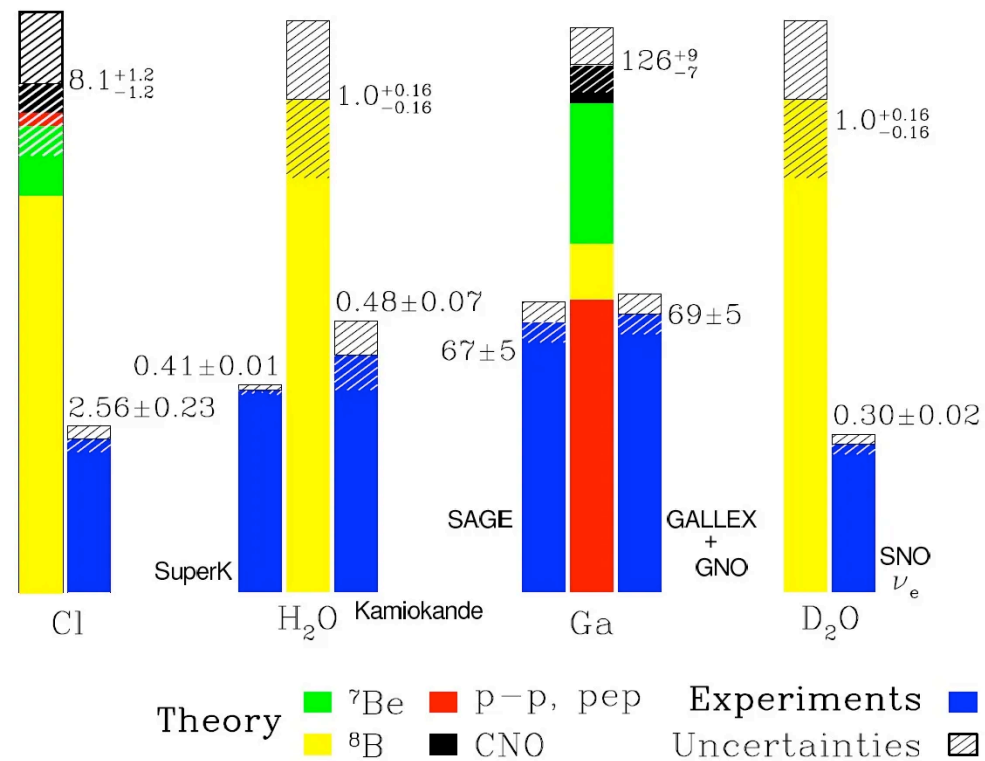
in the SM, only LH neutrinos and RH antineutrinos participate in weak interactions

♦ Interactions conserve total Lepton Number L : $L(l^-) = L(\nu) = -L(l^+) = -L(\bar{\nu}) = 1$

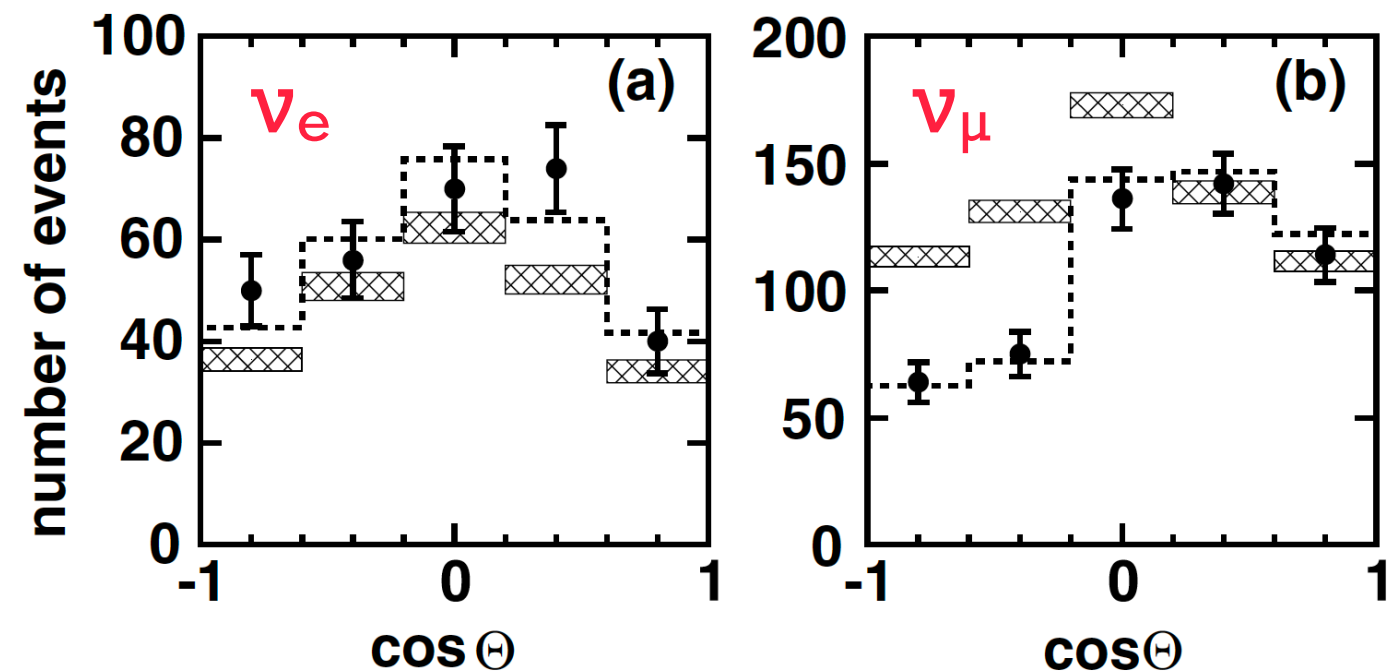
♦ Family lepton numbers L_e, L_{μ}, L_{τ} are also conserved.

Neutrino anomalies

Solar neutrino problem (60's)



Atmospheric neutrino anomaly (80's)



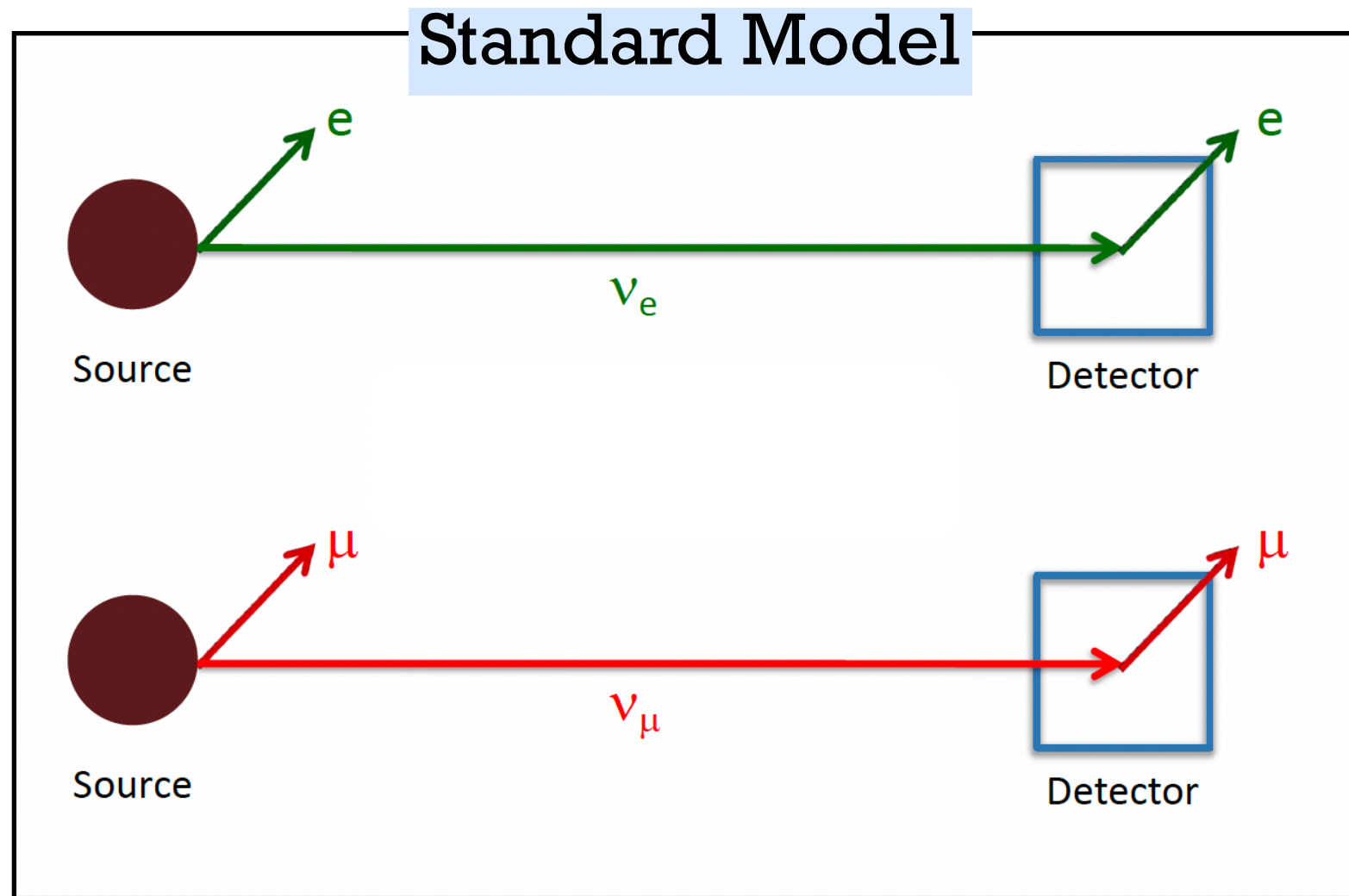
$$\nu_e \rightarrow \nu_\mu, \nu_\tau$$



$$\nu_\mu \rightarrow \nu_\tau$$

2015: Nobel Prize

Neutrino oscillations

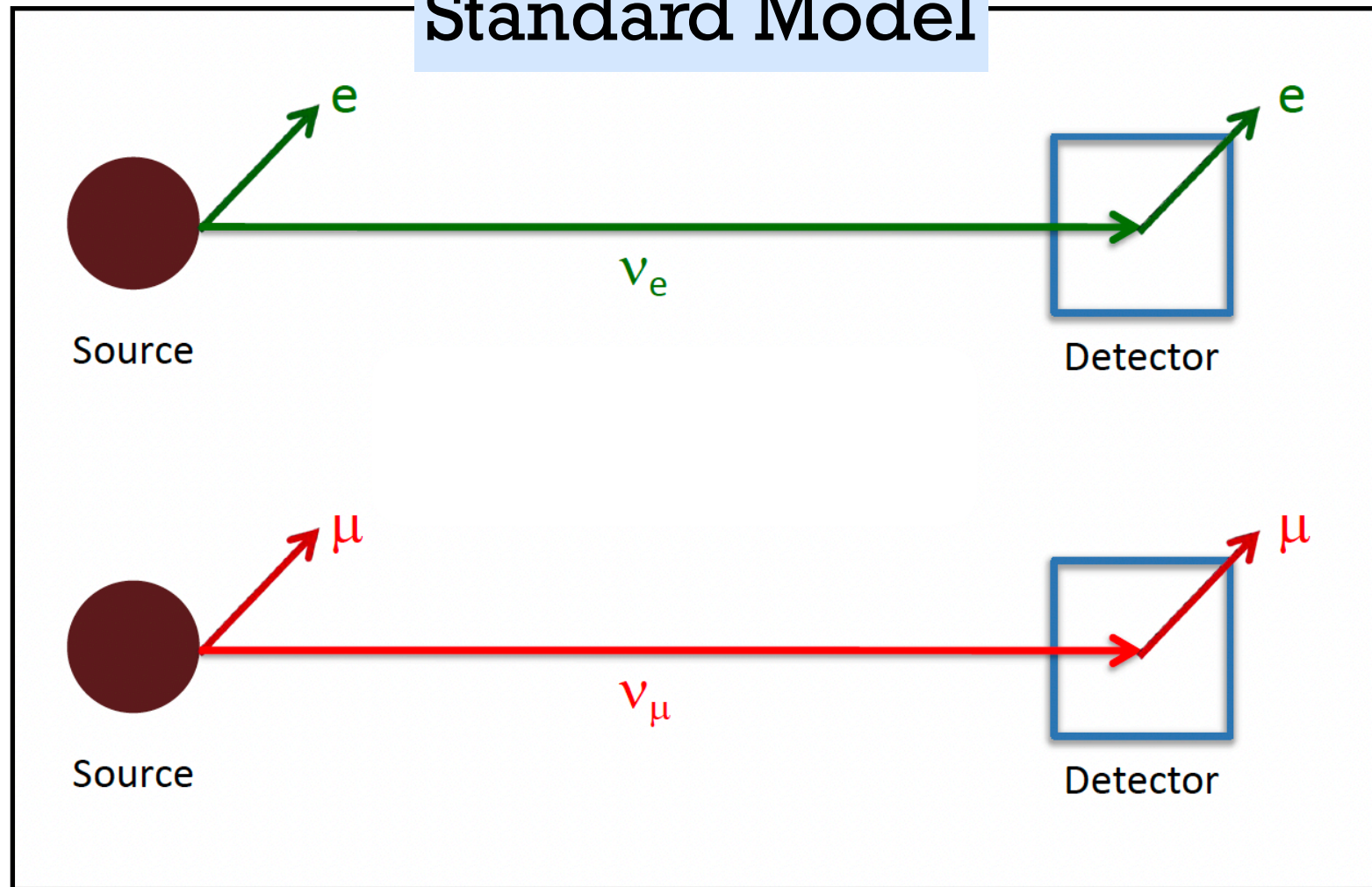


However

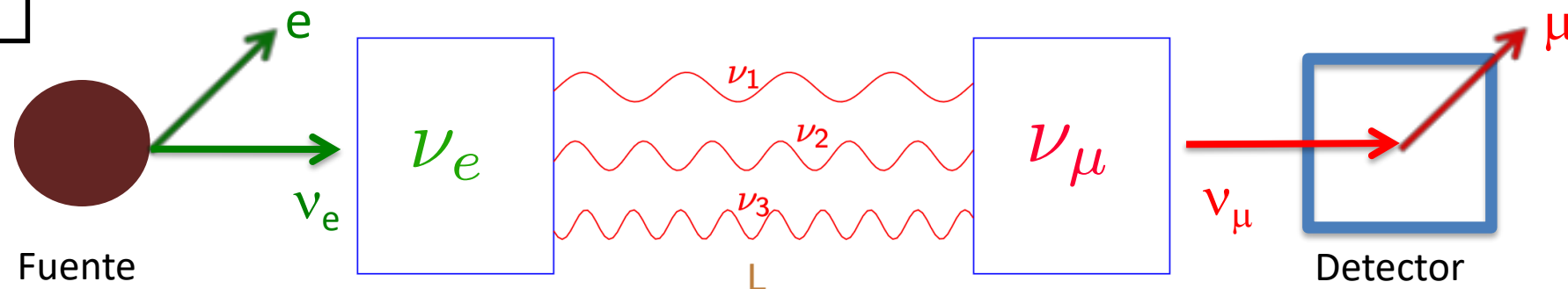


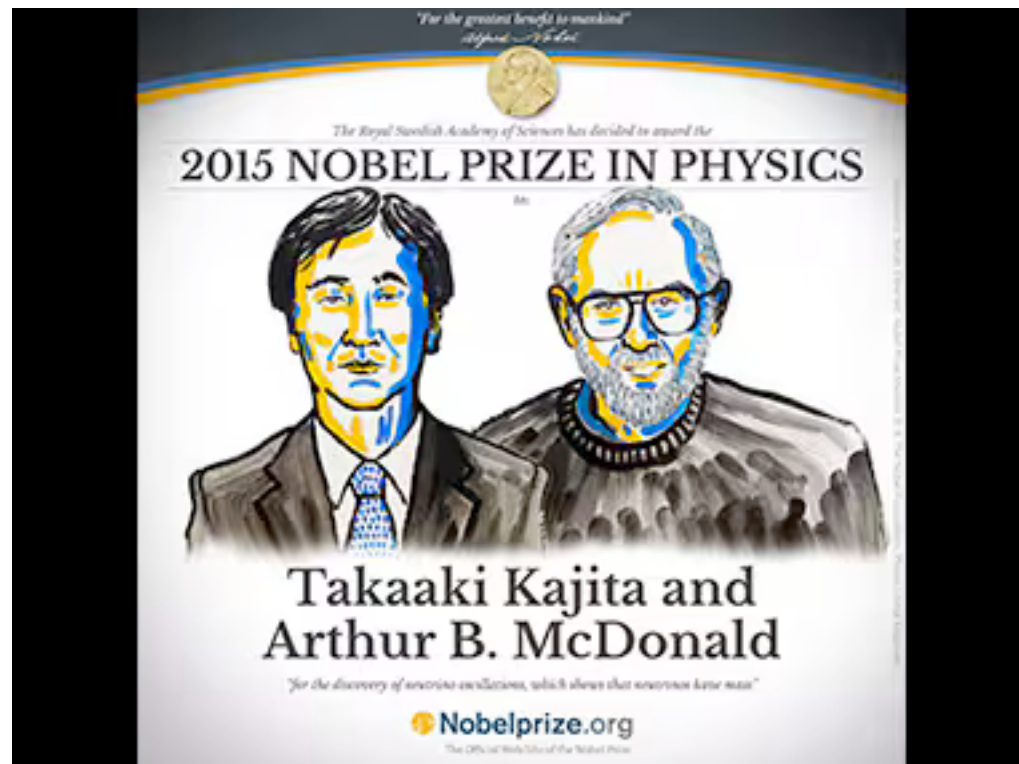
Neutrino oscillations

Standard Model

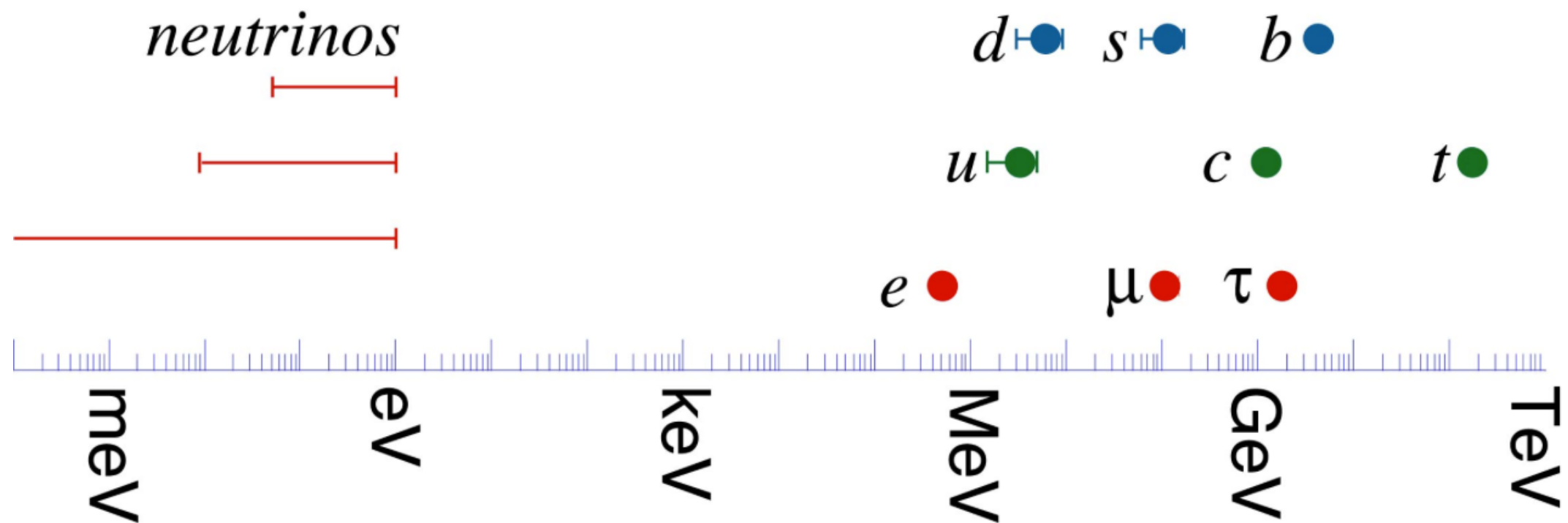


$$\nu_{\alpha L} = \sum_k U_{\alpha k} \nu_{k L}$$





“For the discovery of neutrino oscillations, which shows that
neutrinos have mass”

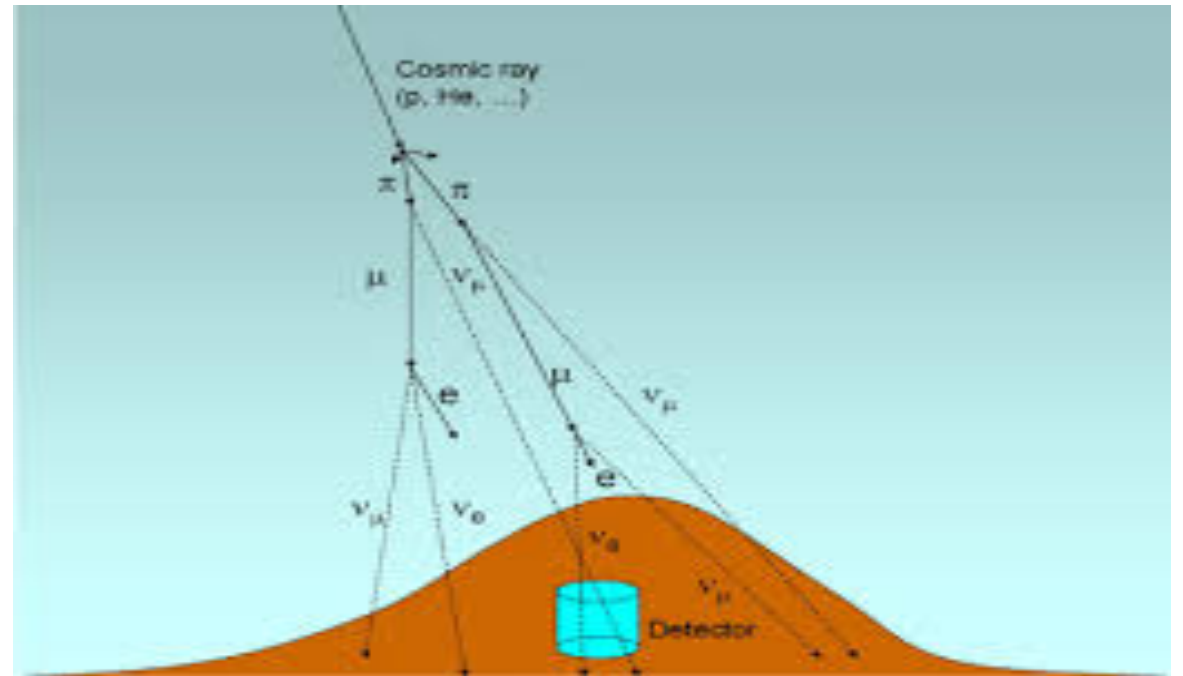


Neutrino oscillations

Solar neutrinos



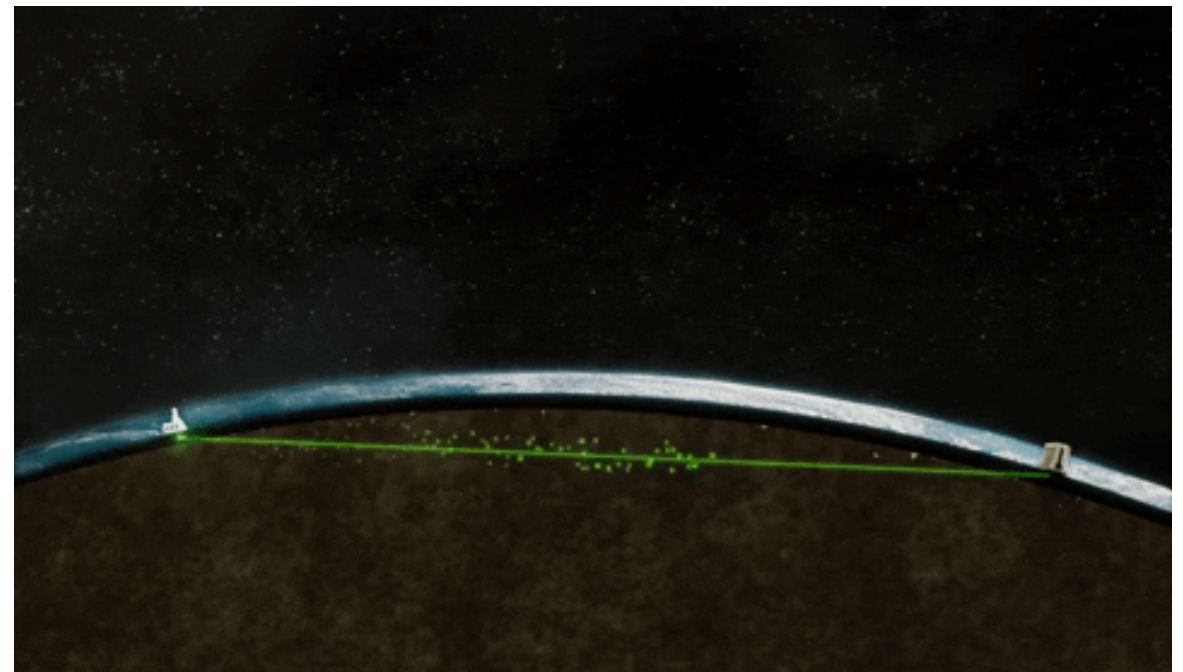
Atmospheric neutrinos



Reactor neutrinos



Accelerator neutrinos



The three-flavour ν picture

neutrino mixing

$$U = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos \theta_{23} & \sin \theta_{23} \\ 0 & -\sin \theta_{23} & \cos \theta_{23} \end{pmatrix} \begin{pmatrix} \cos \theta_{13} & 0 & \sin \theta_{13} e^{-i\delta} \\ 0 & 1 & 0 \\ -\sin \theta_{13} e^{i\delta} & 0 & \cos \theta_{13} \end{pmatrix} \begin{pmatrix} \cos \theta_{12} & \sin \theta_{12} & 0 \\ -\sin \theta_{12} & \cos \theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} e^{i\alpha} & 0 & 0 \\ 0 & e^{i\beta} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

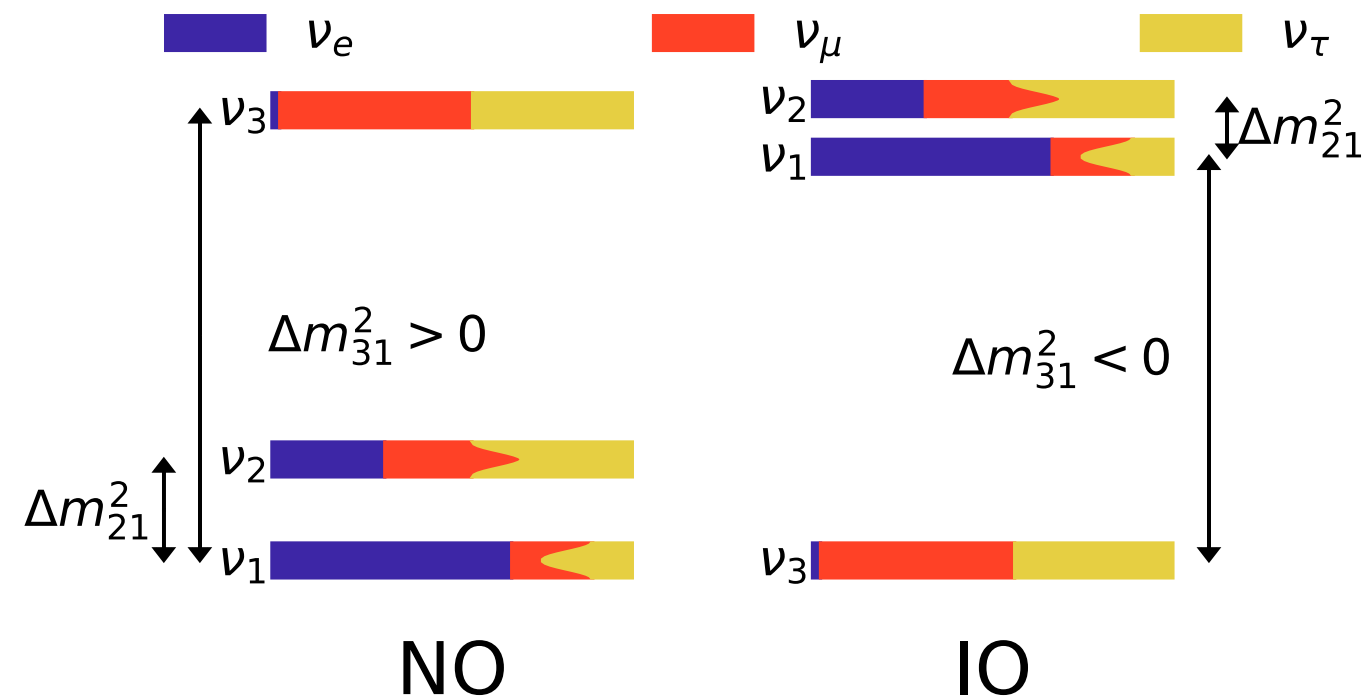
neutrino mass spectrum

- ✓ 3 mixing angles: θ_{12} , θ_{23} , θ_{13}
- ✓ 3 CP phases: 1 Dirac + 2 Majorana
- ✓ 3 masses: m_1 , m_2 , m_3

⇒ absolute neutrino mass: m_0

⇒ two mass splittings:

$$\Delta m_{21}^2, \Delta m_{31}^2$$



de Salas et al, 2018

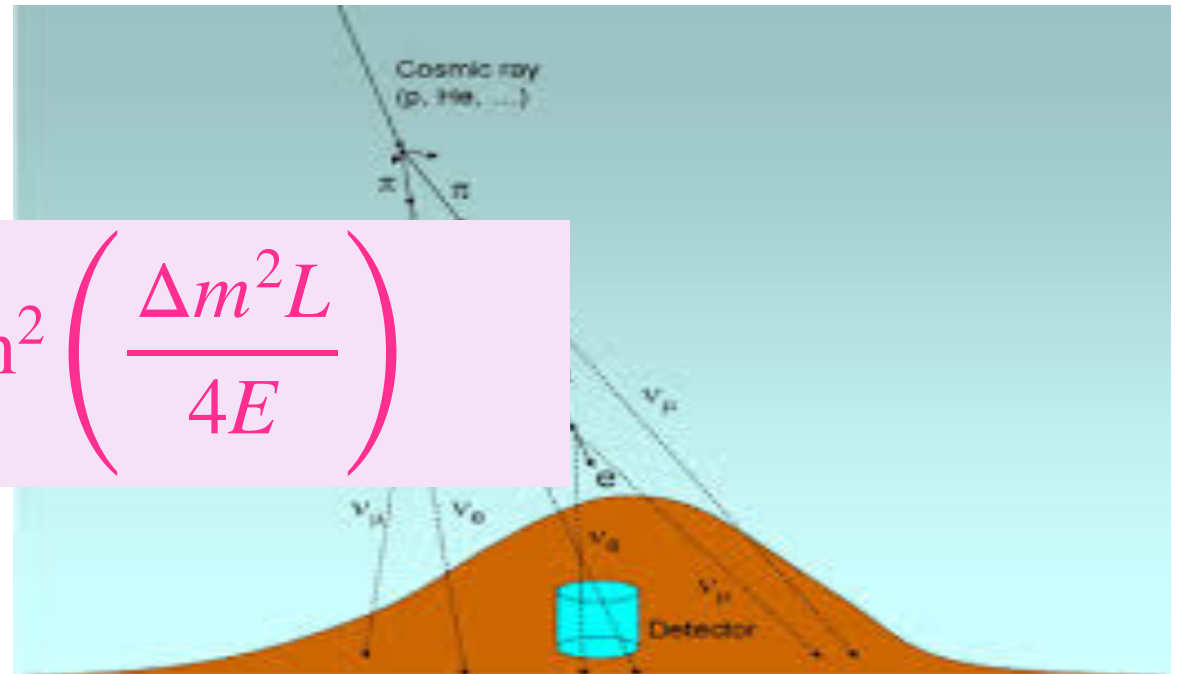
Neutrino oscillations

Solar sector: $\theta_{12}, \Delta m^2_{21}$



$$P_{\alpha\beta} = \sin^2 2\theta \sin^2 \left(\frac{\Delta m^2 L}{4E} \right)$$

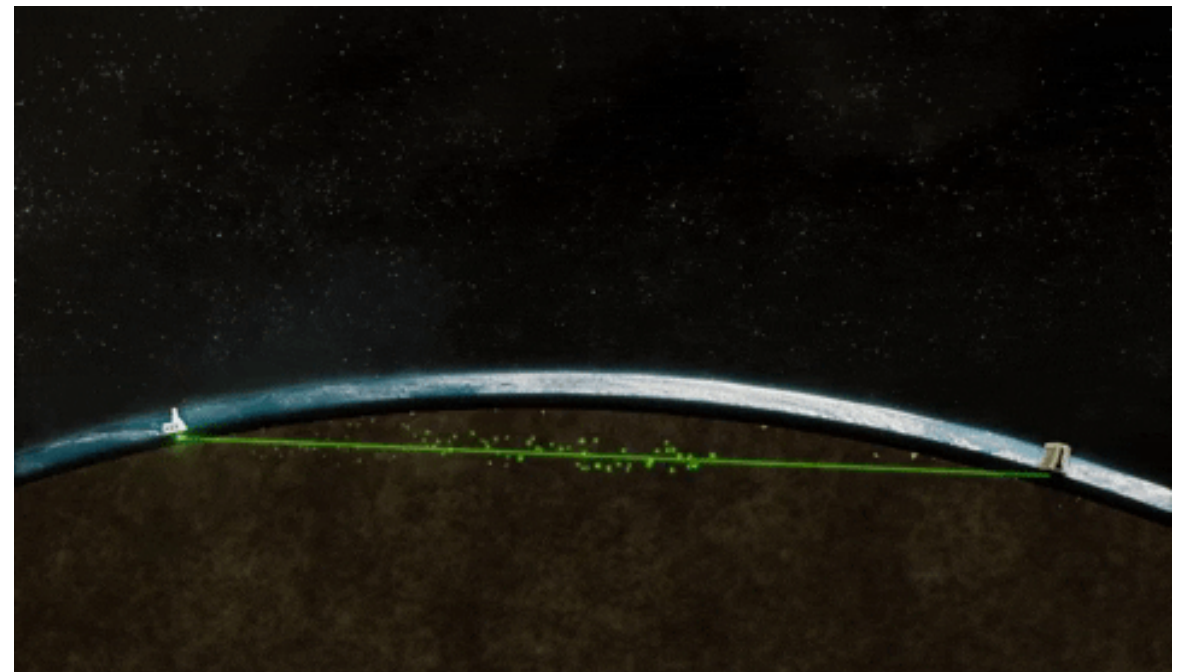
Atmospheric sector: $\theta_{23}, \Delta m^2_{31}$



Reactor sector (SBL): $\theta_{13}, \Delta m^2_{31}$



Accelerator sector: $\theta_{23}, \Delta m^2_{31}$



Three-neutrino oscillations

$$P(\nu_\alpha \rightarrow \nu_\beta) = \delta_{\alpha\beta} - 4 \sum_{i>j} \text{Re}(U_{\alpha i}^* U_{\alpha j} U_{\beta i} U_{\beta j}^*) \sin^2 \left(\frac{\Delta m_{ij}^2 L}{4E} \right) + 2 \sum_{i>j} \text{Im}(U_{\alpha i}^* U_{\alpha j} U_{\beta i} U_{\beta j}^*) \sin \left(\frac{\Delta m_{ij}^2 L}{2E} \right)$$

$$\begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

atmos + accel

$(\nu_\mu \rightarrow \nu_\tau)$

SBL reac + accel

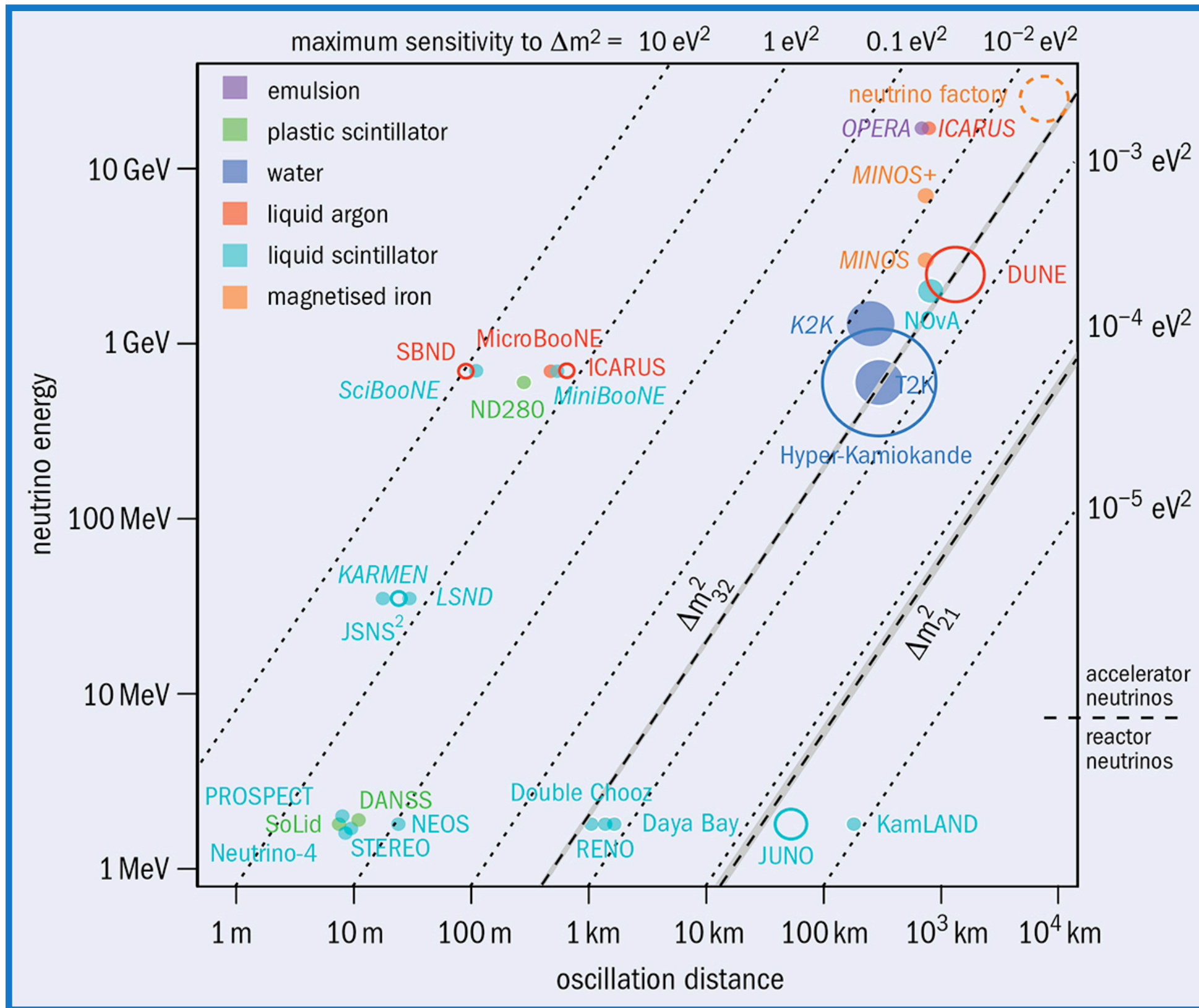
$(\nu_e \rightarrow \nu_e \text{ and } \nu_\mu \rightarrow \nu_e)$

solar + LBL reac

$(\nu_e \rightarrow \nu_e)$

Maximal
sensitivity at

$$\frac{\Delta m_{ij}^2 L}{4E} \sim \frac{\pi}{2} = 1.27 \frac{\Delta m_{ij}^2 [eV^2] L[km]}{E[GeV]}$$



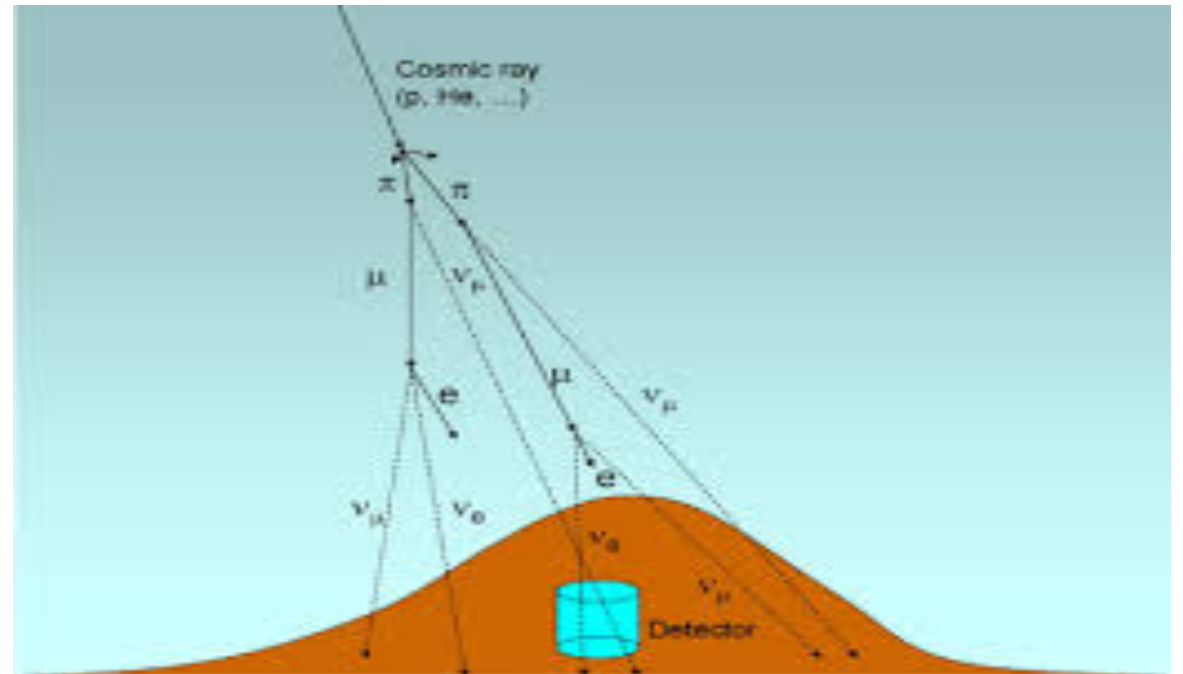
M Rayner, CERN Courier, 2020

Neutrino oscillations

Solar sector: θ_{12} , θ_{13} , Δm_{21}^2



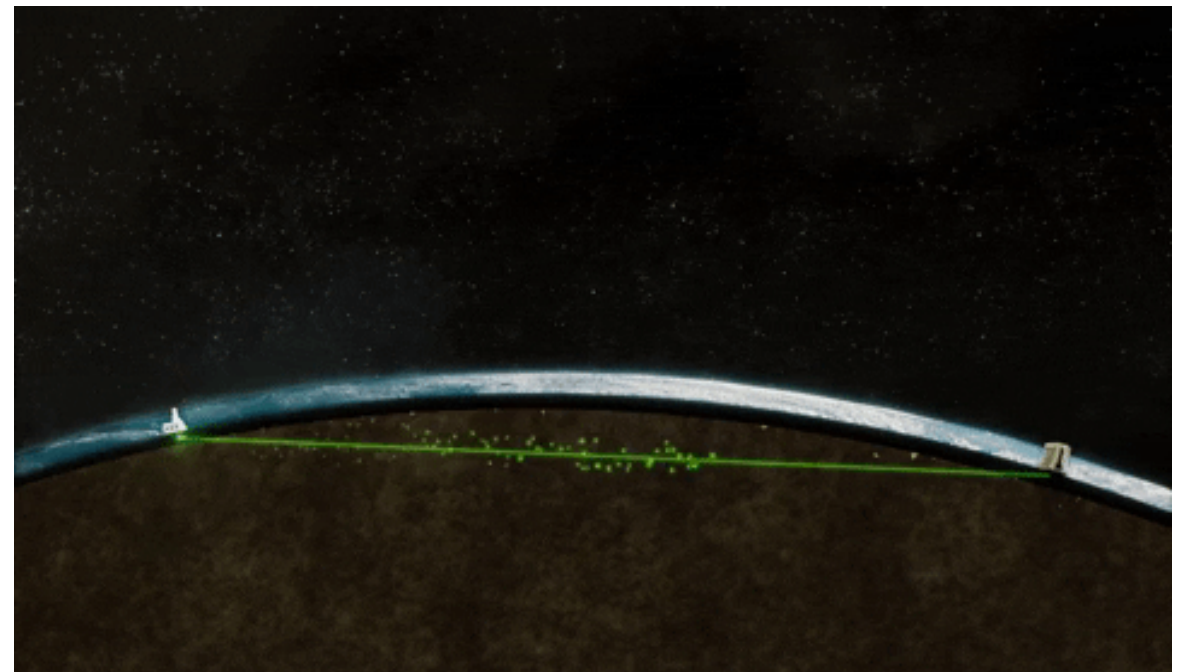
Atmospheric sector: θ_{23} , θ_{13} , Δm_{31}^2 , δ



Reactor sector (SBL): θ_{13} , Δm_{31}^2



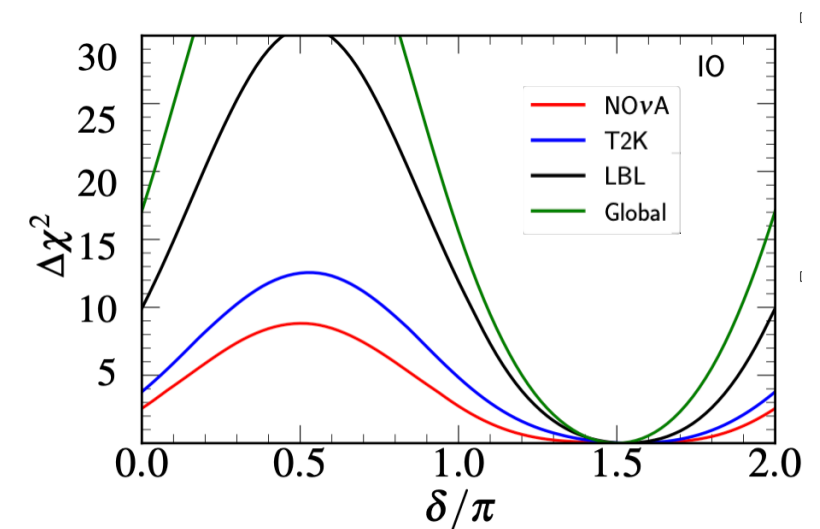
Accelerator sector: θ_{23} , θ_{13} , Δm_{31}^2 , δ



Global analysis to ν oscillations

1

Compensate low statistics in
subleading oscillation effects
searches



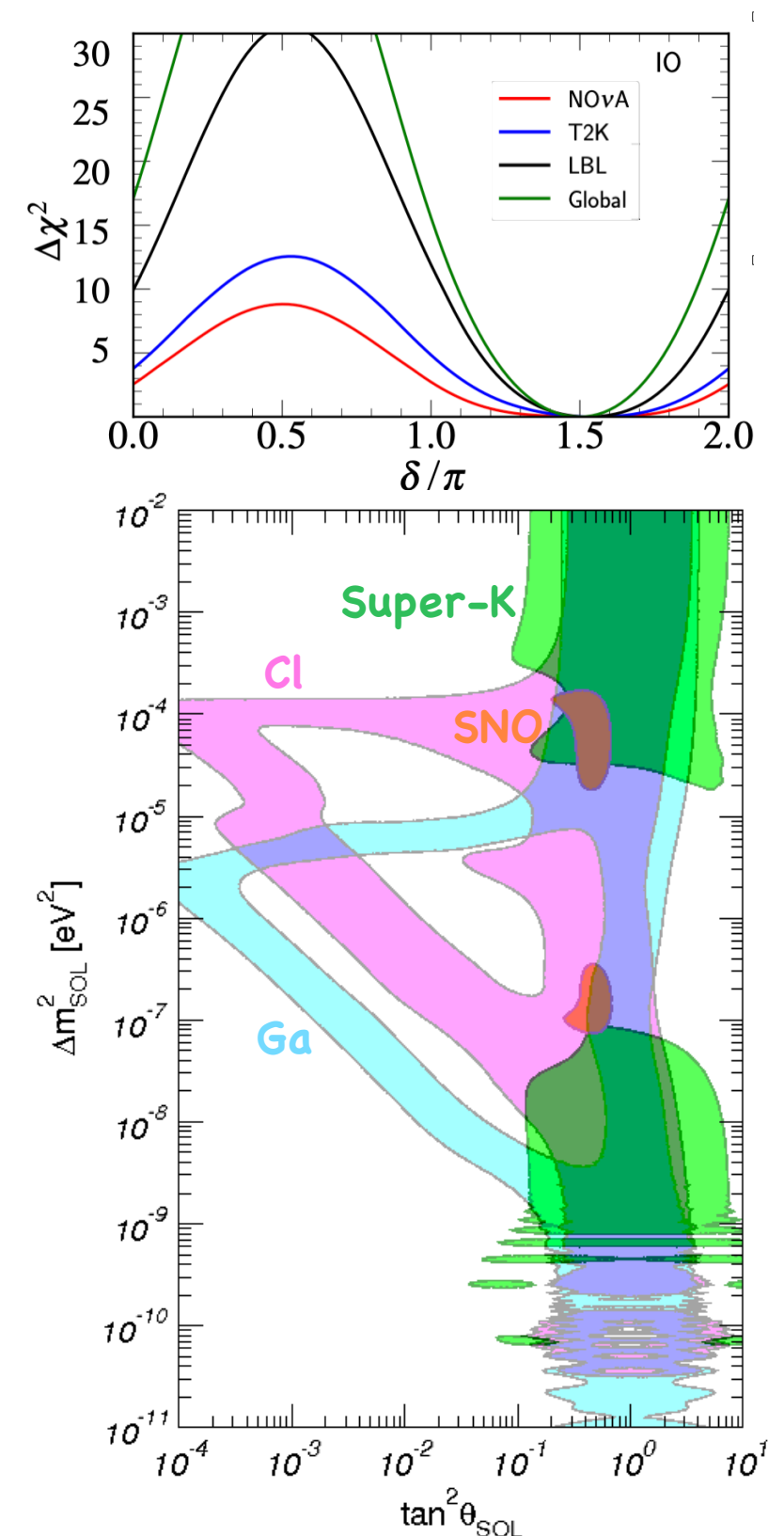
Global analysis to ν oscillations

1

Compensate low statistics in
subleading oscillation effects
searches

2

Exploit synergies among
experiments



Global analysis to ν oscillations

1

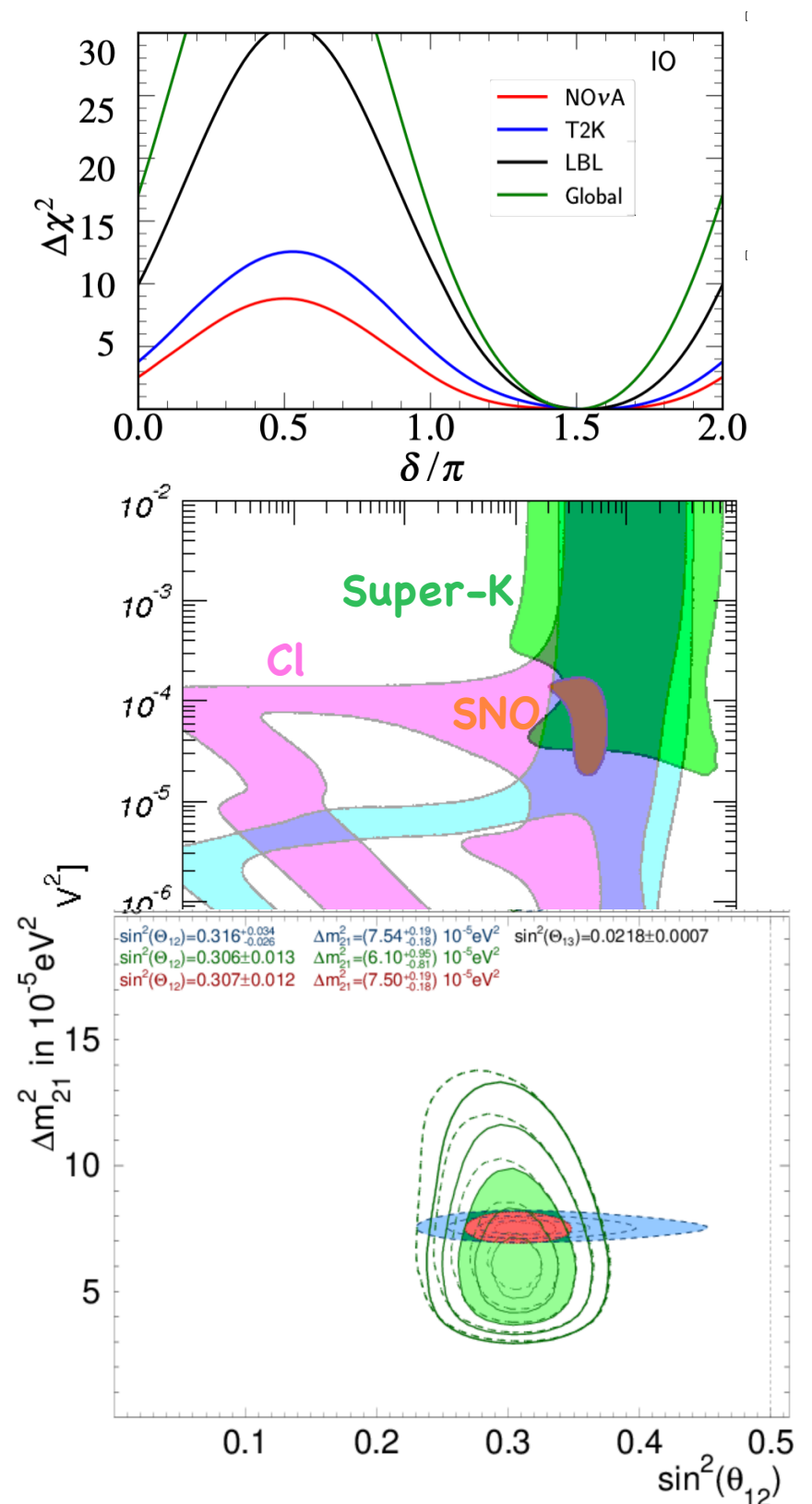
Compensate low statistics in subleading oscillation effects searches

2

Exploit synergies among experiments

3

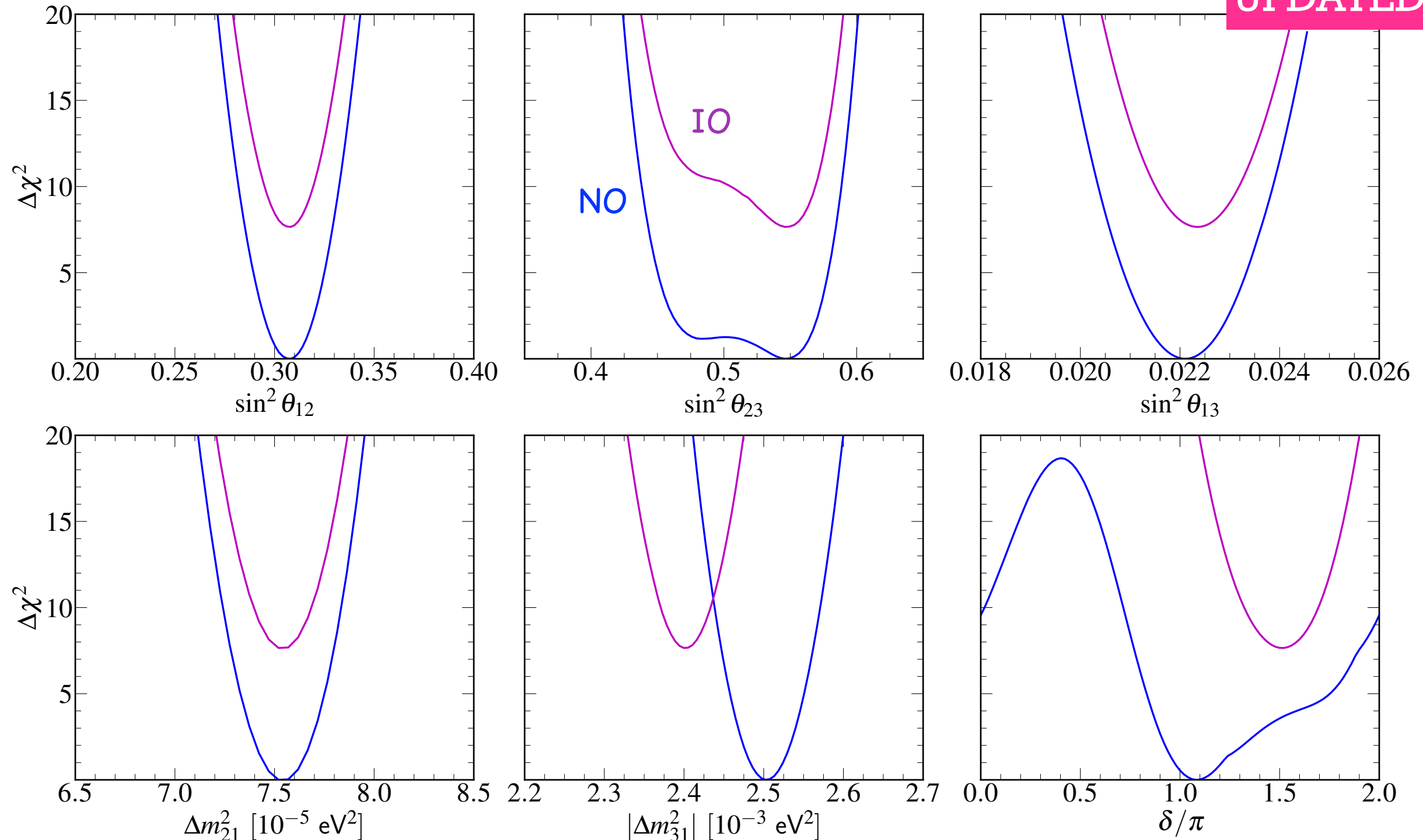
Reveal tensions among data



Global fit to ν oscillation parameters

de Salas et al, **JHEP 02 (2021) 071** <https://globalfit.astroparticles.es/>

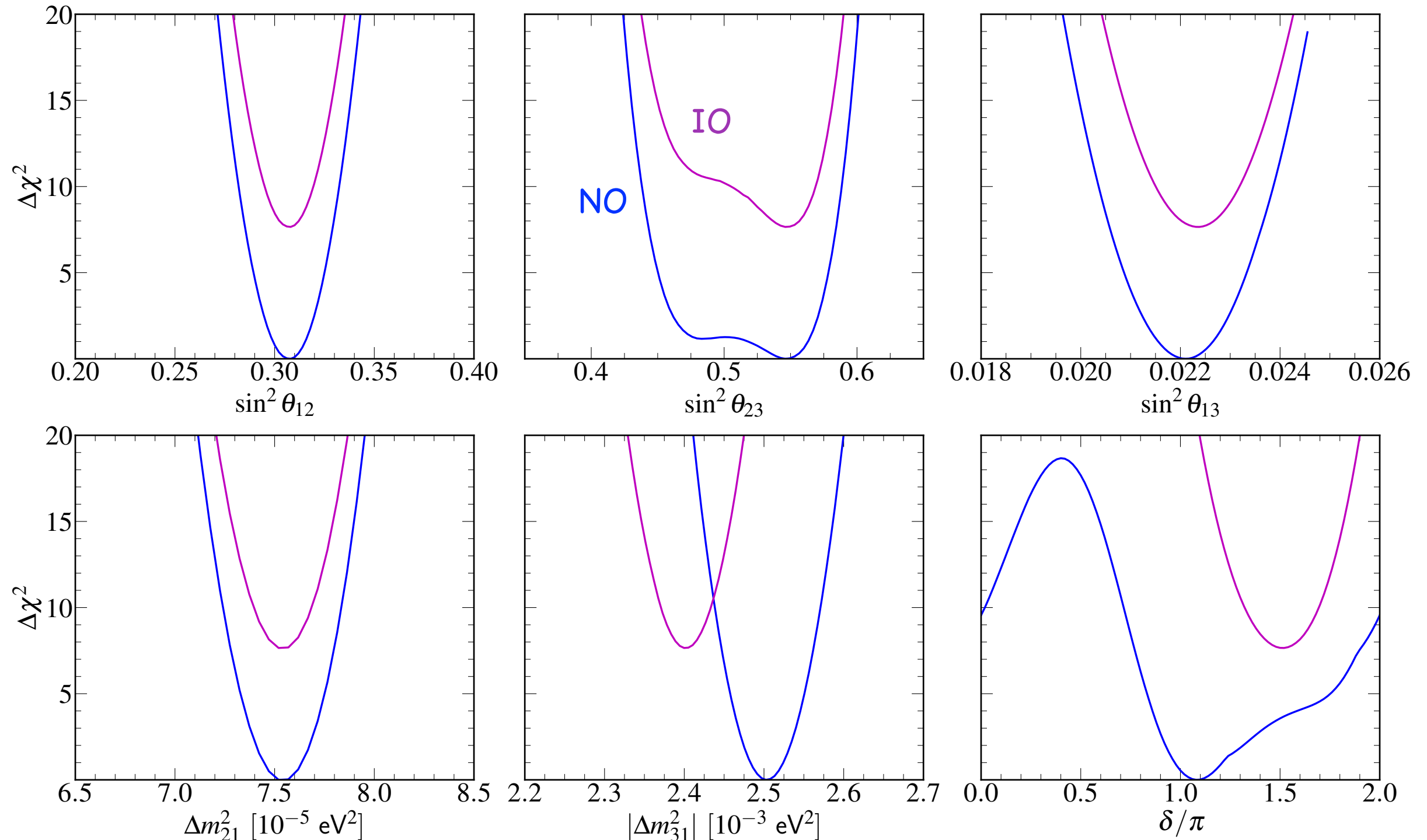
UPDATED 2026



See also NuFIT and Bari analyses

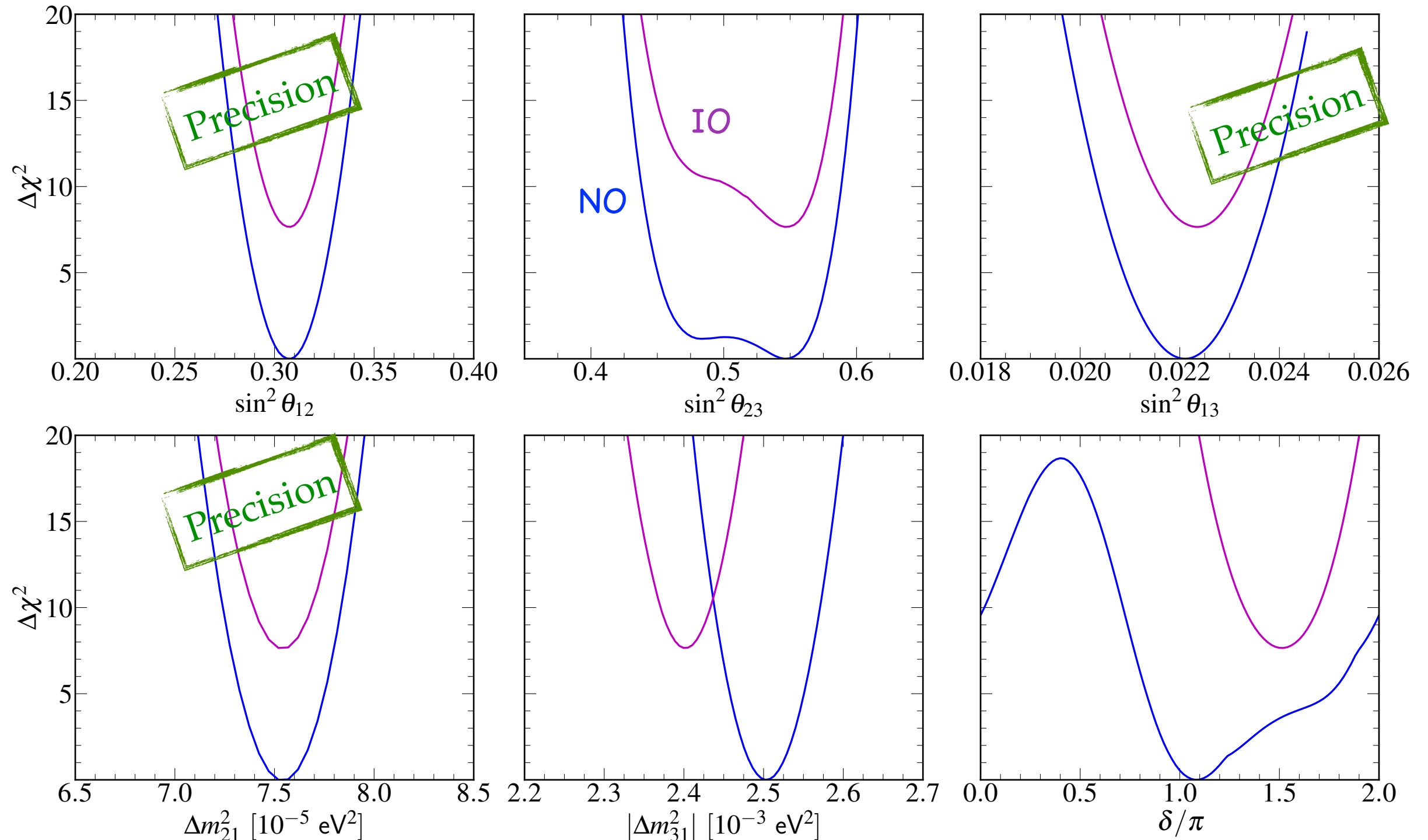
Global fit to ν oscillation parameters

de Salas et al, **JHEP 02 (2021) 071** <https://globalfit.astroparticles.es/>



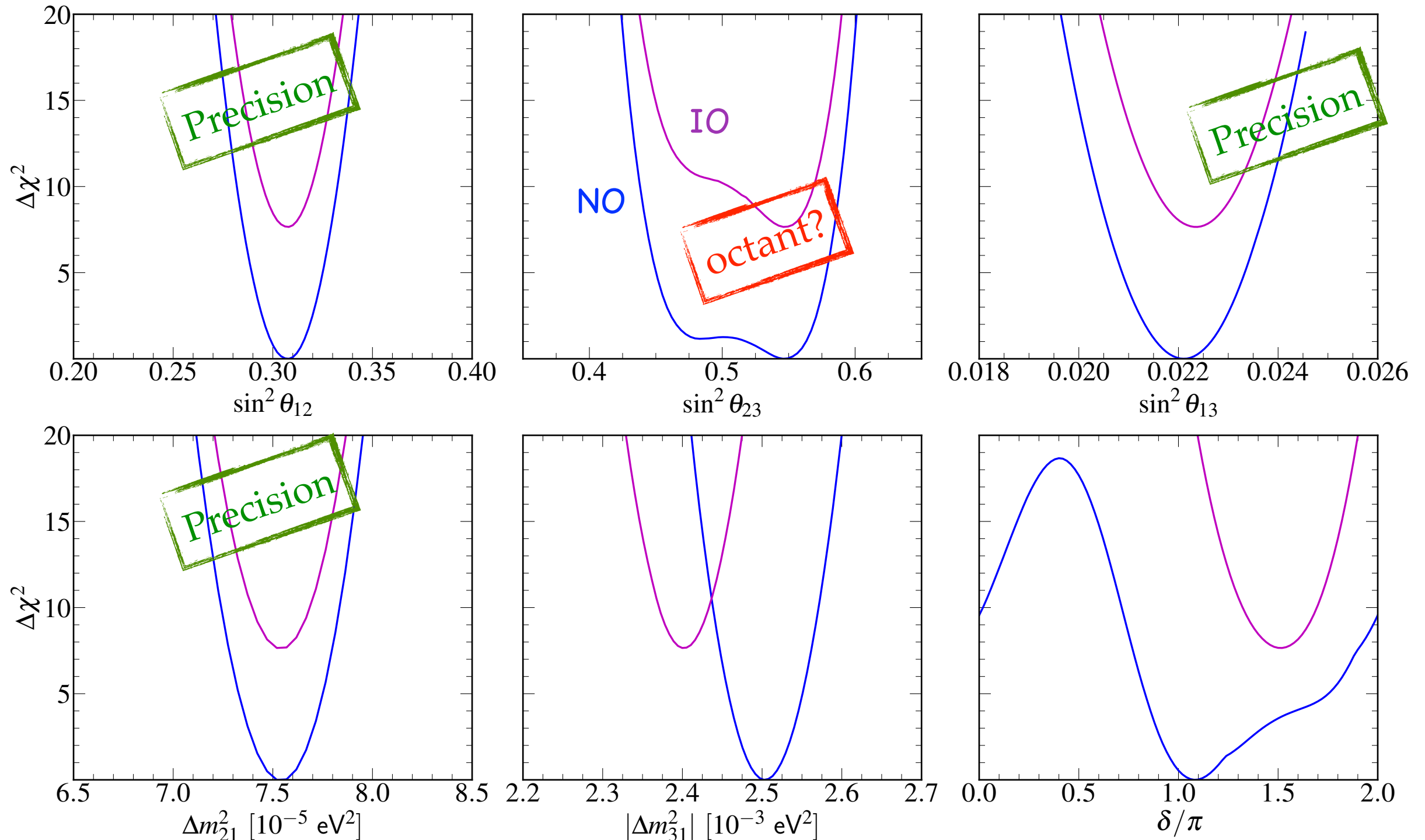
Global fit to ν oscillation parameters

de Salas et al, **JHEP 02 (2021) 071** <https://globalfit.astroparticles.es/>



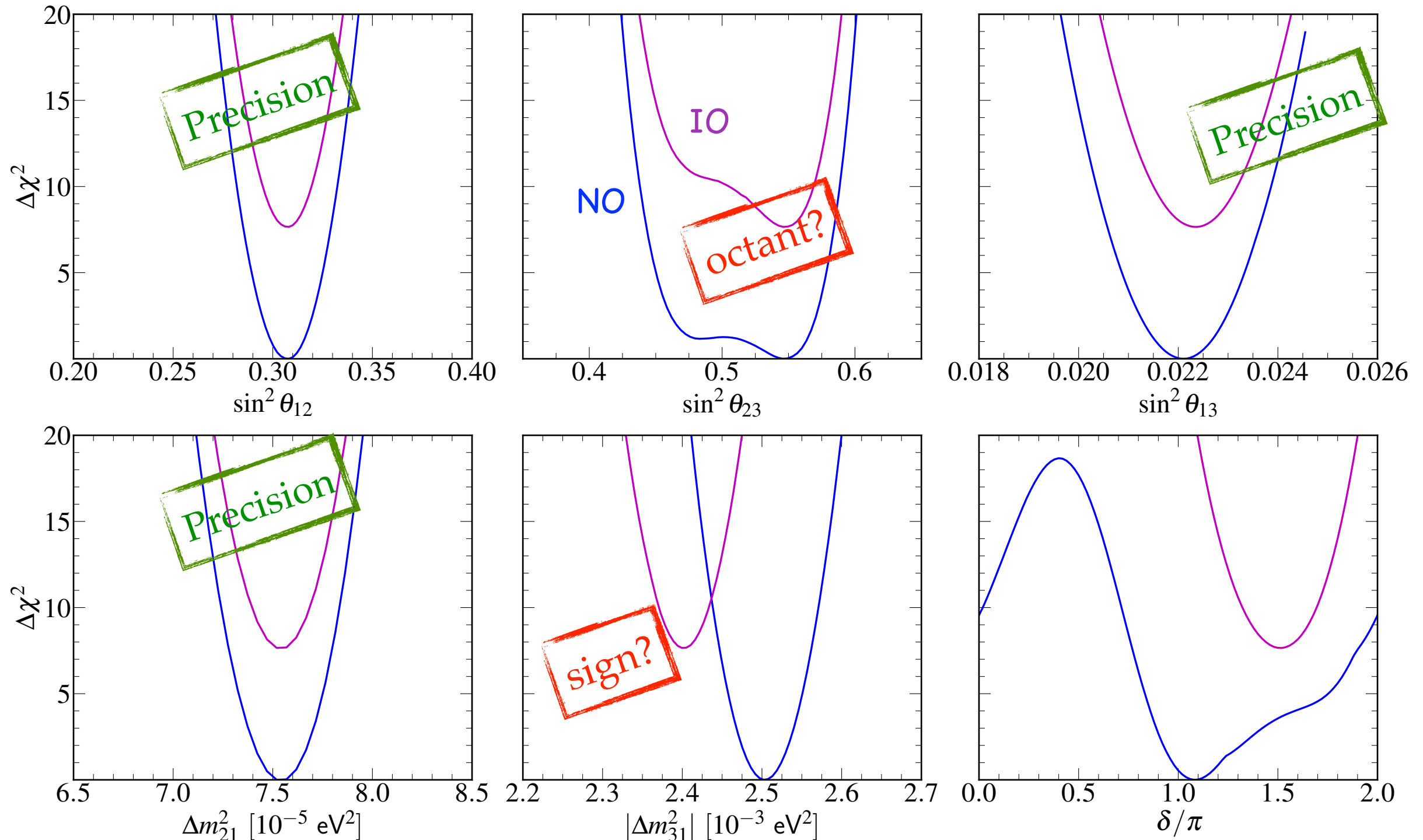
Global fit to ν oscillation parameters

de Salas et al, **JHEP 02 (2021) 071** <https://globalfit.astroparticles.es/>



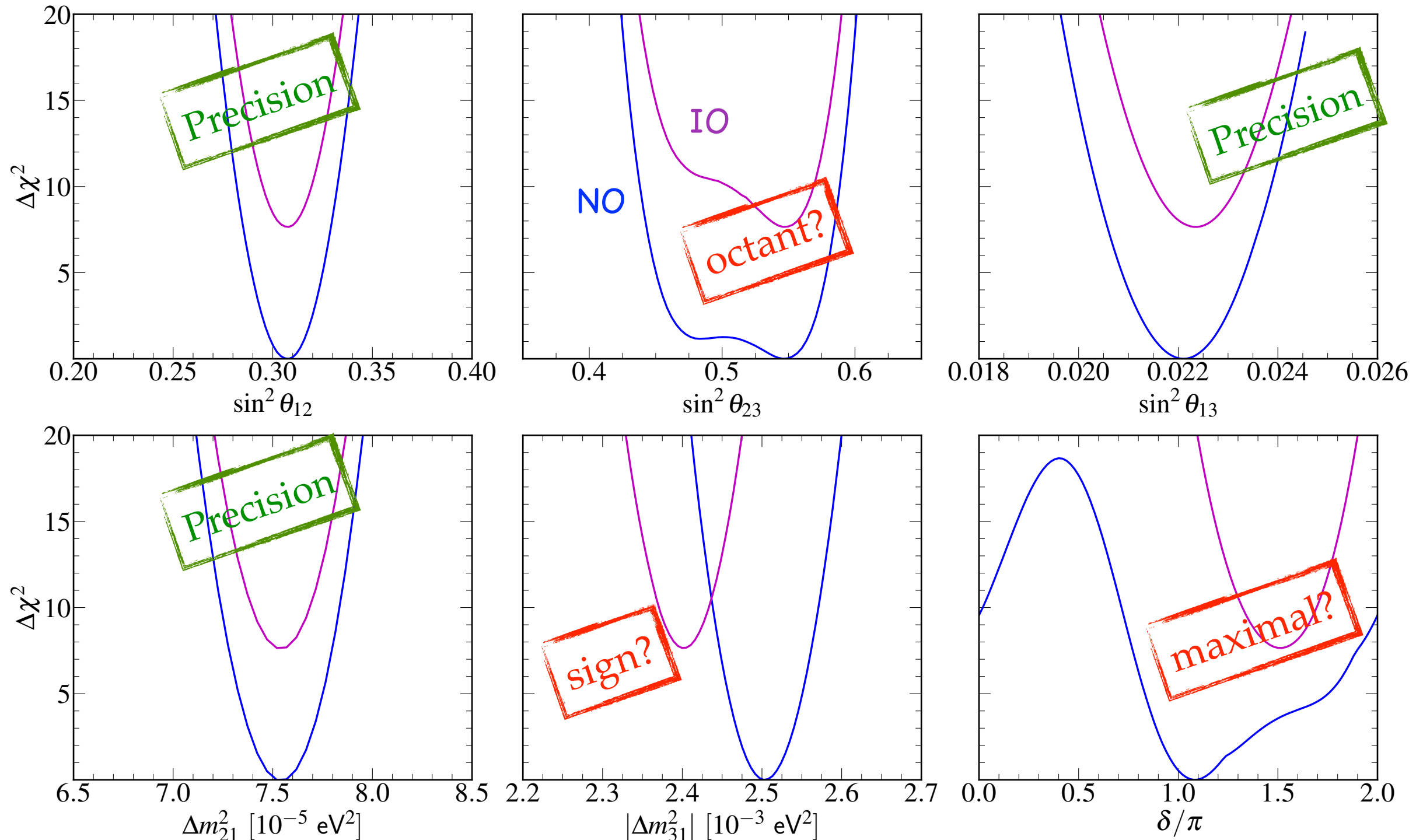
Global fit to ν oscillation parameters

de Salas et al, **JHEP 02 (2021) 071** <https://globalfit.astroparticles.es/>



Global fit to ν oscillation parameters

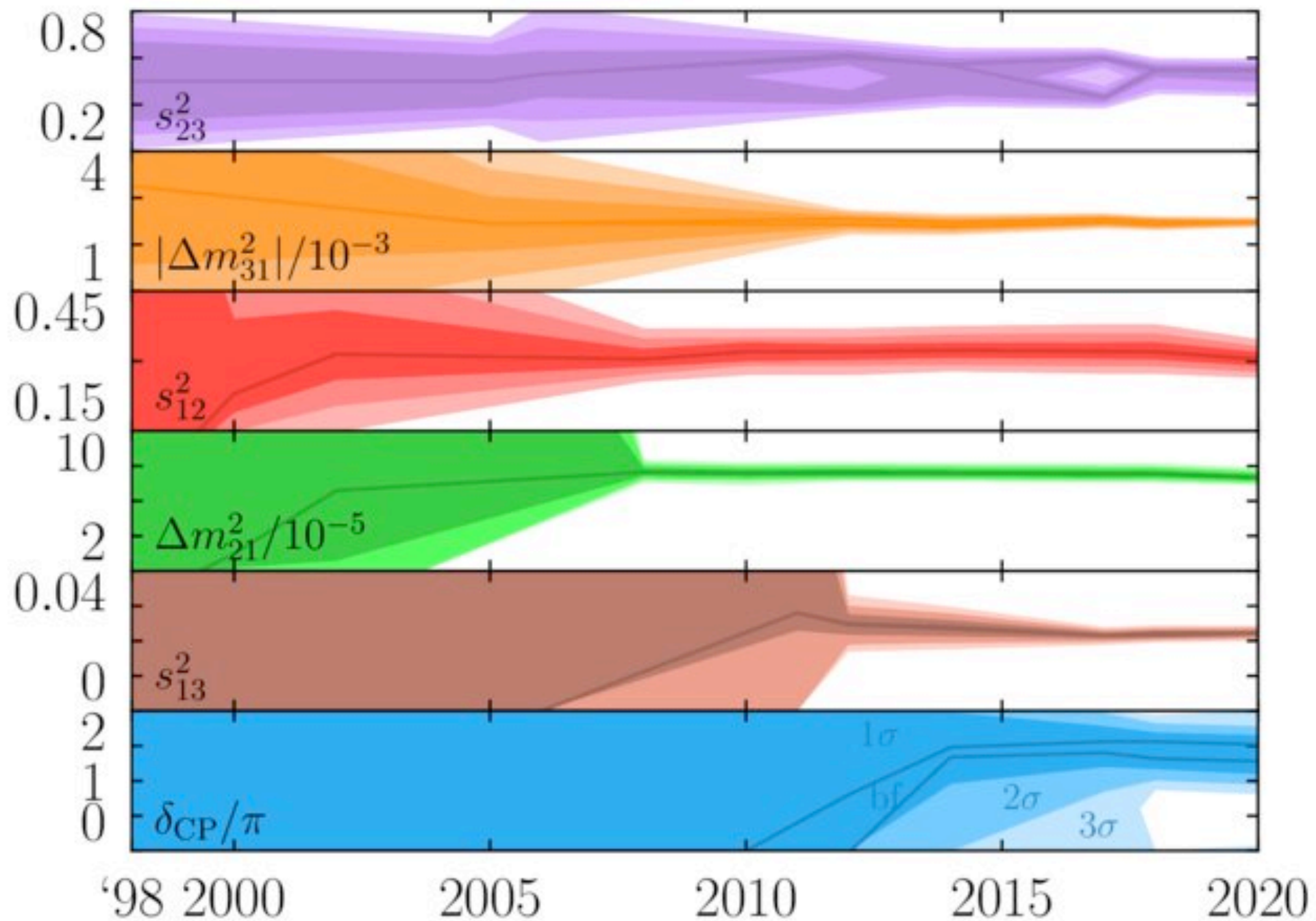
de Salas et al, **JHEP 02 (2021) 071** <https://globalfit.astroparticles.es/>



Global fit to ν oscillation parameters

			relative 1σ uncert	
parameter	best fit $\pm 1\sigma$	3σ range		
Δm_{21}^2 [10^{-5}eV^2]	$7.52^{+0.11}_{-0.07}$	7.26–7.82	1.2 %	
$ \Delta m_{31}^2 $ [10^{-3}eV^2] (NO)	2.50 ± 0.02	2.44–2.57	0.9 %	mass ordering?
$ \Delta m_{31}^2 $ [10^{-3}eV^2] (IO)	2.40 ± 0.02	2.34–2.46		
$\sin^2 \theta_{12}/10^{-1}$	$3.08^{+0.09}_{-0.07}$	2.83–3.31	2.6%	
$\sin^2 \theta_{23}/10^{-1}$ (NO)	$5.46^{+0.16}_{-0.19}$	4.40–5.87	4.5%	octant?
$\sin^2 \theta_{23}/10^{-1}$ (IO)	$5.46^{+0.15}_{-0.18}$	4.45–5.84		
$\sin^2 \theta_{13}/10^{-2}$ (NO)	2.21 ± 0.05	2.04–2.38	2.5%	
$\sin^2 \theta_{13}/10^{-2}$ (IO)	$2.24^{+0.05}_{-0.06}$	2.07–2.40		
δ/π (NO)	$1.08^{+0.13}_{-0.11}$	0.74–1.98	8-19%	maximal CP violation??
δ/π (IO)	$1.52^{+0.11}_{-0.13}$	1.15–1.85		

Three-neutrino oscillation parameters



Denton et al, Snowmass Neutrino Frontier: NF01 Report [arXiv:2212.00809]

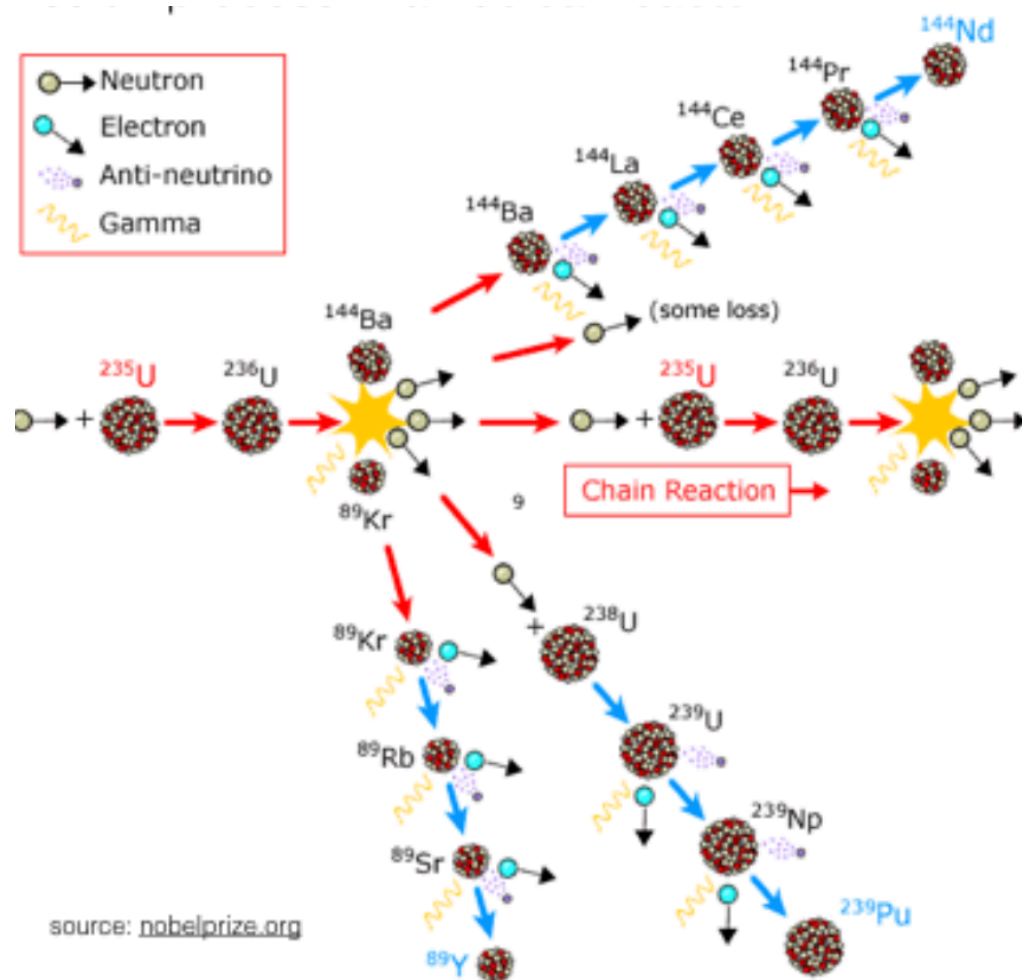
Neutrino oscillations

Reactor sector: θ_{13} , Δm^2_{31}

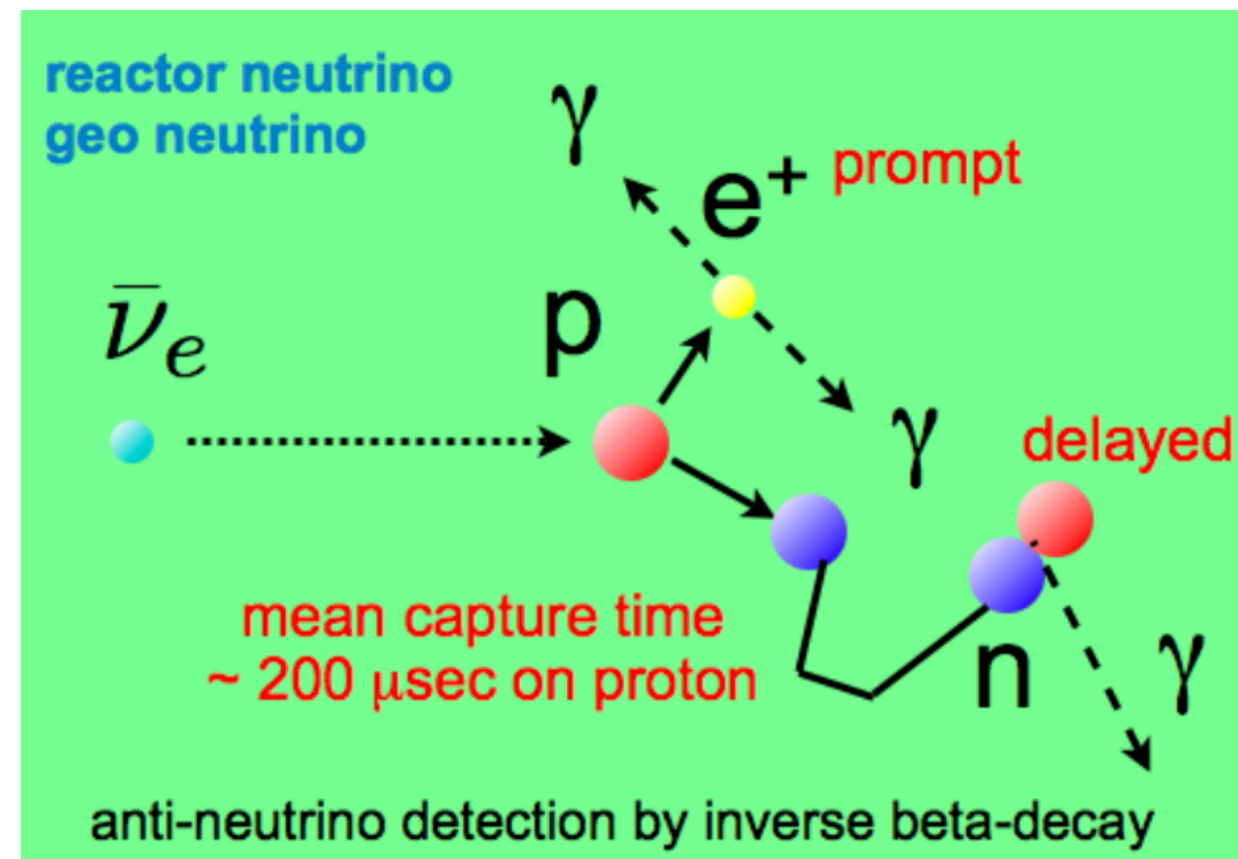


Reactor neutrinos

Production: fission processes in nuclear reactors

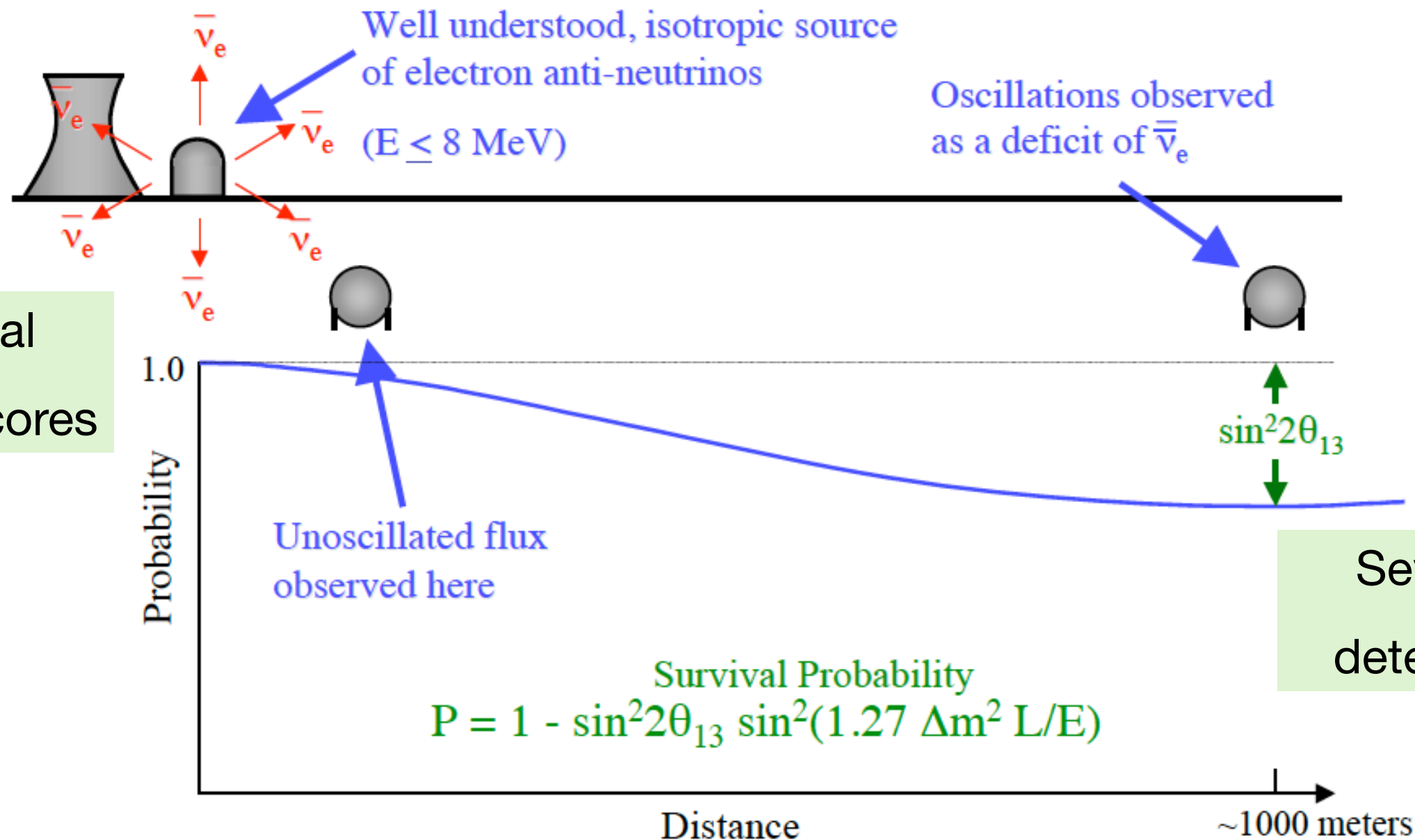


Detection: inverse beta decay



1 GW reactor: more than 10^{20} antineutrinos/s

SBL reactor experiments



$$L \sim 1 \text{ km: } \theta_{13}, |\Delta m^2_{31}| \sim \text{few } 10^{-3} \text{ eV}^2$$

oscillations in vacuum

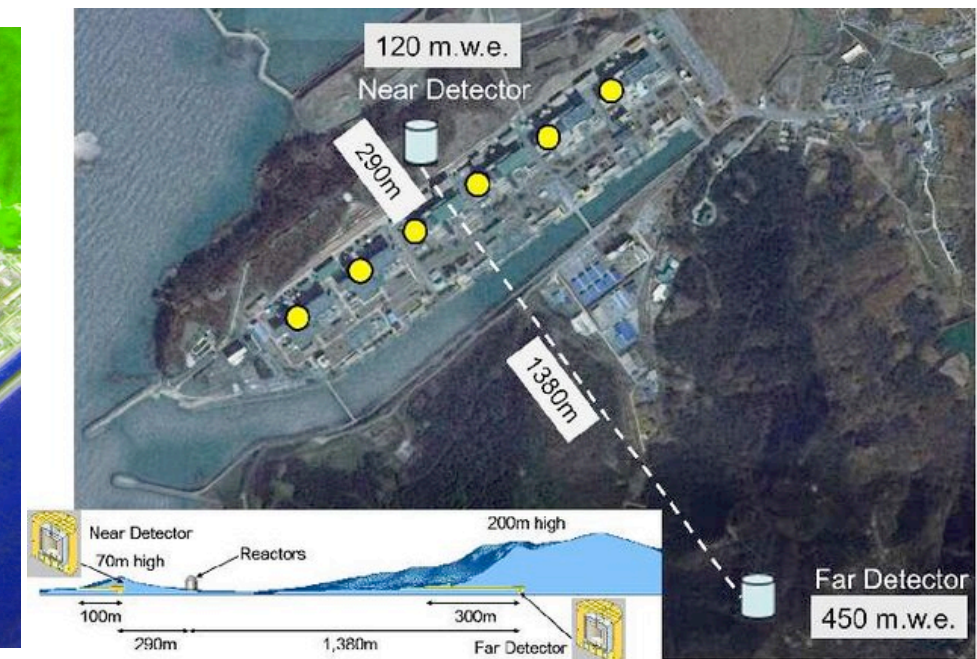
SBL reactor experiments



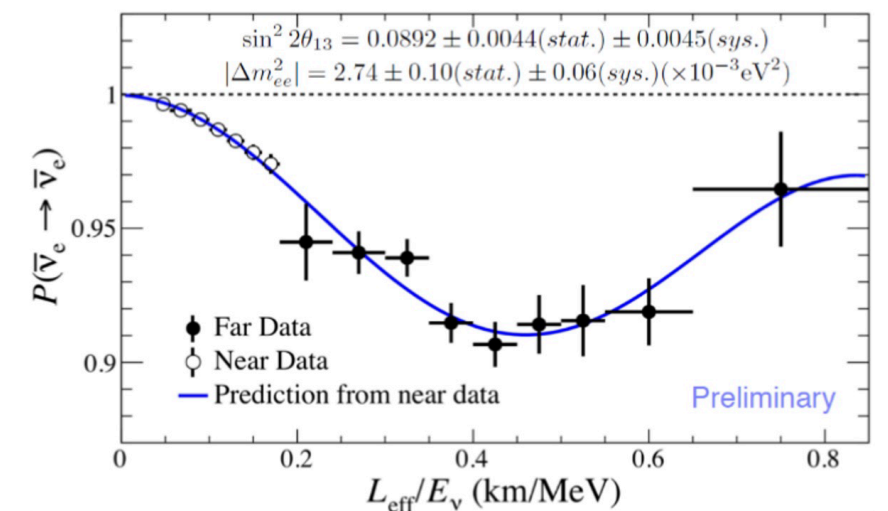
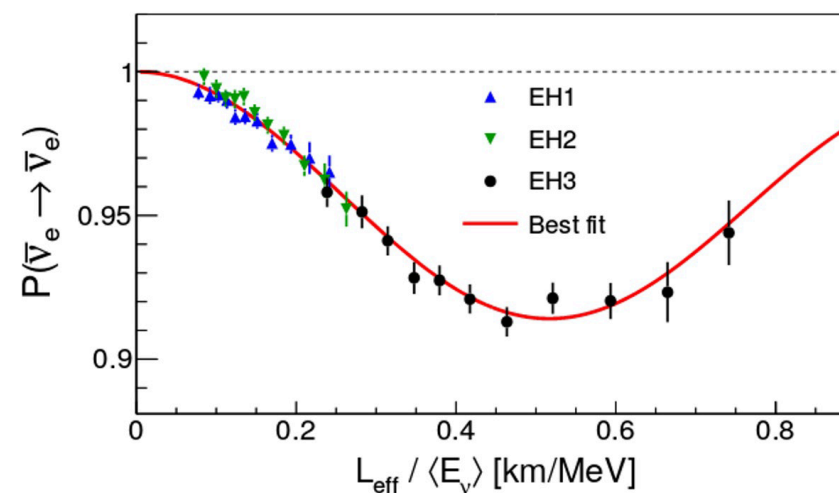
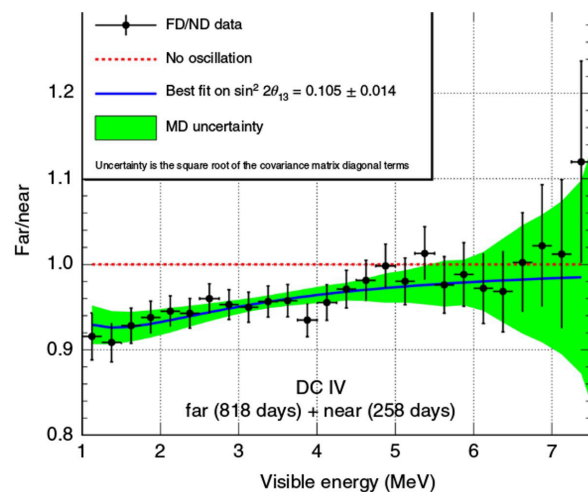
2 reactors + 1 ND + 1 FD (10 ton)



6 reactors + 4 ND + 4FD (20 ton)

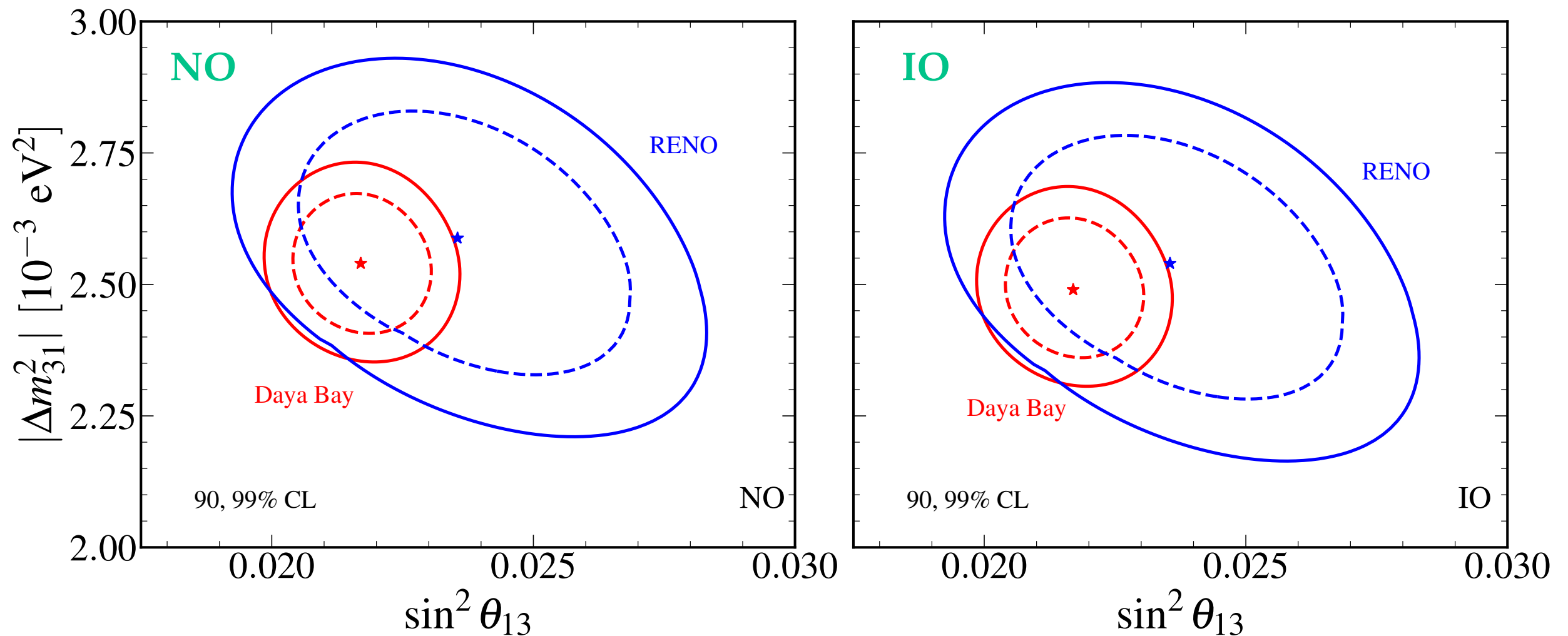


6 reactors + 1 ND + 1 FD (16 ton)



The reactor sector

$$P_{ee} = 1 - \sin^2 2\theta_{13} \sin^2 \left(\frac{\Delta m_{31}^2 L}{4E} \right)$$

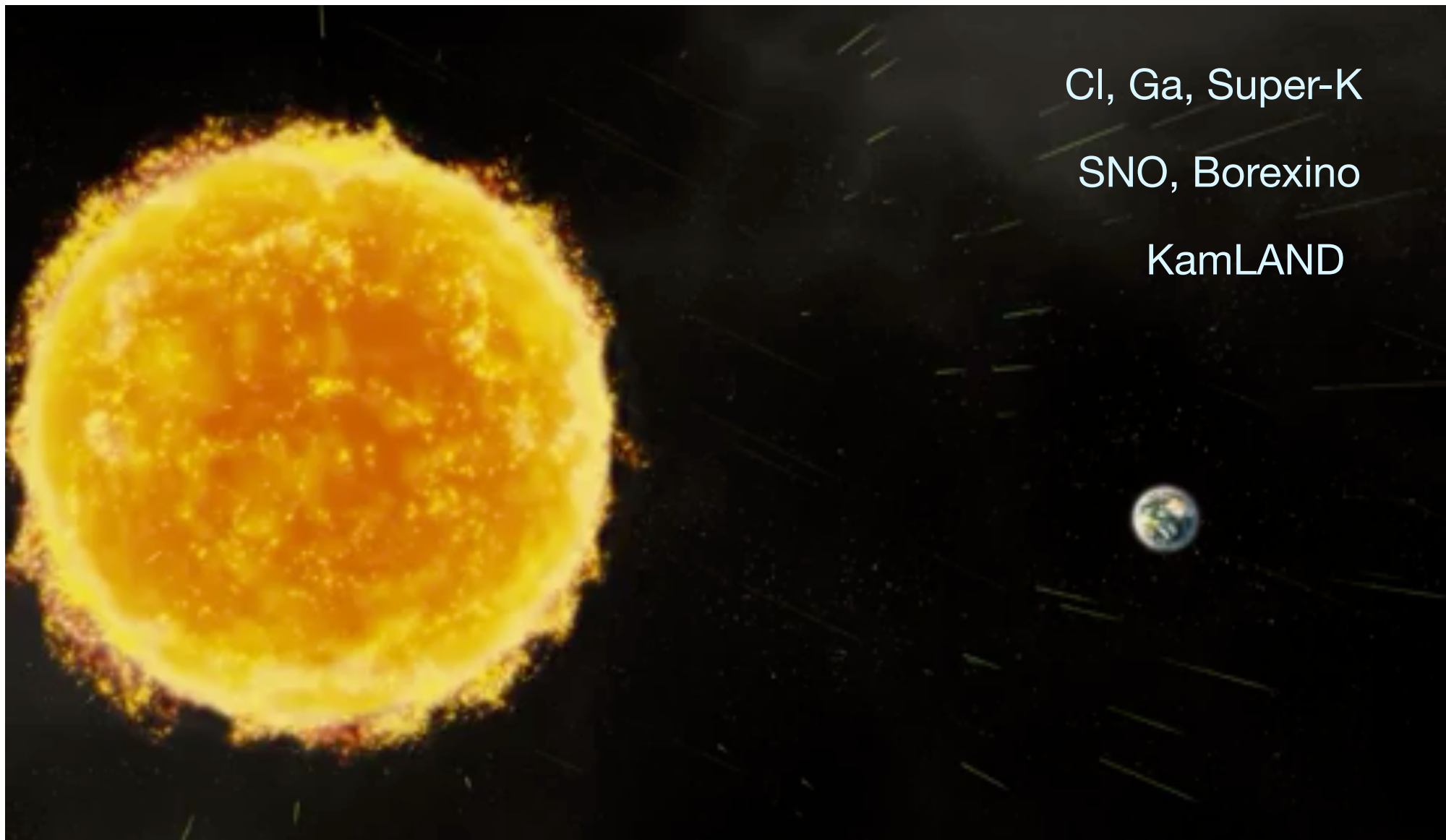


$$\sin^2 \theta_{13} = (2.20^{+0.07}_{-0.04}) \cdot 10^{-2}$$

$$\sin^2 \theta_{13} = (2.23^{+0.05}_{-0.06}) \cdot 10^{-2}$$

Neutrino oscillations

Solar sector: θ_{12} , θ_{13} , Δm^2_{21}



Solar neutrinos

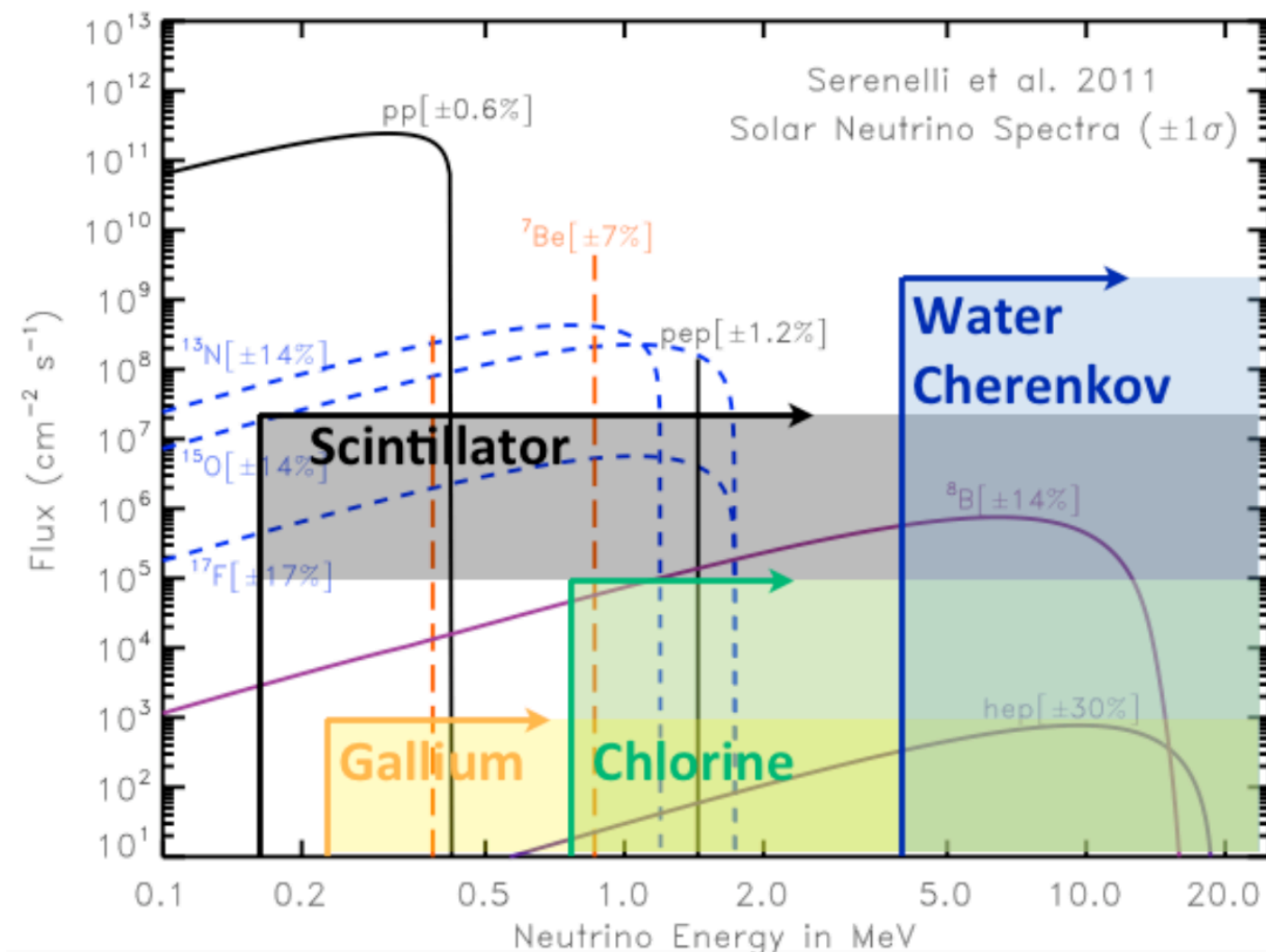
- produced in nuclear reactions in the core of the Sun:



pp cycle

CNO cycle

Reaction	source	Flux ($\text{cm}^{-2}\text{s}^{-1}$)
$p p \rightarrow d e^+ \nu$	pp	$5.97(1 \pm 0.006) \times 10^{10}$
$p e^- p \rightarrow d \nu$	pep	$1.41(1 \pm 0.011) \times 10^8$
${}^3\text{He} p \rightarrow {}^4\text{He} e^+ \nu$	hep	$7.90(1 \pm 0.15) \times 10^3$
${}^7\text{Be} e^- \rightarrow {}^7\text{Li} \nu \gamma$	${}^7\text{Be}$	$5.07(1 \pm 0.06) \times 10^9$
${}^8\text{B} \rightarrow {}^8\text{Be}^* e^+ \nu$	${}^8\text{B}$	$5.94(1 \pm 0.11) \times 10^6$
${}^{13}\text{N} \rightarrow {}^{13}\text{C} e^+ \nu$	${}^{13}\text{N}$	$2.88(1 \pm 0.15) \times 10^8$
${}^{15}\text{O} \rightarrow {}^{15}\text{N} e^+ \nu$	${}^{15}\text{O}$	$2.15(1 \pm {}^{0.17}_{0.16}) \times 10^8$
${}^{17}\text{F} \rightarrow {}^{17}\text{O} e^+ \nu$	${}^{17}\text{F}$	$5.82(1 \pm {}^{0.19}_{0.17}) \times 10^6$



ν fluxes

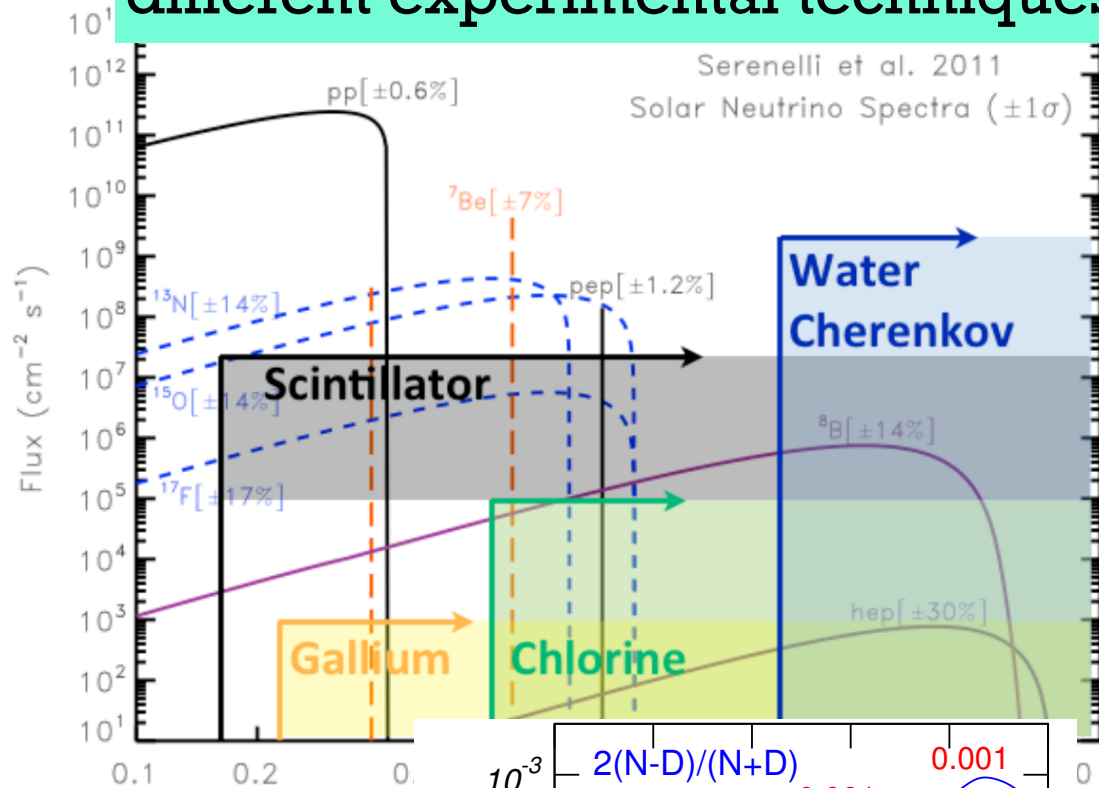
SSM predictions

ν energy spectra

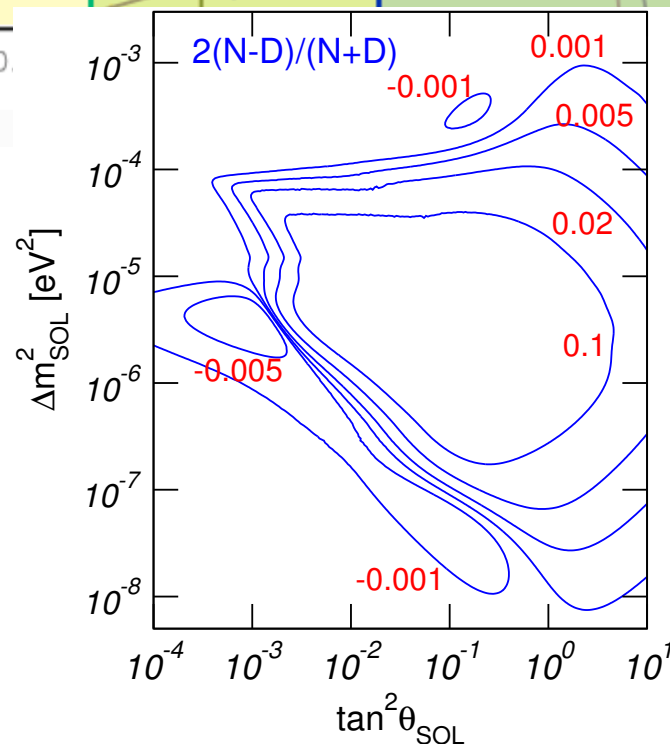
The solar sector

Solar experiments have measured neutrino disappearance for ~ 50 years

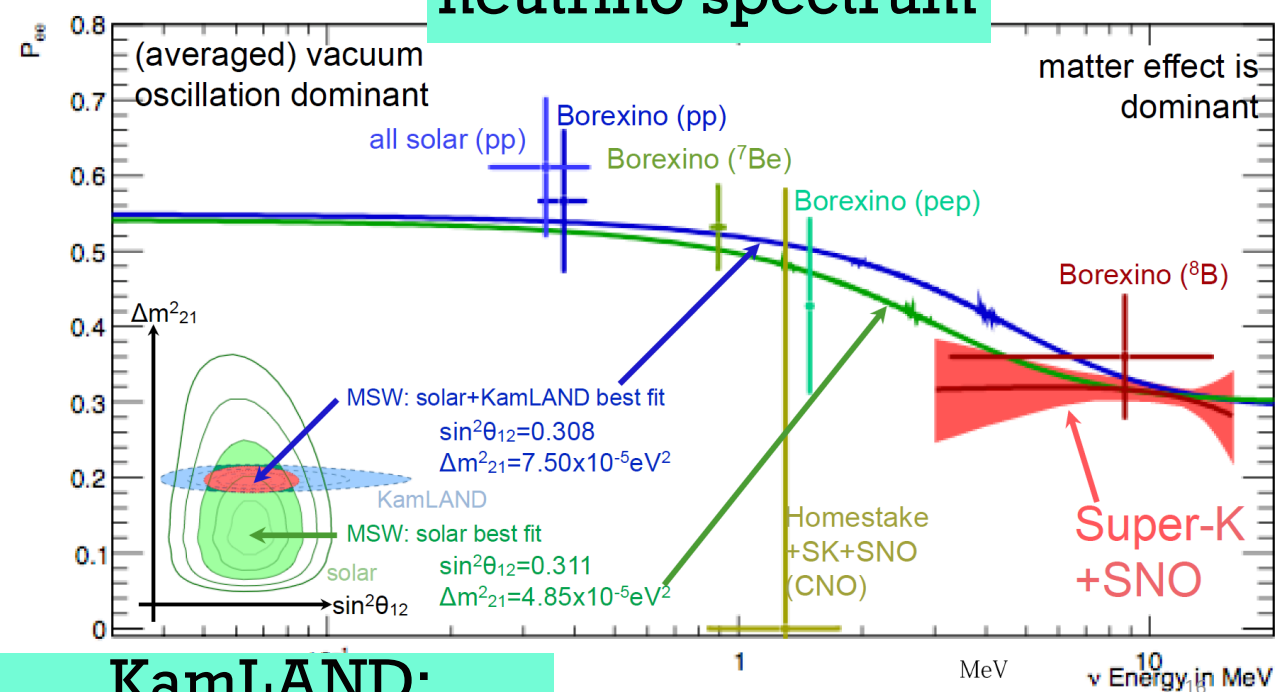
different experimental techniques



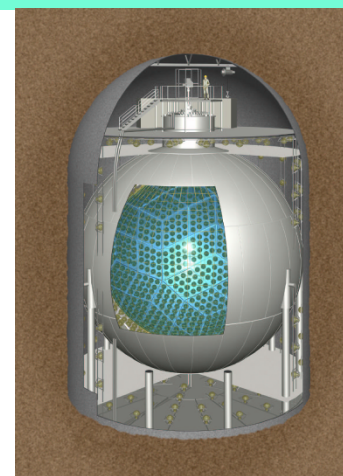
day/night asymmetry



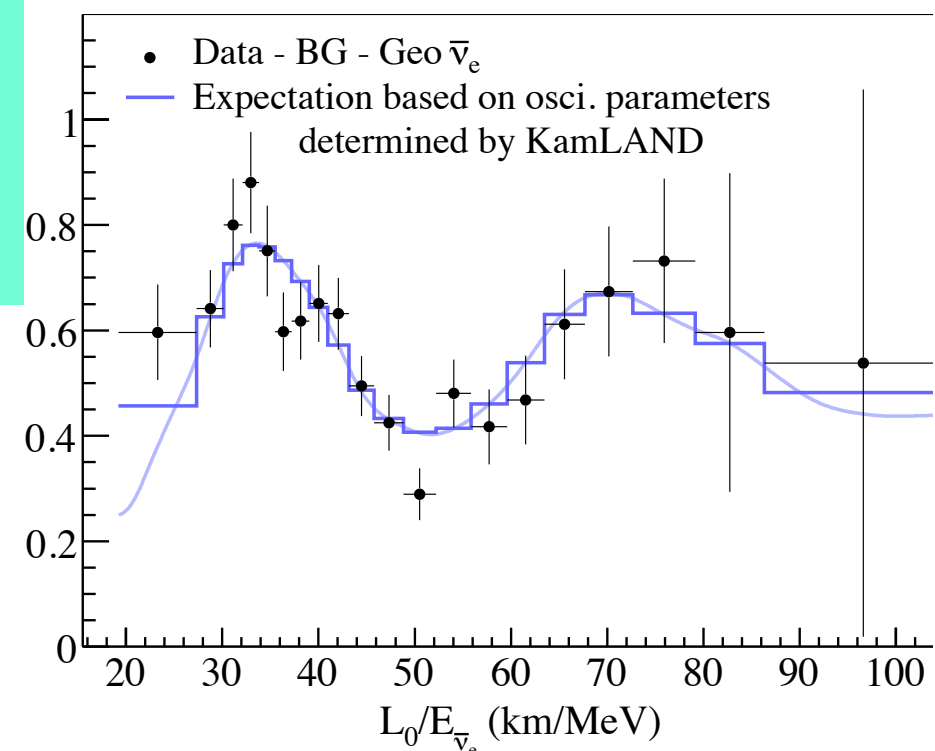
neutrino spectrum



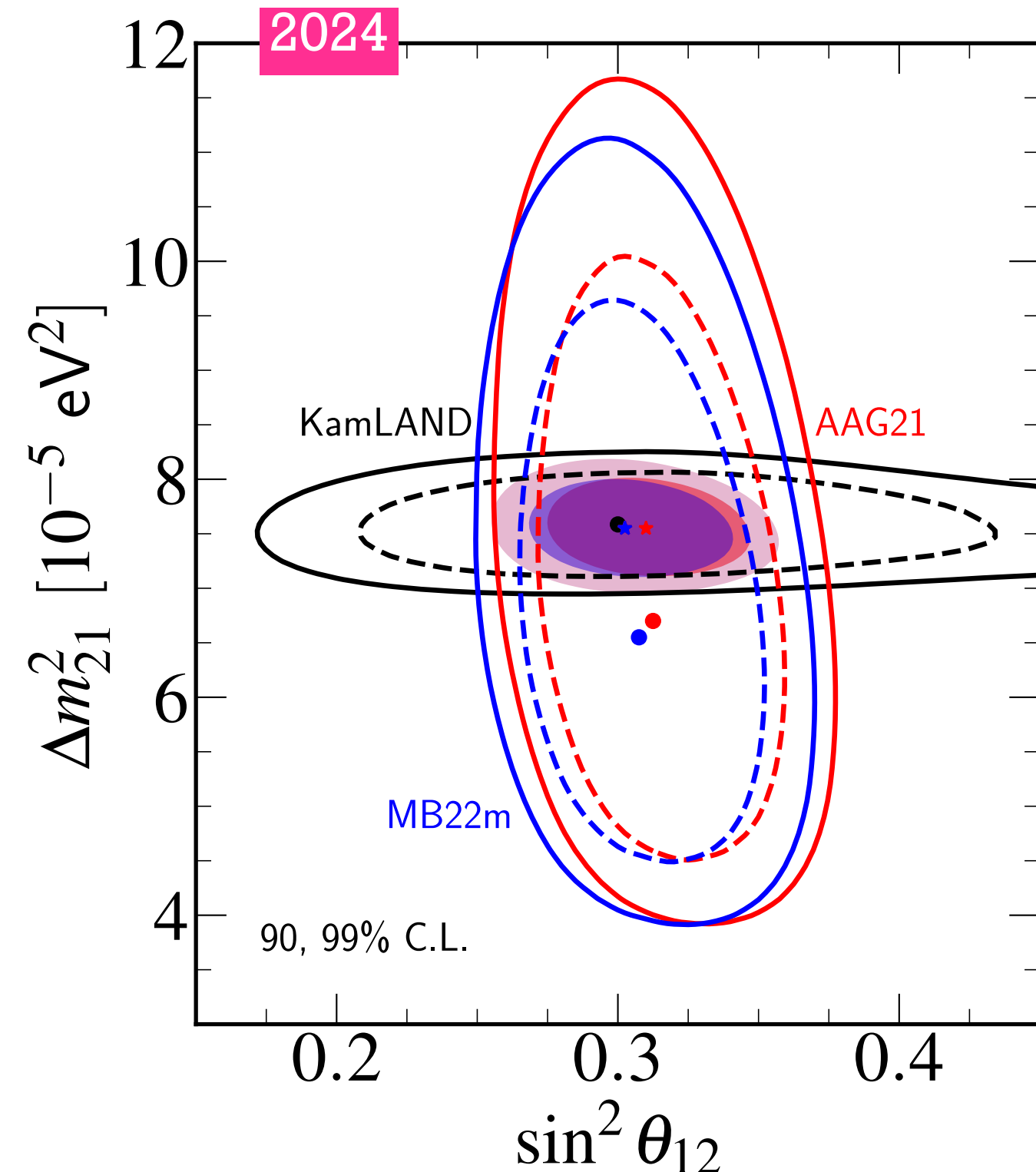
KamLAND:
precise
measurement of
oscillation
frequency



Survival Pr



The solar sector



- ♦ θ_{12} measurement dominated by solar neutrino data
- ♦ Δm_{21}^2 is better measured by KamLAND.
- ♦ **1.5 σ mismatch** between the values of Δm_{21}^2 measured by solar and KamLAND

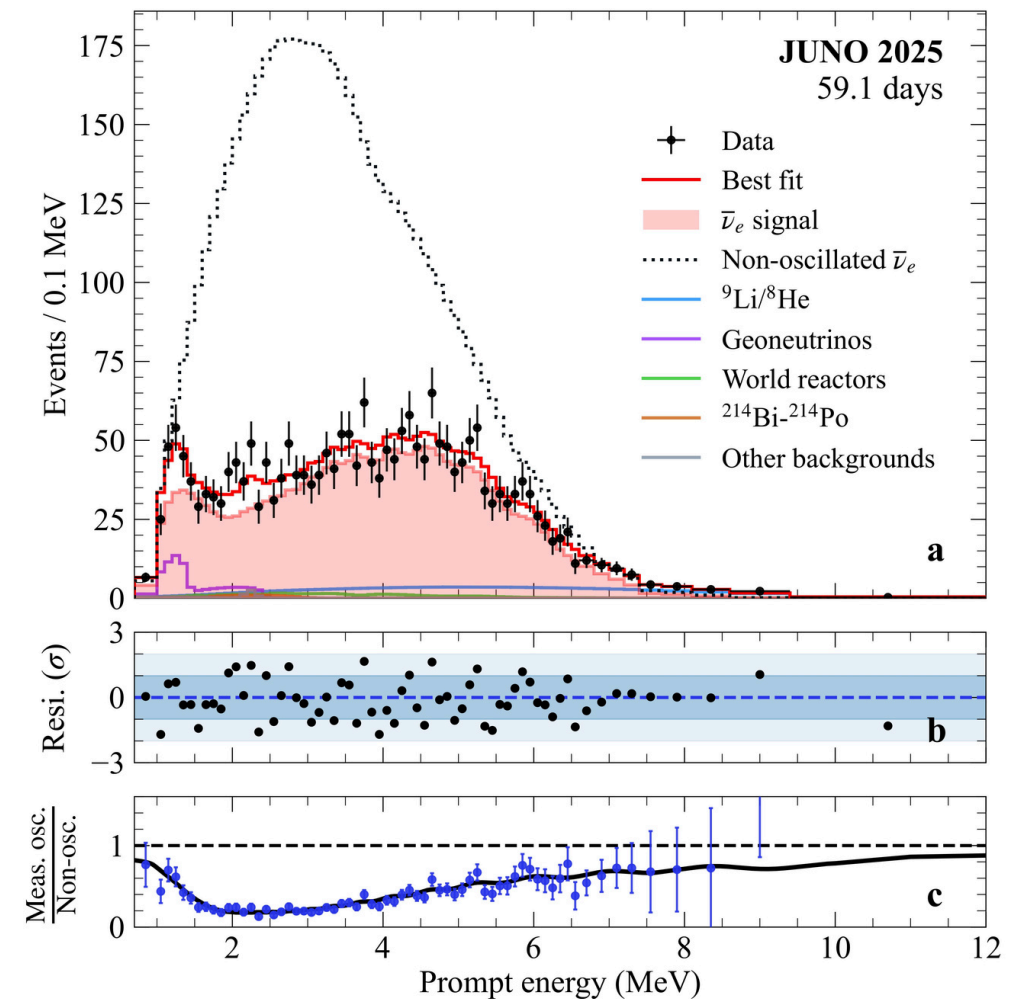
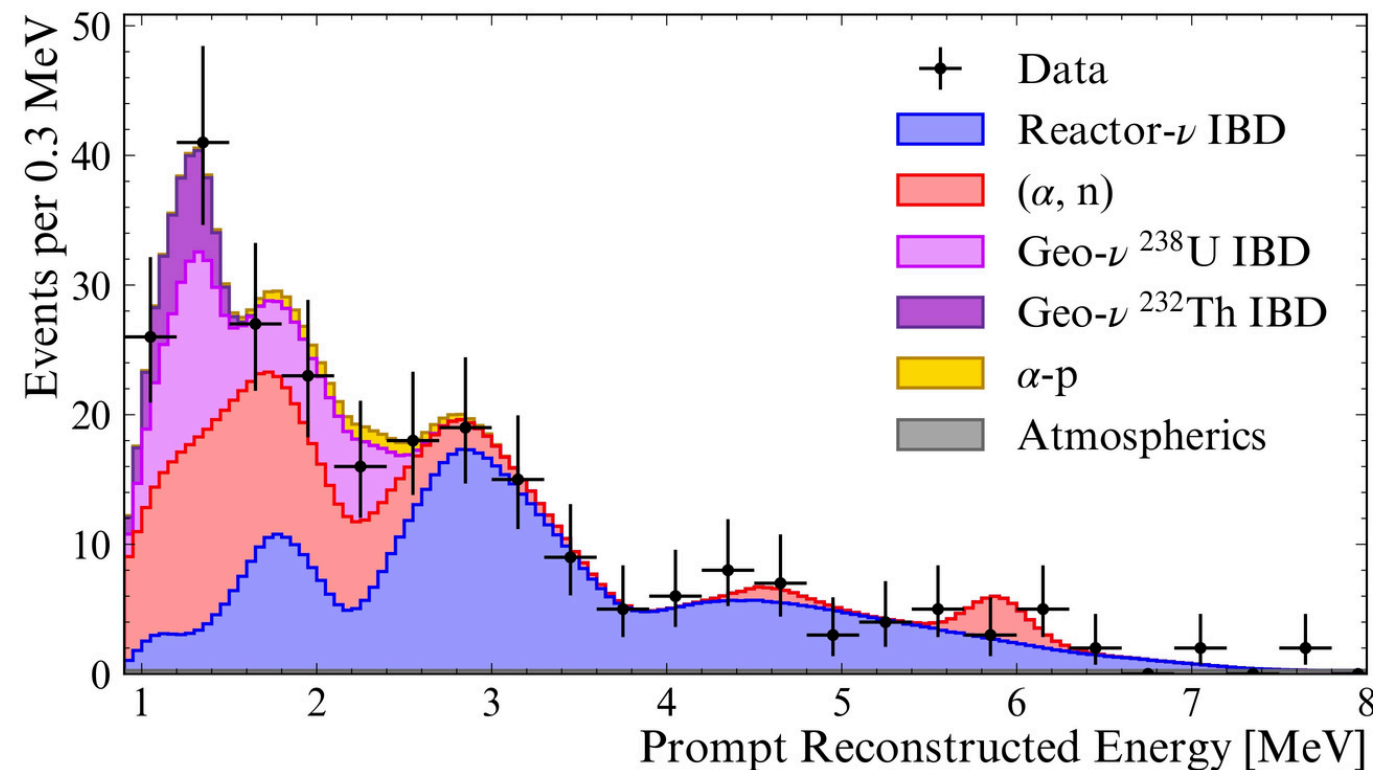
$$\sin^2 \theta_{12} = 0.308^{+0.009}_{-0.007}$$

$$\Delta m_{21}^2 = (7.52^{+0.11}_{-0.07}) \times 10^{-5} \text{eV}^2$$

New reactor data for solar sector

JUNO [arXiv:2511.14593]

SNO+ [arXiv:2511.11856]



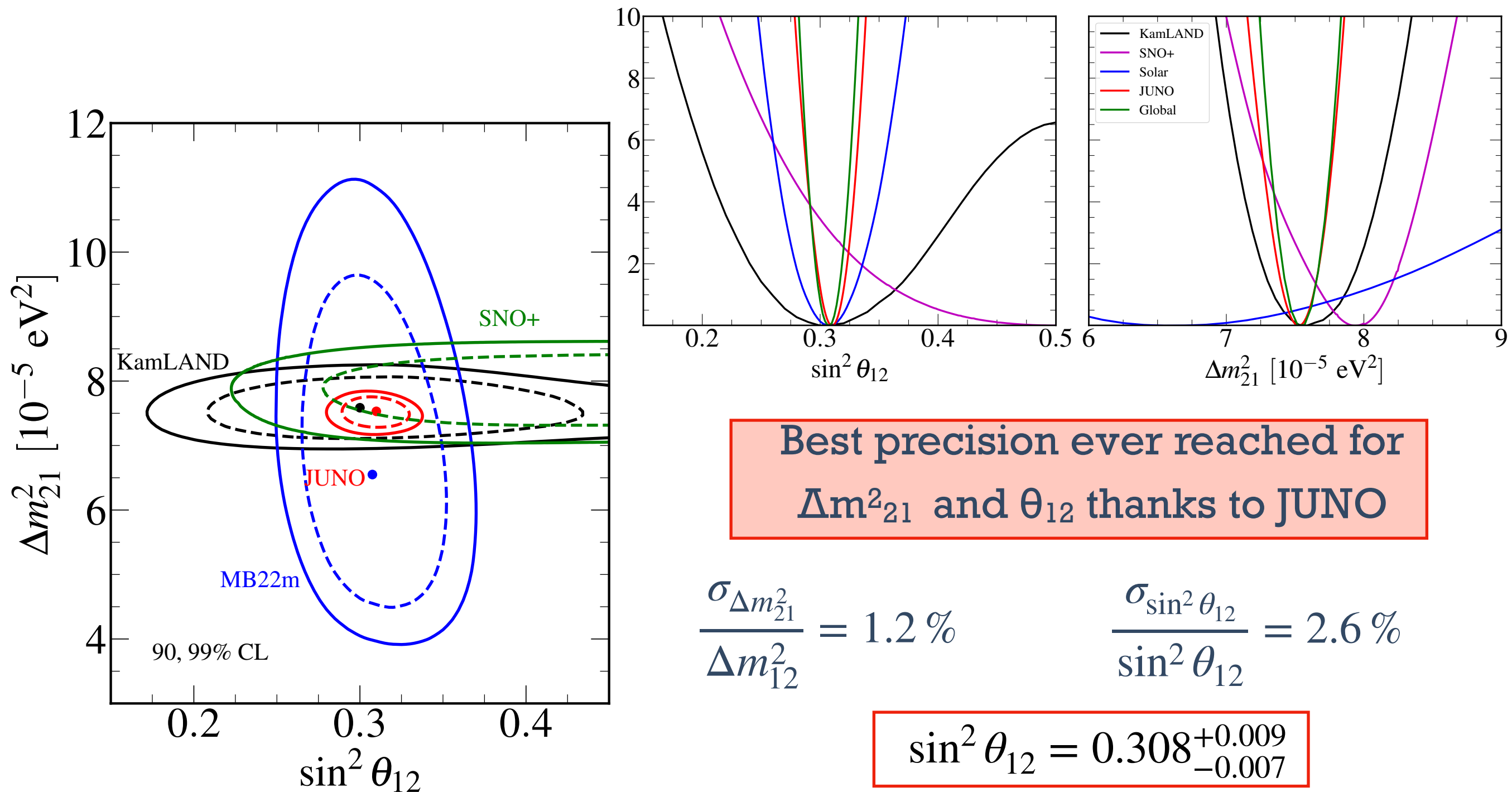
◆ LBL reactor exp (240-350km)

◆ 1.46 kton-years (May 2022-July 2025)

◆ Medium baseline reactor exp (50 km)

◆ 59.1 days of exposure

The solar sector in 2026



Neutrino oscillations

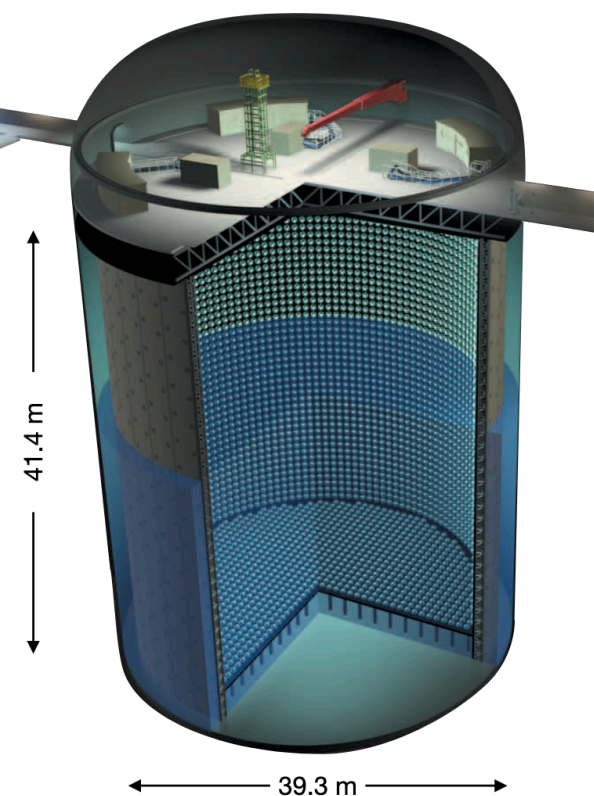
Atmospheric sector: θ_{23} , θ_{13} , Δm^2_{31} , δ



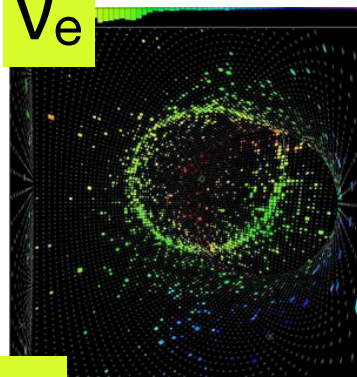
The atmospheric sector

Super-Kamiokande

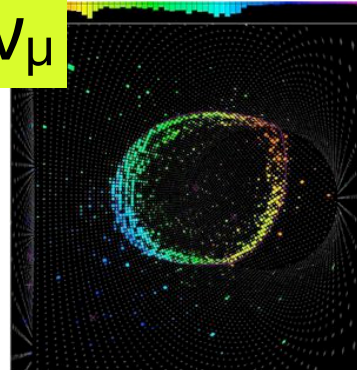
(1 km mountain overburden)



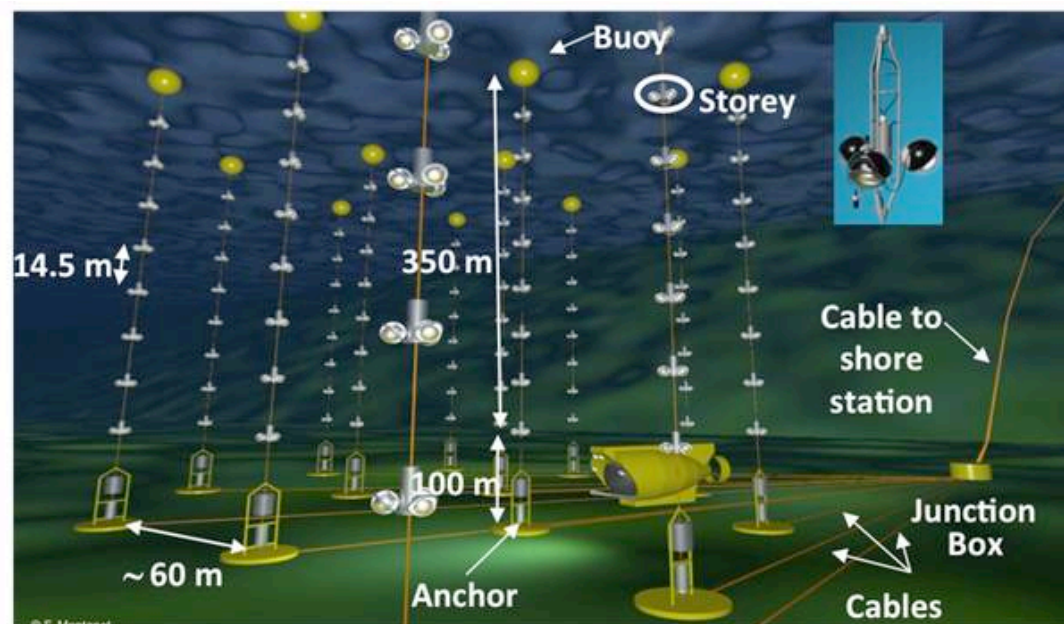
V_e



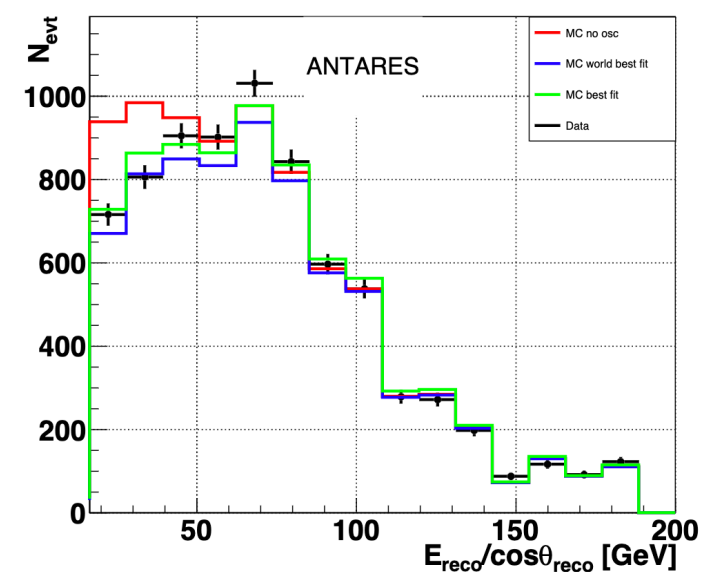
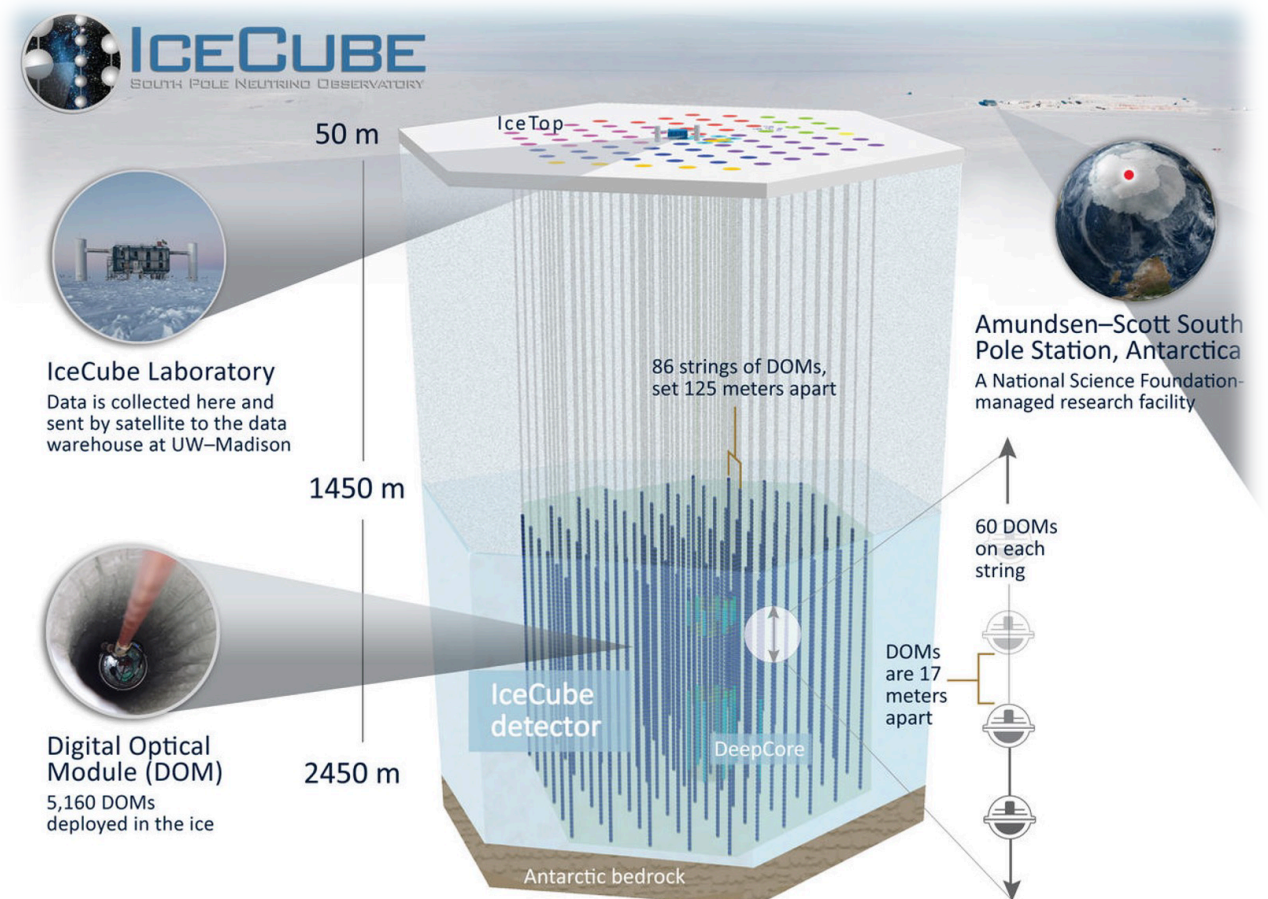
V_μ



ANTARES

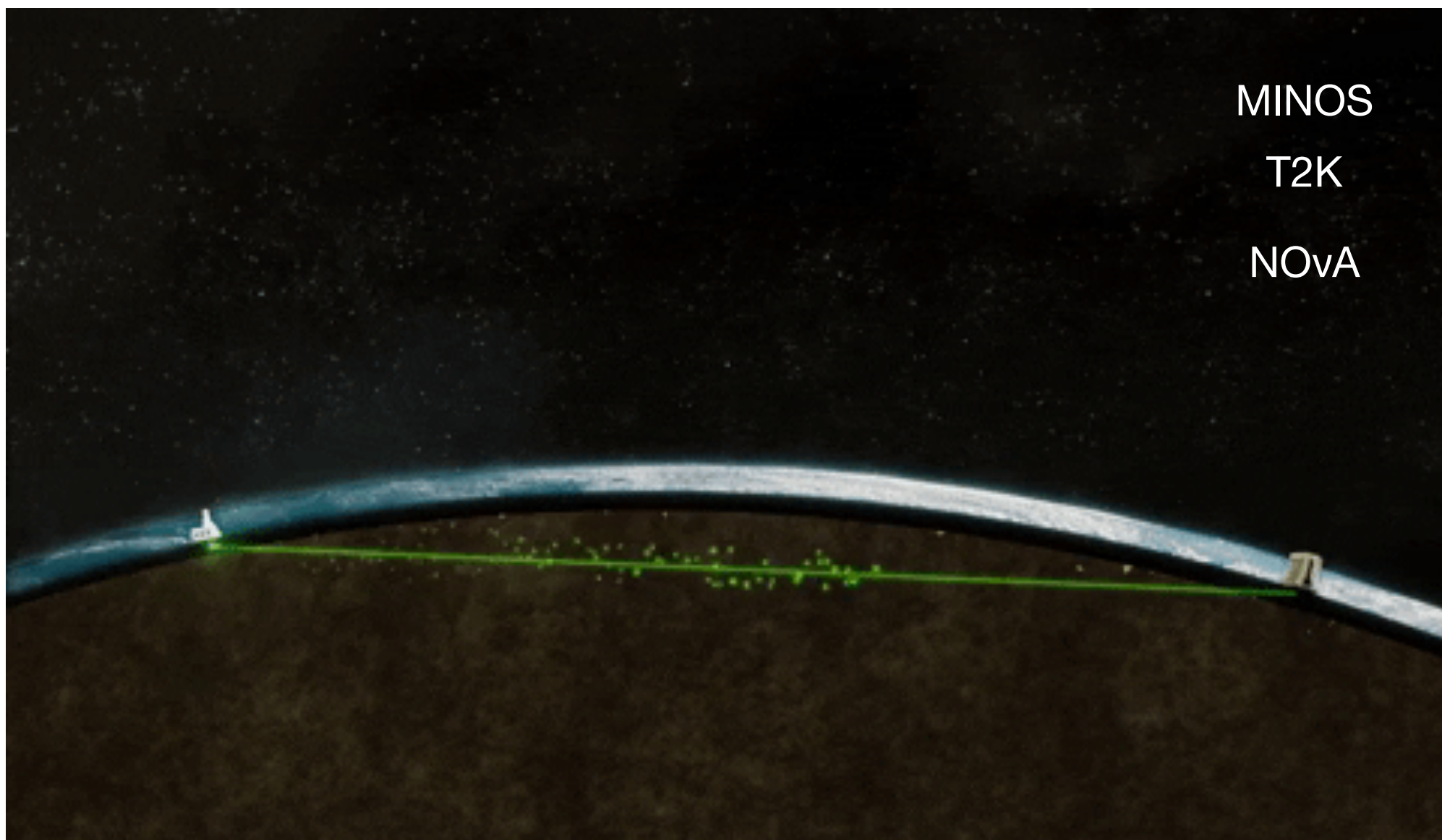


IceCube



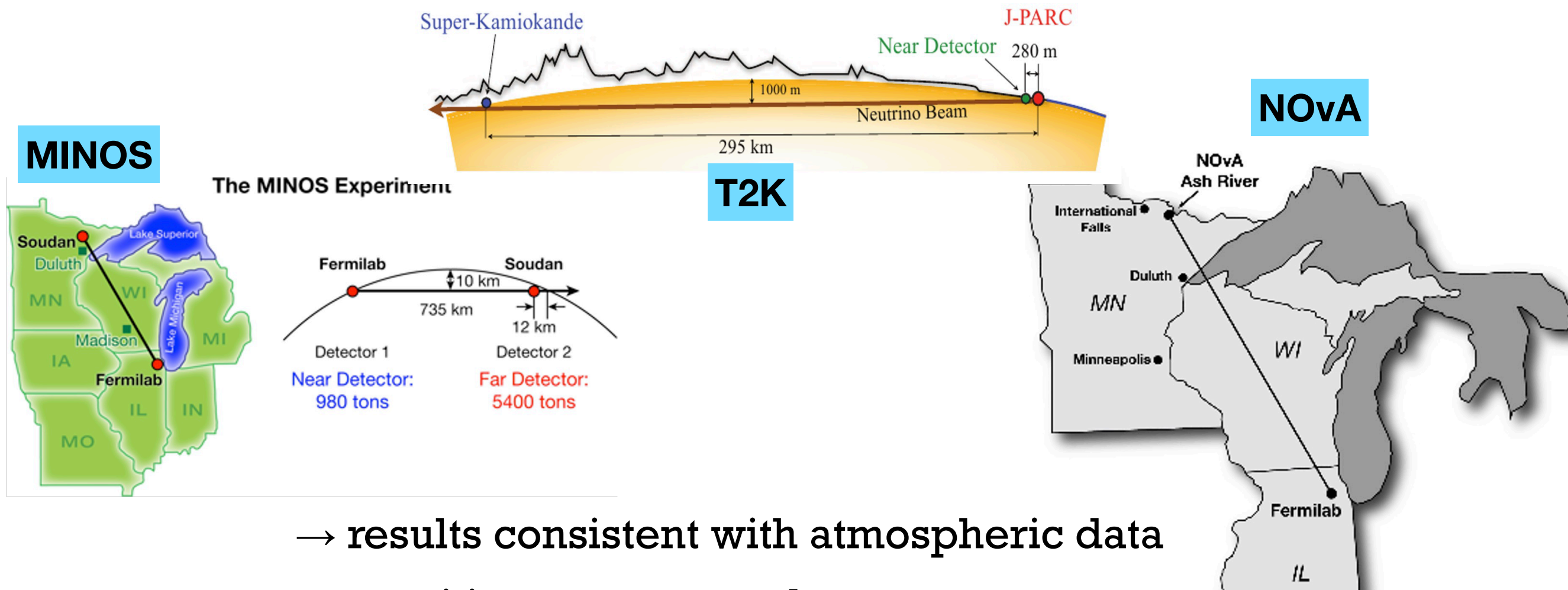
Neutrino oscillations

Accelerator sector: θ_{23} , θ_{13} , Δm^2_{31} , δ



The accelerator sector

- ◆ Designed to test the atmospheric neutrino oscillation channel
- ◆ $L/E \sim 500 \text{ km/GeV}$ to be sensitive to $\Delta m_{31}^2 \sim \text{few } 10^{-3} \text{ eV}^2$
- ◆ Combine near detector + far detector



→ results consistent with atmospheric data

→ sensitive to $\nu_\mu \rightarrow \nu_\mu$ and $\nu_\mu \rightarrow \nu_e$

Atmospheric & accelerator sector

ν_μ and $\bar{\nu}_\mu$ disappearance

$$P(\nu_\mu \rightarrow \nu_\mu) = P(\bar{\nu}_\mu \rightarrow \bar{\nu}_\mu) = 1 - \sin^2(2\theta_{23}) \sin^2\left(1.27 \frac{\Delta m_{32}^2 L}{E}\right)$$

→ only sensitive to $\sin^2 2\theta_{23}$ and $|\Delta m_{32}^2|$

ν_e and $\bar{\nu}_e$ appearance (in matter)

$$P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e) \simeq \sin^2 \theta_{23} \frac{\sin^2 2\theta_{13}}{(A-1)^2} \sin^2[(A-1)\Delta_{31}]$$

$$+ (\mp) \alpha \frac{J_0 \sin \delta_{CP}}{A(1-A)} \sin \Delta_{31} \sin(A\Delta_{31}) \sin[(1-A)\Delta_{31}]$$

$$+ \alpha \frac{J_0 \cos \delta_{CP}}{A(1-A)} \cos \Delta_{31} \sin(A\Delta_{31}) \sin[(1-A)\Delta_{31}] + O(\alpha^2)$$

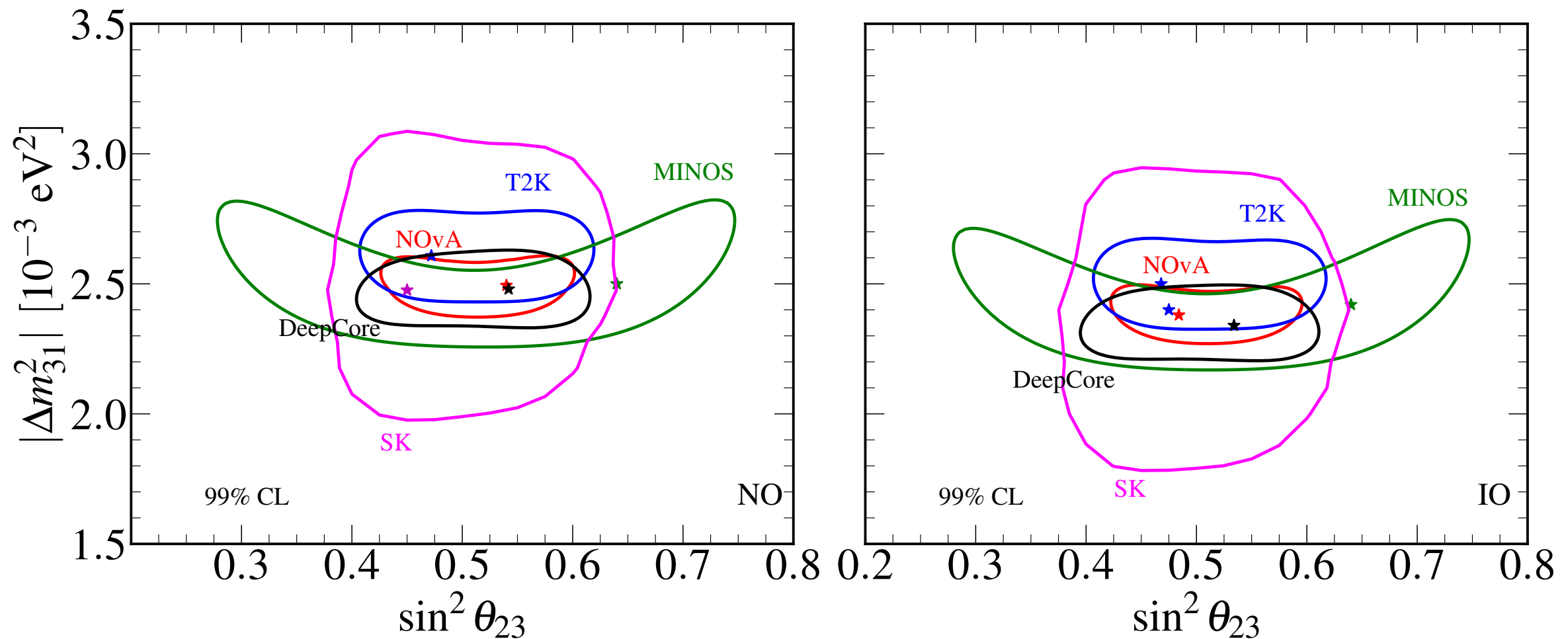
$$\alpha = \Delta m_{21}^2 / \Delta m_{31}^2 \sim 1/30$$

$$J_0 = \sin 2\theta_{12} \sin 2\theta_{13} \sin 2\theta_{23} \cos \theta_{13}$$

$$A = (\mp) 2\sqrt{2} G_F n_e E / \Delta m_{31}^2$$

→ Sensitivity to δ_{CP} , the mass ordering (sign A) and the octant of θ_{23}

Atmospheric & accelerator sector

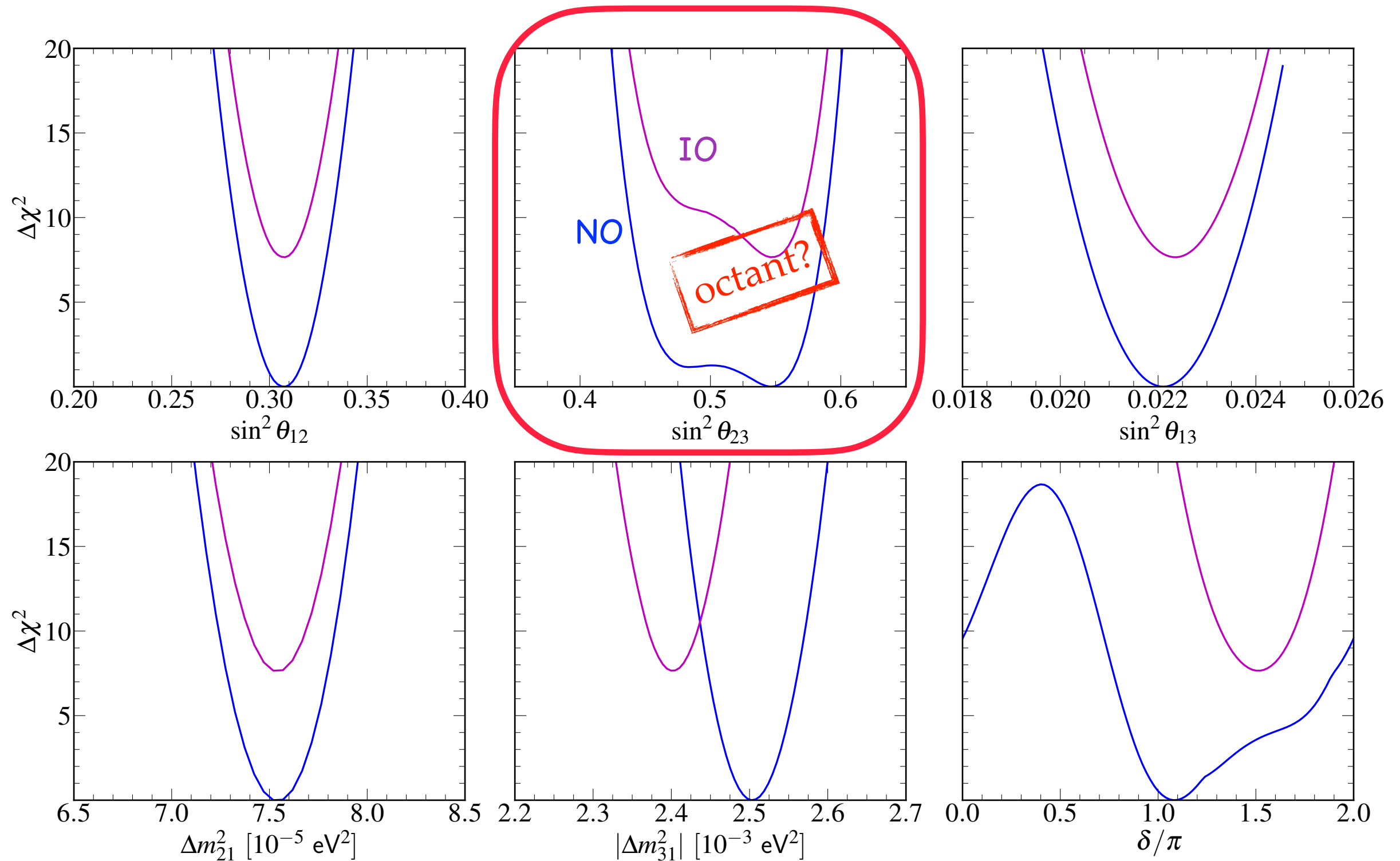


$$|\Delta m_{31}^2| = (2.502^{+0.022}_{-0.019}) \cdot 10^{-3} \text{ eV}^2$$

$$|\Delta m_{31}^2| = (2.400^{+0.022}_{-0.018}) \cdot 10^{-3} \text{ eV}^2$$

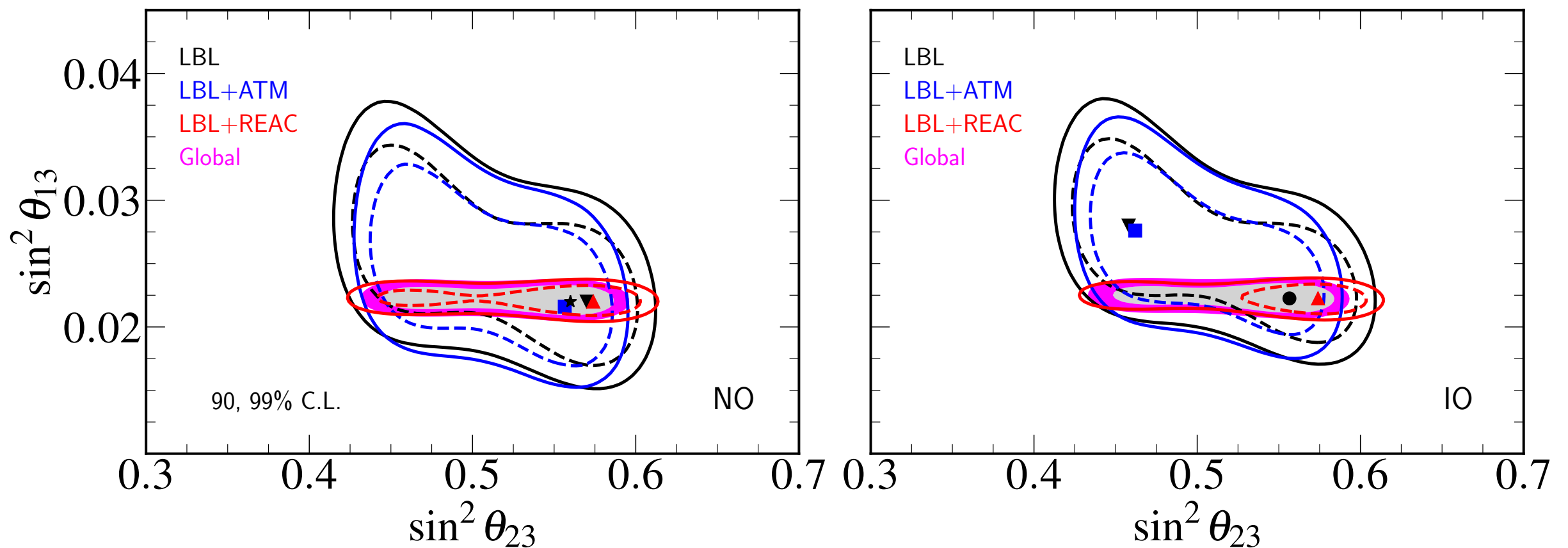
- ◆ Great agreement among all the experiments
- ◆ Best sensitivity obtained by T2K, NOvA and IC-DeepCore.
- ◆ Not possible to resolve the octant of the atmospheric angle.

Global fit to ν oscillation parameters



The octant of θ_{23}

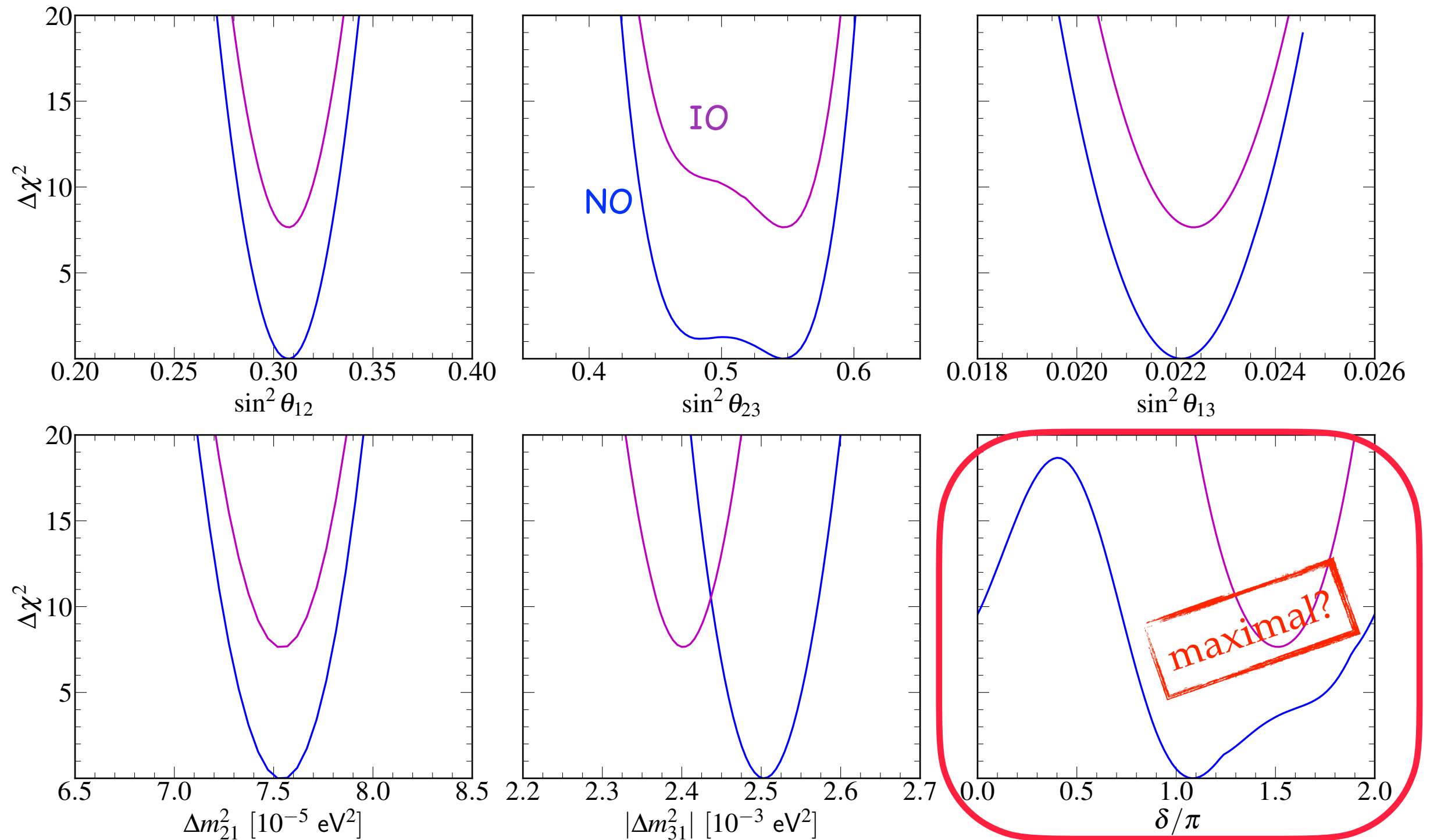
- ♦ **LBL** combination slightly prefer UO (NO) and LO(IO) with $\Delta\chi^2 = 0.2 - 0.5$
- ♦ **LBL + ATM** prefers UO (NO) and LO (IO) with $\Delta\chi^2 \sim 0.2 - 0.7$
- ♦ **LBL + REAC** favors UO (NO and IO) with $\Delta\chi^2 \sim 1.9 - 4.3$ over LO
- ♦ **Global** analysis shows a milder preference for UO with $\Delta\chi^2 \sim 1.2$ (2.7) for NO (IO)



$$\sin^2 \theta_{23} = 0.546^{+0.016}_{-0.019}$$

$$\sin^2 \theta_{23} = 0.546^{+0.015}_{-0.018}$$

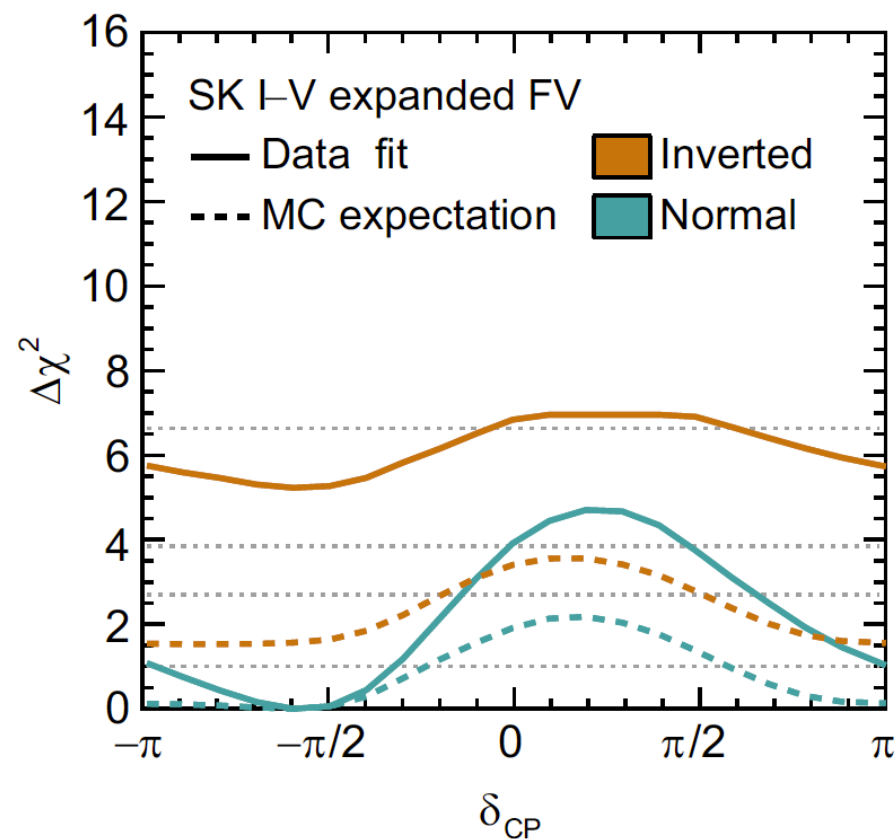
Global fit to ν oscillation parameters



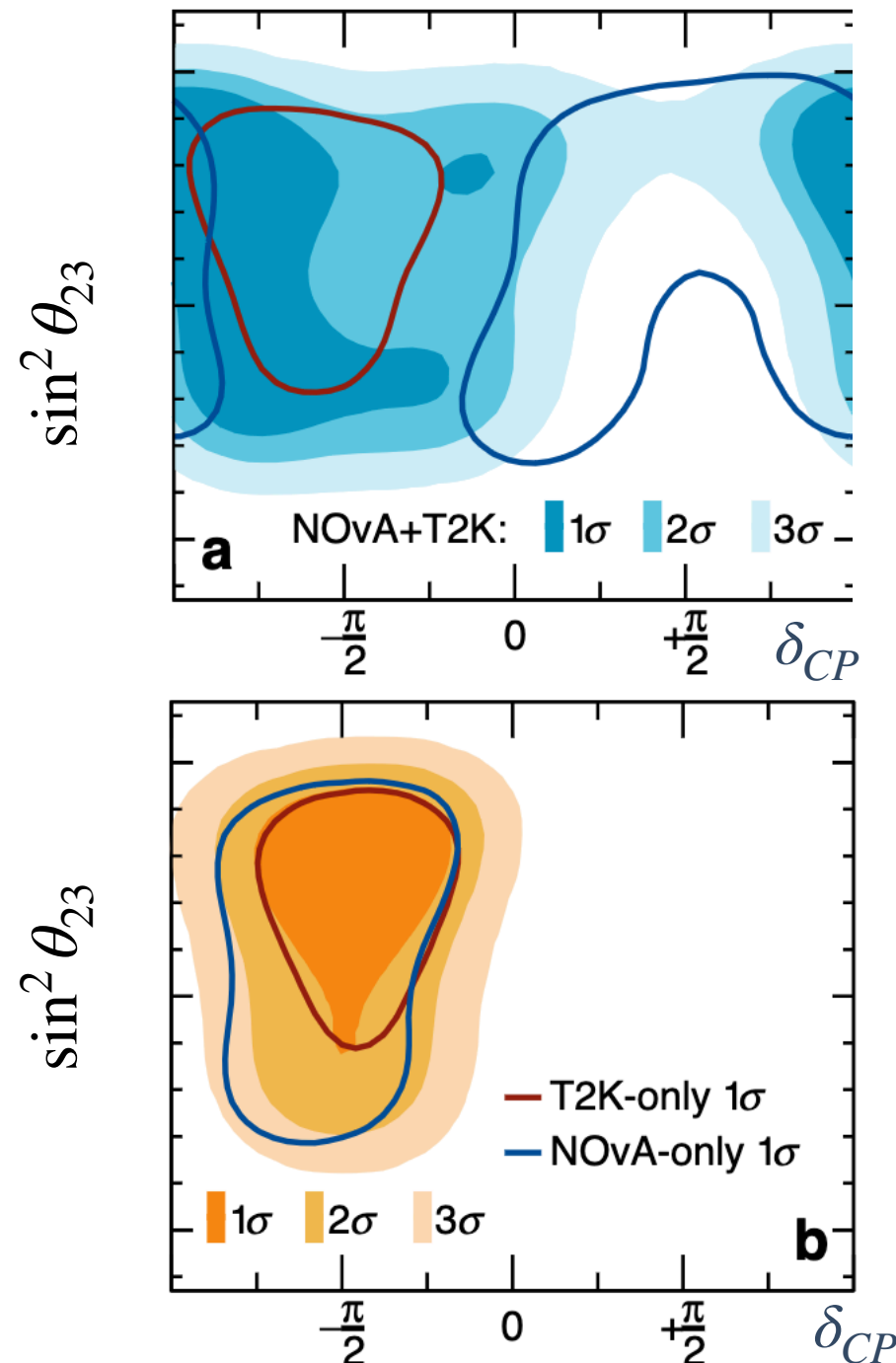
The CP phase

Observation of the appearance channels $\nu_\mu \rightarrow \nu_e$ in atmospheric and accelerator experiments allows to measure δ_{CP}

SK Collab, PRD 109 (2024) 072014



Super-Kamiokande observes a ν_e excess in agreement with maximal CP phase $\delta_{CP} \sim 3\pi/2$

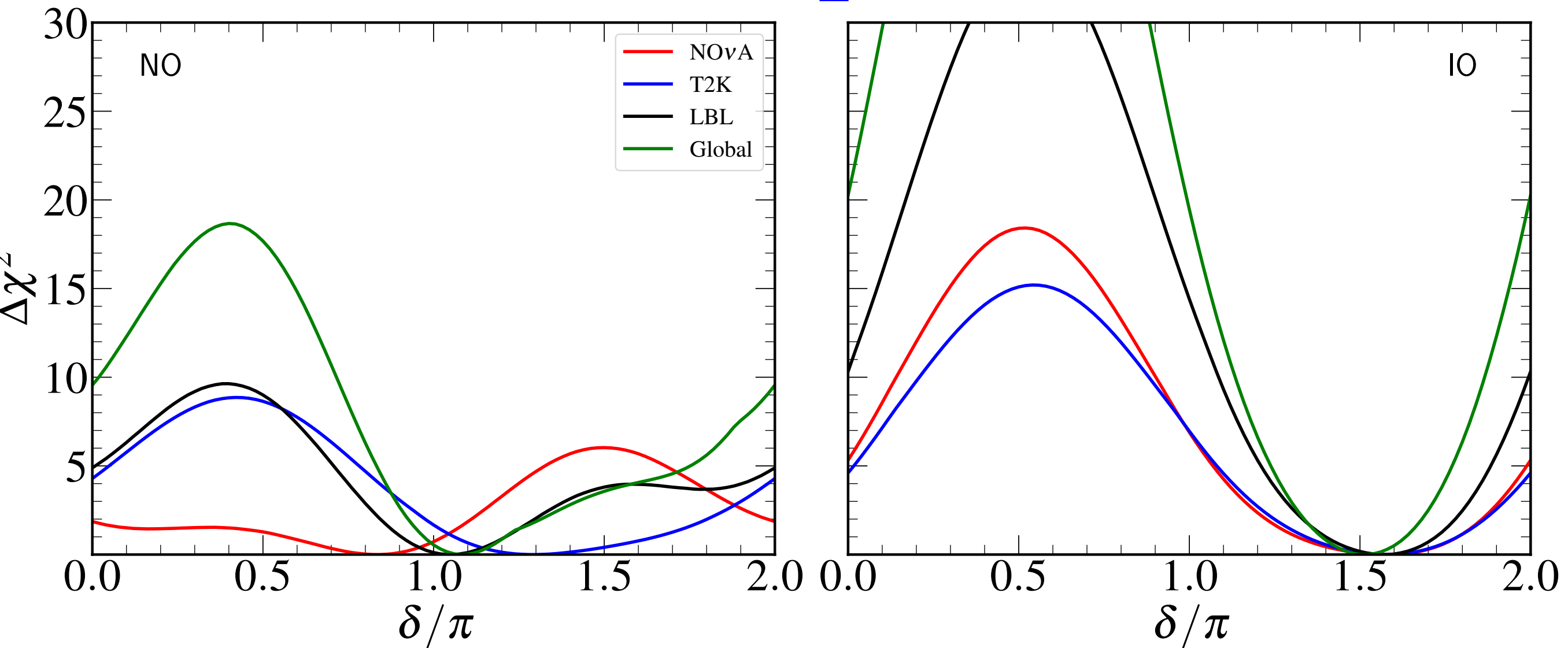


Joint T2K & NOvA analysis
2510.19888

T2K prefers also
 $\delta_{CP} \sim 3\pi/2$

NOvA results
depend on mass
ordering

The CP phase



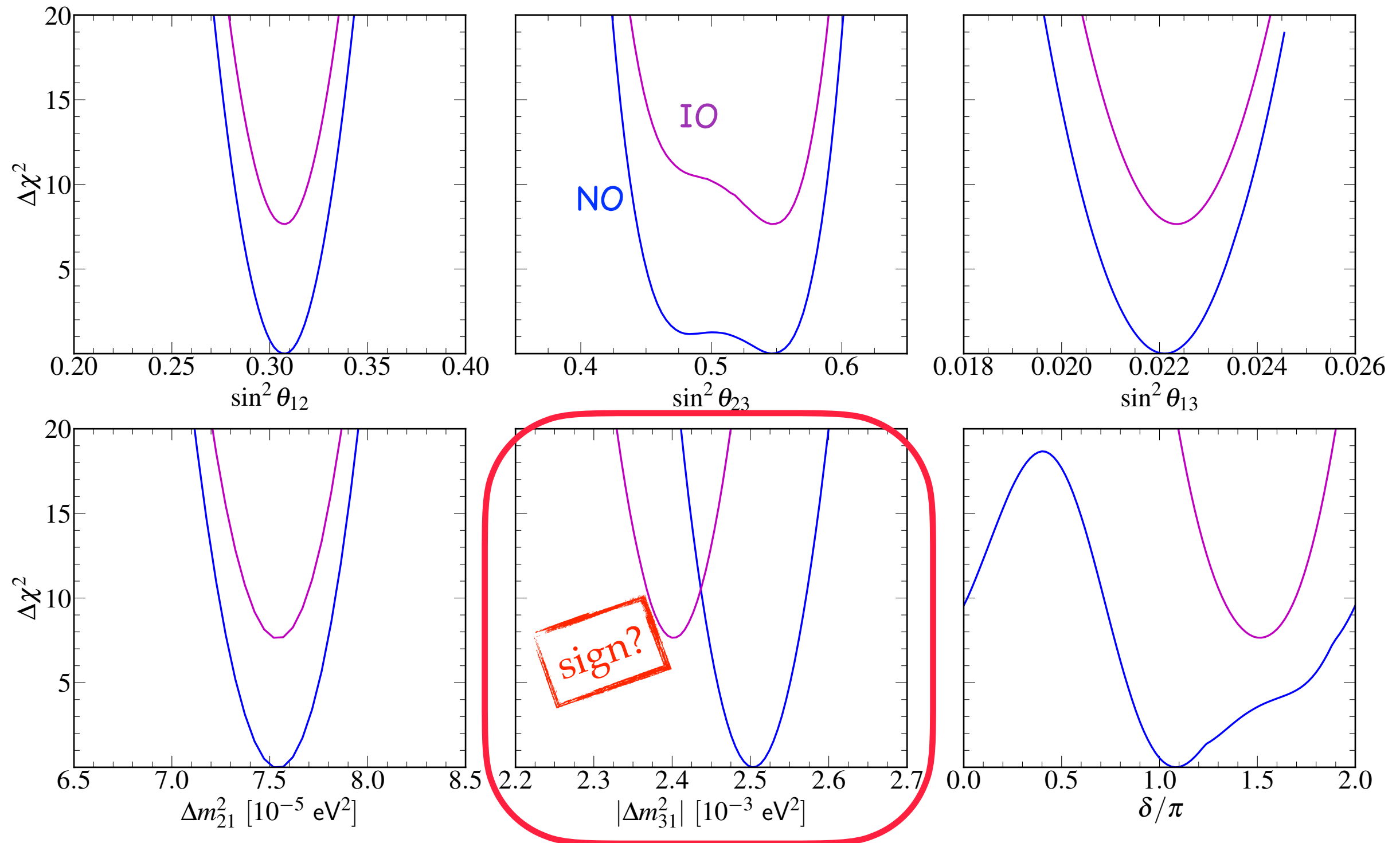
◆ NO: mismatch between NOvA and T2K and SK atmospheric results

$\delta_{\text{BF}} = 1.08\pi$; $\delta = \pi/2$ (0) disfavored at 4.2σ (3.1σ)

◆ IO: all experiments prefer $\delta \approx 3\pi/2$

$\delta_{\text{BF}} = 1.52\pi$; $\delta = \pi/2$ (π) disfavored at 7.5σ (4.4σ)

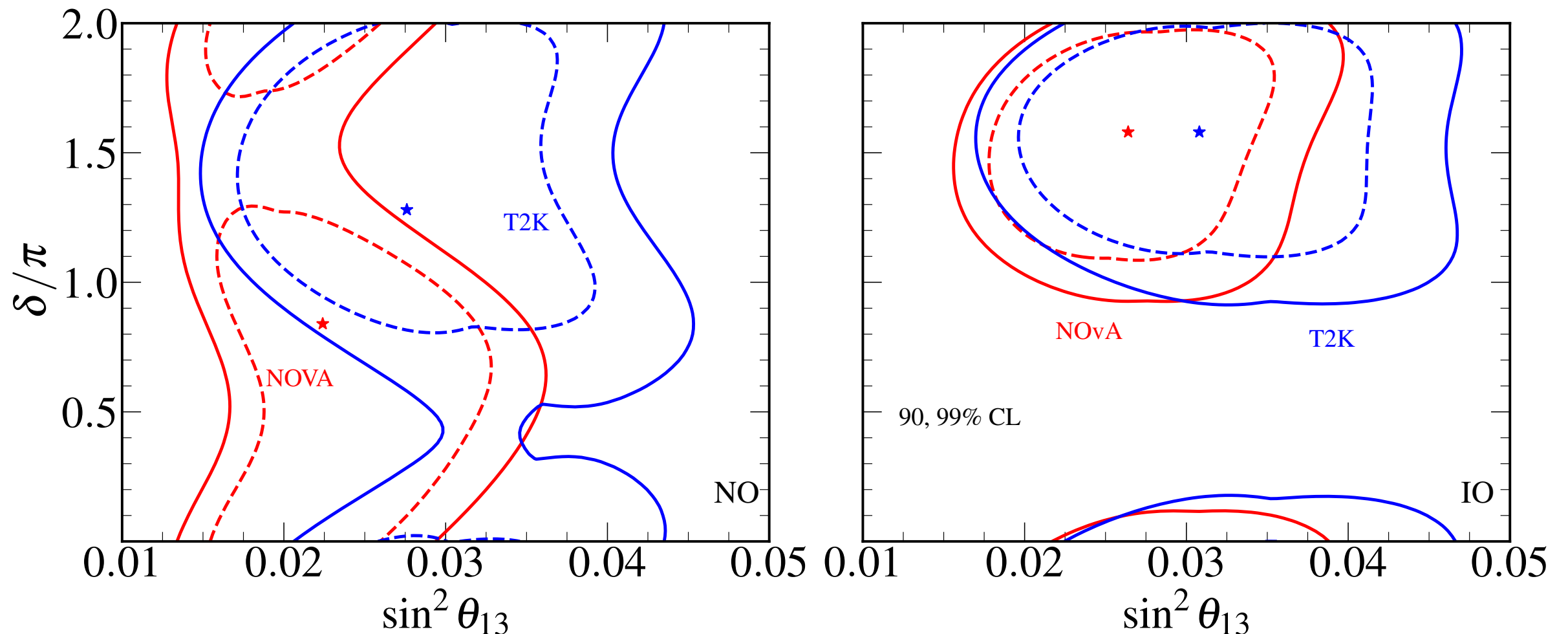
Global fit to ν oscillation parameters



The mass ordering

- ♦ T2K and NOvA separate analyses prefer **NO** with $\Delta\chi^2 \approx 1.1-1.3$

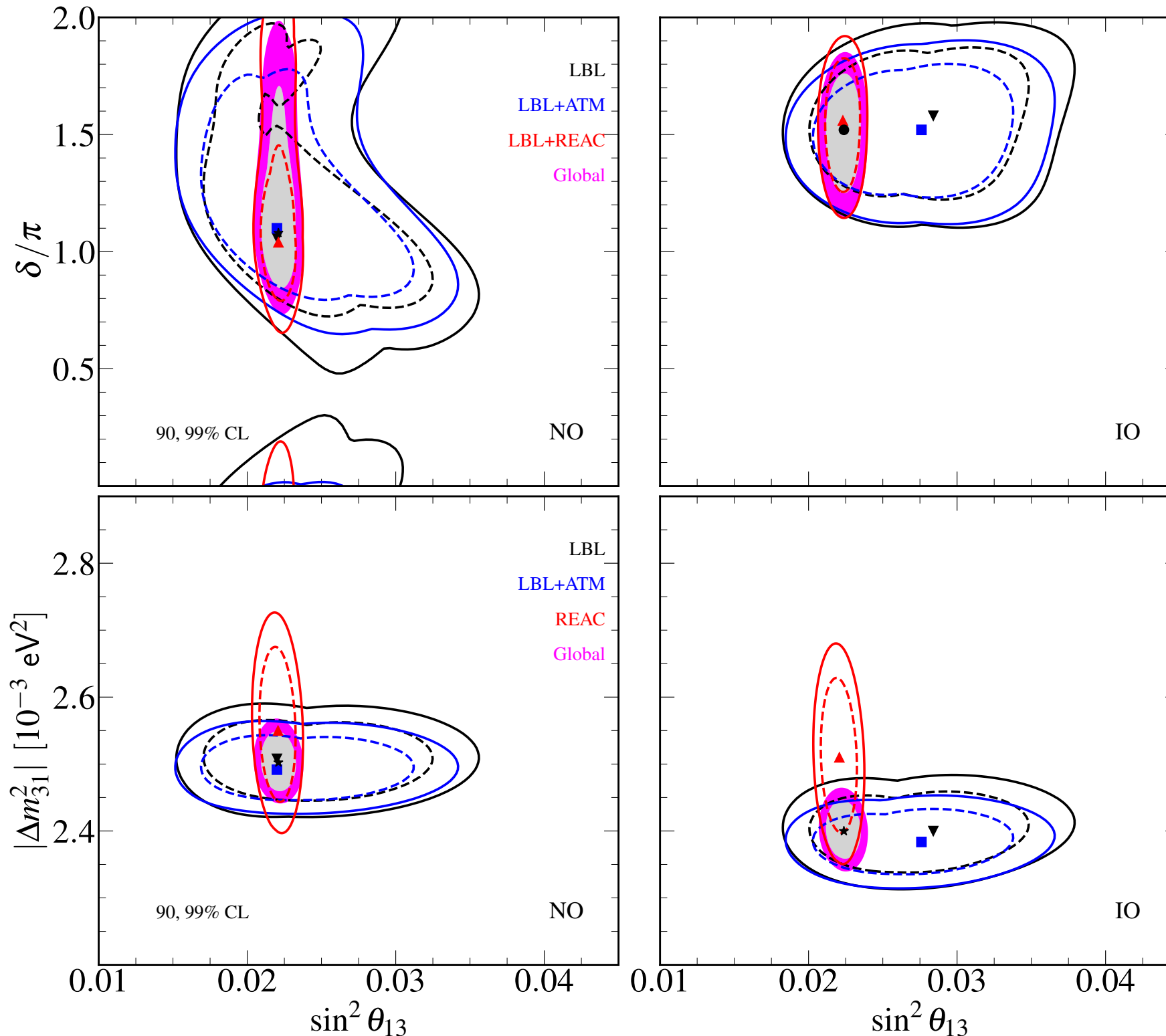
Tension between T2K and NOvA δ preference in NO



- ➔ The LBL combination (T2K + NOvA) prefer **IO** with $\Delta\chi^2 \approx 2.9$

The mass ordering

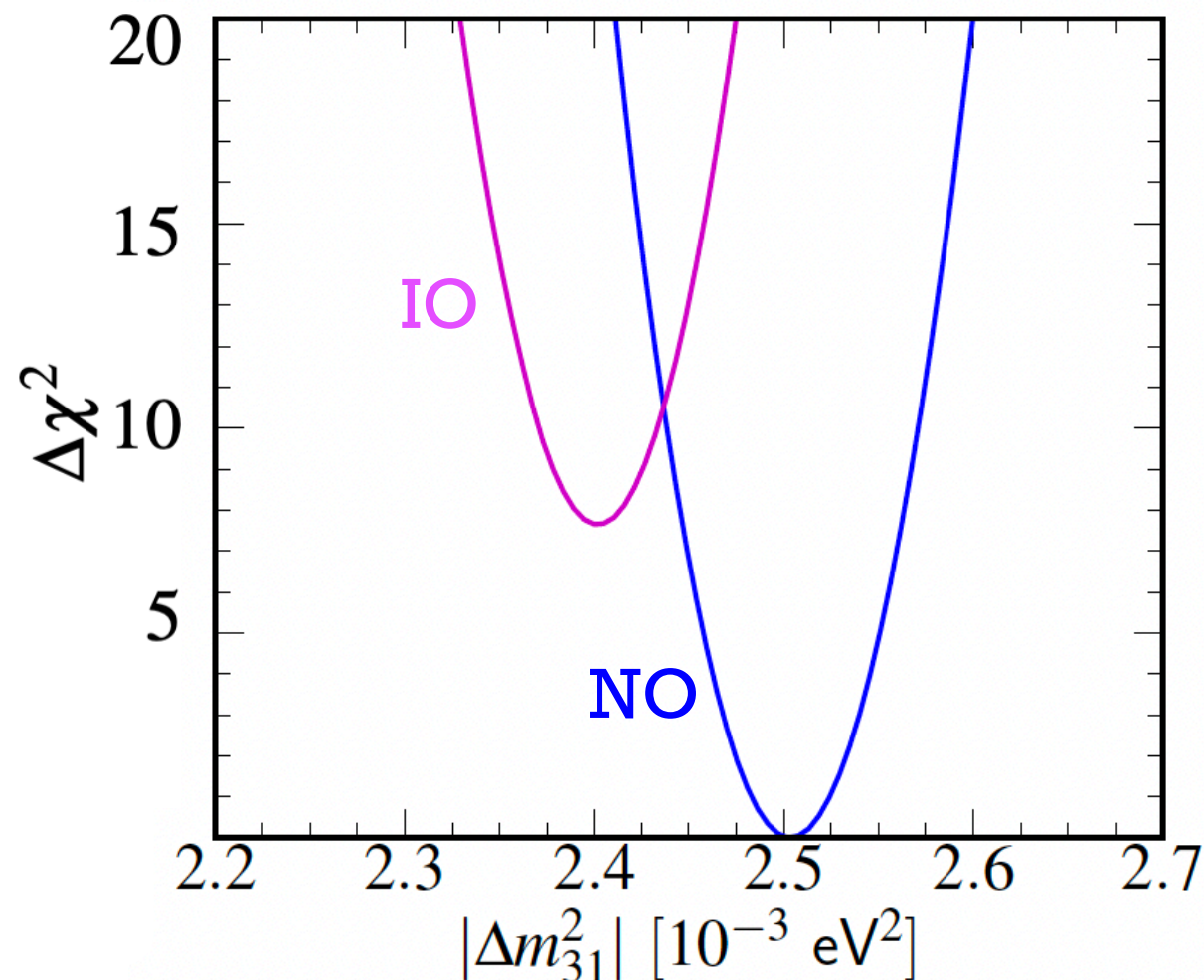
Tension between LBL and REAC Δm^2_{31} preference in IO



◆ LBL and REAC data show better agreement in NO

➔ LBL + REAC prefer **NO** with $\Delta\chi^2 \approx 1.3$

The mass ordering



- ♦ T2K and NOvA separate analyses prefer NO with $\Delta\chi^2 \approx 1.1-1.3$
- ♦ LBL prefer IO with $\Delta\chi^2 \approx 2.9$ (tension NO)
- ♦ **LBL + REAC** prefer NO with $\Delta\chi^2 \approx 1.3$ (tension in Δm^2_{31} measurement in IO)

♦ SK-atm prefers NO with $\Delta\chi^2 = 5.69$ (5.23) for θ_{13} constrained (free)

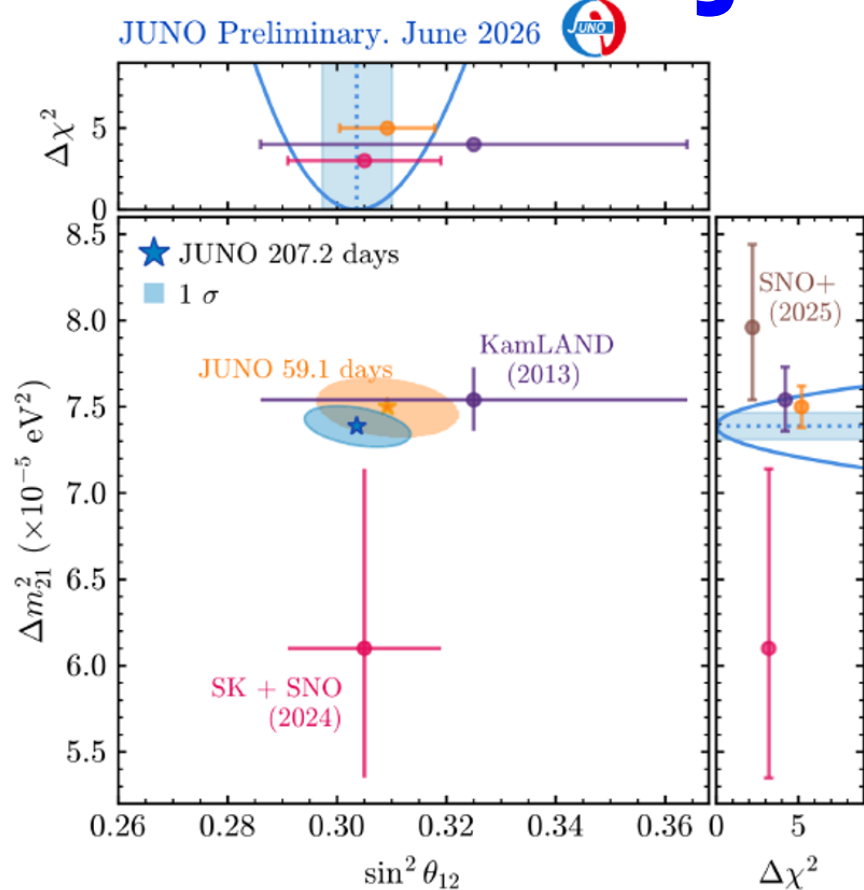
♦ The **global** fit prefers NO **with** $\Delta\chi^2$ (IO-NO) = 7.7

assuming Wilk's theorem: 2.8σ **preference for NO**

Latest JUNO data (207.2 days)

Talk by L. Ludhova

Y. Wang (Neutrino 2026)



$$\Delta m^2_{12} = (7.388 \pm 0.078) \times 10^{-5} \text{ eV}^2 \quad (1.6\% \text{ to } 1.1\%)$$

$$\sin^2 \theta_{12} = 0.3036 \pm 0.0087 \quad (2.8\% \text{ to } 2.1\%)$$

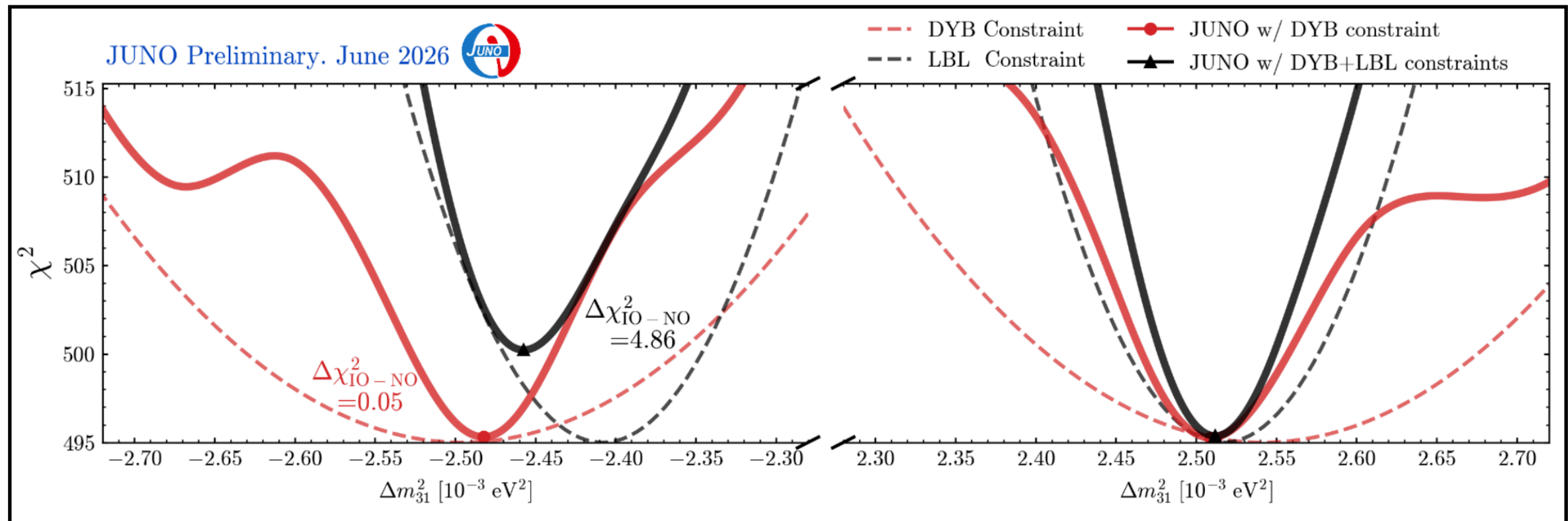
Global precision:

$$\sigma(\Delta m^2_{21}) < 1\% \text{ and } \sigma(\sin^2 \theta_{12}) < 2\%$$

1% precision in Δm^2_{31}

$$\Delta m^2_{31} = (2.509^{+0.027}_{-0.025}) \times 10^{-3} \text{ eV}^2$$

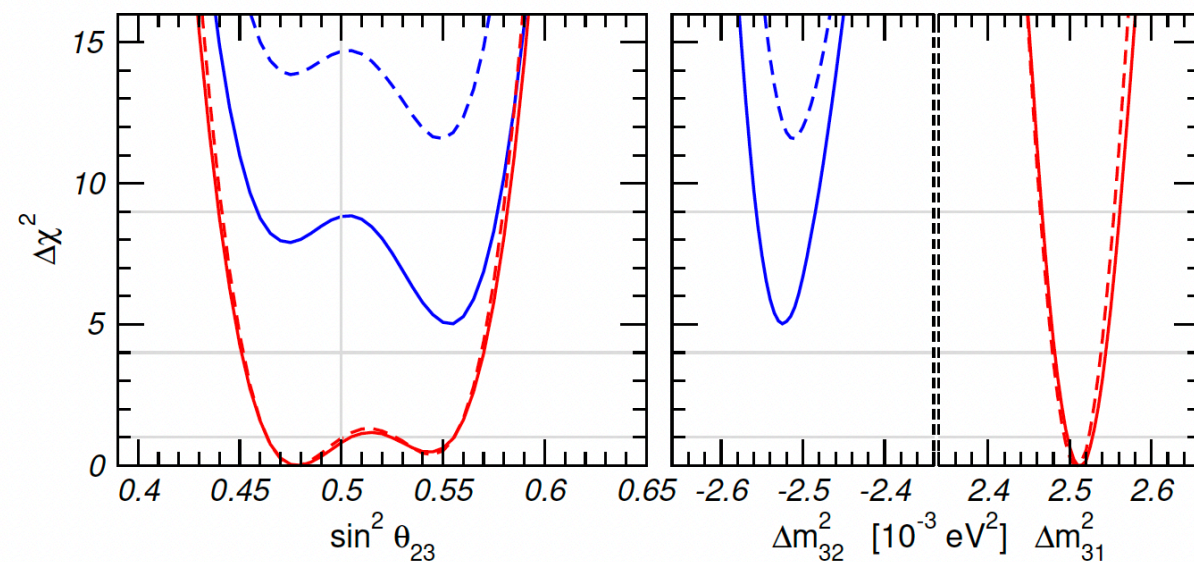
$$\Delta m^2_{31} = (-2.482^{+0.025}_{-0.026}) \times 10^{-3} \text{ eV}^2$$



Latest JUNO data: impact on MO

Combined analysis of JUNO + Daya Bay + LBL prefers NO with $\Delta\chi^2 = 4.86$

◆ Our **LBL + REAC** analysis (without latest JUNO data) prefers NO with $\Delta\chi^2 \approx 1.3$



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

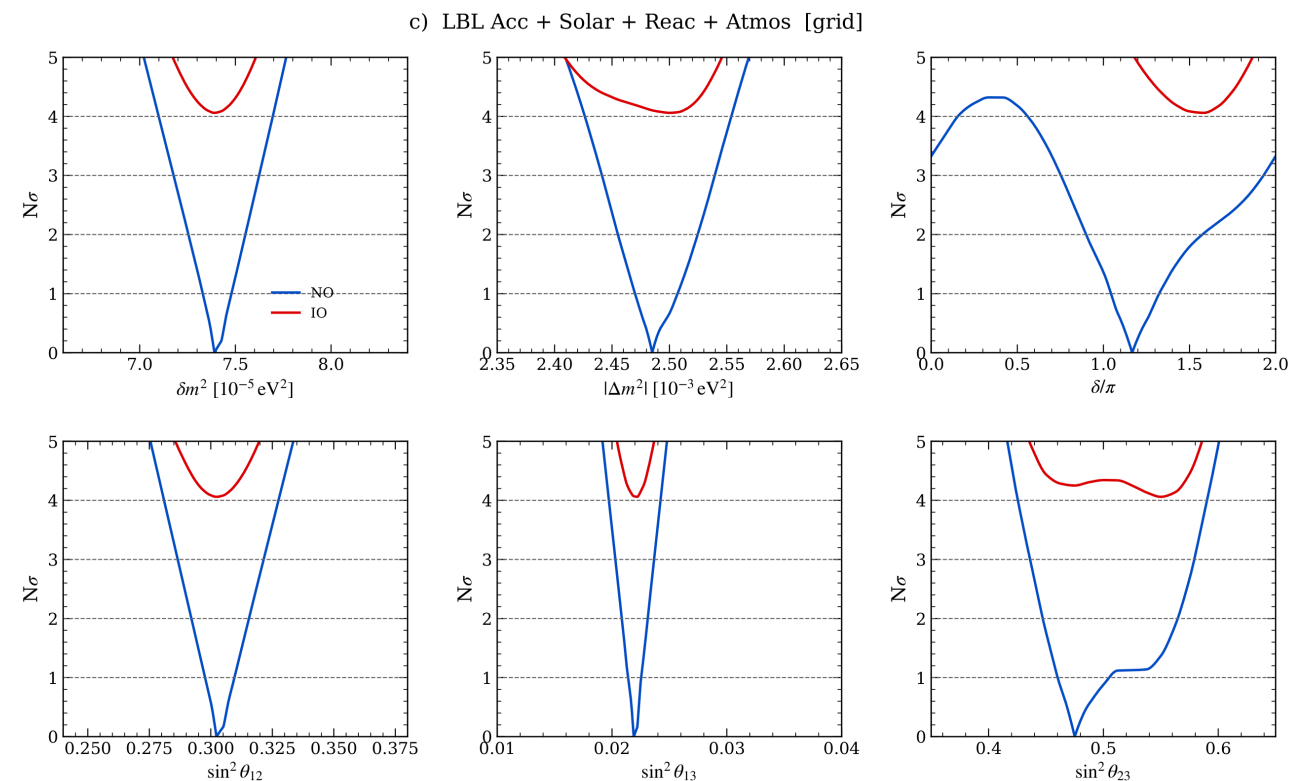
NuFIT 7.0 (prelim)

$$\Delta\chi^2(\text{IO-NO}) = 11.5$$

I. Martinez-Soler, NOW 2026

$$\Delta\chi^2(\text{IO-NO}) = 16$$

F. Marcone, NOW 2026



Summary

- ♦ **Global fits to neutrino oscillations** exploit complementarities of data sets to enhance the sensitivity of individual experiments.
- ♦ From the **updated three-neutrino global fit**:
 - ✓ precise determinations for most parameters ($\sim 1 - 5\%$)
 - ✓ slight preference for $\theta_{23} > 45^\circ$ - LO disfavoured by $\Delta\chi^2 \geq 1.2$ (2.7) for NO (IO)
 - ✓ **normal ordering** preferred over IO with $\Delta\chi^2 = 7.7$ (2.8σ)
 - ✓ $\delta_{\text{BF}} = 1.08\pi$ (1.52π) for NO (IO) ; $\delta = \pi/2$ **disfavored** at 4.2σ (7.5σ) for NO (IO)
- ♦ The tension between **T2K** and **NOvA** impacts the determination of the mass ordering and CP violation.
- ♦ First **JUNO** data established leading precision in solar parameters.

Analysis of latest **JUNO** data in progress: impact in MO sensitivity

Thank you!

The mass ordering

Experimental sensitivity to neutrino masses:

- ♦ ν -oscillations: Δm^2_{ij}
- ♦ β -decay: $m_\beta = f(m_i, \theta_{ij})$ **$m_\beta < 1.1$ eV (90% CL)**
- ♦ $0\nu\beta\beta$: $m_{\beta\beta} = f(m_i, \theta_{ij}, \phi_i)$
- ♦ Cosmology: Σm_i **$\Sigma m_\nu < 0.12$ (0.15) eV NO (IO) (95%CL)**

Results from the combined bayesian analysis:

- ⇒ weak/moderate preference for NO driven by oscillation data (2.0σ)
- ⇒ β -decay and $0\nu\beta\beta$ have little impact on MO.
- ⇒ cosmological data enhances the preference for NO from 2.0σ to 2.7σ

de Salas et al, JHEP 02 (2021) 071

