3ν MASSES AND MIXING: THE GLOBAL PICTURE

Concha Gonzalez-Garcia

(ICREA U. Barcelona & YITP Stony Brook)

SnowMass2021:NF01: Neutrino Oscillations. Sept 3rd, 2020

Global fit to neutrino oscillation data http://www.nu-fit.org

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, 24 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 408-day low-E spect, 42 points.

Reactor experiments

- KamLAND DS1,DS2&DS3 spectra with Daya-Bay fluxes 69 points
- **DChooz FD/ND ratios Kwith 1276-day (FD) and 587-day (ND) exposures , 26 points**.
- Daya-Bay 1958-day EH2/EH1 & EH3/EH1 ratios,52 points.
- **NU2020 Reno 2908-day FD/ND ratios 45 points.**

Atmospheric experiments

- IceCube/DeepCore 3-year data, 64 points.
- *SK I-IV 328 kton-years χ^2 table provided by SK*.

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** 19.7×10^{20} **pot ν_μ-disapp data, 35 points.**
- **T2K** 19.7×10^{20} **pot ν_e-app data, 23 points CCQE and 16 points CC1π.**
- **T2K** 16.3×10^{20} **pot $\bar{\nu}_\mu$-disapp, 35 points.**
- **T2K** 16.3×10^{20} **pot $\bar{\nu}_e$-app, 23 points.**
- **NOνA** 13.6×10^{20} **pot ν_μ-disapp data , 76 points.**
- **NOνA** 13.6×10^{20} **pot ν_e-app data , 13 points.**
- **NOνA** 12.5×10^{20} **pot $\bar{\nu}_\mu$-disapp, 76 points.**
- **NOνA** 12.5×10^{20} **pot $\bar{\nu}_e$-app, 13 points.**

3ν Flavour Parameters

Concha Gonzalez-Garcia

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

$$U_{\rm LEP} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{i\delta_{\rm cp}} \\ 0 & 1 & 0 \\ -s_{13}e^{-i\delta_{\rm cp}} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{21} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \cancel{\begin{pmatrix} e^{i\eta_1} & 0 & 0 \\ 0 & e^{i\eta_2} & 0 \\ 0 & 0 & 1 \end{pmatrix}}$$

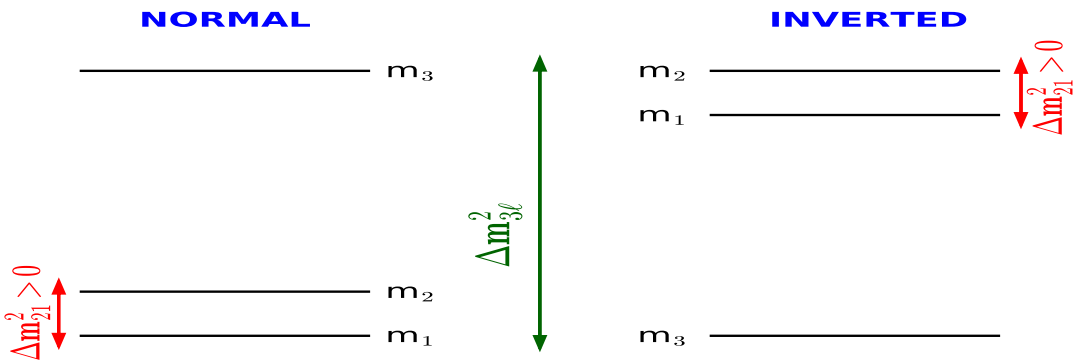
3ν Flavour Parameters

Concha Gonzalez-Garcia

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

$$U_{\rm LEP} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{i\delta_{\rm cp}} \\ 0 & 1 & 0 \\ -s_{13}e^{-i\delta_{\rm cp}} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{21} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \cancel{\begin{pmatrix} e^{i\eta_1} & 0 & 0 \\ 0 & e^{i\eta_2} & 0 \\ 0 & 0 & 1 \end{pmatrix}}$$

- Convention: $0 \leq \theta_{ij} \leq 90^\circ \quad 0 \leq \delta \leq 360^\circ \quad \Rightarrow$ 2 Orderings



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

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

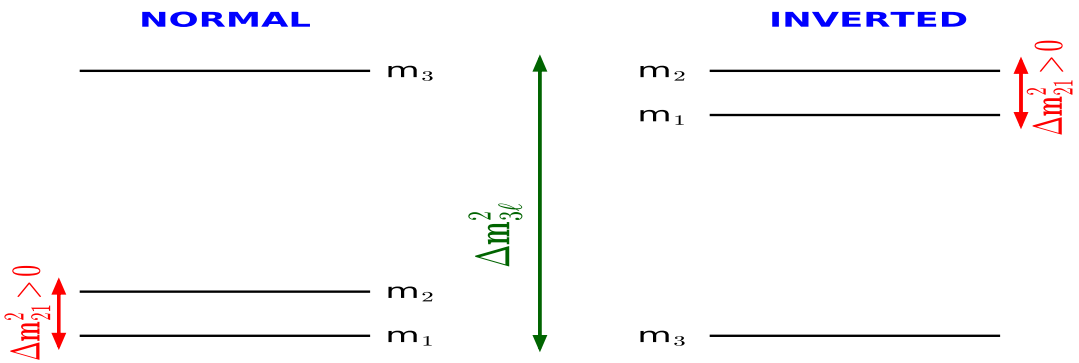
3ν Flavour Parameters

Concha Gonzalez-Garcia

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

$$U_{\rm LEP} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{i\delta_{\rm cp}} \\ 0 & 1 & 0 \\ -s_{13}e^{-i\delta_{\rm cp}} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{21} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \cancel{\begin{pmatrix} e^{i\eta_1} & 0 & 0 \\ 0 & e^{i\eta_2} & 0 \\ 0 & 0 & 1 \end{pmatrix}}$$

- Convention: $0 \leq \theta_{ij} \leq 90^\circ \quad 0 \leq \delta \leq 360^\circ \quad \Rightarrow$ 2 Orderings



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

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

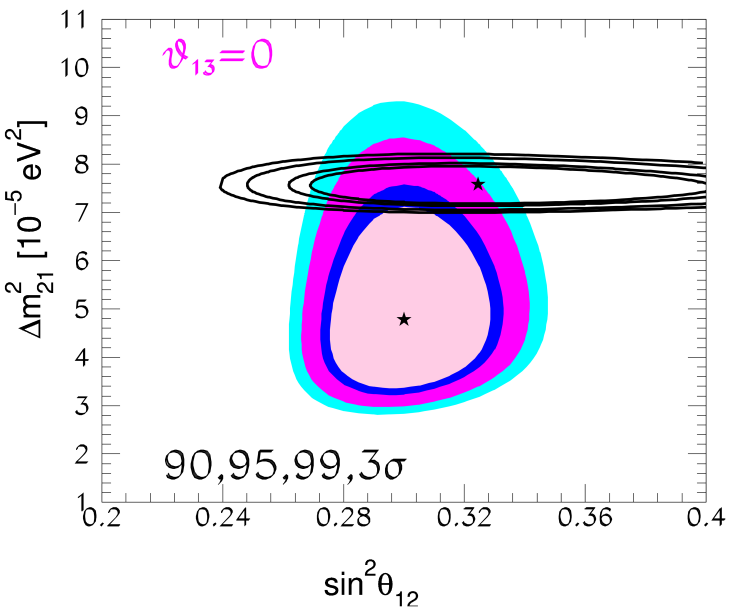
Experiment	Dominant Dependence	Important Dependence
Solar Experiments	θ_{12}	Δm^2_{21} , θ_{13}
Reactor LBL (KamLAND)	Δm^2_{21}	θ_{12} , θ_{13}
Reactor MBL (Daya Bay, Reno, D-Chooz)	θ_{13} $\Delta m^2_{3\ell}$	
Atmospheric Experiments (SK,IC)		θ_{23}, $\Delta m^2_{3\ell}$, θ_{13} ,$\delta_{\rm cp}$
Acc LBL ν_μ Disapp (Minos,T2K,NOvA)	$\Delta m^2_{3\ell}$ θ_{23}	
Acc LBL ν_e App (Minos,T2K,NOvA)	$\delta_{\rm cp}$	θ_{13}, θ_{23}

Issues in 3 ν Analysis: Δm^2_{21} KamLAND vs SOLAR

- $\Delta m^2_{13} \gg E/L \Rightarrow$ $P^{3\nu}_{ee} = c^4_{13} P_{2\nu} + s^4_{13}$

$$i\frac{d}{dt}\begin{pmatrix} \nu_e \\ \nu_a \end{pmatrix} = \left[\frac{\Delta m^2_{21}}{4E}\begin{pmatrix} -\cos 2\theta_{12} & \sin 2\theta_{12} \\ \sin 2\theta_{12} & \cos 2\theta_{12} \end{pmatrix} \pm \sqrt{2} G_F N_e \begin{pmatrix} c^2_{13} & 0 \\ 0 & 0 \end{pmatrix}\right]\begin{pmatrix} \nu_e \\ \nu_a \end{pmatrix}$$

- OLD ANALYSIS: With $\theta_{13} = 0$

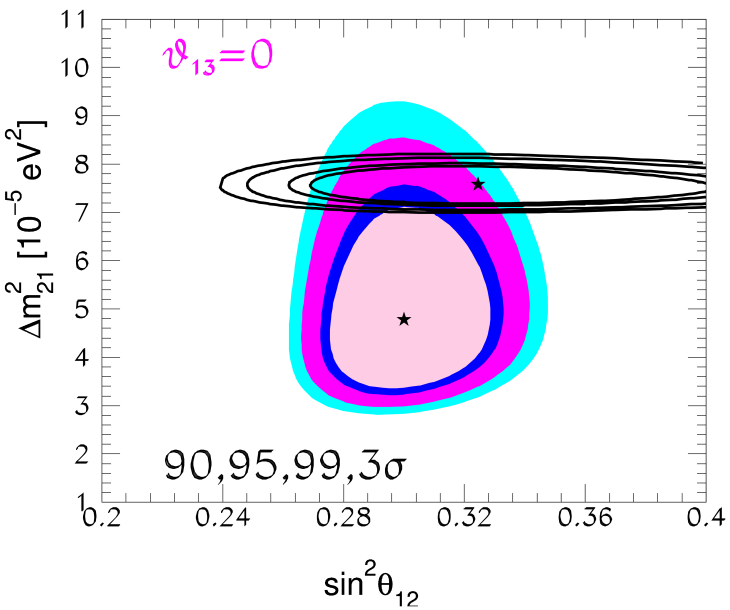


Issues in 3 ν Analysis: Δm^2_{21} KamLAND vs SOLAR

- $\Delta m^2_{13} \gg E/L \Rightarrow$ $P^{3\nu}_{ee} = c^4_{13} P_{2\nu} + s^4_{13}$

$$i\frac{d}{dt}\begin{pmatrix}\nu_e\\ \nu_a\end{pmatrix} = \left[\frac{\Delta m^2_{21}}{4E}\begin{pmatrix}-\cos 2\theta_{12} & \sin 2\theta_{12}\\ \sin 2\theta_{12} & \cos 2\theta_{12}\end{pmatrix} \pm \sqrt{2}G_F N_e \begin{pmatrix}c^2_{13} & 0\\ 0 & 0\end{pmatrix}\right]\begin{pmatrix}\nu_e\\ \nu_a\end{pmatrix}$$

- OLD ANALYSIS: With $\theta_{13} = 0$



- When θ_{13} increases

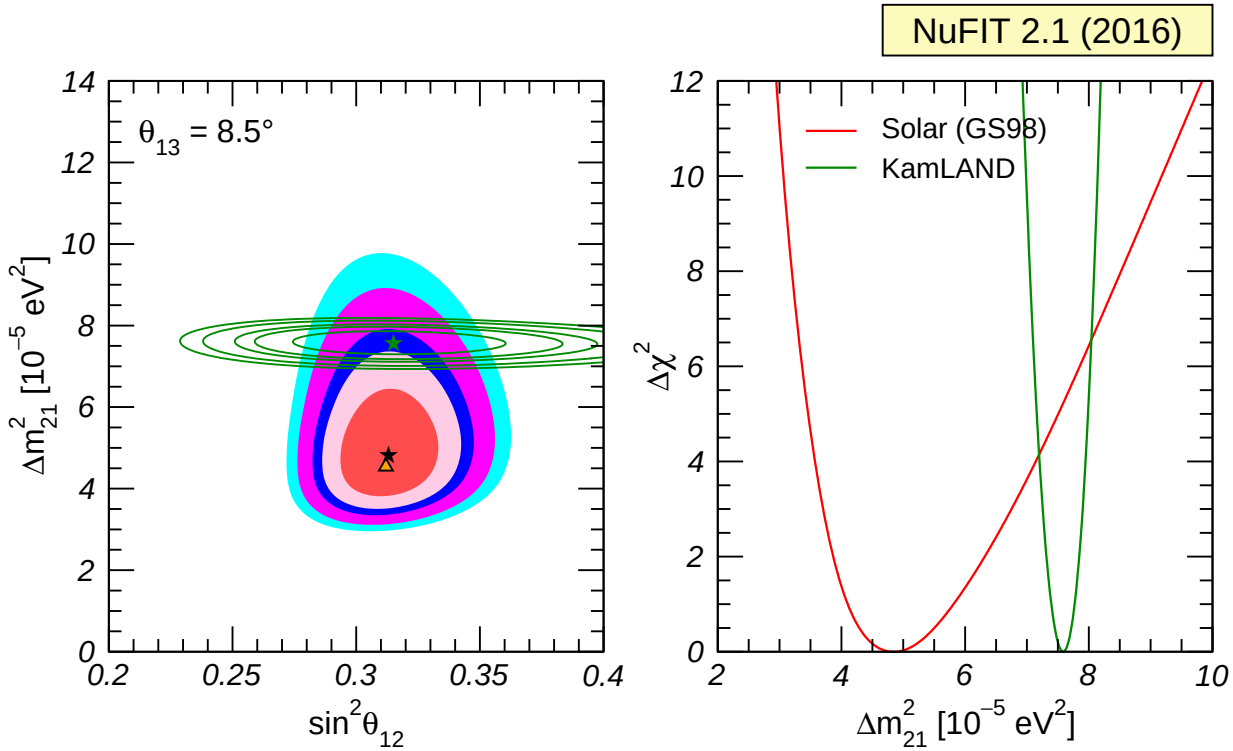
$$P_{ee} \simeq \begin{cases} \text{Solar High E}: c^4_{13}\sin^2 2\theta_{12} \\ \text{Solar Low E}: c^4_{13}\left(1-\sin^2 2\theta_{12}/2\right) \\ \text{Kam}: c^4_{13}\left(1-\sin^2 2\theta_{12}\sin^2\frac{\Delta m^2_{21}L}{4E}\right)\end{cases}$$

$\Rightarrow$ KamLAND region shifts left

$\Rightarrow$ Solar slight shifts right (SK/SNO)

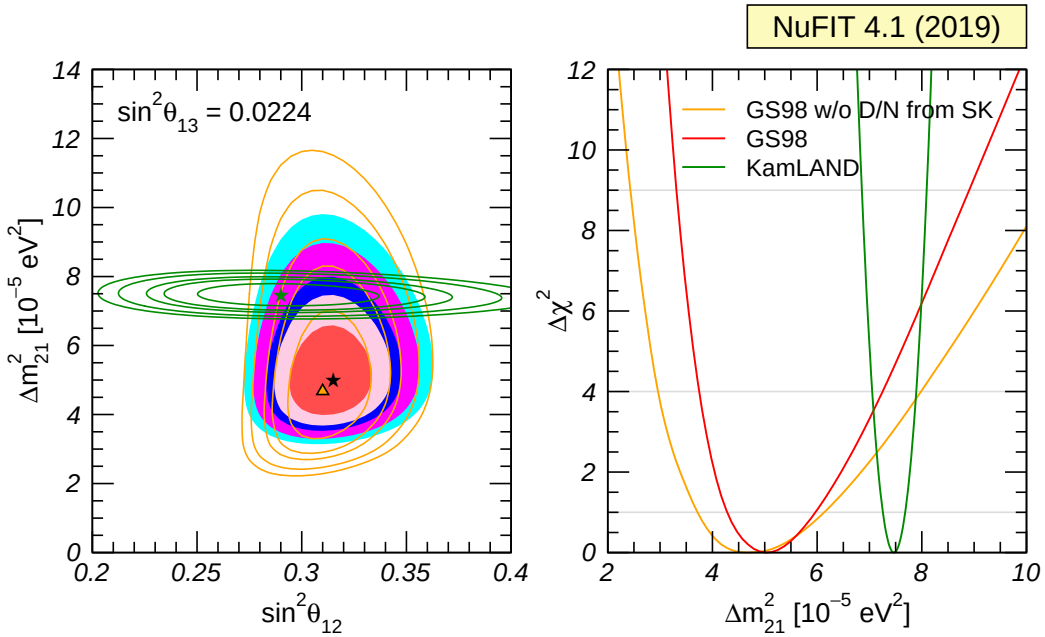
Issues in 3 ν Analysis: Δm^2_{21} KamLAND vs SOLAR

- Last decade: $\theta_{13} \simeq 9^\circ$ θ_{12} OK. But $\sim 2\sigma$ tension on Δm^2_{12}



• BEFORE NU2020: With SK4 2055 days D/N and 2860 day spectrum

Concha Gonzalez-Garcia

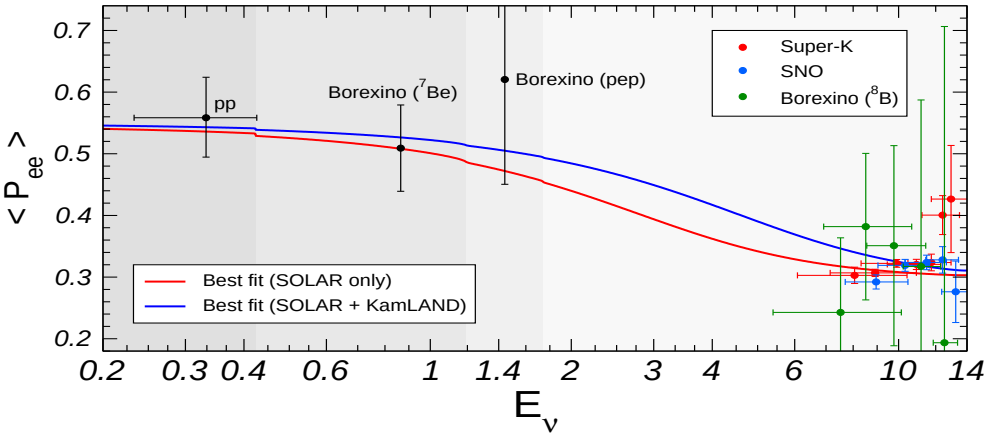


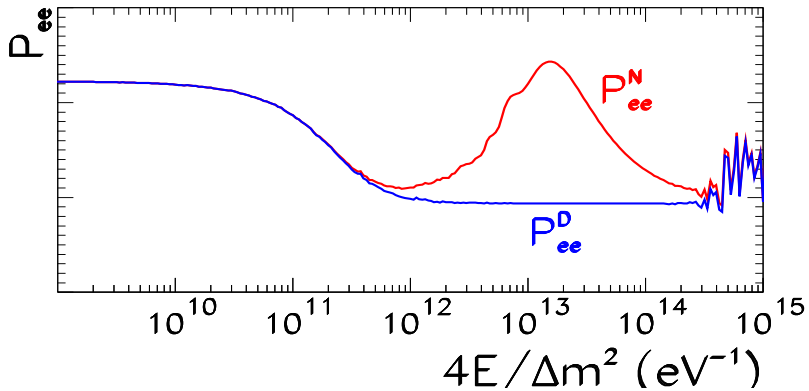
• Tension arising from:

Smaller-than-expected low-E turn-up in SK/SNO from MSW at global b.f.

"too large" of Day/Night at SK

$A_{\mathrm{D/N,SK4-2055}} = [-3.1 \pm 1.6(\mathrm{stat.}) \pm 1.4(\mathrm{sys.})]\%$

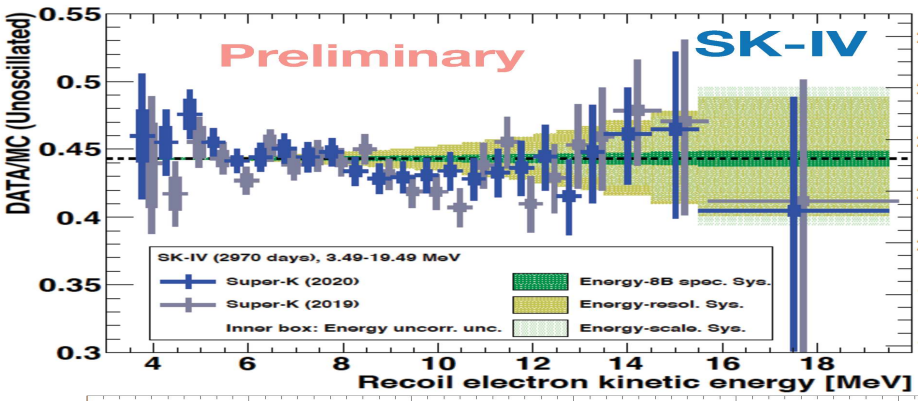




⇒ "hint" of NP in propagation: NSI?

- AFTER NU2020: With SK4 2970 days data

Slightly more pronouncced low-E turn-up



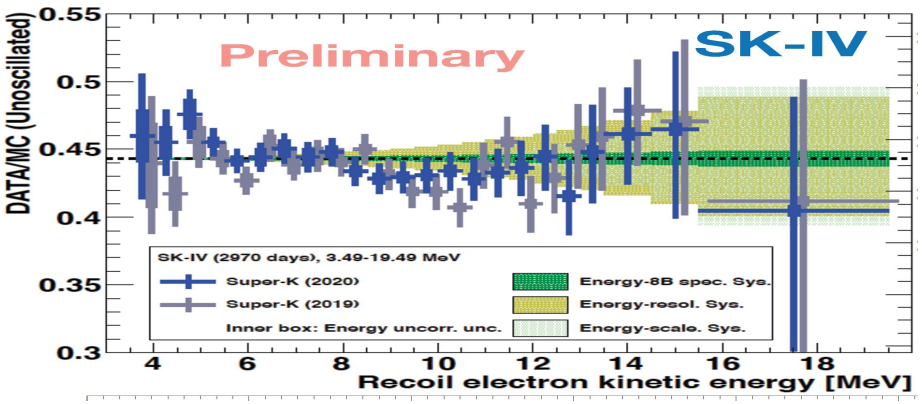
Smaller of Day/Night at

$$A_{\mathrm{D/N,SK4-2055}} = [-3.1 \pm 1.6(\mathrm{stat.}) \pm 1.4(\mathrm{sys.})]\%$$

$$A_{\mathrm{D/N,SK4-2970}} = [-2.1 \pm 1.1]\%$$

- AFTER NU2020: With SK4 2970 days data

Slightly more pronouncced low-E turn-up

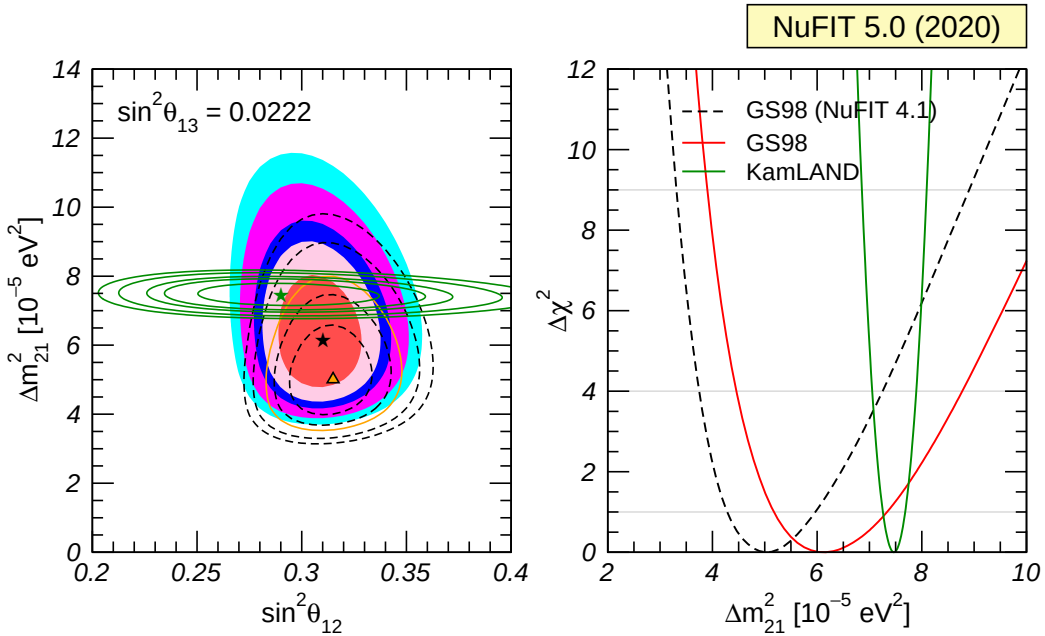


Smaller of Day/Night at

$$A_{\mathrm{D/N,SK4-2055}} = [-3.1 \pm 1.6(\mathrm{stat.}) \pm 1.4(\mathrm{sys.})]\%$$

$$A_{\mathrm{D/N,SK4-2970}} = [-2.1 \pm 1.1]\%$$

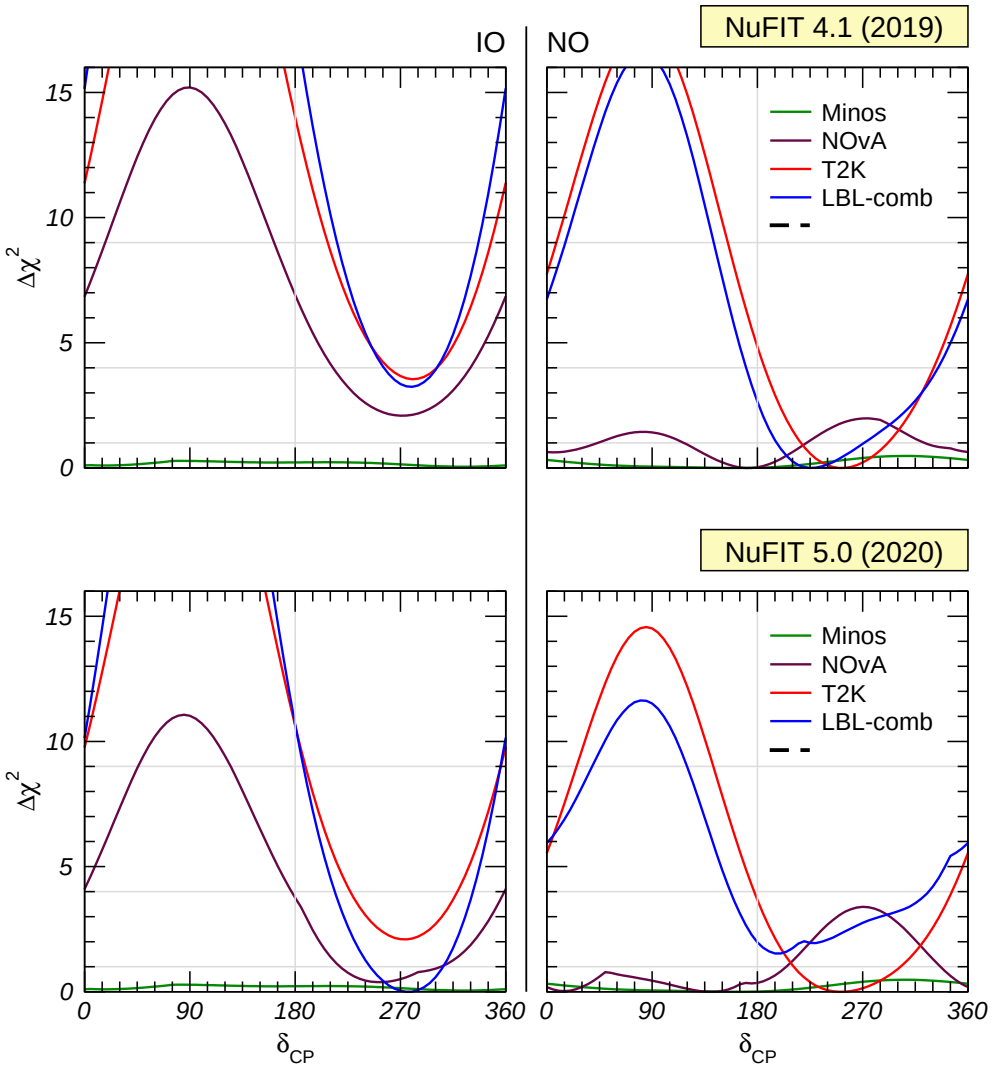
- In NuFIT 5.0



$\Rightarrow$ Agreement of Δm^2_{21} between solar and KamLAND at 1 σ

3 ν Analysis: CPV and Ordering in LBL

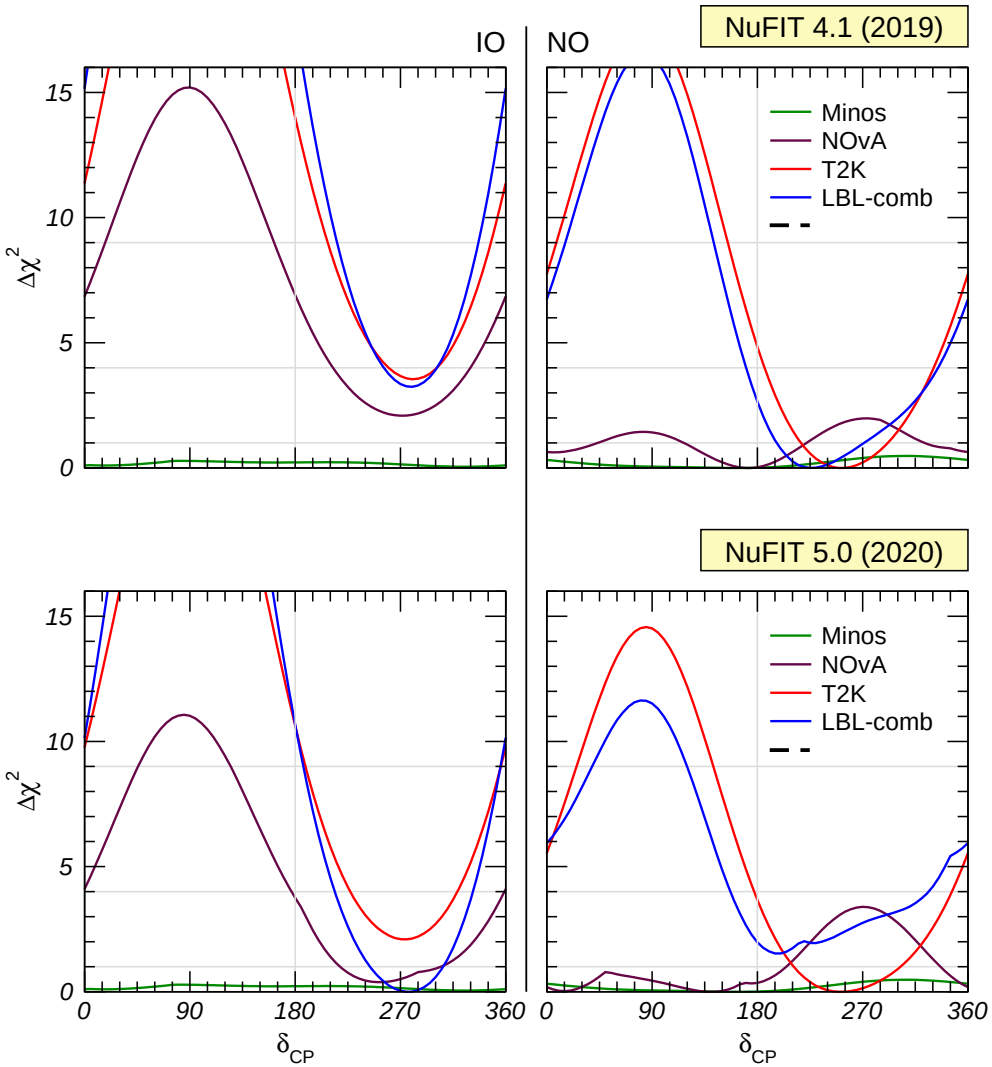
$\sin^2\theta_{13} = 0.0224$. Marg. $\Delta m^2_{3\ell}$ and θ_{23}



- Samples 4.1 $\Rightarrow$ 5.0
  - T2K ν $14.93 \times 10^{20} \Rightarrow 19.7 \times 10^{20}$ pot
  - T2K $\bar{\nu}$ 16.3×10^{20} pot (same)
  - NOνA ν $8.85 \times 10^{20} \Rightarrow 13.6 \times 10^{20}$
  - NOνA $\bar{\nu}$ $12.33 \times 10^{20} \Rightarrow 12.5 \times 10^{20}$

3 ν Analysis: CPV and Ordering in LBL

$\sin^2\theta_{13} = 0.0224$. Marg. $\Delta m^2_{3\ell}$ and θ_{23}

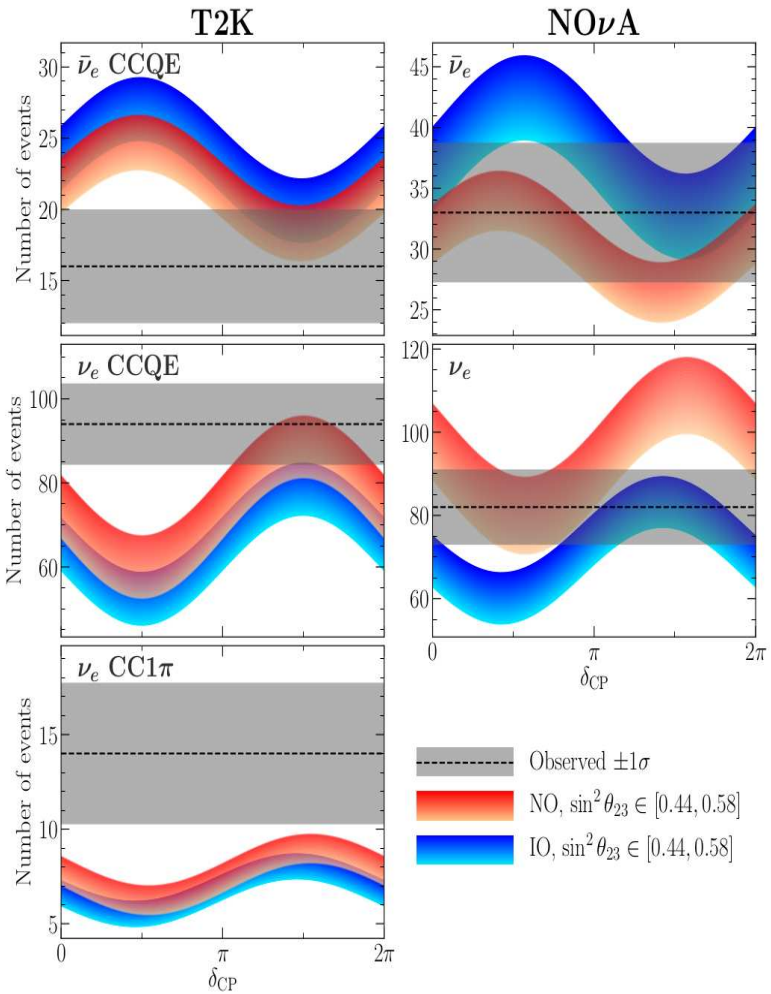


- Samples 4.1 $\Rightarrow$ 5.0
  - T2K ν $14.93 \times 10^{20} \Rightarrow 19.7 \times 10^{20}$ pot
  - T2K $\bar{\nu}$ 16.3×10^{20} pot (same)
  - NOνA ν $8.85 \times 10^{20} \Rightarrow 13.6 \times 10^{20}$
  - NOνA $\bar{\nu}$ $12.33 \times 10^{20} \Rightarrow 12.5 \times 10^{20}$
- CPV & Ordering "hints": 4.1 $\Rightarrow$ 5.0

T2K	$\Delta\chi^2_{\mathrm{NO-IO}}$	$3.5 \Rightarrow 2.1$
	$\Delta\chi^2_{\mathrm{CPC,NO}}$	$4.8 \Rightarrow 3.7$
	$\Delta\chi^2_{\mathrm{CPC,IO}}$	$8.0 \Rightarrow 7.8$
NOνA	$\Delta\chi^2_{\mathrm{NO-IO}}$	$2.1 \Rightarrow 0.4$
	$\Delta\chi^2_{\mathrm{CPC,NO}}$	$0.03 \Rightarrow 0.03$
	$\Delta\chi^2_{\mathrm{CPC,IO}}$	$4.8 \Rightarrow 3.4$
LBL-COMB	$\Delta\chi^2_{\mathrm{NO-IO}}$	$3.3 \Rightarrow -1.5$
	$\Delta\chi^2_{\mathrm{CPC,NO}}$	$2.6 \Rightarrow 0.4$
	$\Delta\chi^2_{\mathrm{CPC,IO}}$	$11.8 \Rightarrow 10.1$

Total apperance events

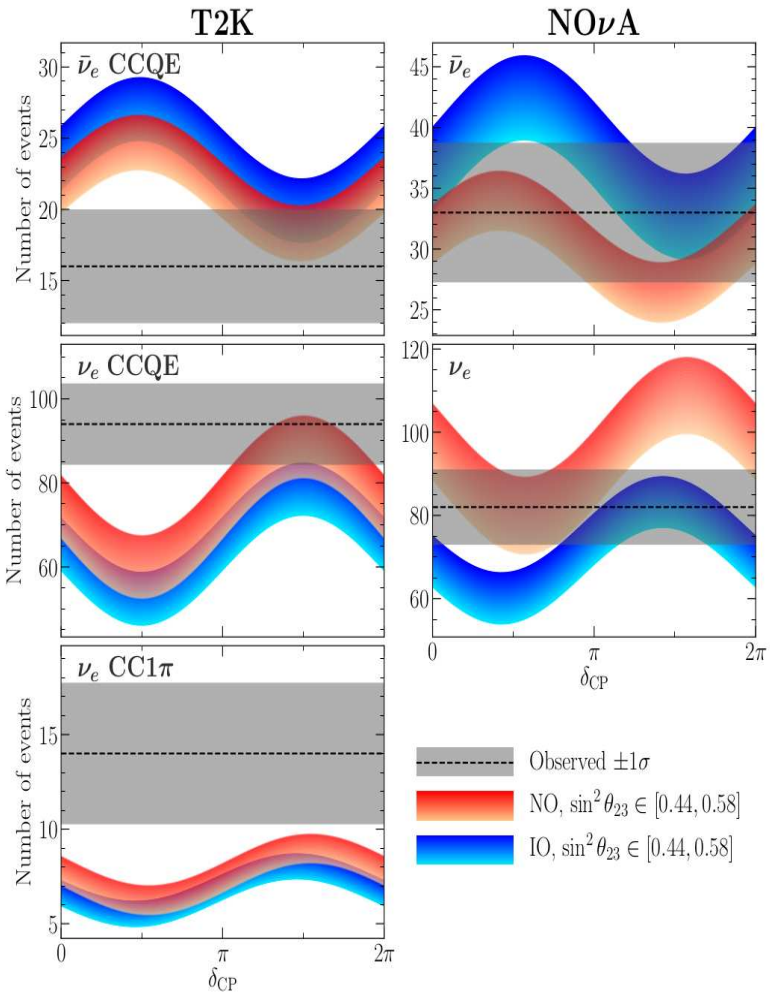
	T2K-ν			T2K-$\bar{\nu}$	NOvA-ν	NOvA-$\bar{\nu}$
	CCQE	CC1π	sum			
$N_{\rm obs}$	94	14	108	16	82	33
$N_{\rm obs} - N_{\rm bck}$	76	12.1	88.1	9.8	55.2	19



In Fig $s^2_{13} = 0.0224$, $|\Delta m^2_{3\ell}| = 2.5 \times 10^{-3}$ eV^2

Total apperance events

	T2K-ν			T2K-$\bar{\nu}$	NOvA-ν	NOvA-$\bar{\nu}$
	CCQE	CC1π	sum			
$N_{\rm obs}$	94	14	108	16	82	33
$N_{\rm obs} - N_{\rm bck}$	76	12.1	88.1	9.8	55.2	19



In Fig $s^2_{13} = 0.0224$, $|\Delta m^2_{3\ell}| = 2.5 \times 10^{-3}$ eV^2

Qualitatively in each ordering $o \equiv {\rm sgn}(\Delta m^2_{3\ell})$

$$N_{\nu_e} \approx \mathcal{N}_\nu \left[2 s^2_{23}(1+oA) - C \sin\delta_{\rm CP}(1+oA)\right] ,$$
$$N_{\bar{\nu}_e} \approx \mathcal{N}_{\bar{\nu}} \left[2 s^2_{23}(1-2oA) + C \sin\delta_{\rm CP}(1-oA)\right] .$$

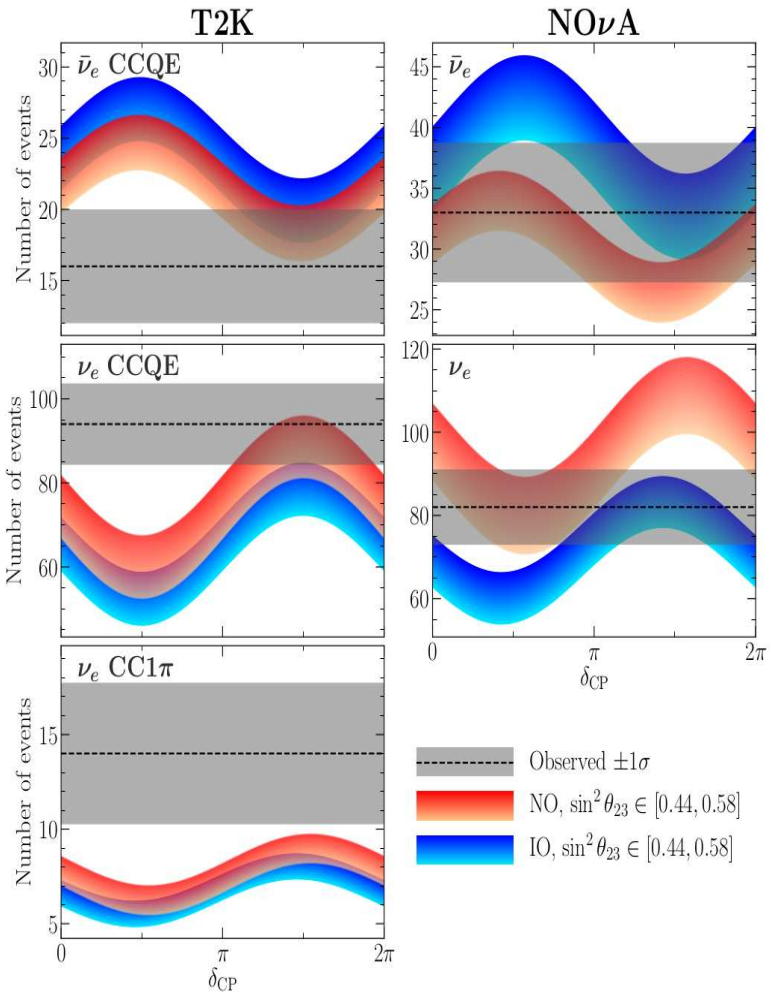
$C \sim \langle \frac{\Delta m^2_{21} L}{4E_\nu} \rangle s_{2\theta_{12}} s_{2\theta_{13}} s_{2\theta_{23}} \simeq 0.28$ for T2K or NOνA

$A \equiv \langle | \frac{2E_\nu V}{\Delta m^2_{3\ell}} | \rangle \simeq 0.05$ (T2K) & 0.1 (NOνA)

	T2K-ν			T2K-$\bar{\nu}$	NOvA-ν	NOvA-$\bar{\nu}$
	CCQE	CC1π	sum			
$\mathcal{N}$	48.5	5	53.5	16	48.5	23
$r = \frac{N_{\rm obs} - N_{\rm bck}}{\mathcal{N}}$	1.6 (1.5)	2.4 (3.6)	1.65 (1.71)	0.61 (0.7)	1.14 (1.3)	0.83 (0.7)

Total apperance events

	T2K-ν			T2K-$\bar\nu$	NOvA-ν	NOvA-$\bar\nu$
	CCQE	CC1π	sum			
$N_{\rm obs}$	94	14	108	16	82	33
$N_{\rm obs} - N_{\rm bck}$	76	12.1	88.1	9.8	55.2	19



In Fig $s^2_{13} = 0.0224$, $|\Delta m^2_{3\ell}| = 2.5 \times 10^{-3}$ eV^2

Qualitatively in each ordering $o \equiv {\rm sgn}(\Delta m^2_{3\ell})$

$$N_{\nu_e} \approx \mathcal{N}_\nu \left[2 s^2_{23}(1+oA) - C \sin\delta_{\rm CP}(1+oA)\right] ,$$
$$N_{\bar\nu_e} \approx \mathcal{N}_{\bar\nu} \left[2 s^2_{23}(1-2oA) + C \sin\delta_{\rm CP}(1-oA)\right] .$$

$C \sim \langle \frac{\Delta m^2_{21} L}{4E_\nu} \rangle s_{2\theta_{12}} s_{2\theta_{13}} s_{2\theta_{23}} \simeq 0.28$ for T2K or NOνA

$A \equiv \langle | \frac{2E_\nu V}{\Delta m^2_{3\ell}} | \rangle \simeq 0.05$ (T2K) & 0.1 (NOνA)

	T2K-ν			T2K-$\bar\nu$	NOvA-ν	NOvA-$\bar\nu$
	CCQE	CC1π	sum			
$\mathcal{N}$	48.5	5	53.5	16	48.5	23
$r = \frac{N_{\rm obs} - N_{\rm bck}}{\mathcal{N}}$	1.6 (1.5)	2.4 (3.6)	1.65 (1.71)	0.61 (0.7)	1.14 (1.3)	0.83 (0.7)

T2K:

– $r_\nu > 1$ ($r_{\bar\nu} < 1$)

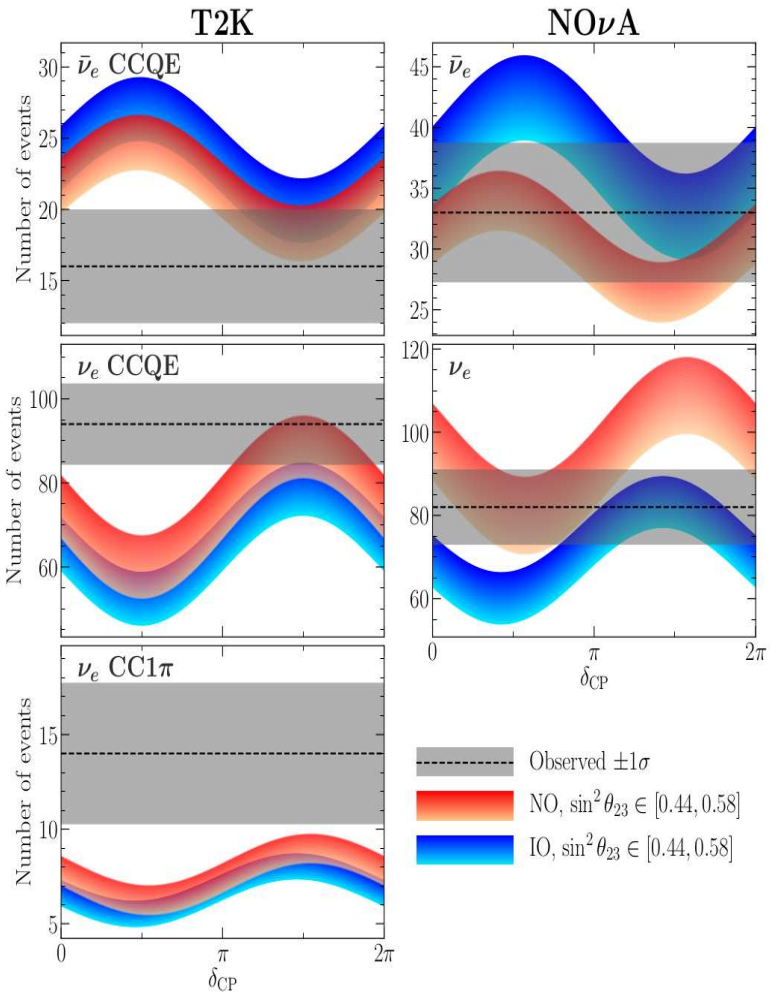
$\Rightarrow [2 s^2_{23} \ldots]$ enhanced (suppresed) $\Rightarrow$ NO with $\delta_{\rm CP} \sim 270^\circ$

– CC1π-ν larger excess

– tendency weaker after NU2020

Total apperance events

	T2K-ν			T2K-$\bar{\nu}$	NOvA-ν	NOvA-$\bar{\nu}$
	CCQE	CC1π	sum			
$N_{\rm obs}$	94	14	108	16	82	33
$N_{\rm obs} - N_{\rm bck}$	76	12.1	88.1	9.8	55.2	19



In Fig $s^2_{13} = 0.0224$, $|\Delta m^2_{3\ell}| = 2.5 \times 10^{-3}$ eV^2

Qualitatively in each ordering $o \equiv {\rm sgn}(\Delta m^2_{3\ell})$

$$N_{\nu_e} \approx \mathcal{N}_\nu \left[2 s^2_{23}(1+oA) - C \sin\delta_{\rm CP}(1+oA)\right] ,$$
$$N_{\bar{\nu}_e} \approx \mathcal{N}_{\bar{\nu}} \left[2 s^2_{23}(1-2oA) + C \sin\delta_{\rm CP}(1-oA)\right] .$$

$C \sim \langle \frac{\Delta m^2_{21} L}{4E_\nu} \rangle s_{2\theta_{12}} s_{2\theta_{13}} s_{2\theta_{23}} \simeq 0.28$ for T2K or NOνA

$A \equiv \langle | \frac{2E_\nu V}{\Delta m^2_{3\ell}} | \rangle \simeq 0.05$ (T2K) & 0.1 (NOνA)

	T2K-ν			T2K-$\bar{\nu}$	NOvA-ν	NOvA-$\bar{\nu}$
	CCQE	CC1π	sum			
$\mathcal{N}$	48.5	5	53.5	16	48.5	23
$r = \frac{N_{\rm obs} - N_{\rm bck}}{\mathcal{N}}$	1.6 (1.5)	2.4 (3.6)	1.65 (1.71)	0.61 (0.7)	1.14 (1.3)	0.83 (0.7)

T2K:

– $r_\nu > 1$ ($r_{\bar{\nu}} < 1$)

$\Rightarrow [2 s^2_{23} \ldots]$ enhanced (suppresed) $\Rightarrow$ NO with $\delta_{\rm CP} \sim 270^\circ$

– CC1π-ν larger excess

– tendency weaker after NU2020

NOνA':

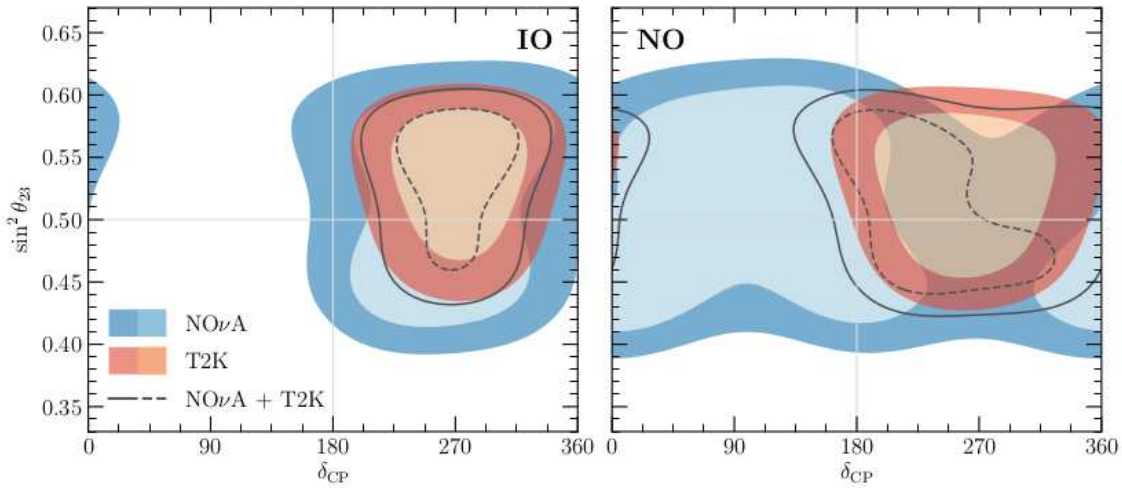
– $r_\nu \simeq 1 \Rightarrow$ NO with $\delta_{\rm CP} \sim 90^\circ$ or IO with $\delta_{\rm CP} \sim 270^\circ$

– consitent with NOνA-$\bar{\nu}$ but "tension" with T2K in NO

$\Rightarrow$ IO favoured in T2K+NOνA Combination

3ν Analysis: Compatibility T2K/NOνA

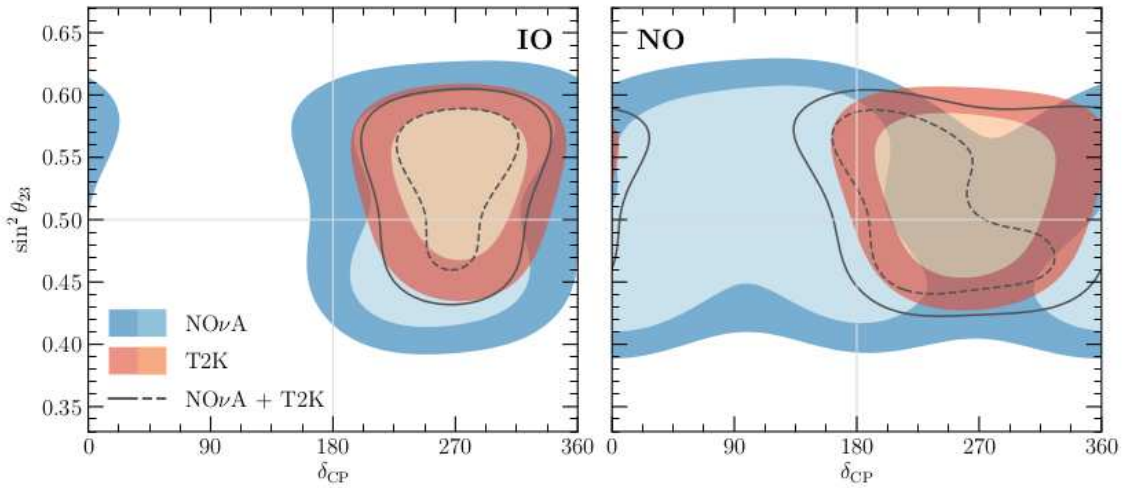
- 1 and 2 σ (2dof) allowed regions (for $s^2_{13} = 0.0224$, marg over $|\Delta m^2_{3\ell}|$)



$\Rightarrow$ Better agreement in IO but NO 1σ regions "touch"

3ν Analysis: Compatibility T2K/NOνA

- 1 and 2 σ (2dof) allowed regions (for $s^2_{13} = 0.0224$, marg over $|\Delta m^2_{3\ell}|$)



$\Rightarrow$ Better agreement in IO but NO 1σ regions "touch"

- Parameter goodness-of-fit (PG) test:

$$\chi^2_{\rm PG} = \chi^2_{\rm min,comb} - \sum_i \chi^2_{{\rm min},i} \text{ follows } \chi^2 \text{ dist with } n = \sum_i n_i - n_{\rm comb} \text{ dof}$$

	normal ordering			inverted ordering		
	$\chi^2_{\rm PG}/n$	p-value	#σ	$\chi^2_{\rm PG}/n$	p-value	#σ
T2K vs NOvA (θ_{13} free)	6.7/4	0.15	1.4σ	3.6/4	0.46	0.7σ
T2K vs NOvA (θ_{13} fix)	6.5/3	0.088	1.7σ	2.8/3	0.42	0.8σ

No significant incompatibility

3 ν Analysis: Δm^2_{3l} in LBL & Reactors

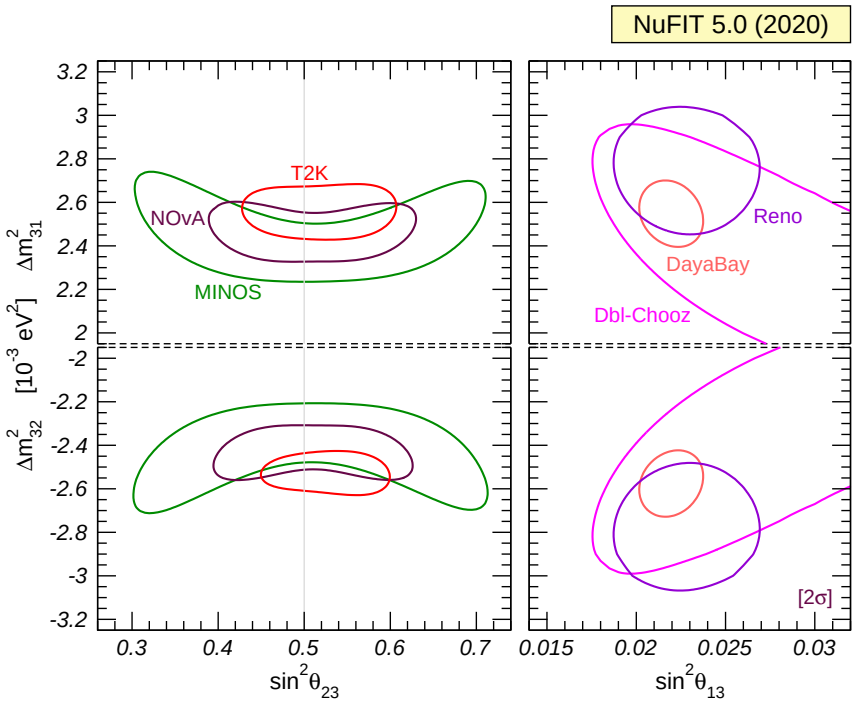
- At LBL determined in ν_μ and $\bar{\nu}_\mu$ disapperance spectrum

$$\Delta m^2_{\mu\mu} \simeq \Delta m^2_{3l} + {}^{c^2_{12}\Delta m^2_{21}\ \text{NO}}_{s^2_{12}\Delta m^2_{21}\ \text{IO}} + \ldots$$

- At MBL Reactors (Daya-Bay, Reno, D-Chooz) determined in $\bar{\nu}_e$ disapp spectrum

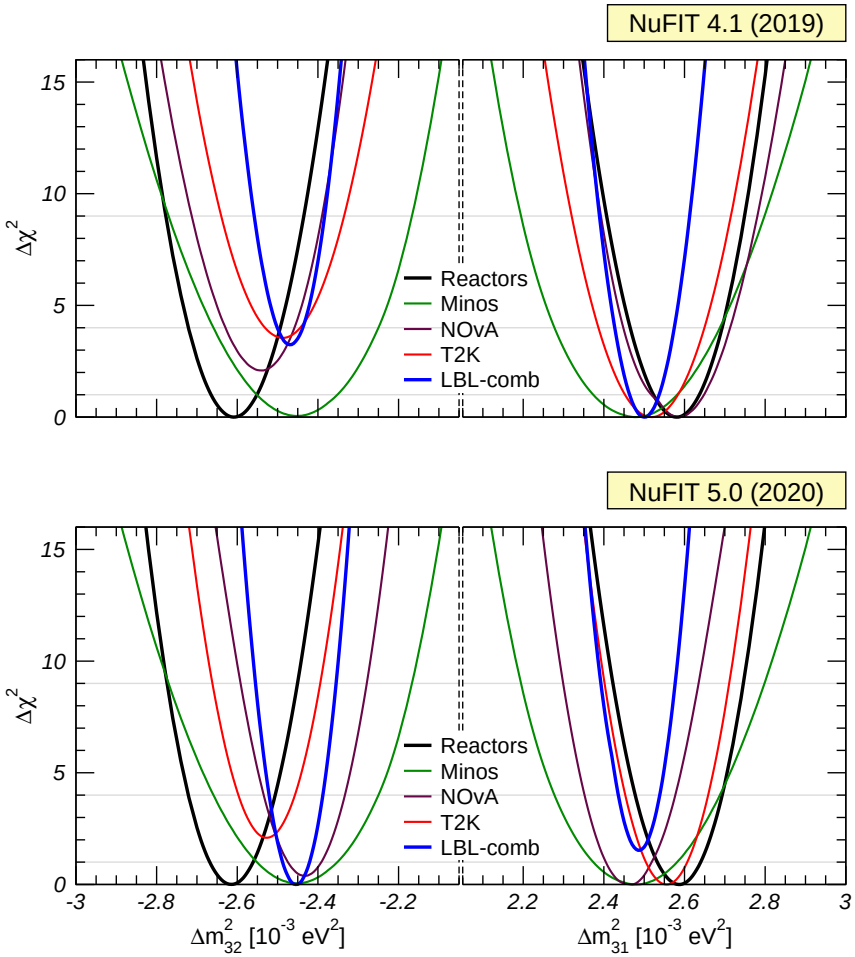
$$\Delta m^2_{ee} \simeq \Delta m^2_{3l} + {}^{s^2_{12}\Delta m^2_{21}\ \text{NO}}_{c^2_{12}\Delta m^2_{21}\ \text{IO}}$$

Nunokawa,Parke,Zukanovich (2005)



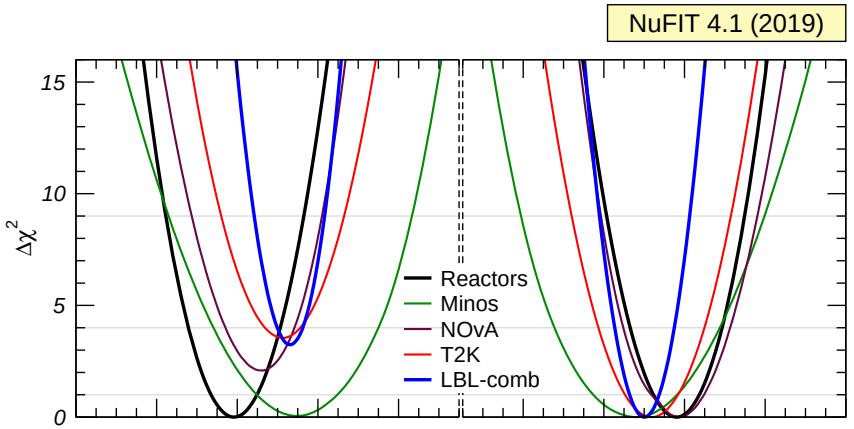
$\Rightarrow$ Contribution to NO/IO
from combination with reactor data

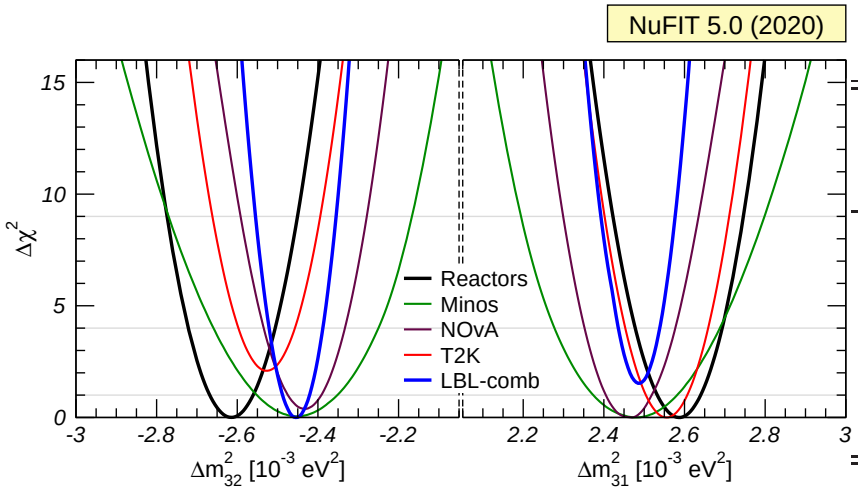
3 ν Analysis: Δm^2_{3l} in LBL & Reactors



$\Rightarrow$ LBL & REAC more compatible in NO

3 ν Analysis: Δm^2_{3l} in LBL & Reactors

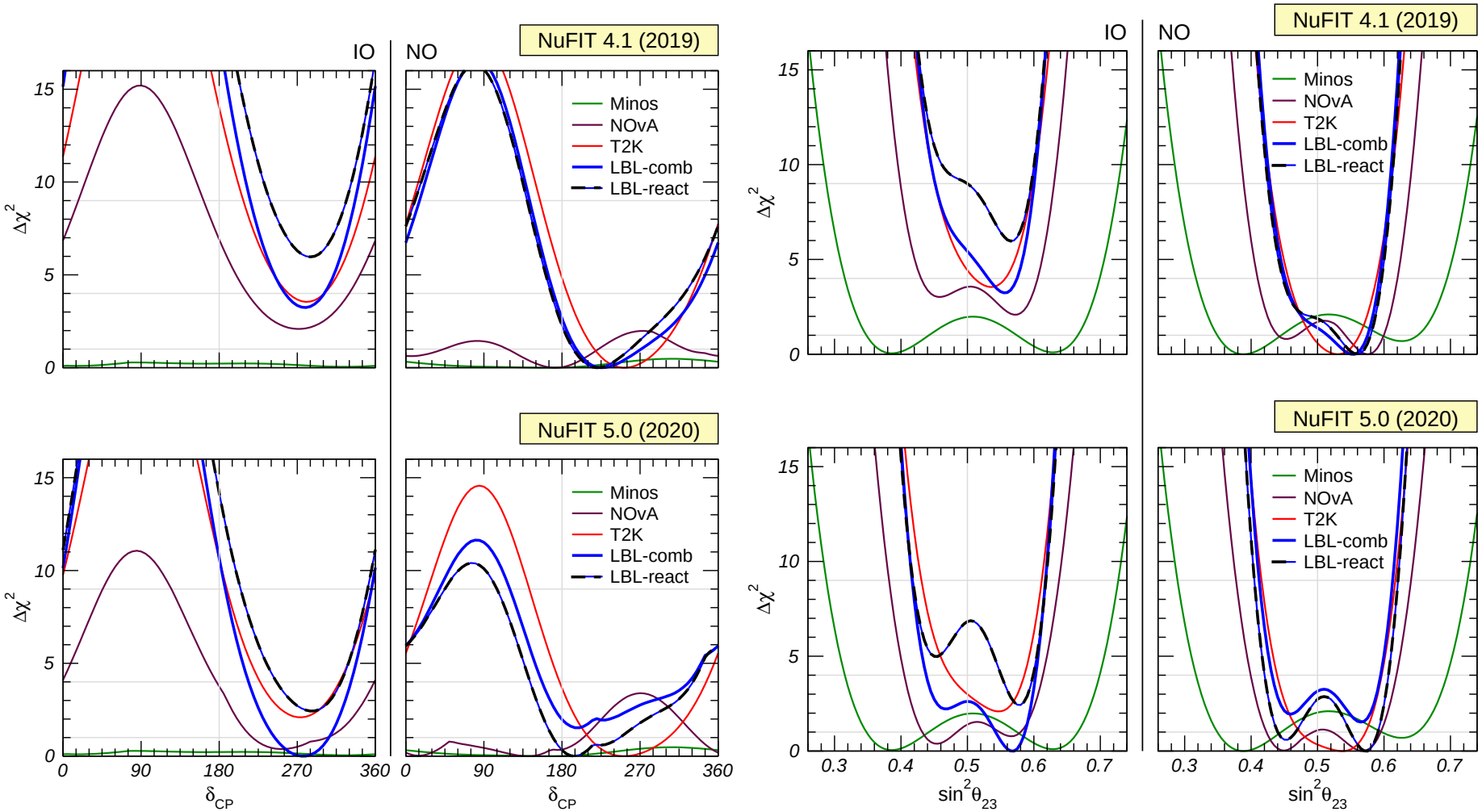




$\Rightarrow$ LBL & REAC more compatible in NO

data sets	normal ordering			inverted ordering		
	$\chi^2_{\rm PG}/n$	p-value	#σ	$\chi^2_{\rm PG}/n$	p-value	#σ
T2K vs React	0.3/2	0.87	0.2σ	2.5/2	0.29	1.1σ
NOvA vs React	3.0/2	0.23	1.2σ	6.2/2	0.045	2.0σ
T2K vs NOvA vs React	8.4/6	0.21	1.3σ	8.9/6	0.18	1.3σ
T2K+NOvA vs React	1.7/2	0.45	0.8σ	5.3/2	0.07	1.8σ

3 ν Analysis: LBL & Reactors Combination



$\Rightarrow$ LBL+Reac: NO back to better: $\Delta\chi^2_{\rm NO-IO} = +2.7$ (down from 6.2 in NuFIT 4.1)

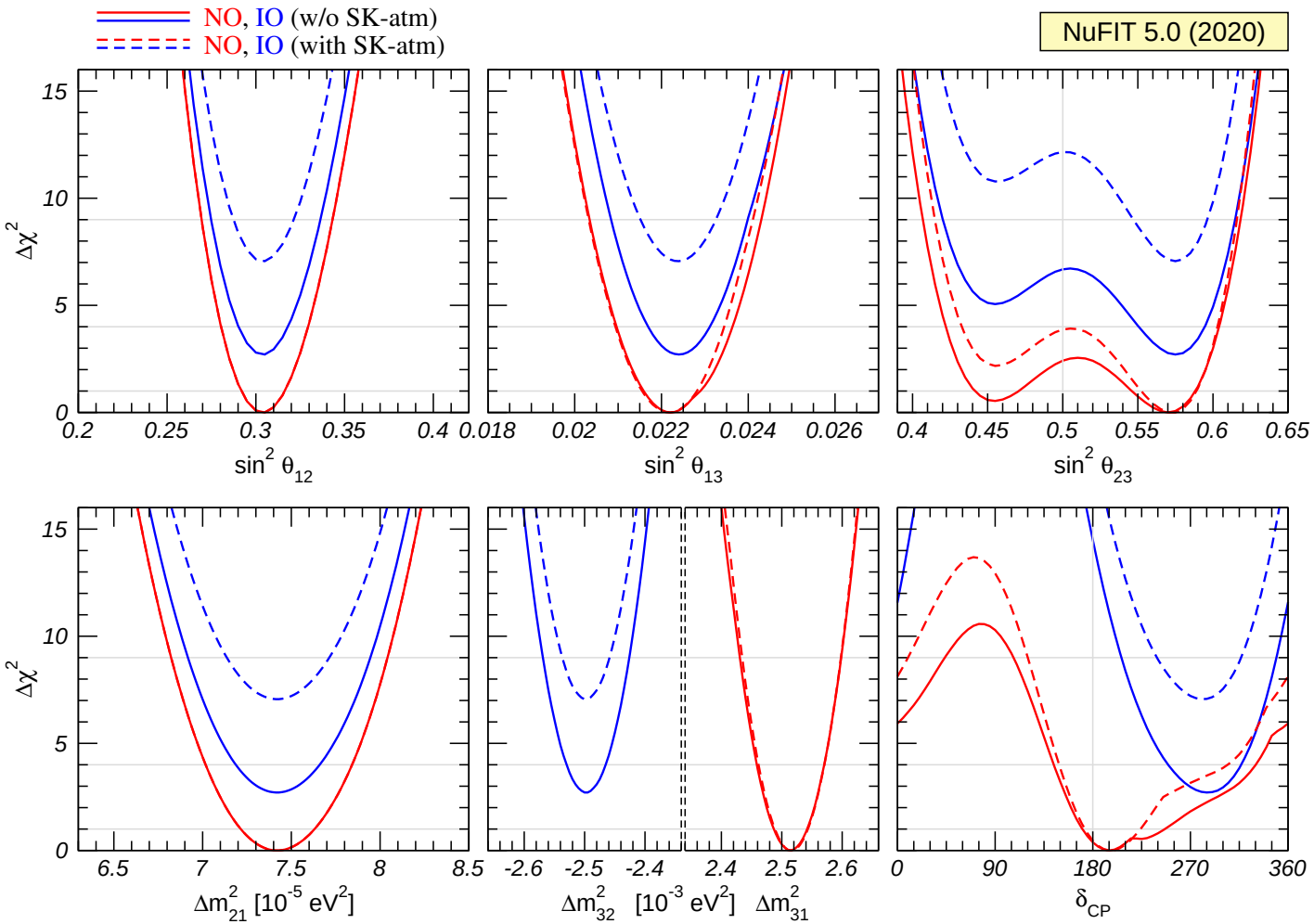
$\Rightarrow$ LBL+Reac: NO: b.f. CP phase shifted towards π (CPC)

$\Rightarrow$ LBL+Reac: IO: b.f. CPC at $\sim 3\sigma$

Summary: Global 3 ν Flavour Parameters

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

Esteban, Maltoni, Schwetz, Zhou, MCG-G ArXiv:2007.14792 (to appear in JHEP)



SK-at $\equiv \chi^2$ table from SK1-4 for 328 kton-years

Not avaible for updated SK4

Decrease ordering/CP info?

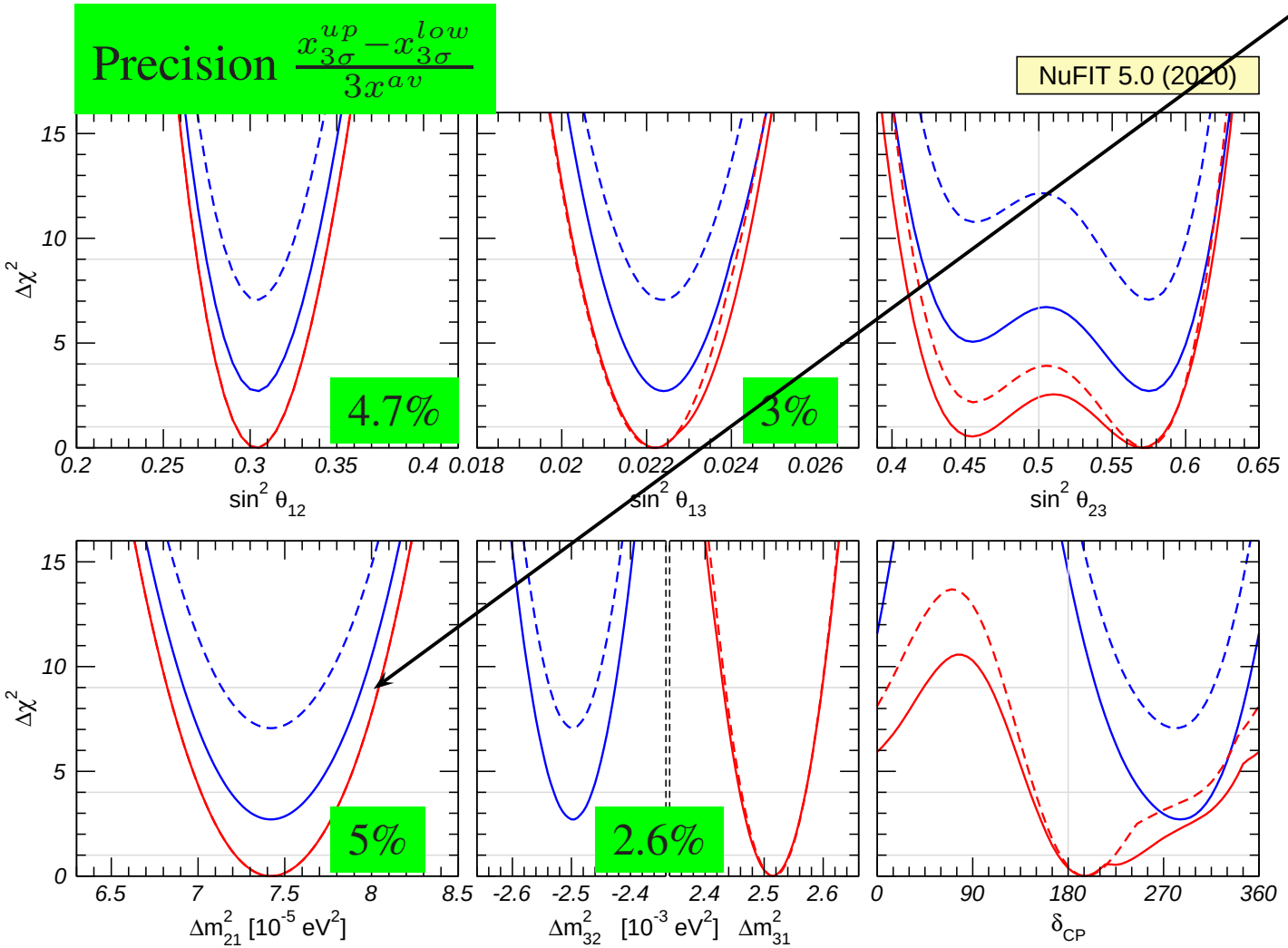
Summary: Global 3 ν Flavour Parameters

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

Esteban, Maltoni, Schwetz, Zhou, MCG-G ArXiv:2007.14792 (to appear in JHEP)

- Δm^2_{21} Solar vs KLAND

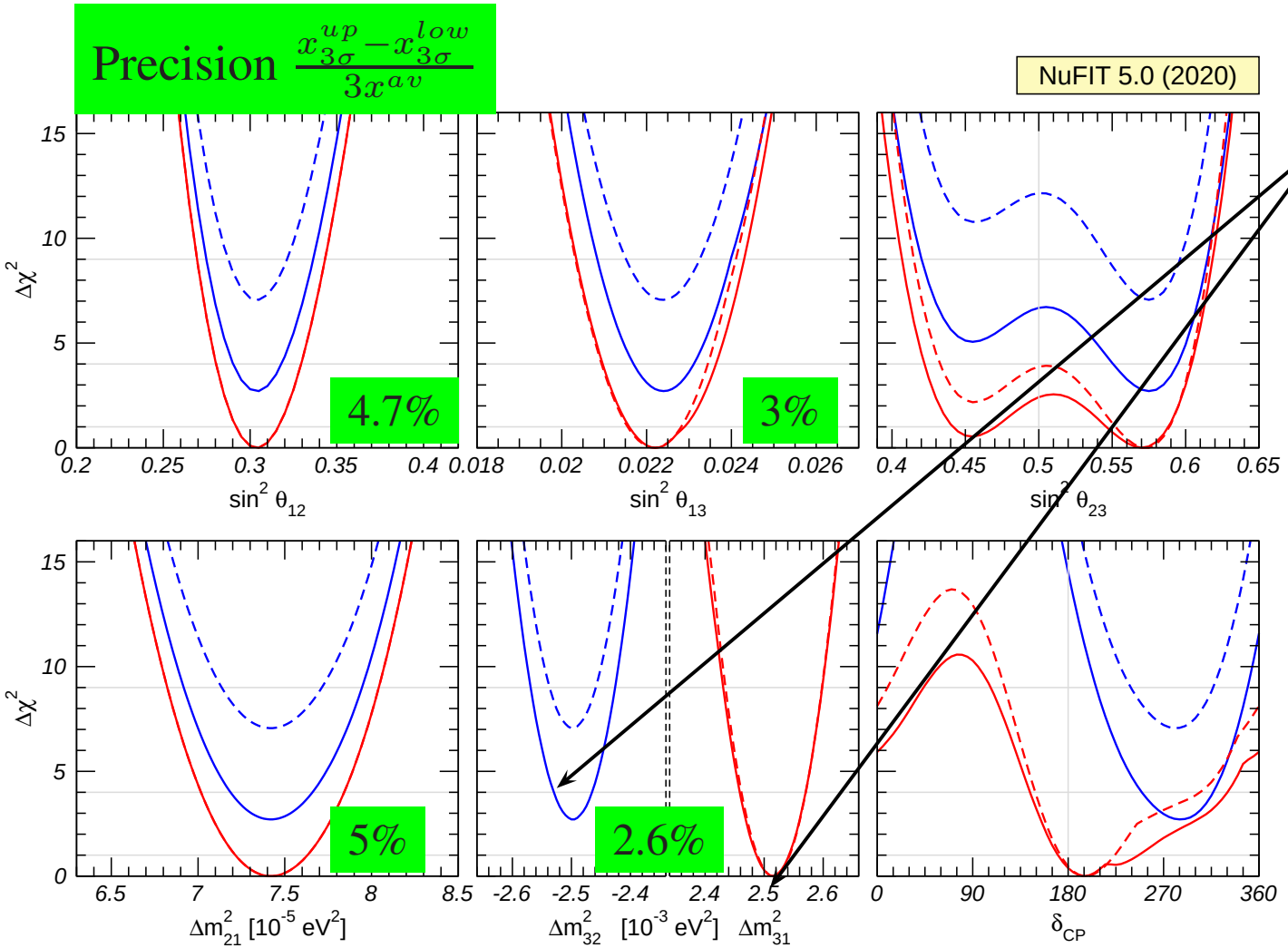
  Now in agreement at 1σ



Summary: Global 3 ν Flavour Parameters

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

Esteban, Maltoni, Schwetz, Zhou, MCG-G ArXiv:2007.14792 (to appear in JHEP)



- Δm^2_{21} Solar vs KLAND

  Now in agreement at 1σ

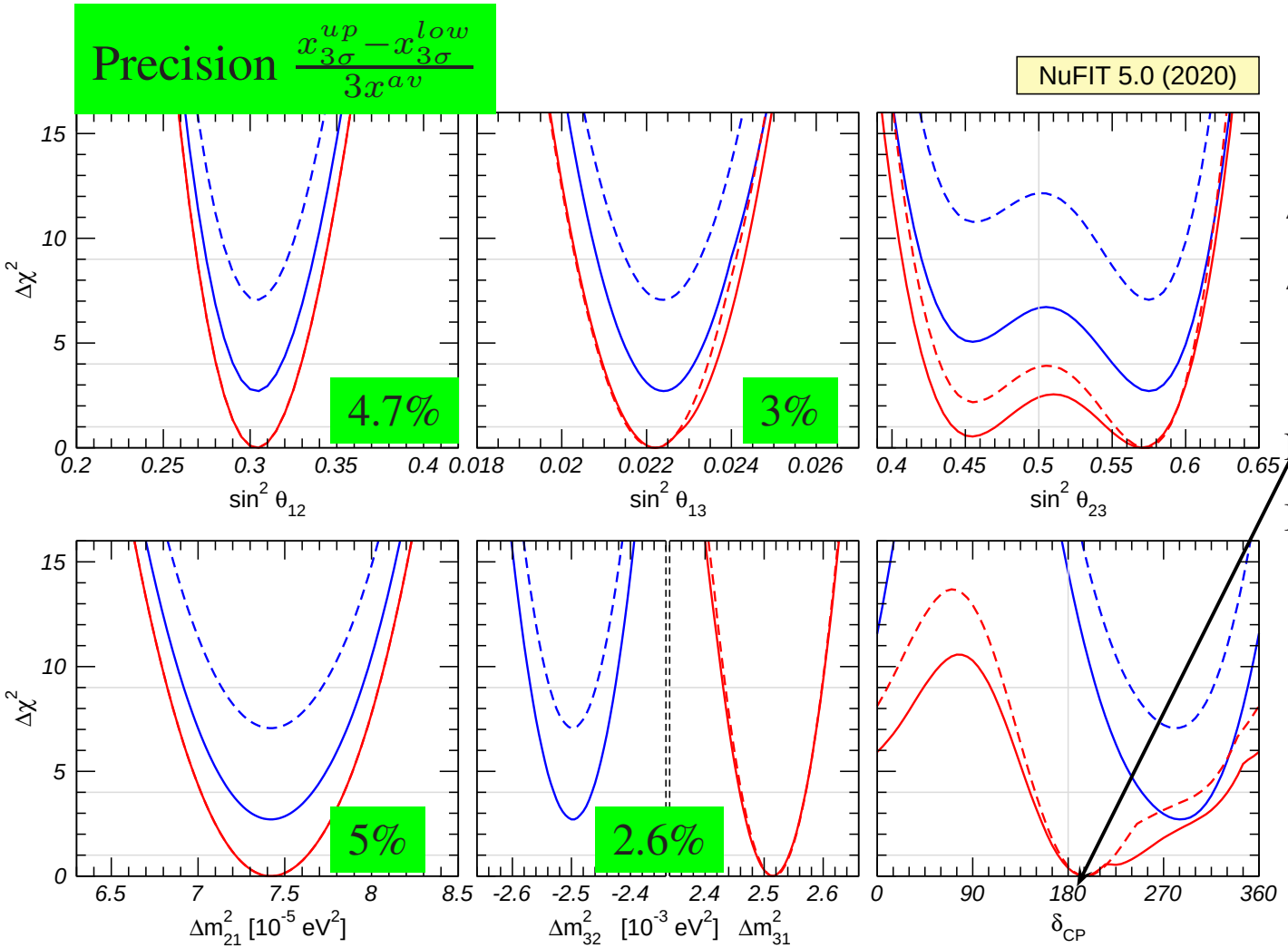
- Mass Ordering

	$\Delta\chi^2_{\rm NO-IO}$
T2K	2.1
NOνA	0.4
LBL-Comb	-1.5
LBL+Reac	2.7
Glob w/o SK-atm	2.7
Glob w SK-atm	7.1

Summary: Global 3 ν Flavour Parameters

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

Esteban, Maltoni, Schwetz, Zhou, MCG-G ArXiv:2007.14792 (to appear in JHEP)



- Δm^2_{21} Solar vs KLAND

  Now in agreement at 1σ

- Mass Ordering

$\Delta\chi^2_{\rm NO-IO,w/o\ SK-atm} = 2.7$

$\Delta\chi^2_{\rm NO-IO,with\ SK-atm} = 7.1$

- CPV:

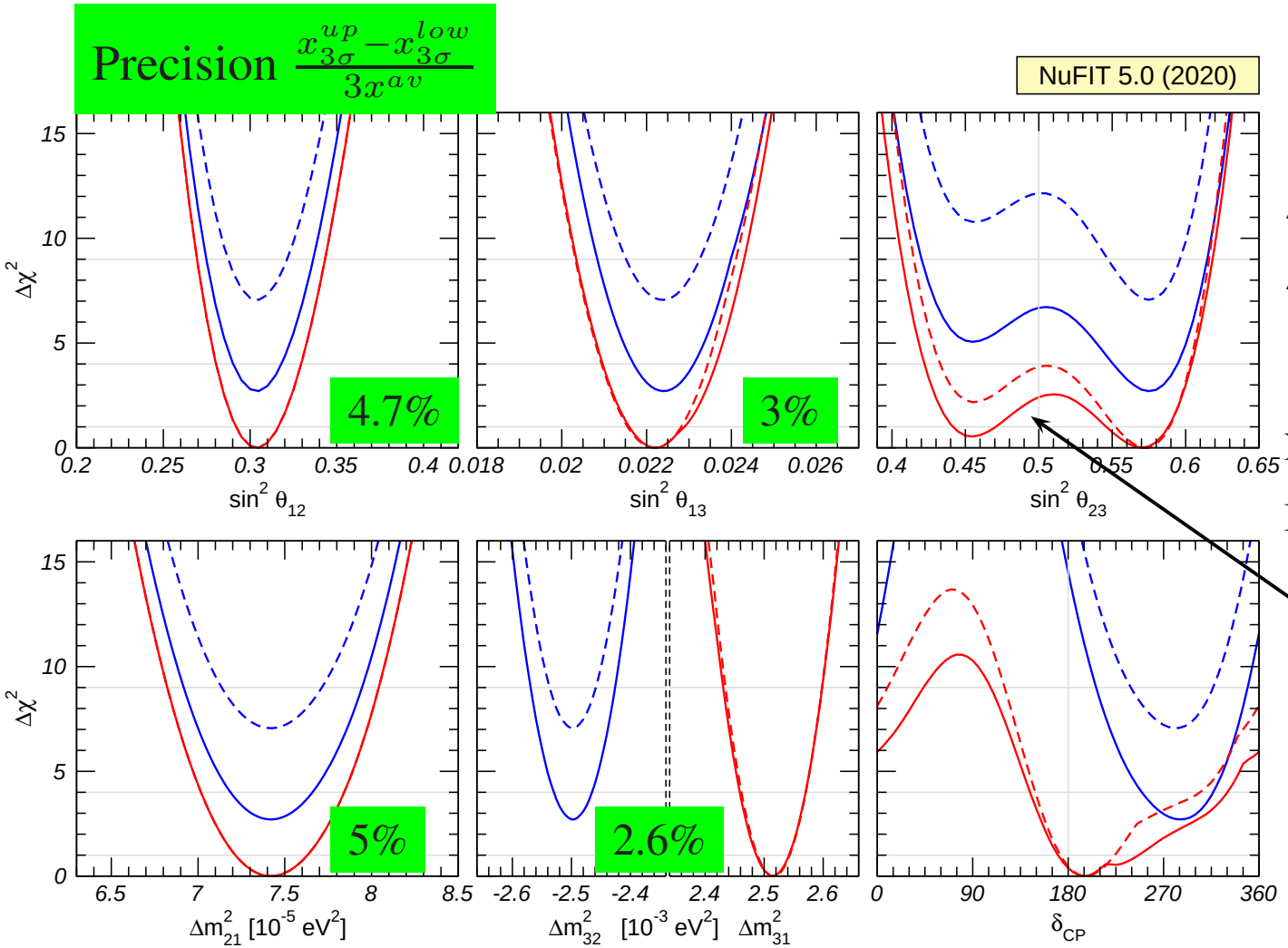
NO: b.f $\delta_{\rm CP} = 195^\circ$ CPC at 0.6σ

IO: b.f $\delta_{\rm CP} = 286^\circ$ CPC at 3σ

Summary: Global 3 ν Flavour Parameters

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

Esteban, Maltoni, Schwetz, Zhou, MCG-G ArXiv:2007.14792 (to appear in JHEP)



- Δm^2_{21} Solar vs KLAND

  Now in agreement at 1σ

- Mass Ordering

$\Delta\chi^2_{\rm NO-IO,w/o\ SK-atm} = 2.7$

$\Delta\chi^2_{\rm NO-IO,with\ SK-atm} = 7.1$

- CPV:

NO: b.f $\delta_{\rm CP} = 195^\circ$ CPC at 0.6σ

IO: b.f $\delta_{\rm CP} = 286^\circ$ CPC at 3σ

- θ_{23}:

NO: bf $s^2_{23} = 0.57$

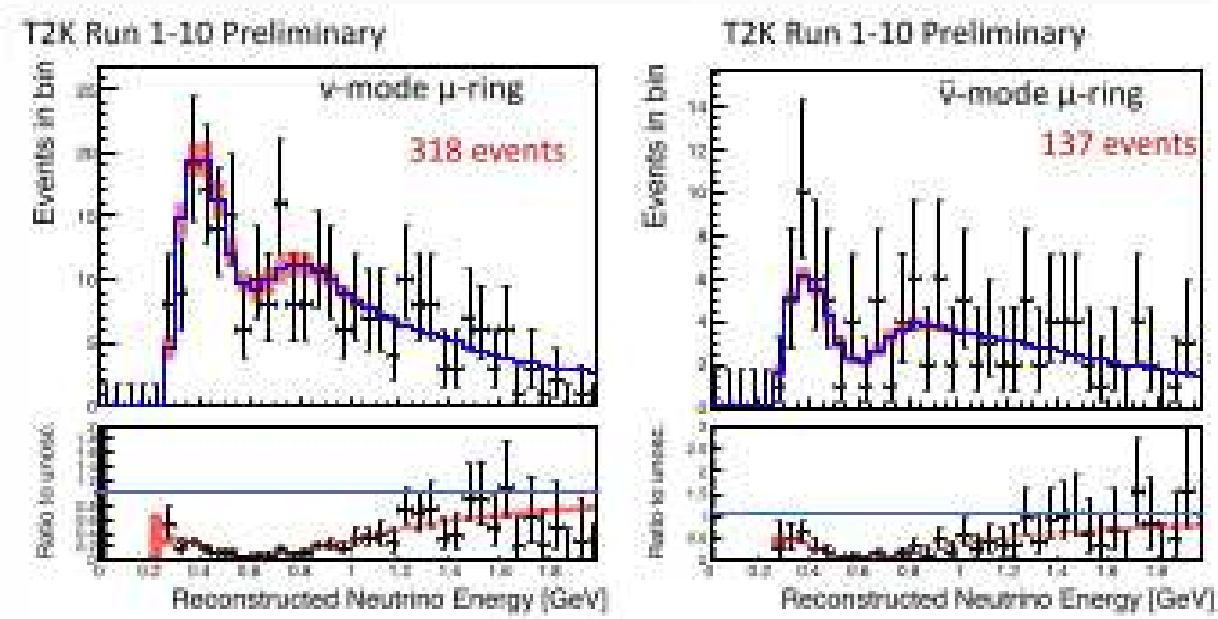
$\Delta\chi^2_{\rm w/o\ SK-atm}(\text{1st oct}) = 0.53$

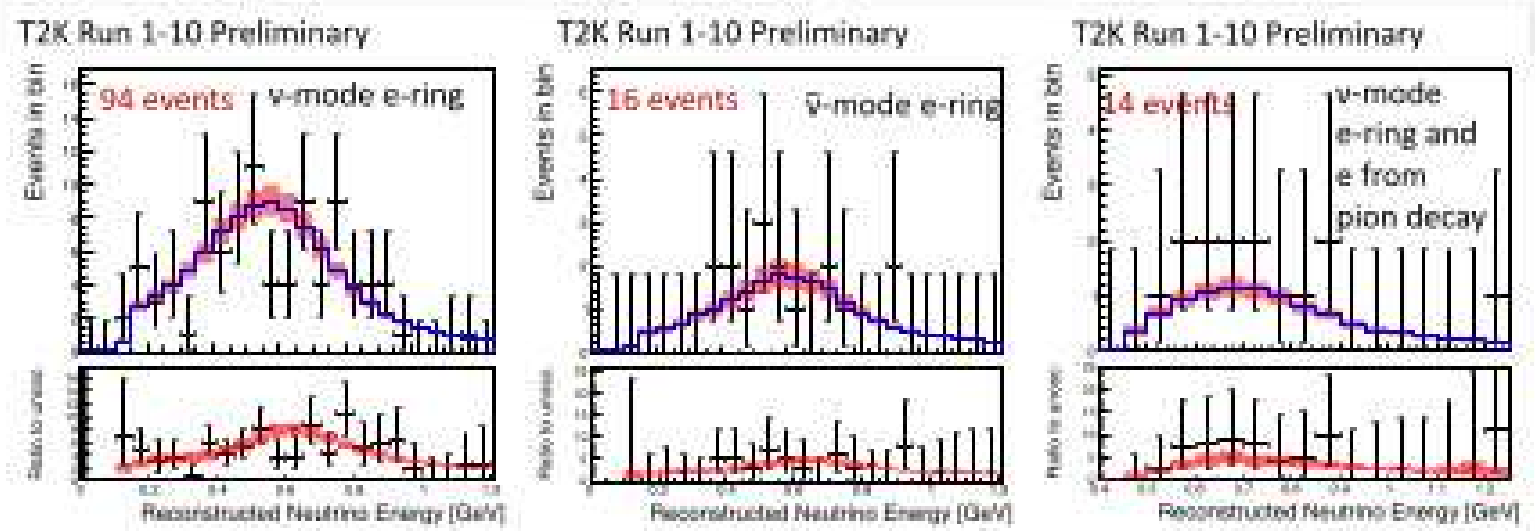
$\Delta\chi^2_{\rm with\ SK-atm}(\text{1st oct}) = 2.2$

$\Delta\chi^2_{\rm w/o\ SK-atm}(\text{Maxmix}) = 2.4$

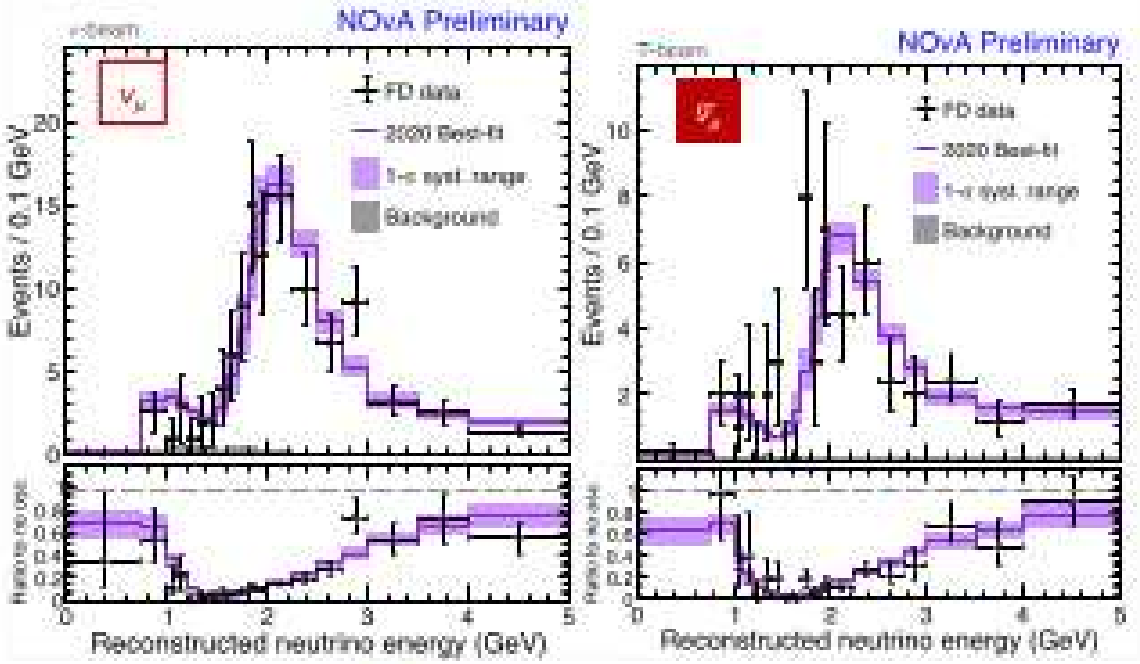
$\Delta\chi^2_{\rm with\ SK-atm}(\text{Maxmix}) = 3.9$

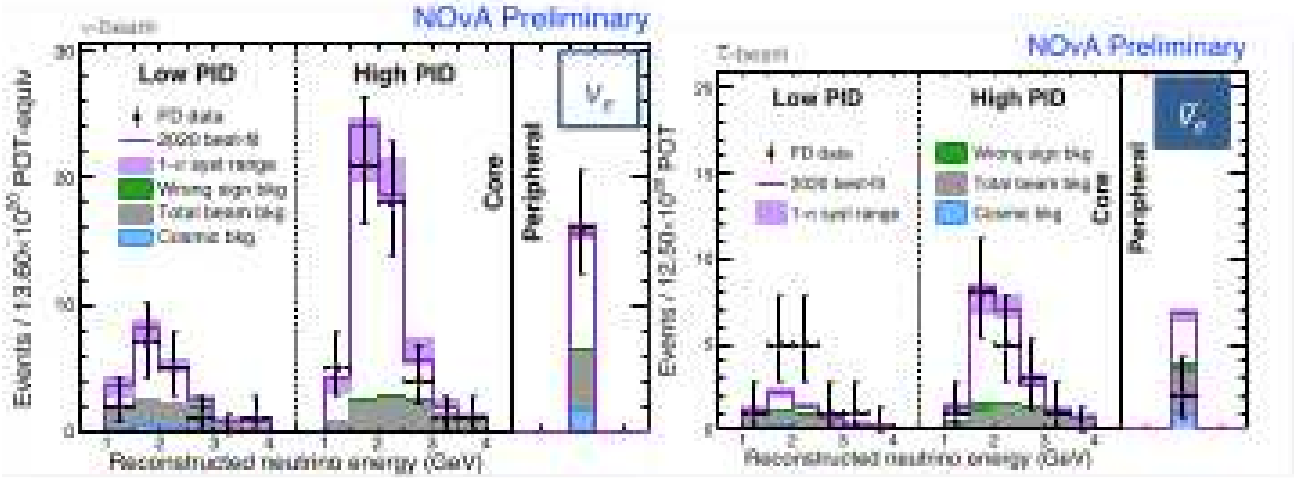
T2K


T2K Run 1-10 Preliminary
ν-mode μ-ring
318 events
Events in bin
Reconstructed Neutrino Energy [GeV]
T2K Run 1-10 Preliminary
ν̄-mode μ-ring
137 events
Events in bin
Reconstructed Neutrino Energy [GeV]


T2K Run 1-10 Preliminary
94 events
ν-mode e-ring
Events in bin
Reconstructed Neutrino Energy [GeV]
T2K Run 1-10 Preliminary
16 events
ν̄-mode e-ring
Events in bin
Reconstructed Neutrino Energy [GeV]
T2K Run 1-10 Preliminary
14 events
ν-mode
e-ring and
e from
pion decay
Events in bin
Reconstructed Neutrino Energy [GeV]

NOνA


NOvA Preliminary
FD data
2020 Best-fit
1-σ syst. range
Background
Events / 0.1 GeV
Reconstructed neutrino energy (GeV)
NOvA Preliminary
FD data
2020 Best-fit
1-σ syst. range
Background
Events / 0.1 GeV
Reconstructed neutrino energy (GeV)


NOvA Preliminary
Low PID
High PID
Core
Peripheral
Reconstructed neutrino energy (GeV)
NOvA Preliminary
Low PID
High PID
Core
Peripheral
Reconstructed neutrino energy (GeV)