3ν Masses and Mixing: The Global Picture

Concha Gonzalez-Garcia

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Neutrino Town-Meeting: Oct 22-24 CERN

The Status of Neutrino Parameters (3f)

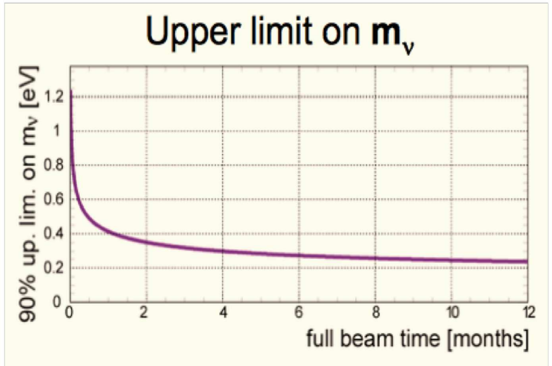
See e.g. Esteban, Gonzalez-Garcia, Maltoni, Martinez-Soler, Schwetz

	Normal Ordering (best fit)		Inverted Ordering ($\Delta\chi^2 = 0.83$)		Any Ordering
	bfp $\pm 1\sigma$	3σ range	bfp $\pm 1\sigma$	3σ range	3σ range
$\sin^2\theta_{12}$	$0.306^{+0.012}_{-0.012}$	$0.271 \to 0.345$	$0.306^{+0.012}_{-0.012}$	$0.271 \to 0.345$	$0.271 \to 0.345$
$\theta_{12}/^\circ$	$33.56^{+0.77}_{-0.75}$	$31.38 \to 35.99$	$33.56^{+0.77}_{-0.75}$	$31.38 \to 35.99$	$31.38 \to 35.99$
$\sin^2\theta_{23}$	$0.441^{+0.027}_{-0.021}$	$0.385 \to 0.635$	$0.587^{+0.020}_{-0.024}$	$0.393 \to 0.640$	$0.385 \to 0.638$
$\theta_{23}/^\circ$	$41.6^{+1.5}_{-1.2}$	$38.4 \to 52.8$	$50.0^{+1.1}_{-1.4}$	$38.8 \to 53.1$	$38.4 \to 53.0$
$\sin^2\theta_{13}$	$0.02166^{+0.00075}_{-0.00075}$	$0.01934 \to 0.02392$	$0.02179^{+0.00076}_{-0.00076}$	$0.01953 \to 0.02408$	$0.01934 \to 0.02397$
$\theta_{13}/^\circ$	$8.46^{+0.15}_{-0.15}$	$7.99 \to 8.90$	$8.49^{+0.15}_{-0.15}$	$8.03 \to 8.93$	$7.99 \to 8.91$
$\delta_{CP}/^\circ$	261^{+51}_{-59}	$0 \to 360$	277^{+40}_{-46}	$145 \to 391$	$0 \to 360$
$\frac{\Delta m^2_{21}}{10^{-5}\ \text{eV}^2}$	$7.50^{+0.19}_{-0.17}$	$7.03 \to 8.09$	$7.50^{+0.19}_{-0.17}$	$7.03 \to 8.09$	$7.03 \to 8.09$
$\frac{\Delta m^2_{3\ell}}{10^{-3}\ \text{eV}^2}$	$+2.524^{+0.039}_{-0.040}$	$+2.407 \to +2.643$	$-2.514^{+0.038}_{-0.041}$	$-2.635 \to -2.399$	$\begin{bmatrix} +2.407 \to +2.643 \\ -2.629 \to -2.405 \end{bmatrix}$

UPDATE REQUIRED

Absolute mass limits from Mainz and Troitsk: $m_1 < 2.2$ eV
Limits from cosmology: 0.15-0.2 eV
KATRIN: started operation ➔ 0.2eV ; Project8, …

Important:
- **Active ν unitarity already tested > 95%**
- **origin of ν masses unknown**



➔ **Talks by E. Martinez, T. Schwetz, Ch. Weinheimer and others**

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 bins.
- SK2 E and D/N spect, 33 bins.
- SK3 E and D/N spect, 42 bins.
- SK4 2055-day E and D/N spect , 46 bins.
- SNO combined analysis, 7 points.
- Borexino Ph-I 740.7-day low-E spect 33 bins.
- Borexino Ph-I 246-day high-E spect ,6 bins.
- Borexino Ph-II 408-day low-E spect, 42 bins.

Reactor experiments

- KamLAND DS1,DS2&DS3 spectra with Daya-Bay fluxes 69 bins
- D-Chooz FD-I/ND and FD-II spectral ratios with 455-day (FD-I), 363-day (FD-II) and 285 ND exposures , 56 bins.
- **SUMMER 18** Daya-Bay 1958-day EH2/EH1 & EH3/EH1 spectral ratios, 70 bins.
- **SUMMER 18** Reno 2200-day spec ratios 26 bins.

Atmospheric experiments

- IceCube/DeepCore 3-year data, 64 bins.
- *SK I-IV χ^2 table provided by the experiment.*

Accelerator experiments

- MINOS 10.71×10^{20} pot ν_μ-disapp data, 39 bins.
- MINOS 3.36×10^{20} pot $\bar{\nu}_\mu$-disapp data , 14 bins.
- MINOS 10.6×10^{20} pot ν_e-app data , 5 bins.
- MINOS 3.3×10^{20} pot $\bar{\nu}_e$-app data , 5 bins.
- T2K 14.93×10^{20} pot ν_μ-disapp data, 55 bins.
- T2K 14.93×10^{20} pot ν_e-app data, 39 bins.
- **SUMMER 18** T2K 11.2×10^{20} pot $\bar{\nu}_\mu$-disapp, 55 bins.
- **SUMMER 18** T2K 11.2×10^{20} pot $\bar{\nu}_e$-app, 23 bins.
- NOνA 8.85×10^{20} pot ν_μ-disapp data , 76 bins.
- NOνA 8.85×10^{20} pot ν_e-app data , 13 bins.
- **SUMMER 18** NOνA 6.9×10^{20} pot $\bar{\nu}_\mu$-disapp, 76 bins.
- **SUMMER 18** NOνA 6.9×10^{20} pot $\bar{\nu}_e$-app, 12 bins.

3ν Flavour Parameters

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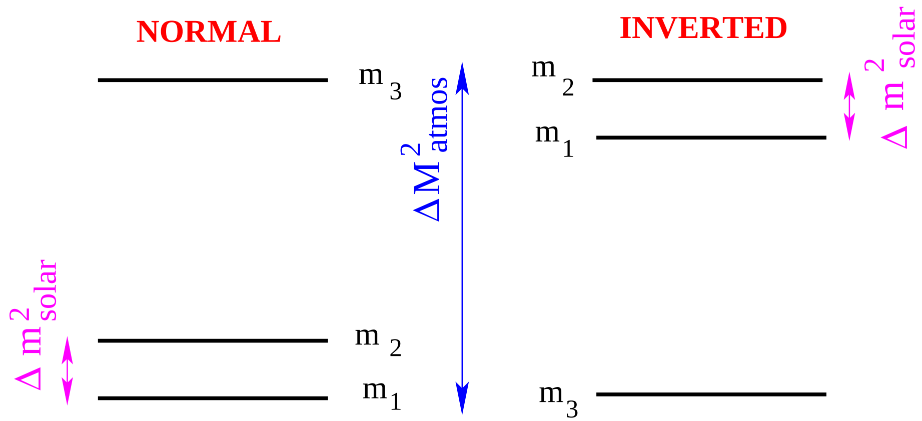
- For for 3 ν's : 3 Mixing angles + 1 Dirac Phase + 2 Majorana Phases

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

- Two Possible Orderings

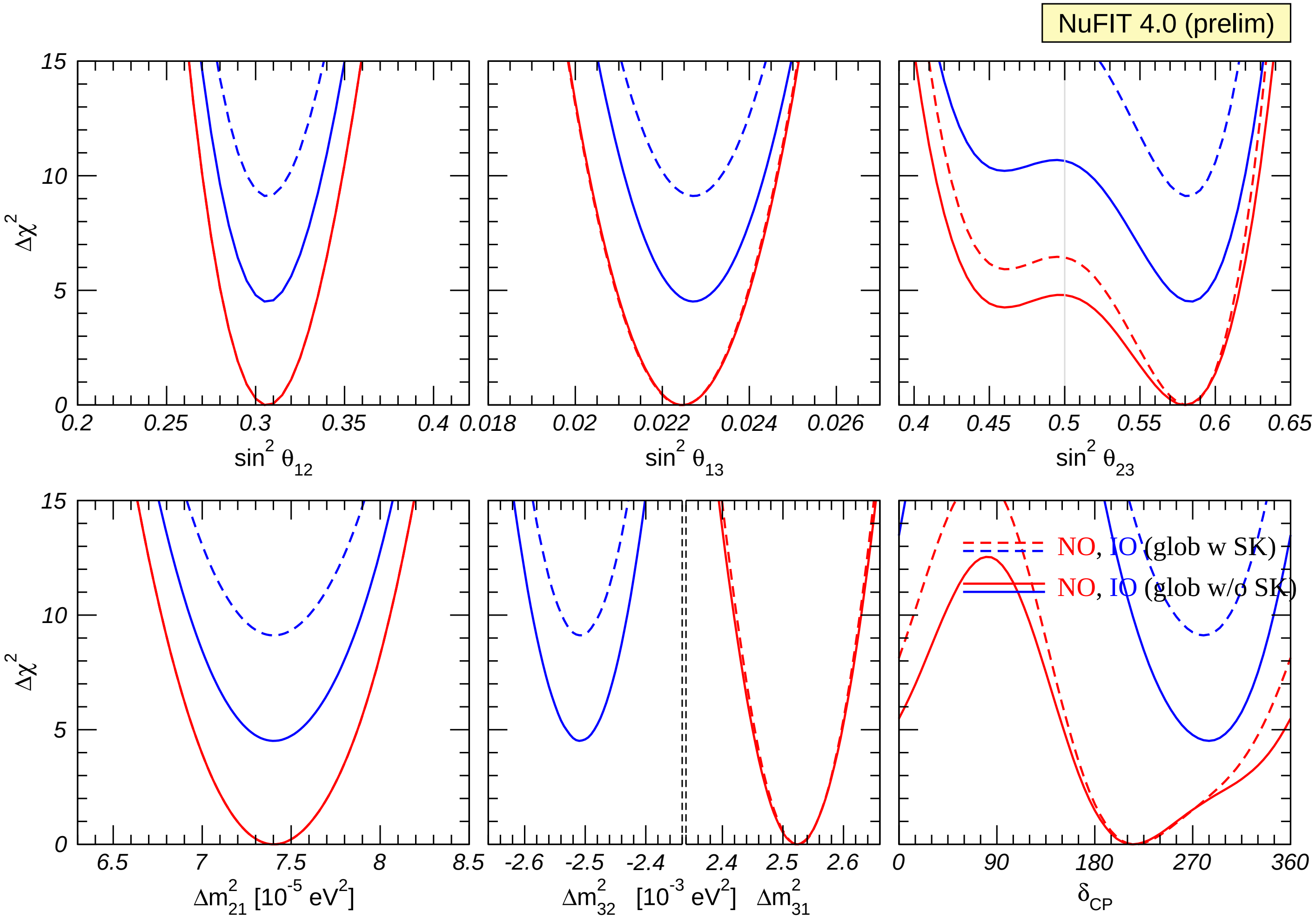


Experiment	Dominant Dependence	Important Dependence
Solar Experiments	$\to \theta_{12}$	Δm^2_{21} , θ_{13}
Reactor LBL (KamLAND)	$\to \Delta m^2_{21}$	θ_{12} , θ_{13}
Reactor MBL (Daya Bay, Reno, D-Chooz)	$\to \theta_{13}$	$\Delta m^2_{\rm atm}$
Atmospheric Experiments	$\to \theta_{23}$	$\Delta m^2_{\rm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

3 ν Flavour Parameters: Status OCT 2018

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

Esteban, Hernandez-Cabezudo,Maltoni, Schwetz, MCG-G PRELIMINARY



3 ν Flavour Parameters: Status OCT 2018

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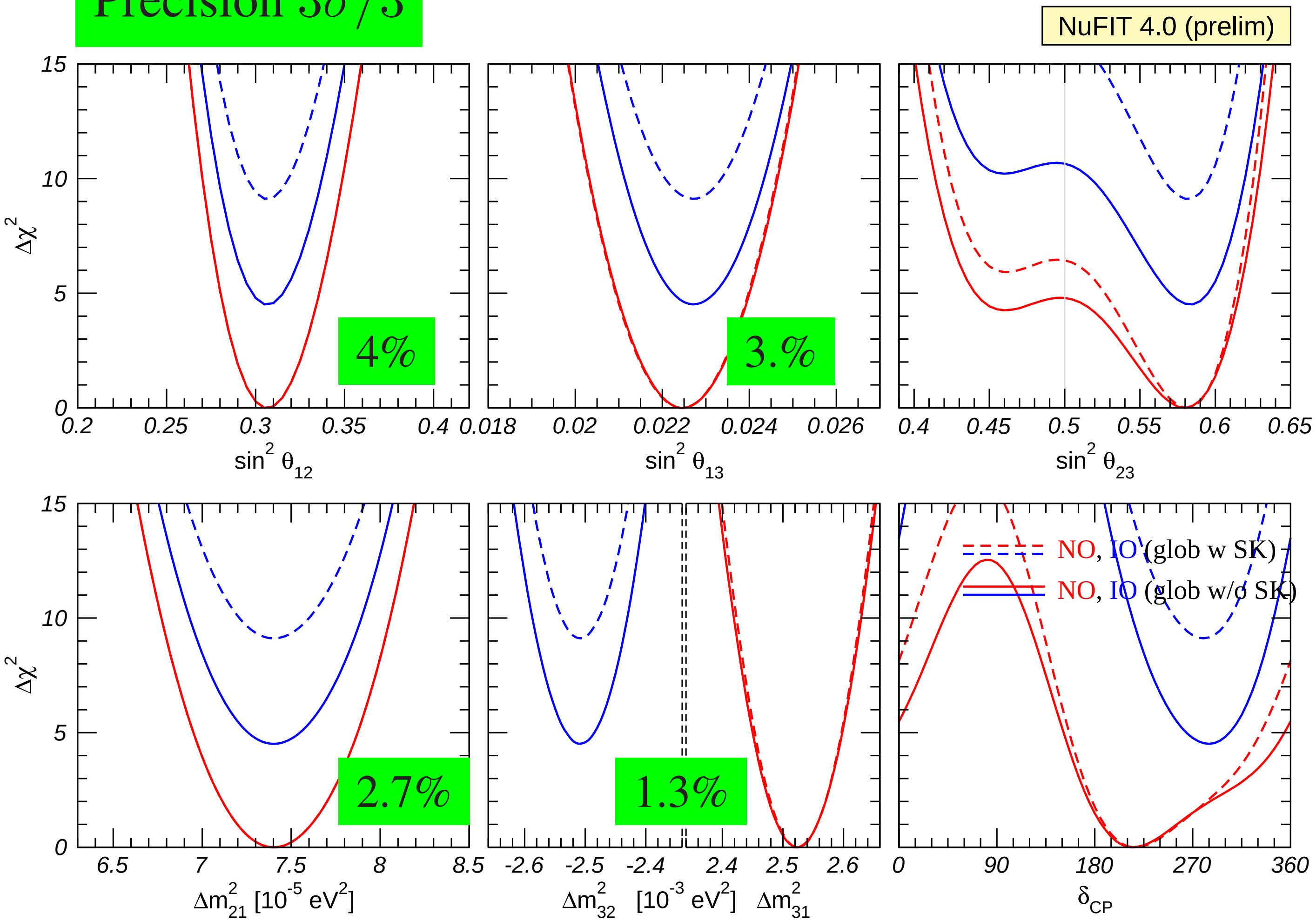
Esteban, Hernandez-Cabezudo,Maltoni, Schwetz, MCG-G PRELIMINARY

Precision $3\sigma/3$



- Best determined:

  θ_{12}, θ_{13},Δm^2_{21}, $|\Delta m^2_{3l}|$

  $[\Delta m^2_{3l} = \Delta m^2_{31} > 0$ (NO)

  $\Delta m^2_{3l} = \Delta m^2_{32} < 0$ (IO)$]$

3 ν Flavour Parameters: Status OCT 2018

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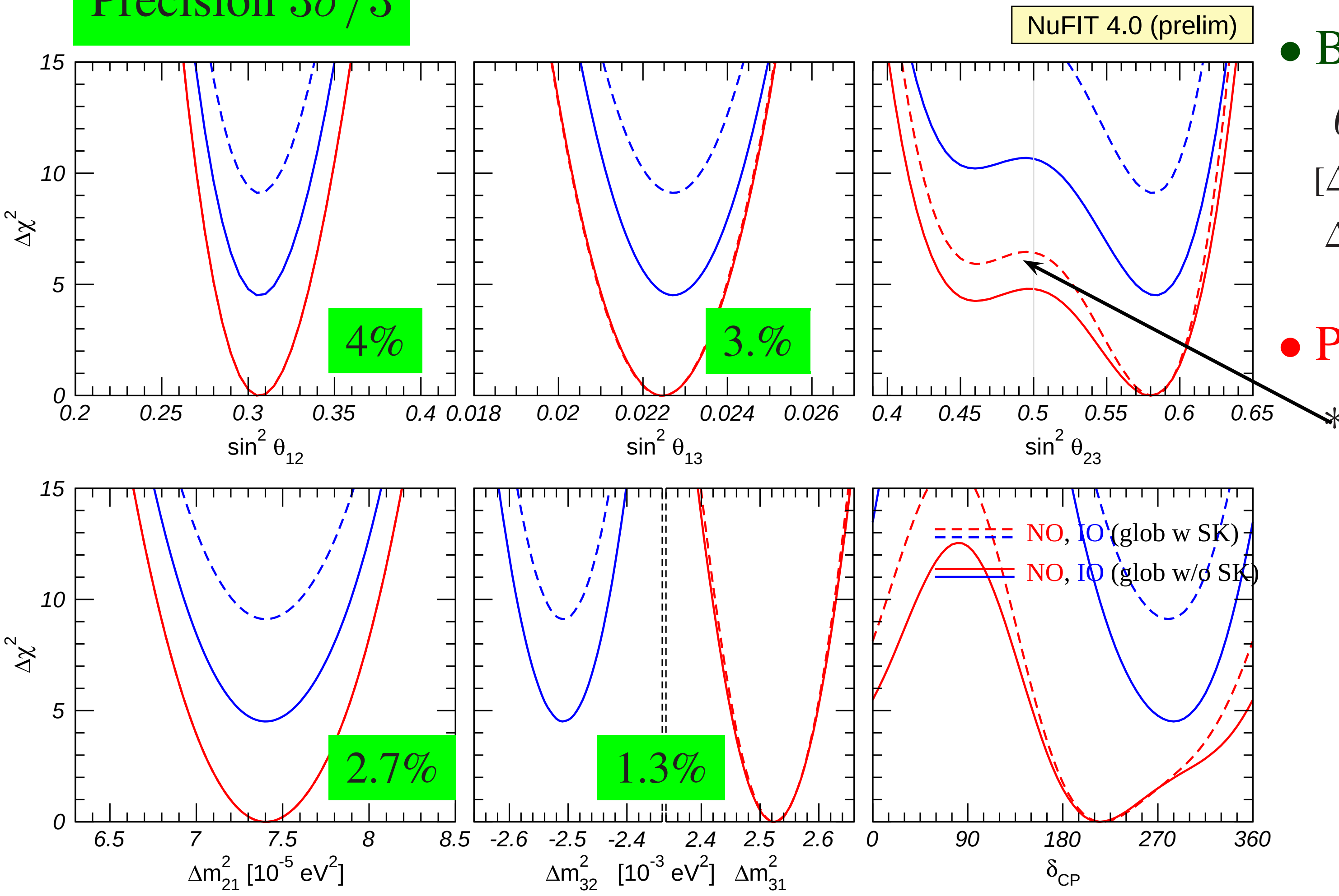

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- Pending issues:

  $*$ θ_{23}: Maximality/Octant

3 ν Flavour Parameters: Status OCT 2018

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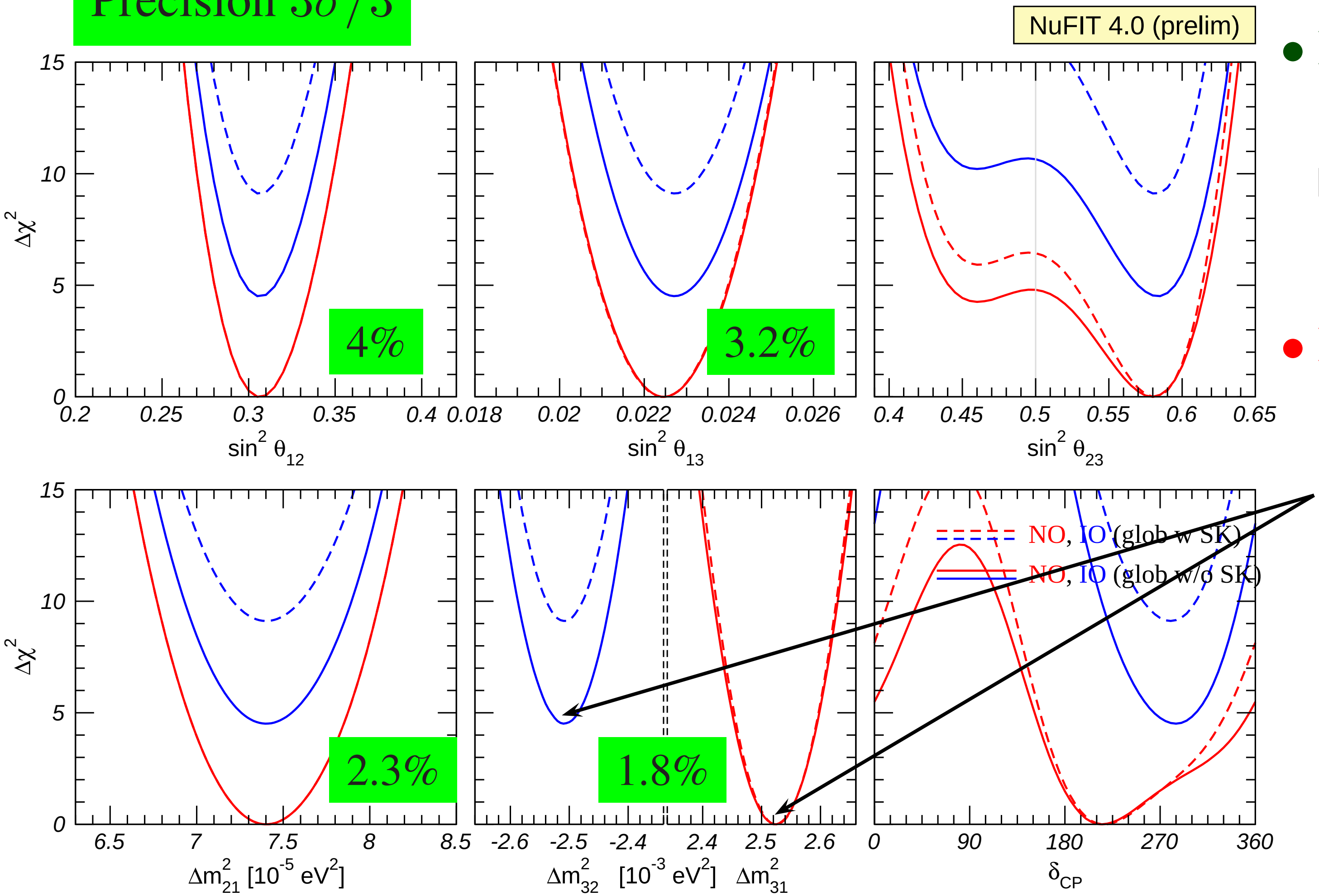

- Best determined:

  θ_{12}, θ_{13},Δm^2_{21}, $|\Delta m^2_{3l}|$

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- Pending issues:

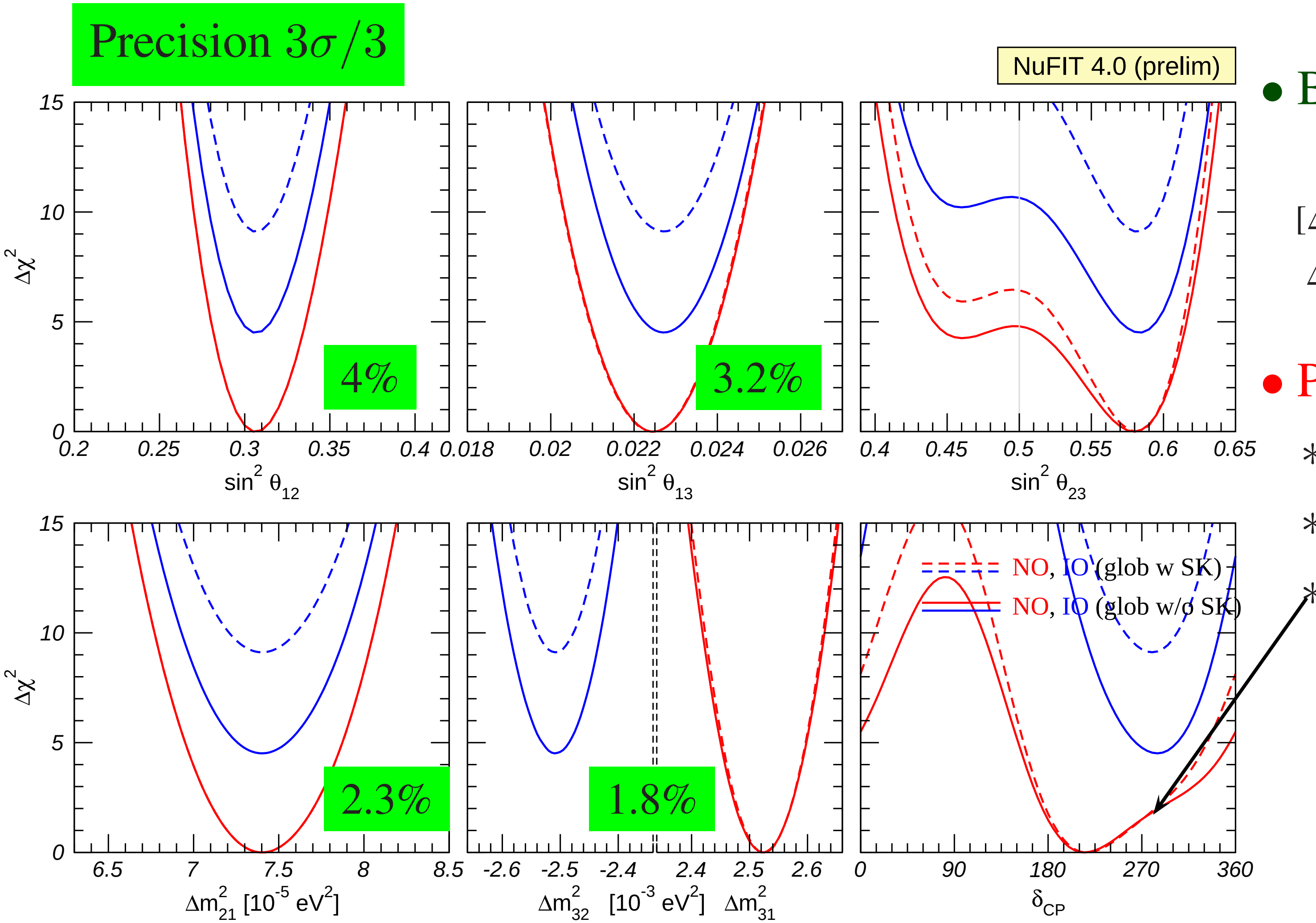
  $*$ θ_{23}: Maximality/Octant

  $*$ Mass Ordering

3 ν Flavour Parameters: Status OCT 2018

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

Esteban, Hernandez-Cabezudo,Maltoni, Schwetz, MCG-G PRELIMINARY



- Best determined:

  θ_{12}, θ_{13}, Δm^2_{21}, $|\Delta m^2_{3l}|$

  [$\Delta m^2_{3l} = \Delta m^2_{31} > 0$ (NO)

  $\Delta m^2_{3l} = \Delta m^2_{32} < 0$ (IO)]

- Pending issues:

  $*$ θ_{23}: Maximality/Octant

  $*$ Mass Ordering

  $*$ CP phase: $> \pi$?

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3 ν Analysis: "12" Sector

- $\Delta m^2_{13} \gg E/L \Rightarrow$ $P^{2\nu}_{ee}$ obtained by solving

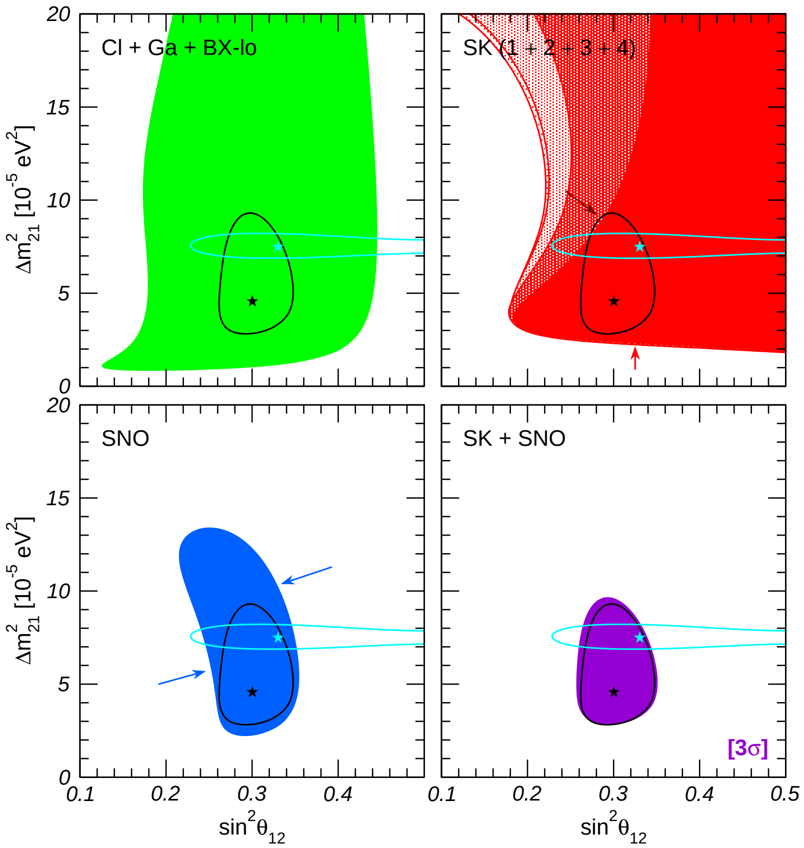
$$i\frac{d}{dt}\begin{pmatrix}\nu_e\\ \nu_a\end{pmatrix} = \left[\frac{\Delta m^2_{21}}{4E}\begin{pmatrix}-\cos 2\theta_{12} & \sin 2\theta_{12}\\ \sin 2\theta_{12} & \cos 2\theta_{12}\end{pmatrix} \pm \sqrt{2}G_F N_e \begin{pmatrix}1 & 0\\ 0 & 0\end{pmatrix}\right]\begin{pmatrix}\nu_e\\ \nu_a\end{pmatrix}$$

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

$*$ Solar region determined by High E data

$*$ Param's $\begin{cases}\theta_{12} \text{ SNO most sensitivity} \\ \Delta m^2_{21} \text{ by KamLAND}\end{cases}$

For 2ν's



2 ν Analysis: "12" Sector

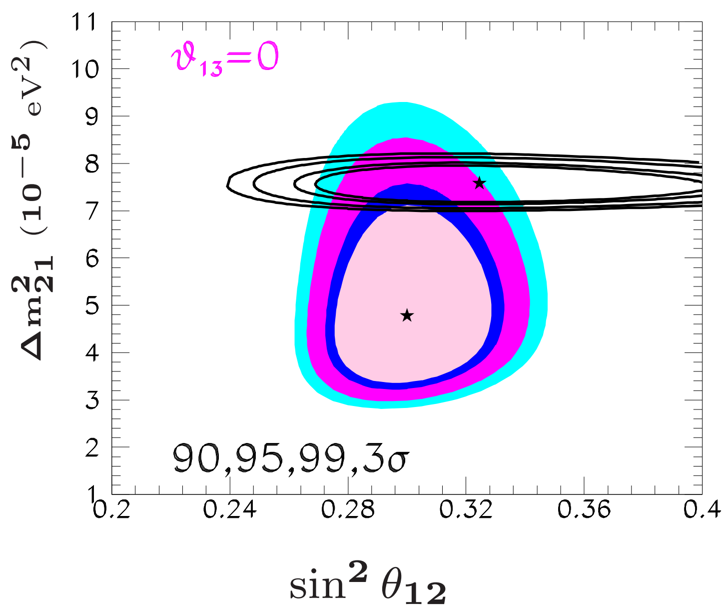
- $\Delta m^2_{13} \gg E/L \Rightarrow$ $P^{2\nu}_{ee}$ obtained by solving

$$i\frac{d}{dt}\begin{pmatrix}\nu_e\\ \nu_a\end{pmatrix} = \left[\frac{\Delta m^2_{21}}{4E}\begin{pmatrix}-\cos 2\theta_{12} & \sin 2\theta_{12}\\ \sin 2\theta_{12} & \cos 2\theta_{12}\end{pmatrix} \pm \sqrt{2}G_F N_e \begin{pmatrix}1 & 0\\ 0 & 0\end{pmatrix}\right]\begin{pmatrix}\nu_e\\ \nu_a\end{pmatrix}$$

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

$*$ Solar region determined by High E data

$*$ Param's $\begin{cases} \theta_{12} \text{ SNO most sensitivity} \\ \Delta m^2_{21} \text{ by KamLAND} \end{cases}$



$$\sin^2\theta_{12} = \begin{cases} 0.3 \text{ From Solar} \\ 0.325 \text{ From KLAND} \end{cases}$$

3 ν Analysis: "12" Sector and θ_{13}

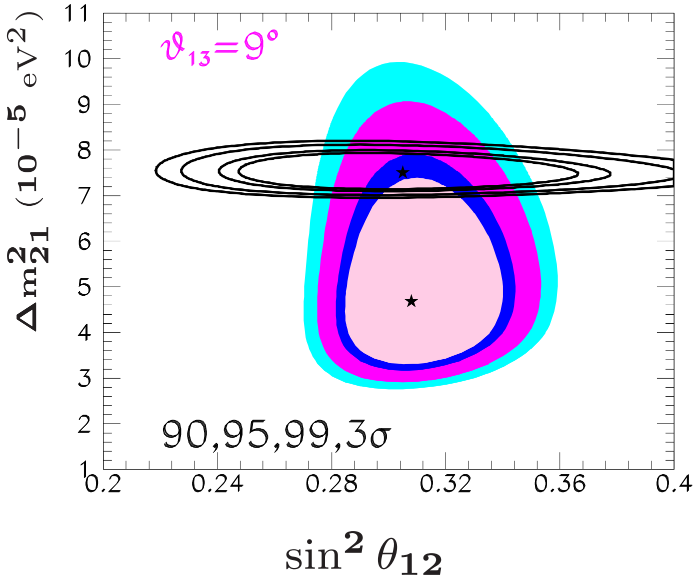
- $\Delta m^2_{13} \gg E/L \Rightarrow$ $P^{3\nu}_{ee} = c^4_{13} P_{2\nu} + s^4_{13}$

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

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

$\Rightarrow$ KamLAND region shifts left

$\Rightarrow$ Solar slight shifts right (due to High E)

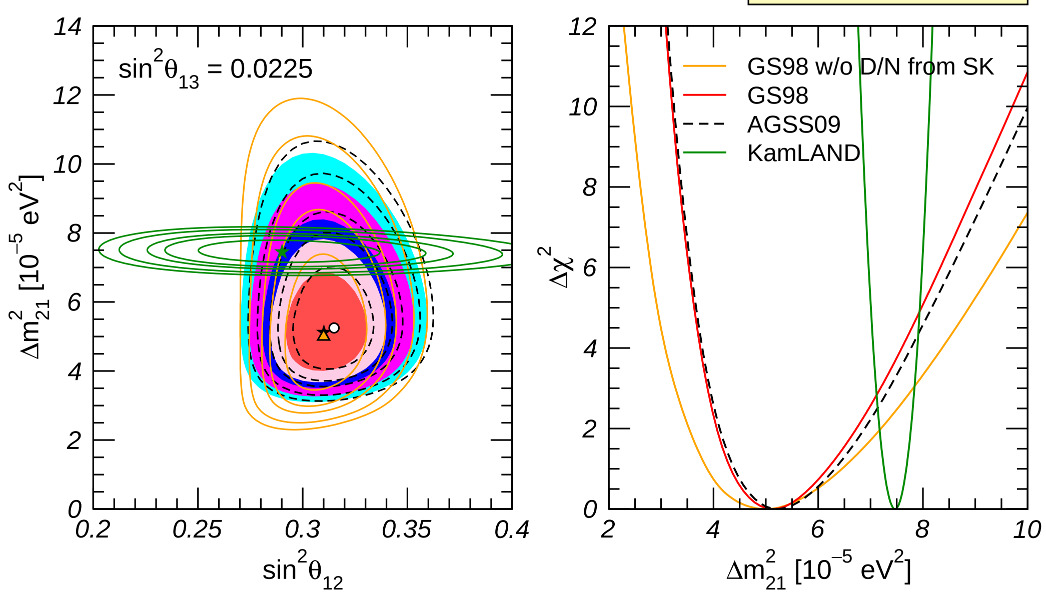


$\Rightarrow$ Good agreement of best fit θ_{12}

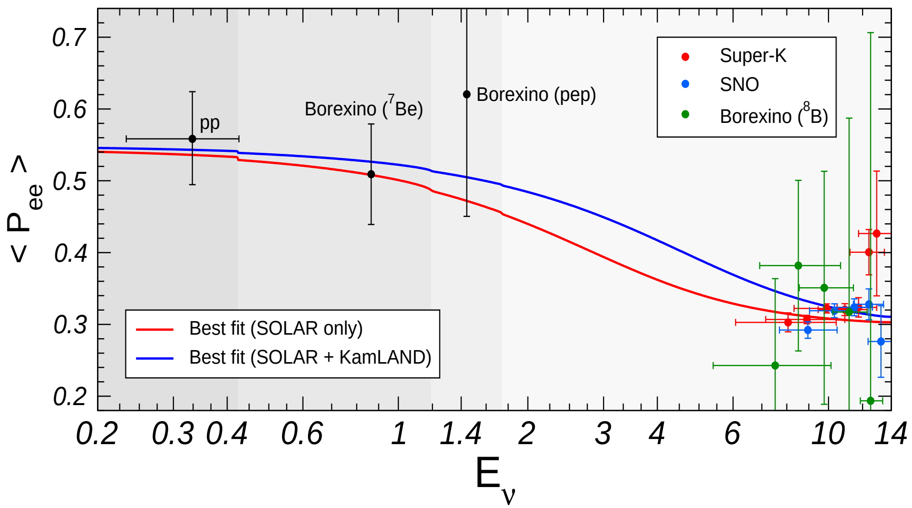
$\Rightarrow$ Residual tension on Δm^2_{21}

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

For $\theta_{13} \simeq 8.5°$ θ_{12} OK. But residual tension on Δm^2_{21}



Tension related to: a)“too large” of Day/Night at SK



b) smaller-than-expected
low-E turn up from MSW
at best global fit

Modified matter potential?

see Jordi Salvado’s talk

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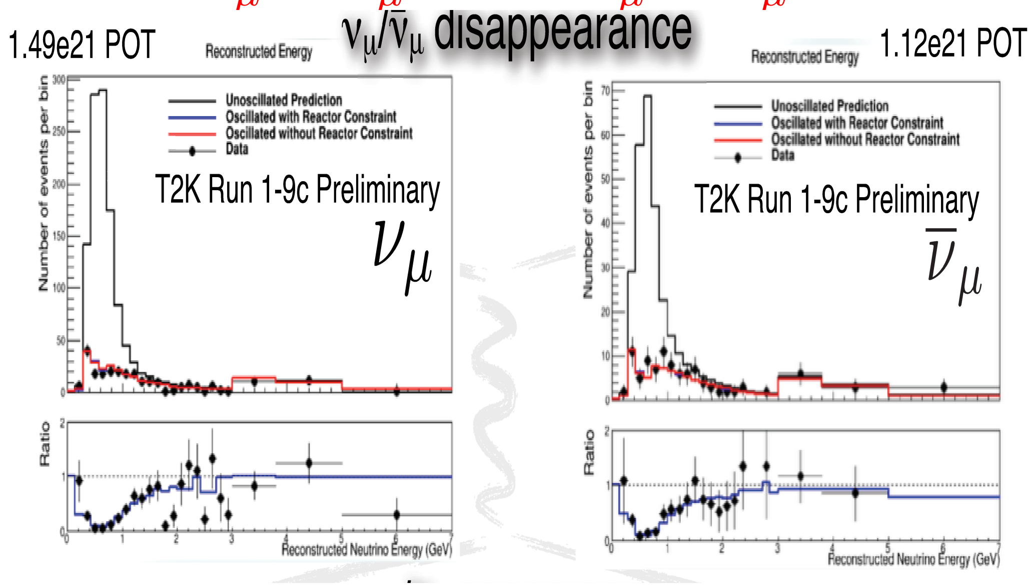
3 ν Analysis: θ_{23}

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

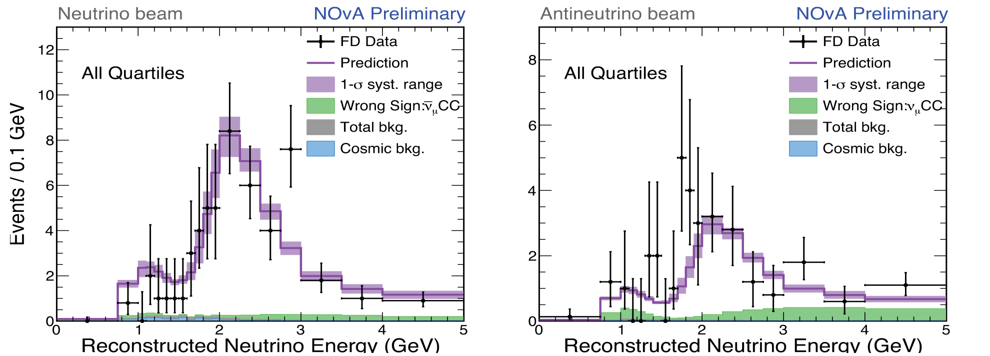
$$P_{\mu\mu} \simeq 1 - (c_{13}^4 \sin^2 2\theta_{23} + s_{23}^2 \sin^2 2\theta_{13}) \sin^2 \left(\frac{\Delta m_{31}^2 L}{4E}\right) + \mathcal{O}(\Delta m_{21}^2)$$

- At osc maximum $\sin^2\left(\frac{\Delta m_{31}^2 L}{4E}\right) = 1 \Rightarrow P_{\mu\mu} \simeq 0$ for $\theta_{23} \simeq \frac{\pi}{4}$

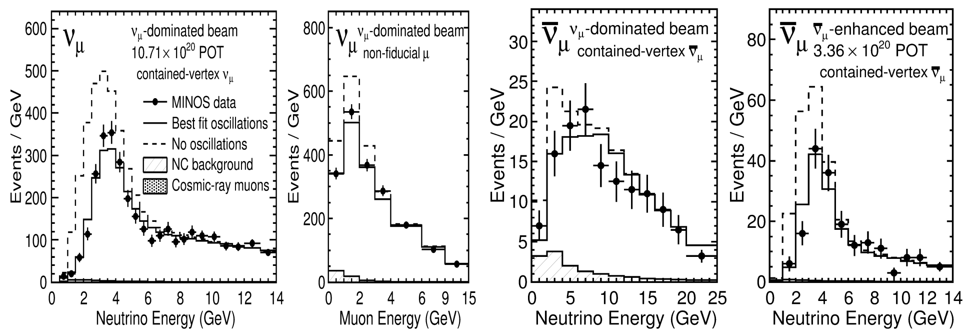
T2K $\nu_\mu \to \nu_\mu$ $\quad$ $\bar{\nu}_\mu \to \bar{\nu}_\mu$



NOvA $\nu_\mu \to \nu_\mu$ $\quad$ $\bar{\nu}_\mu \to \bar{\nu}_\mu$



MINOS $\nu_\mu \to \nu_\mu$ $\quad$ $\bar{\nu}_\mu \to \bar{\nu}_\mu$



T2K Fig M.Wascko ν-2018 Talk

T2K data: T.Koga Phd Thesis

NOvA Fig/data: M. Sanchez M.Wascko ν-2018 Talk

MINOS PRL 2013

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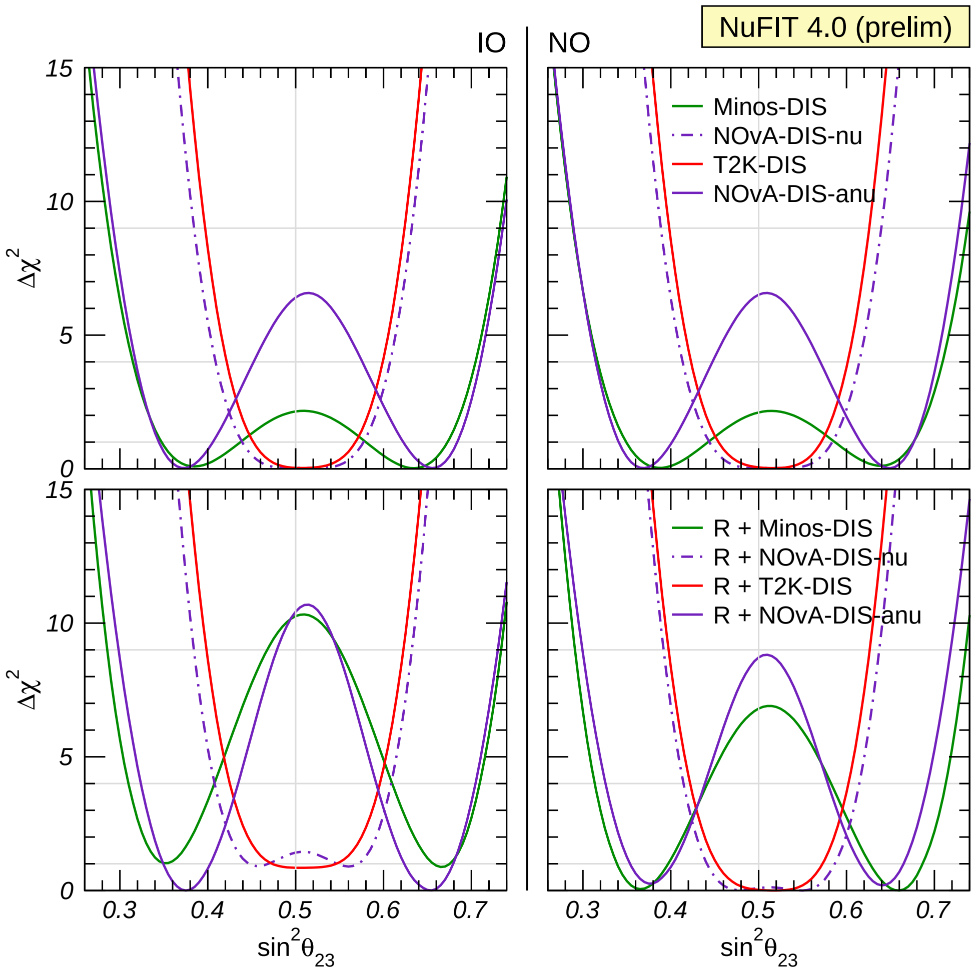
3 ν Analysis: θ_{23}

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

$$P_{\mu\mu} \simeq 1 - (c_{13}^4 \sin^2 2\theta_{23} + s_{23}^2 \sin^2 2\theta_{13}) \sin^2 \left(\frac{\Delta m_{31}^2 L}{4E} \right) + \mathcal{O}(\Delta m_{21}^2)$$



$*$ Upper panels use prior θ_{13} from reactors
(procedure in LBL experment analysis)

$*$ Lower panels:
full combination with $\chi^2_{\rm react}(\theta_{13}, \Delta m^2_{31})$

$\Rightarrow$ Non-maximality
driven by NOνA $\bar{\nu}$ and MINOS

$\Rightarrow$ More significant when full comb with React

$\Rightarrow$ Small contribution to NO/IO from disapp data

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

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

$$P_{\mu\mu} \simeq 1 - (c^4_{13}\sin^2 2\theta_{23} + s^2_{23}\sin^2 2\theta_{13}) \sin^2\left(\frac{\Delta m^2_{\mu\mu} L}{4E}\right) + \mathcal{O}[(\Delta m^2_{21})^2]$$

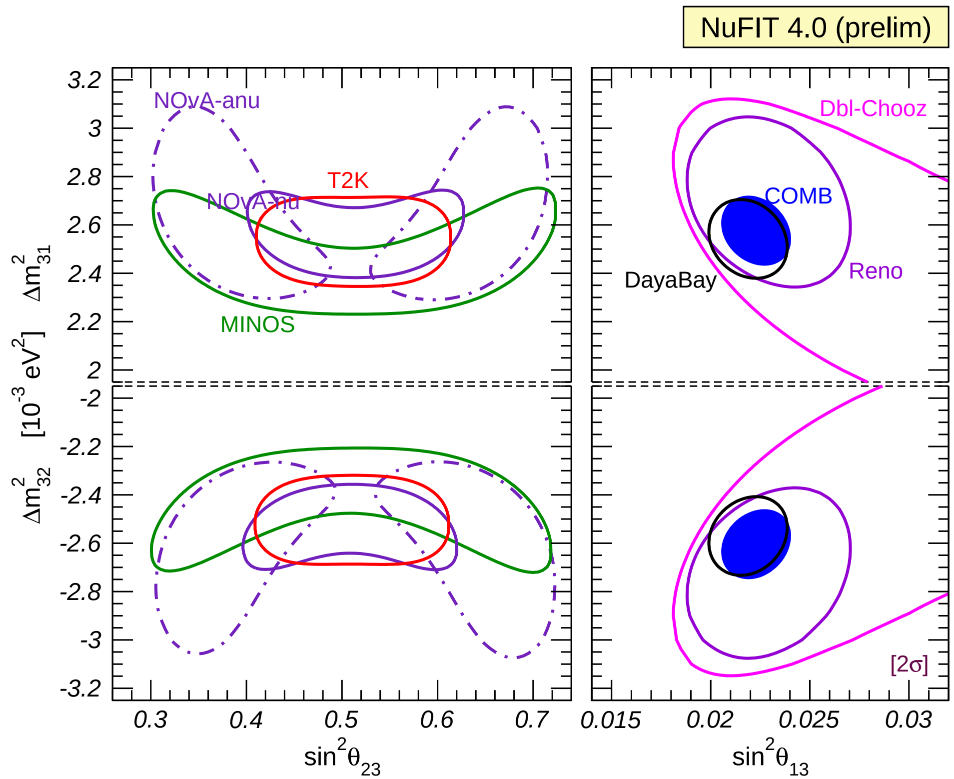
$$\Delta m^2_{\mu\mu} \simeq \Delta m^2_{3l} + \begin{matrix} c^2_{12}\Delta m^2_{21} & \text{NO} \\ s^2_{12}\Delta m^2_{21} & \text{IO} \end{matrix} + \ldots$$

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

$$P_{ee} \simeq 1 - \sin^2 2\theta_{13} \sin^2\left(\frac{\Delta m^2_{ee} L}{4E}\right) + \mathcal{O}[(\Delta m^2_{21})^2]$$

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

Nunokawa,Parke,Zukanovich (2005)



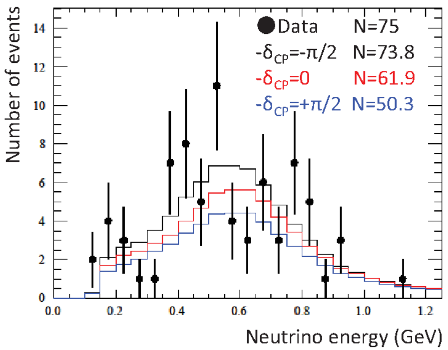
3 ν Analysis: θ_{23} Octant, Ordering, δ_{CP} in LBL

- Dominant information from ν_e apperance in LBL

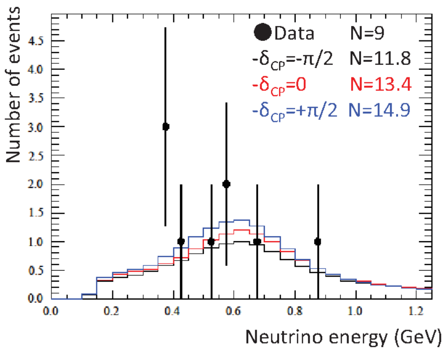
$$P_{\mu e} \simeq s_{23}^2 \sin^2 2\theta_{13} \left(\frac{\Delta_{31}}{B_\mp}\right)^2 \sin^2\left(\frac{B_\mp L}{2}\right) + \tilde{J}\,\frac{\Delta_{21}}{V_E}\,\frac{\Delta_{31}}{B_\mp} \sin\left(\frac{V_E L}{2}\right) \sin\left(\frac{B_\mp L}{2}\right) \cos\left(\frac{\Delta_{31} L}{2} \pm \delta_{CP}\right)$$

$$\Delta_{ij} = \frac{\Delta m_{ij}^2}{4E} \qquad B_\pm = \Delta_{31} \pm V_E \qquad \tilde{J} = c_{13} \sin^2 2\theta_{13} \sin^2 2\theta_{23} \sin^2 2\theta_{12}$$

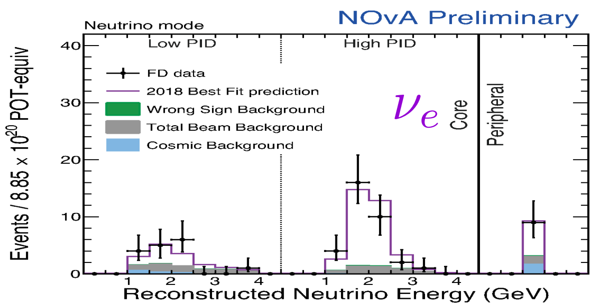
T2K $\nu_\mu \to \nu_e$ $\qquad$ $\bar\nu_\mu \to \bar\nu_e$ $\qquad$ NOvA

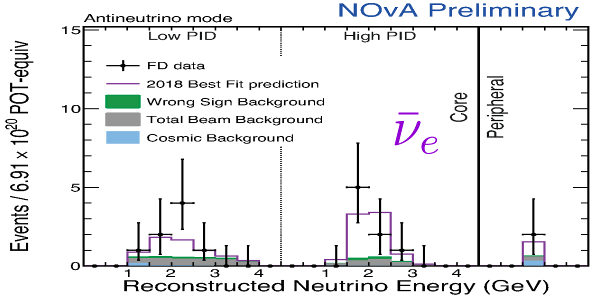


FHC 1Rν_e, δ_{CP}



RHC 1Rν_e, δ_{CP}





	SAMPLE	PREDICTED in NO				OBSERVED
		$\delta_{CP}=-\pi/2$	$\delta_{CP}=0$	$\delta_{CP}=+\pi/2$	$\delta_{CP}=\pi$	
ν_μ	FHC 1Rμ	268.5	268.2	268.5	268.9	243
$\bar\nu_\mu$	RHC 1Rμ	95.5	95.3	95.5	95.8	102
ν_e	FHC 1Re 0 decay-e	73.8	61.6	50.0	62.2	75
ν_e	FHC 1Re 1 decay-e	6.9	6.0	4.9	5.8	15
$\bar\nu_e$	RHC 1Re 0 decay-e	11.8	13.4	14.9	13.2	9

NOVA OBSERVES: 58 EVENTS IN NEUTRINO, 18 EVENTS IN ANTINEUTRINO MODE.

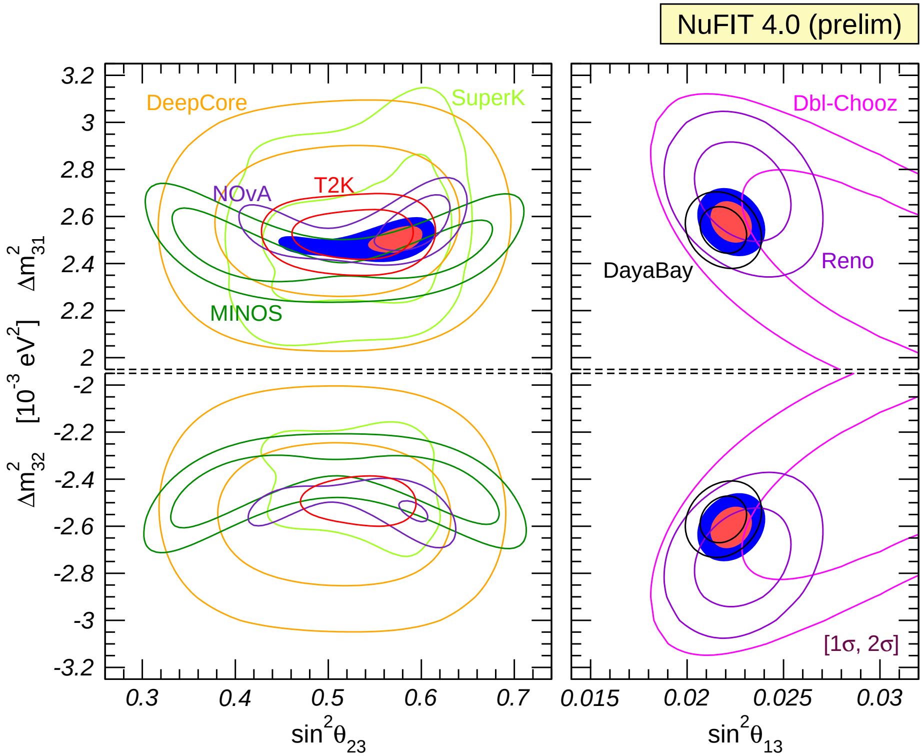
EXPECT 30-75 EVENTS FOR NEUTRINO MODE AND 10-22 FOR ANTINEUTRINO MODE

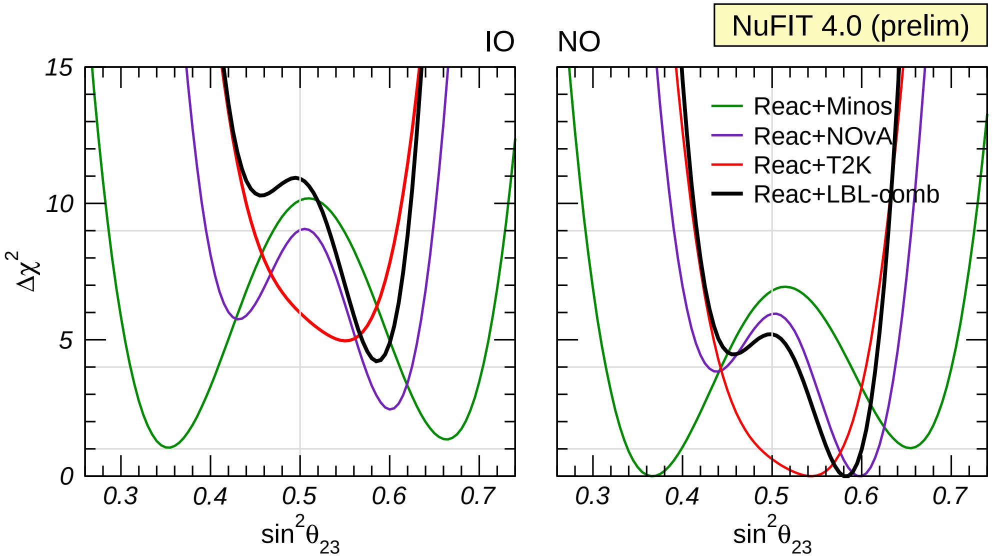
3 ν Analysis: θ_{23} Octant, Ordering, δ_{CP} in LBL

- Dominant information from ν_e apperance in LBL

$$P_{\mu e} \simeq s_{23}^2 \sin^2 2\theta_{13} \left(\frac{\Delta_{31}}{B_\mp}\right)^2 \sin^2\left(\frac{B_\mp L}{2}\right) + \tilde{J}\,\frac{\Delta_{21}}{V_E}\,\frac{\Delta_{31}}{B_\mp}\,\sin\left(\frac{V_E L}{2}\right)\sin\left(\frac{B_\mp L}{2}\right)\cos\left(\frac{\Delta_{31} L}{2} \pm \delta_{CP}\right)$$

$$\Delta_{ij} = \frac{\Delta m^2_{ij}}{4E} \qquad B_\pm = \Delta_{31} \pm V_E \qquad \tilde{J} = c_{13}\,\sin^2 2\theta_{13}\,\sin^2 2\theta_{23}\,\sin^2 2\theta_{12}$$





REAC+LBL-COMB:

– In both orderings best fit $\sin^2\theta_{23} \sim 0.58$

– $\theta_{23} = \frac{\pi}{4}$ at $\Delta\chi^2 \sim 5(6)$ of b.f. in NO(IO)

3 ν Analysis: θ_{23} Octant, Ordering, δ_{CP} in LBL

- Dominant information from ν_e apperance in LBL

$$P_{\mu e} \simeq s_{23}^2 \sin^2 2\theta_{13} \left(\frac{\Delta_{31}}{B_{\mp}}\right)^2 \sin^2\left(\frac{B_{\mp} L}{2}\right) + \tilde{J} \frac{\Delta_{21}}{V_E} \frac{\Delta_{31}}{B_{\mp}} \sin\left(\frac{V_E L}{2}\right) \sin\left(\frac{B_{\mp} L}{2}\right) \cos\left(\frac{\Delta_{31} L}{2} \pm \delta_{CP}\right)$$

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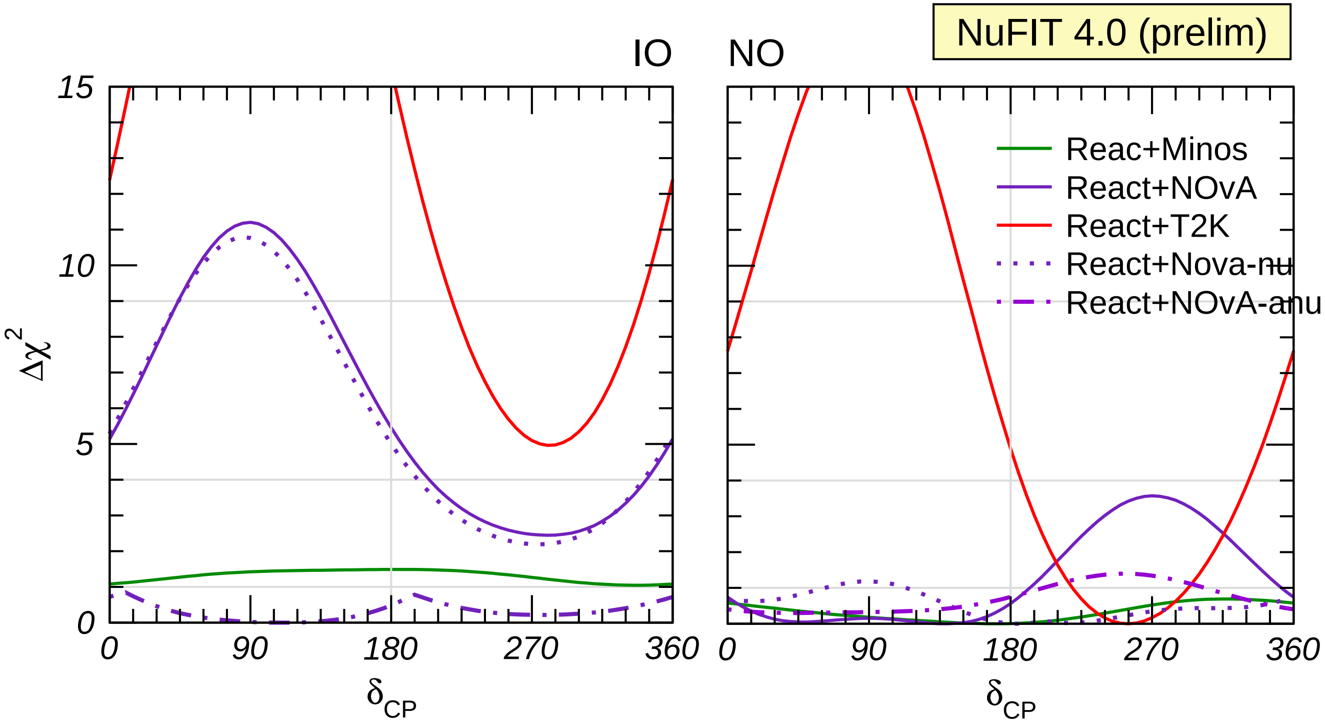

3 ν Analysis: θ_{23} Octant, Ordering, $\delta_{\rm CP}$ in LBL

- Dominant information from ν_e apperance in LBL

$$P_{\mu e} \simeq s^2_{23} \sin^2 2\theta_{13} \left(\frac{\Delta_{31}}{B_\mp}\right)^2 \sin^2\left(\frac{B_\mp L}{2}\right) + \tilde{J}\, \frac{\Delta_{21}}{V_E} \frac{\Delta_{31}}{B_\mp} \sin\left(\frac{V_E L}{2}\right) \sin\left(\frac{B_\mp L}{2}\right) \cos\left(\frac{\Delta_{31} L}{2} \pm \delta_{CP}\right)$$

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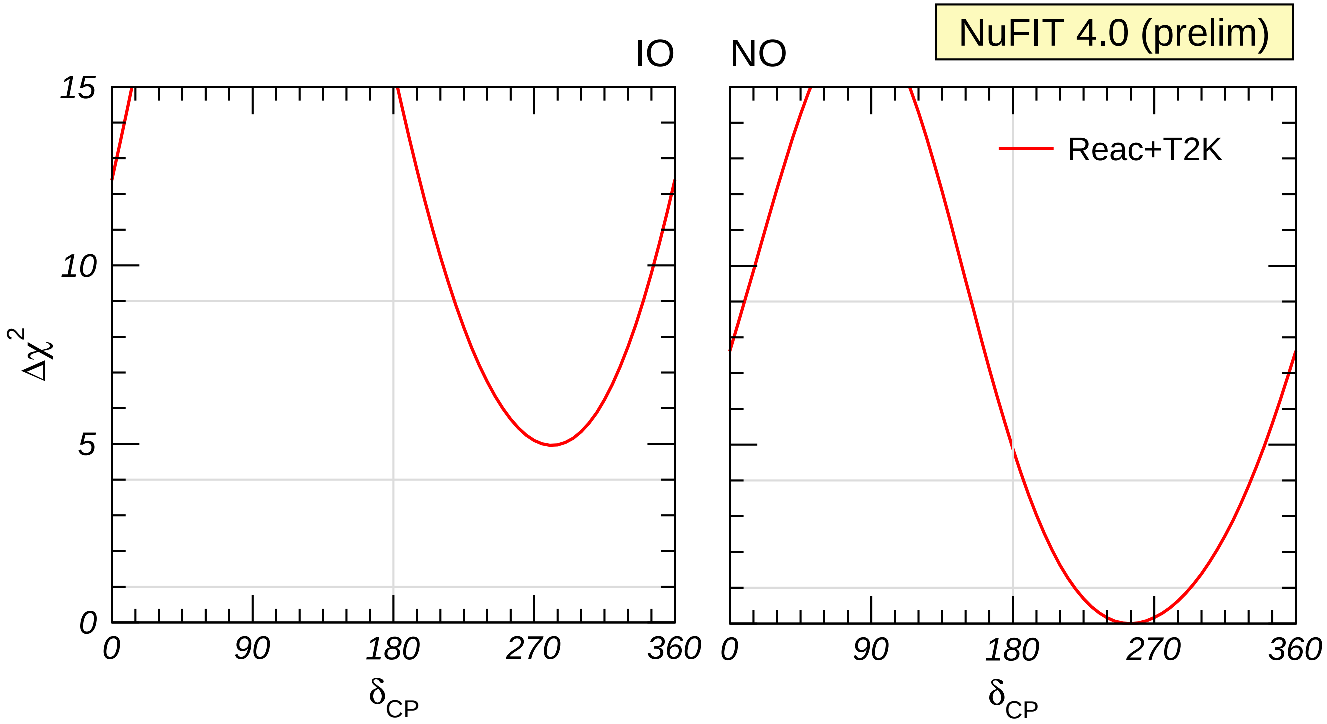

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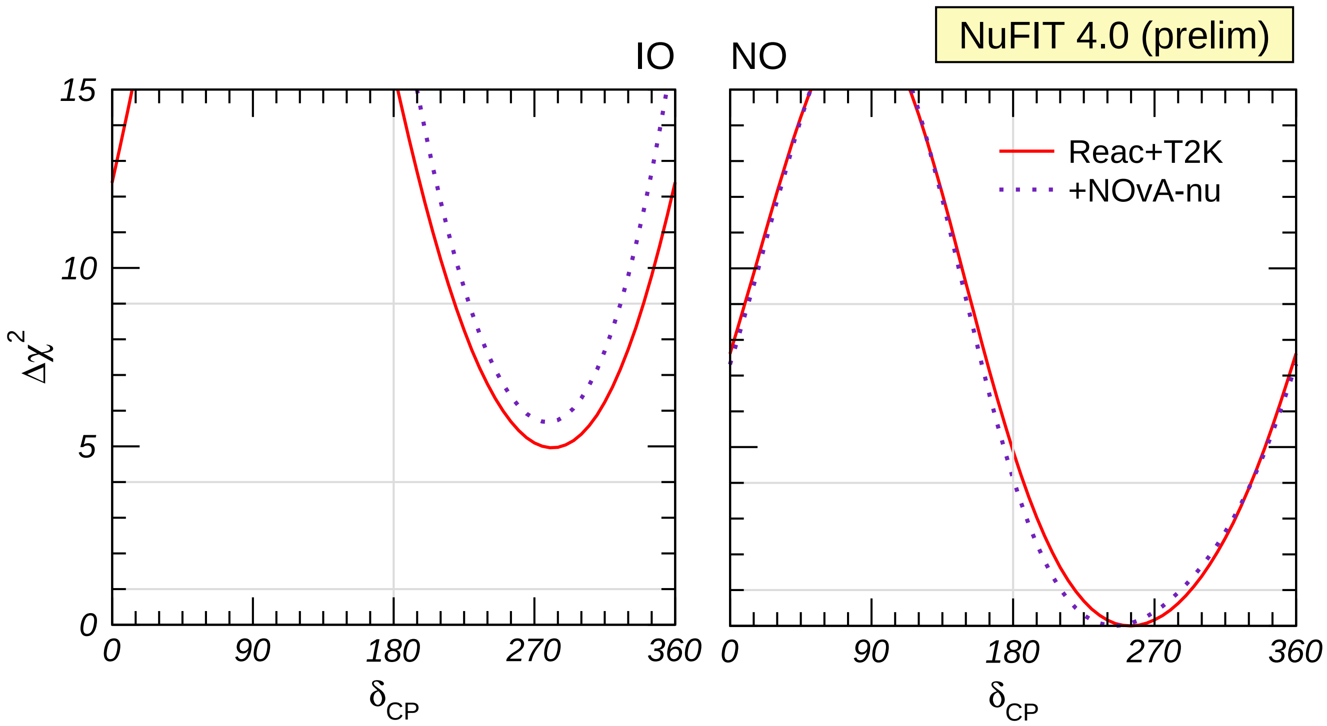

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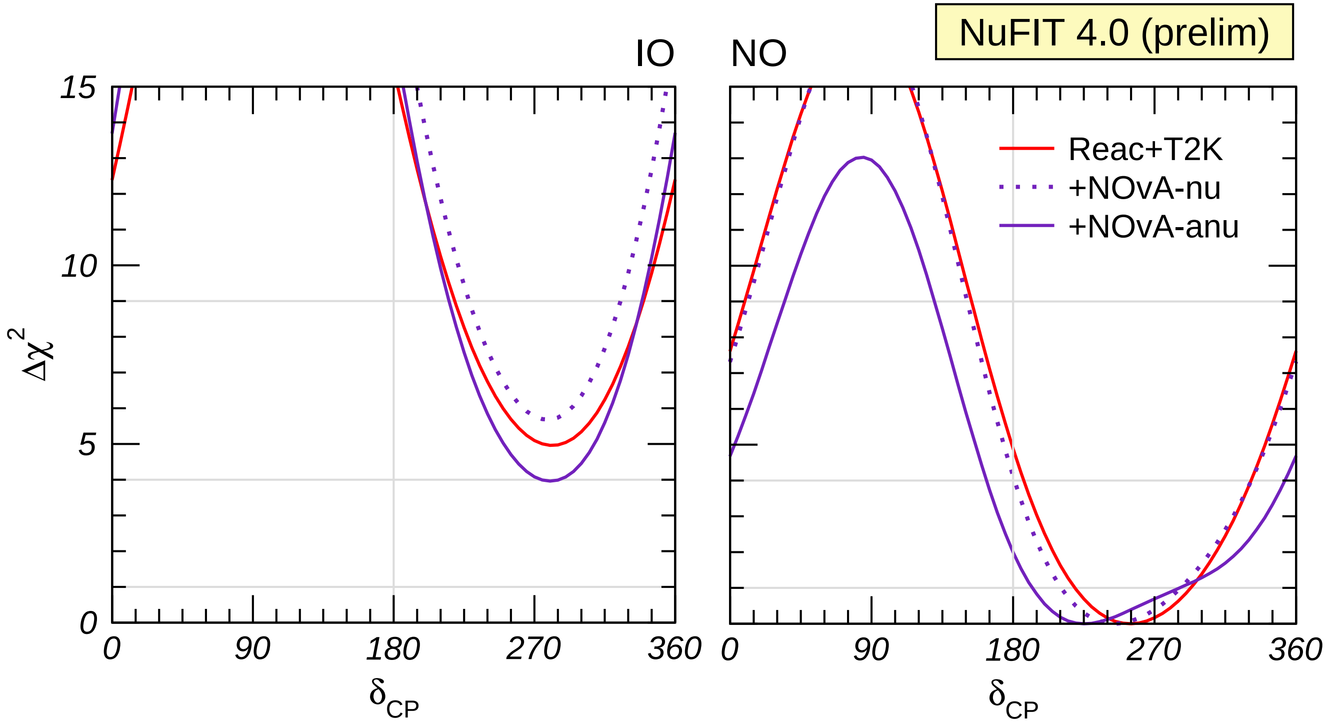

3 ν Analysis: θ_{23} Octant, Ordering, $\delta_{\rm CP}$ in LBL

- Dominant information from ν_e apperance in LBL

$$P_{\mu e} \simeq s_{23}^2 \sin^2 2\theta_{13} \left(\frac{\Delta_{31}}{B_\mp}\right)^2 \sin^2\left(\frac{B_\mp L}{2}\right) + \tilde{J}\, \frac{\Delta_{21}}{V_E}\, \frac{\Delta_{31}}{B_\mp} \sin\left(\frac{V_E L}{2}\right) \sin\left(\frac{B_\mp L}{2}\right) \cos\left(\frac{\Delta_{31} L}{2} \pm \delta_{CP}\right)$$

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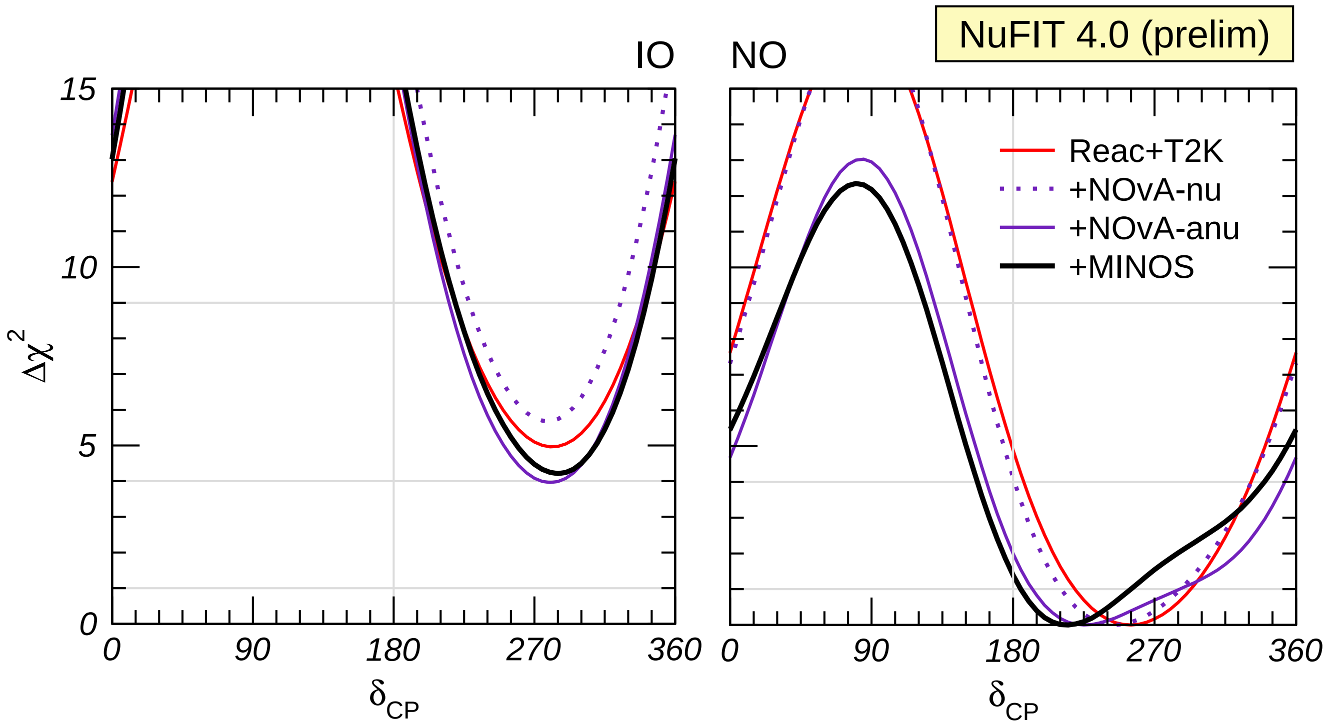


From LBL-COMB:

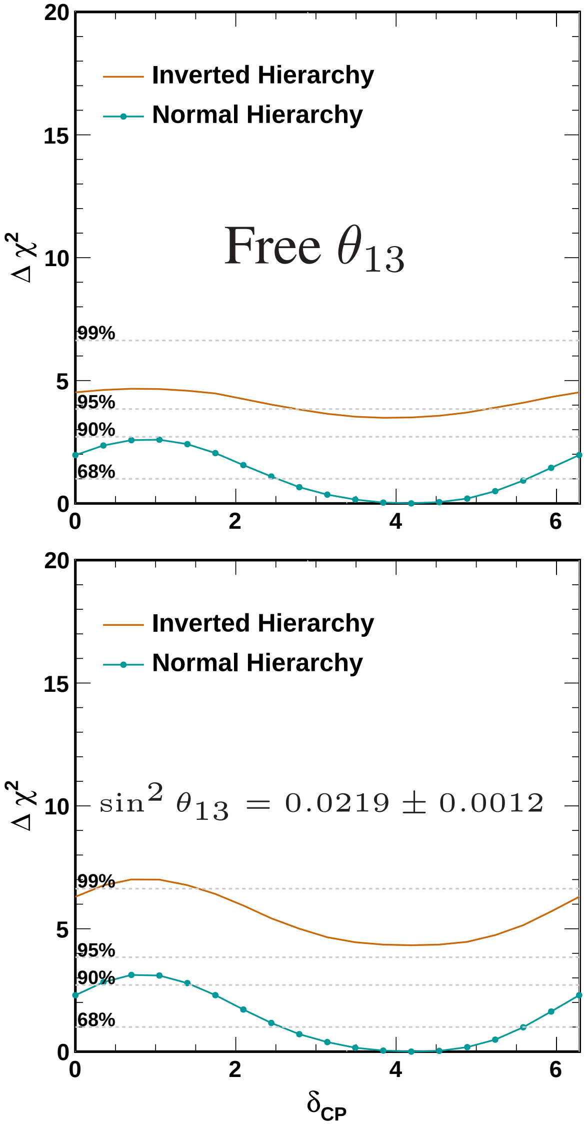
∗ IO disfavoured at 2σ

∗ NO: CP conservation allowed at $\sim 1.2\sigma$

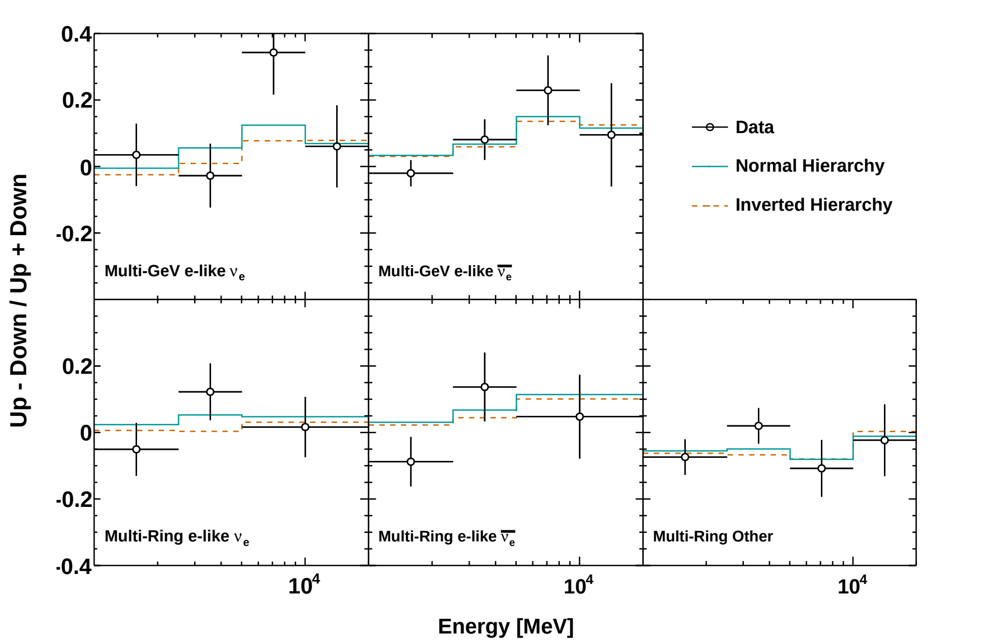
∗ NO: $-20 \lesssim \delta_{\rm CP} \lesssim 160$ ($35 \lesssim \delta_{\rm CP} \lesssim 125$) disfavoured at 2σ (3σ)

θ_{23}, CP & Ordering: Effect in SK ATM

Latest SK analysis (PRD 2018) yelds:



From SK paper: *"Small excesses seen between a few and ten GeV in the Multi-GeV e-like ν_e and the Multi-Ring e-like ν_e and $\bar{\nu}_e$ samples drive these preferences".*

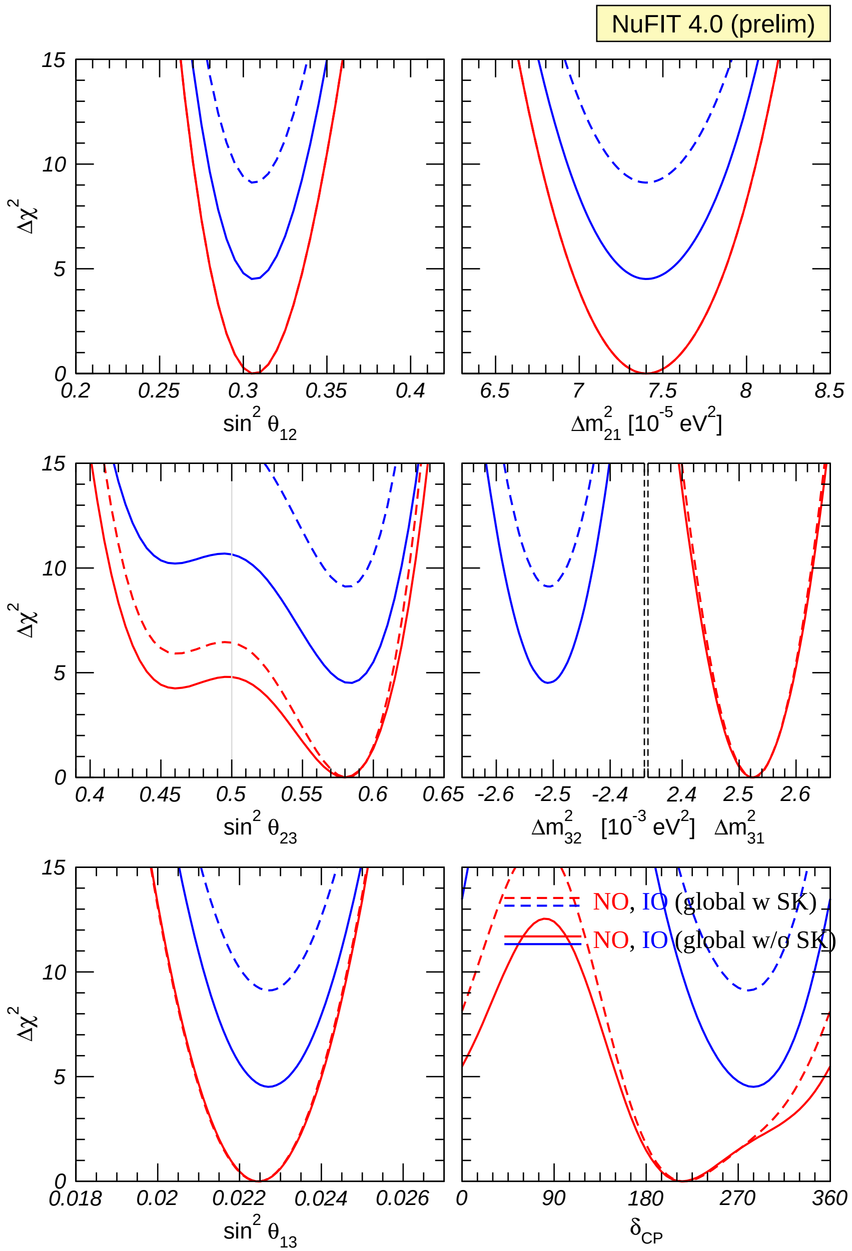


– No pheno group reproduces SK analysis

– Only possibility is combine with SK χ^2 tables

Summary

Concha Gonzalez-Garcia



- From Global Analysis w ATM IC/DC w/o SK :

	NO	
	bf $\pm 1\sigma$	3σ
$\sin^2\theta_{12}$	$0.307^{+0.013}_{-0.012}$	$0.272 \to 0.346$
$\sin^2\theta_{13}$	$0.02246^{+0.00069}_{-0.00067}$	$0.02043 \to 0.02453$
$\frac{\Delta m^2_{21}}{10^{-5}\,\text{eV}^2}$	$7.40^{+0.21}_{-0.20}$	$6.80 \to 8.02$
$\frac{\Delta m^2_{3l}}{10^{-3}\,\text{eV}^2}$	2.523 ± 0.033	$2.424 \to 2.623$
$\sin^2\theta_{23}$	$0.580^{+0.018}_{-0.021}$	$0.417 \to 0.627$
δ_{CP}	215^{+41}_{-29}	$125 \to 393$

	IO $\Delta\chi^2 = 4.5$	
	bf $\pm 1\sigma$	3σ
$\sin^2\theta_{12}$	$0.307^{+0.013}_{-0.012}$	$0.272 \to 0.346$
$\sin^2\theta_{13}$	$0.02271^{+0.00070}_{-0.00068}$	$0.02068 \to 0.02480$
$\frac{\Delta m^2_{21}}{10^{-5}\,\text{eV}^2}$	$7.40^{+0.21}_{-0.20}$	$6.80 \to 8.02$
$\frac{\Delta m^2_{3l}}{10^{-3}\,\text{eV}^2}$	$-2.510^{+0.035}_{-0.032}$	$-2.610 \to -2.409$
$\sin^2\theta_{23}$	$0.583^{+0.017}_{-0.020}$	$0.423 \to 0.629$
δ_{CP}	285^{+27}_{-30}	$193 \to 360$

$\Rightarrow$ Including SK:

- NO vs IO: $\Delta\chi^2 = 4.5 \Rightarrow 9.1$
- NO: $\theta_{23} = \frac{\pi}{4}$: $\Delta\chi^2 = 4.4 \Rightarrow 6.2$
- NO: CP conserv: $\Delta\chi^2 = 1.7 \Rightarrow 1.8$