Review on global fits

What's ν - Invisibles12, GGI, Florence, 25 June 2012

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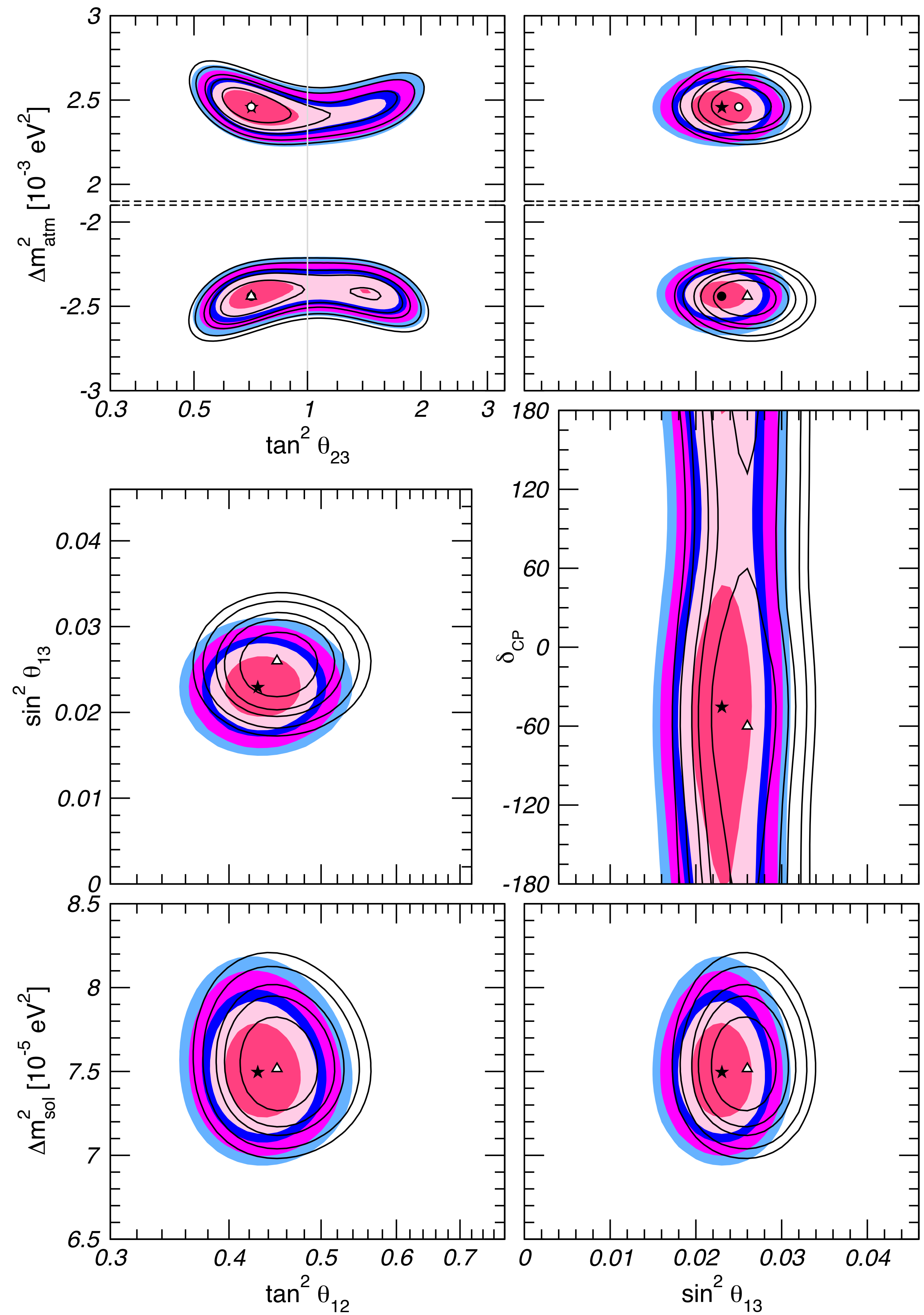
Heidelberg

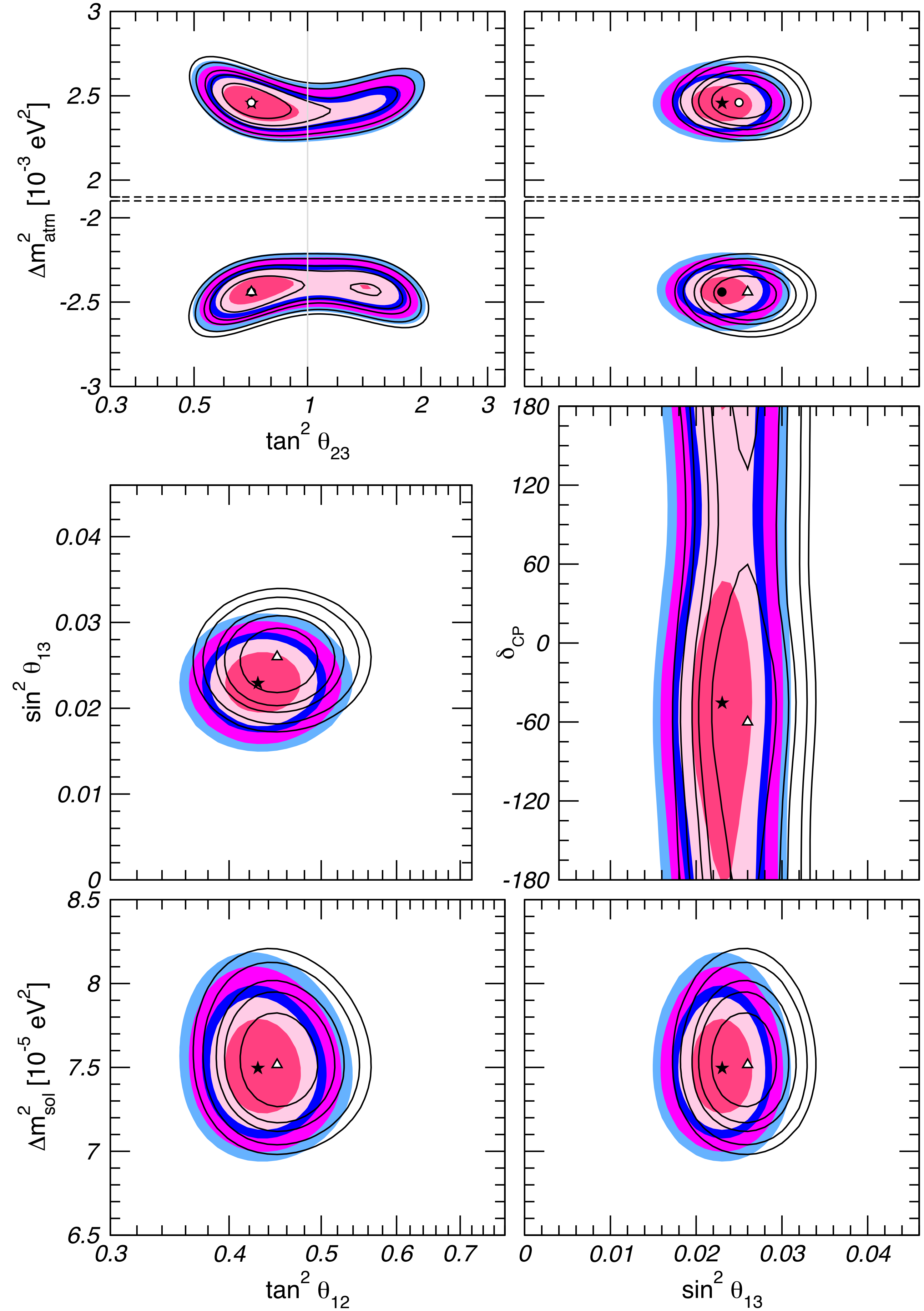
preliminary results from work in collab. with C. Gonzalez-Garcia, M. Maltoni, J. Salvado including latest data from Neutrino2012



preliminary results from work in collab. with C. Gonzalez-Garcia, M. Maltoni, J. Salvado including latest data from Neutrino2012

Outline:

- *the θ_{13} revolution*
- *non-maximality of θ_{23}*
- *CP phase and hierarchy*

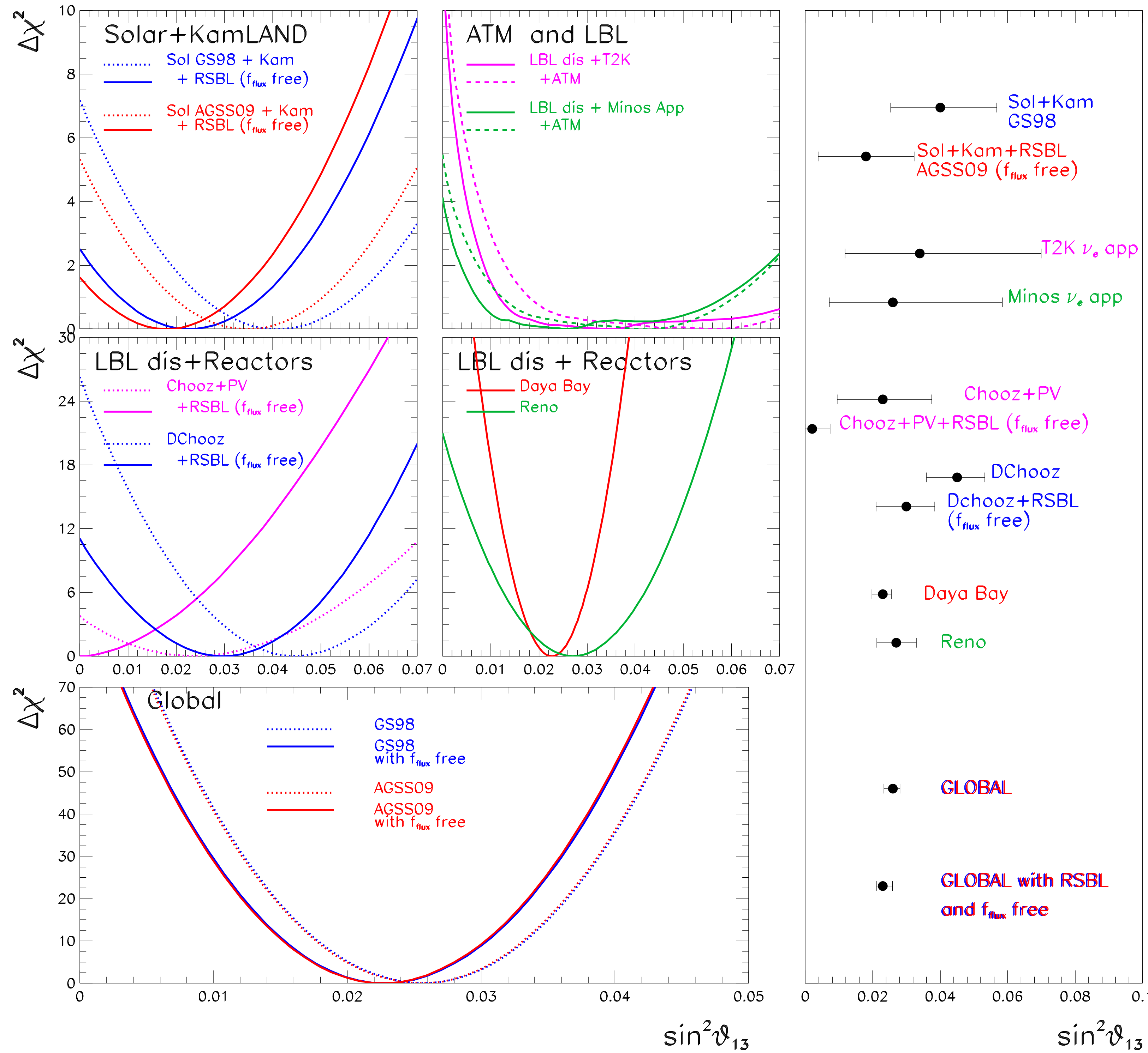


The θ_{13} revolution

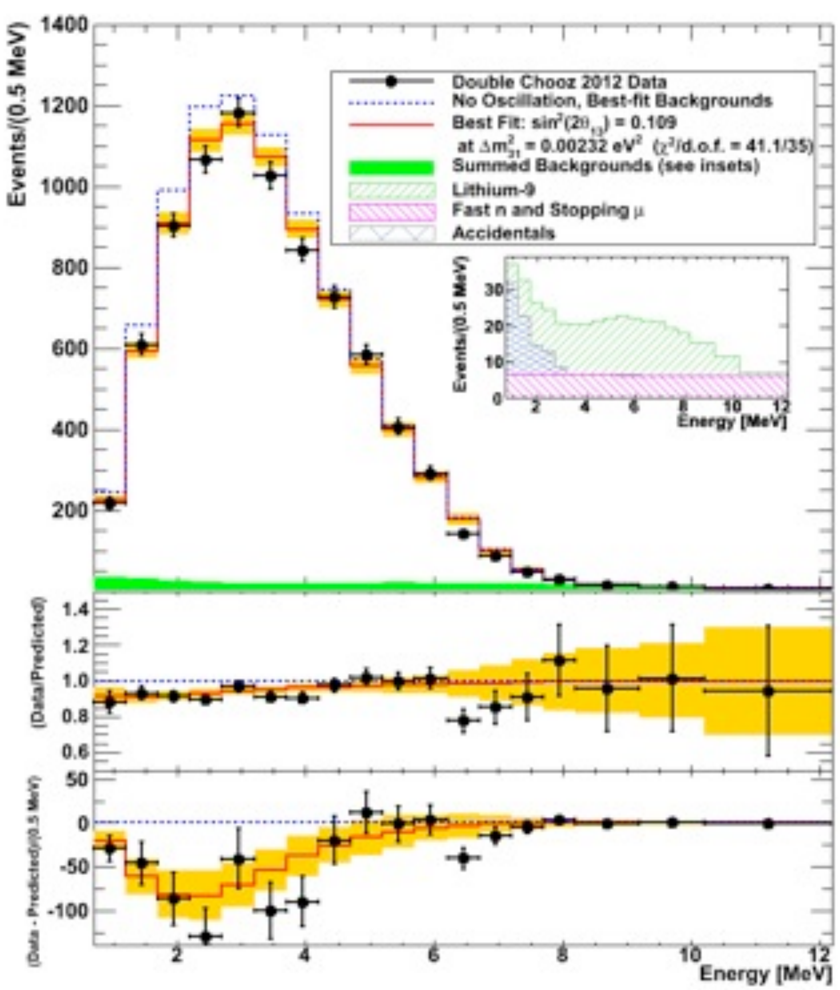
- *About 1 year ago: 6 events in T2K: 2.5σ*
  - *global fits gave >3σ for the first time*

Fogli et al, 1106.6028
TS, Tortola, Valle 1108.1376

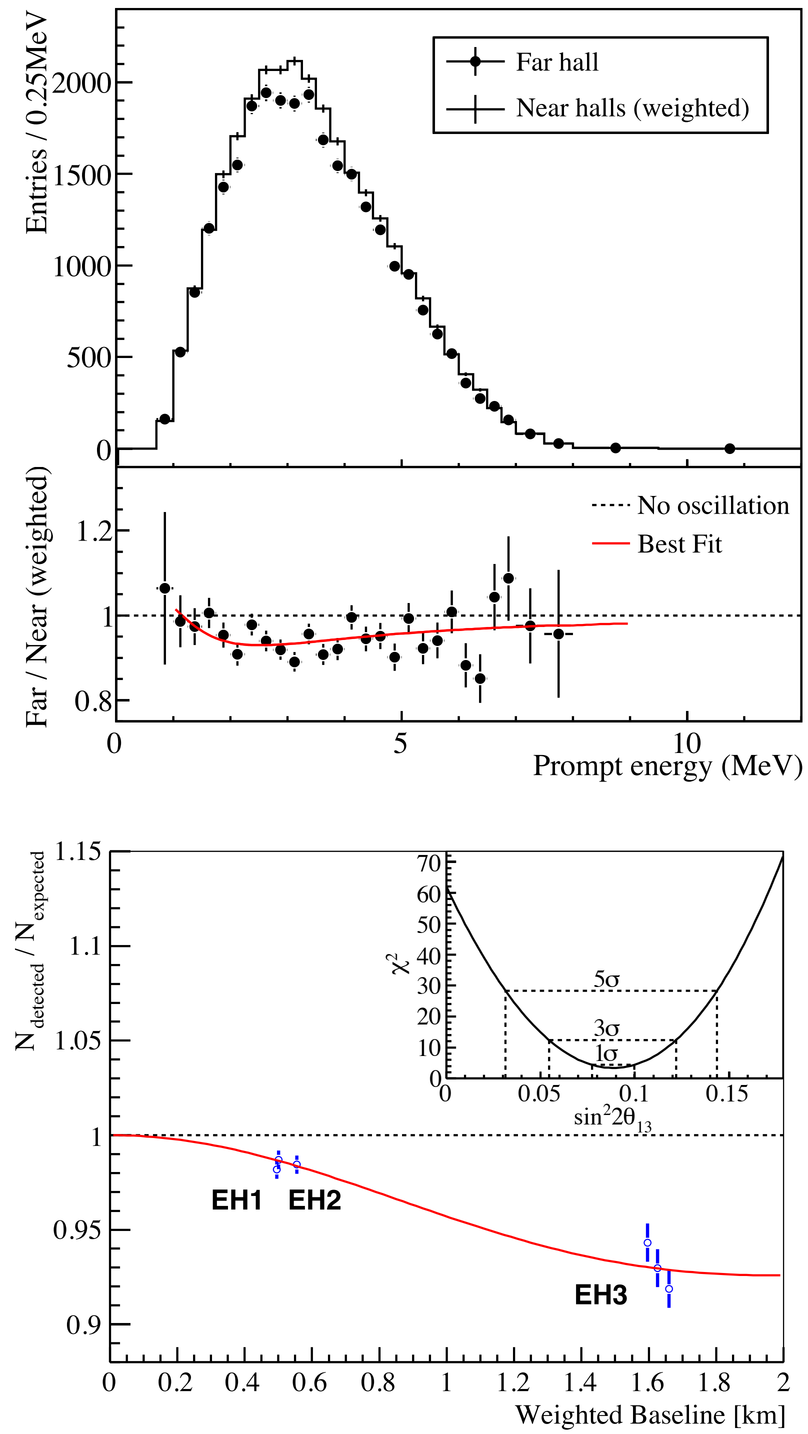
- *DoubleChooz, DayaBay, RENO*
  - *post-Neutrino12: $\Delta\chi^2 \approx 100$ in the global fit*



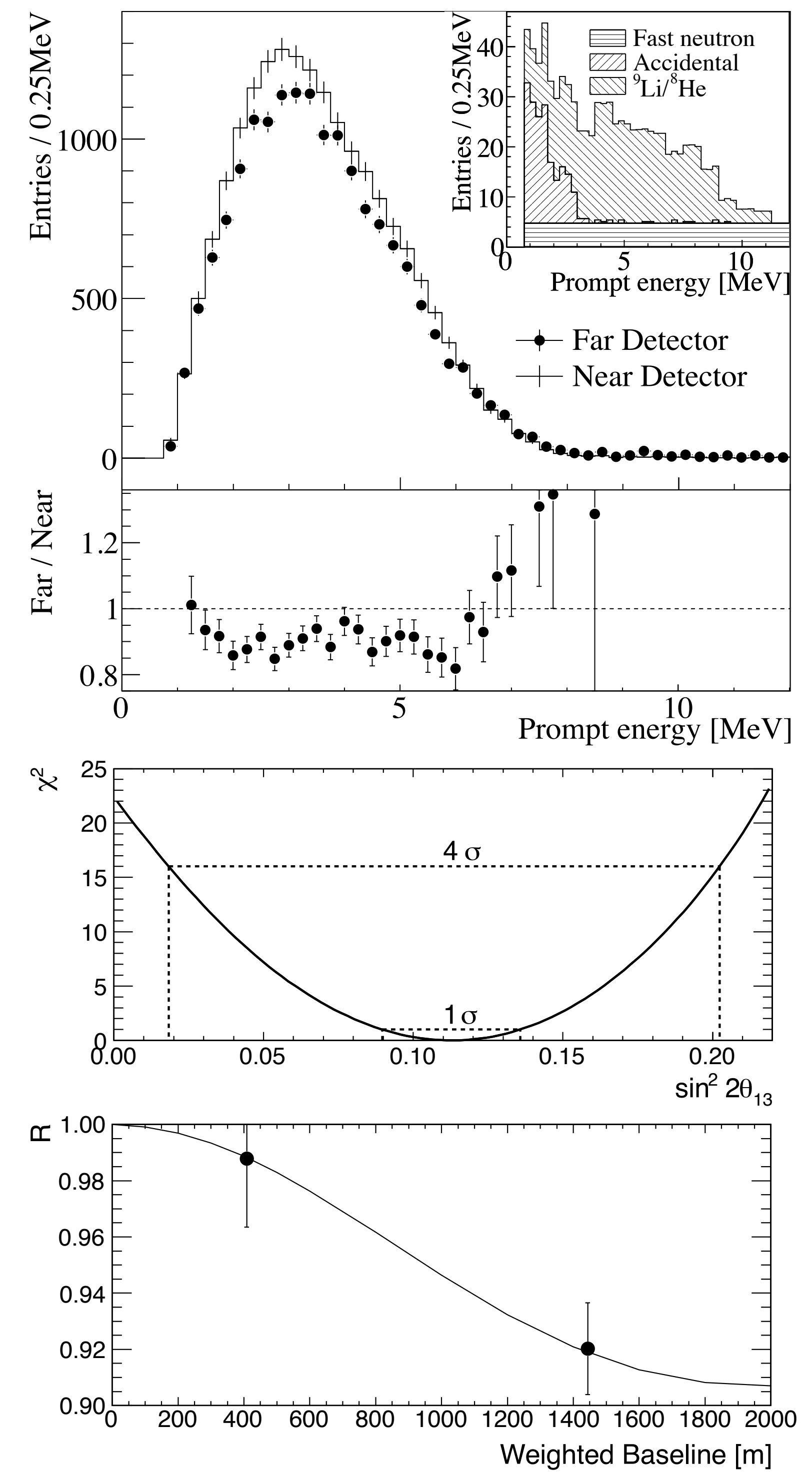
The θ_{13} revolution - the reactors



DoubleChooz @ Neutrino2012



DayaBay @ Neutrino2012



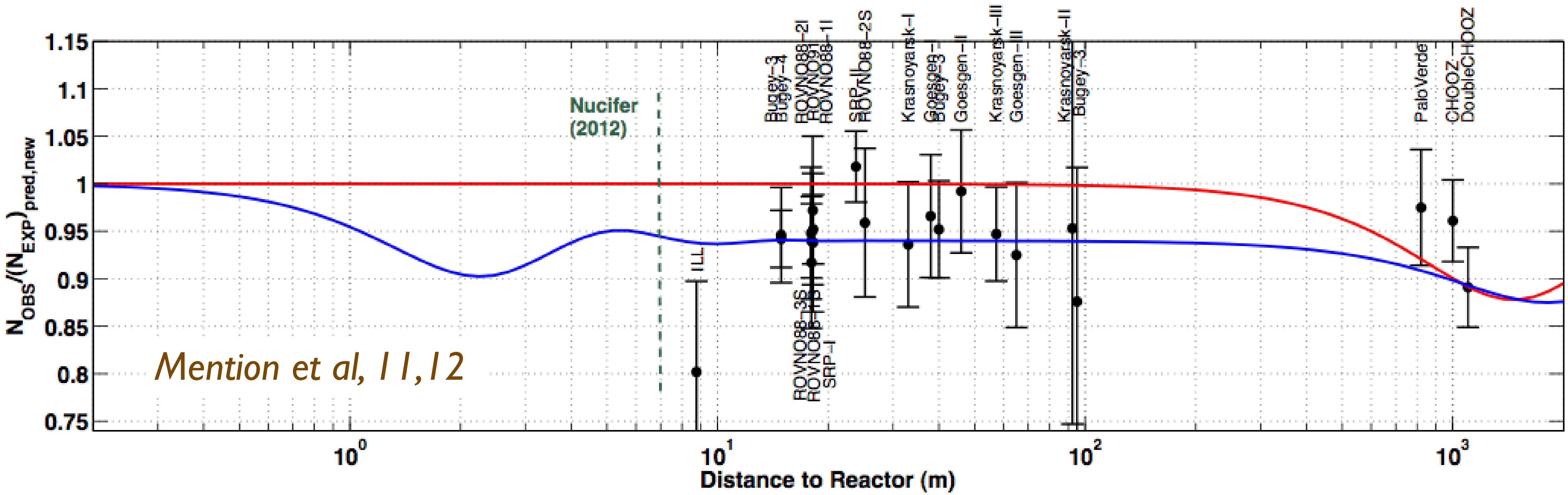
RENO, 1204.0626

The reactor anomaly

- to predict the $\bar{\nu}_e$ flux from nuclear reactors one has to convert the measured e^- spectra from ^{235}U, ^{239}Pu, ^{241}Pu into neutrino spectra
  Schreckenbach et al., 82, 85, 89
- recent improved calculation Mueller et al., 1101.2663 $\sim$ 3% higher fluxes (ab initio calculations + virtual branches for missing part)
- confirmed by independent calculation P. Huber, 1106.0687 (virtual branches)
- increase of predicted number of neutrino-induced events compared to old flux calculations:

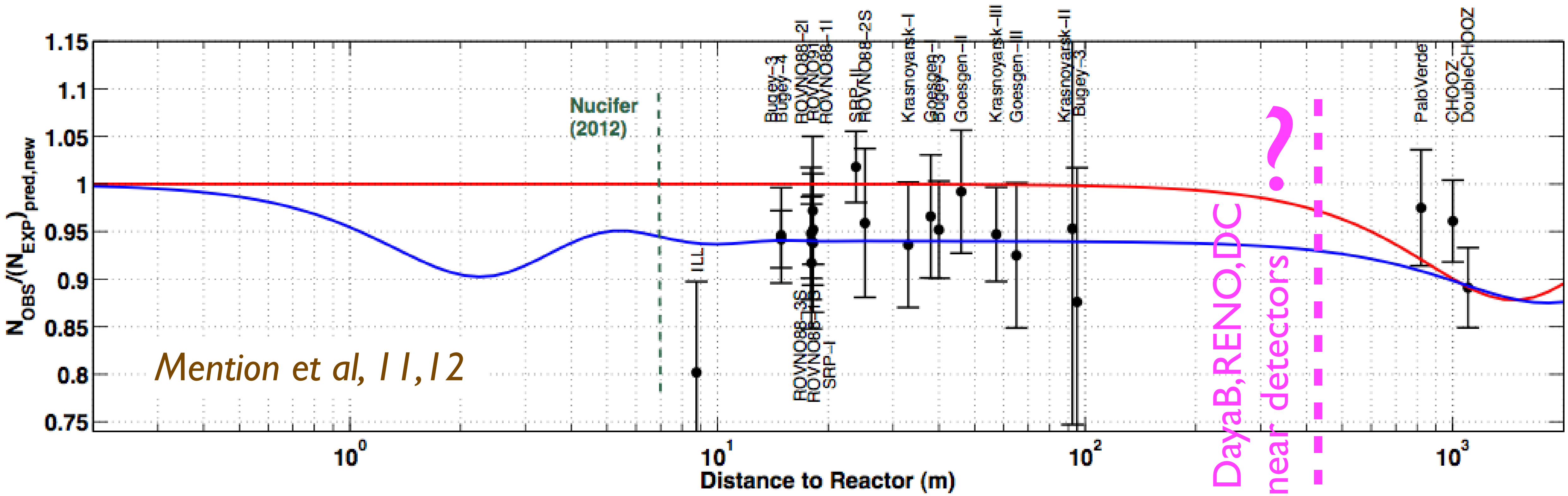
^{235}U	^{239}Pu	^{241}Pu	^{238}U
3.7%	4.2%	4.7%	9.8%

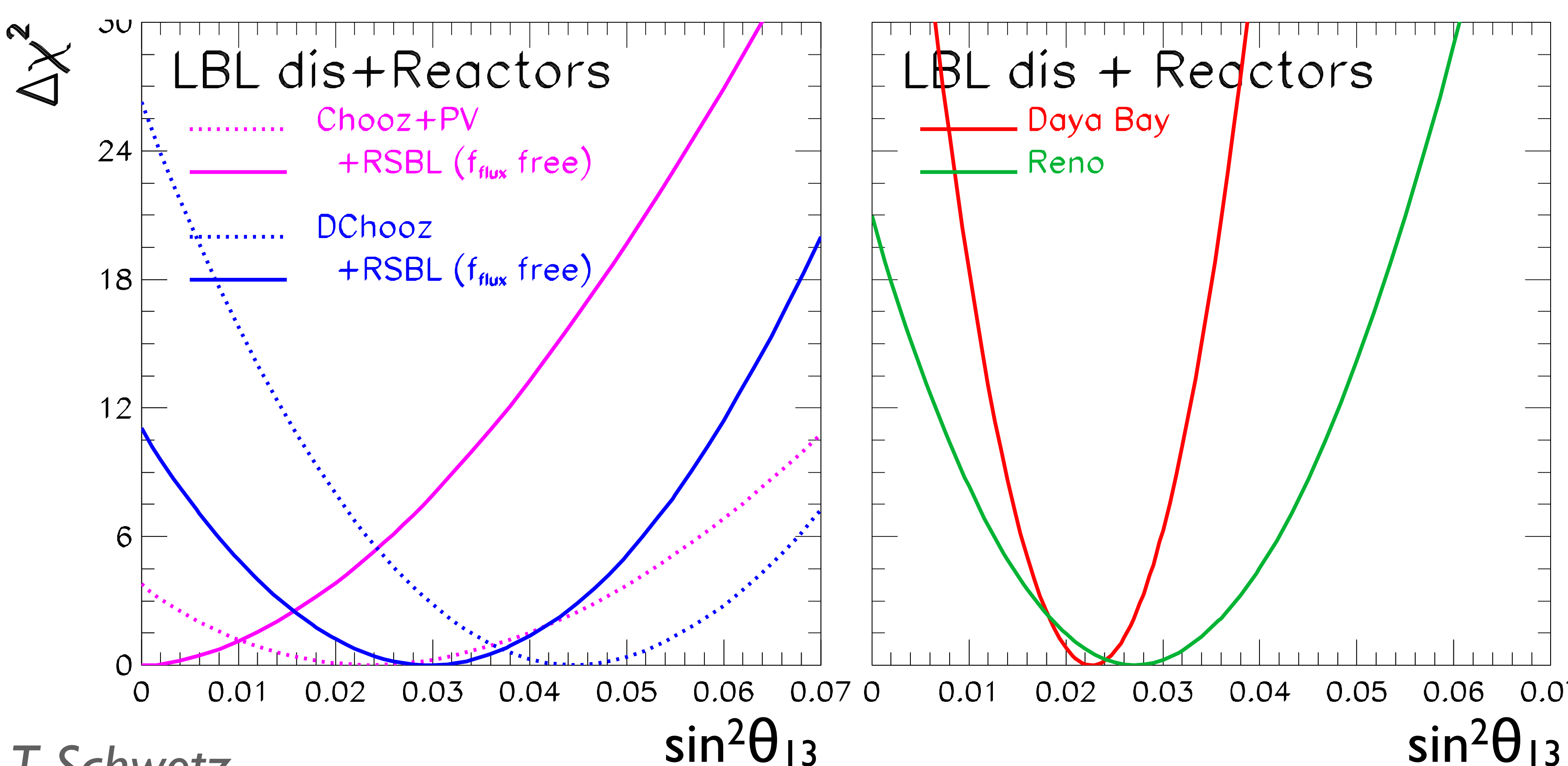
The reactor anomaly



- *SBL reactor data (L < 100m) in tension with predicted flux $f = 0.935 \pm 0.024$ (different from 1 @ 2.7σ)*
- *systematics?*
  - *normalization of ILL electron spectra*
  - *neutron lifetime (use 2012 PDG value)*
- *sterile neutrinos at the eV scale?* *talk by Maltoni*

The reactor anomaly and the θ_{13} determination





two extreme assumptions:

- *use fluxes from Huber, 1106.0687 without SBL reactor data*
- *leave reactor flux free and include SBL data in fit*

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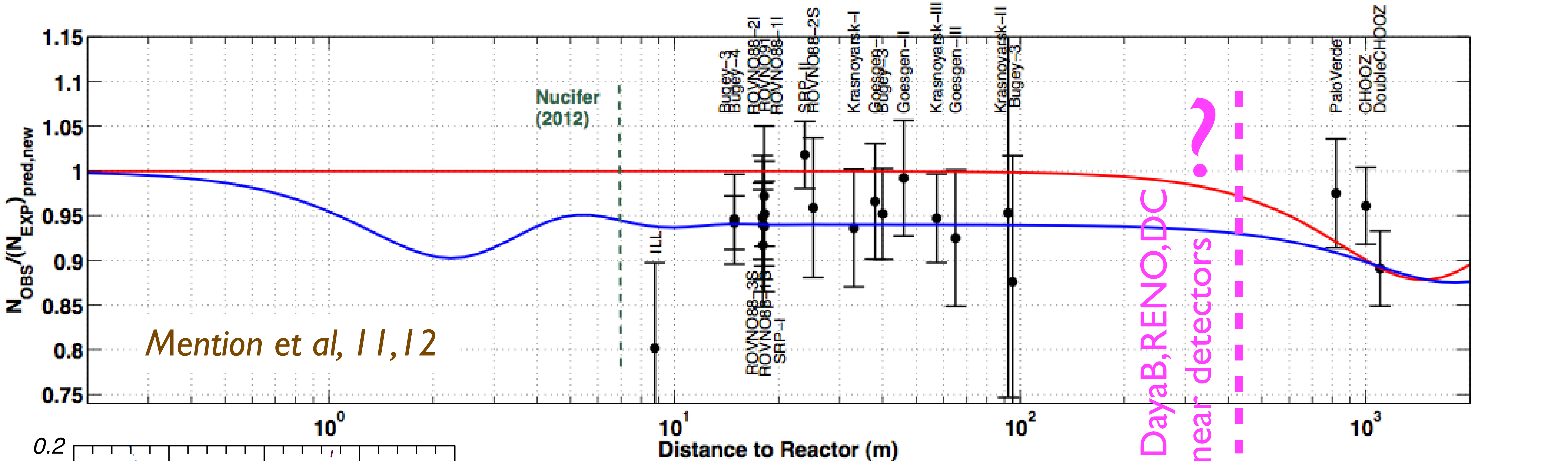
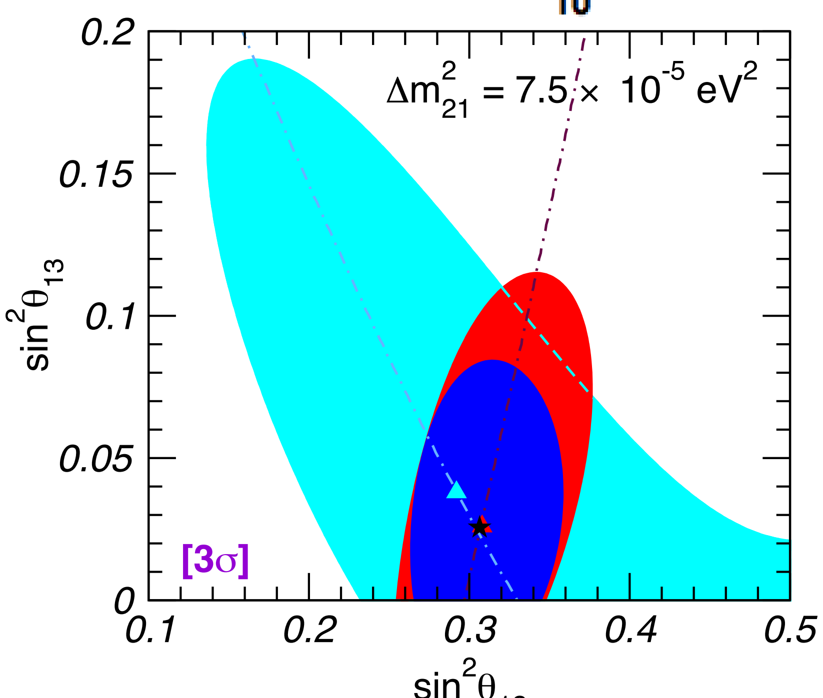
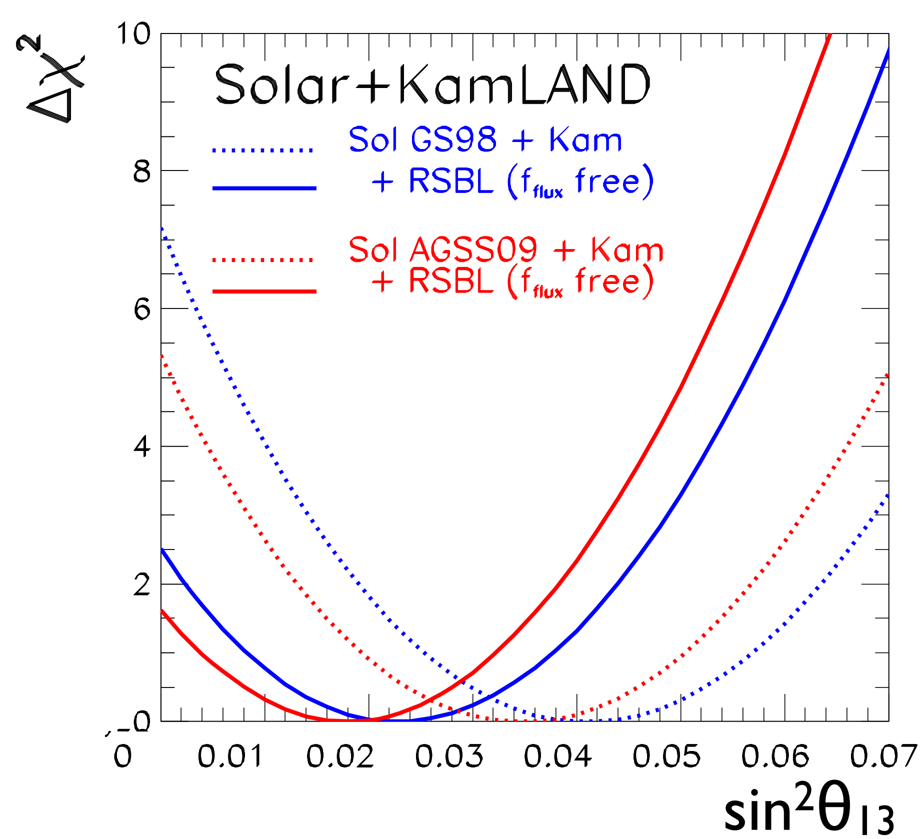




plot by M. Maltoni; Fogli et al, 08; TS, Tortola, Valle, 08



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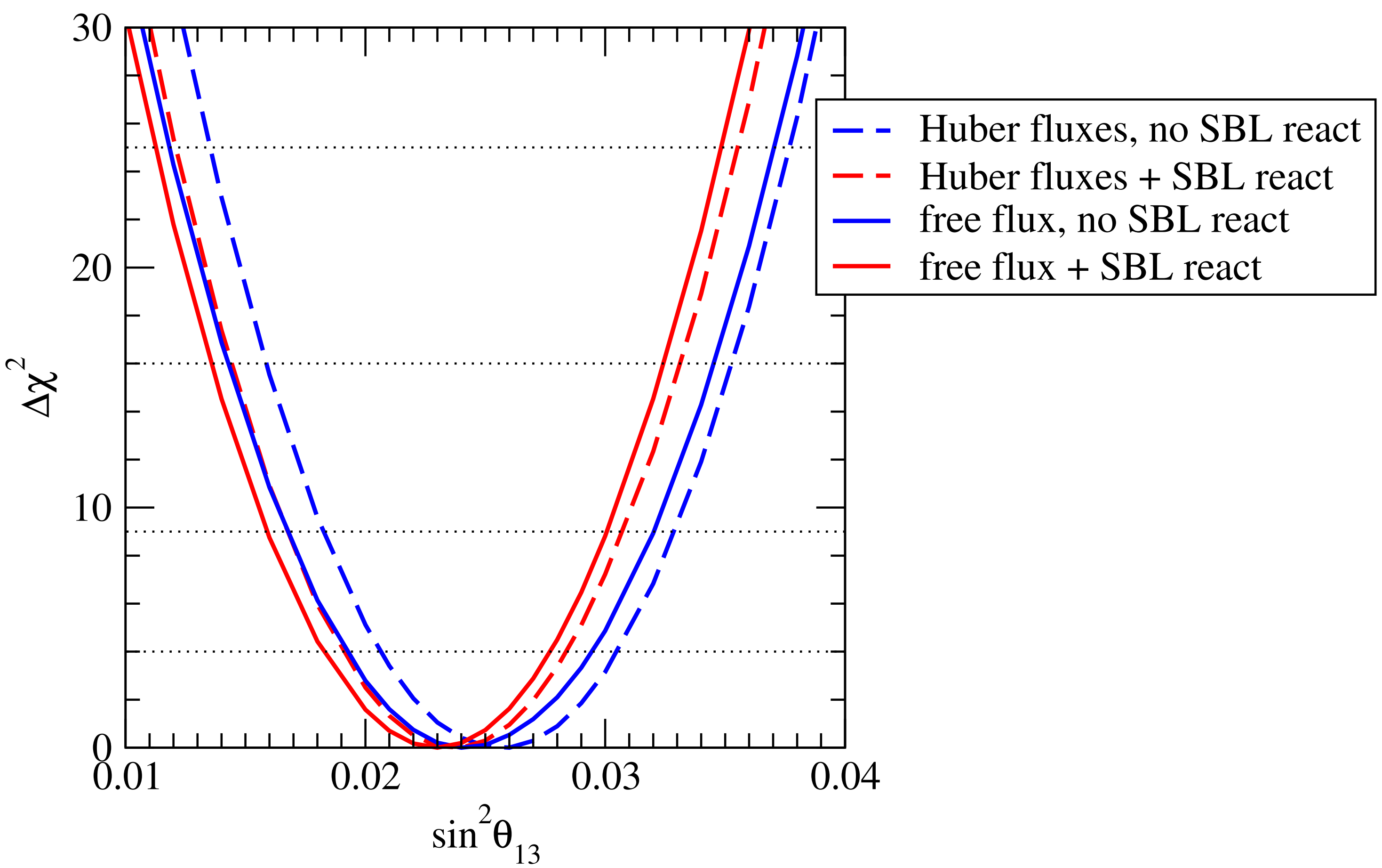

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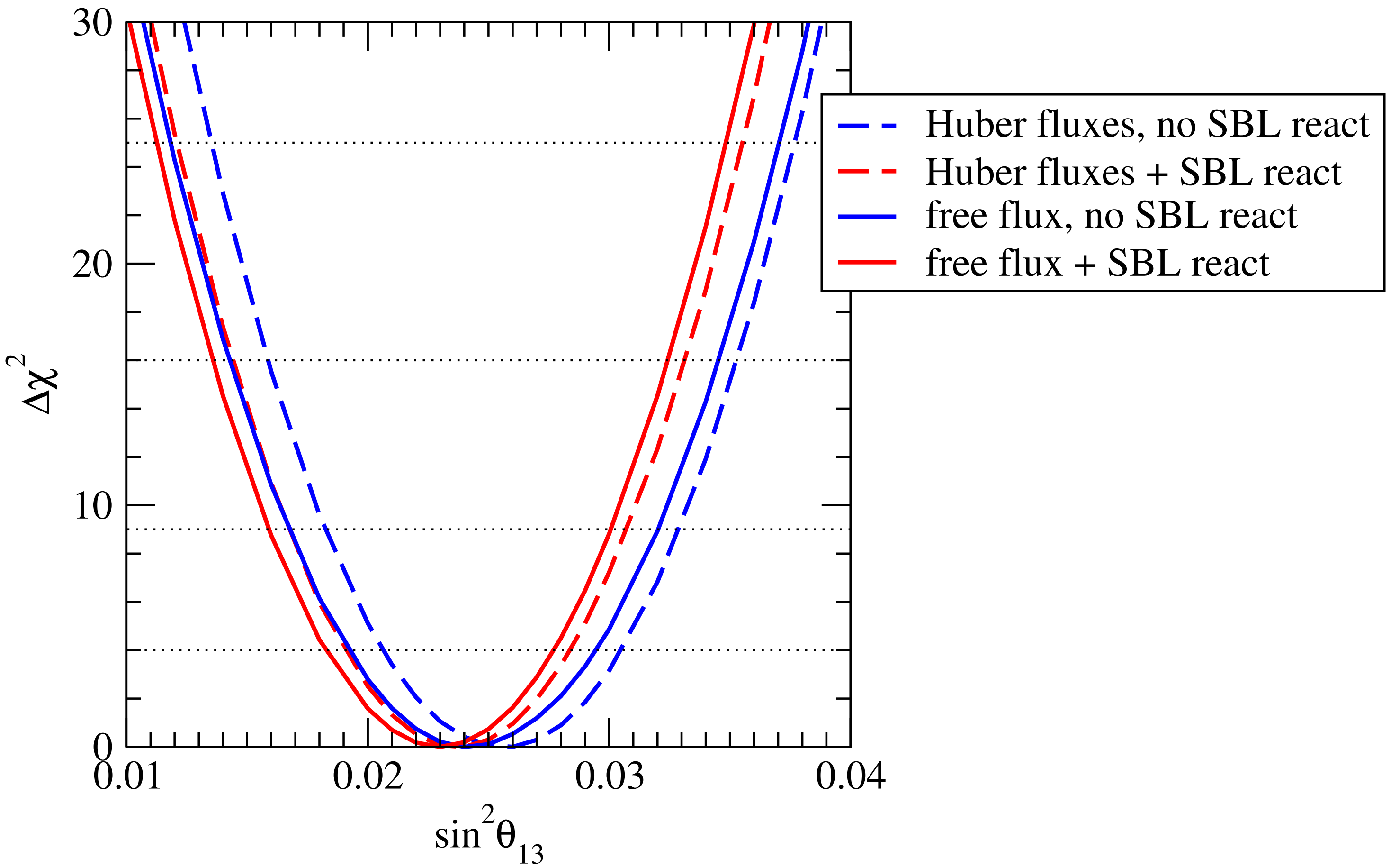
$$\sin^2\theta_{13} = 0.0257 \pm 0.0025\,, \quad \theta_{13} = (9.2 \pm 0.46)^\circ\,, \quad \sin^2 2\theta_{13} = 0.100 \pm 0.0095$$

- *leave reactor flux free and include SBL data in fit*

$$\sin^2\theta_{13} = 0.0230 \pm 0.0023\,, \quad \theta_{13} = (8.7 \pm 0.44)^\circ\,, \quad \sin^2 2\theta_{13} = 0.090 \pm 0.0090$$

The reactor anomaly and the θ_{13} determination

- *result depends on data which in principle is not sensitive to θ_{13}*
- *shift at the level of 1σ*



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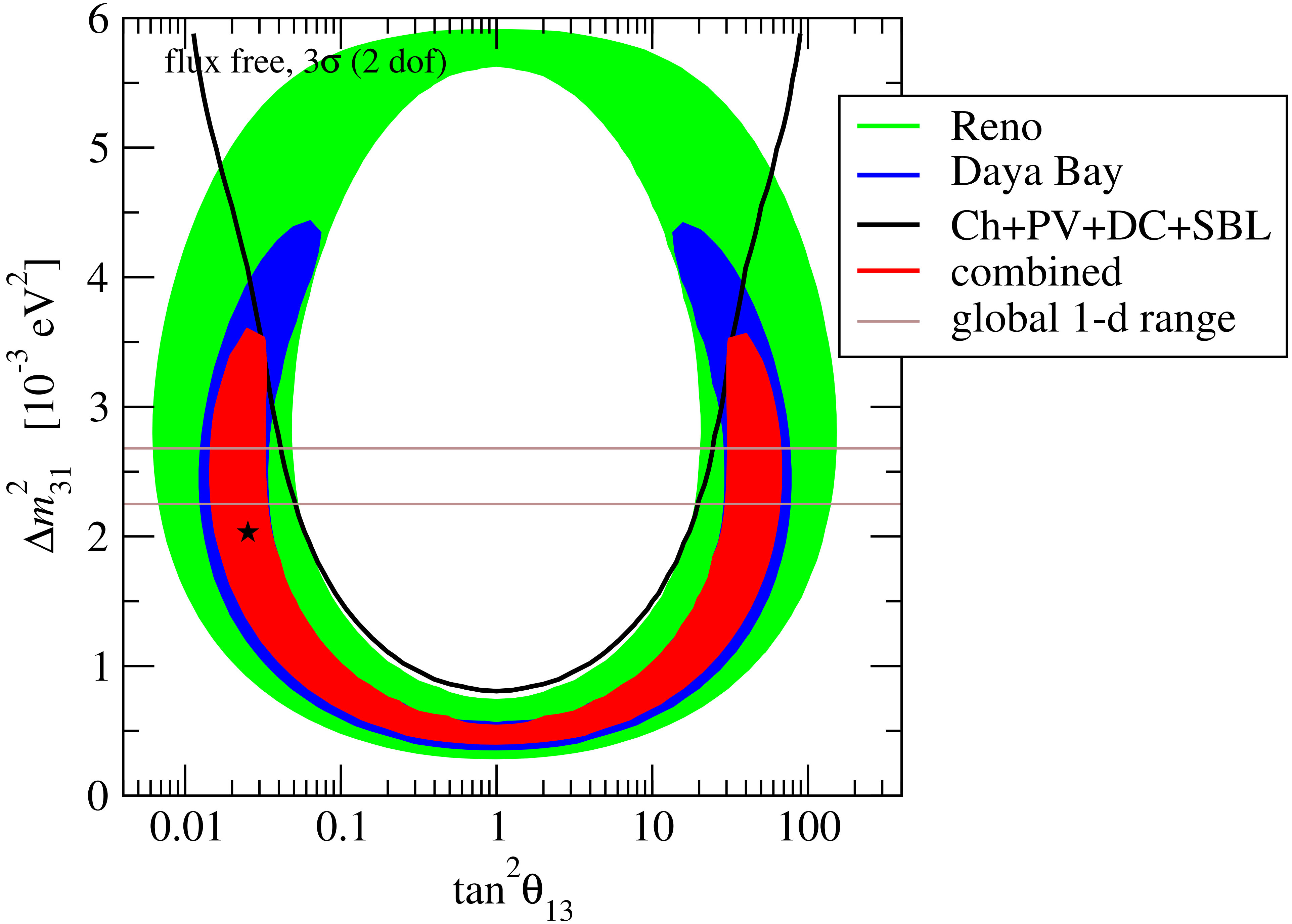
Measuring $\Delta m^2{}_{31}$ with reactors



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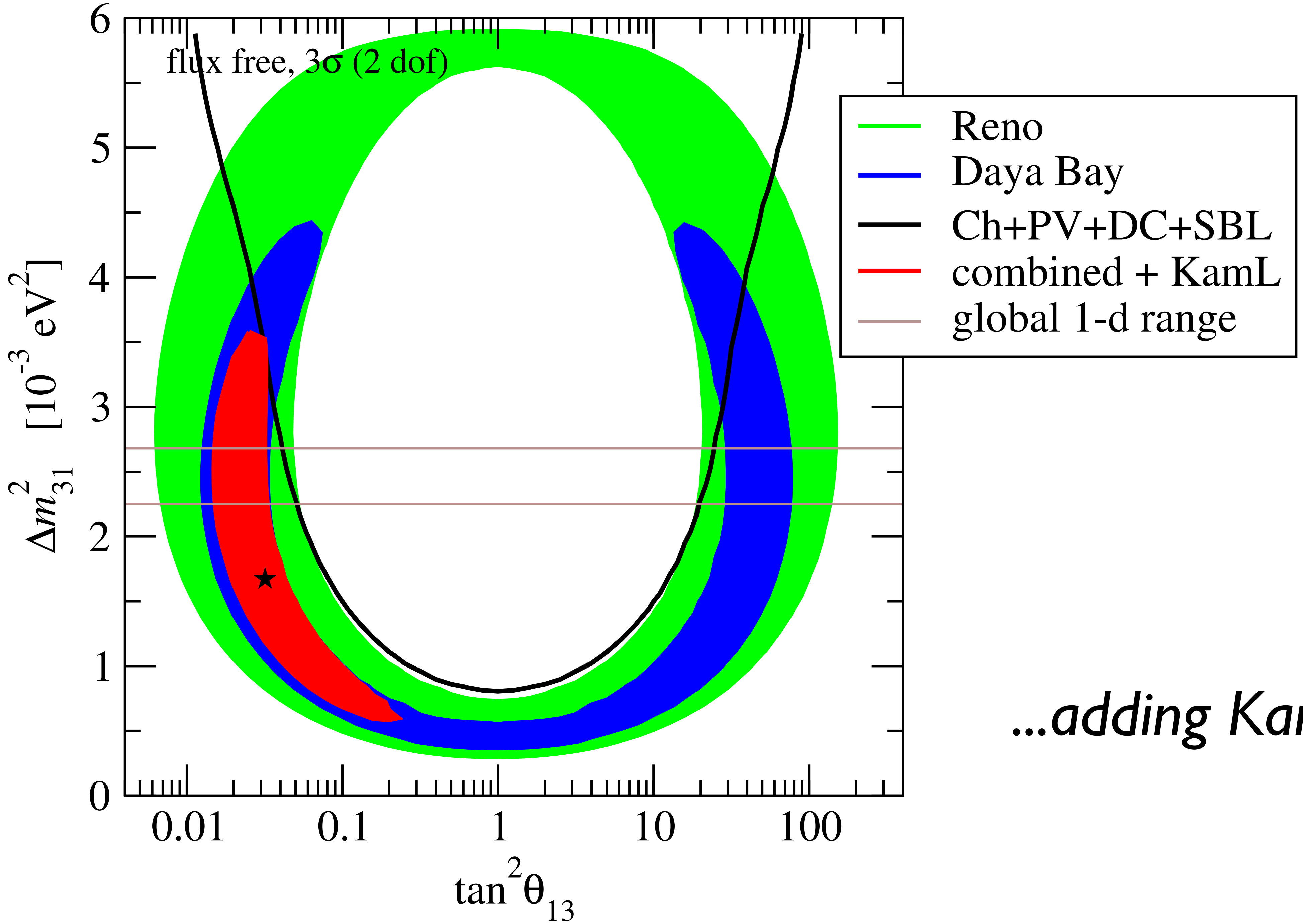

...adding KamLAND

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On non-maximal 23 mixing

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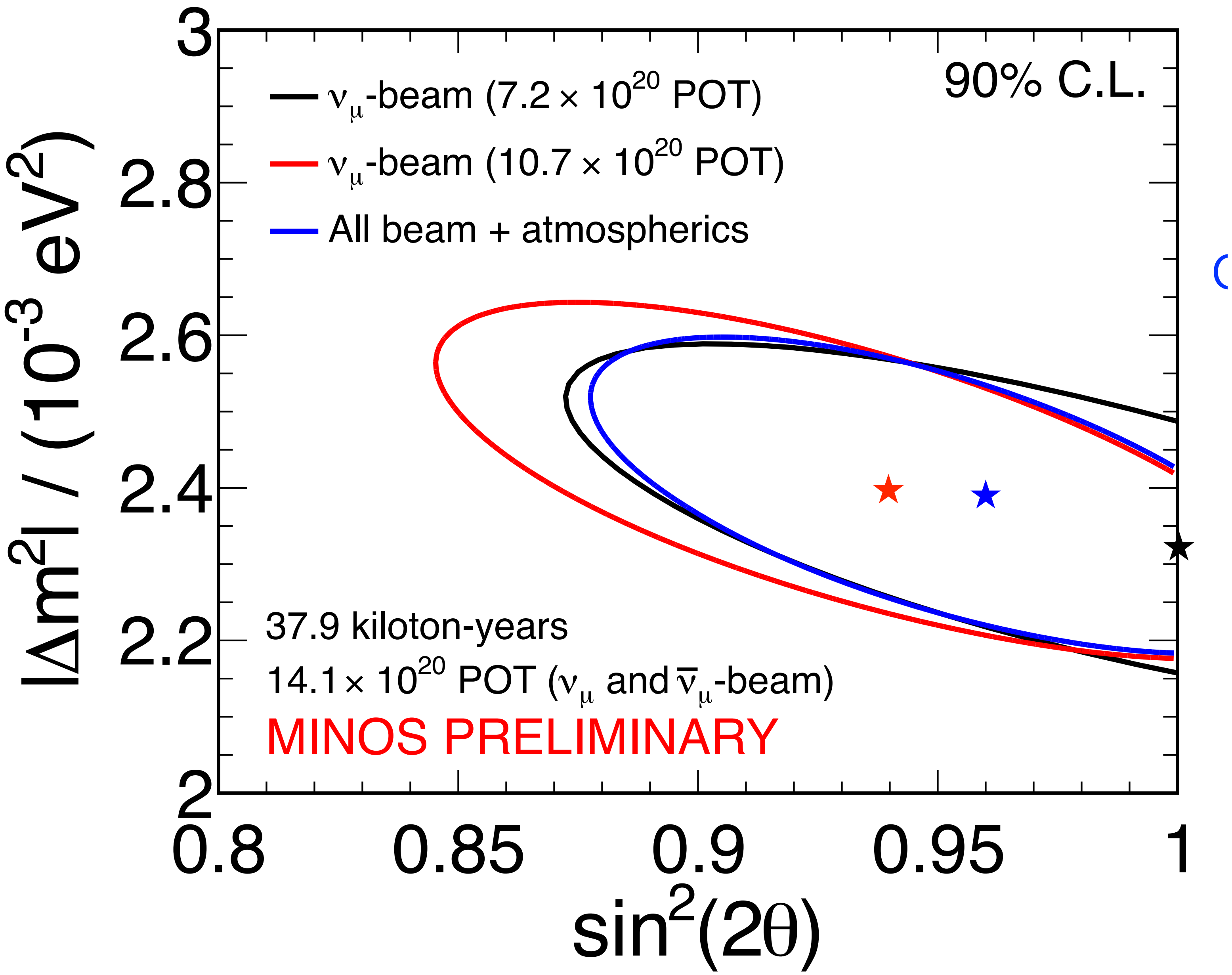
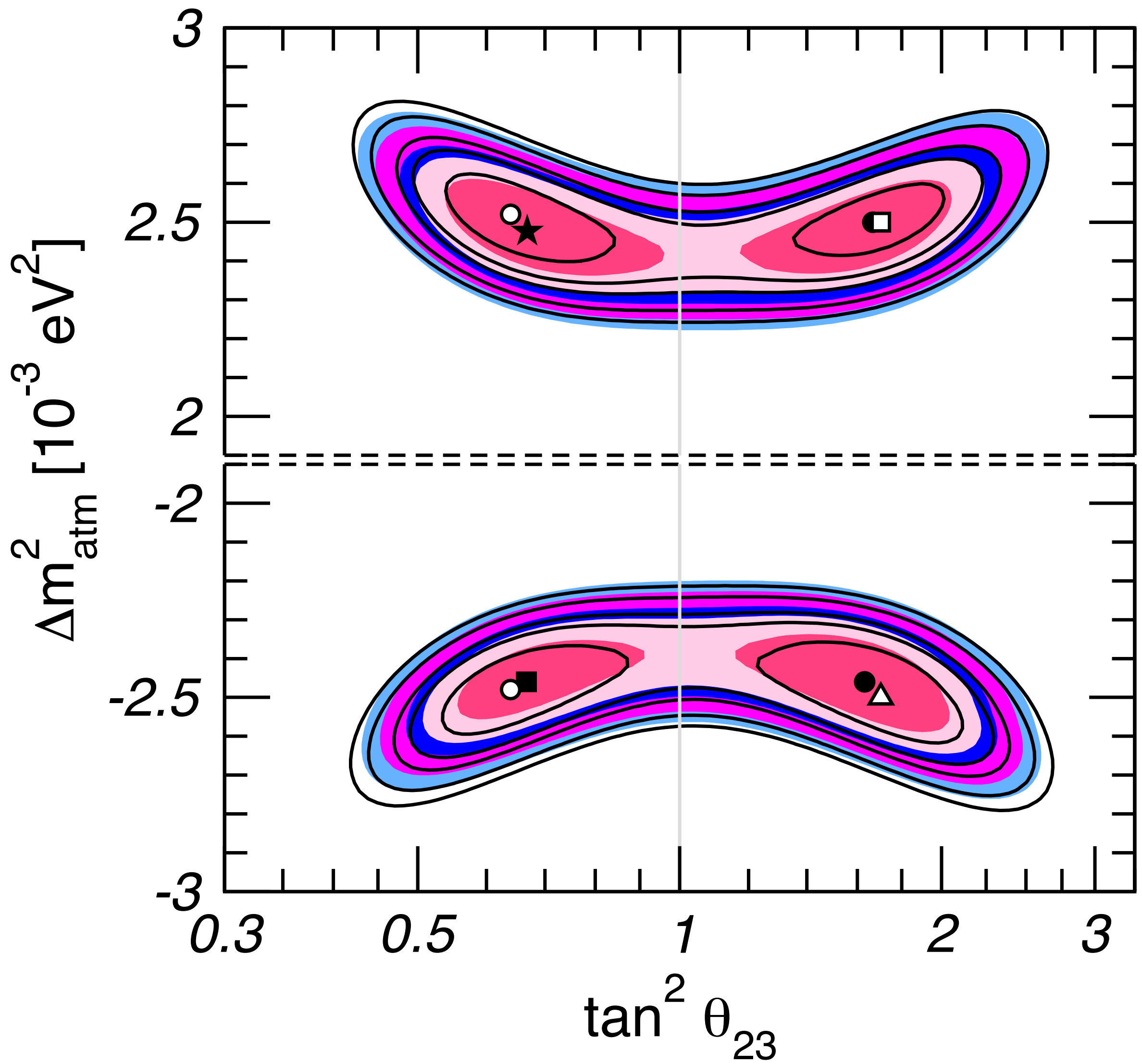


Nichol (MINOS), talk at Neutrino2012

On non-maximal 23 mixing

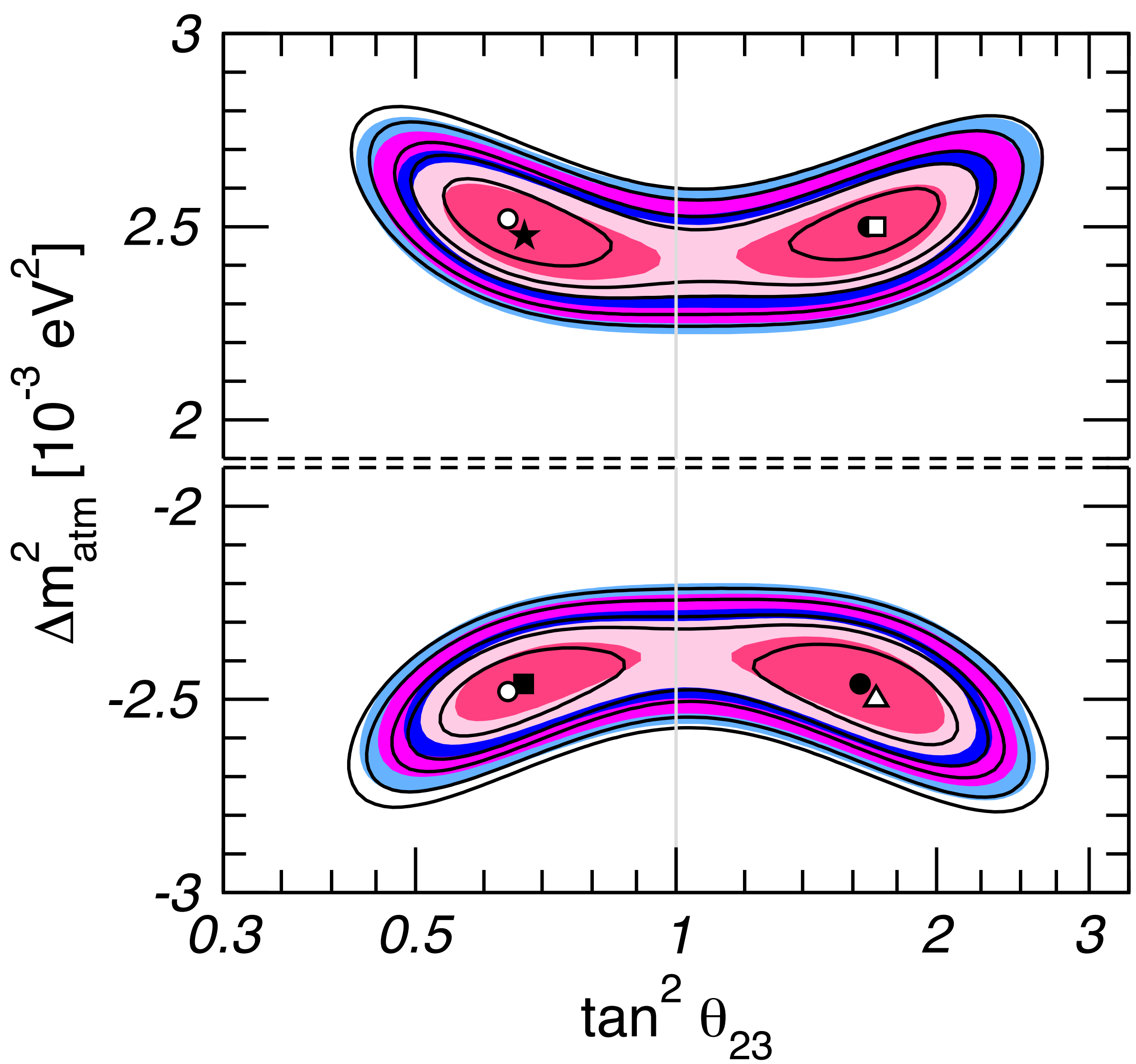


global data without atmospheric (MINOS and T2K disappearance most important)

$\sin^2\theta_{23} \approx 0.40$
$\sin^2\theta_{23} \approx 0.62$

degeneracy between the two θ_{23} octants

On non-maximal 23 mixing



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neglecting Δm^2_{21}: $P_{\mu\mu} \approx 1 - 4|U_{\mu 3}|^2(1-|U_{\mu 3}|^2)\sin^2\frac{\Delta m^2_{\rm atm}L}{4E} \quad \Rightarrow \quad \sin^2\theta_{23} = \frac{|U_{\mu 3}|^2}{\cos^2\theta_{13}}$

slight shift to larger values of $\sin^2\theta_{23}$

Octant degeneracy and LBL appearance

Fogli, Lisi, hep-ph/9604415

$$P_{\mu e} \simeq \sin^2 2\theta_{13} \sin^2\theta_{23} \frac{\sin^2(1-A)\Delta}{(1-A)^2}$$
$$+ \sin 2\theta_{13}\, \hat{\alpha}\, \sin 2\theta_{23} \frac{\sin(1-A)\Delta}{1-A} \frac{\sin A\Delta}{A} \cos(\Delta + \delta_{CP})$$
$$+ \hat{\alpha}^2 \cos^2\theta_{23} \frac{\sin^2 A\Delta}{A^2}$$

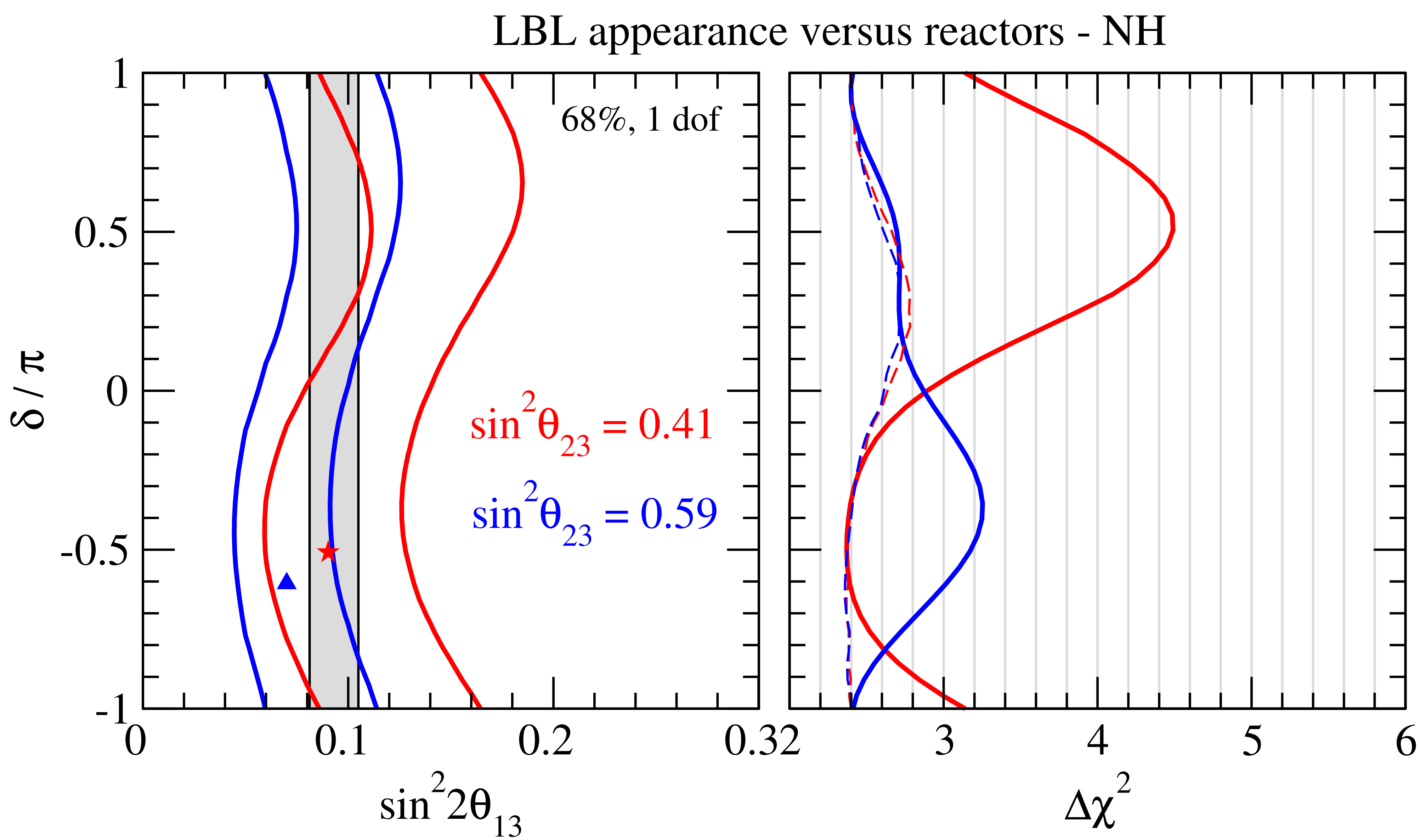
with

$$\Delta \equiv \frac{\Delta m^2_{31} L}{4E_\nu}, \quad \hat{\alpha} \equiv \frac{\Delta m^2_{21}}{\Delta m^2_{31}} \sin 2\theta_{12}, \quad A \equiv \frac{2E_\nu V}{\Delta m^2_{31}}$$

- *for large θ_{13} the leading term depends on octant*
- *beam+reactor combination may be sensitive to octant*

  Minakata et al. hep-ph/0211111; McConnel, Shaevitz, hep-ex/0409028

Octant degeneracy and LBL appearance



present data from LBL appearance versus reactor cannot discriminate between the octants

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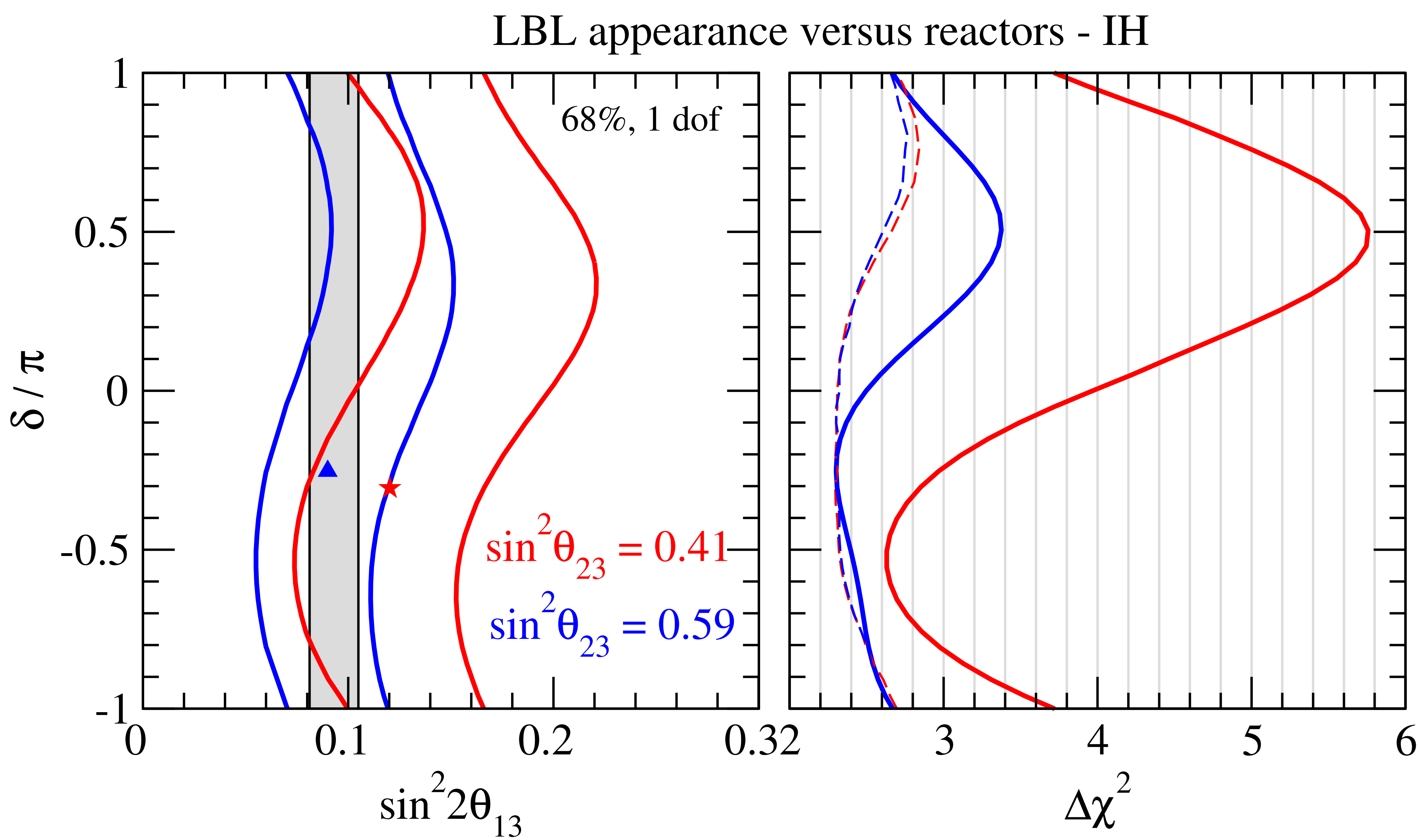

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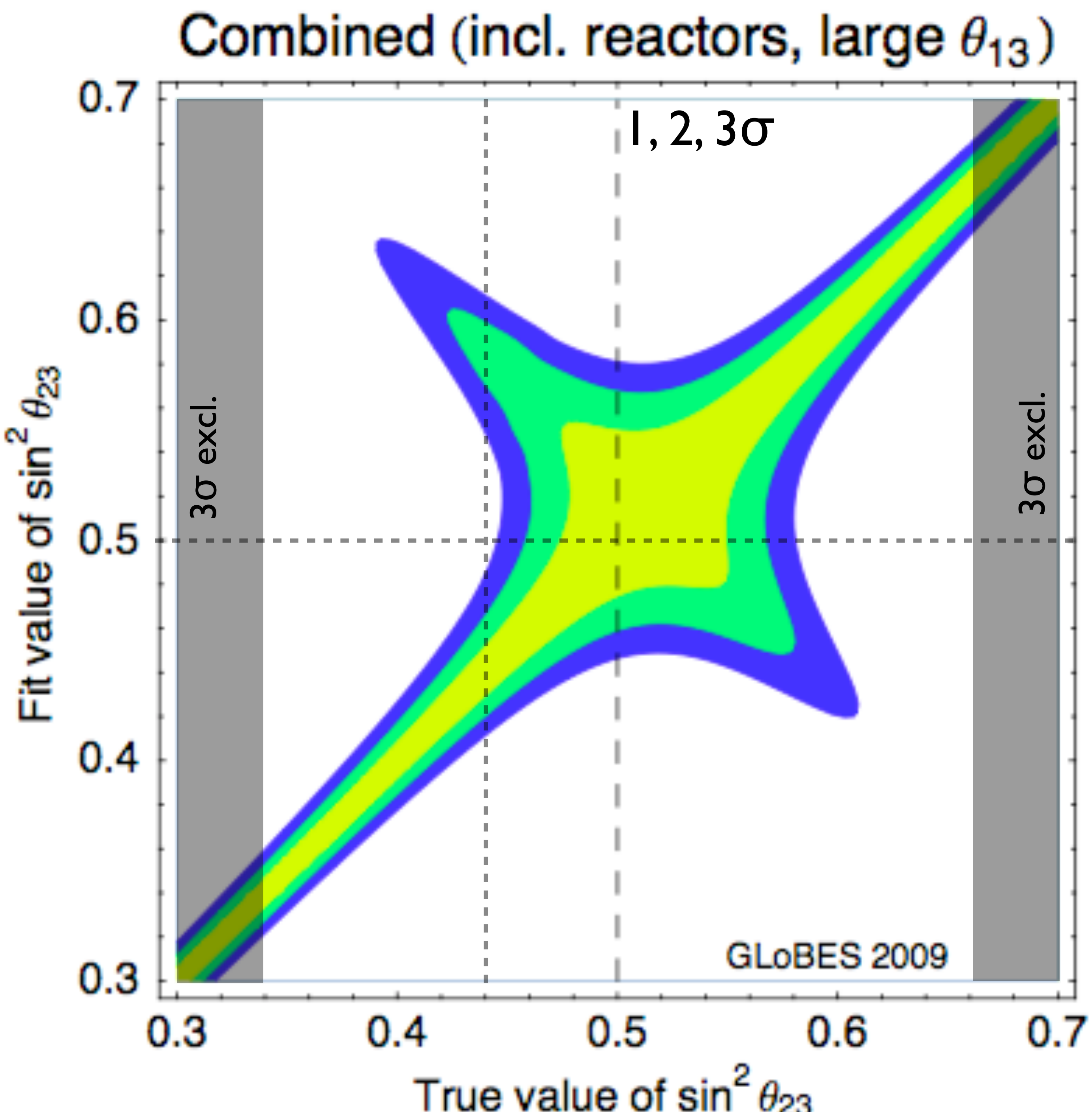
Global fit ~2020 - θ23 octant

final exposure of T2K, NOvA, DayaBay combined



$\sin^2 2\theta_{13} = 0.1$
$\delta = 0$

Huber, Lindner, TS, Winter, 0907.1896

3-flavor effects in atmospheric neutrinos

excess in electron-like events:

$$\frac{N_e}{N_e^0} - 1 \simeq (r\, s_{23}^2 - 1)\, P_{2\nu}(\Delta m_{31}^2, \theta_{13}) \qquad \theta_{13}\text{-effects}$$

$$+ \; (r\, c_{23}^2 - 1)\, P_{2\nu}(\Delta m_{21}^2, \theta_{12}) \qquad \Delta m_{21}^2\text{-effects}$$

$$- \; 2 s_{13} s_{23} c_{23}\, r\, \mathrm{Re}(A_{ee}^* A_{\mu e}) \qquad \text{interference: } \delta_{\mathrm{CP}}$$

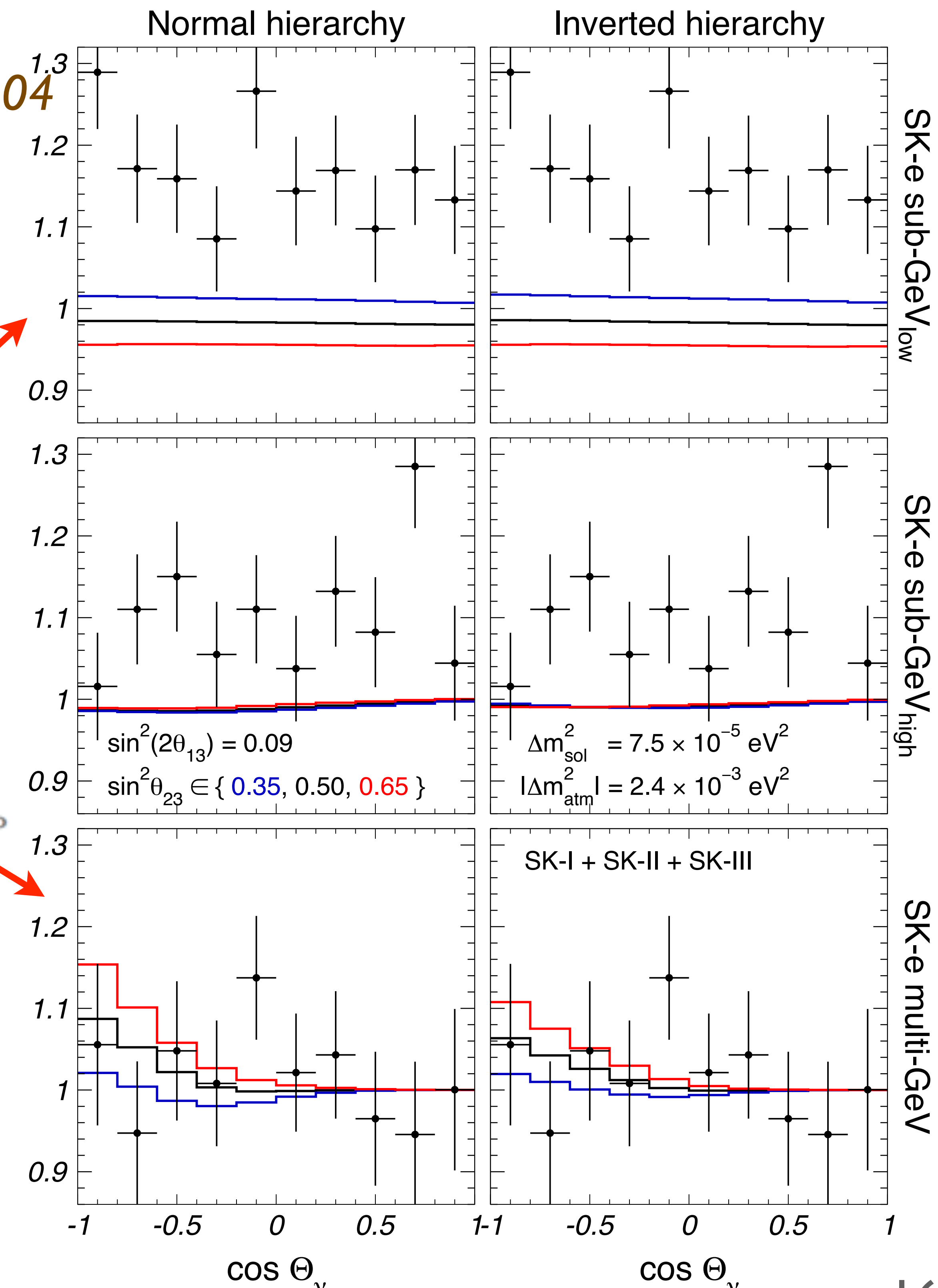
$$r = r(E_\nu) \equiv \frac{F_\mu^0(E_\nu)}{F_e^0(E_\nu)}$$

$r \approx 2$ (sub-GeV)

$r \approx 2.6 - 4.5$ (multi-GeV)

3-flavor effects in atmospheric neutrinos

Peres, Smirnov, 99;
Gonzalez-Garcia, Maltoni, Smirnov, 04



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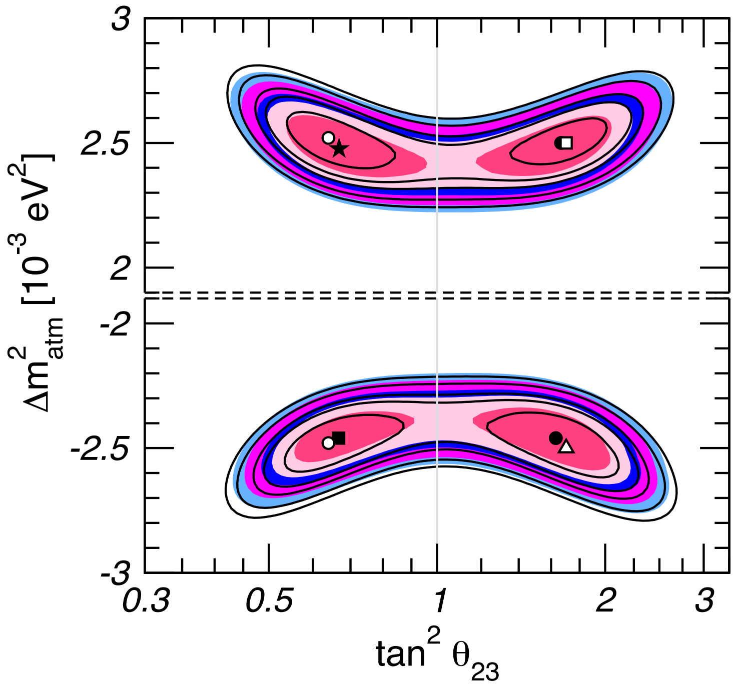
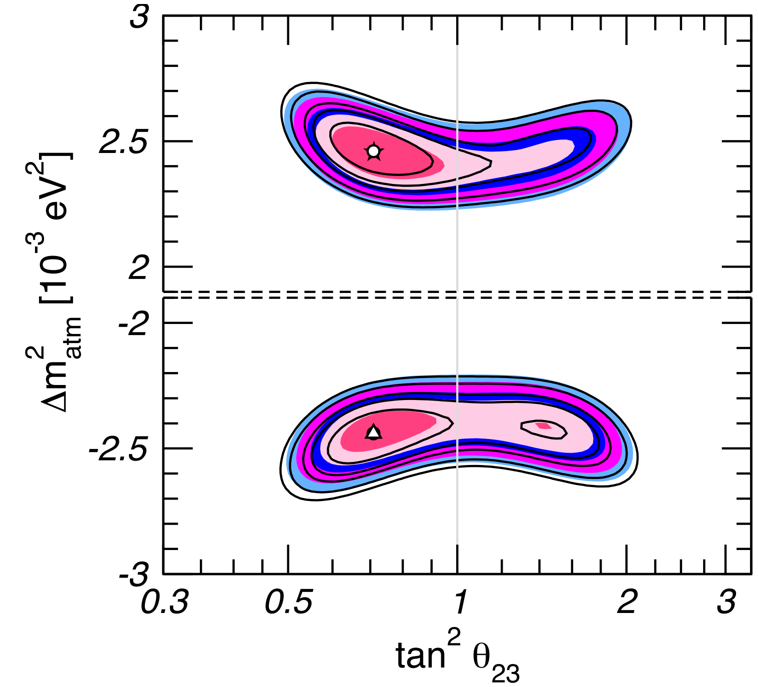
The octant and atmospheric neutrino data



adding atmospheric →

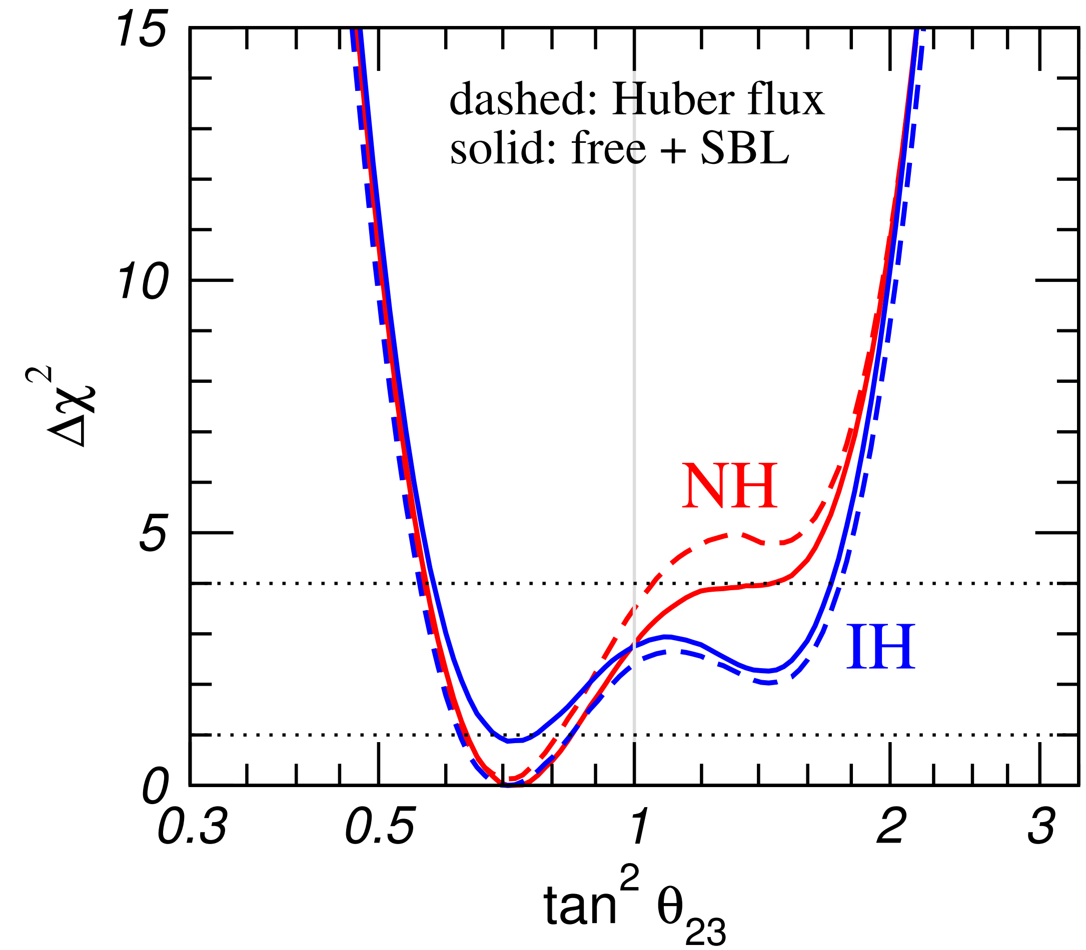


$$\sin^2\theta_{23} = 0.42^{+0.037}_{-0.031}$$

$$0.34 - 0.66 \, @ \, 3\sigma$$

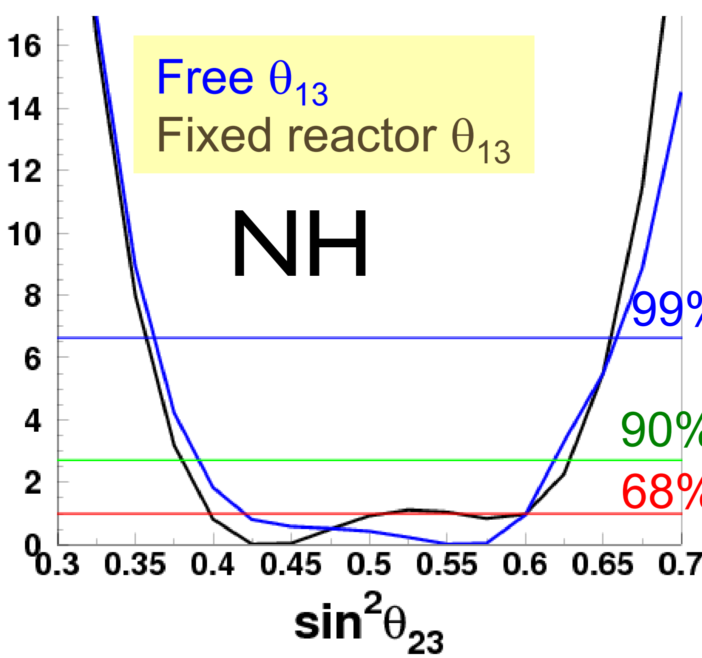
$$(\theta_{23} \approx 40^\circ)$$

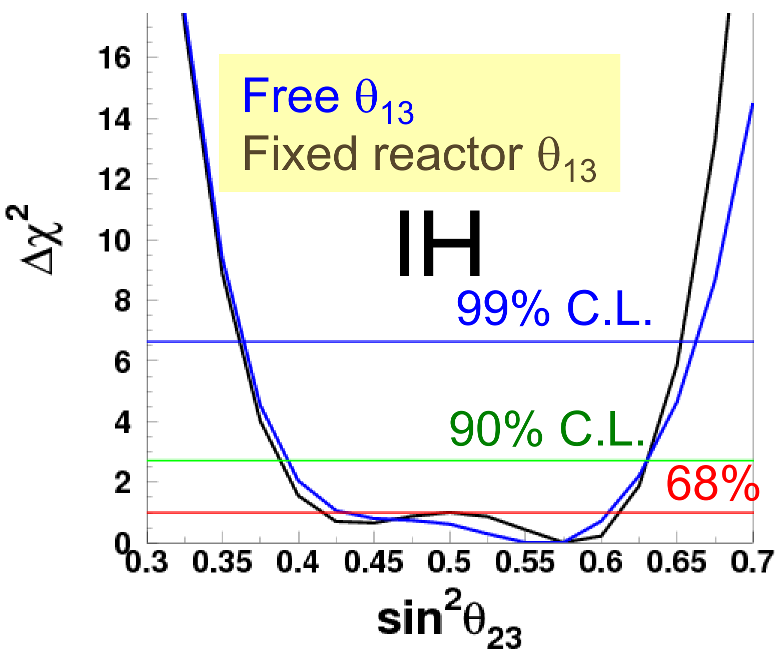
- *slight preference for 1st octant by atmospheric data*
- *more pronounced for NH (~2σ)*
- *depends on θ_{13}*

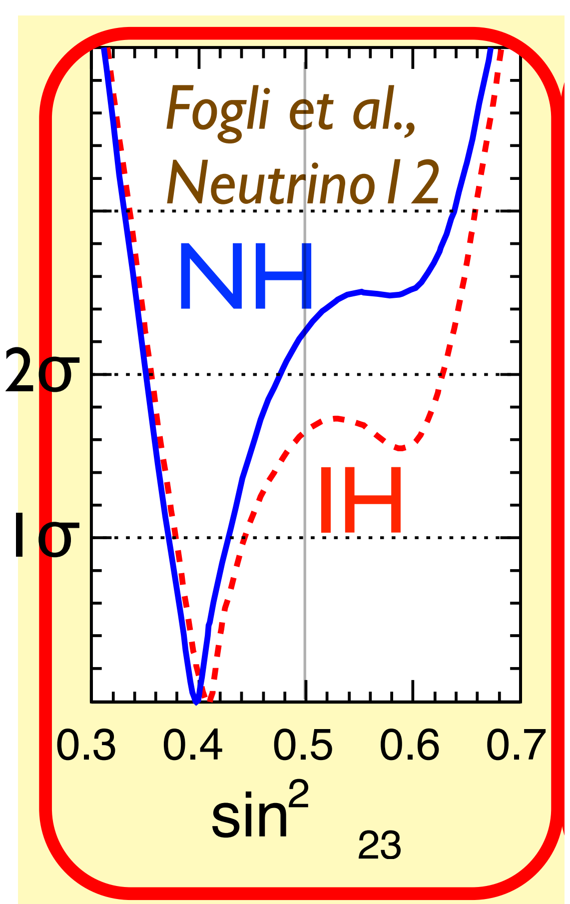


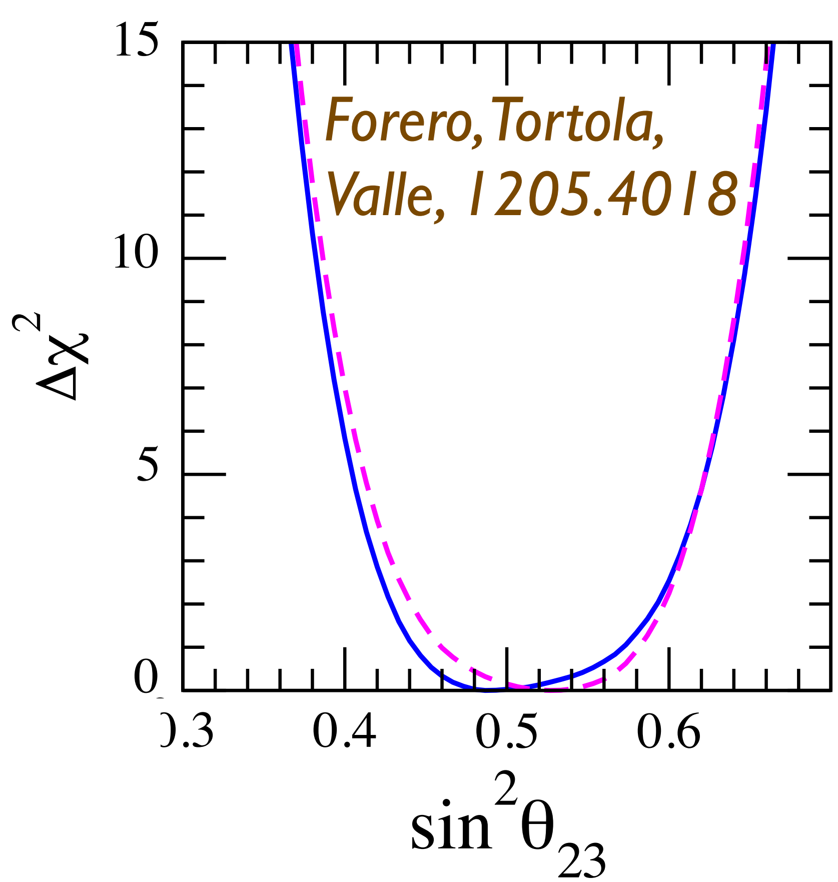
A word of warning

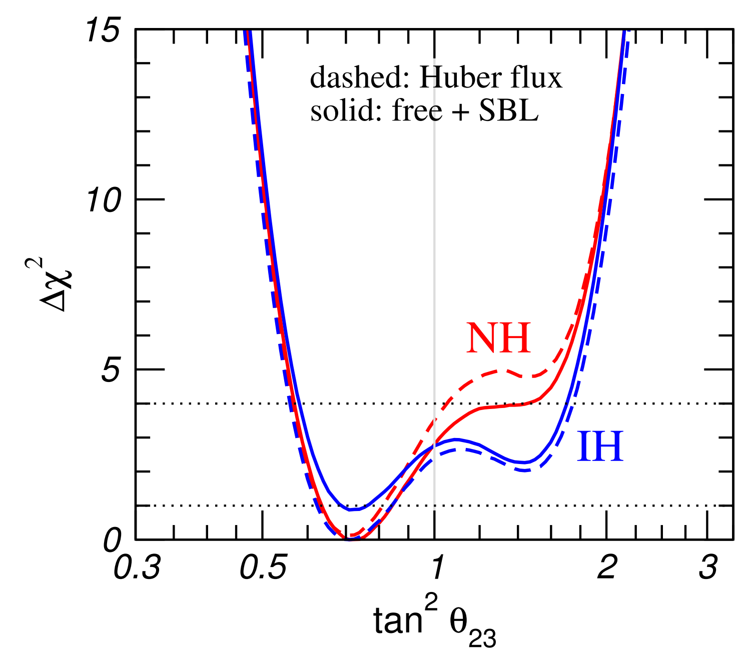
Itow (SuperK), talk at Neutrino2012











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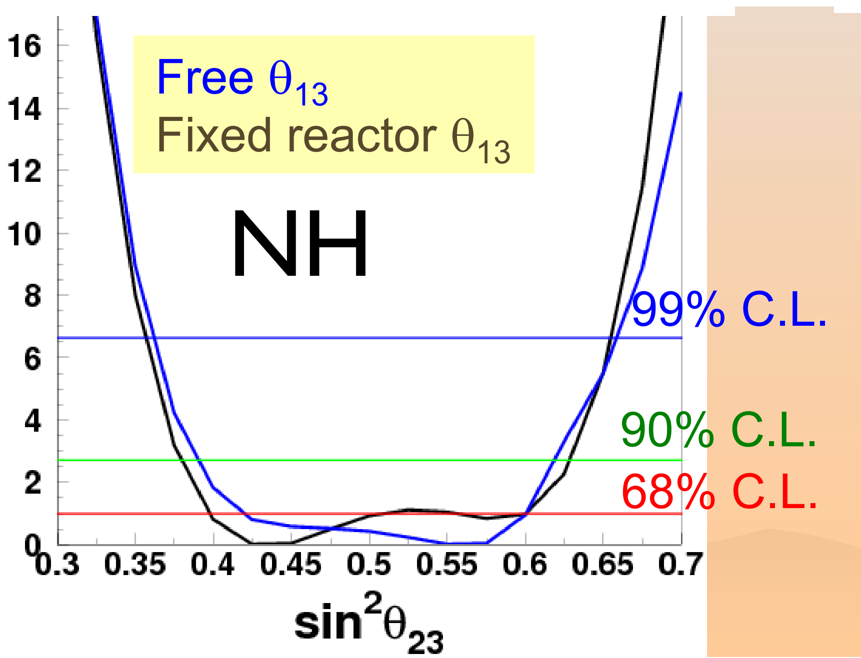
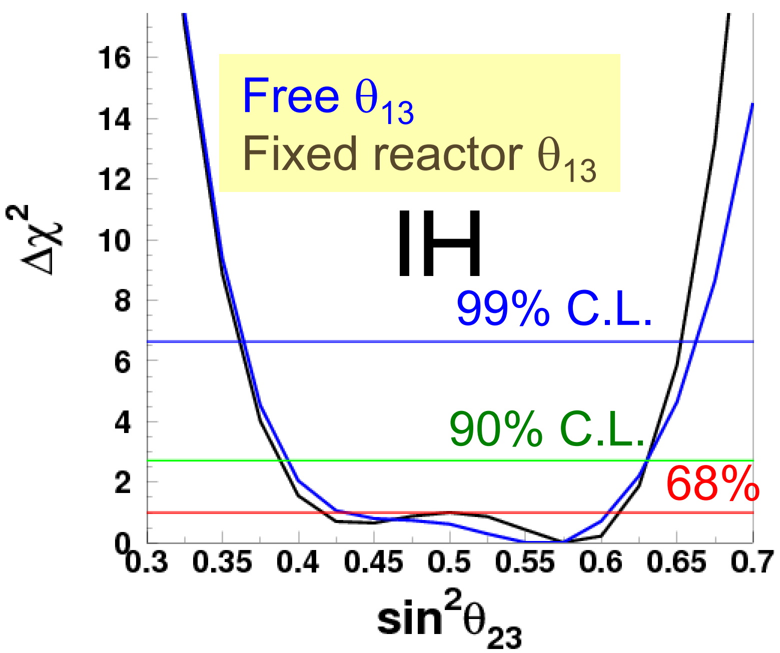
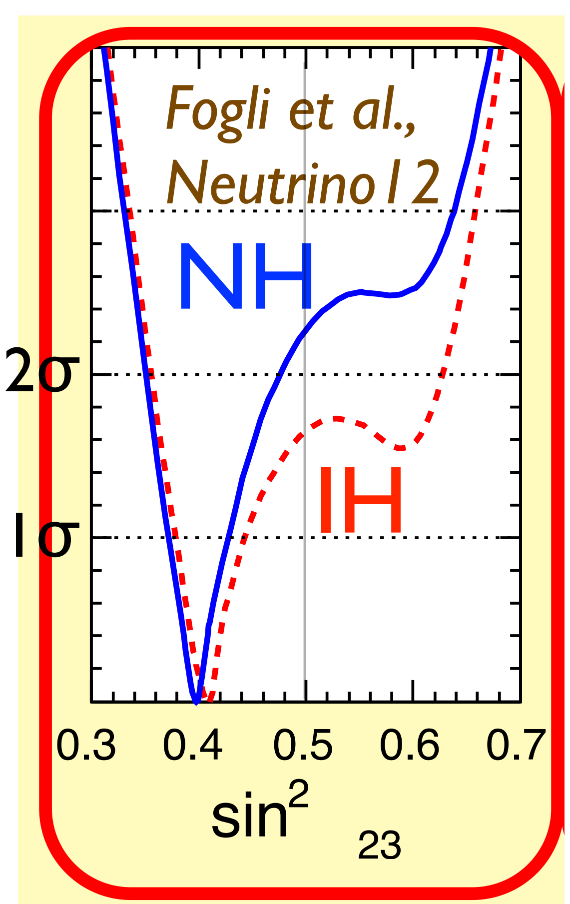
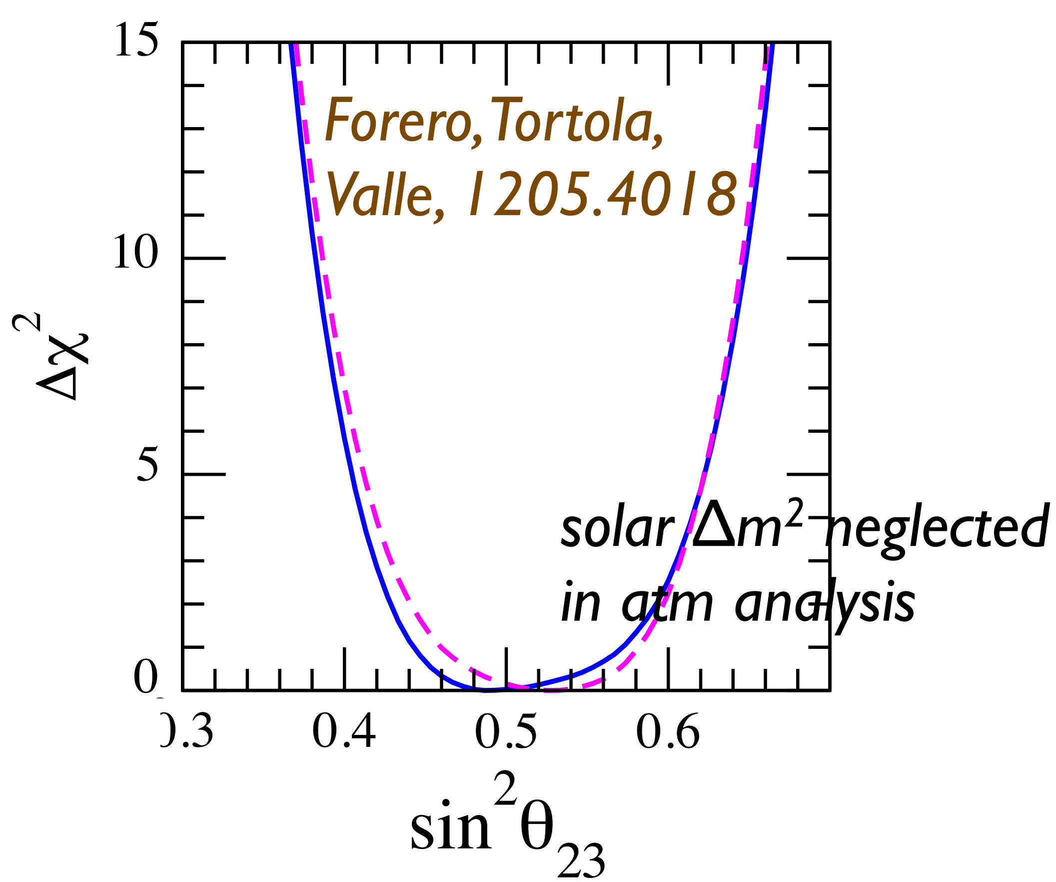
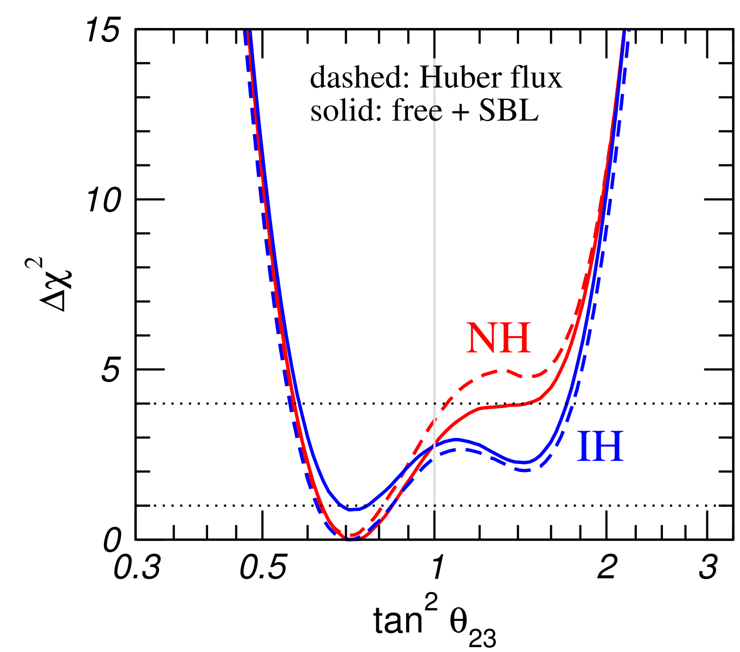




MINOS data from Neutrino2012 not included yet







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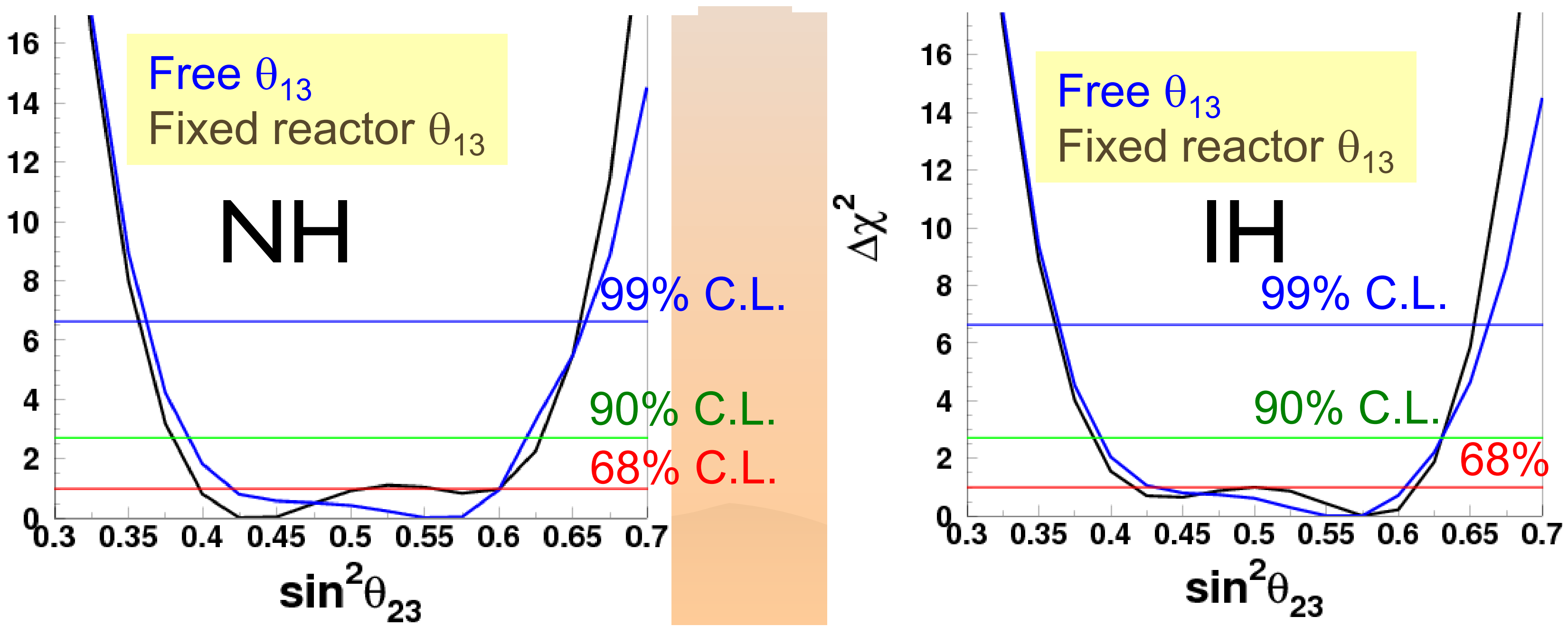


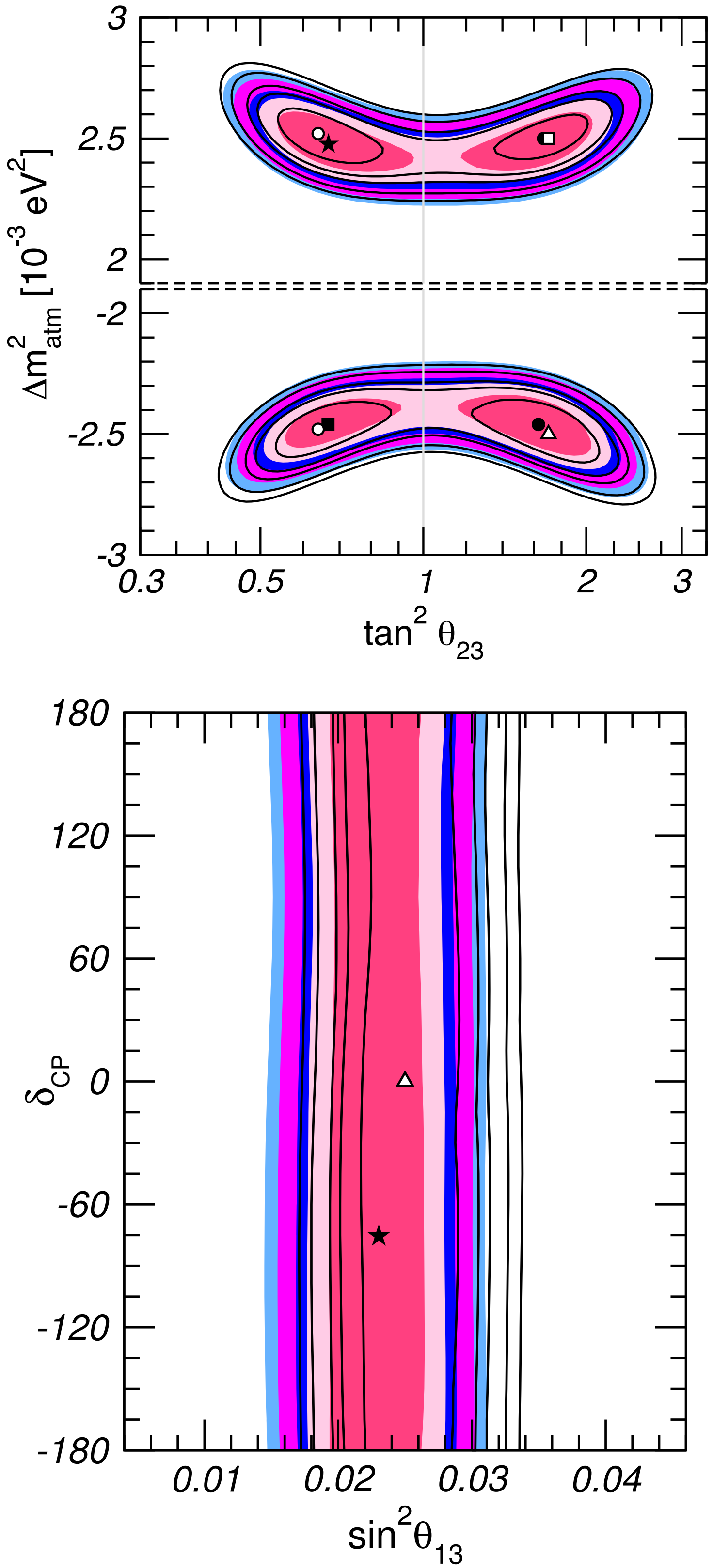
Itow (SuperK), talk at Neutrino2012

personal interpretation:

- *there seem to be subtle effects in SK atm data pulling into different directions*
- *sub-GeV data vs multi-GeV (?) data (θ_{13} / hierarchy dependent)*
- *which effect wins depends on fine details of the analysis / system. treatment*

before drawing definite conclusions it is mandatory to identify the physics and understand the origin of the different resuls from SK and phenomenologists

The CP phase and atmospheric neutrino data



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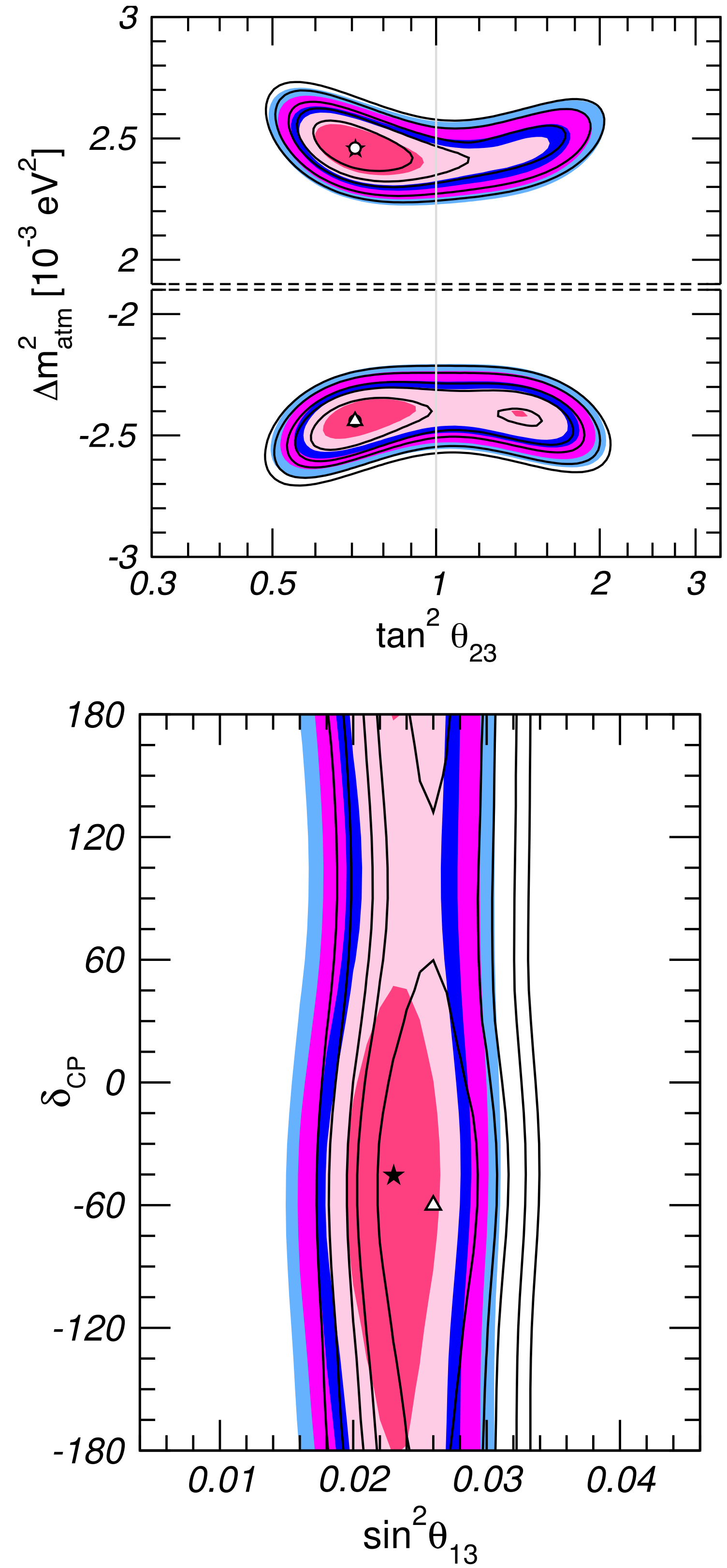

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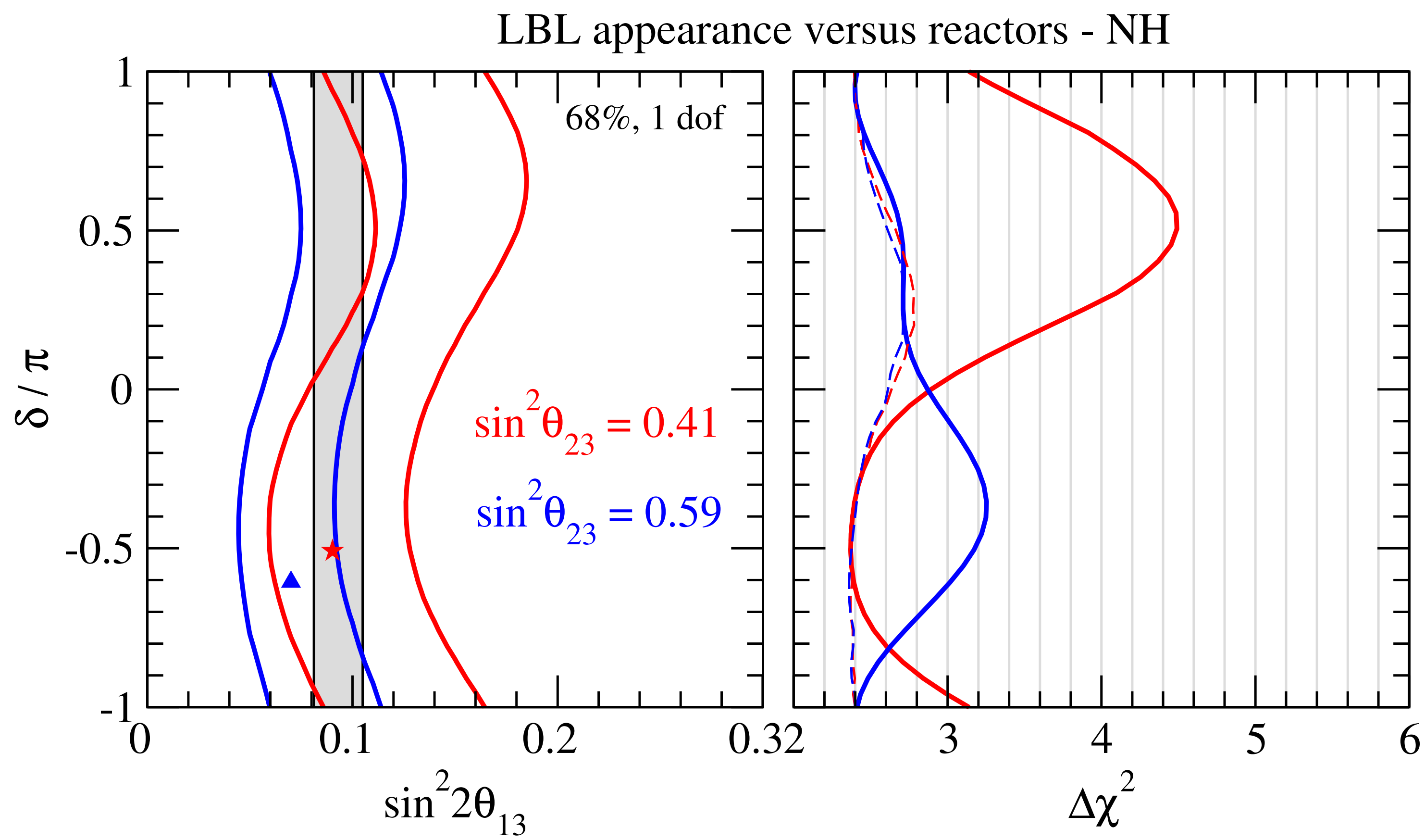
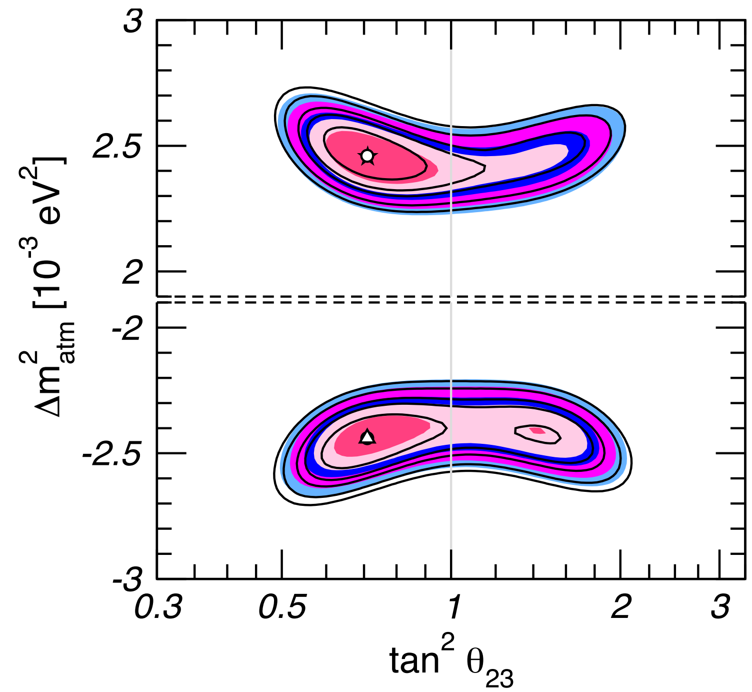
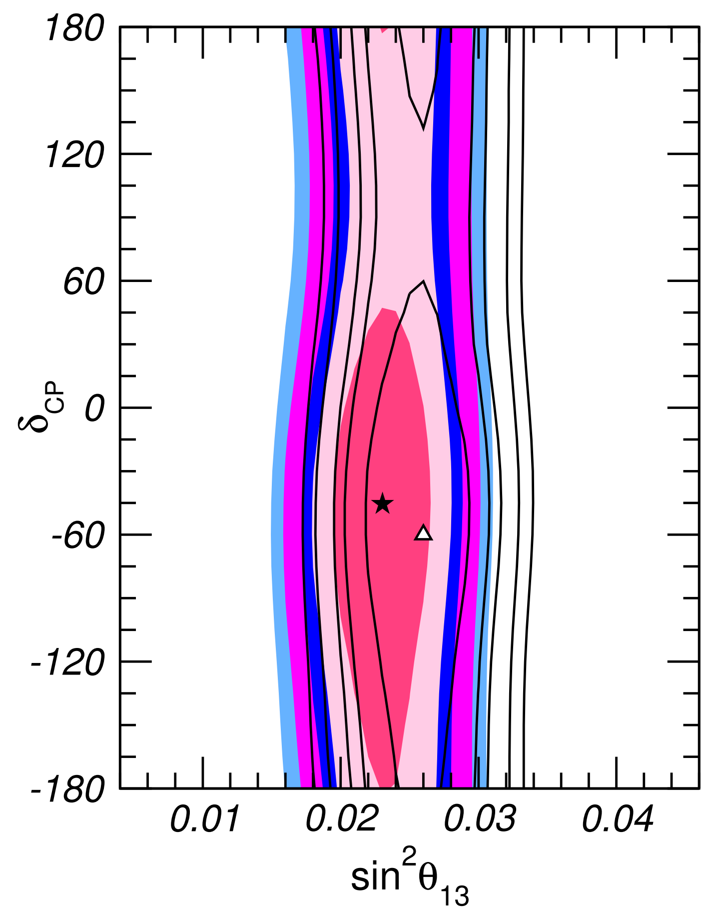
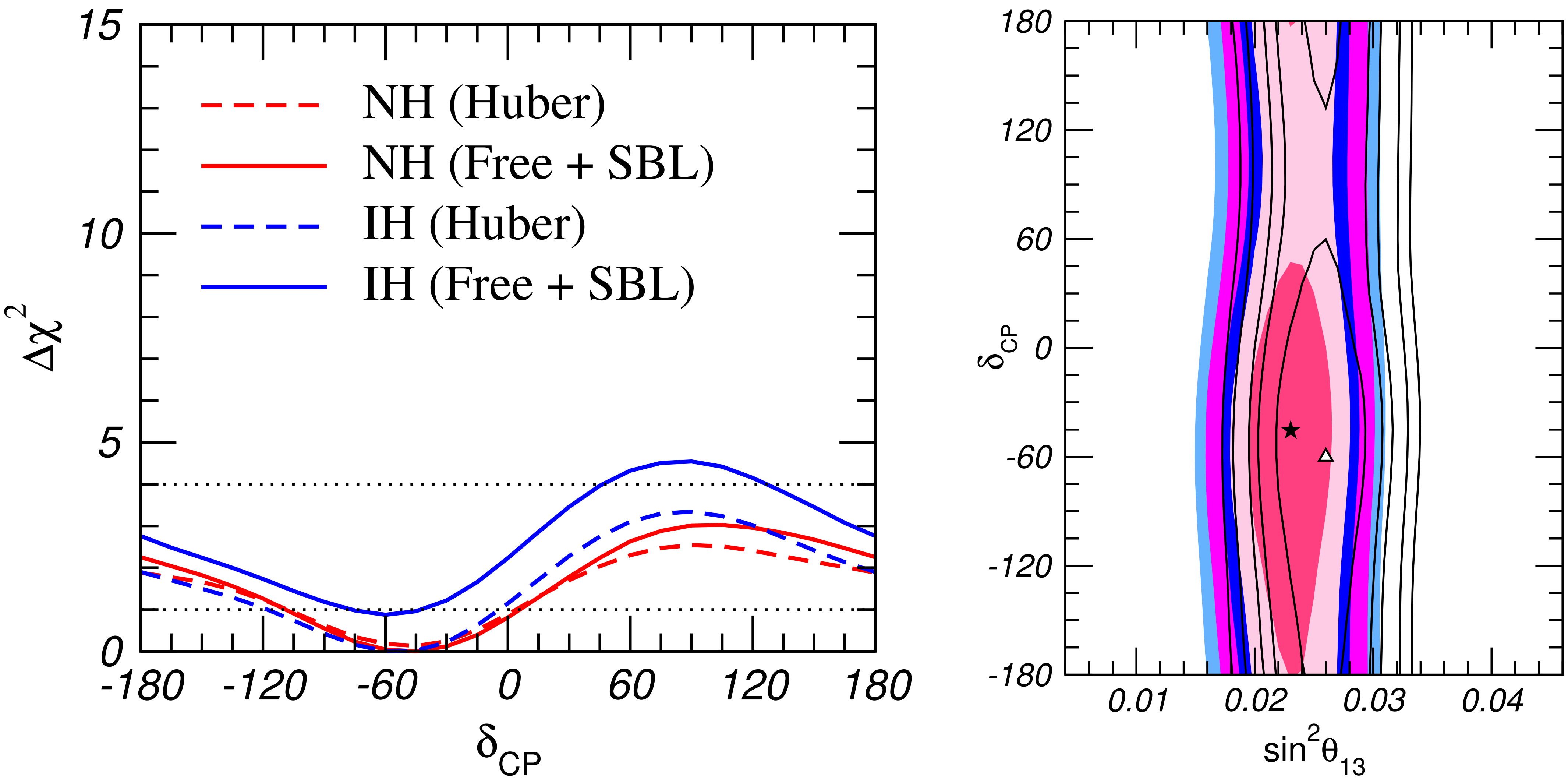






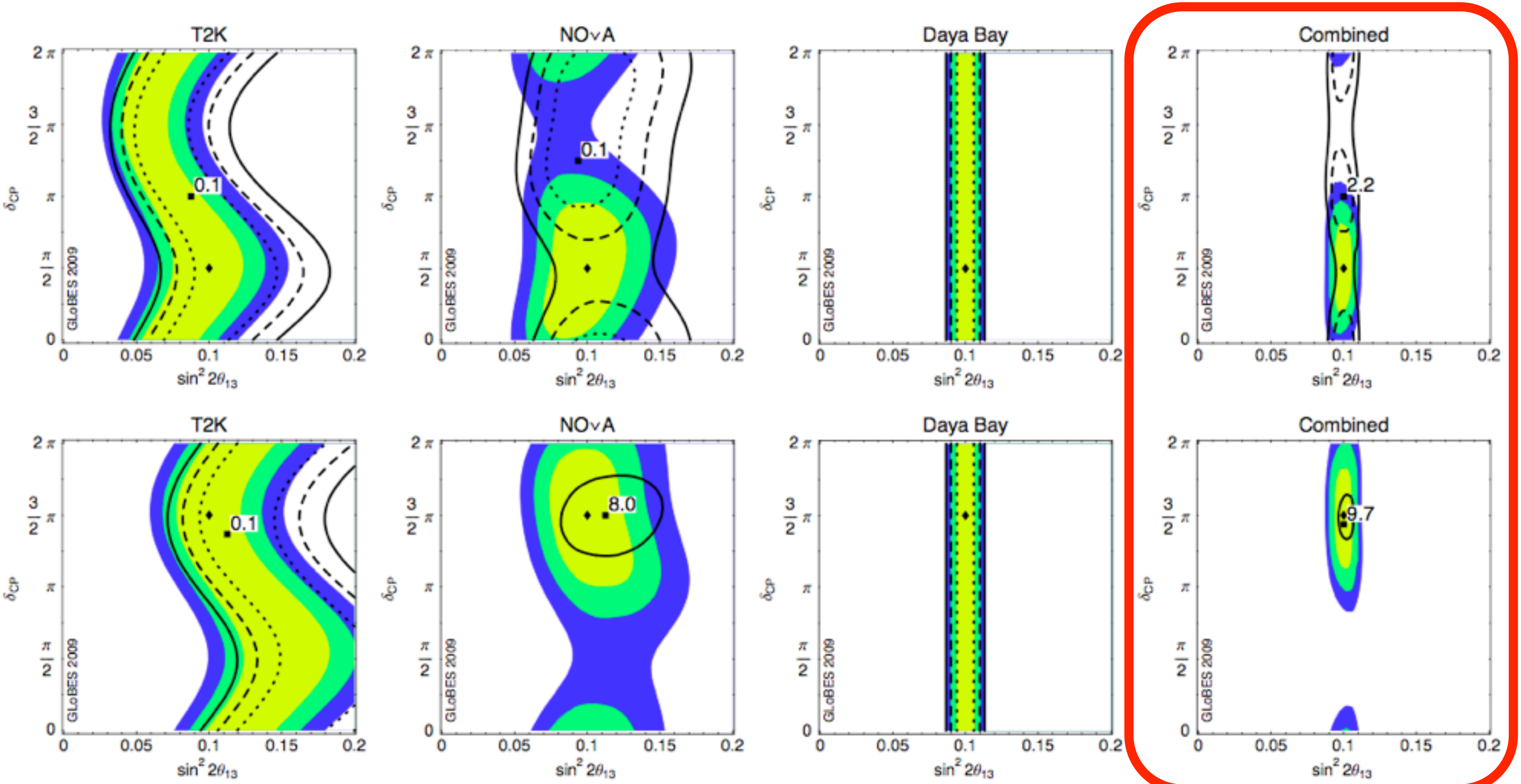
- *non-maximality from LBL disapp*
- *preference for 1st octant from atm*
- *sensitivity to δ from LBL appearance + reactors*

The CP phase



- *“preferred” regions for δ~ -60° at 1σ (everything allowed at 2σ)*
- *difference between NH and IH of $\Delta\chi^2 \approx 1$*

Global fit ~2020 Huber, Lindner, TS, Winter, 0907.1896

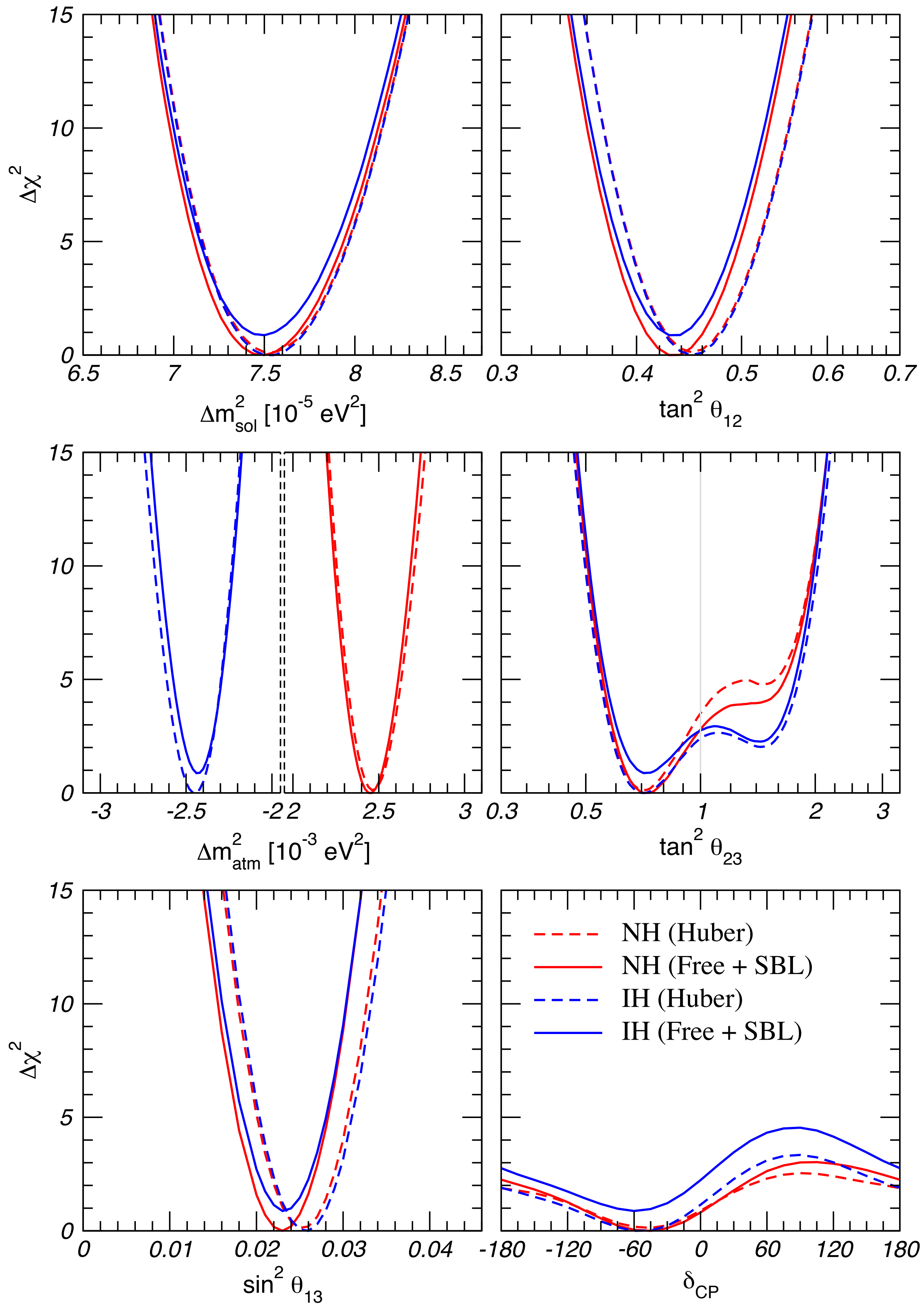


some regions of δ will appear but CP violation and hierarchy will be very hard with this generation of experiments

Summary

	bfp $\pm 1\sigma$	3σ range
$\sin^2\theta_{12}$	$0.30^{+0.13}_{-0.12}$	$0.27 - 0.34$
$\sin^2\theta_{23}$	$0.42^{+0.037}_{-0.031}$	$0.34 - 0.66$
$\sin^2\theta_{13}$	0.023 ± 0.0023	$0.016 - 0.030$
$\delta/^\circ$ (NH)	-48^{+53}_{-59}	–
$\delta/^\circ$ (IH)	-59^{+49}_{-60}	–
$\Delta m^2_{21}/10^{-5}\mathrm{eV}^2$	7.50 ± 0.185	$7.00 - 8.09$
$\Delta m^2_{31}/10^{-3}\mathrm{eV}^2$ (NH)	$2.45^{+0.067}_{-0.071}$	$2.25 - 2.67$
$\|\Delta m^2_{32}\|/10^{-3}\mathrm{eV}^2$ (IH)	2.43 ± 0.068	$2.23 - 2.65$

(reactor flux-free analysis + SBL react.)



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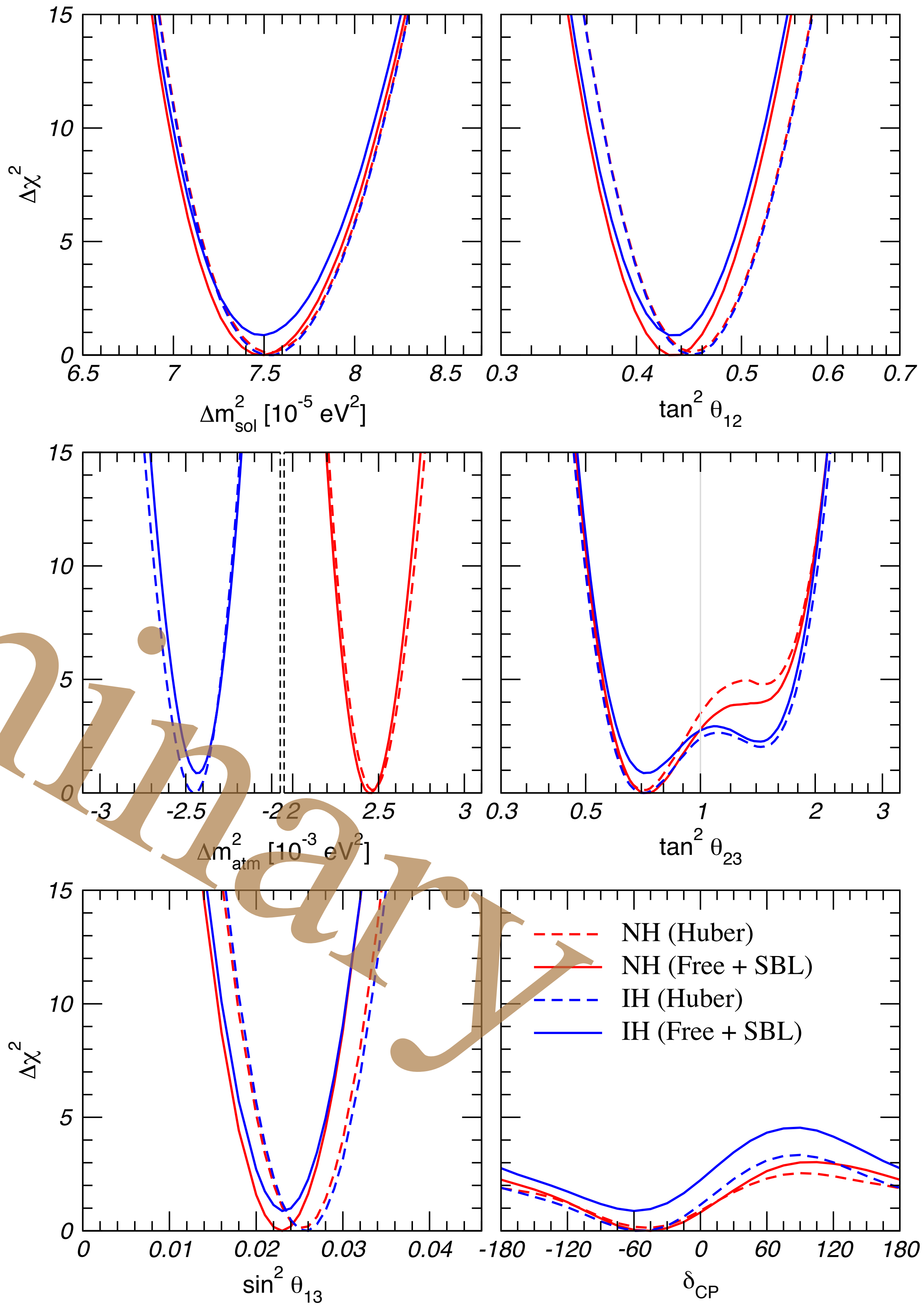
$\lvert\Delta m^2_{32}\rvert/10^{-3}\mathrm{eV}^2$ (IH)	2.43 ± 0.068	$2.23 - 2.65$

(reactor flux-free analysis + SBL react.)



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Thank you for your attention!