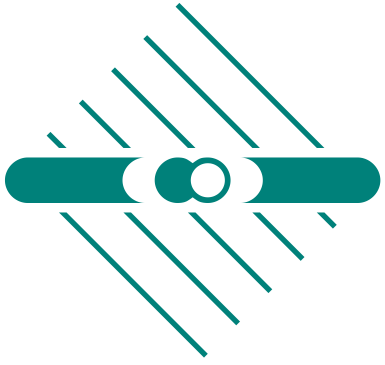
GDR neutrino 2009

Present neutrino situation

Thomas Schwetz



Max-Planck-Institute for Nuclear Physics, Heidelberg

Outline

- Global fit to present oscillation data in the three-neutrino framework
  comment on possible “hints” for non-zero θ_{13}
- Brief comments on recent MiniBooNE results
  the fate of the LSND signal and sterile neutrino oscillation schemes
- Outlook for upcoming oscillation experiments

Global data and three-neutrino oscillations

Maltoni, TS, Tortola, Valle, hep-ph/0309130, hep-ph/0405172

TS, Tortola, Valle, 0808.2016

Neutrino oscillation experiments

natural neutrino sources:

- solar neutrinos
  Homestake, SAGE+GNO, Super-K, SNO, Borexino
- atmospheric neutrinos
  Super-Kamiokande

artificial neutrino sources:

- reactor neutrinos
  Chooz (1 km), KamLAND (180 km)
- long-baseline accelerator experiments
  K2K (250 km), MINOS (735 km)

3-flavour oscillation parameters

$$\Delta m^2_{31} \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad \Delta m^2_{21}$$

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

atmospheric+LBL — Chooz — solar+KamLAND

3-flavour effects are suppressed because

$\Delta m^2_{21} \ll |\Delta m^2_{31}|$ and $\theta_{13} \ll 1$

$\Rightarrow$ dominant oscillations are well described by effective two-flavour oscillations

The “solar” parameters Δm^2_{21}, θ_{12}

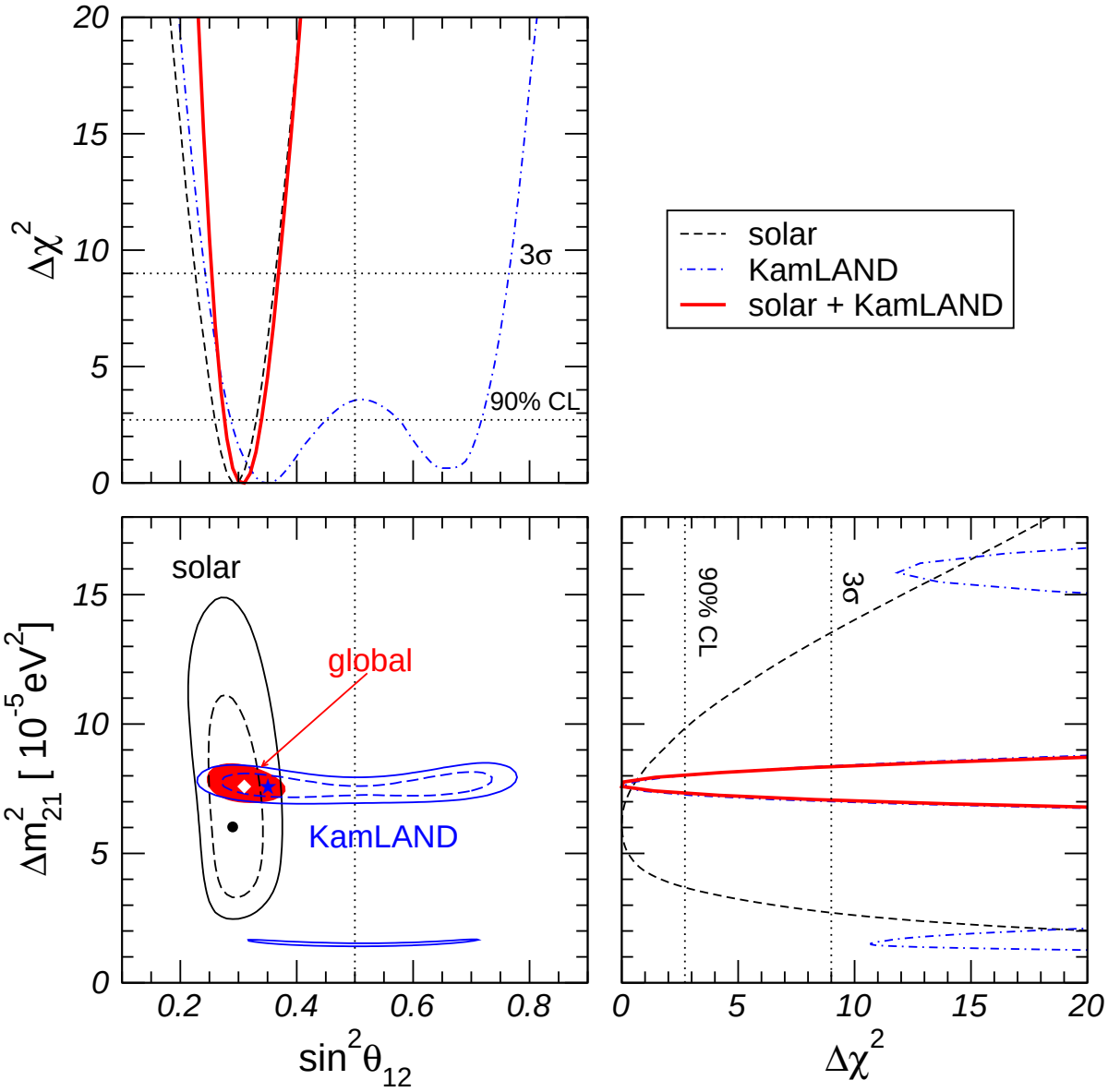
$$U = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & e^{-i\delta} s_{13} \\ 0 & 1 & 0 \\ -e^{i\delta} s_{13} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

Δm^2_{31} — atmospheric+LBL

Chooz

Δm^2_{21} — solar+KamLAND

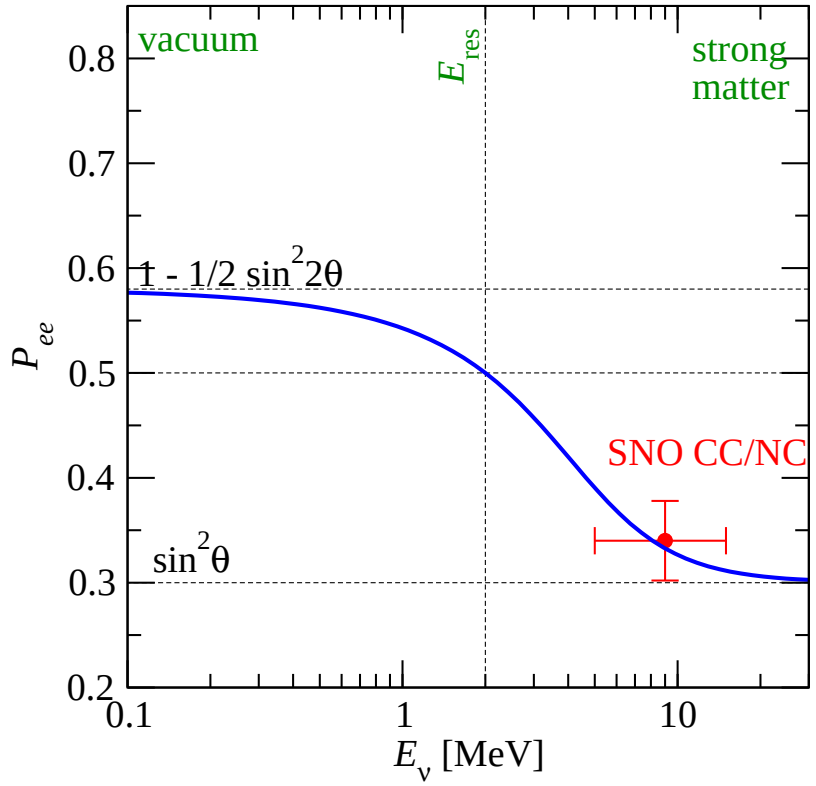
KamLAND vs solar data



$$\sin^2\theta_{12} = 0.304^{+0.022}_{-0.016}\,, \qquad \Delta m^2_{21} = 7.65^{+0.23}_{-0.20} \times 10^{-5}\,\mathrm{eV}^2$$

The LMA-MSW solution

adiabatic evolution of the neutrino state from the center of the sun to the surface



SNO CC/NC: constraint on $\sin^2\theta_{12}$, evidence for MSW effect

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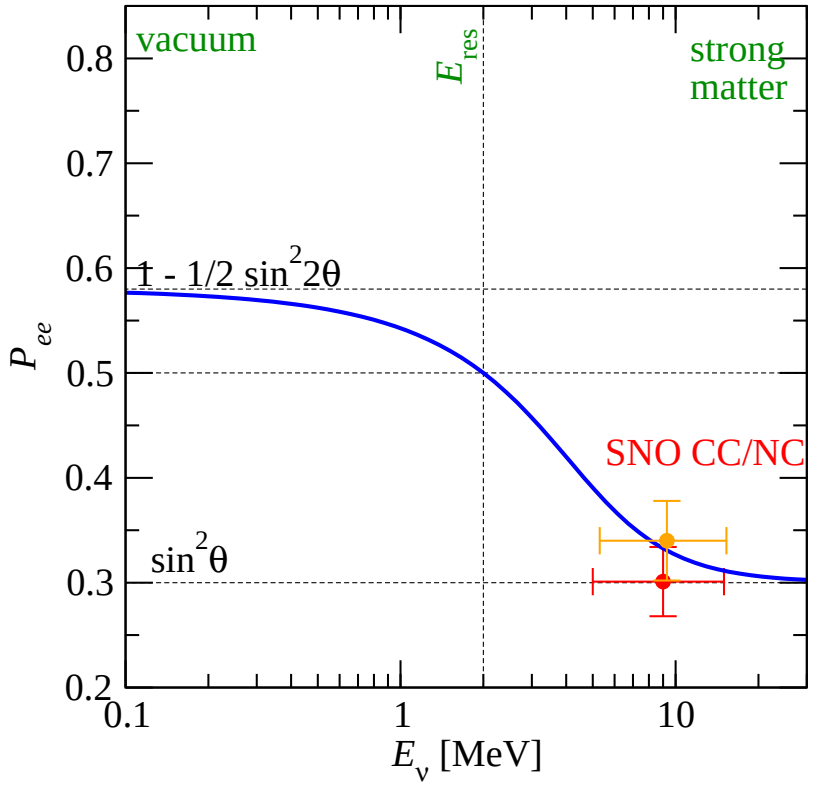

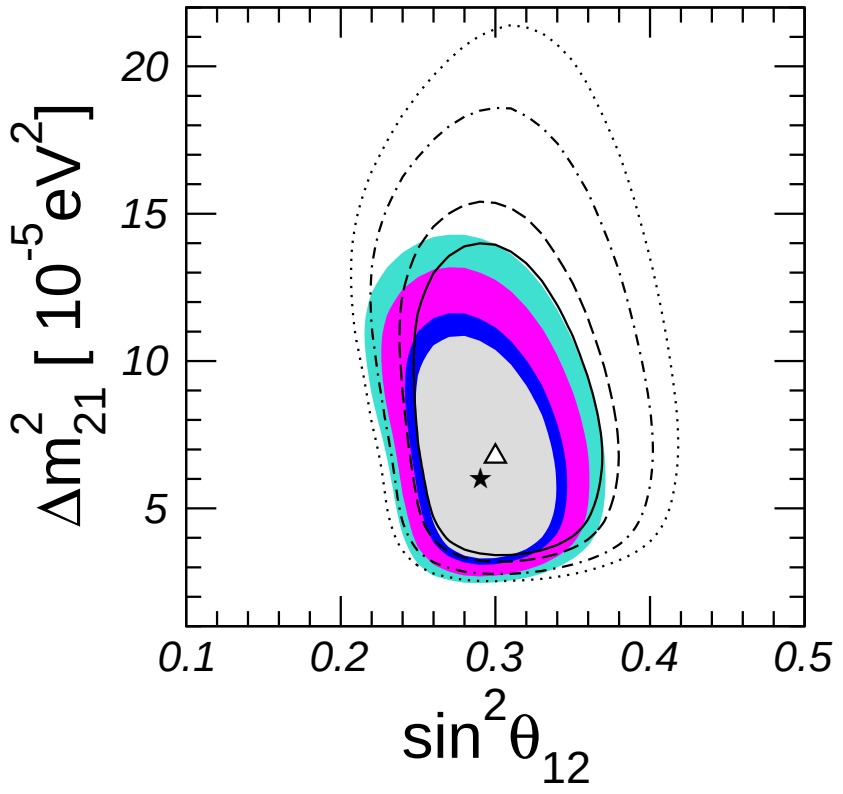

$$(\phi_{CC}/\phi_{NC})_{\rm salt} = 0.340 \pm 0.038 \rightarrow (\phi_{CC}/\phi_{NC})_{\rm NCD} = 0.301 \pm 0.033$$

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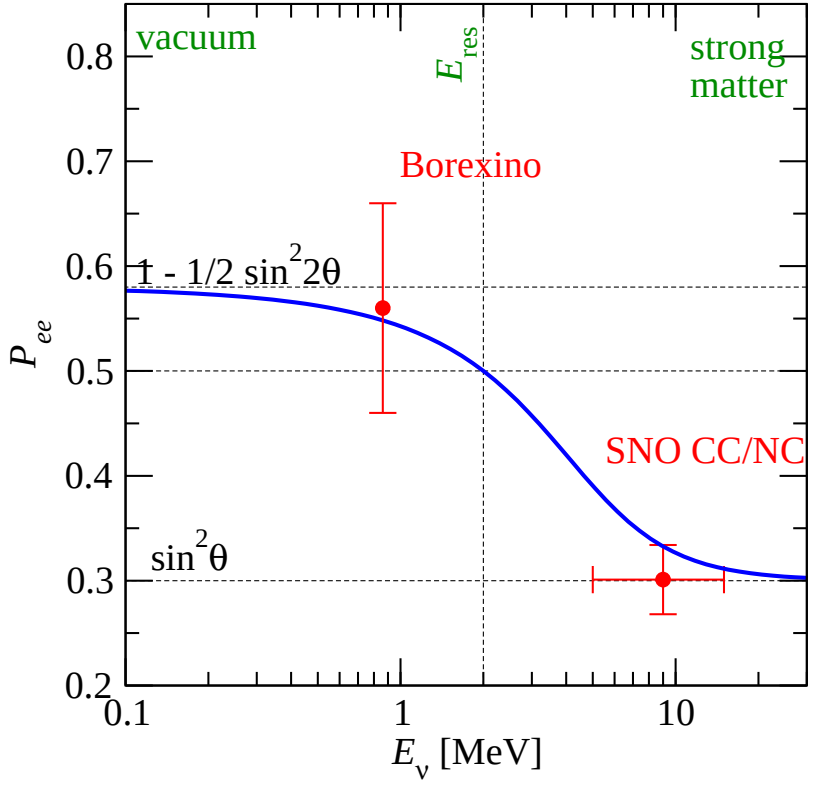
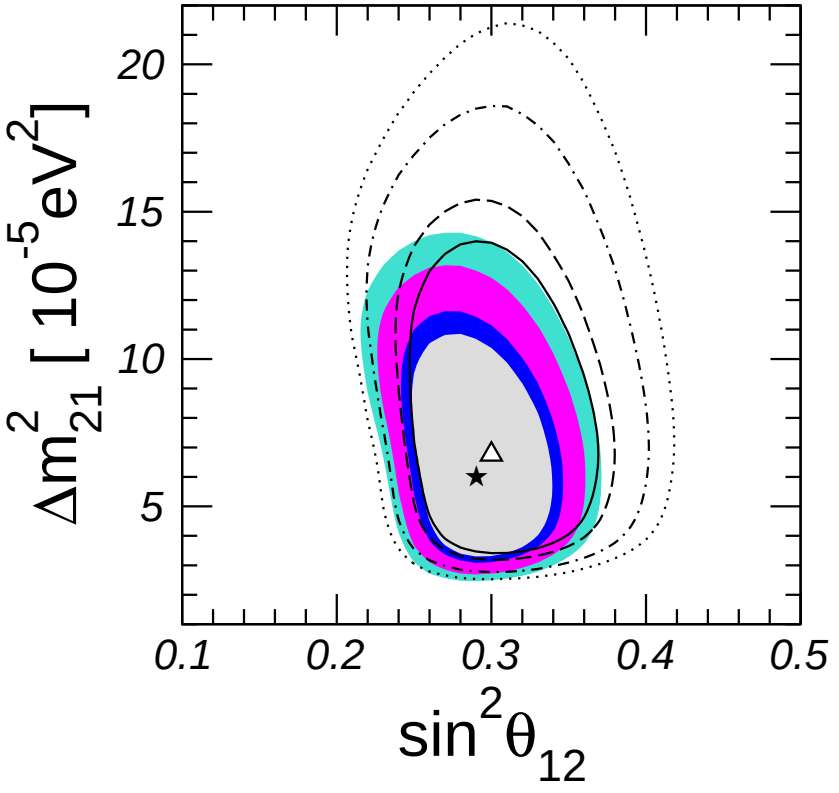
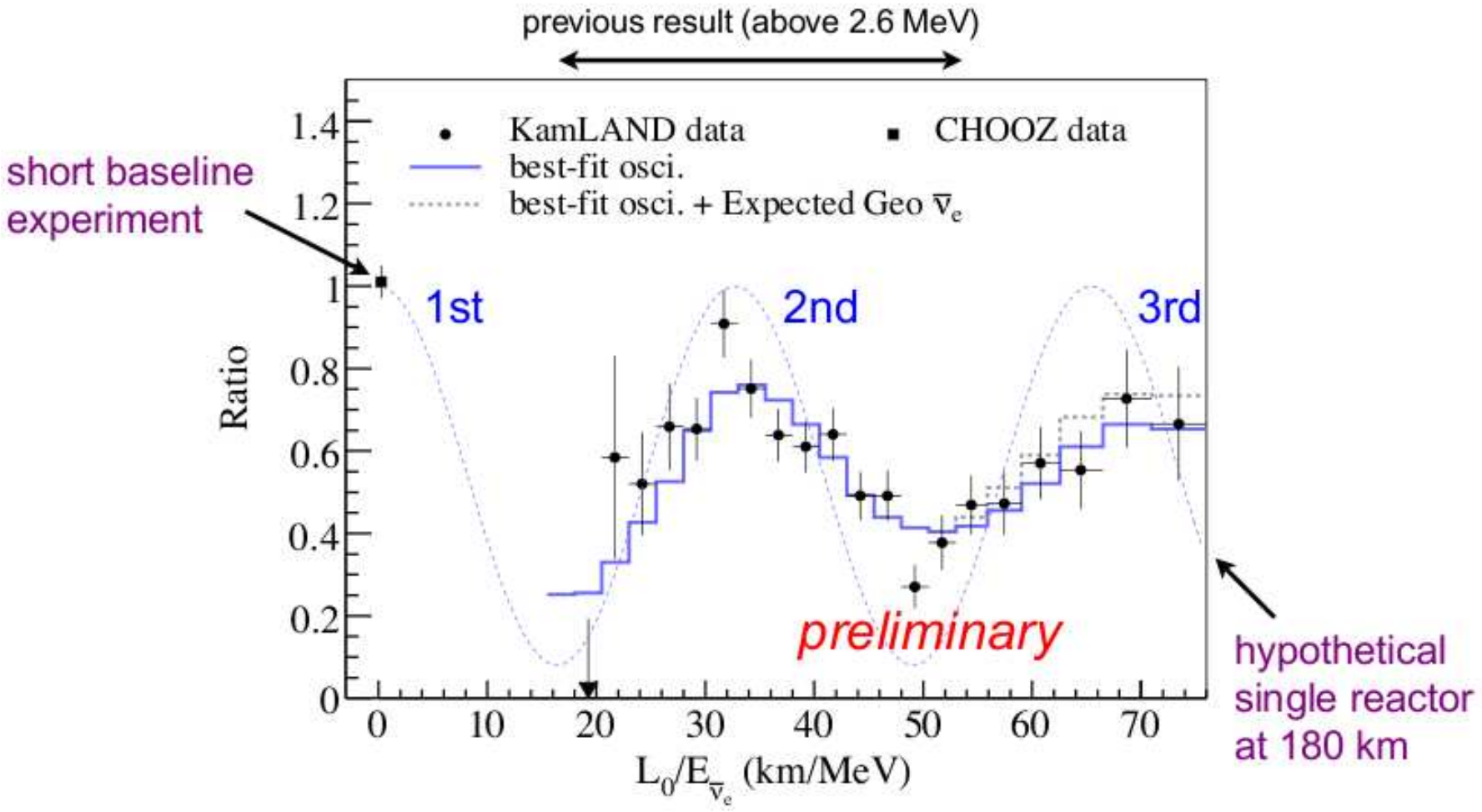




BOREXINO: measurment of the Be7 neutrino line at 0.862 MeV

The KamLAND energy spectrum



evidence for oscillations in $1/E_\nu$

The "atmospheric" parameters Δm^2_{31}, θ_{23}

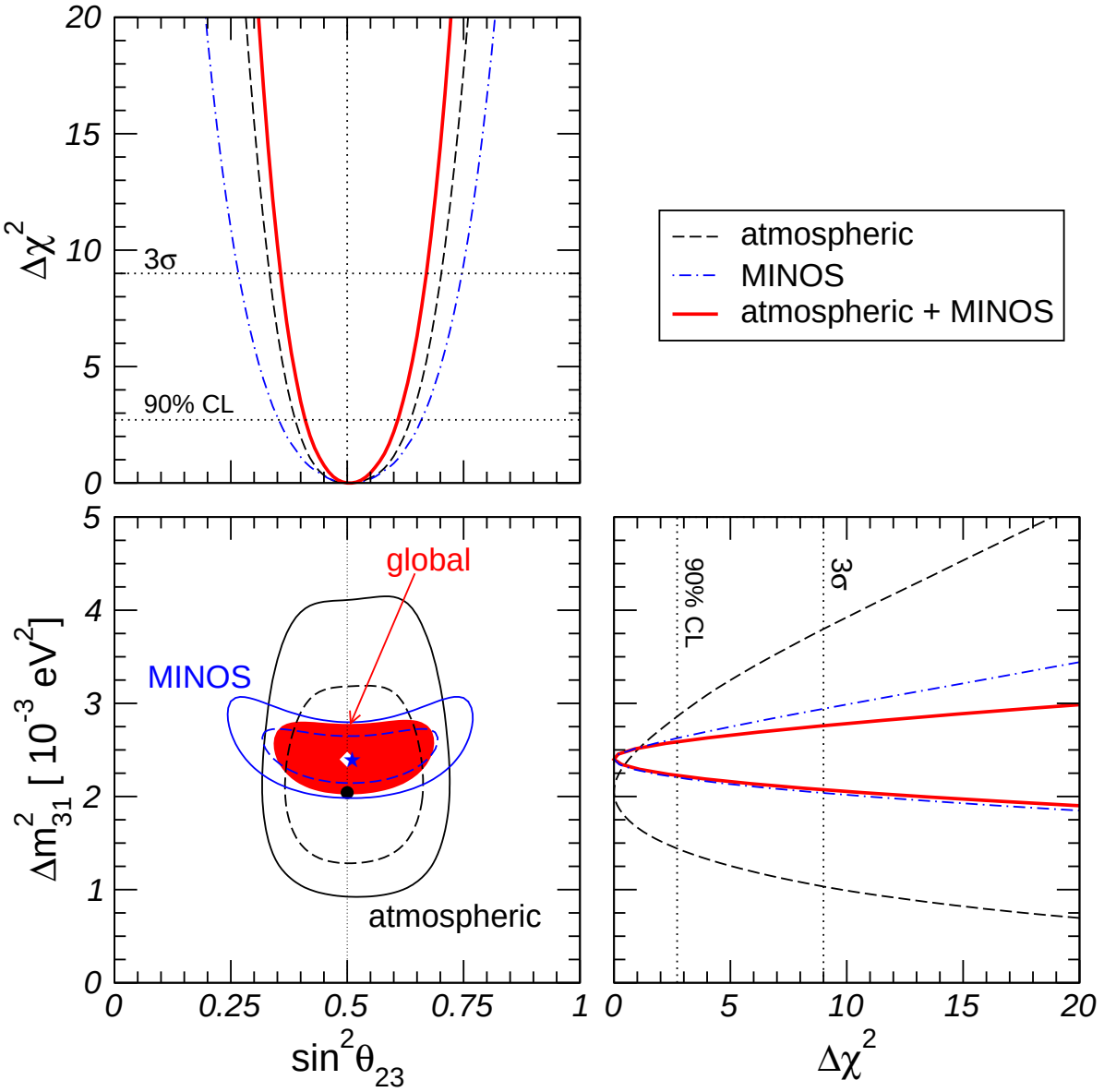
$$U = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & e^{-i\delta} s_{13} \\ 0 & 1 & 0 \\ -e^{i\delta} s_{13} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

Δm^2_{31} — atmospheric+LBL

Chooz

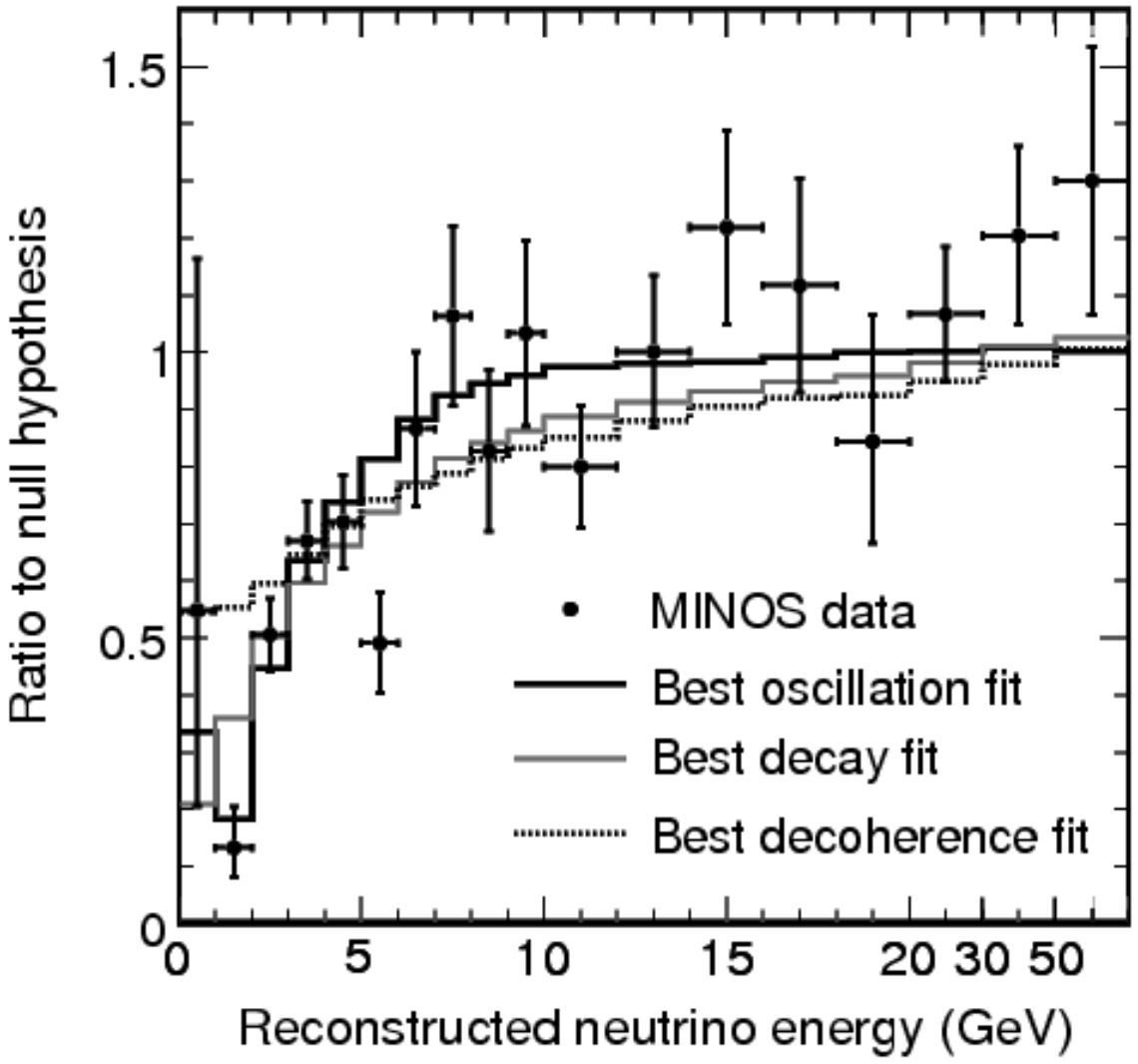
Δm^2_{21} — solar+KamLAND

Super-K + K2K + MINOS



$$\sin^2\theta_{23} = 0.50^{+0.07}_{-0.06}\,, \qquad |\Delta m^2_{31}| = 2.40^{+0.12}_{-0.11} \times 10^{-3}\,\mathrm{eV}^2$$

MINOS energy spectrum



arxiv:0806.2237, 3.4×10^{20} pot

The status of θ_{13}

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

Δm^2_{31} — atmospheric+LBL

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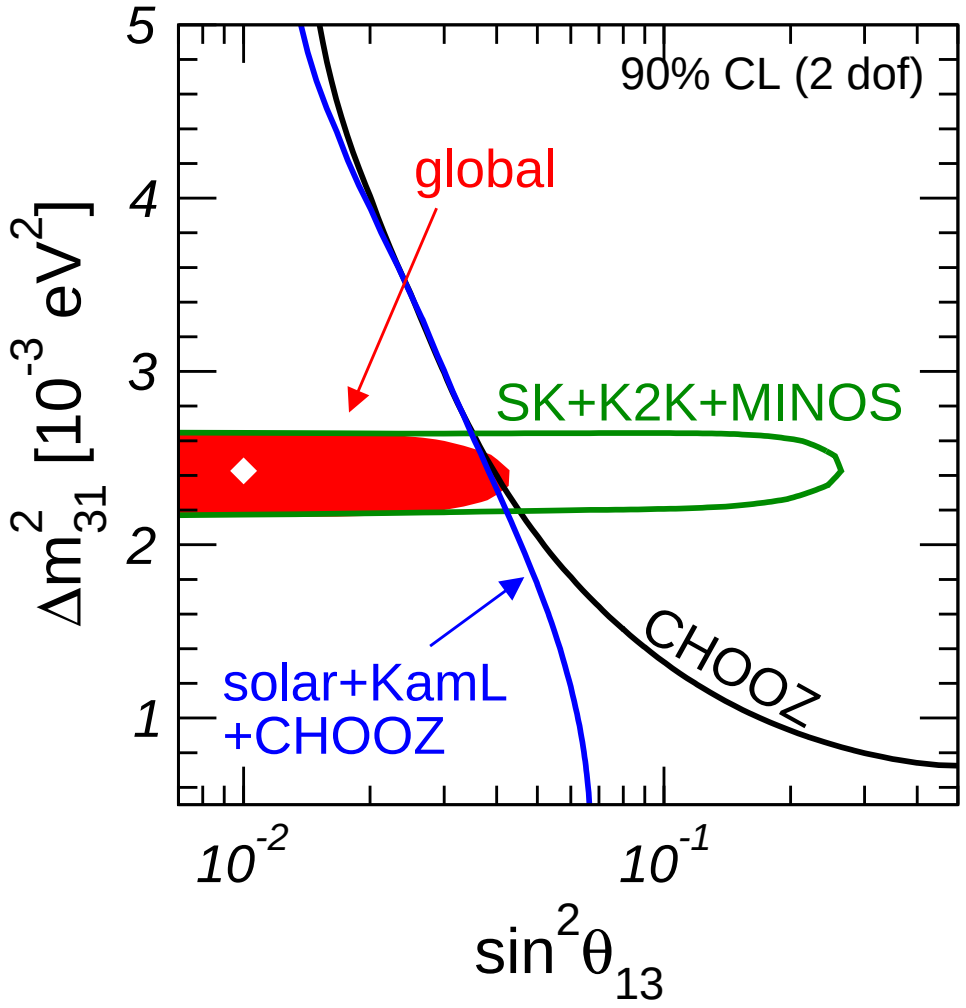
The bound on θ_{13}

global data: $\sin^2\theta_{13} < 0.035\,(0.056)$ at 90% CL (3σ)



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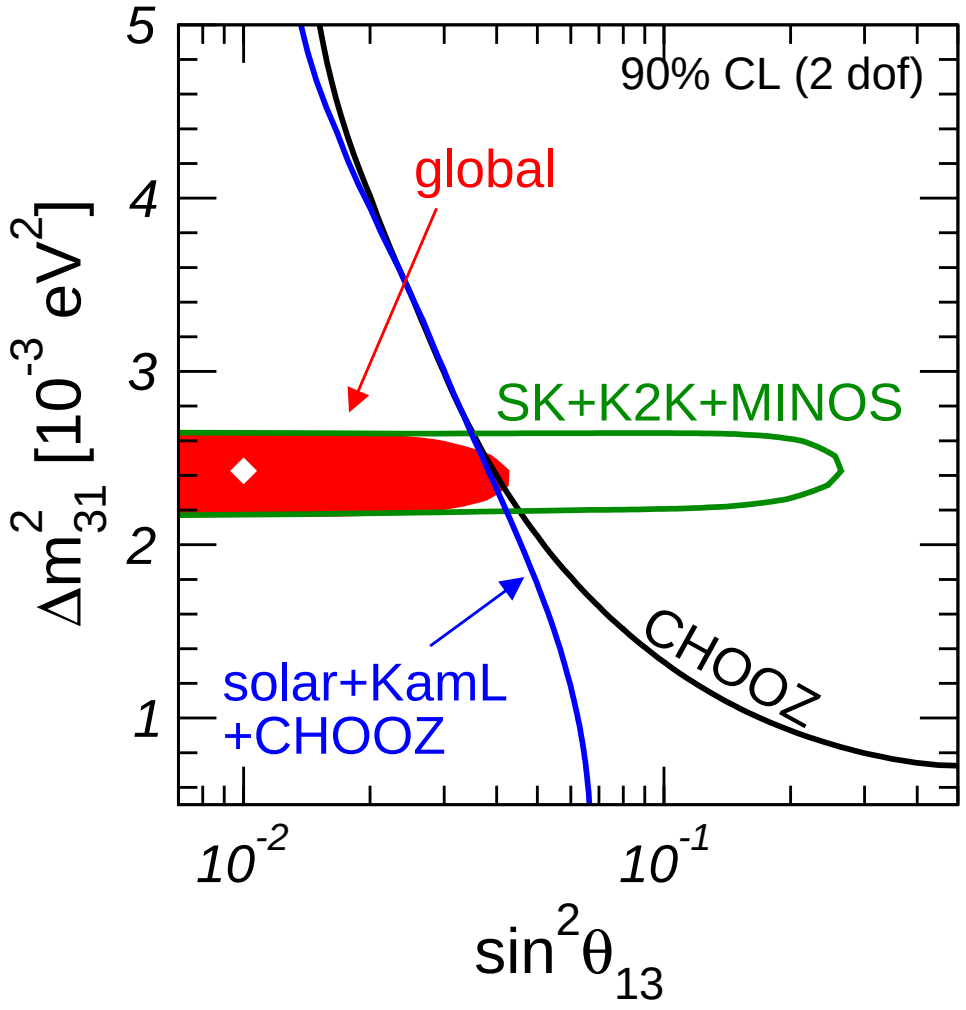
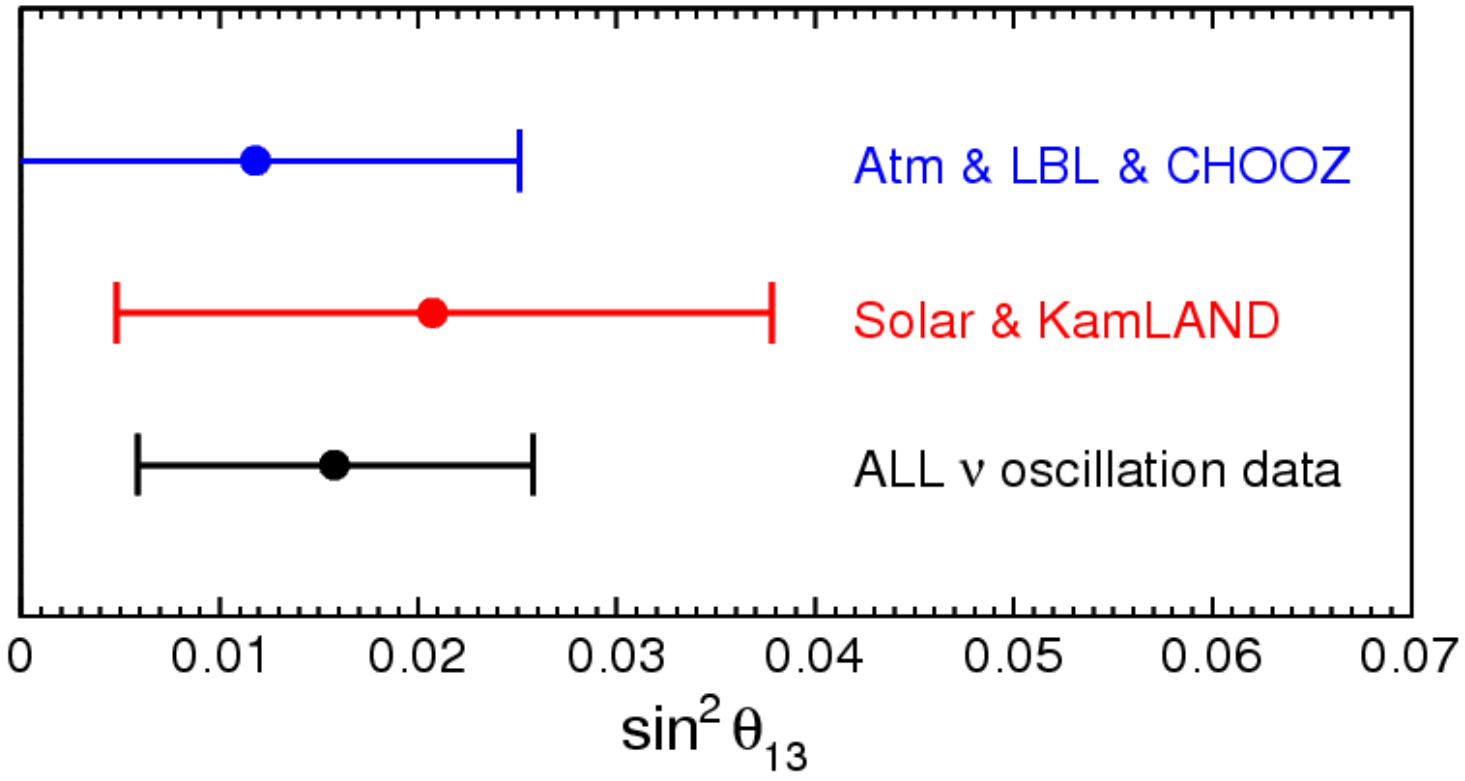


$$\sin\theta_{13} = |U_{e3}| < 0.237\,(3\sigma) \quad \leftrightarrow \quad |V_{us}| = 0.2257 \pm 0.0021$$

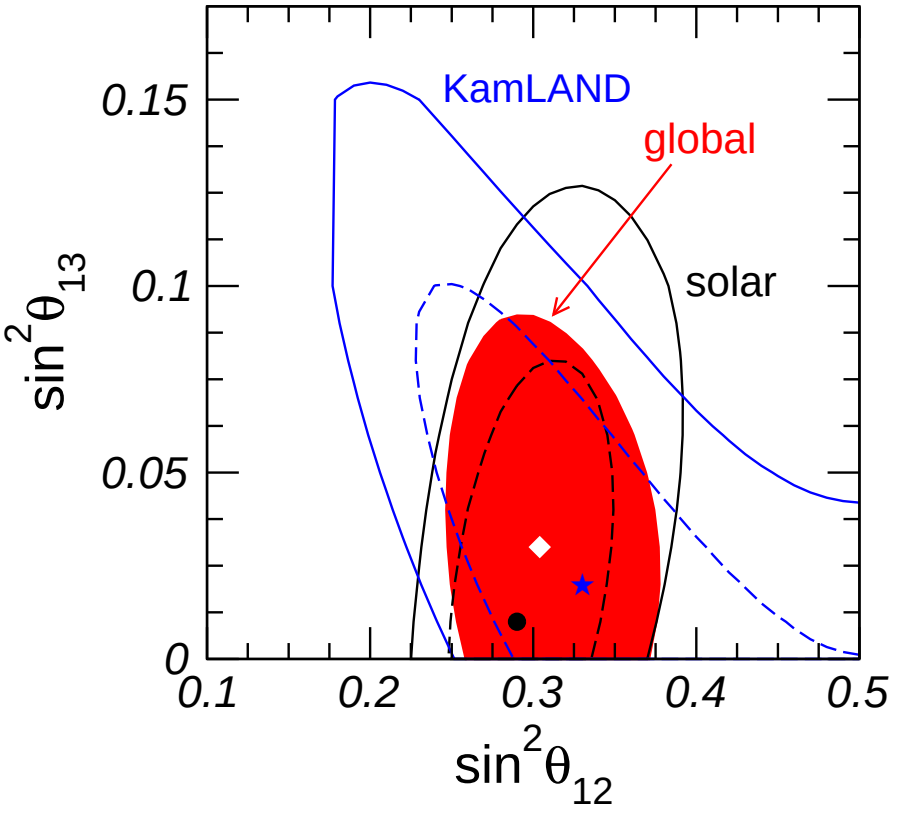
Hint for non-zero θ_{13}?



$$\sin^2\theta_{13} = 0.016 \pm 0.01 \quad (1\sigma)$$

Fogli, Lisi, Marrone, Palazzo, Rotunno, arxiv:0806.2649

θ_{13} in Solar and KamLAND



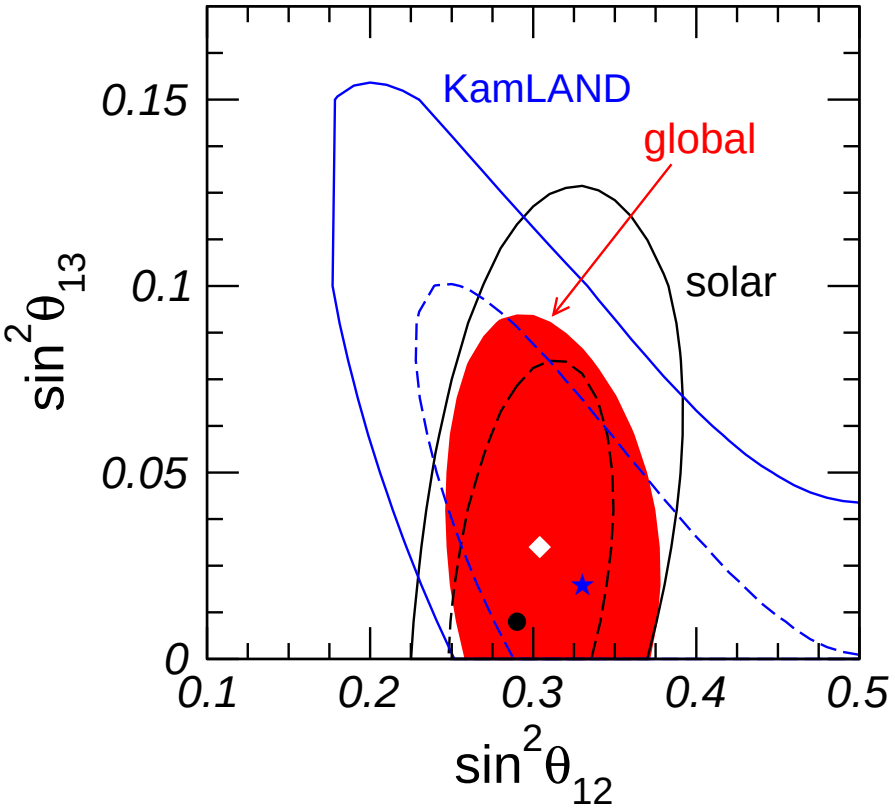
TS, Tortola, Valle, 0808.2016

see also Fogli et al., 0806.2649,
Balantekin, Yilmaz, 0804.3345,
Goswami,Smirnov,hep-ph/0411359,
Maltoni et al., hep-ph/0405172

$$P_{\rm KL} \approx \left(1 - 2\sin^2\theta_{13}\right)\left(1 - \sin^2 2\theta_{12}\,\sin^2\frac{\Delta m^2_{21} L}{4E_\nu}\right)$$

$$P_{\rm Sol} \approx \left(1 - 2\sin^2\theta_{13}\right)\begin{cases}\sin^2\theta_{12} & \text{high } E_\nu \\ \left(1 - 0.5\sin^2 2\theta_{12}\right) & \text{low } E_\nu\end{cases}$$

θ_{13} *in Solar and KamLAND*



TS, Tortola, Valle, 0808.2016

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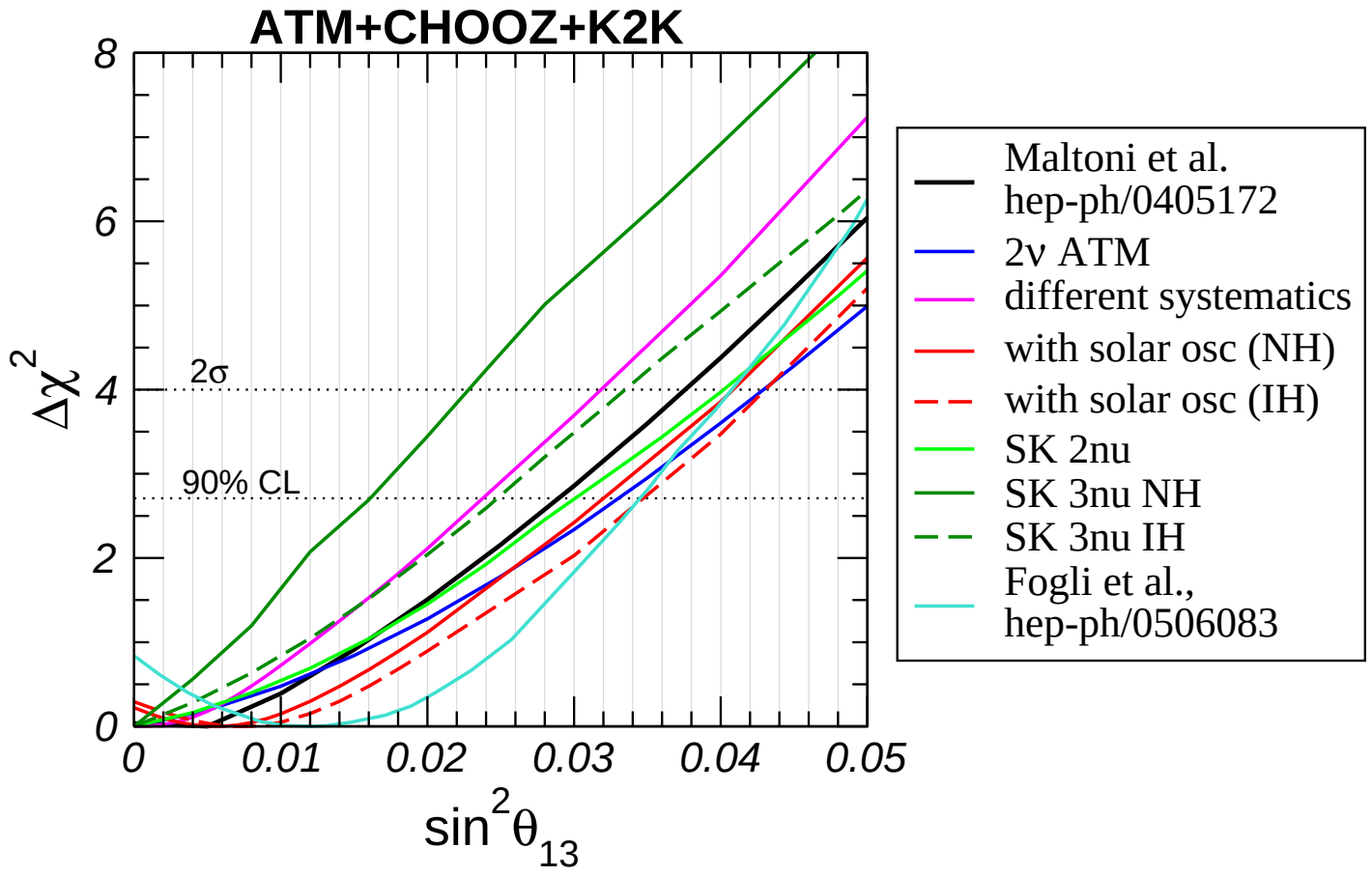
Maltoni et al., hep-ph/0405172

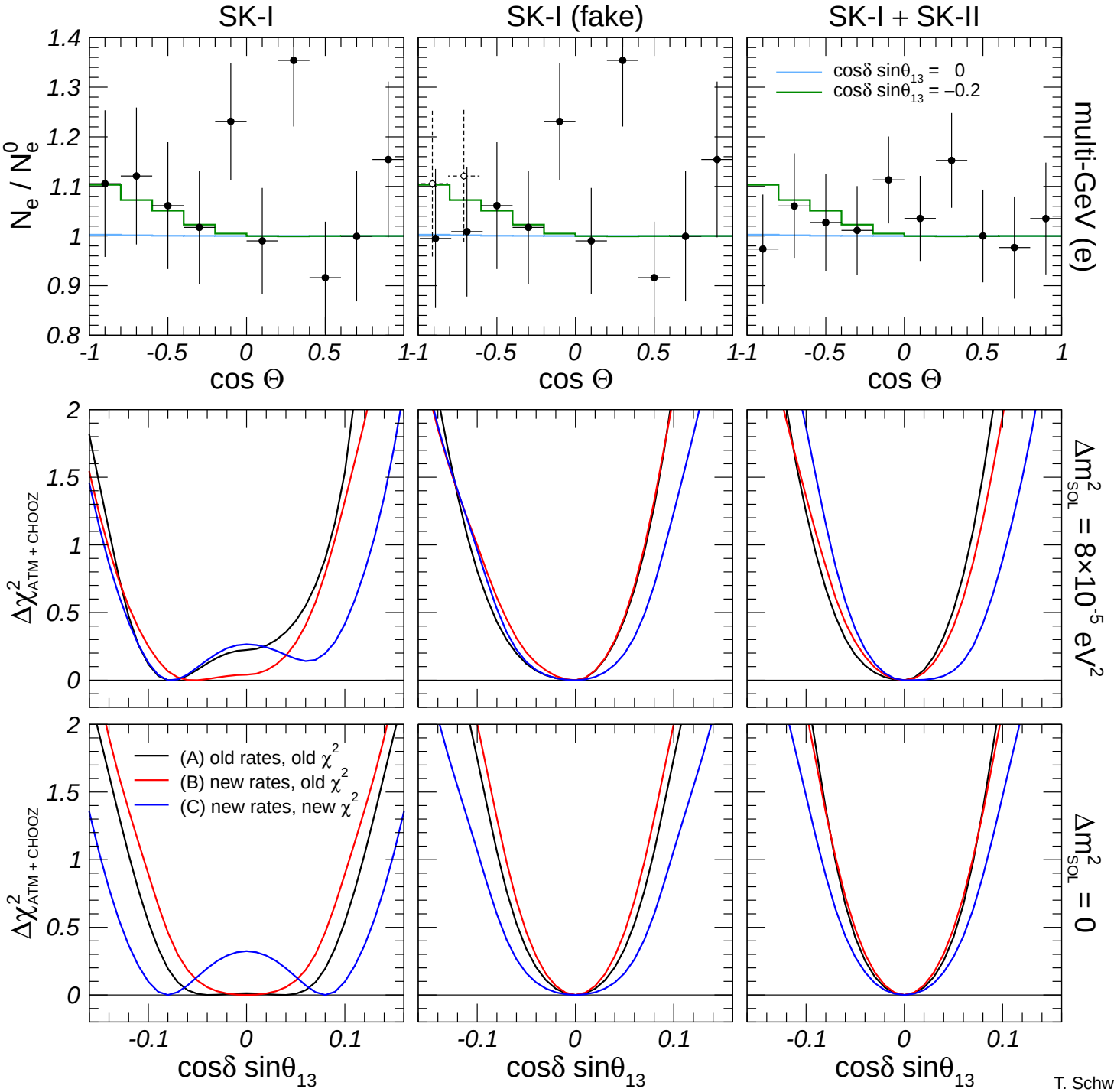
solar + KamLAND: $\sin^2\theta_{13} = 0.03 > 0$ at 1.5σ

Hint from atmospheric data??



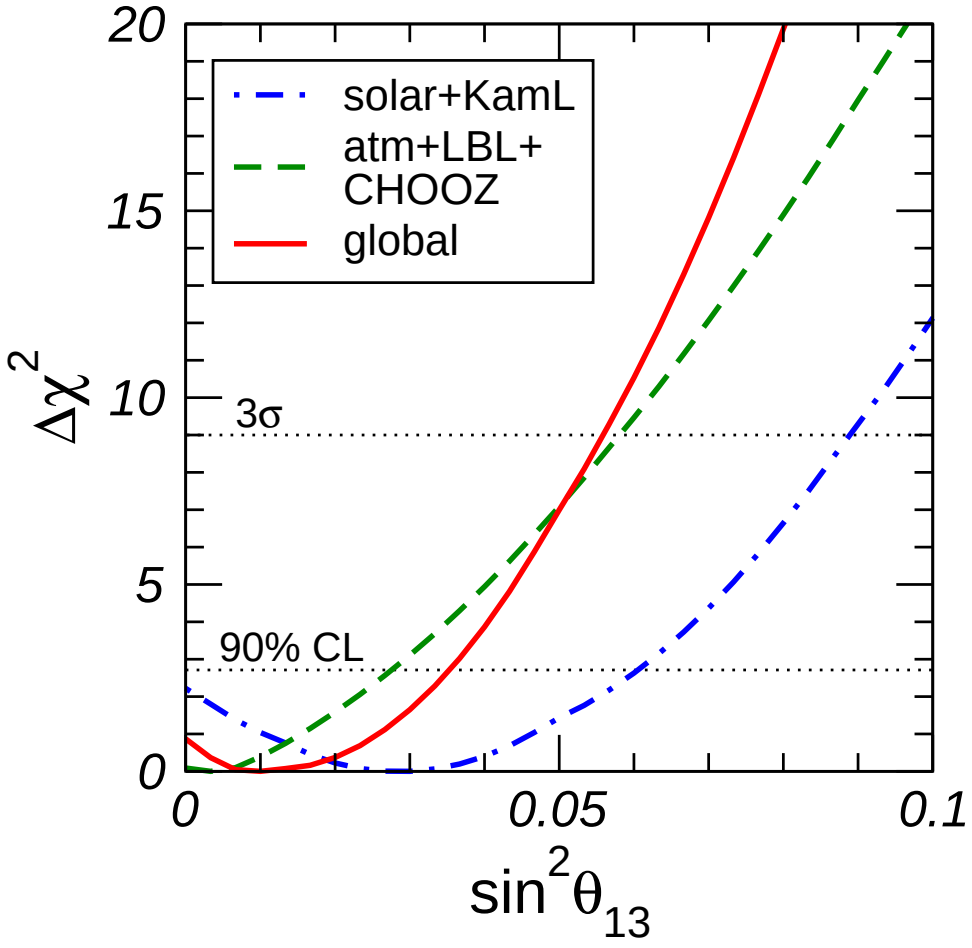
TS, hep-ph/0606060

"hint" from atmospheric data depends on subtle effects (details of the analysis/treatment of systematics...)



Maltoni, TS
0812.3161

No hint from global data?

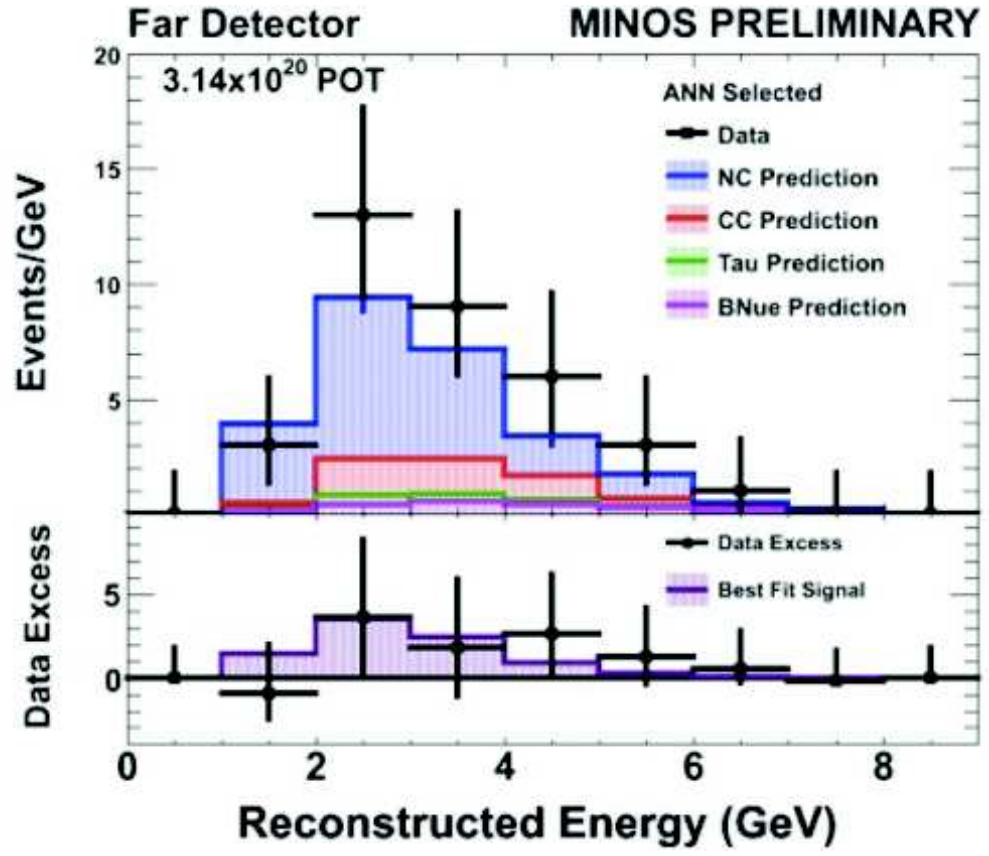


global: $\sin^2\theta_{13} = 0.01^{+0.016}_{-0.011} \qquad (0.9\sigma)$

TS, Tortola, Valle, 08

More hints?

preliminary MINOS $\nu_\mu \to \nu_e$ appearance data:
obs.: 35 events, expected bckg: $27 \pm 5 \pm 2$ (1.5σ)



Talk by M. Sanchez @ FermiLab, 27 Feb 2009

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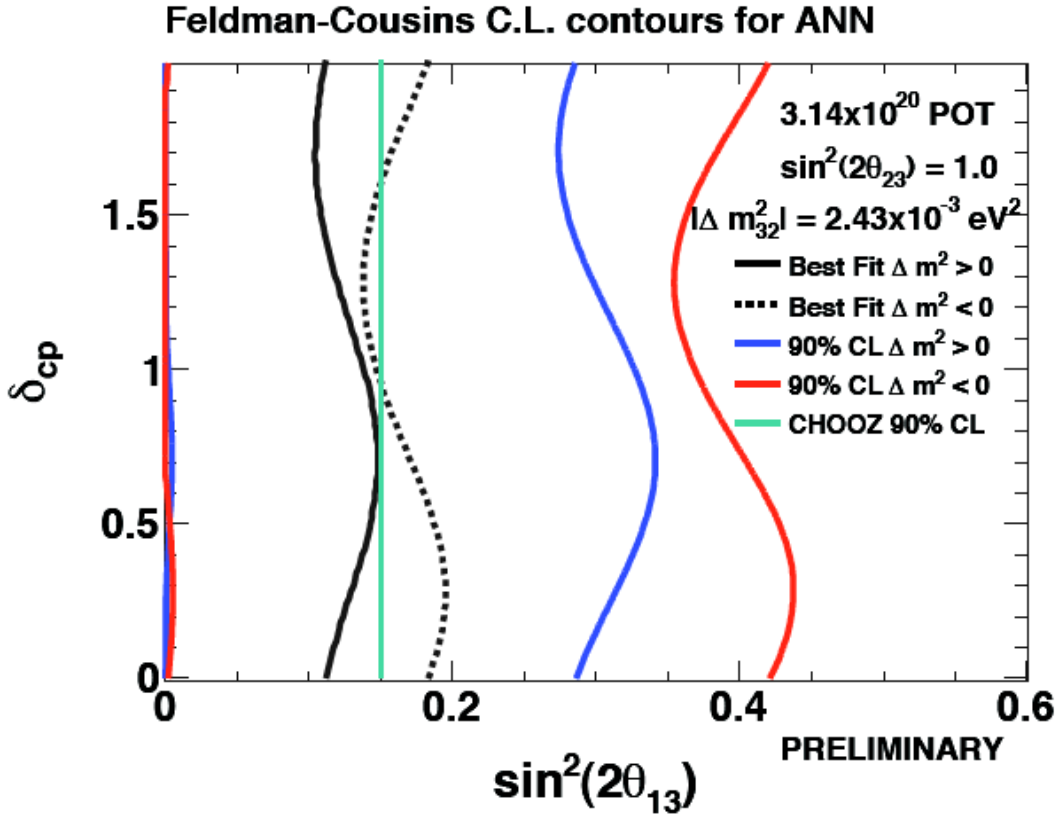

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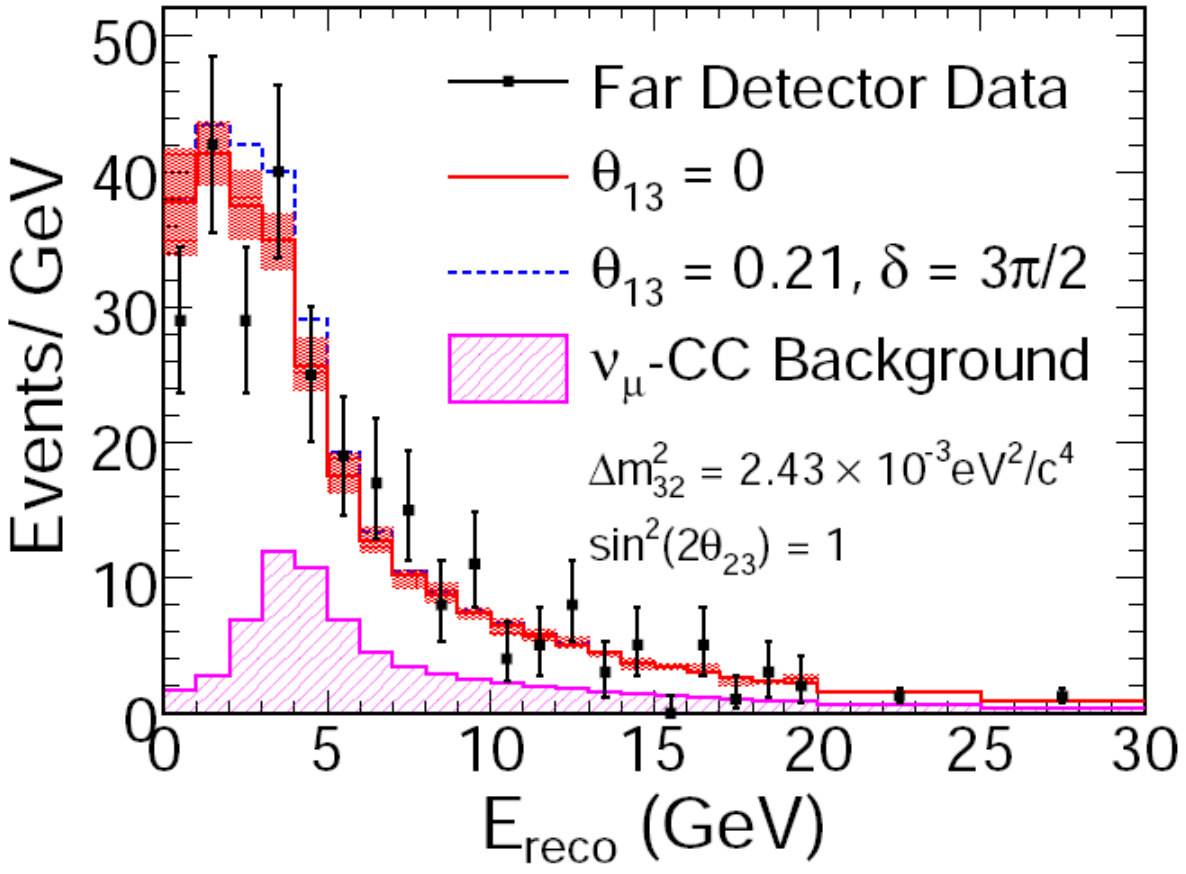
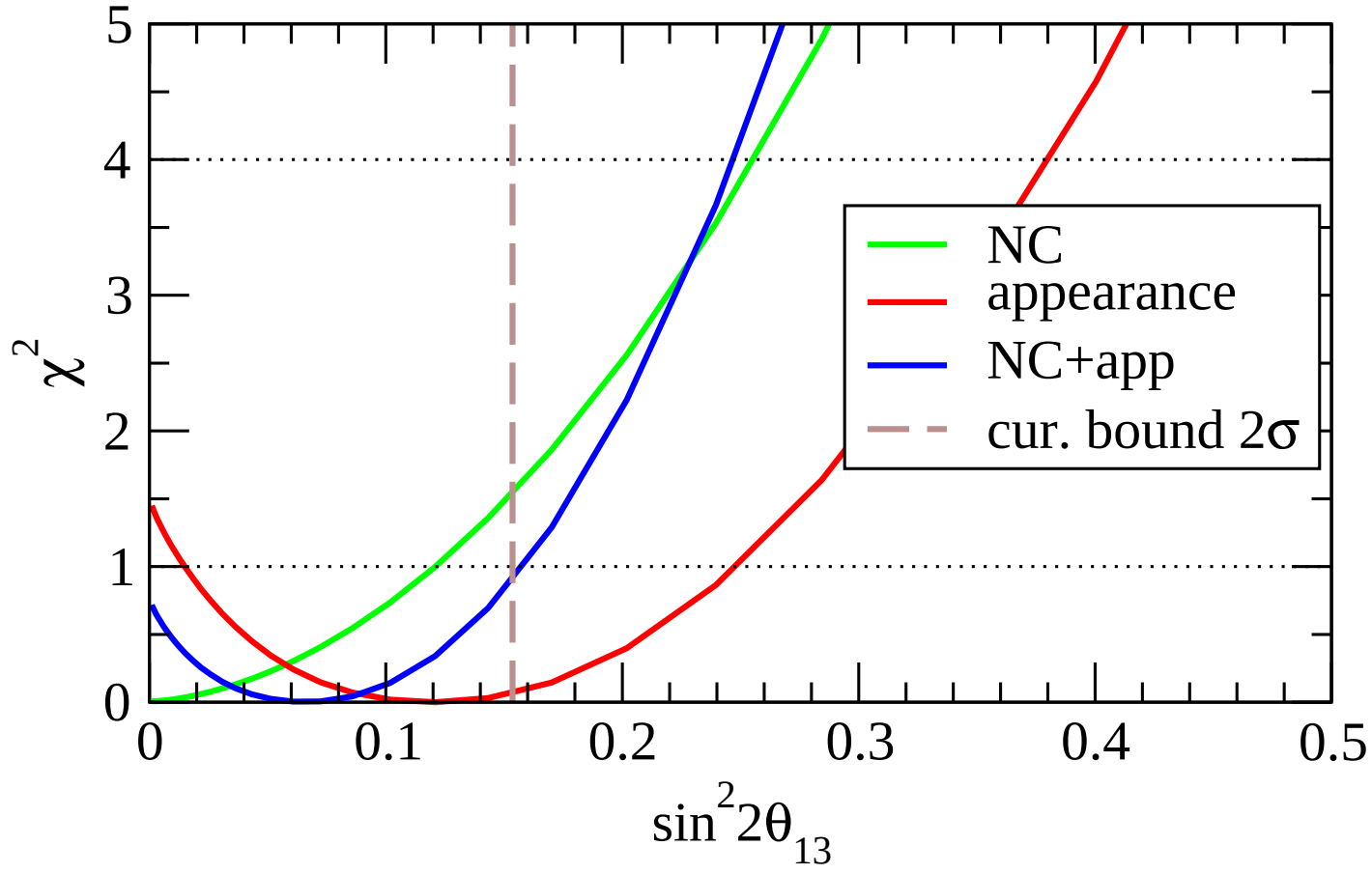
Also anti-hints?

MINOS NC data: includes NC + ν_e events!



MINOS arXiv:0807.2424

MINOS appearance + NC data



Personal comment:

Current hints for non-zero θ_{13} are at the level of 1σ and should not be taken more serious than that!

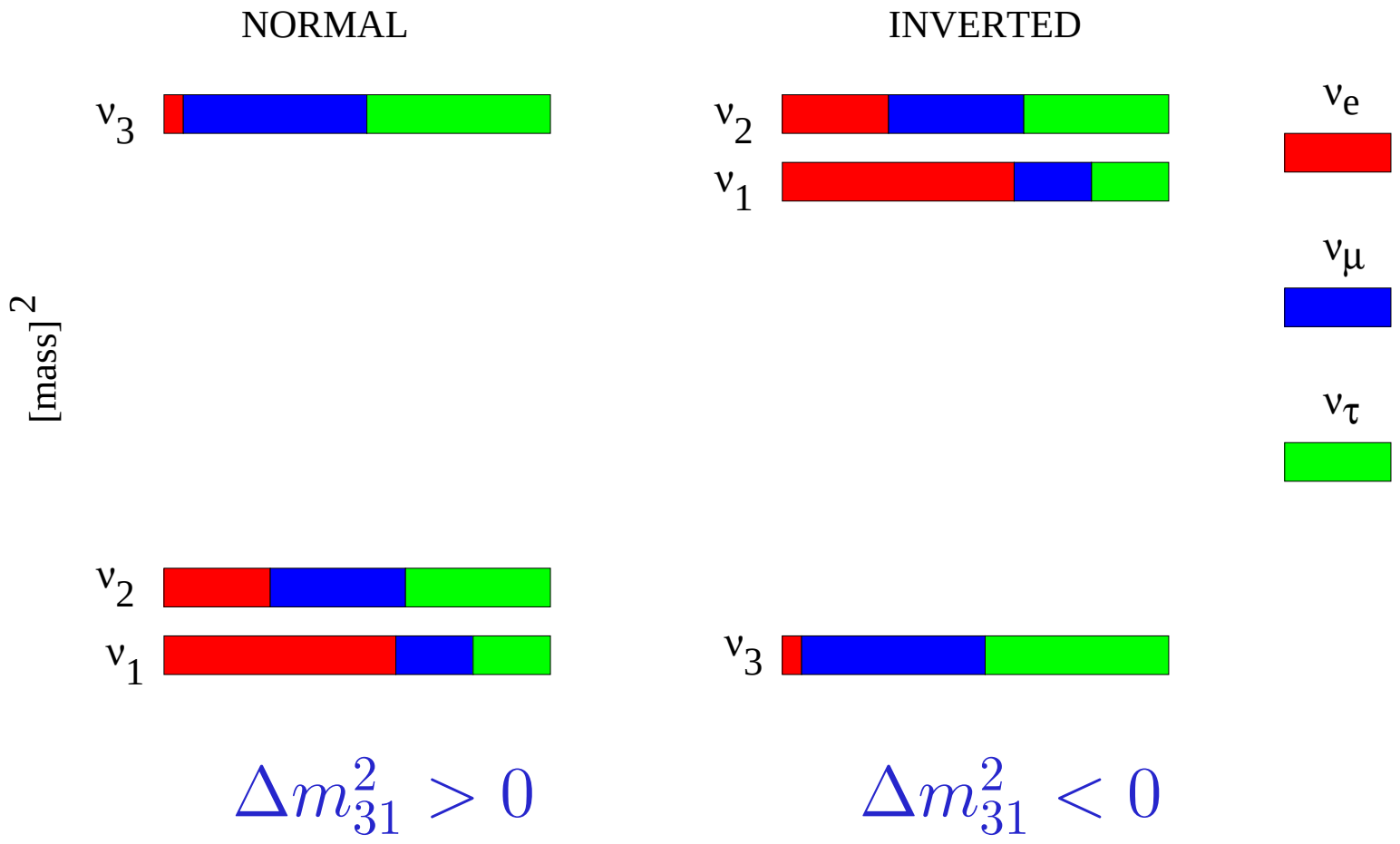
Three flavour osc. parameters summary

	bf $\pm 1\sigma$	acc. @ 3σ	
Δm^2_{21}	$(7.65^{+0.23}_{-0.20})\,10^{-5}\,\mathrm{eV}^2$	(8%)	KamLAND
$\sin^2\theta_{12}$	$0.304^{+0.022}_{-0.016}$	(19%)	SNO
$\lvert\Delta m^2_{31}\rvert$	$(2.40^{+0.12}_{-0.11})\,10^{-3}\,\mathrm{eV}^2$	(14%)	MINOS
$\sin^2\theta_{23}$	$0.50^{+0.07}_{-0.06}$	(30%)	SK atm
$\sin^2\theta_{13} < 0.056$ @ 3σ			CHOOZ

TS, Tortola, Valle, 0808.2016

Three flavour osc. parameters summary

two possibilities for the neutrino mass spectrum



Open questions:

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  non-standard effects beyond oscillations?
- Is θ_{23} exactly 45°?
- How small is θ_{13}?
- What is the value of the CP phase δ?
- Type of the neutrino mass ordering (sign of Δm^2_{31})

The LSND puzzle and MiniBooNE results

The LSND puzzle and MiniBooNE results

- $\nu_\mu \to \nu_e$ search at same L/E as LSND, April 2007:
  $475 < E_\nu^{\rm QE} < 1250\,{\rm MeV}$: $22 \pm 19 \pm 35$ ev. (cons. with zero)
  $300 < E_\nu^{\rm QE} < 475\,{\rm MeV}$: $96 \pm 17 \pm 20$ ev. (3.6σ exc.)
- LSND signal not confirmed in neutrinos (90%)
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- ν_μ disappearance search arXiv:0903.2465
  consistent with no oscillations
  bound comparable to existing constraint from CDHS
- no excess in $\bar{\nu}_\mu \to \bar{\nu}_e$ anti-neutrino search arXiv:0904.1958
  still compatible with LSND signal
  no excess seen at low energies

MiniBooNE

my personal summary:

- no hint in favour of the LSND signal, however,
- exclusion of LSND is not yet fully convincing

- low energy excess (if taken serious)
  - is difficult to explain by new physics
  - might be relevant for future experiments

Upcoming oscillation experiments

Huber, Lindner, TS, Winter, in preparation

Upcoming oscillation experiments

Reactor experiments with near and far detectors:

Off-axis superbeams:

Upcoming oscillation experiments

	baseline	power	FD mass	channel
Reactor experiments with near and far detectors:				
D-Chooz	$1.05\,\mathrm{km}$	$8.6\,\mathrm{GW_{th}}$	$\sim 10\,\mathrm{t}$	$\bar{\nu}_e \to \bar{\nu}_e$
Daya Bay	$2./1.6\,\mathrm{km}$	$17.4\,\mathrm{GW_{th}}$	$\sim 80\,\mathrm{t}$	$\bar{\nu}_e \to \bar{\nu}_e$
Off-axis superbeams:				

D-Chooz: start fall 2009 FD only, after 1.5 yr ND

Daya Bay: start 07/2011 with all ND and FD (8×20 t)

Upcoming oscillation experiments

	baseline	power	FD mass	channel
Reactor experiments with near and far detectors:				
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Off-axis superbeams:				
T2K	$295\,\mathrm{km}$	$0.75\,\mathrm{MW}$	$22.5\,\mathrm{kt}$	$\nu_\mu \to \nu_e, \nu_\mu$
NOνA	$812\,\mathrm{km}$	$0.7\,\mathrm{MW}$	$15\,\mathrm{kt}$	$\nu_\mu \to \nu_e, \nu_\mu$

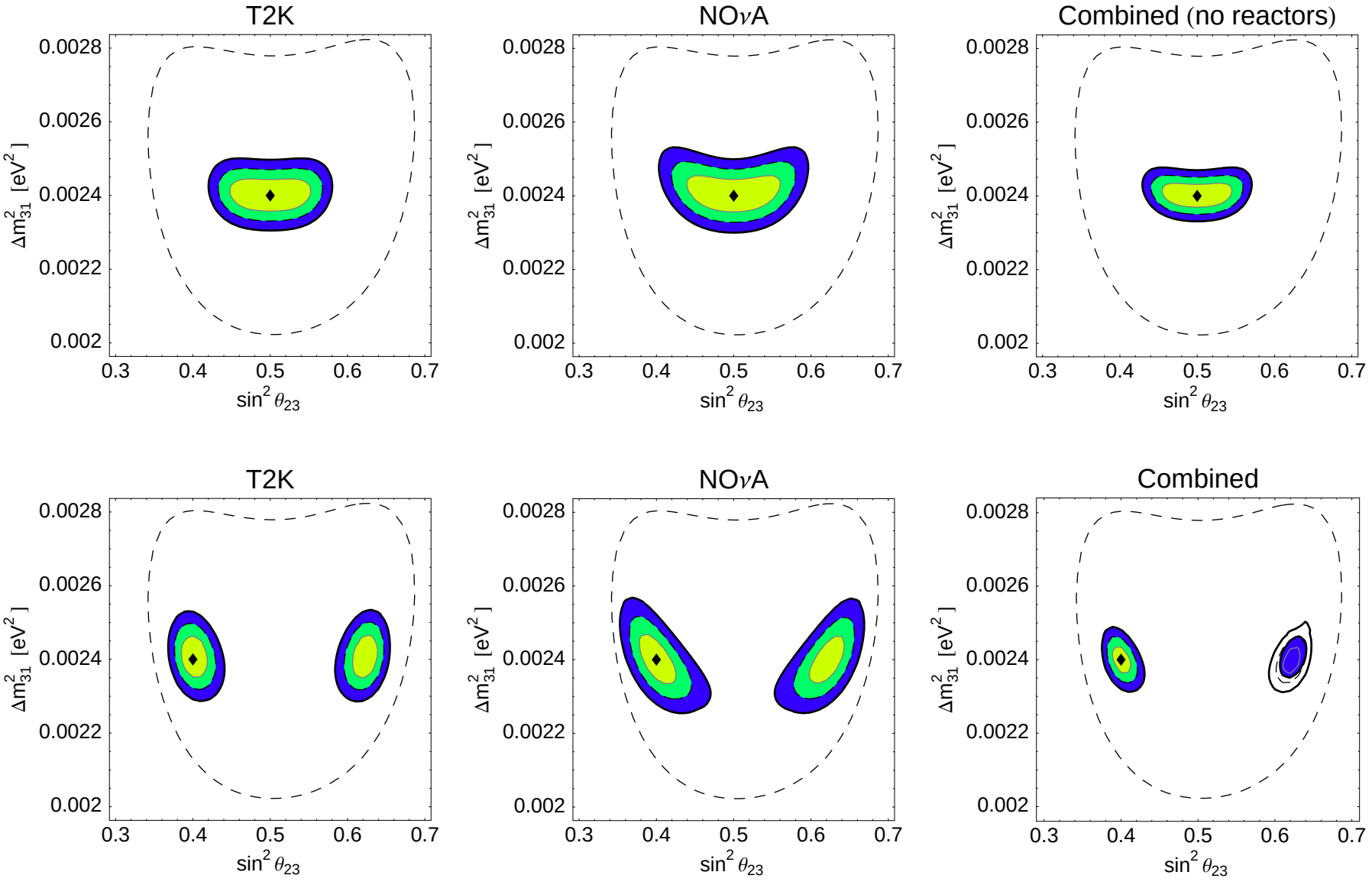
T2K: start 09/2009

linear increase of beam from 0 to 0.75 MW in 01/2014

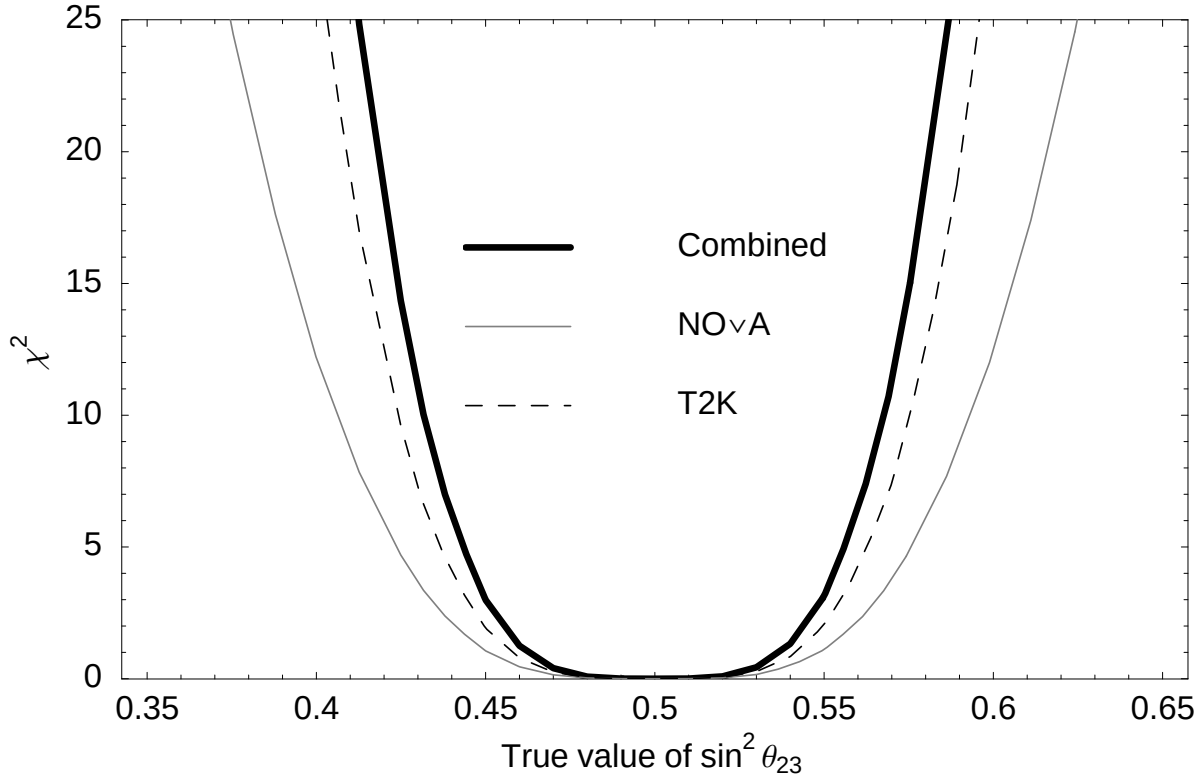
NOνA: start 08/2012

increase of det. from 2.5 kt to 15 kt in 01/2014 ($\bar{\nu}$ in 03/2016)

The "atmospheric" parameters



Deviations from $\theta_{23} = 45^\circ$



$$\theta_{23} \neq 45^\circ \,@\, 2\sigma \text{ for } \begin{cases} |\sin^2\theta_{23} - 0.5| > 0.07 & \textbf{NO}\nu\textbf{A} \\ |\sin^2\theta_{23} - 0.5| > 0.06 & \textbf{T2K} \\ |\sin^2\theta_{23} - 0.5| > 0.05 & \textbf{T2K} + \textbf{NO}\nu\textbf{A} \end{cases}$$

What is the value of θ_{13}?

- naively one would expect $\theta_{12} \sim \theta_{23} \sim \theta_{13}$
  $\longrightarrow \theta_{13}$ around the corner
- $\theta_{13} \ll 1$ hint for some symmetry
- relatively large θ_{13} opens the possibilty to observe generic 3-flavour effects (CP-violation)

Measuring θ_{13}

- $\bar{\nu}_e \longrightarrow \bar{\nu}_e$ disappearance reactor experiments with near and far detectors: **D-Chooz, Daya Bay, RENO**

  "clean" measurement of θ_{13}:

$$P_{ee} \approx 1 - \sin^2 2\theta_{13} \, \sin^2 \frac{\Delta m^2_{31} L}{4E_\nu} + \mathcal{O}\left(\frac{\Delta m^2_{21}}{\Delta m^2_{31}}\right)^2$$

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- LBL $\nu_\mu \longrightarrow \nu_e$ appearance experiments **(MINOS, CNGS) T2K, NOνA**

  θ_{13} is correlated with other parameters, especially with the CP-phase δ.

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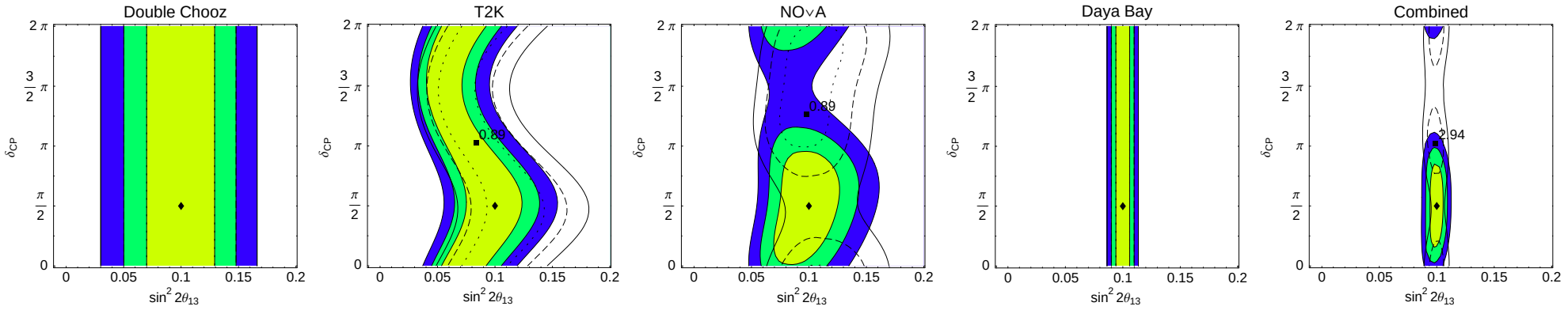
- LBL $\nu_\mu \longrightarrow \nu_e$ appearance experiments **(MINOS, CNGS) T2K, NOνA**

  θ_{13} is correlated with other parameters, especially with the CP-phase δ.

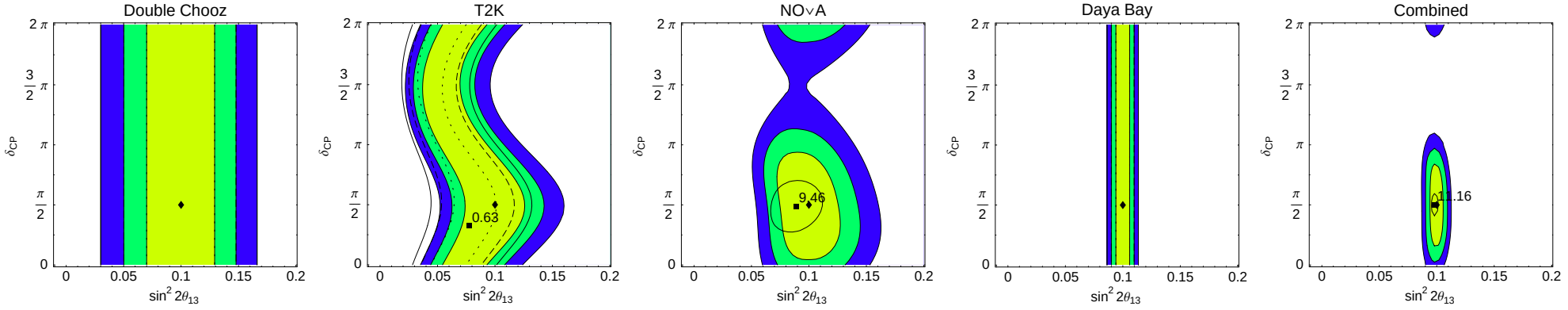
$\Rightarrow$ Provide complementary information

assume $\sin^2 2\theta_{13} = 0.1$

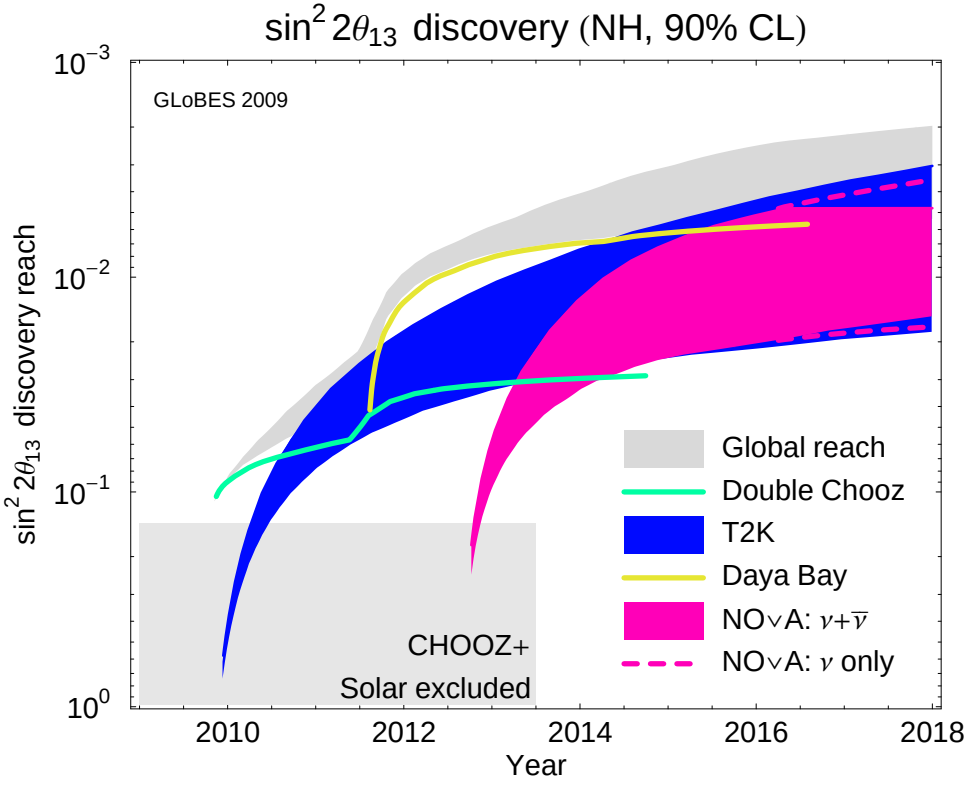
NH:

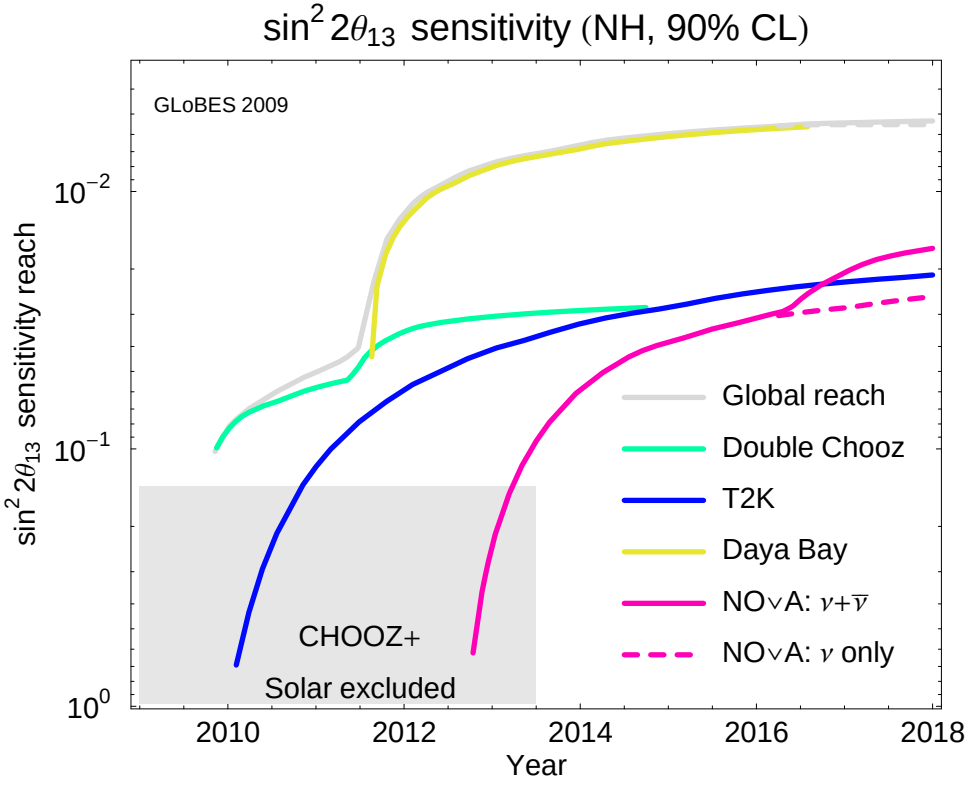


IH:



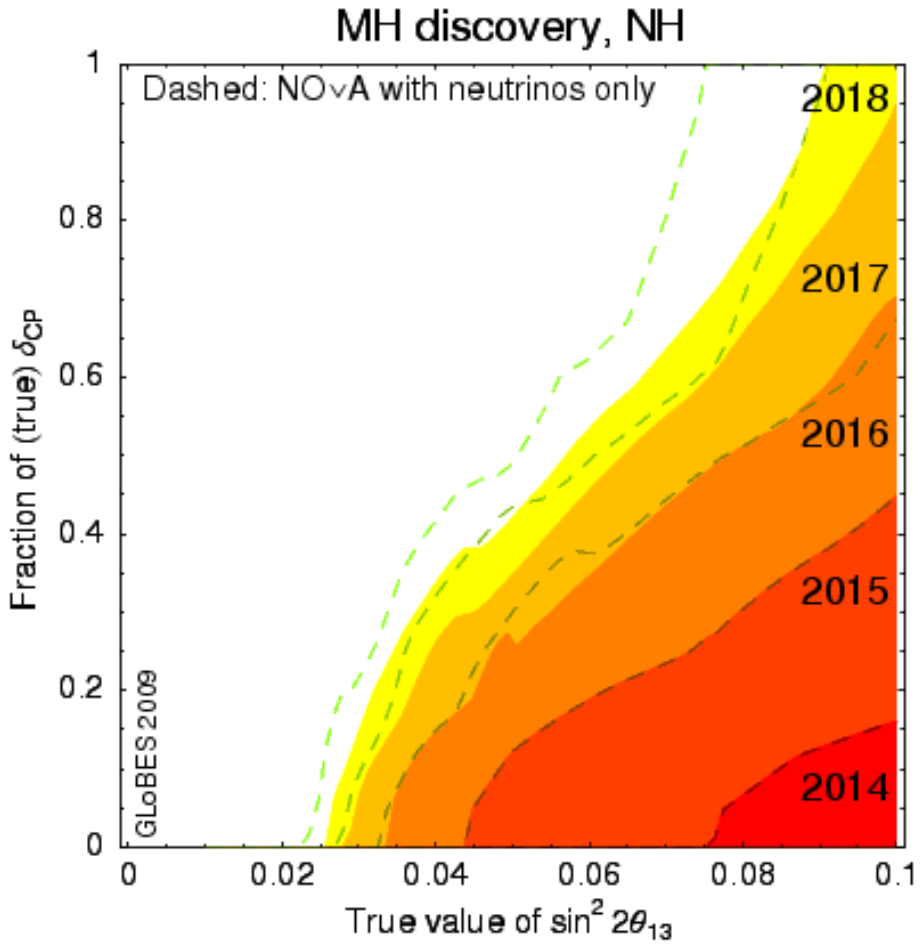
The race for θ_{13}

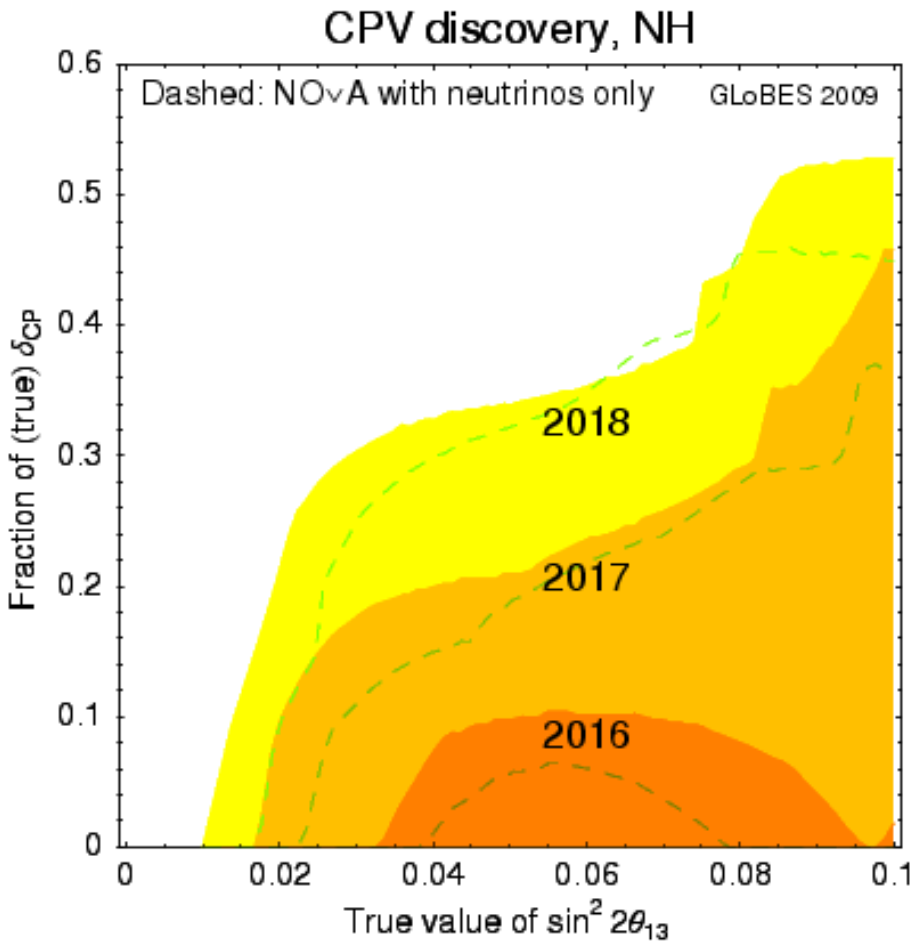




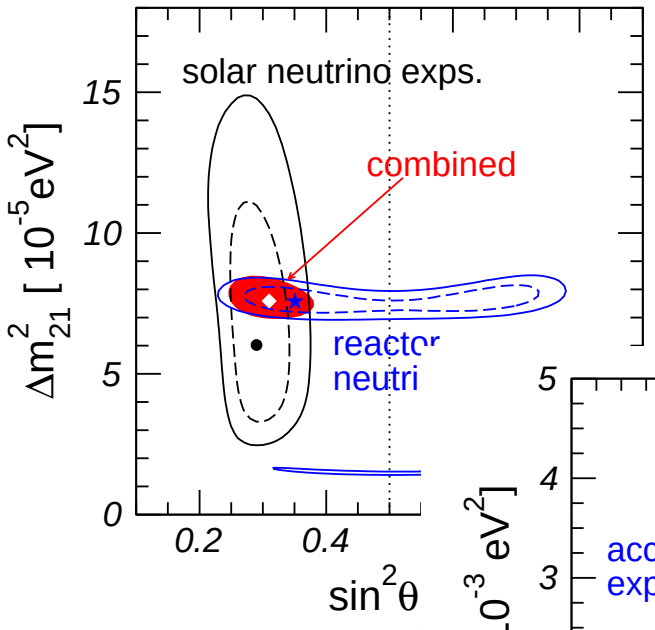
Huber, Lindner, TS, Winter, in preparation

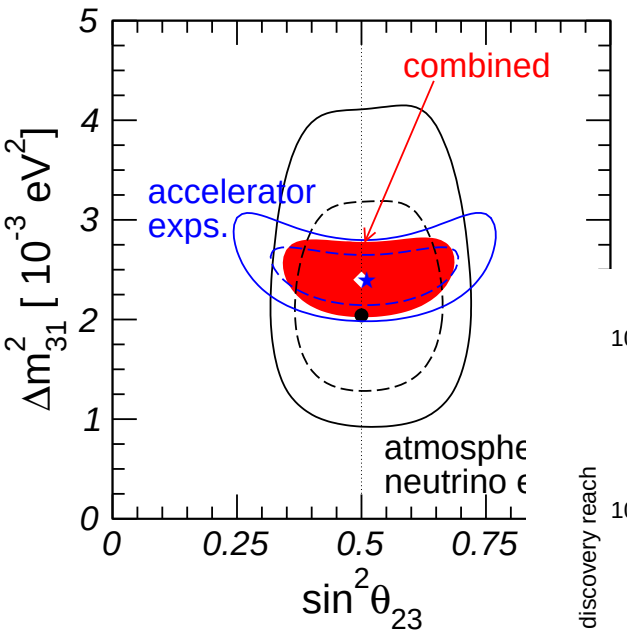
Mass hierarchy & CPV

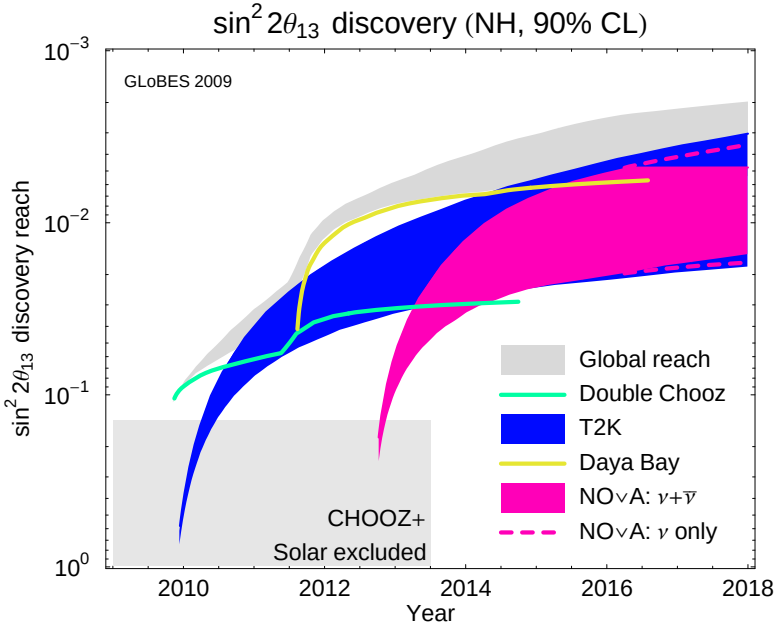




Huber, Lindner, TS, Winter, in preparation







Thank you for your attention!