EUROν meeting, Strasbourg 2010

Status of θ_{13} and perspectives

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M. Mezzetto, T.S., "θ_{13}: phenomenology, present status and prospect", 1003.5800

thanks to my collaborators: P. Huber, M. Lindner, M. Maltoni, M. Tortola, J. Valle, W. Winter

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

Δm^2_{31} — atmospheric+LBL

Chooz

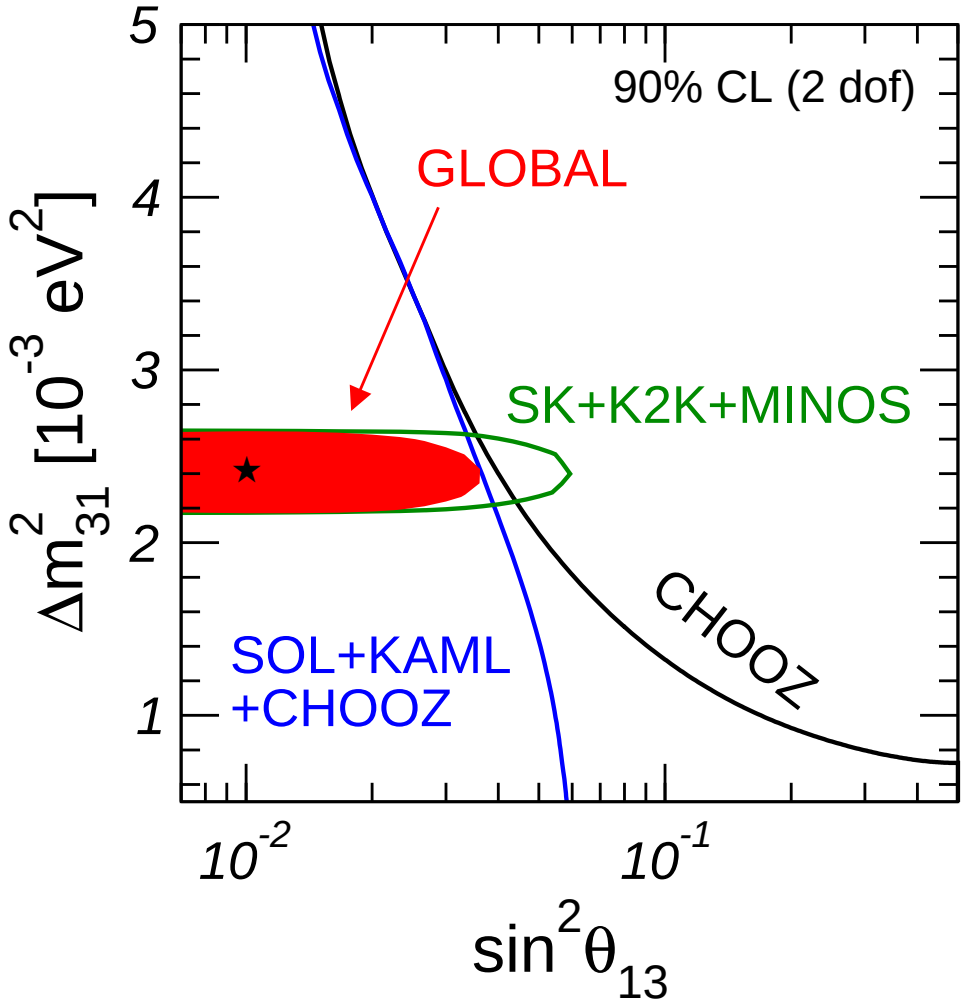
Δm^2_{21} — solar+KamLAND

θ_{13} is the key to CPV and MH

. . . so let's have a look on where we are and what the near future will bring

The status of θ_{13}

$\sin^2\theta_{13} < 0.031\,(0.047)$ at 90% CL (3σ)



interplay of different data sets from global data

Hint for non-zero θ_{13}?

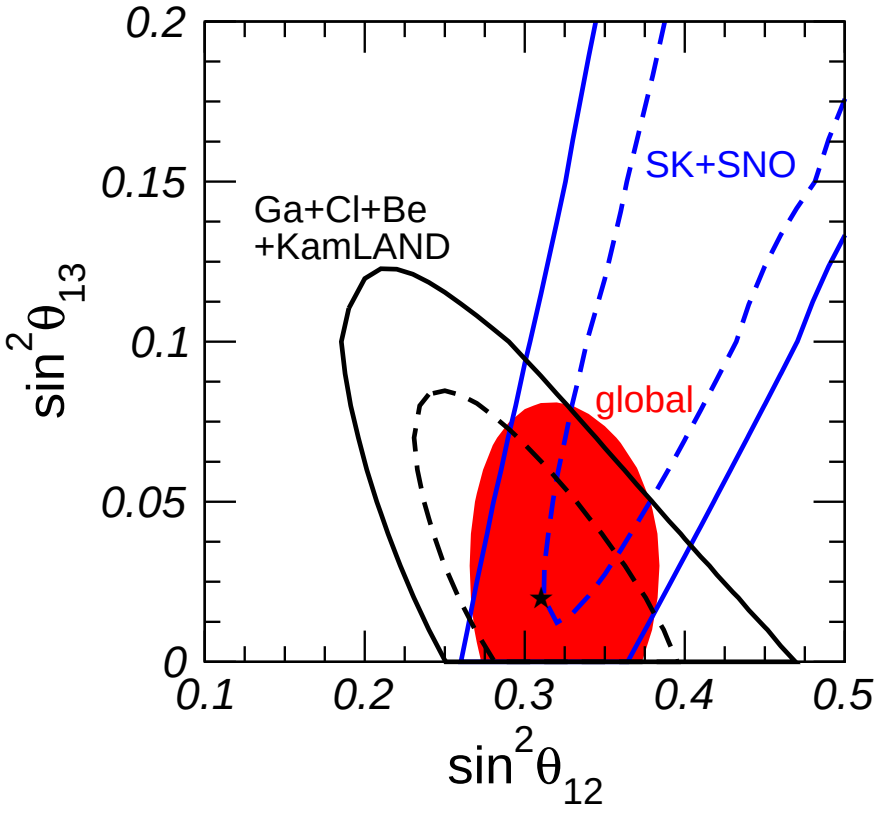
Fogli, Lisi, Marrone, Palazzo, Rotunno
"Hints of theta(13) > 0 from global neutrino data analysis." PRL08 [0806.2649]

- Hint from solar+KamLAND data ($\sim 1.5\sigma$)
  fragile, but agreement among groups
  depends somewhat on assumptions on solar metalicity

- Hint from atmospheric data
  controversial, not confirmed by SuperK Wendell et al., 1002.3471

- MINOS appearance data ($\nu_\mu \longrightarrow \nu_e$)
  initial $\sim 1.5\sigma$ hint has recently decreased to $\sim 0.7\sigma$

θ_{13} in Solar and KamLAND



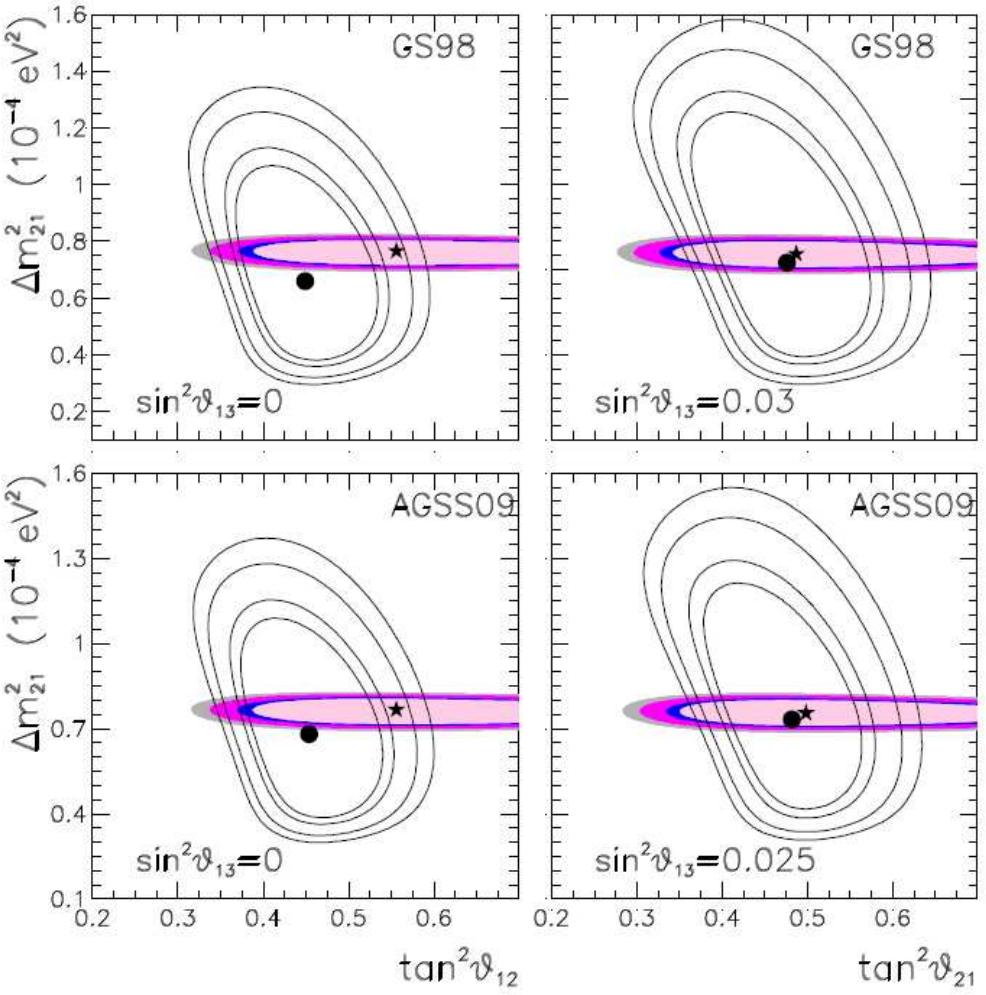
Maltoni et al., hep-ph/0405172,
Goswami,Smirnov,hep-ph/0411359,
Balantekin, Yilmaz, 0804.3345,
Fogli et al., 0806.2649,
TS, Tortola, Valle, 0808.2016
Gonzalez-Garcia, Maltoni, Salvado,
1001.4524

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

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

θ_{13} *in Solar and KamLAND*

Gonzalez-Garcia, Maltoni, Salvado, 1001.4524



SSM: AGSS09 (GS98): low (high) metallicity, ^{8}B, ^{7}Be $\downarrow$ ($\uparrow$) [Serenelli et al, 0909.2668]

θ_{13} in Solar and KamLAND

SNO Coll., 0910.2984

$$\sin^2\theta_{13} = 0.020^{+0.021}_{-0.016}$$

TS, Tortola, Valle, 0808.2016 (2010 upd)

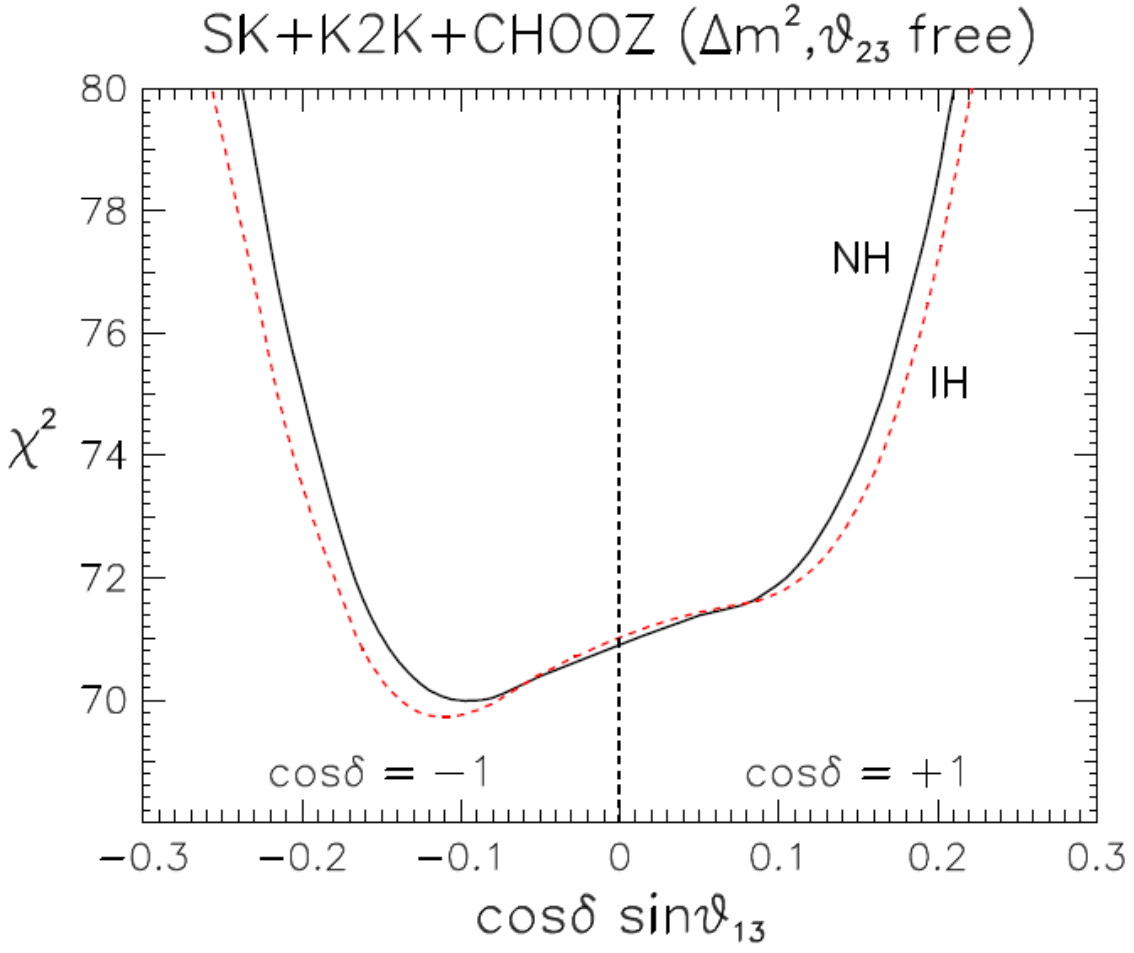
$$\sin^2\theta_{13} = \begin{cases} 0.022^{+0.018}_{-0.015} & 1.5\sigma \quad (\text{AGSS09}) \\ 0.027^{+0.019}_{-0.015} & 1.7\sigma \quad (\text{GS98}) \end{cases}$$

Gonzalez-Garcia, Maltoni, Salvado, 1001.4524

$$\sin^2\theta_{13} = \begin{cases} 0.021 \pm 0.017 & (\text{GS98}) \\ 0.017 \pm 0.017 & (\text{AGSS09}) \\ 0.015 \pm 0.017 & (\text{AGSS09, mod. } \sigma_{\text{Ga}}) \end{cases}$$

Hint from atmospheric data?

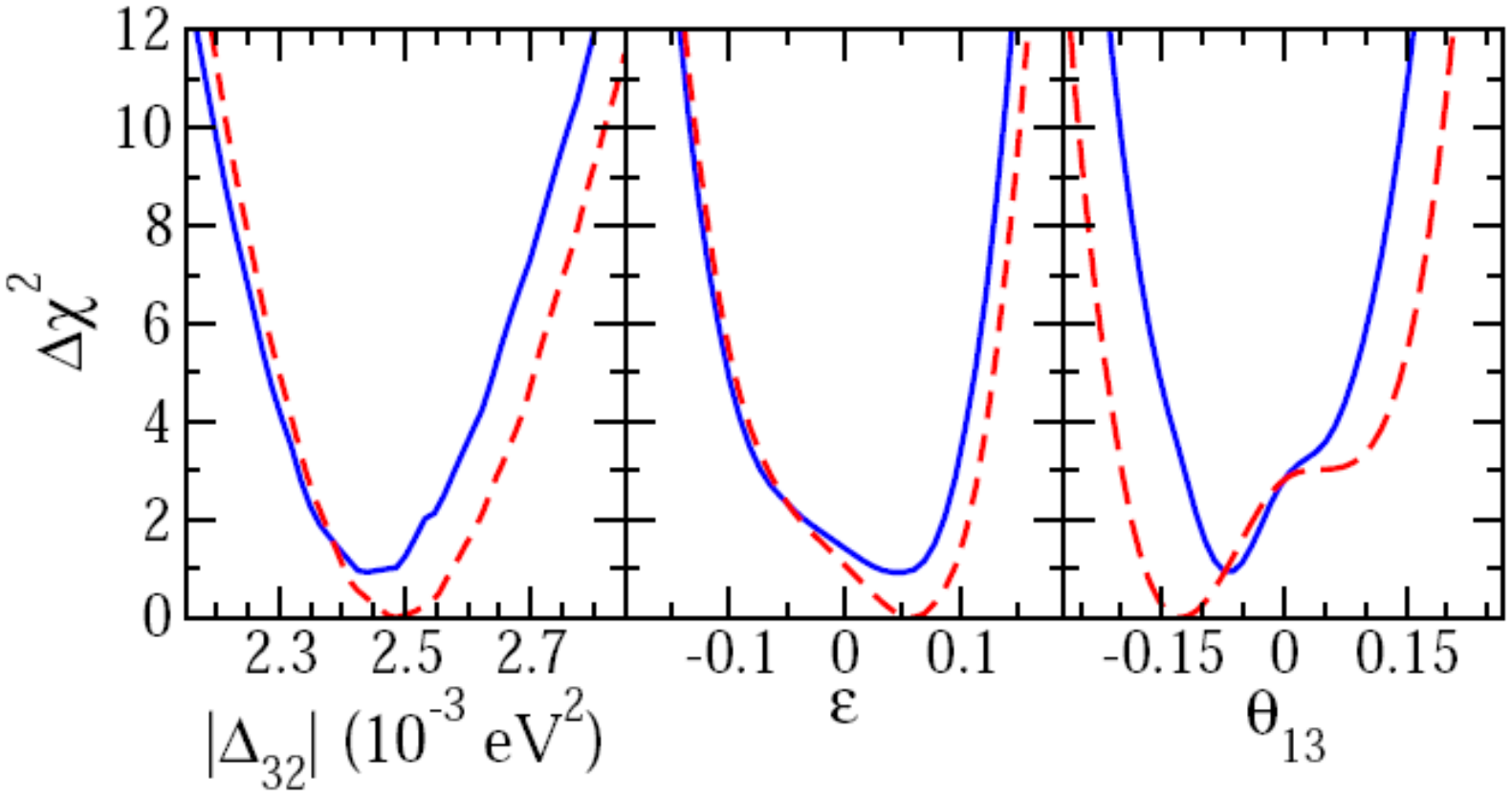
Fogli, Lisi, Marrone, Palazzo, hep-ph/0506083



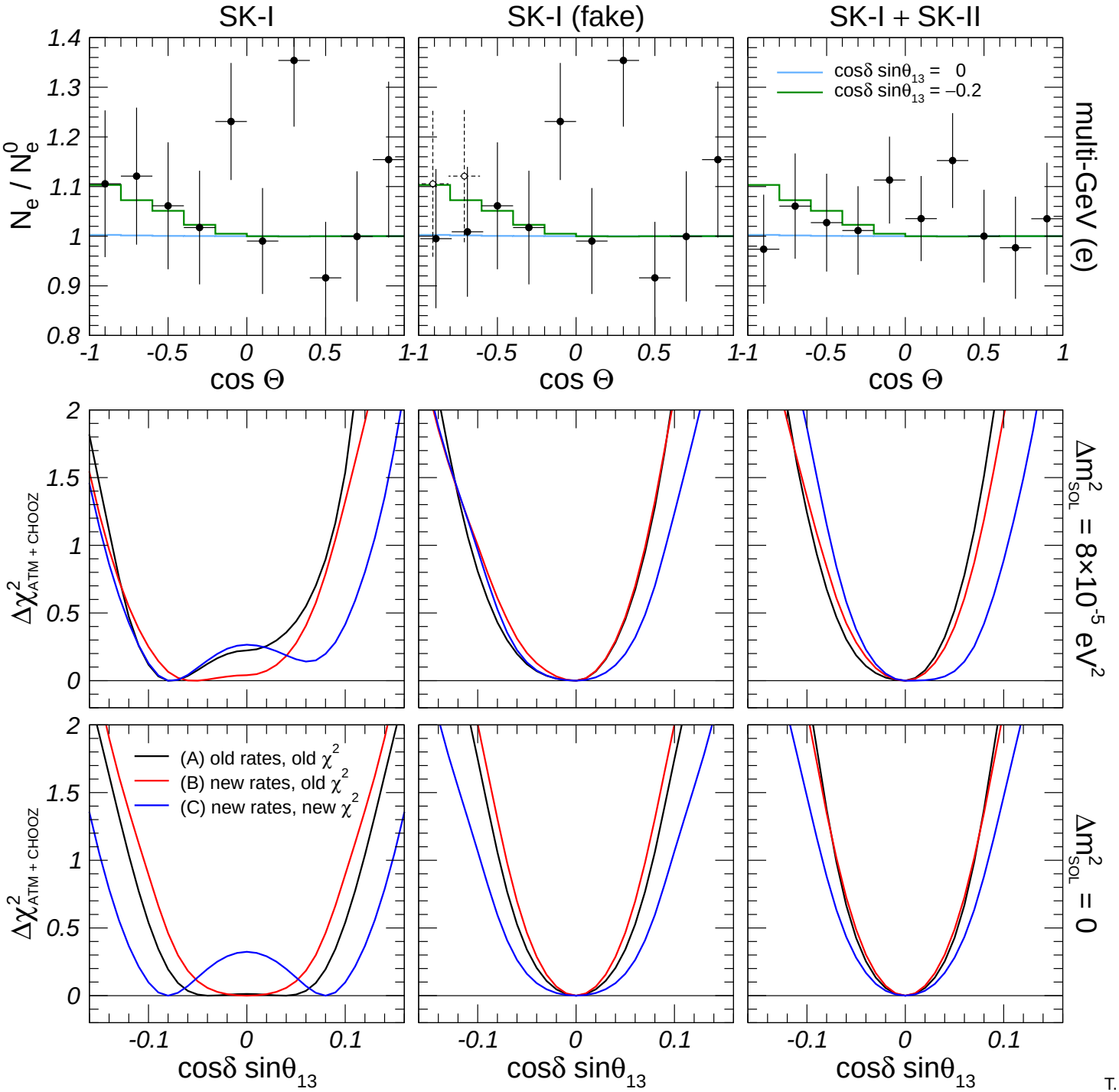
SK-I data: best fit $\sin^2\theta_{13} \approx 0.01$ ($\theta_{13} > 0$ at 0.9σ)

Hint from atmospheric data?

Escamilla-Roa, Latimer, Ernst, 0904.3930, 1005.4651

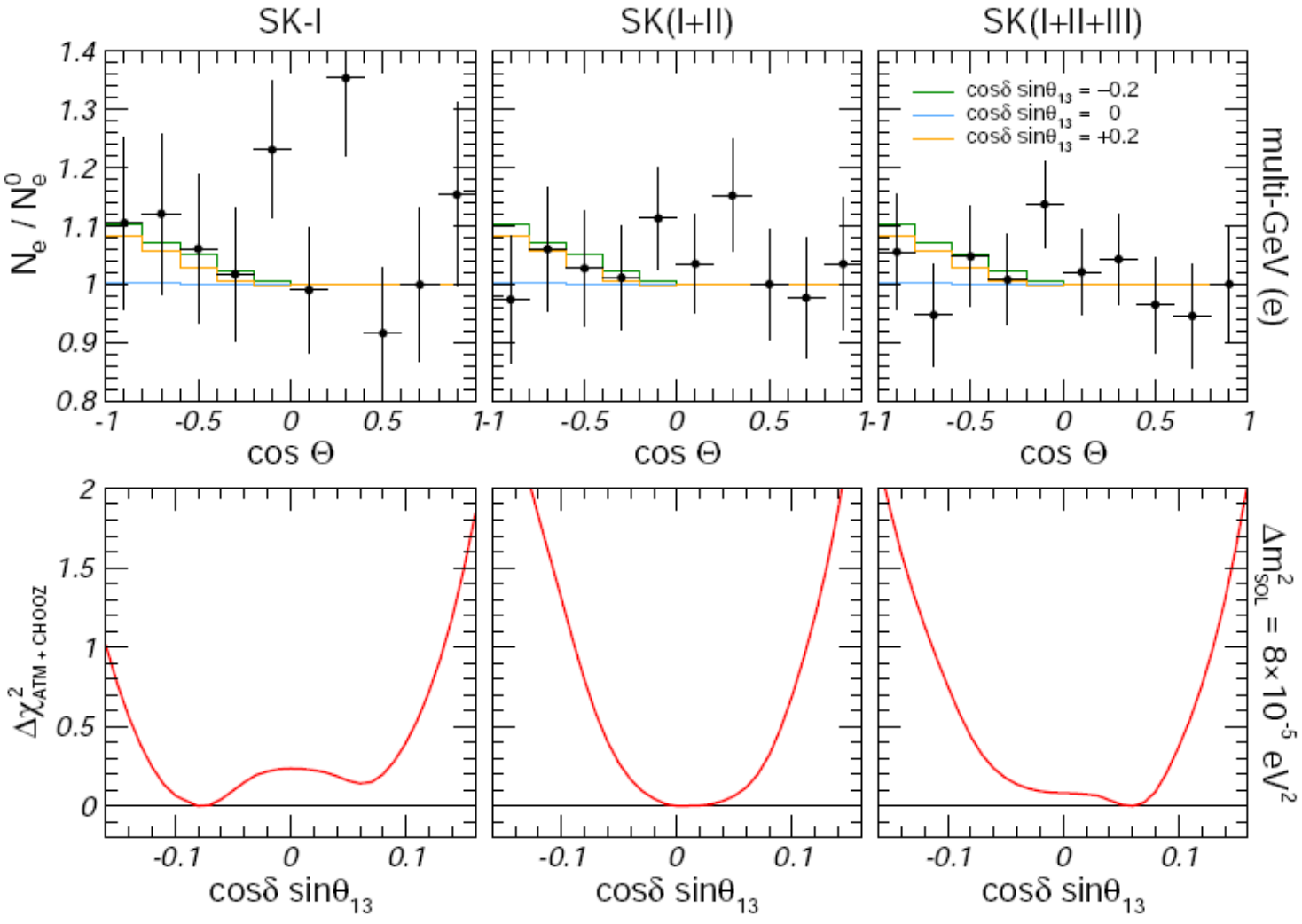


SK-I data: $\theta_{13} > 0$ at 1.4σ (NH, blue) or 1.7σ (IH, red)



Maltoni, TS
0812.3161

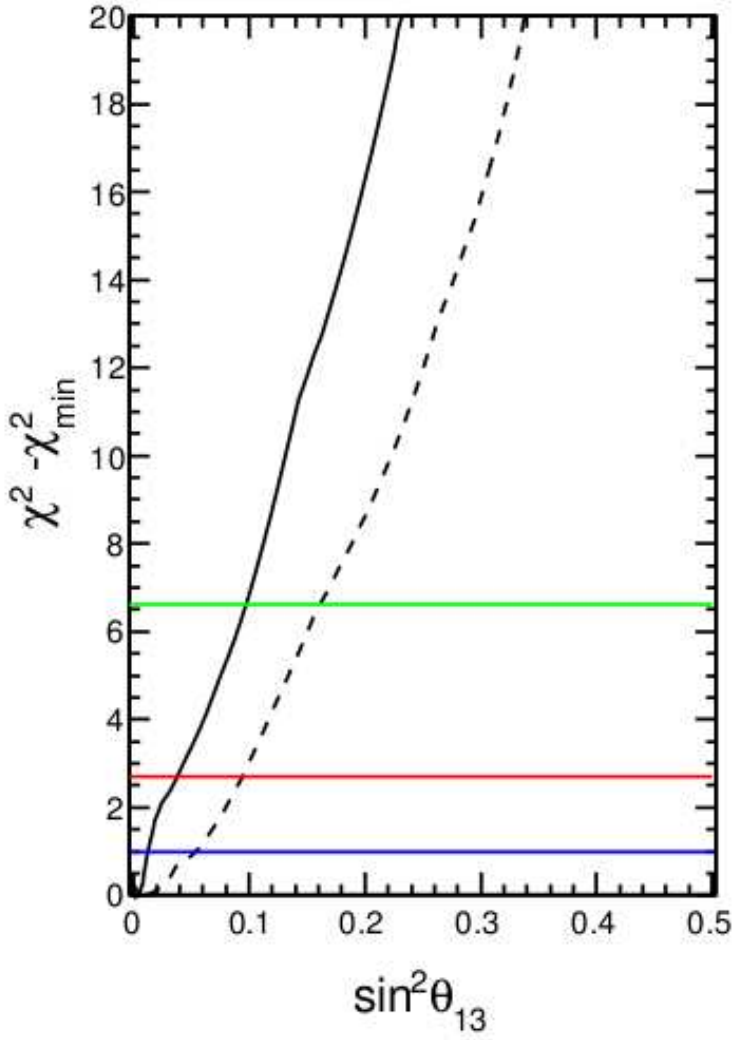
Hint from atmospheric data?



Gonzalez-Garcia, Maltoni, Salvado, 1001.4524

Hint from atmospheric data?

Recent paper from SuperK: Wendell et al., 1002.3471

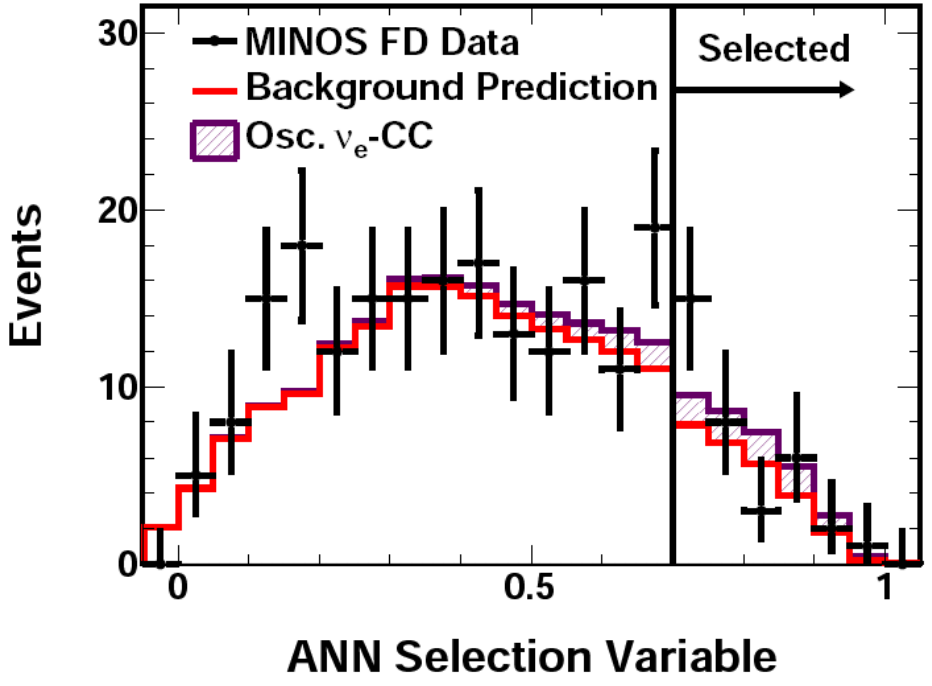


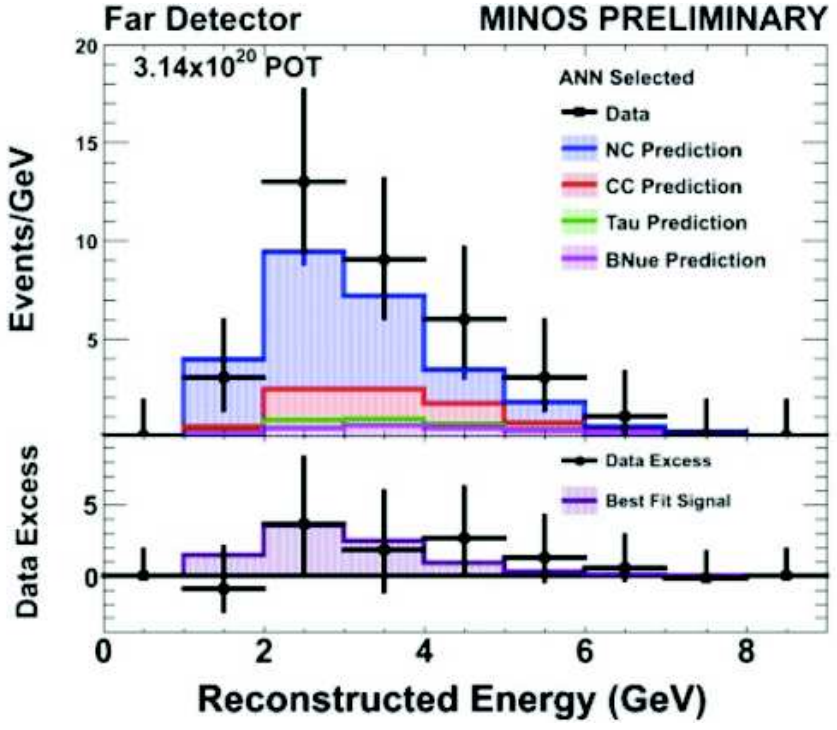
Analysis of
SK I+II+III data:
no hint for θ_{13}

in the approximation
$\Delta m^2_{21} = 0$

MINOS search for ν_e appearance

MINOS $\nu_\mu \rightarrow \nu_e$ appearance data, 3.14×10^{20} POT
obs.: 35 events, expected bckg: $27 \pm 5 \pm 2$ (1.5σ)

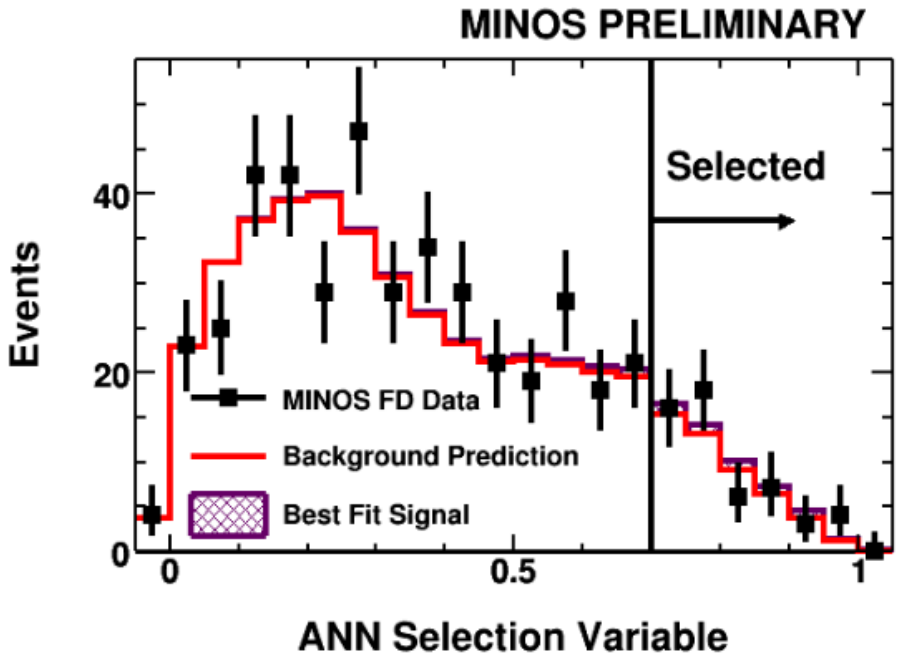


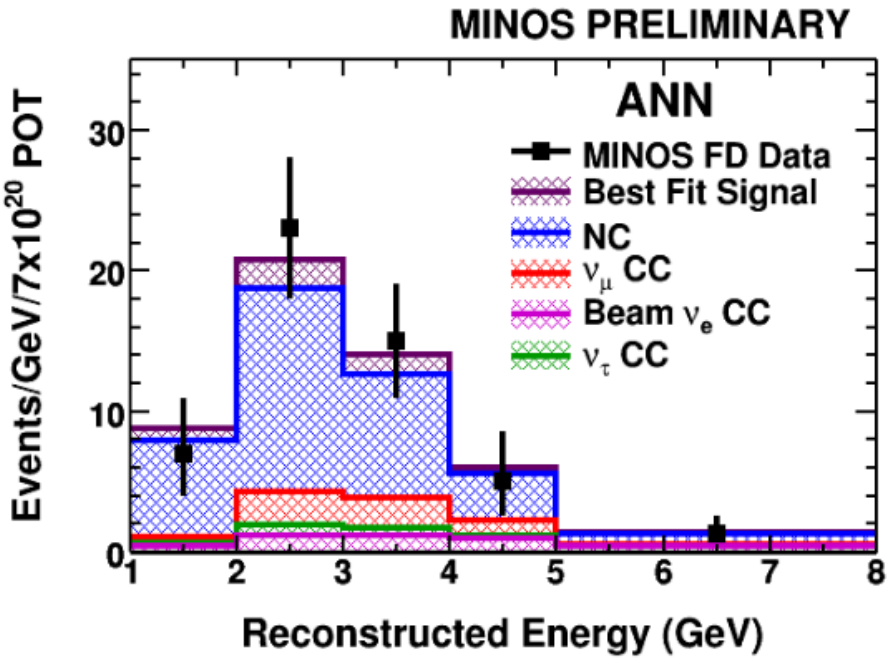


MINOS Coll, arXiv:0909.4996

MINOS search for ν_e appearance

MINOS $\nu_\mu \rightarrow \nu_e$ appearance data, 7×10^{20} POT
obs.: 54 events, expected bckg: $49.1 \pm 7.0 \pm 2.7$ (0.7σ)





R. Patterson, FNAL seminar, 9 April 2010

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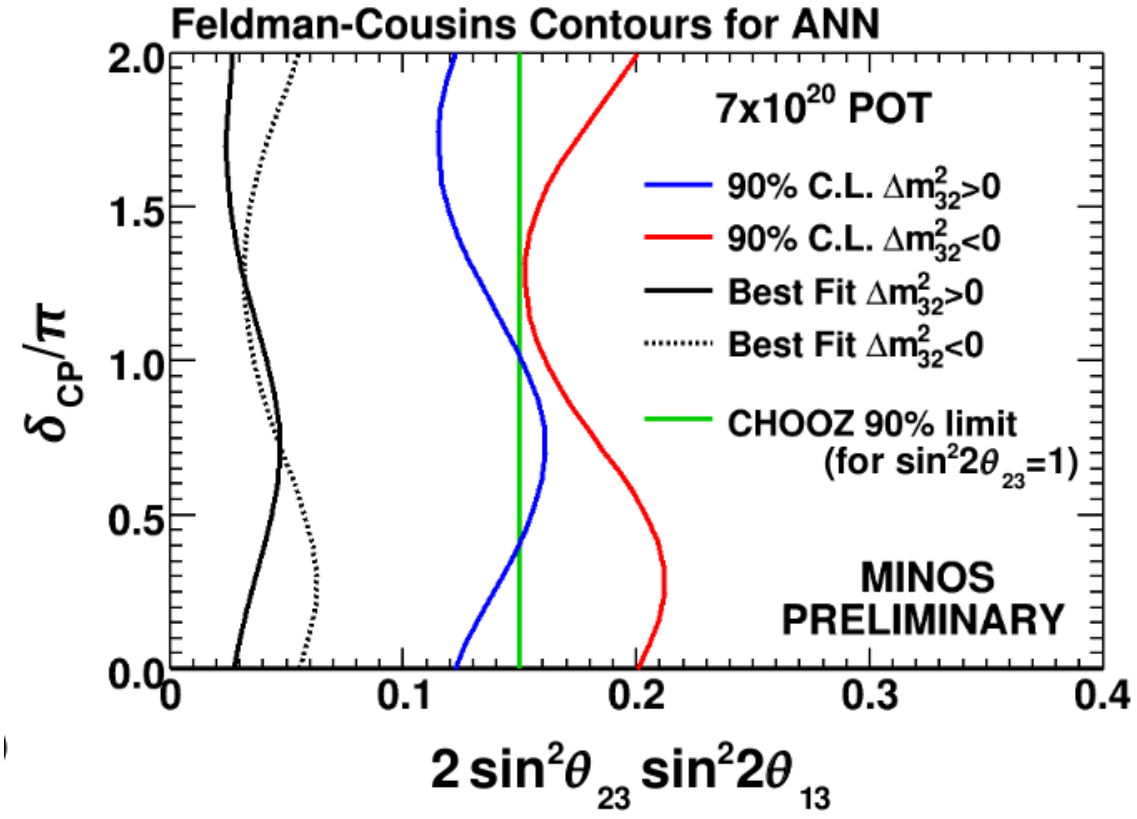
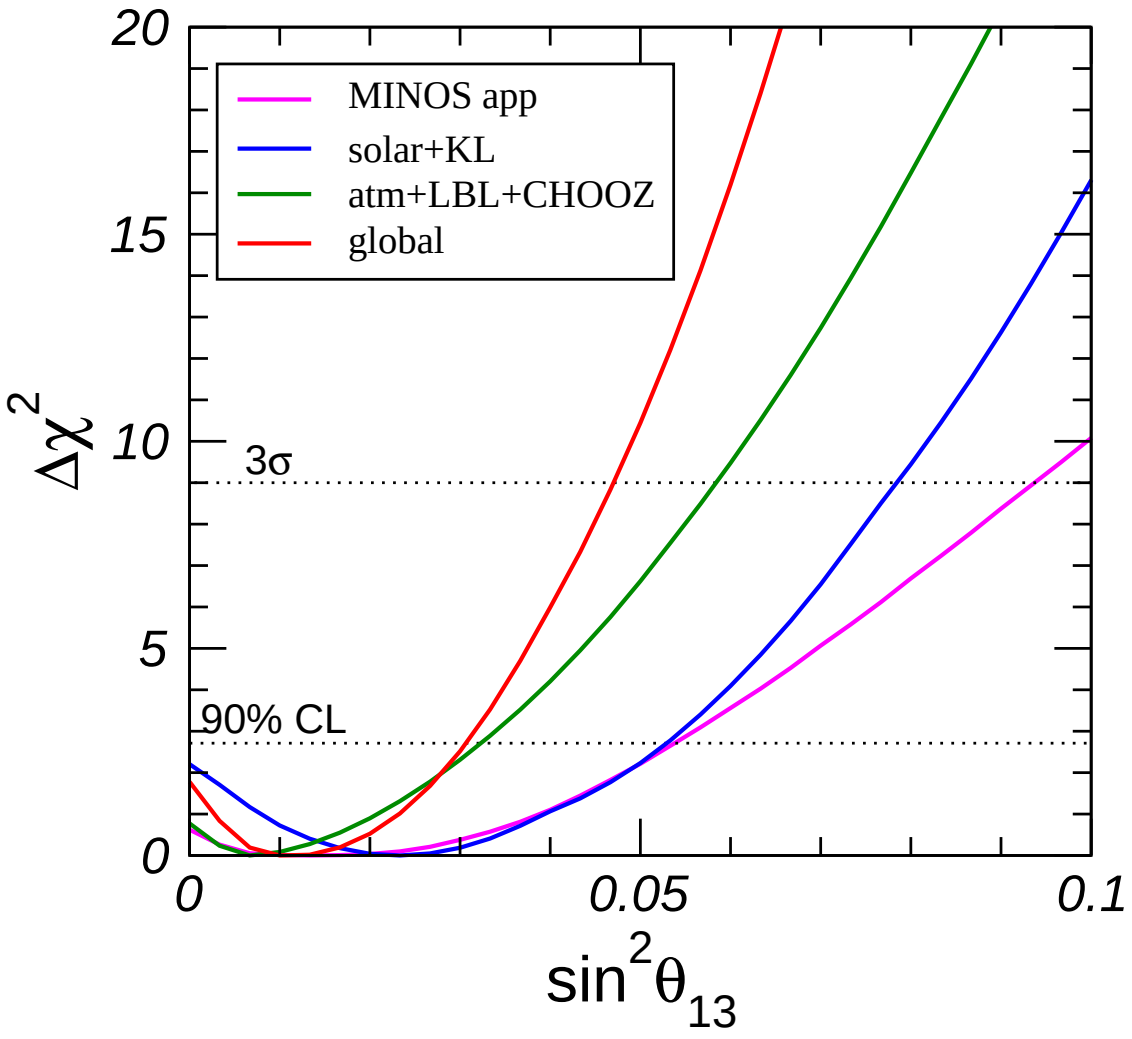


R. Patterson, FNAL seminar, 9 April 2010

Hint from global data



Hint from global data

reference	best-fit and 1σ errors	significance
Fogli et al. [84]	$\sin^2\theta_{13} = 0.02 \pm 0.01$	2σ
Gonzalez-Garcia et al. [18] (GS98)	$\sin^2\theta_{13} = 0.0095^{+0.013}_{-0.007}$	1.3σ
Gonzalez-Garcia et al. [18] (AGSS09)	$\sin^2\theta_{13} = 0.008^{+0.012}_{-0.007}$	1.1σ
Schwetz et al. [14] (GS98)	$\sin^2\theta_{13} = 0.013^{+0.013}_{-0.010}$	1.5σ
Schwetz et al. [14] (AGSS09)	$\sin^2\theta_{13} = 0.010^{+0.013}_{-0.008}$	1.3σ

[84] Fogli, Lisi, Marrone, Palazzo, Rotunno, arxiv:0905.3549 (MINOS 2010 not yet incl.)
[18] Gonzalez-Garcia, Maltoni, Salvado, 1001.4524
[14] TS, Tortola, Valle, 0808.2016 (updated 2010)

Upcoming oscillation experiments and the race for θ_{13}

Measuring θ_{13} at reactors

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

$\Rightarrow$ bring stat. and syst. errors below % level:

- make the experiment "big":

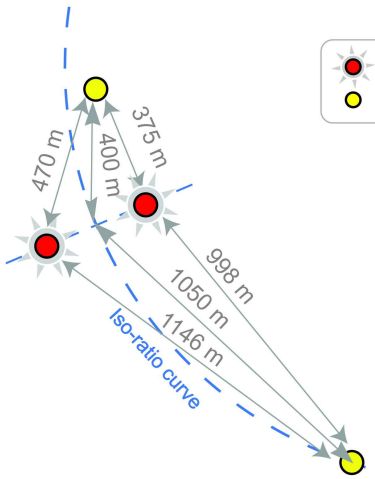
  $\sigma_{\rm stat} \approx 1/\sqrt{N} = 0.5\% \quad \Rightarrow \quad N \approx 40\,000$

  $$N \simeq 23\,000 \, (L/{\rm km})^{-2} {\rm yr}^{-1} \, {\rm GW}_{\rm th}^{-1} \, (100\,{\rm t})^{-1}$$

- careful design to reduce systematics
  near/far comparison

Upcoming reactor experiments

D-Chooz



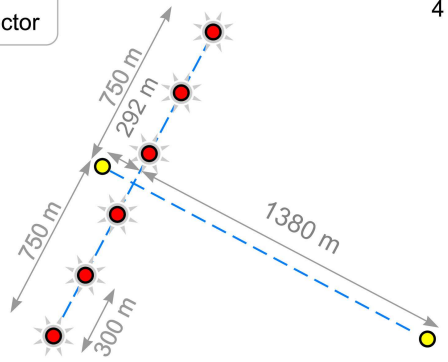
Double Chooz

$P = 8.6\,\mathrm{GW_{th}}$

$M = 8.3\,\mathrm{t}$

$N = 1.5 \times 10^4$

RENO



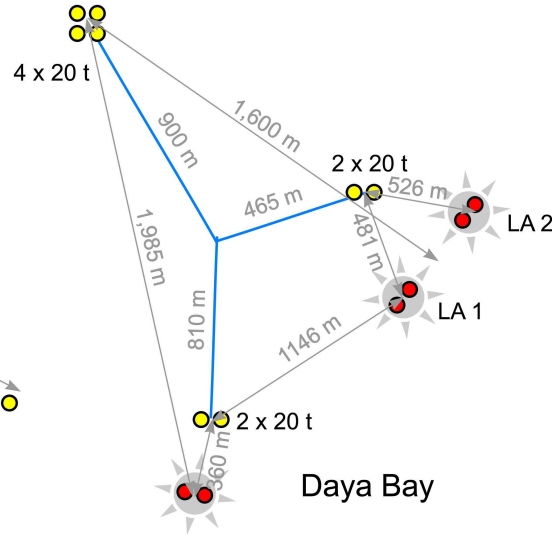
RENO

$P = 16.4\,\mathrm{GW_{th}}$

$M = 15.4\,\mathrm{t}$

$N = 3 \times 10^4$

Daya Bay



Daya Bay

$P = 17.4\,\mathrm{GW_{th}}$

$M = 80\,\mathrm{t}$

$N = 10^5$

M . . . far detector mass

N . . . # events in far detector per year

Measuring θ_{13} at beams by $\nu_\mu \longrightarrow \nu_e$

- search for a ν_e signal on top of background
  (intrinsic ν_e beam contamination, NC & ν_μ-CC mis-ID)

$$\frac{S}{\sqrt{B + \sigma_{\rm bg}^2 B^2}}$$

Measuring θ_{13} at beams by $\nu_\mu \longrightarrow \nu_e$

- search for a ν_e signal on top of background
  (intrinsic ν_e beam contamination, NC & ν_μ-CC mis-ID)

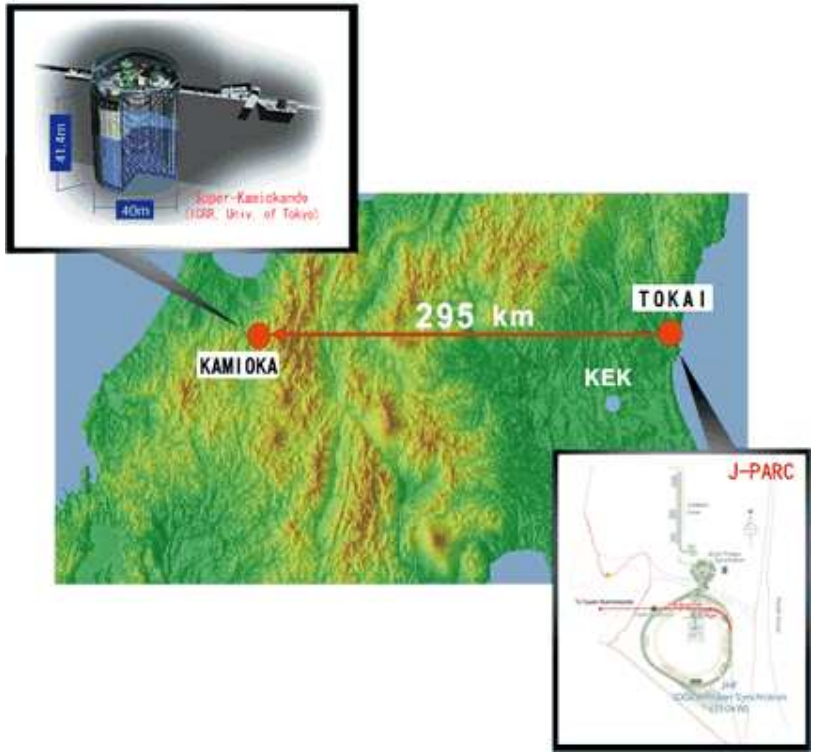
$$\frac{S}{\sqrt{B + \sigma_{\rm bg}^2 B^2}}$$

- $P_{\mu e}$ is a complicated function of all 3-flavour parameters

  θ_{13} is correlated with other parameters (CP-phase δ, sign of Δm^2_{31})

Upcoming superbeam experiments

T2K

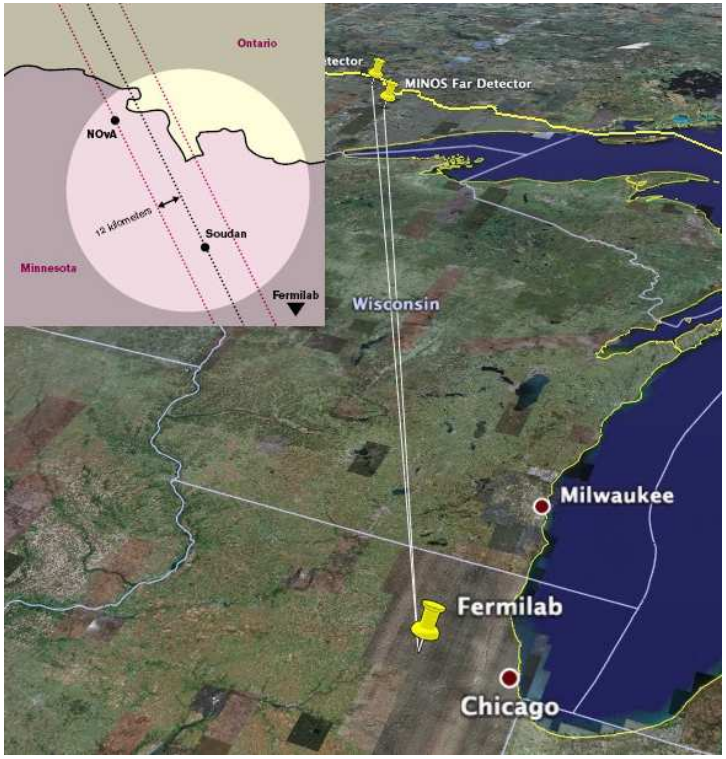


$$P = 0.75\,\mathrm{MW}$$

$$L = 295\,\mathrm{km}$$

SuperK WC, $M = 22.5\,\mathrm{kt}$

NOνA

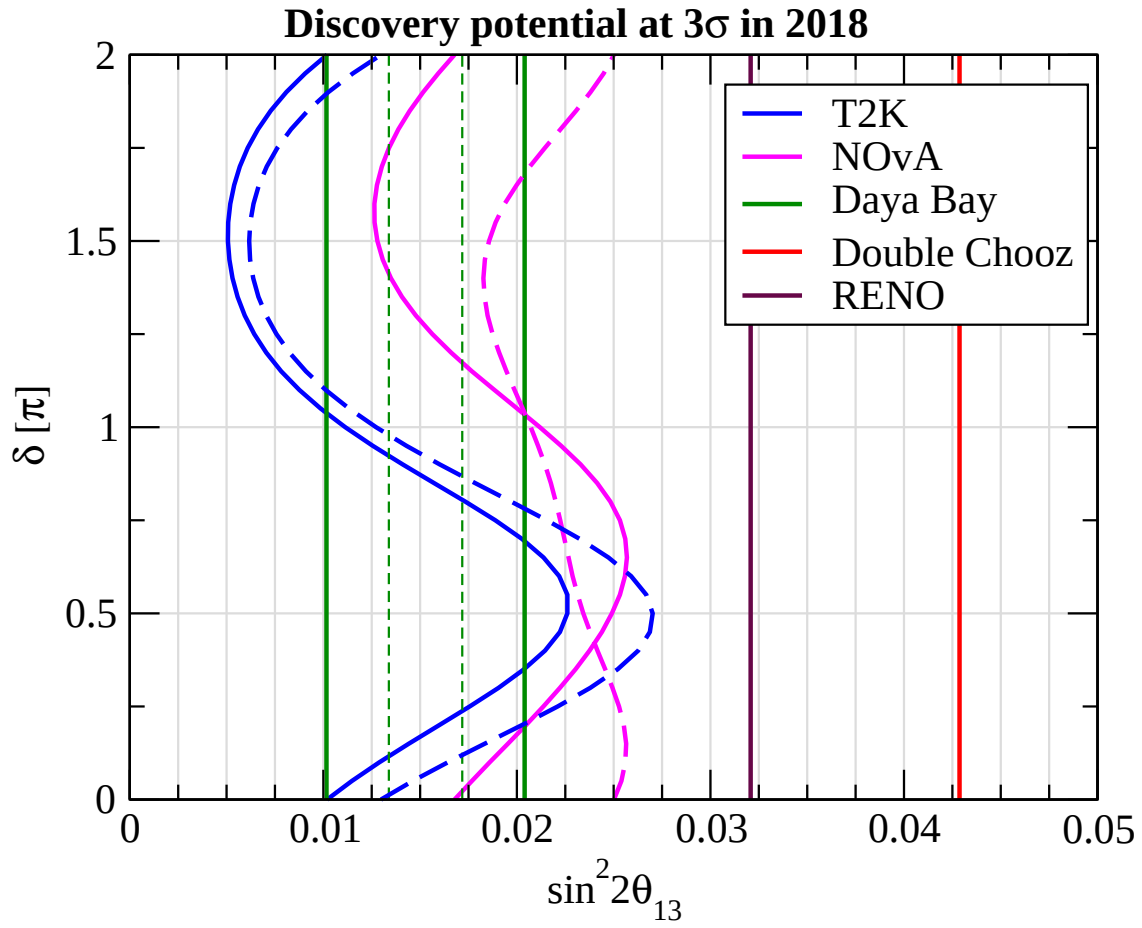


$$P = 0.7\,\mathrm{MW}$$

$$L = 812\,\mathrm{km}$$

TASD, $M = 15\,\mathrm{kt}$

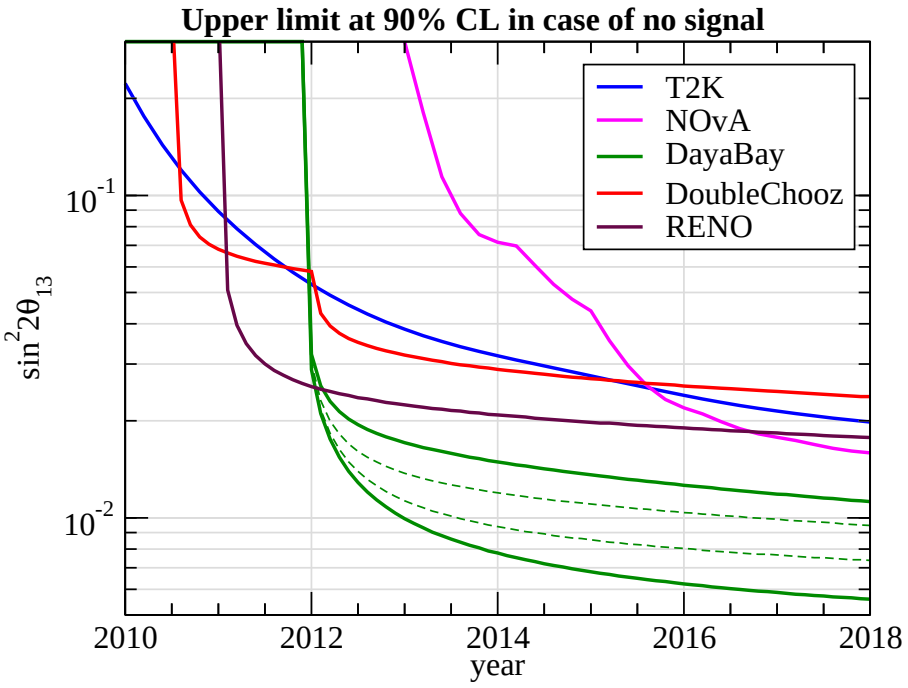
Prospects for θ_{13}

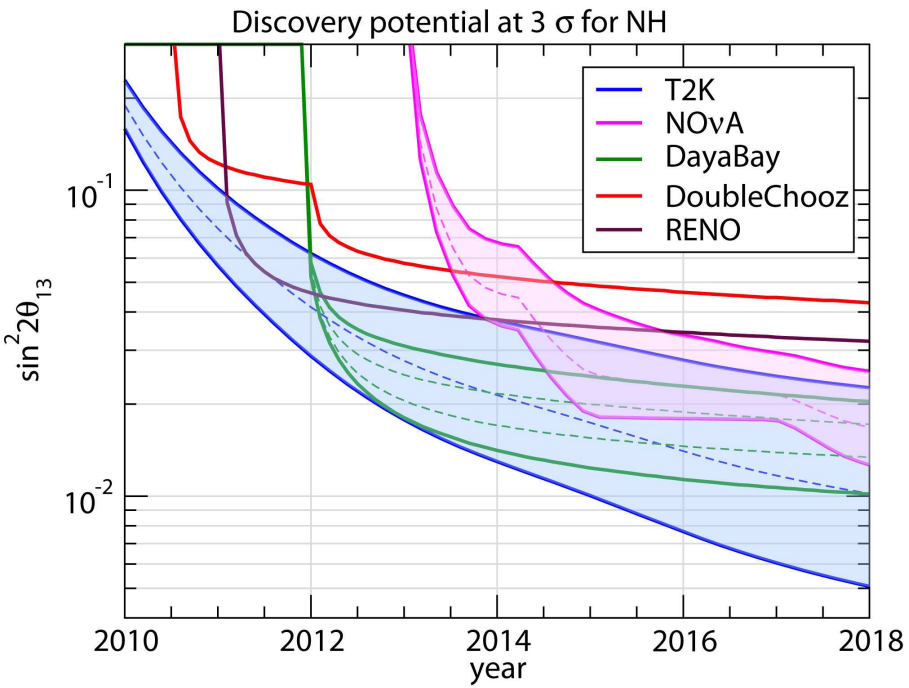


solid (dashed): NH (IH)

DayaBay: $\sigma_{\rm syst} = 0.6\%$ corr, 0.38% corr, 0.38% uncorr, 0.18% uncorr

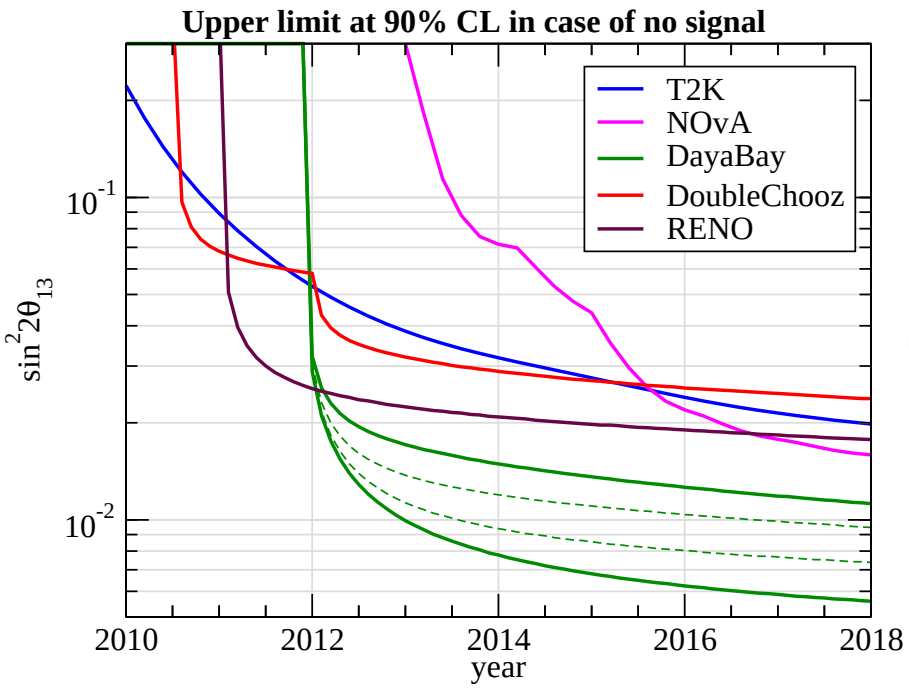
Prospects for θ_{13}

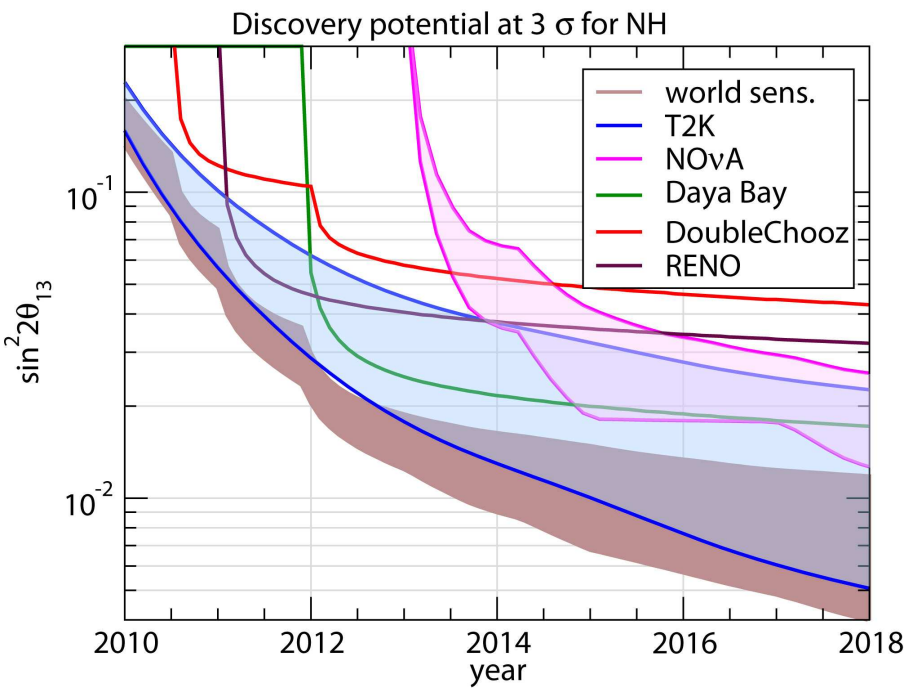




Mezzetto, TS, 1003.5800; Huber, Lindner, TS, Winter, 0907.1896

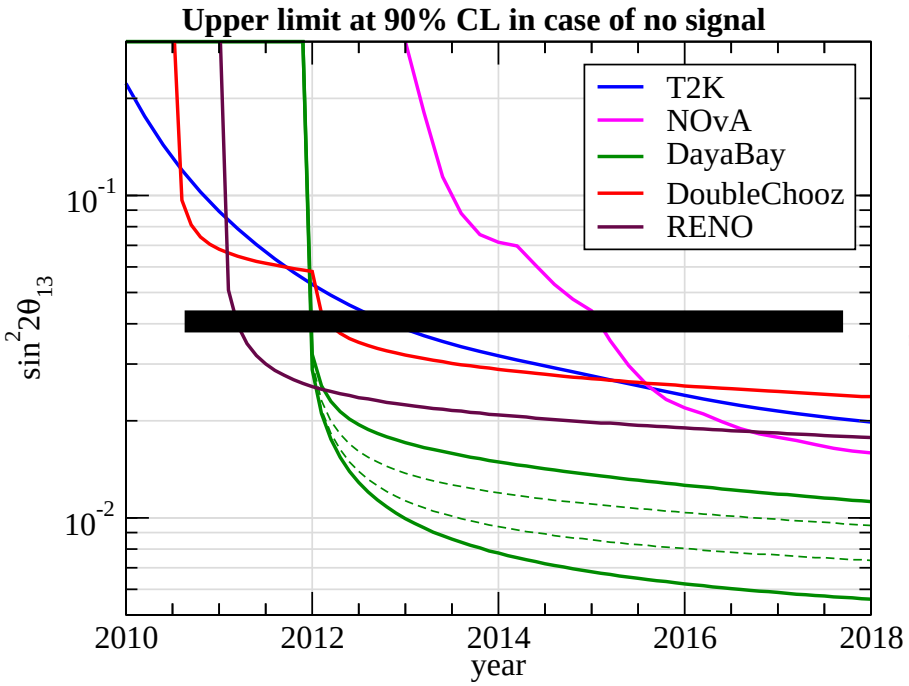
Prospects for θ_{13}

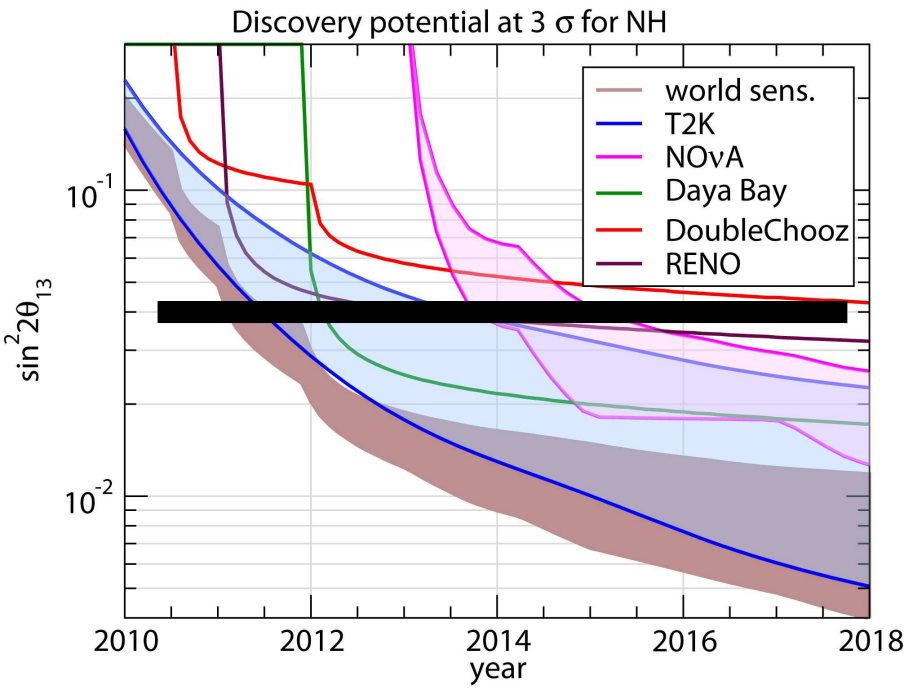




Mezzetto, TS, 1003.5800; Huber, Lindner, TS, Winter, 0907.1896

Prospects for θ_{13}

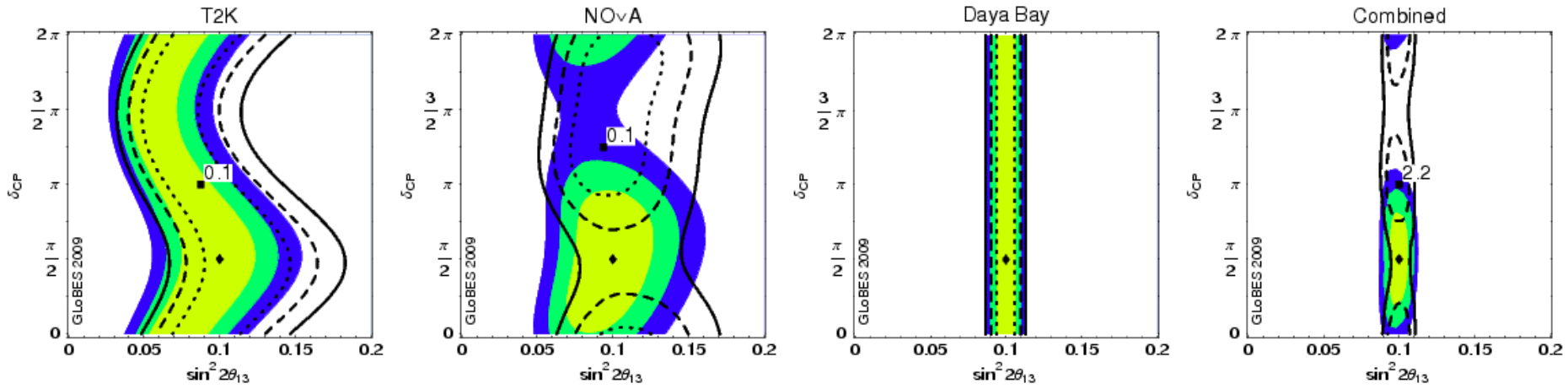




Mezzetto, TS, 1003.5800; Huber, Lindner, TS, Winter, 0907.1896

"hint": $\sin^2 \theta_{13} = 0.01$

Assume “large” θ_{13}: can we measure CPV and the mass hierarchy with the upcoming generation of experiments?

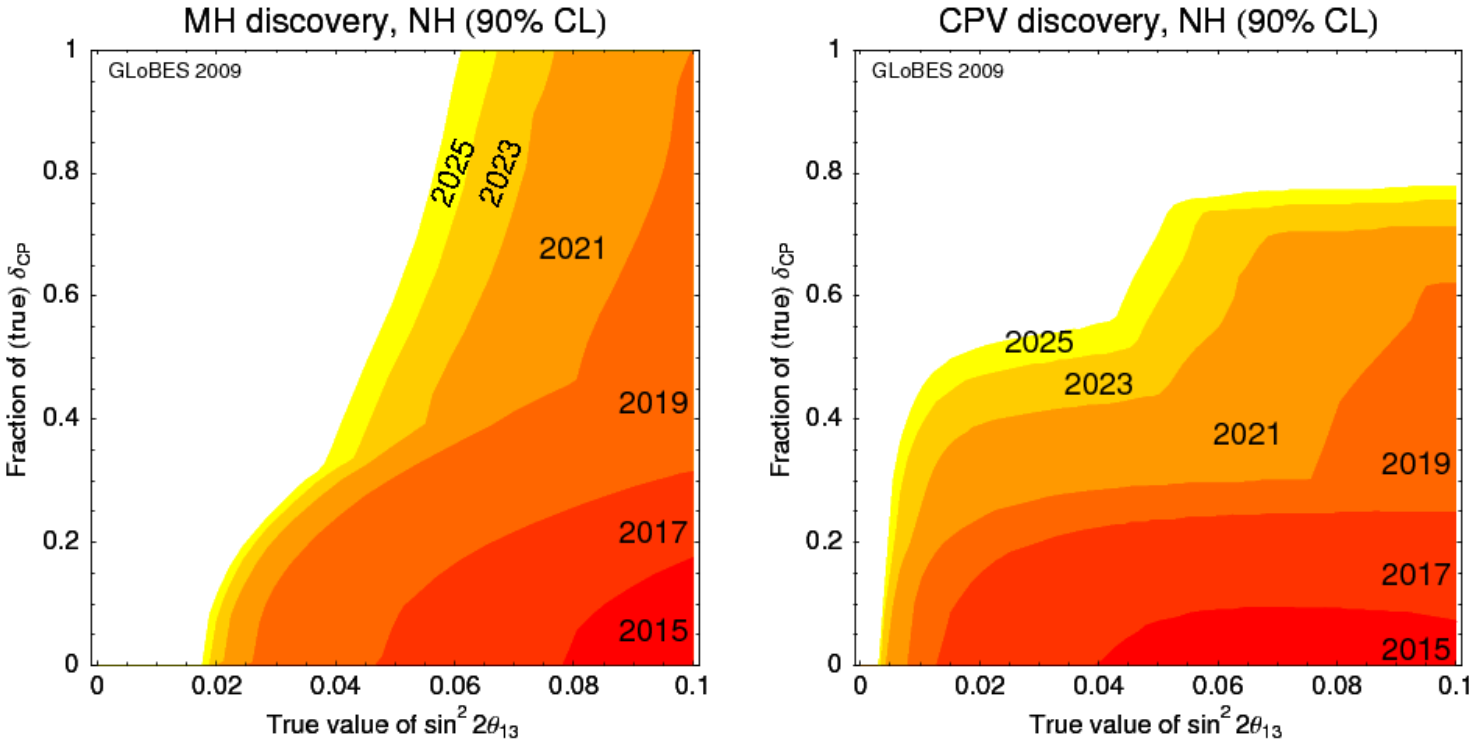


Assume “large” θ_{13}: can we measure CPV and the mass hierarchy with the upcoming generation of experiments?

toy scenario:

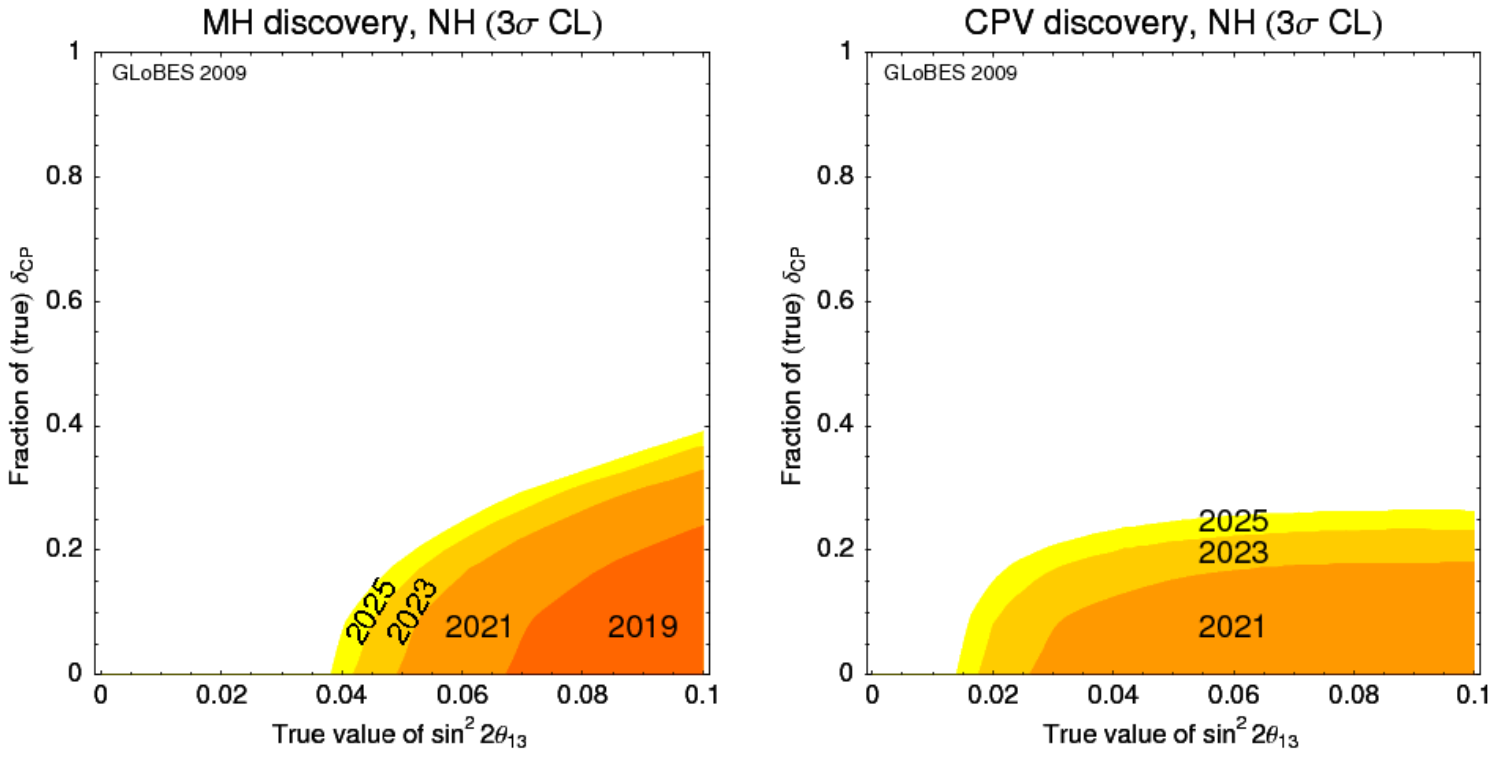
- **T2K**: proton driver @ 2015: beam power $0.75 \rightarrow 1.66\,\mathrm{MW}$
- **NOνA**: project X @ 2018: beam power $0.7 \rightarrow 2.3\,\mathrm{MW}$
- combined data from **T2K**, **NOνA**, **Daya Bay**
- fully optimized $\nu/\bar{\nu}$ switching between **T2K** and **NOνA**

MH & CPV with T2K & NOvA & DayaB



Huber, Lindner, TS, Winter, 0907.1896

MH & CPV with T2K & NOvA & DayaB



Huber, Lindner, TS, Winter, 0907.1896

Conclusions

Conclusions

- Hints for a finite θ_{13} in the global fit are at the 1σ level, driven by solar+KamLAND data (some dependence on solar model)
- Hints from SK-I atmospheric data are fragile and seem not to persist in SK-II and SK-III data.
- An initial hint from MINOS appearance data is now below 1σ
- Within next few years there is good prospect to explore the

$$\sin^2 2\theta_{13} \gtrsim 0.01 \qquad (\sin^2 \theta_{13} \gtrsim 0.0025)$$

range.