Impact of systematic errors on precision at future long baseline experiments

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The leptonic mixing matrix

Pontecorvo, 1957

Maki, Nakagawa, Sakata, 1962

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

Atmospheric Interference Solar

$$\sin^2\theta_{23} = 0.52^{+0.06}_{-0.07}$$

$$\Delta m^2_{31} = \begin{matrix} 2.50^{+0.09}_{-0.16} \\ -(2.40^{+0.08}_{-0.09}) \end{matrix} \times 10^{-3}\mathrm{eV}^2$$

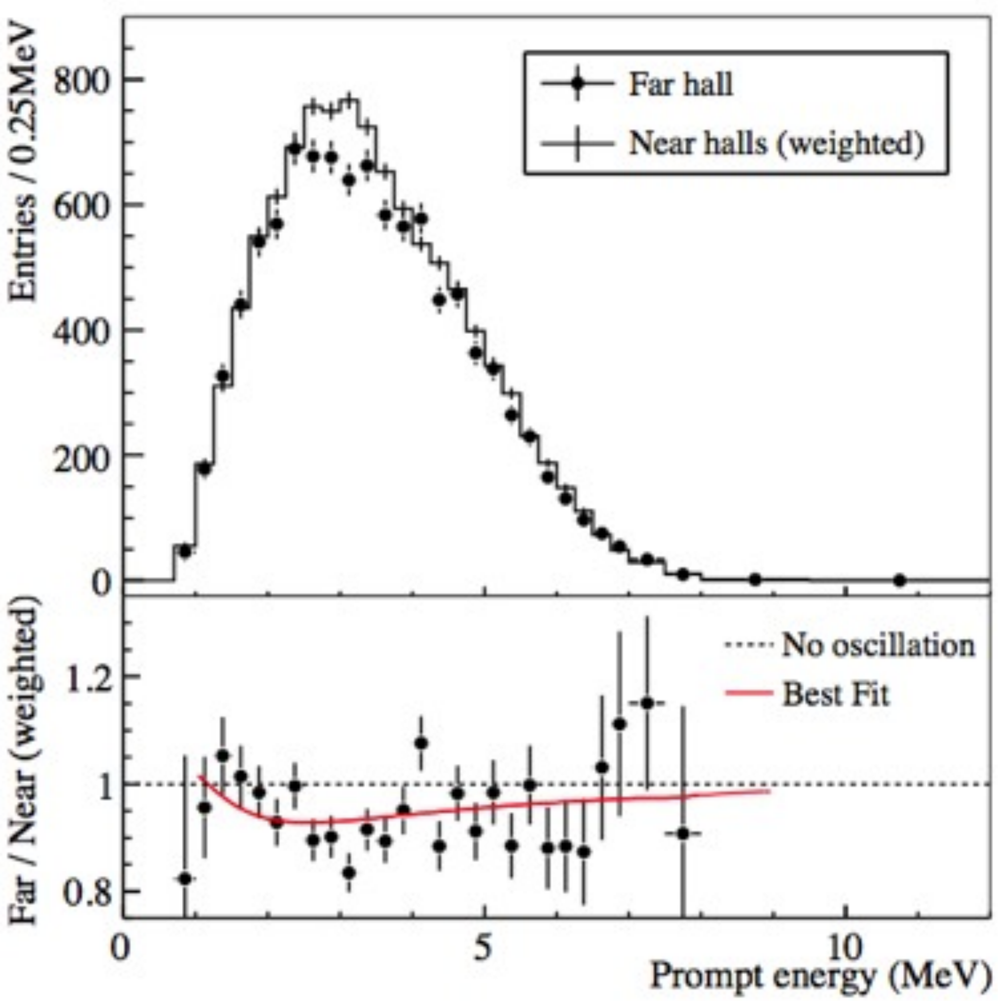
$$\sin^2\theta_{12} = 0.312^{+0.017}_{-0.015}$$

$$\Delta m^2_{12} = (7.59^{+0.20}_{-0.18}) \times 10^{-5}\,\mathrm{eV}^2$$

Schwetz, Tortola, Valle, 1108.1376 [hep-ph]

Results on θ_{13}

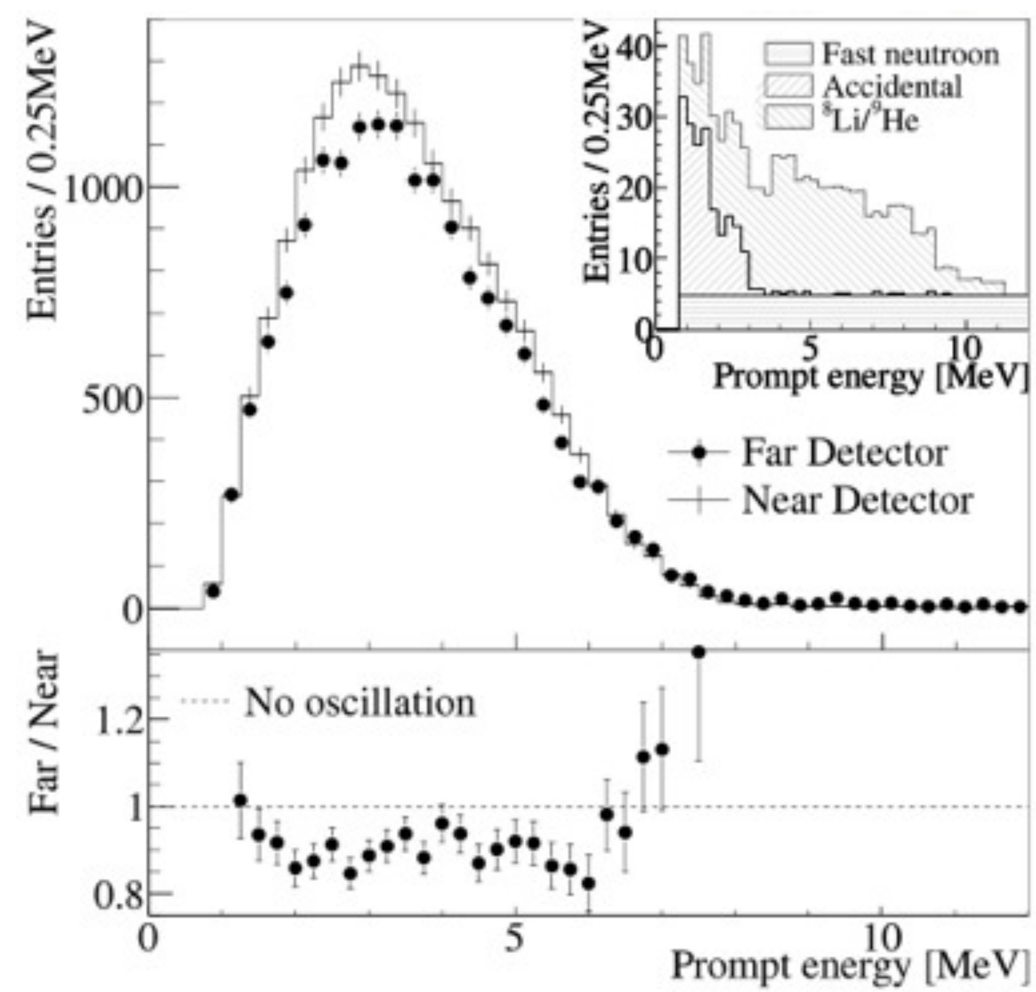
Daya Bay (5.2 σ)



$$\sin^2 2\theta_{13} = 0.092 \pm 0.016 \pm 0.005$$

1203.1669 [hep-ex]

RENO (4.9 σ)



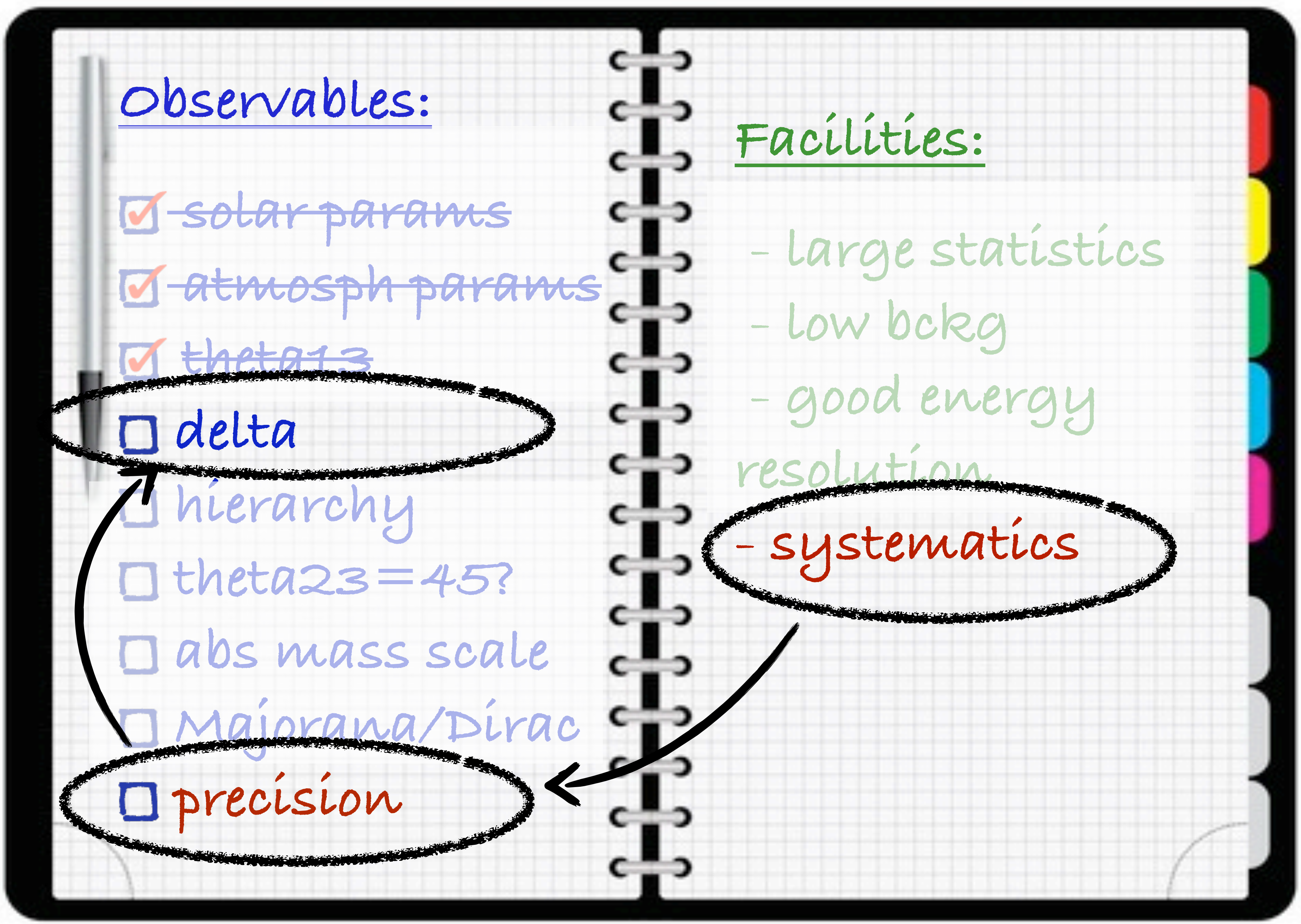
$$\sin^2 2\theta_{13} = 0.113 \pm 0.013 \pm 0.019$$

1204.0626 [hep-ex]

Plus a hint at 90% CL from Double Chooz, 1112.6353 [hep-ex]

Does this change anything?

Does this change anything?



Future oscillation facilities

- Super-Beams
  - Japan: T2HK
  - USA: NOvA, LBNE
  - Europe: LAGUNA-LBNO (C2P? SPL?)
- Beta-Beams
  - Low gamma ($\gamma \sim 100$)
  - High gamma ($\gamma \sim 350$ - 580)
- Neutrino Factories
  - High energy ($E_\mu = 25$ - 50 GeV)
  - Low energy ($E_\mu = 4.5$ - 10 GeV)

General landscape

BB100,BB350:
hep-ph/0406132
hep-ph/0503021

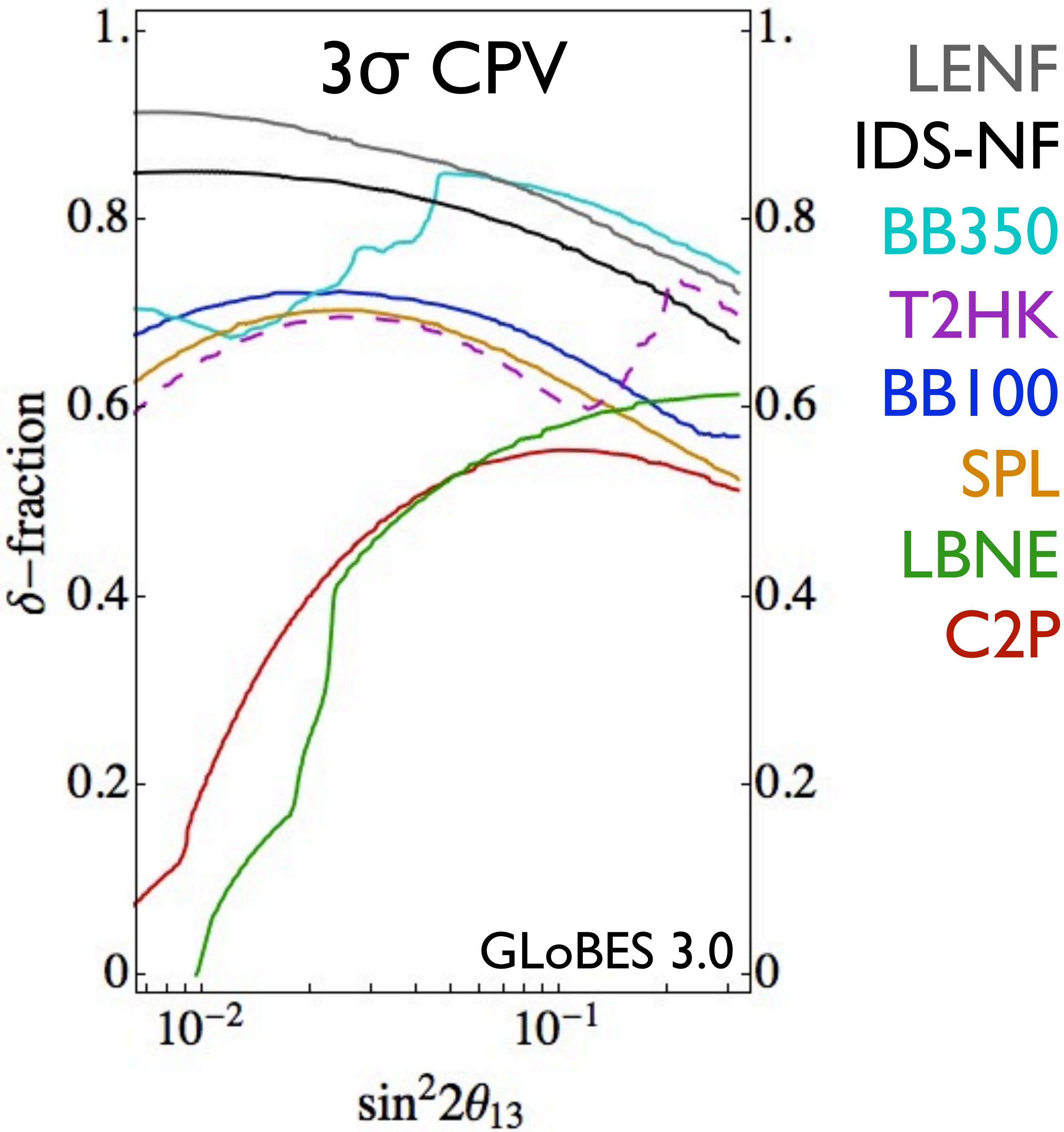
T2HK: hep-ex/0106019

C2P, SPL:
1001.0077 [physics.ins-det]
hep-ex/0411062
1106.1096 [physics.acc-ph]

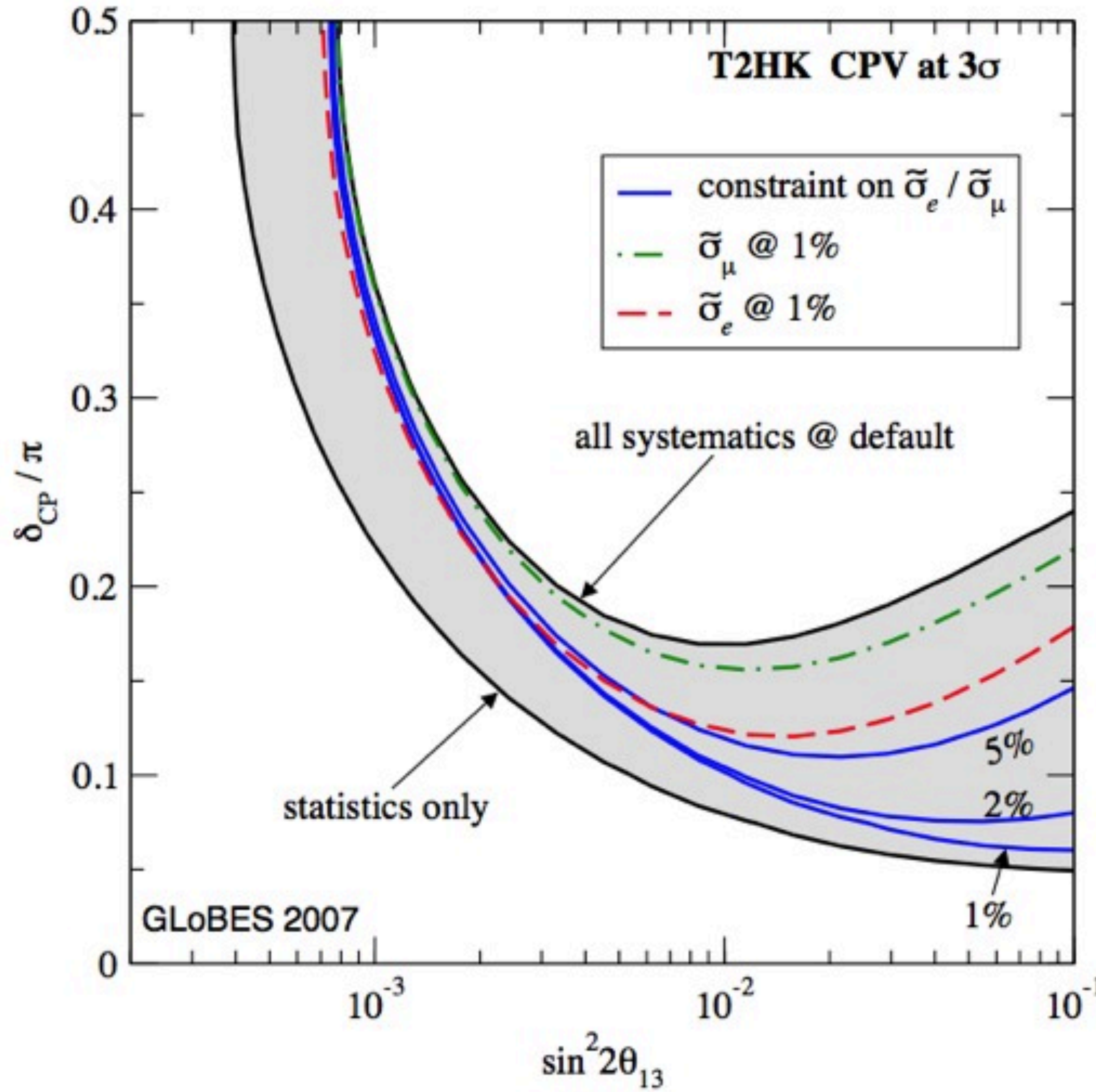
LENF: 1012.1872 [hep-ph]

LBNE: 1110.6249 [hep-ex]

IDS: 1112.2853 [hep-ex]

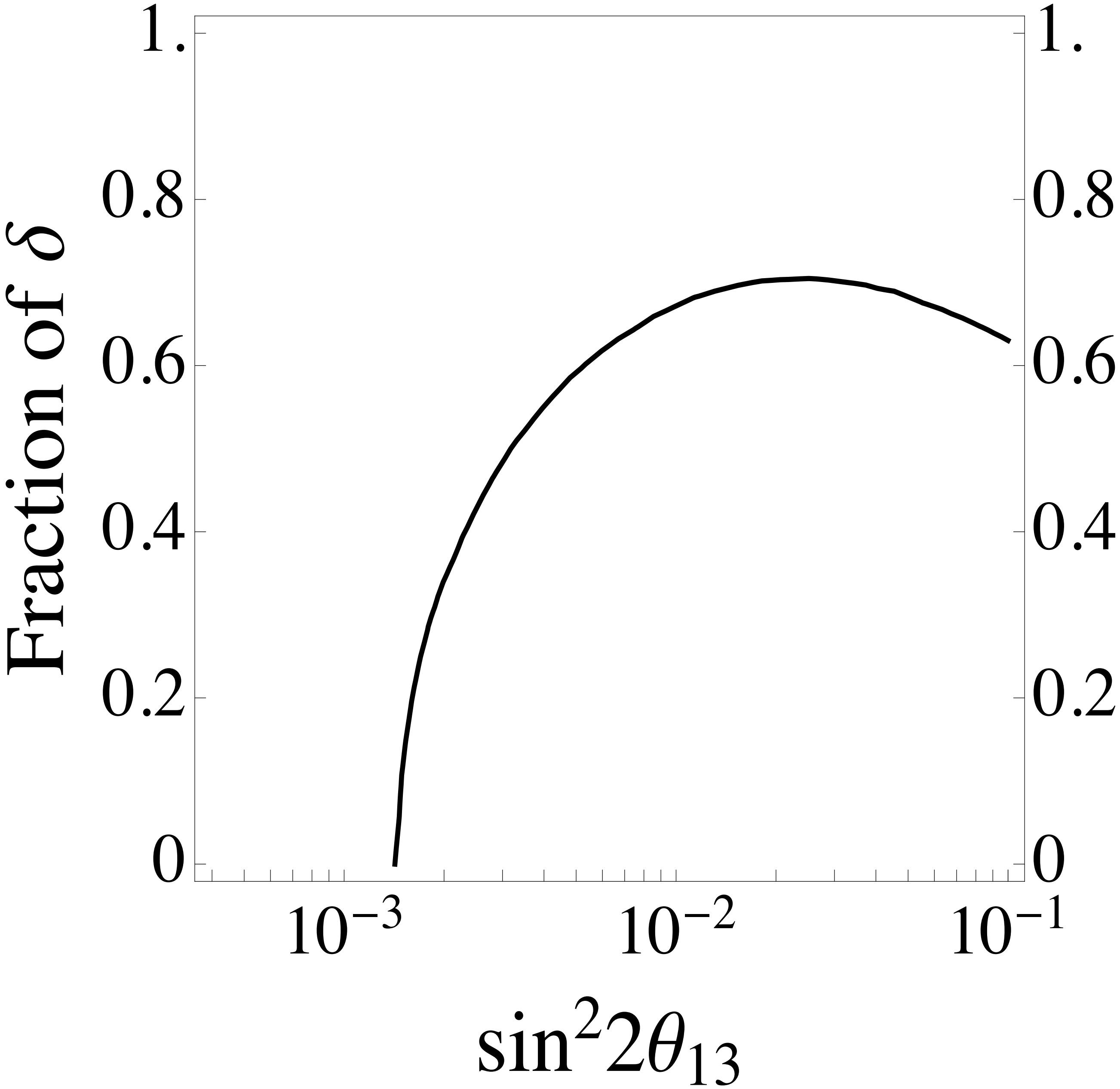


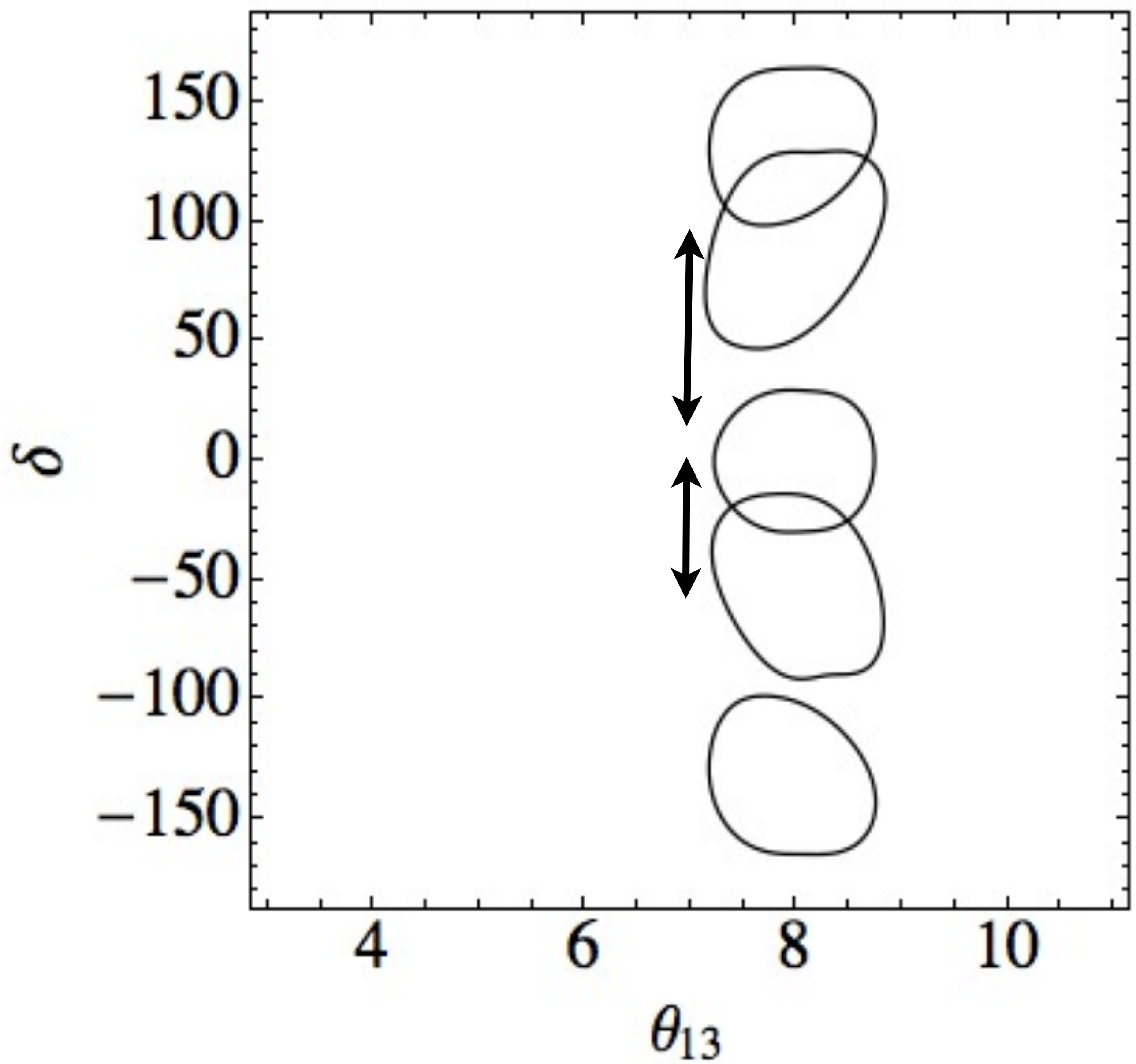
The impact of systematics



Huber, Mezzetto, Schwetz, 0711.2950 [hep-ph]

Discovery vs precision





Precision

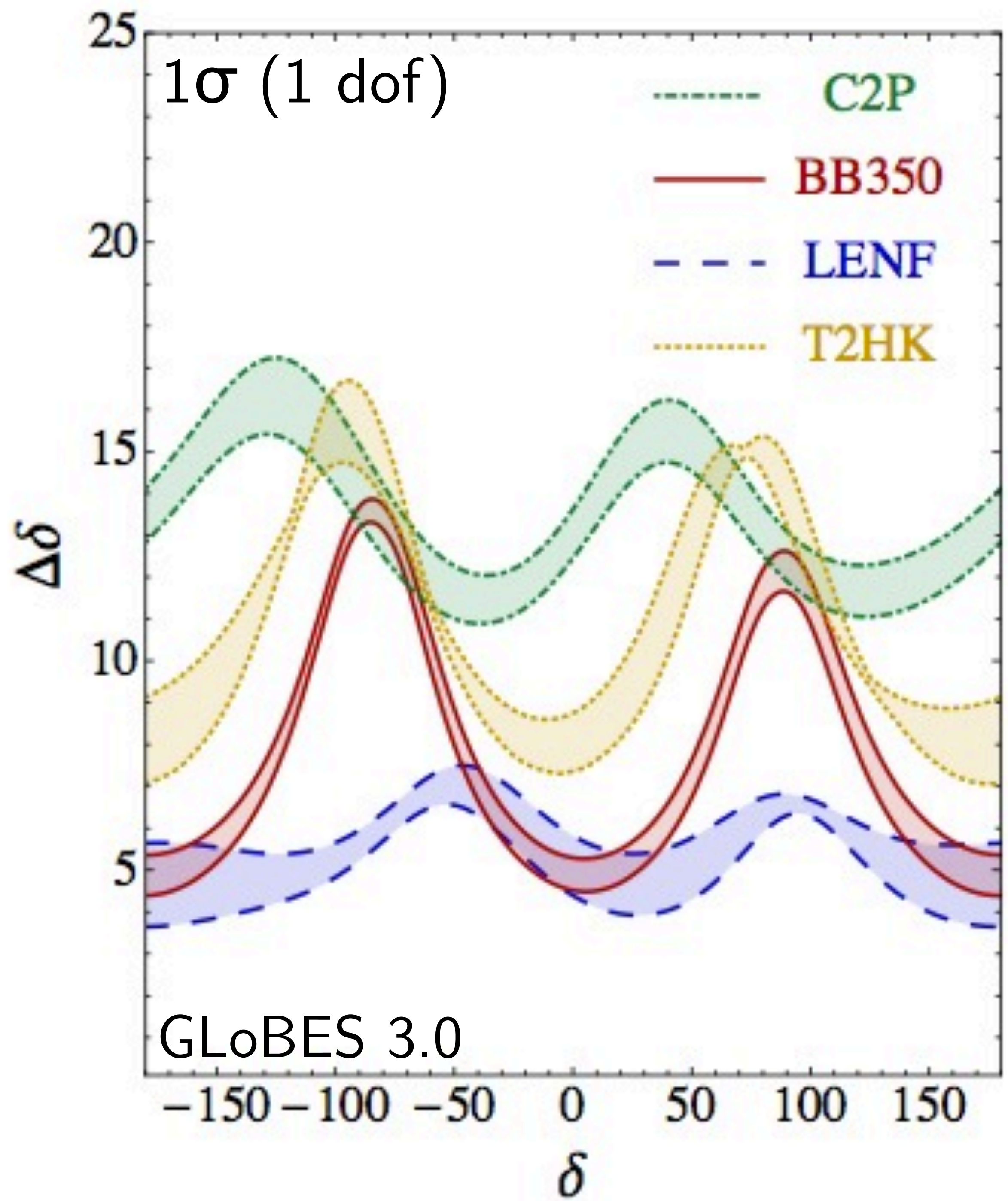
T2HK: 4 MW, 500 kton WC, 295 km, 5% sys

C2P: 800 kW, 100 kton LAr, 2300 km, 5% sys

BB350: 1.1(2.8) x10^{18} ions, 500 kton WC, 650 km, 2.5% sys

LENF: 1.4x10^{21} μ decays 100 kton MIND, 2000 km, 2.5% sys

More in A. Donini's talk



Coloma, Donini, Fernández-Martínez, Hernández, 1203.5651 [hep-ph]

Systematics strike again…

The importance of a near detector

- Up to now, each facility has made its own assumptions about systematic uncertainties. Generally,
    - BB and NF are assumed to have low sys
    - SB are assumed to have high sys
- However, this may change if a near detector is included and correlations are considered carefully

    (For instance, if final flavour cross sections could be measured at the ND)

Simulation details

$$\chi^2 = \sum_{D,C,i} \frac{\left[(1+\xi_{D,C,i})N_{D,C,i} - \overline{N}_{D,C,i}\right]^2}{\overline{N}_{D,C,i}} + \sum_k \left(\frac{\xi_k}{\sigma_k}\right)^2$$

- GLoBES software used hep-ph/0407333, hep-ph/0701187
- Input values in agreement with best fits 1108.1376 [hep-ph]
- Marginalization over solar and atmospheric params performed assuming 1σ gaussian priors
- No degeneracies have been accounted for: atmospheric angle set to maximal, normal hierarchy
- $\sin^2 2\theta_{13} = 0.1$
- 1σ (1 dof) unless stated otherwise

Simulation details

	SB		BB		NF	
Systematics	Opt.	Cons.	Opt.	Cons.	Opt.	Cons.
Fiducial volume ND	0.2%	1%	0.2%	1%	0.2%	1%
Fiducial volume FD	2.5%	5%	2.5%	5%	2.5%	5%
(incl. near-far extrapolation)						
Flux error signal ν	5%	10%	1%	2.5%	0.1%	1%
Flux error background ν	10%	20%	correlated		correlated	
Flux error signal $\bar{\nu}$	10%	20%	1%	2.5%	0.1%	1%
Flux error background $\bar{\nu}$	20%	40%	correlated		correlated	
Background uncertainty	5%	10%	5%	10%	10%	20%
Cross sections × efficiencies QE	10%	20%	10%	20%	10%	20%
Cross sections × efficiencies RES	10%	20%	10%	20%	10%	20%
Cross sections × efficiencies DIS	5%	10%	5%	10%	5%	10%
Cross sec. × efficiency ratio ν_e/ν_μ QE	Energy-dependent					
Cross sec. × efficiency ratio ν_e/ν_μ RES	2.7%	11%	2.7%	11%	2.7%	11%
Cross sec. × efficiency ratio ν_e/ν_μ DIS	2.5%	10%	2.5%	10%	2.5%	10%

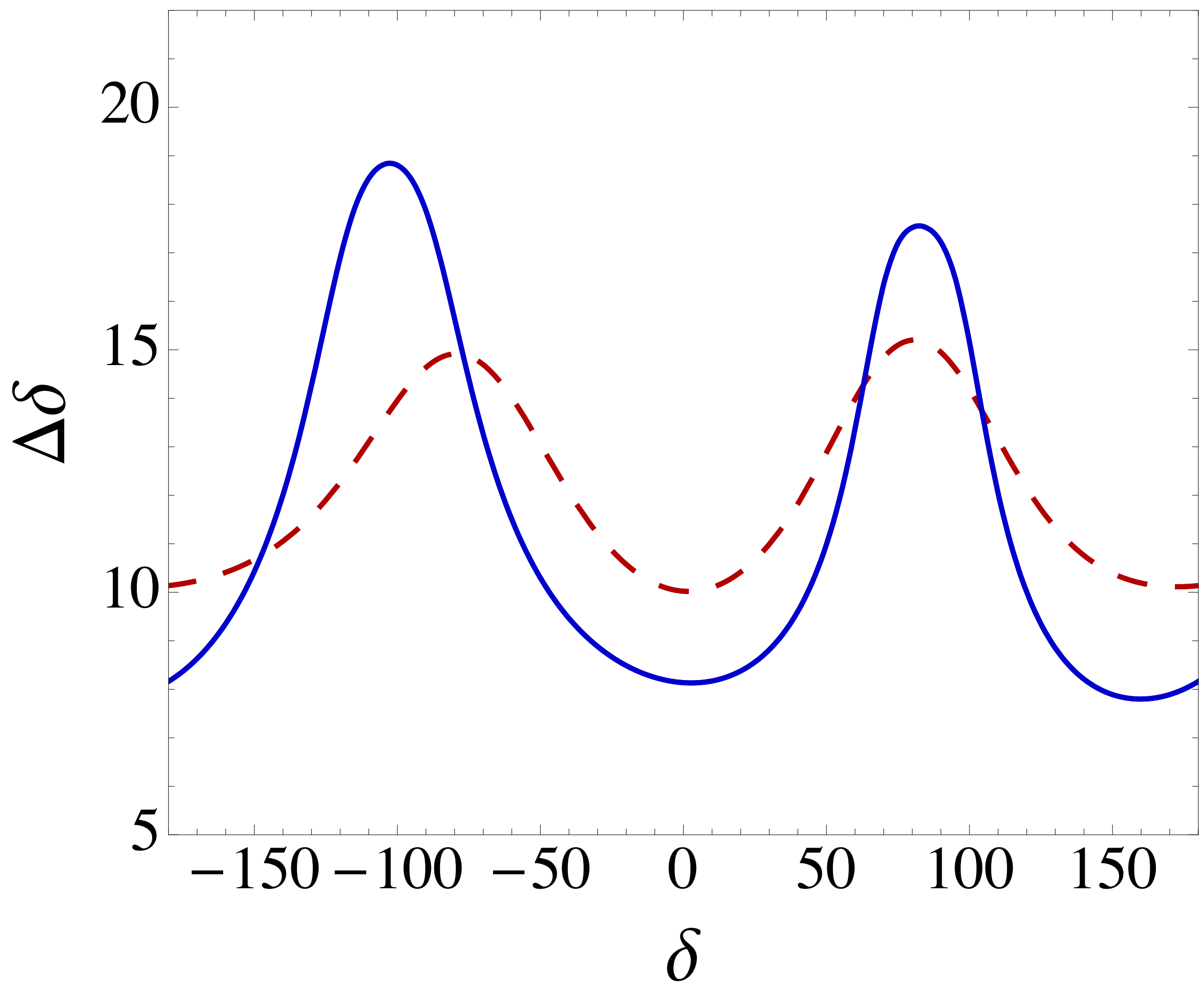
[8%, 2.5%] in opt. case

[32%, 10%] in cons. case

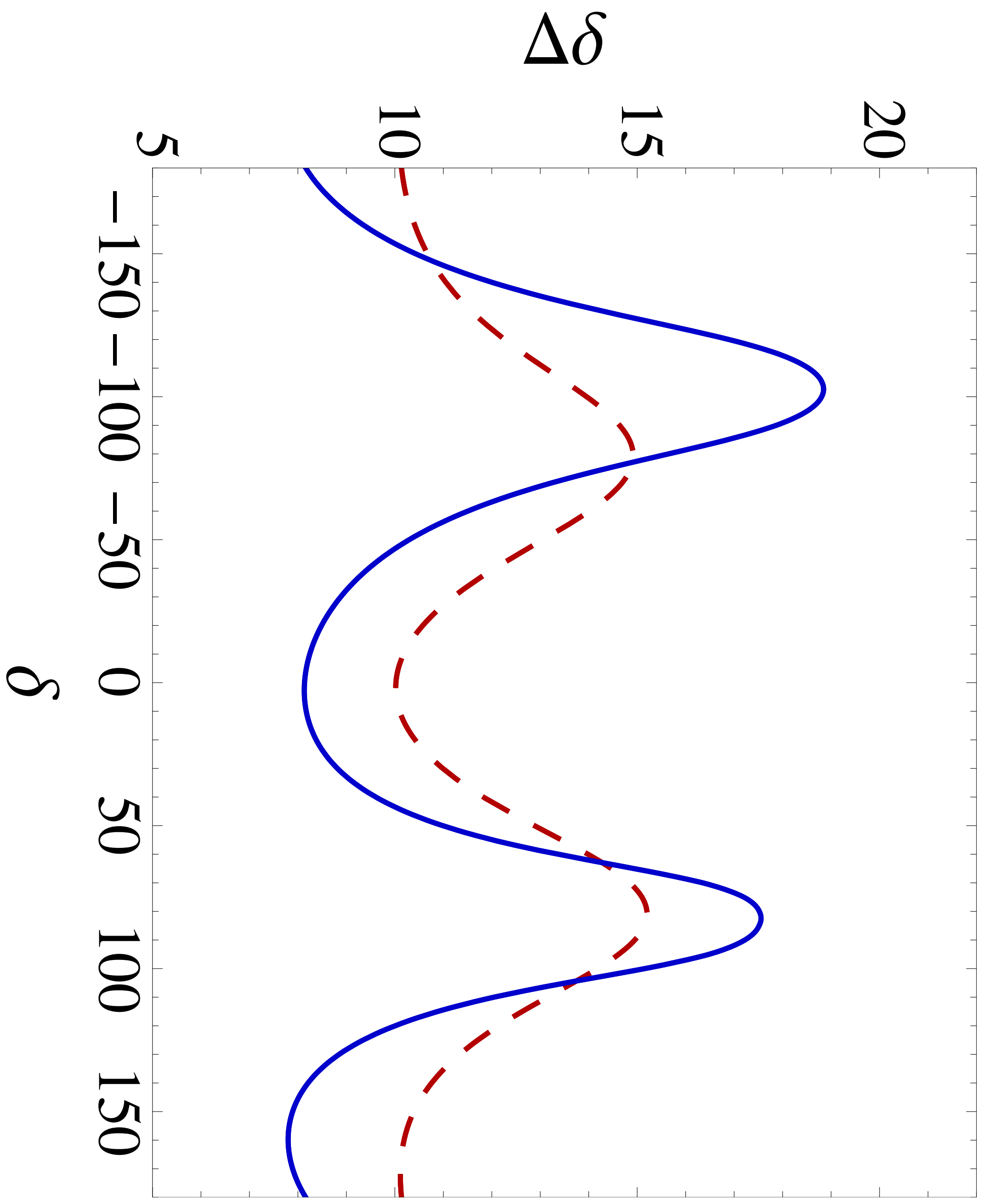
The setups

- T2HK (1109.3262 [hep-ex]): 1.66 MW, 5 years (1.5+3.5), 560 kton WC simulated as in 0711.2950 [hep-ph], L=295 km
- LBNO (1001.0077 [physics.ins-det]): 800 kW, fluxes from PoS ICHEP2010 (2010) 325, 10 years (5+5), 100 kton LAr, L=2300 km
- BB350 (hep-ph/0312068, hep-ph/0503021): γ=350, 1.1(2.8)e18 useful Ne (He) ion decays per year, 10 years (5+5), 500 kton WC, L=650 km
- LENF (1012.1872 [hep-ph]): 10 GeV muons, 1.4e21 useful muon decays per year and polarity, 100 kton MIND (Andrew's MM), L=2000 km
- LBNE (1110.6249 [hep-ex]): 700 kW, 10 years (5+5), 33.4 kton LAr, L=1290 km

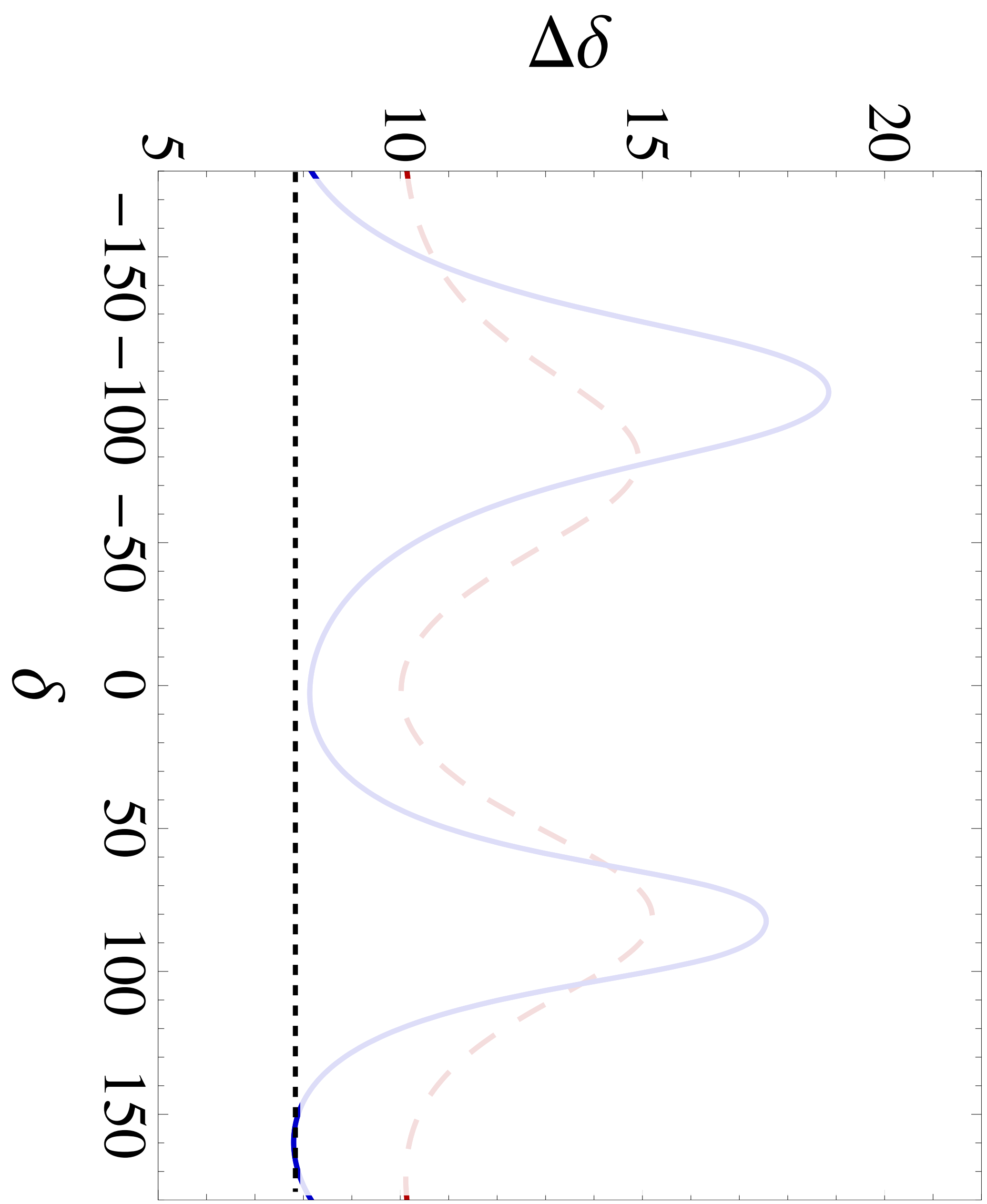
Precision and CP fraction

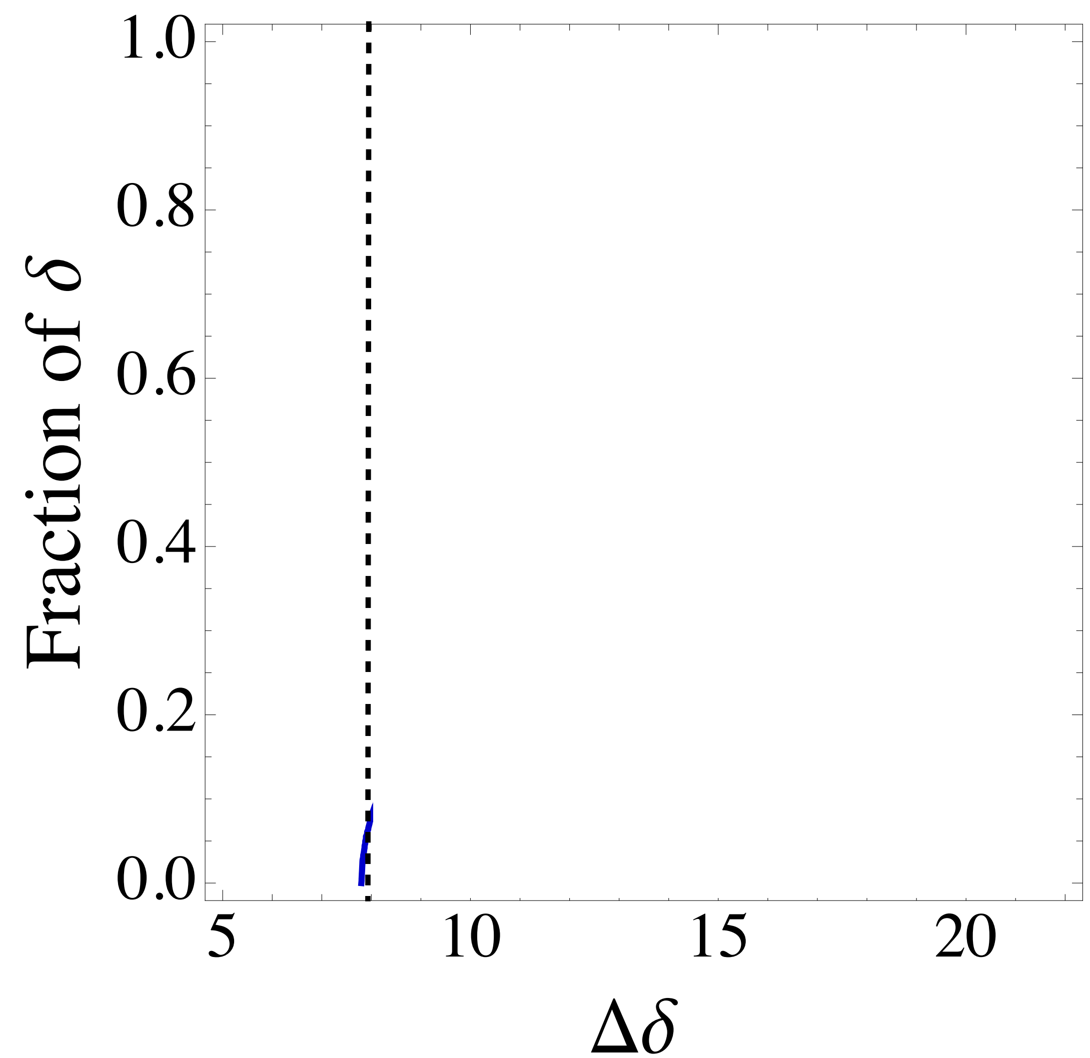


Precision and CP fraction

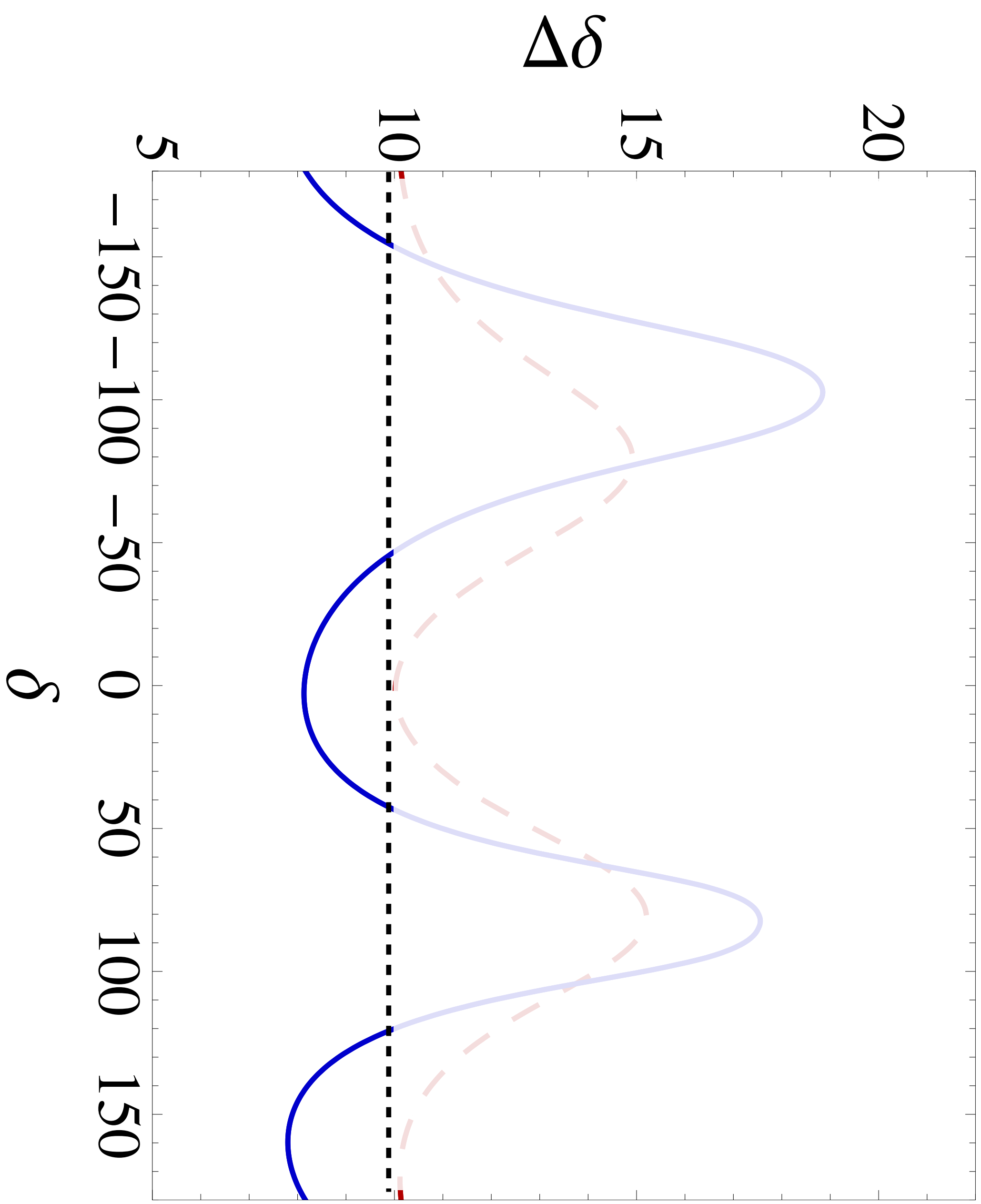


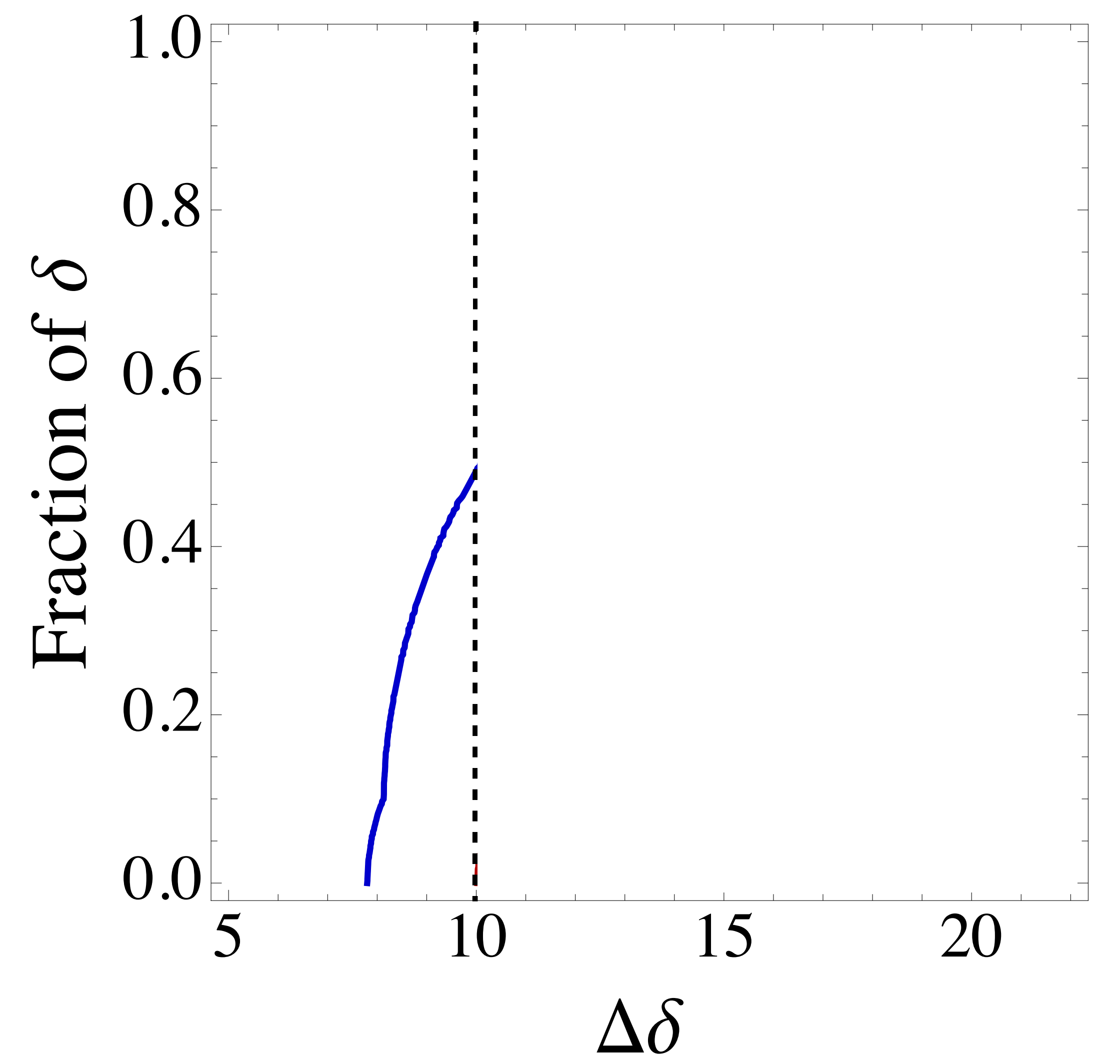
Precision and CP fraction



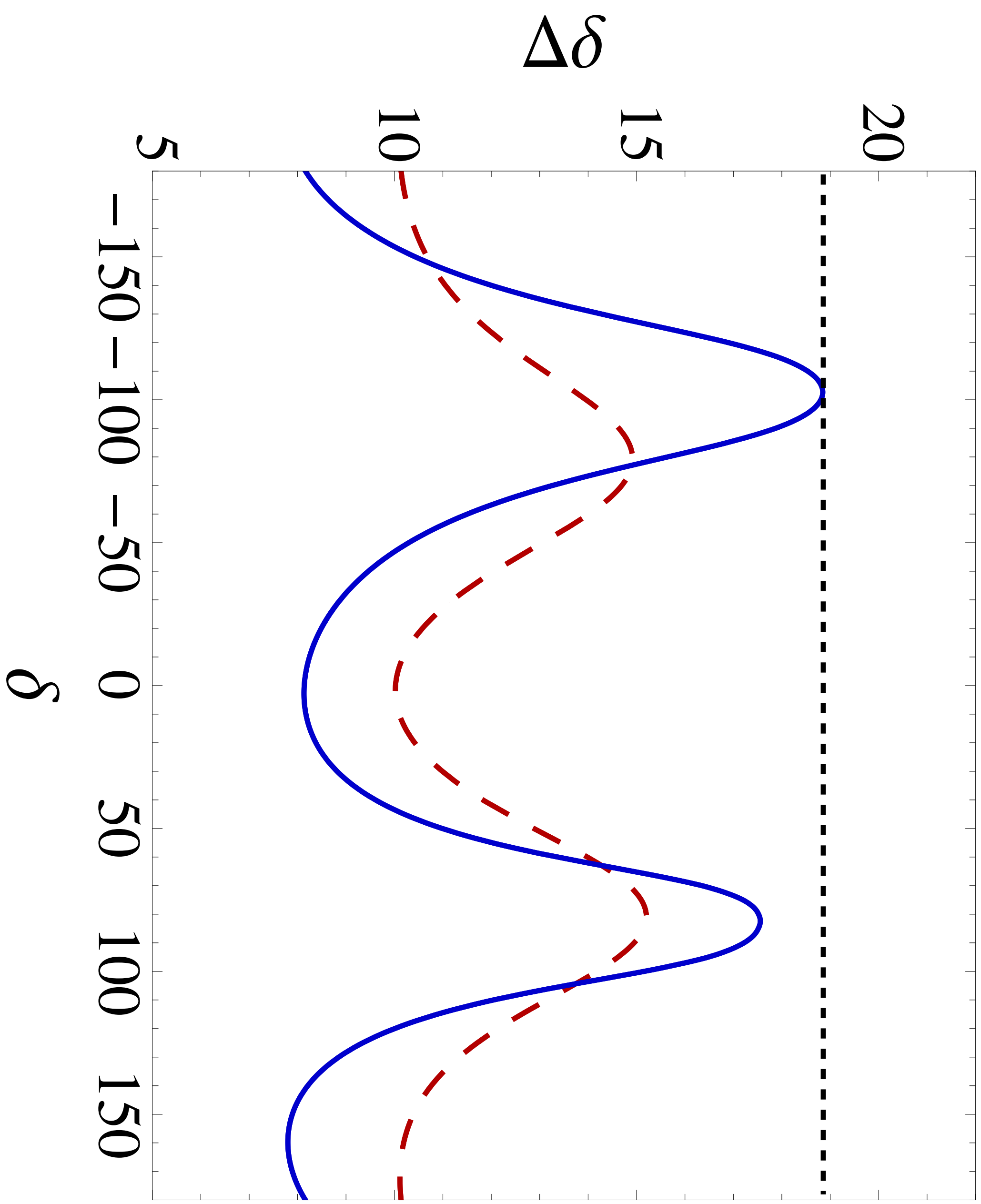


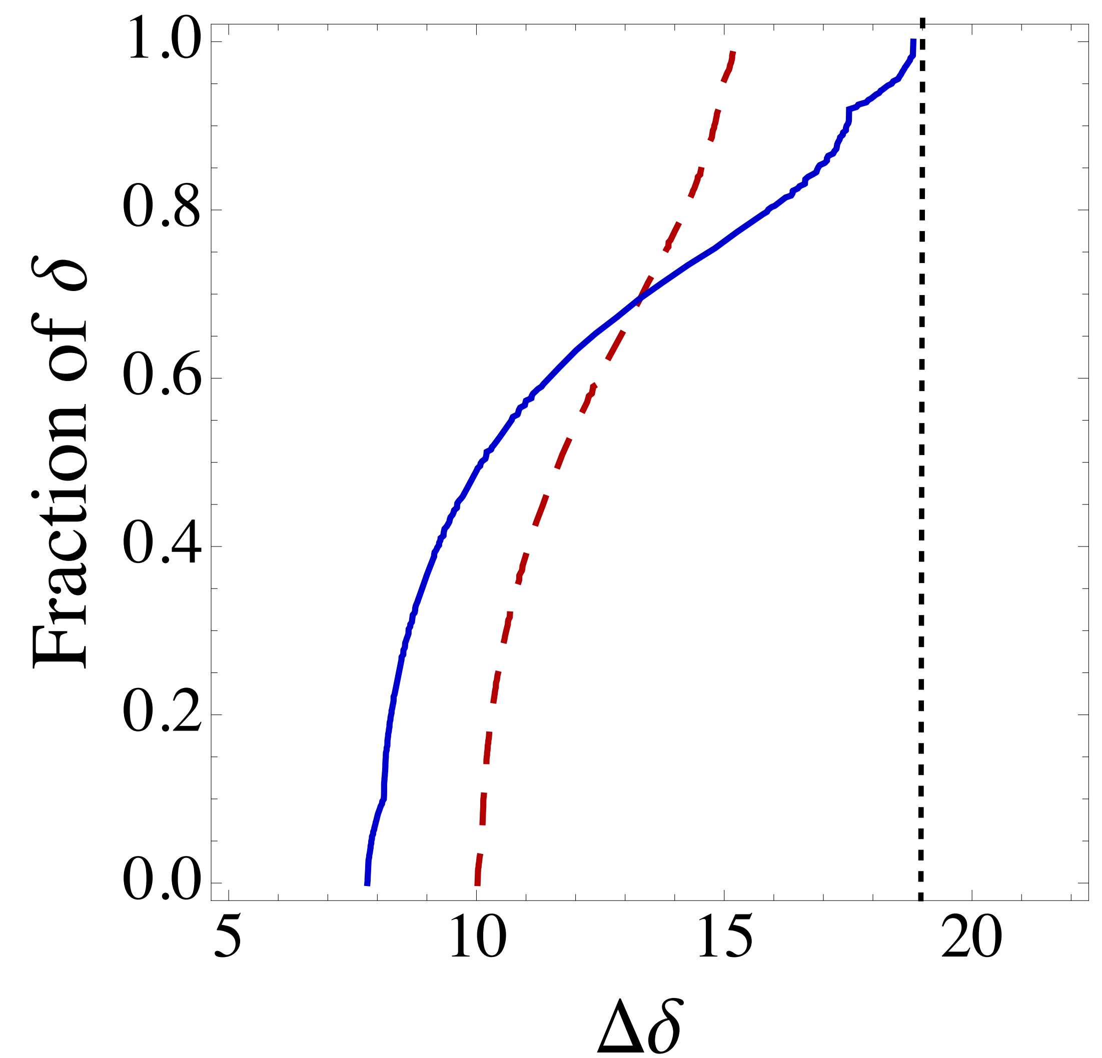
Precision and CP fraction





Precision and CP fraction





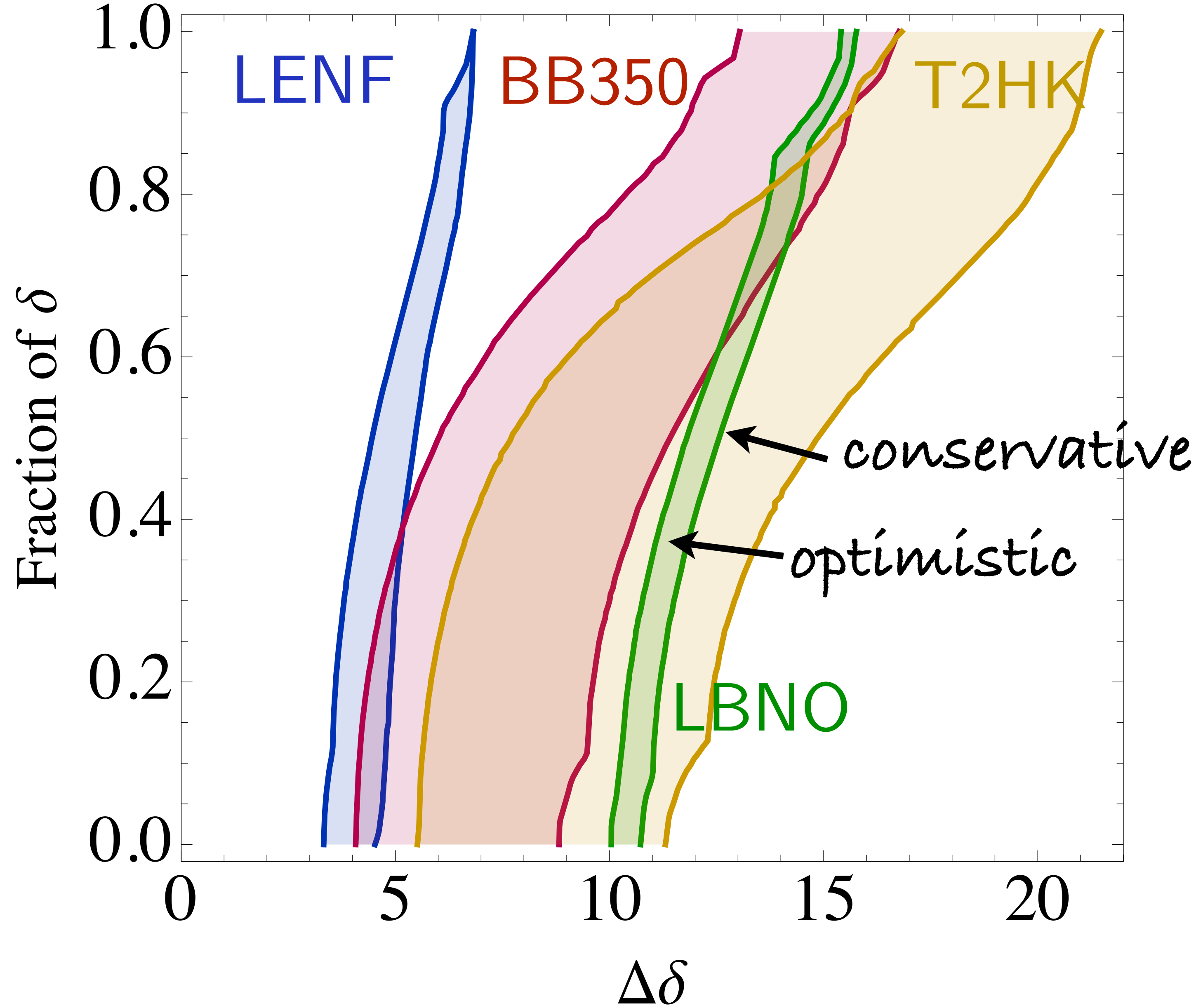
Impact of systematics

Preliminary

Difference between optimistic and pessimistic assumptions (two-det case):

$$L_{ND} \sim 1 - 2 \text{ km}$$

$$M_{ND} \sim 25 - 100 \text{ tons}$$



Coloma, Huber, Kopp, Mezzetto, Winter, In preparation

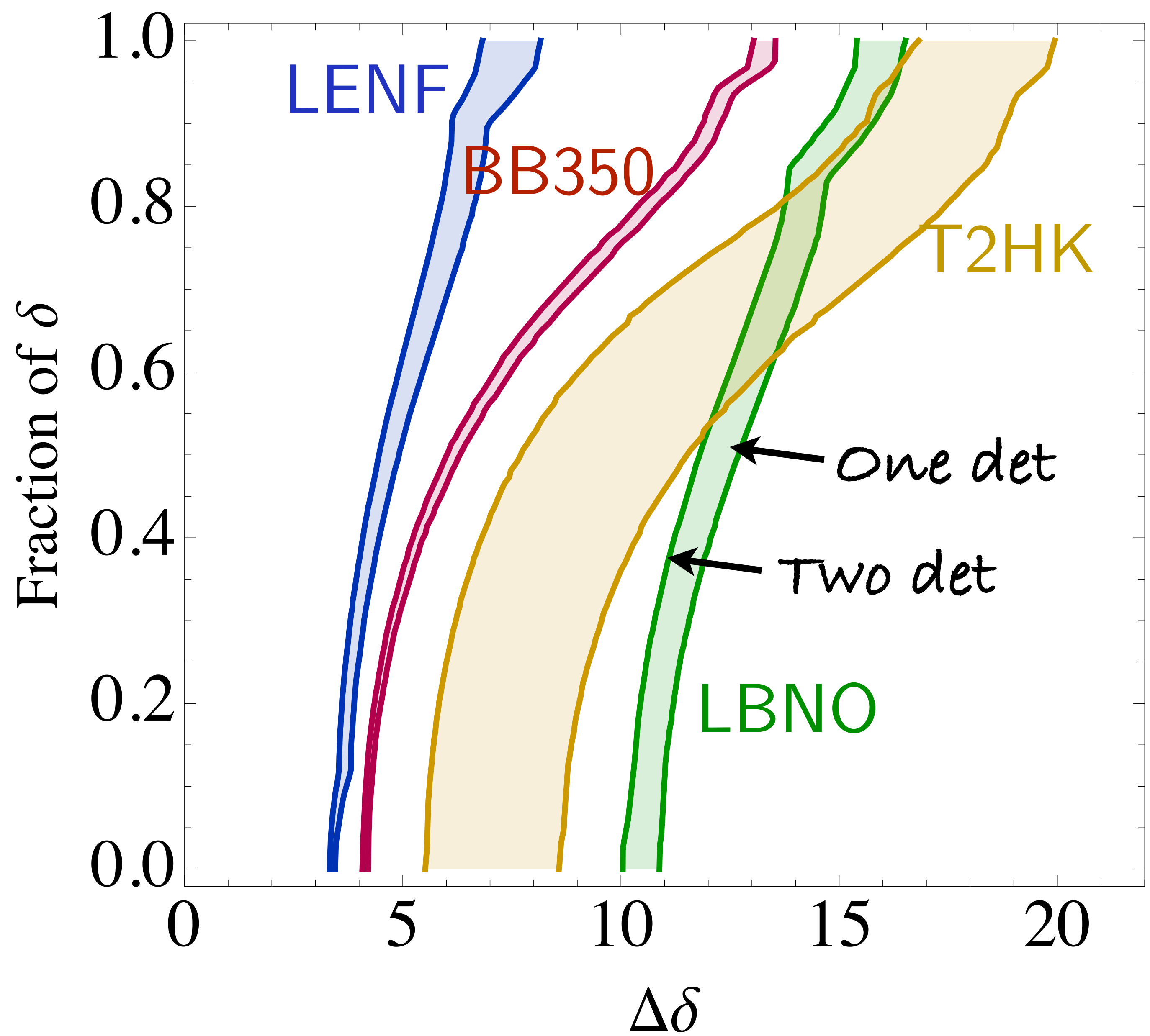
Impact of systematics

Preliminary

Difference between 1 detector and 2 detectors (optimistic case):

$$L_{ND} \sim 1 - 2 \text{ km}$$

$$M_{ND} \sim 25 - 100 \text{ tons}$$

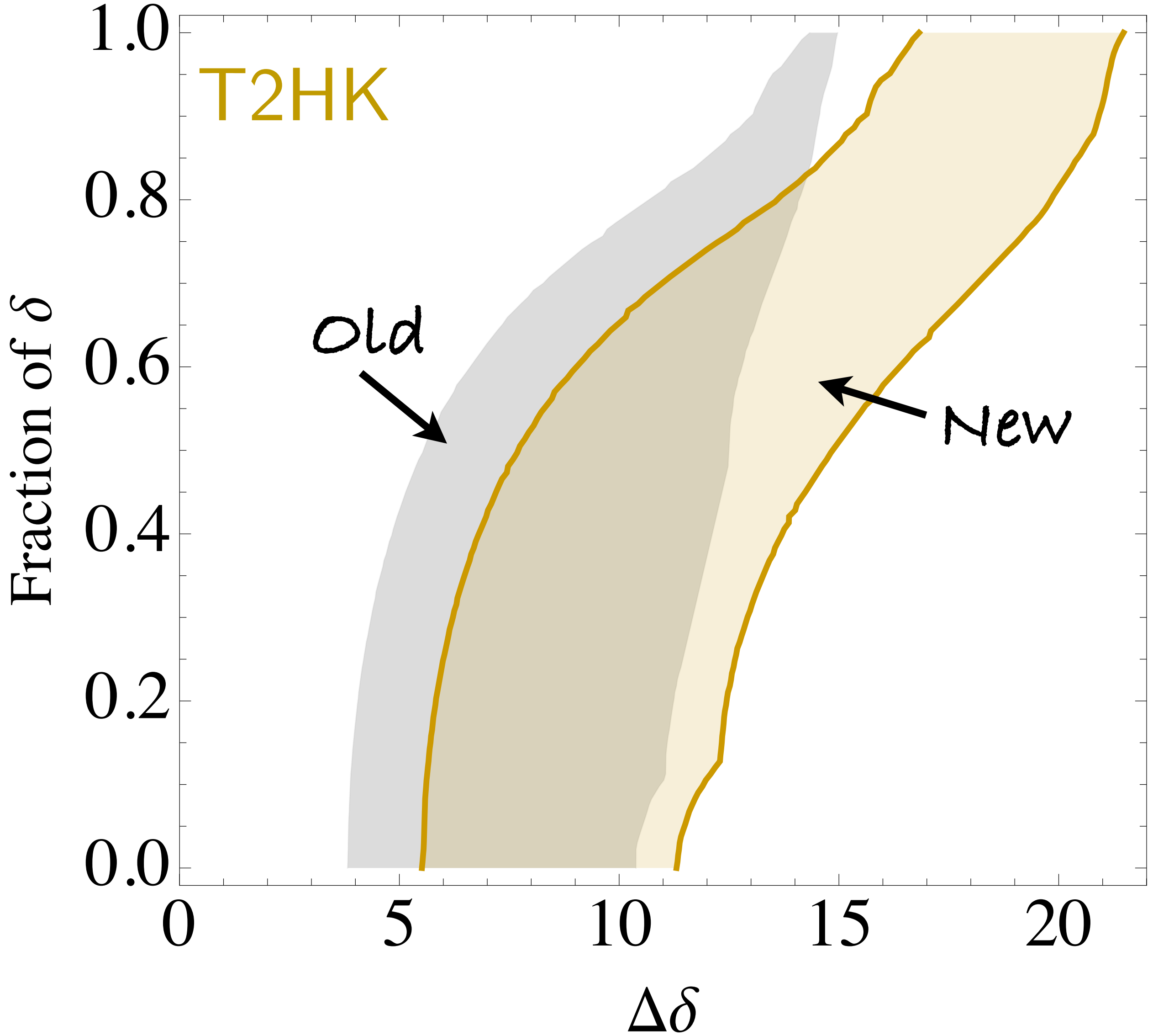


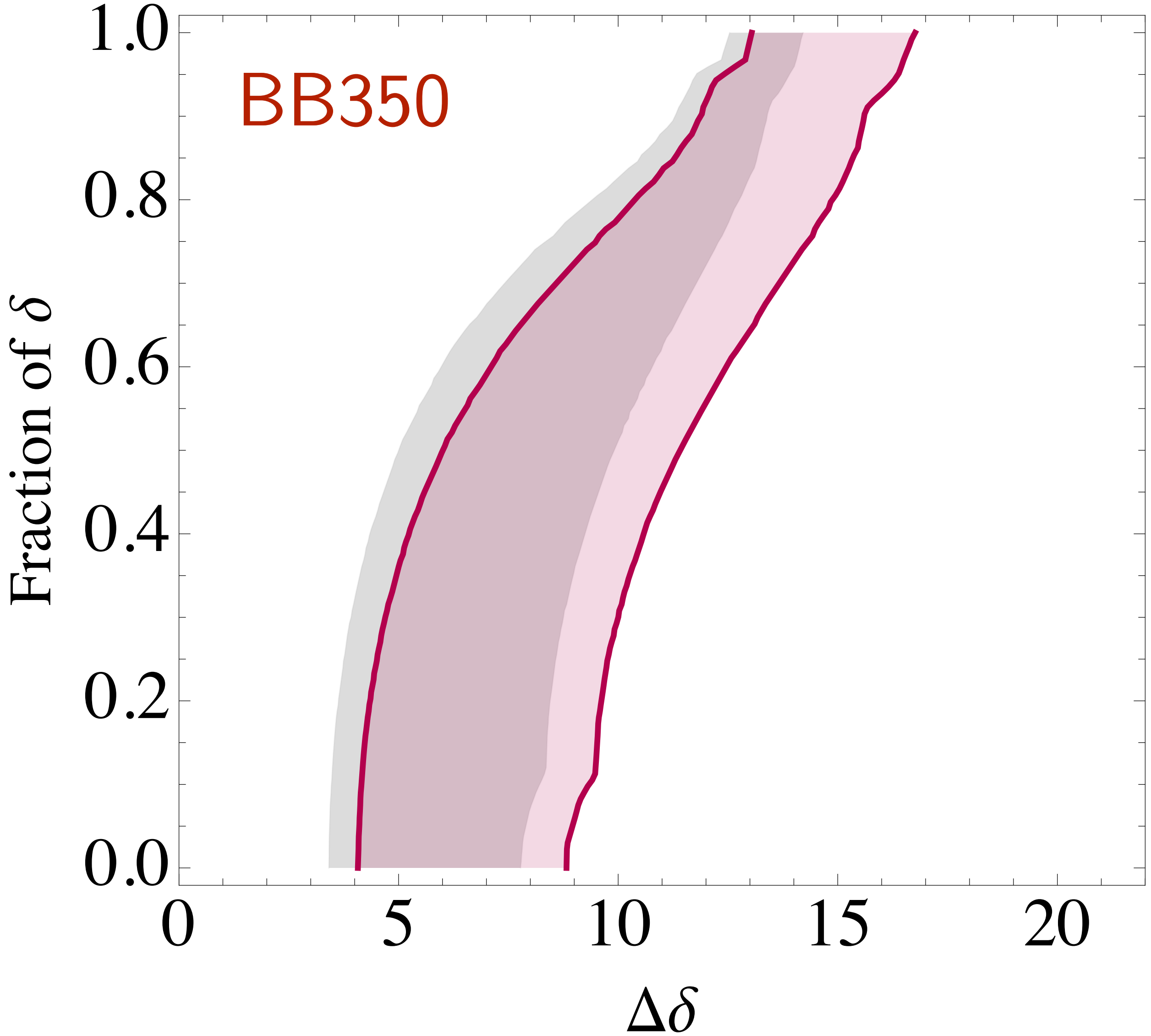
Coloma, Huber, Kopp, Mezzetto, Winter, In preparation

Impact of systematics

Preliminary

Differences with the old implementation:





Coloma, Huber, Kopp, Mezzetto, Winter, In preparation

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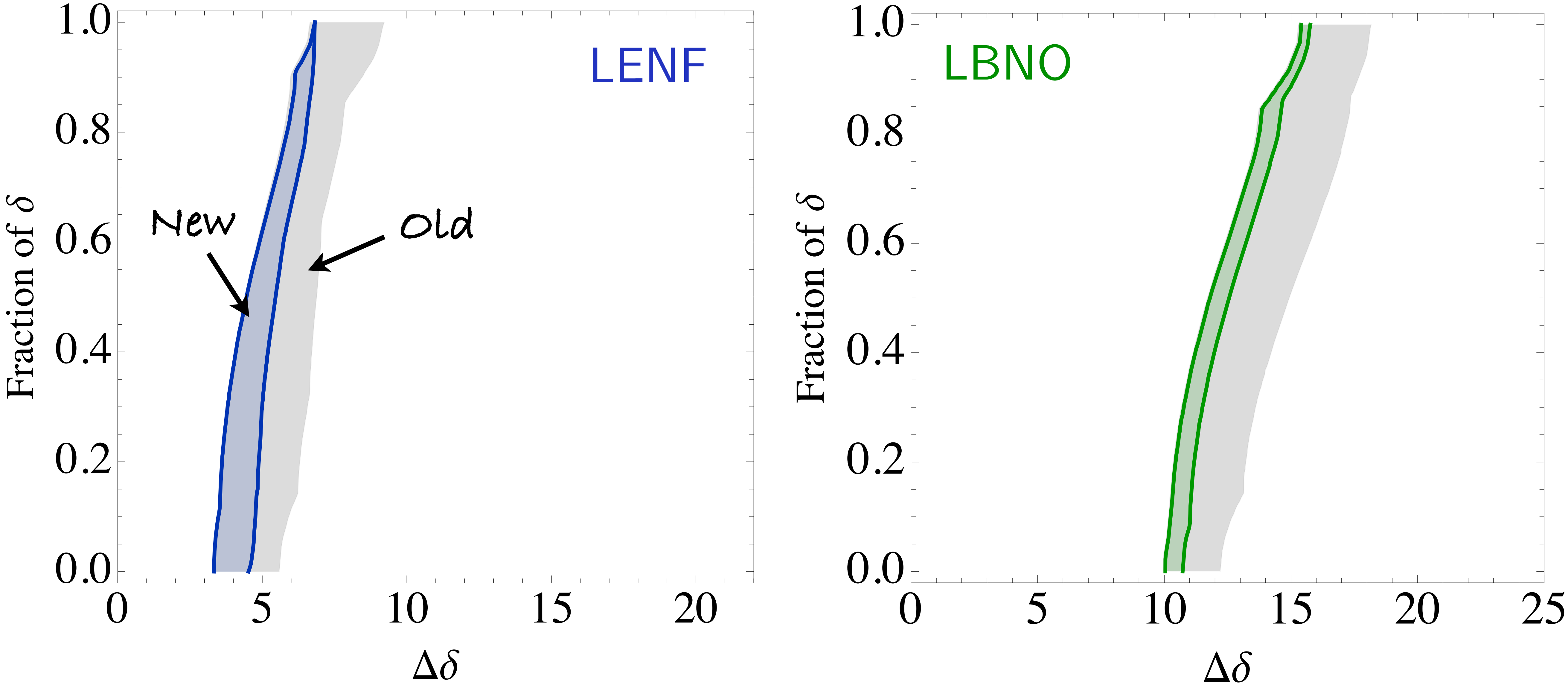


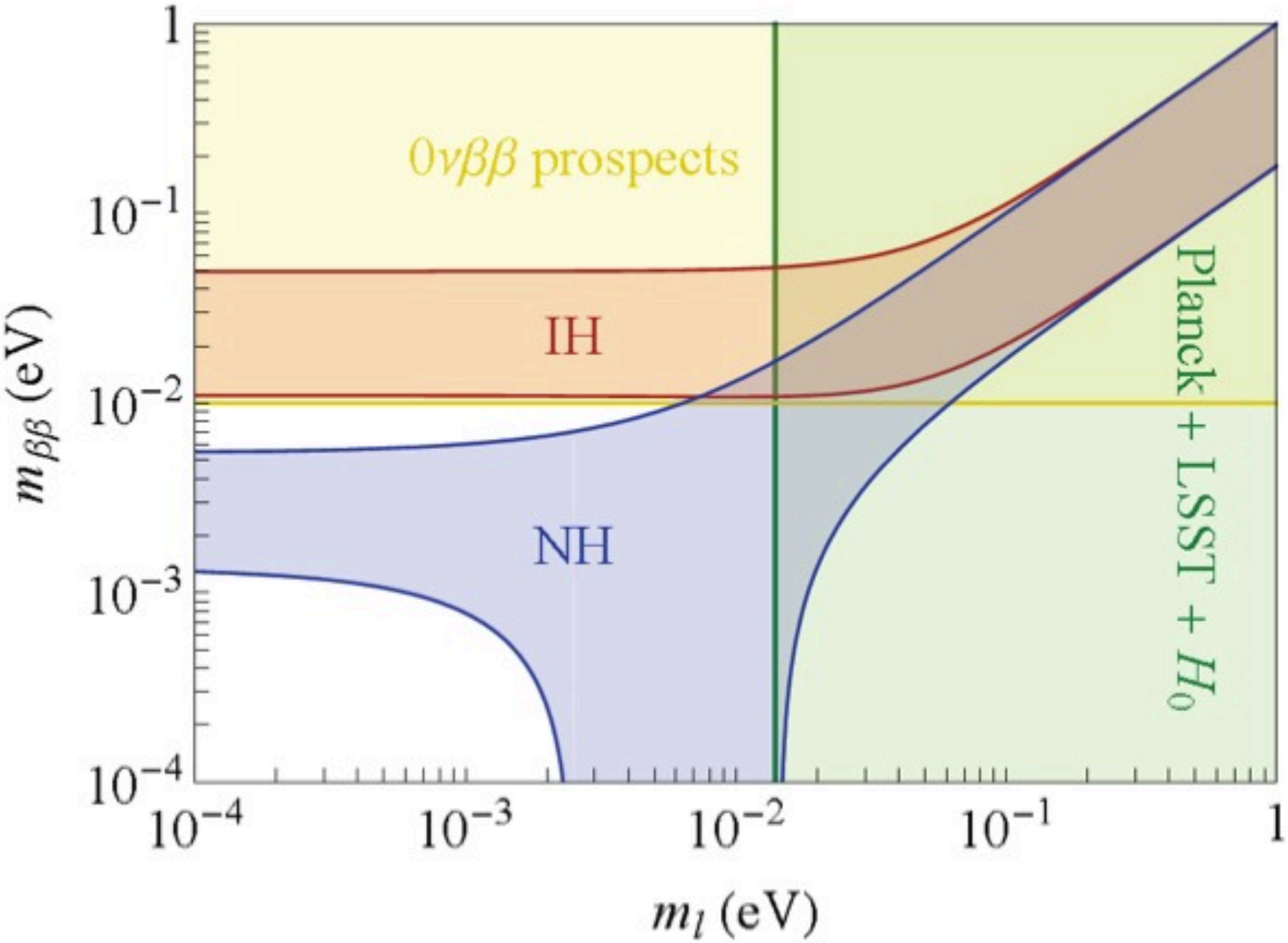
Coloma, Huber, Kopp, Mezzetto, Winter, In preparation

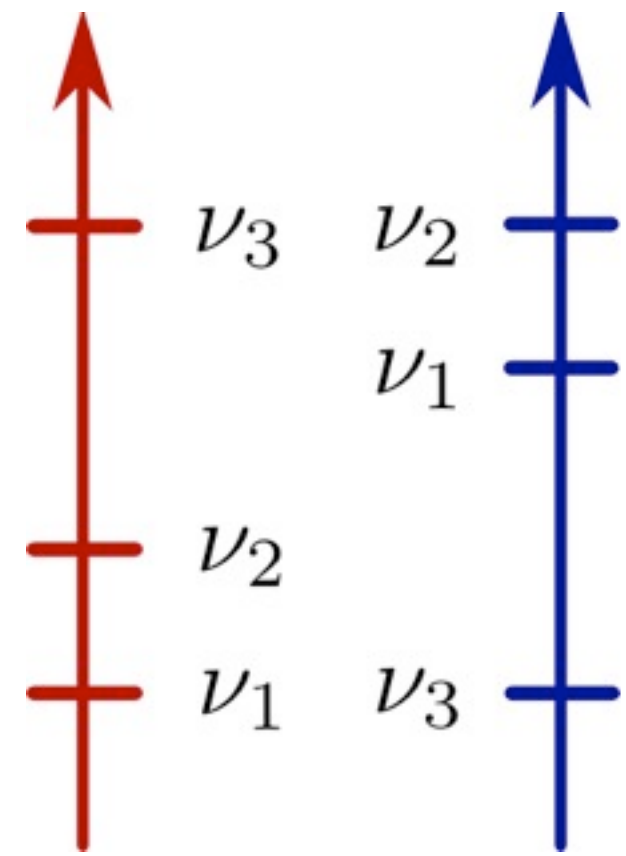
Conclusions

- We have done a comparison on equal footing between the most relevant setups in the literature for long baseline oscillation experiments. We have:
  - included a ND for all setups
  - included same sources of systematic errors
  - we have tested how the specific values impact our results
- The impact of a ND does not seem so relevant if data from disappearance at the FD is used
- Low energy setups seem to be more affected by systematics
- Old and new implementation in rough agreement
- All results shown here are preliminary: any input/feedback is very welcome!

Backup

Are ν masses different?

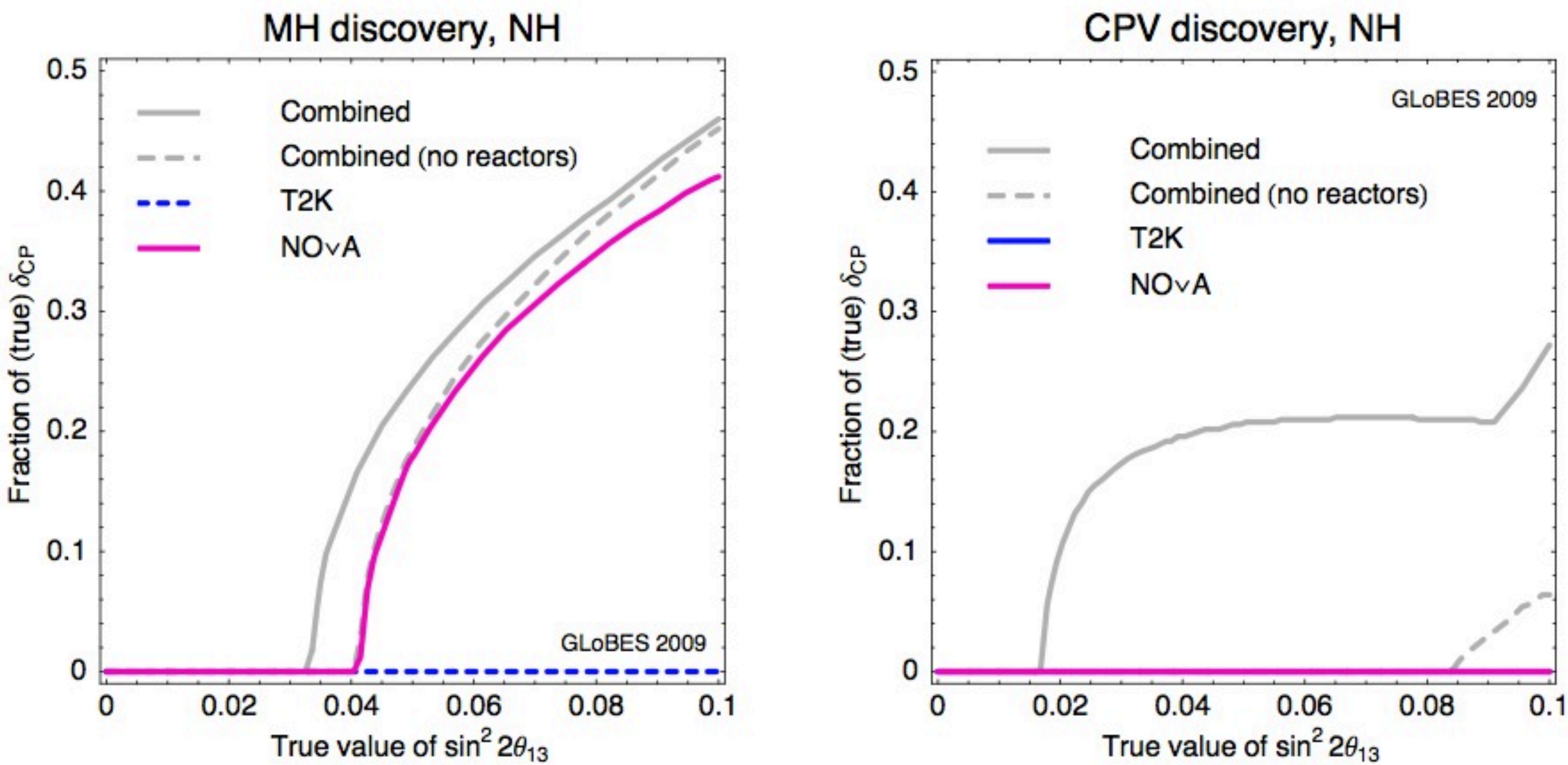




Courtesy of E. Fernández-Martínez

Present oscillation facilities

Discovery potential at the 90% CL

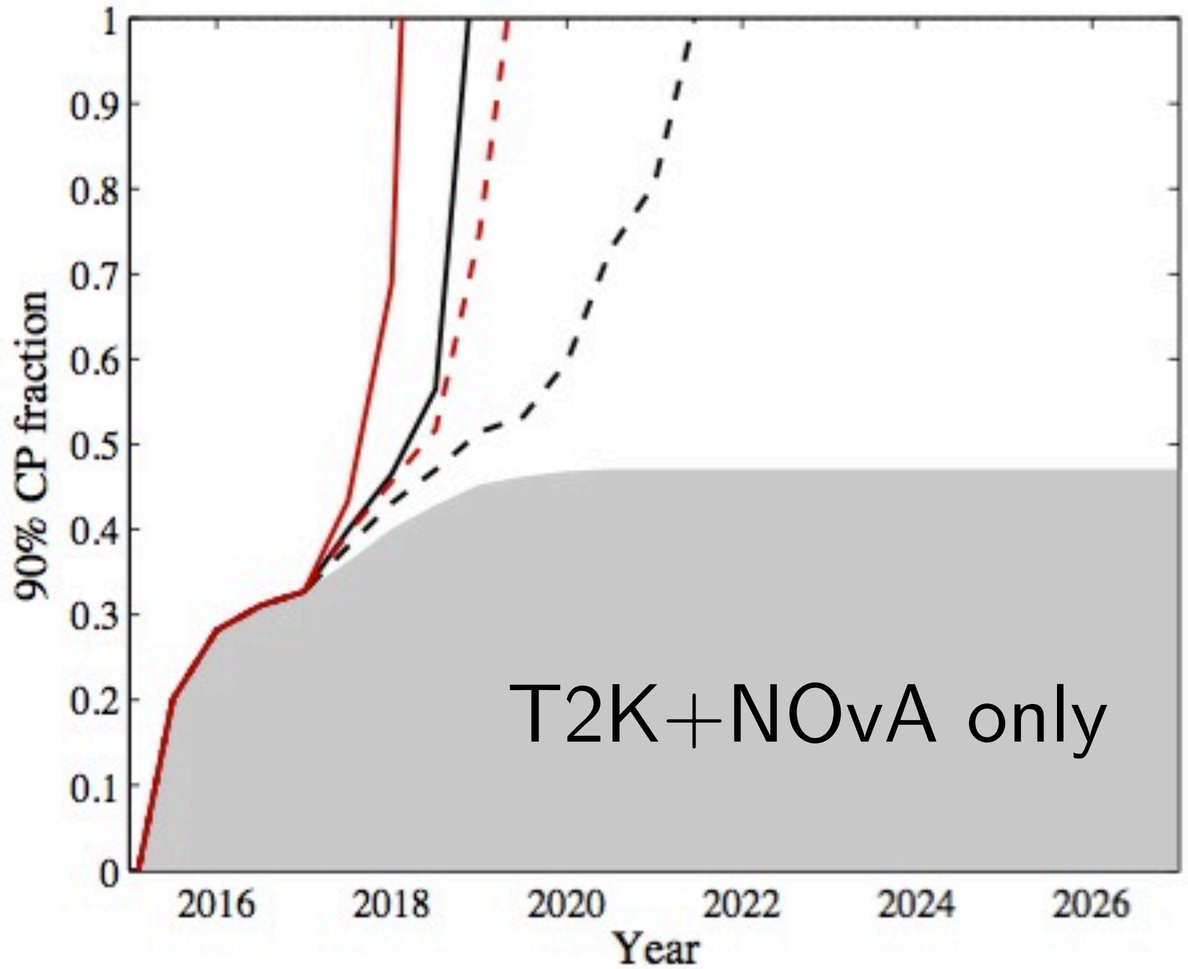


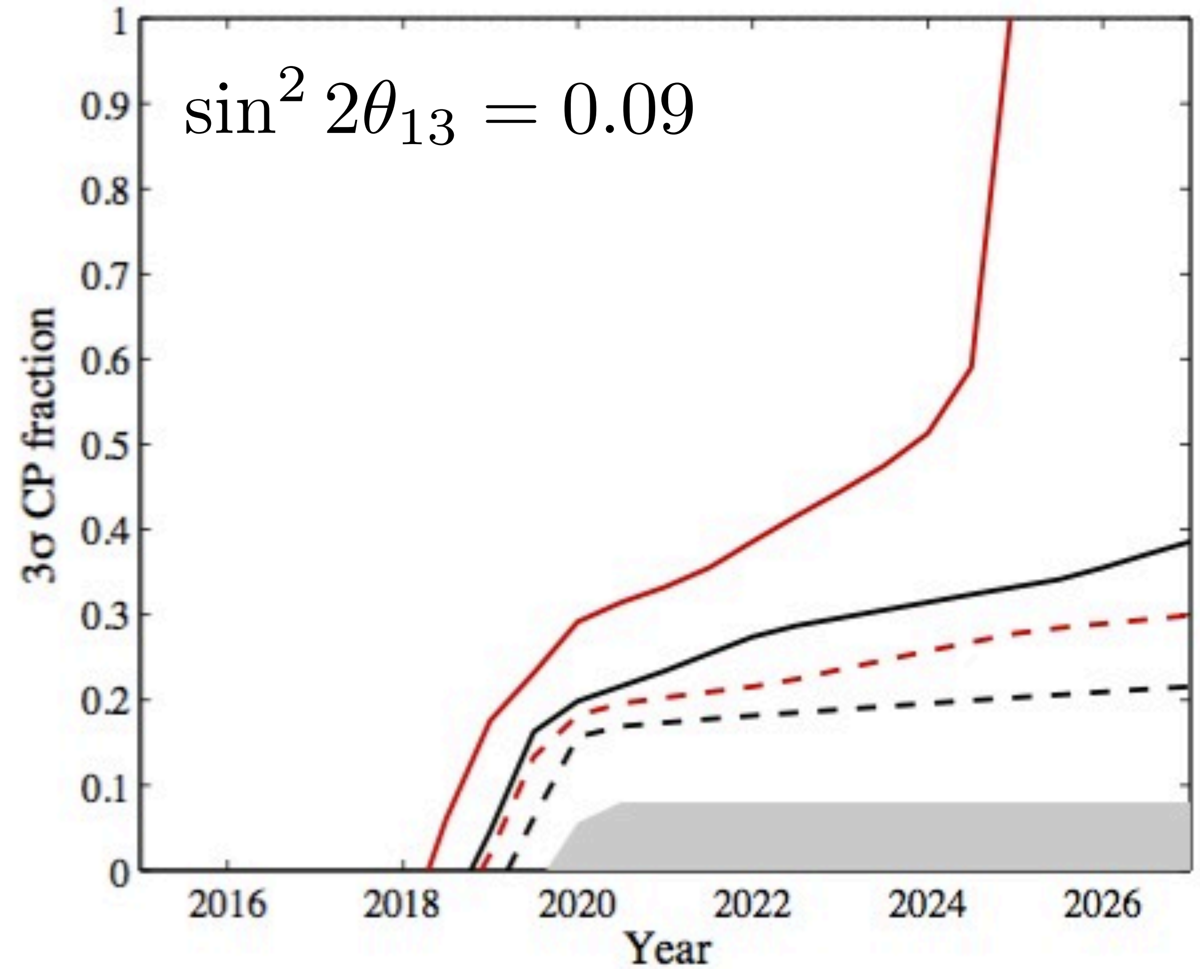
Huber, Lindner, Schwetz, Winter, 0907.1896 [hep-ph]

Present oscillation facilities

T2K+NOvA+INO

(50kt/100kt; low/high res)

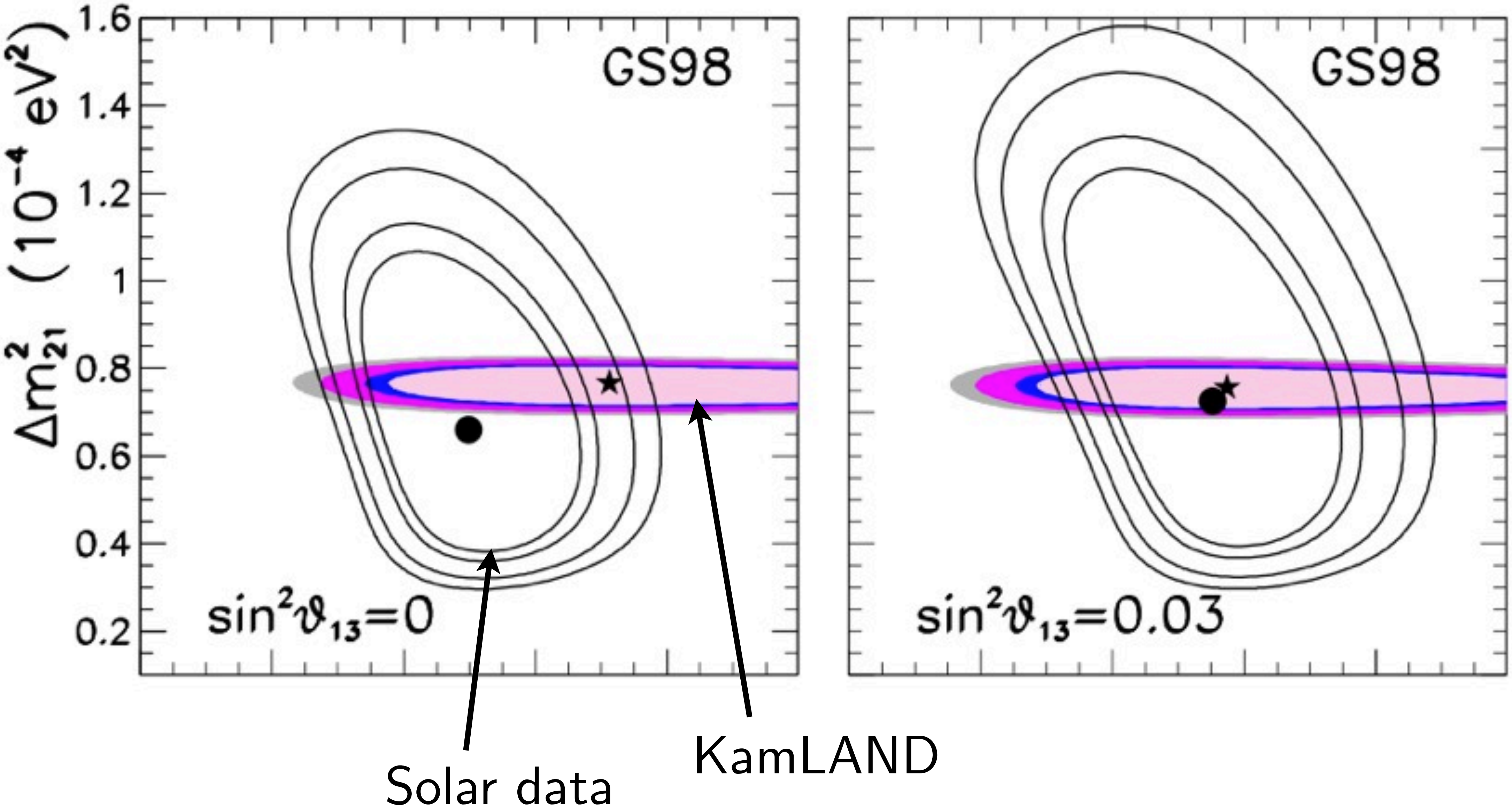




Blennow, Schwetz, 1203.3388 [hep-ph]

Previous hints on θ_{13}

Previous hints from global fits pointed to nonzero θ_{13}...



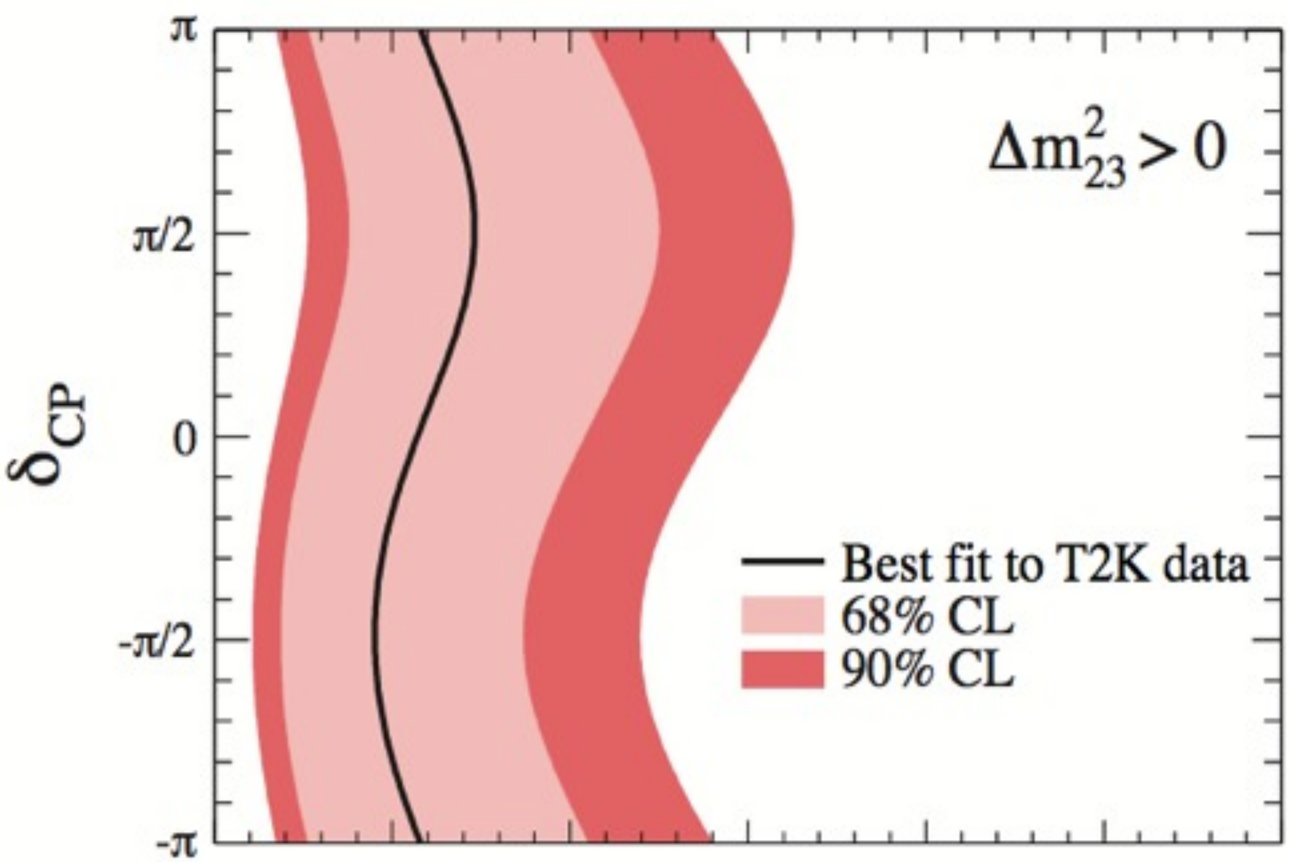
González-García, Maltoni,Salvado, 1001.4524 [hep-ph]

Hints from LBL beams

T2K

(295 km, 22.5 kt WC,

2.5° OA, E~0.6 GeV)



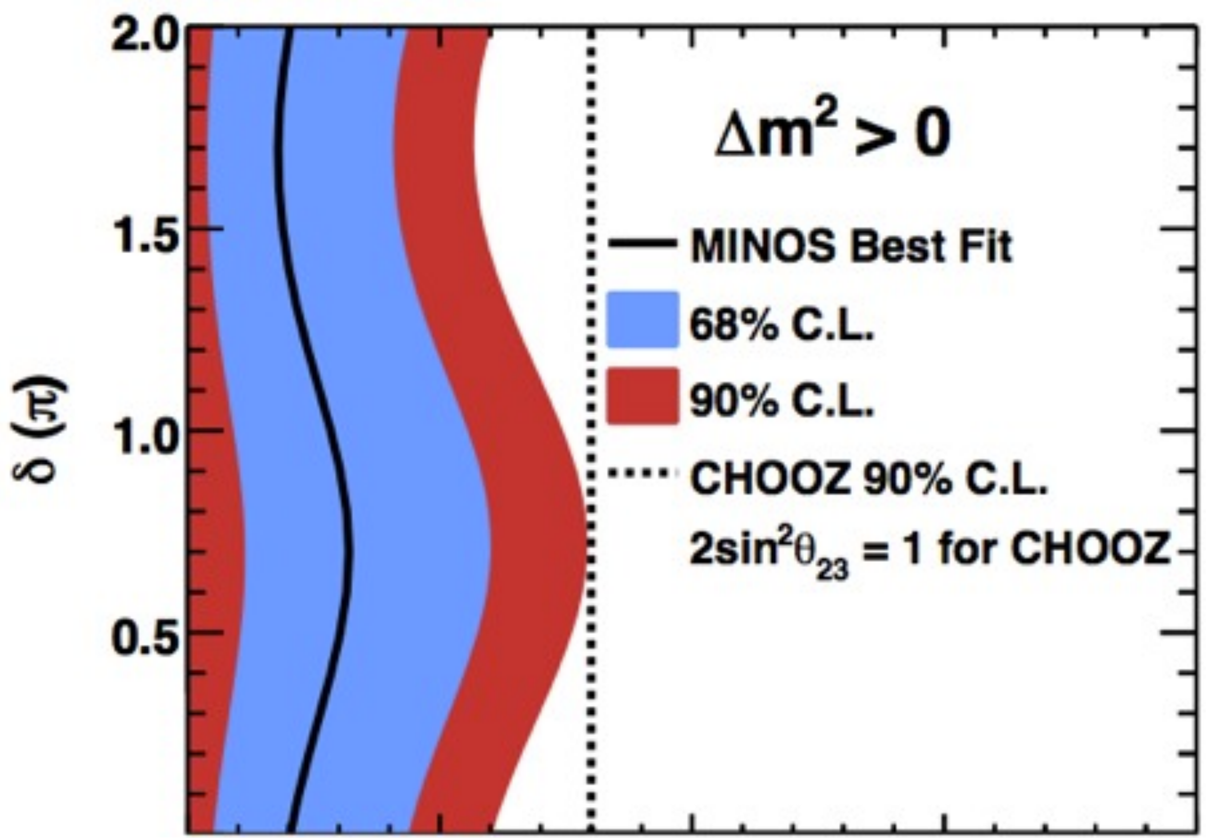
1106.2822 [hep-ex]

MINOS

(735 km, 5.4 kt magnetized

tracking calorimeter,

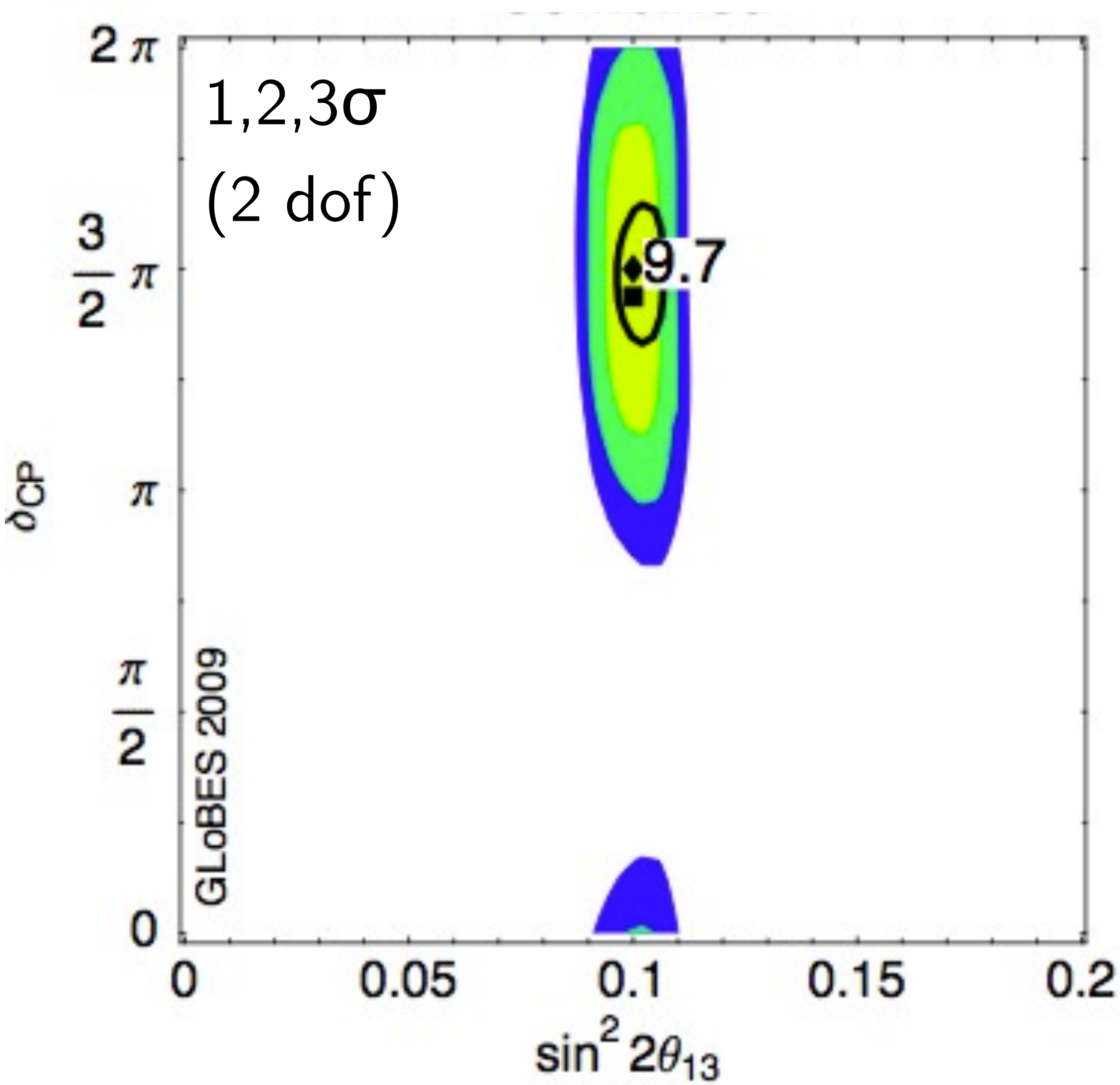
on axis, E~4.5 GeV)

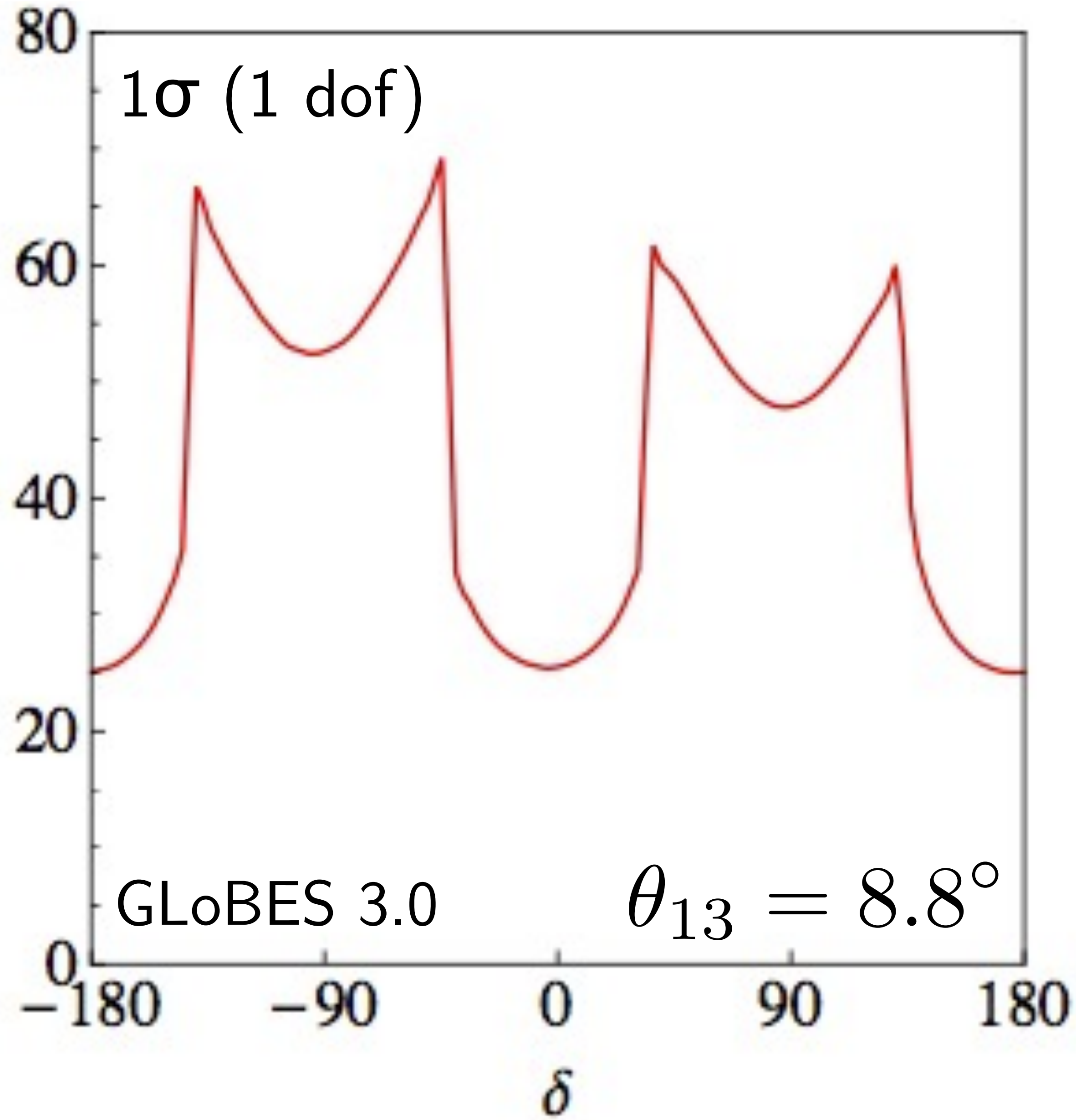


1108.0015 [hep-ex]

The starting point

NOvA+T2K+Daya Bay

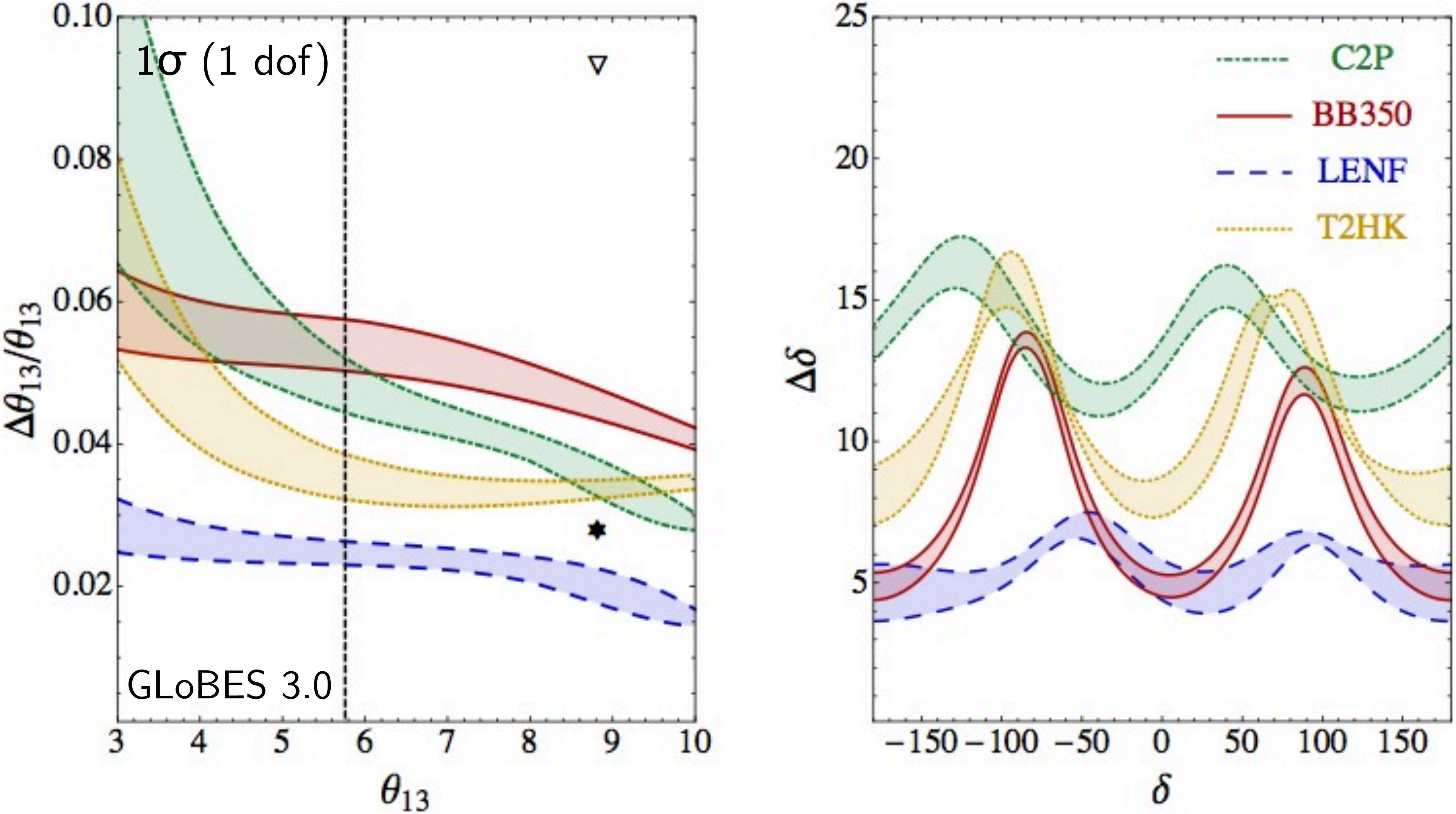




Huber, Lindner, Schwetz, Winter, 0907.1896 [hep-ph]

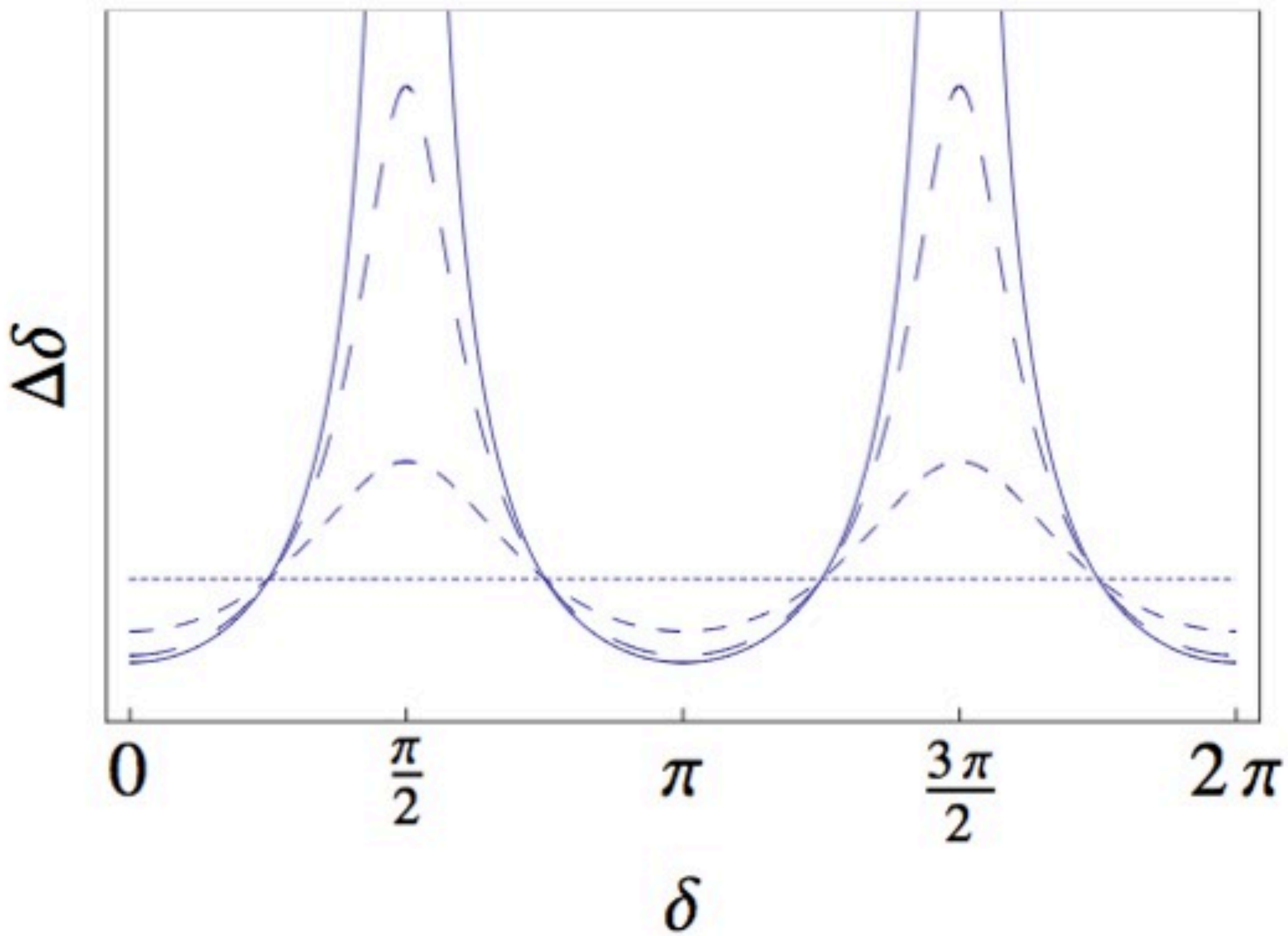
Coloma, Donini, Fernández-Martínez, Hernández, 1203.5651 [hep-ph]

Precision



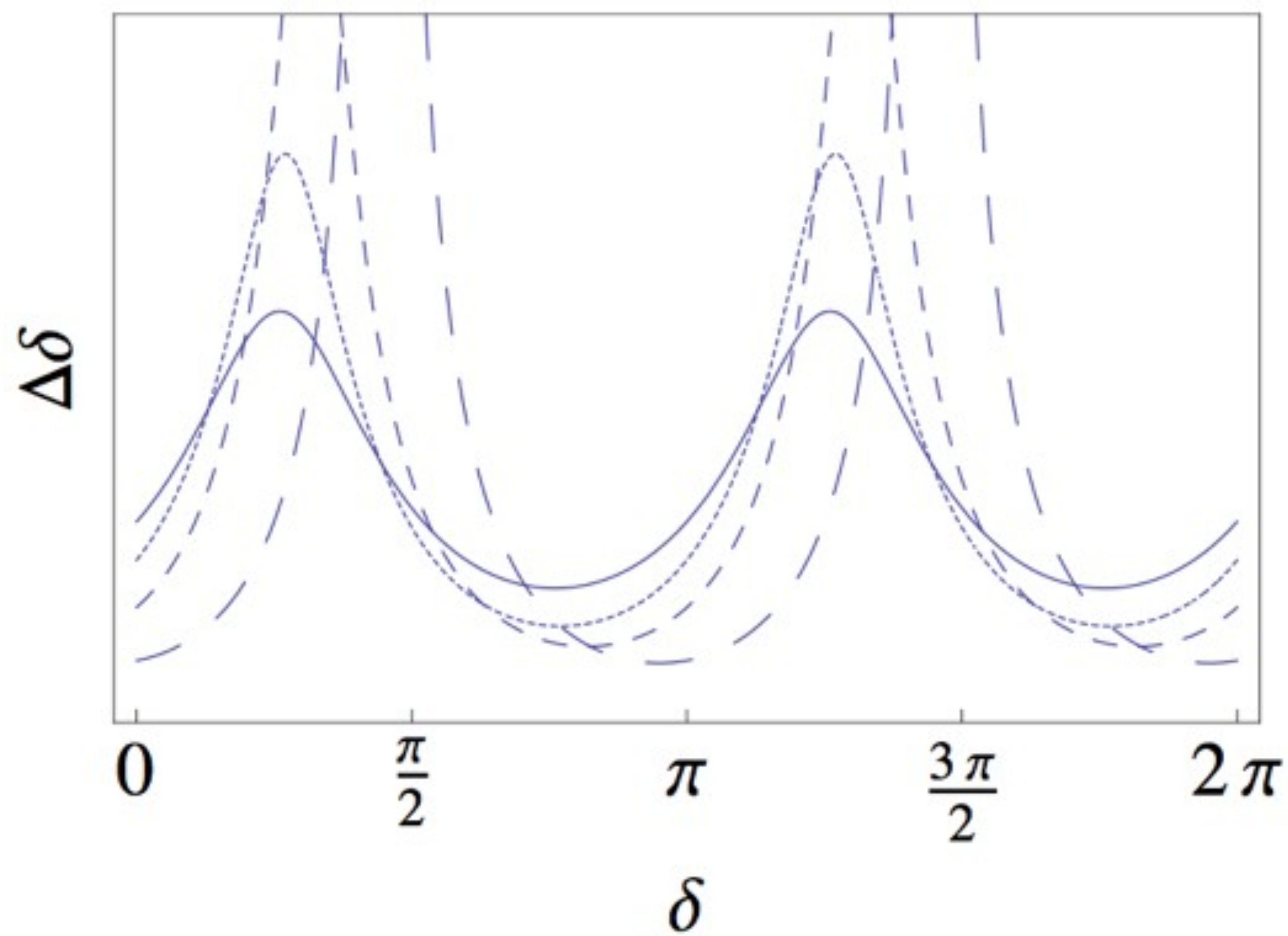
Coloma, Donini, Fernández-Martínez, Hernández, 1203.5651 [hep-ph]

On/Off peak (vacuum)



$$(\Delta\delta)_{\pm} \propto \frac{1}{\sin\left(\frac{\pi}{2} \mp \delta\right)}$$

Importance of matter effects



$$\boxed{(\Delta\delta)_{\pm} \propto \frac{1}{\sin\left(\frac{\pi}{2}\frac{1}{(1\mp\hat{A})} \mp \delta\right)}} \qquad \left(\hat{A} \equiv \frac{\sqrt{2}G_F n_e L}{2\Delta}\right)$$