The physics case of a Low Energy Neutrino Factory

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Invent the Future

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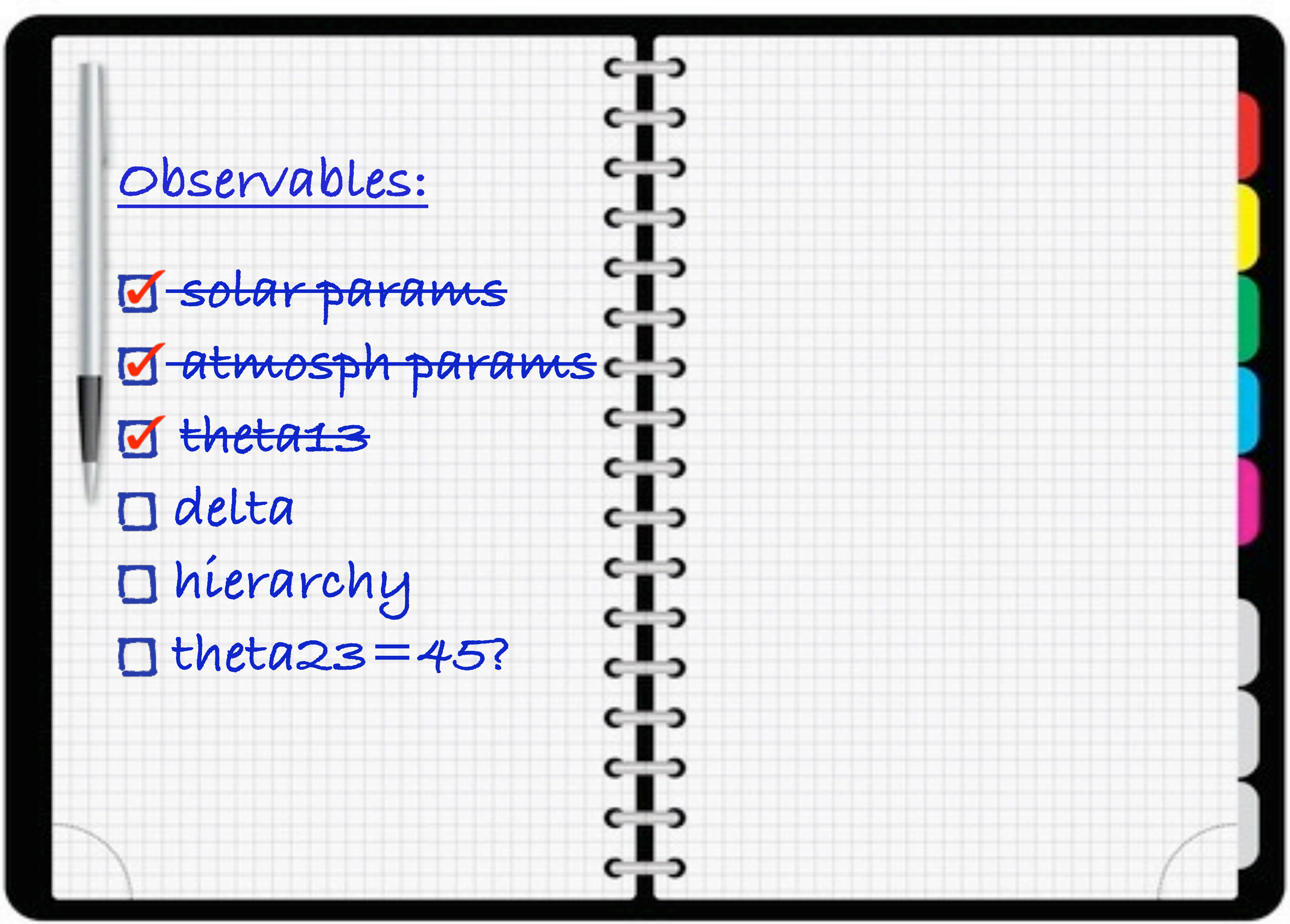
Outline

- General landscape for the future
- Why a NF?
- The LENF concept
- Physics reach of a LENF from RAL to GS
- Precision measurements

The shopping list in ν oscillations



General Landscape

- 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

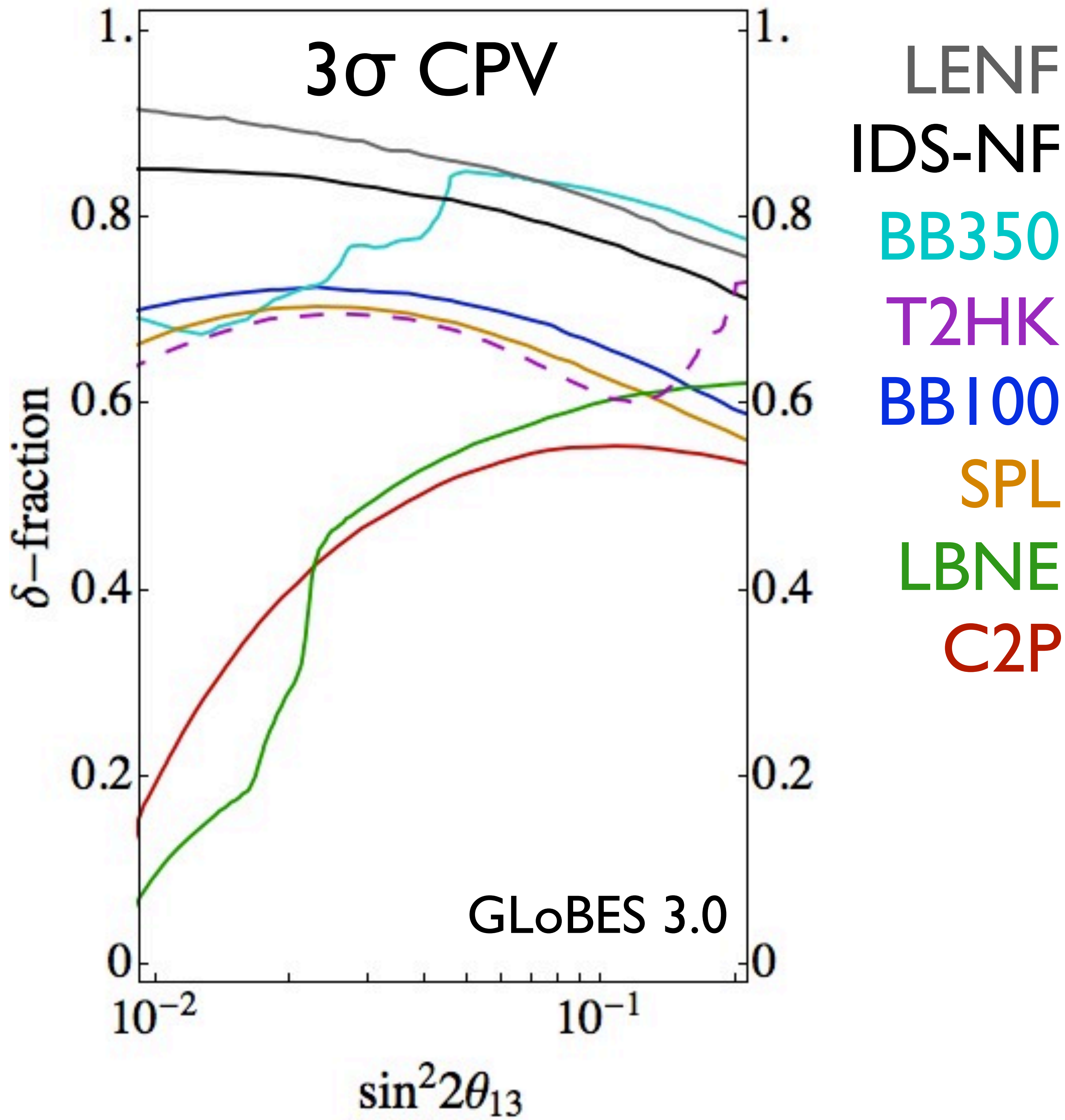
T2HK: hep-ex/0106019
1109.3262 [hep-ex]

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

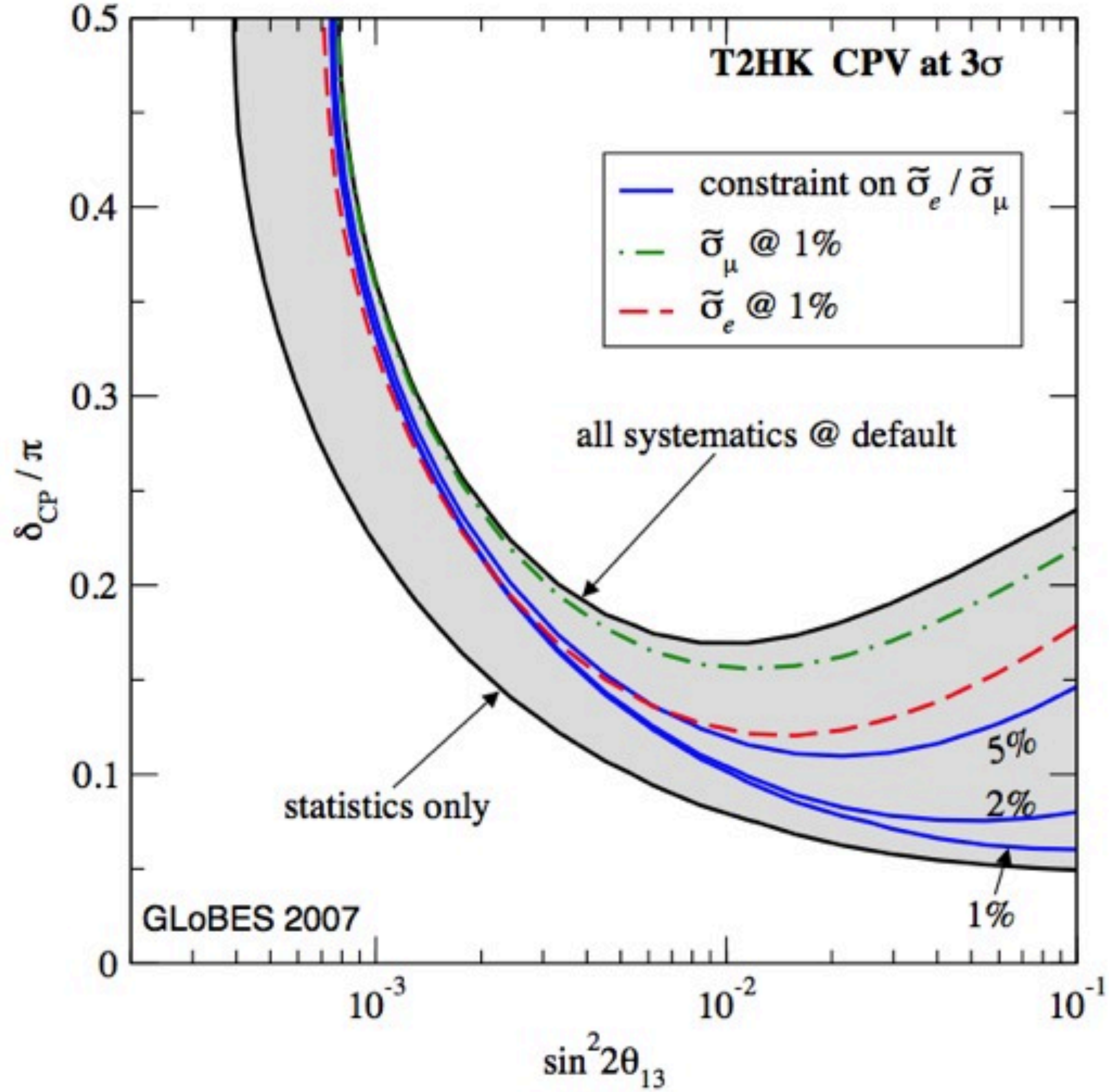
LENF: 1012.1872 [hep-ph]

LBNE: 1110.6249 [hep-ex]

IDS: 1112.2853 [hep-ex]

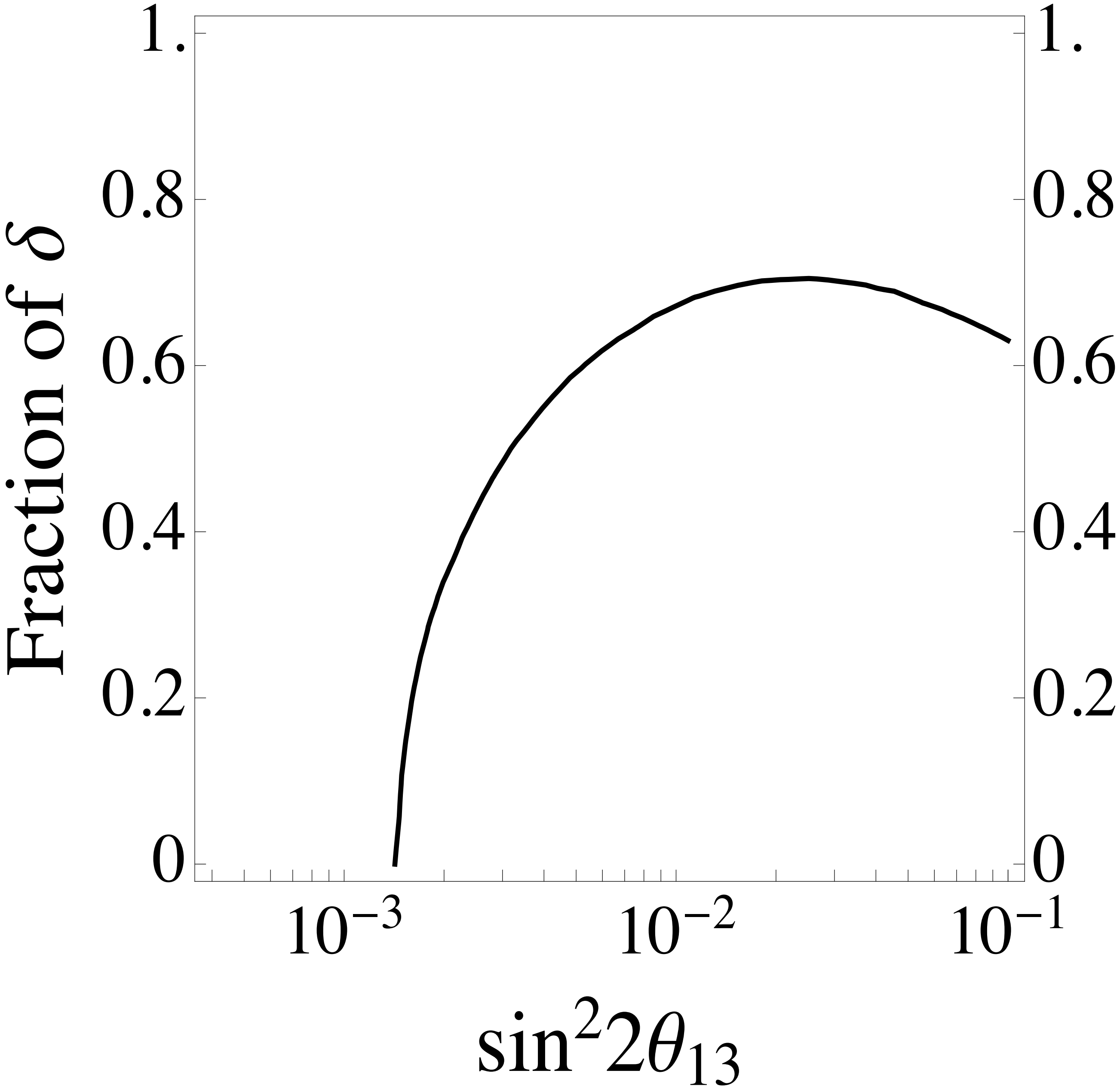


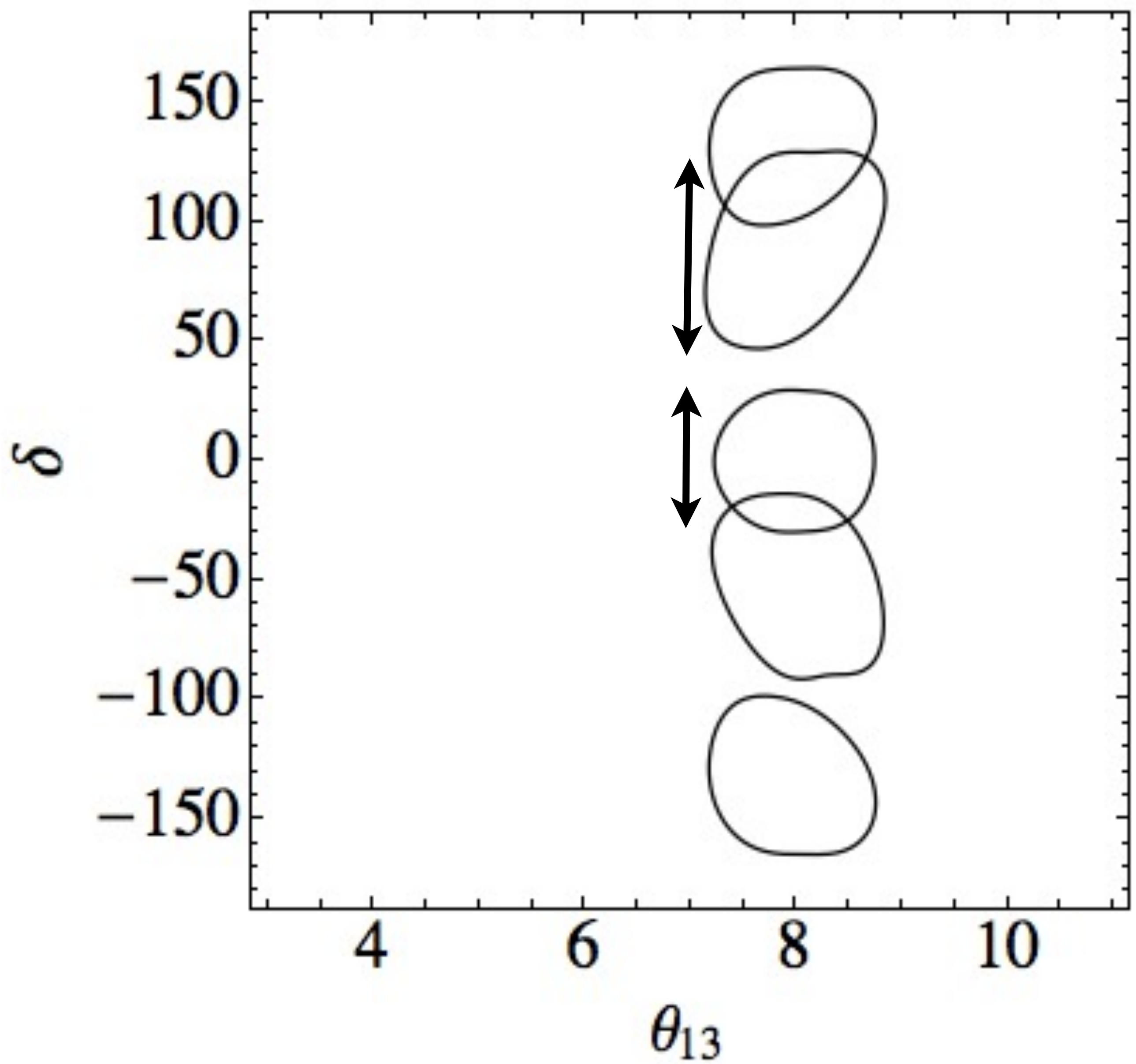
The impact of systematics



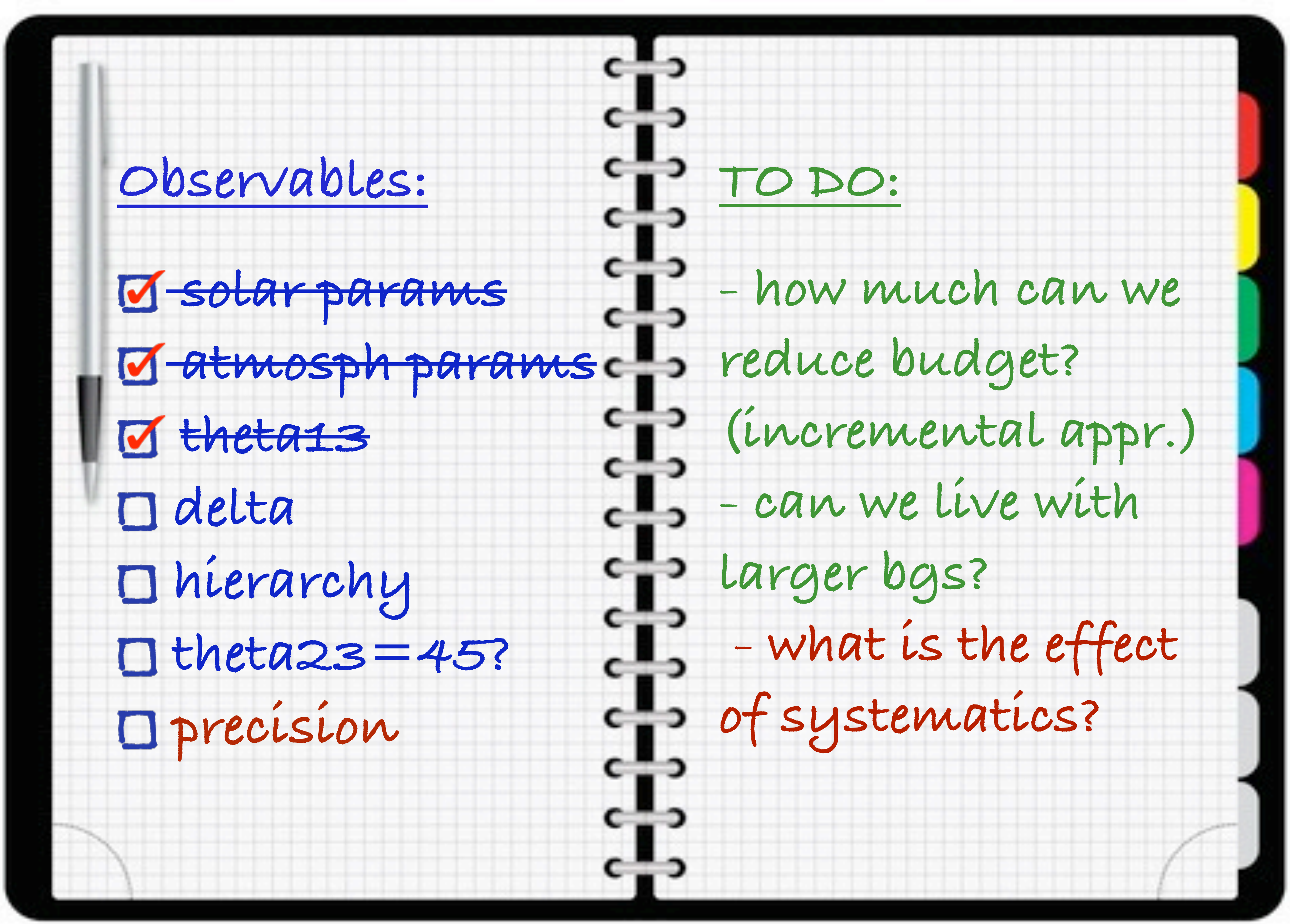
Huber, Mezzetto, Schwetz, 0711.2950 [hep-ph]

Discovery vs precision





Does a large θ_{13} change anything?



Why a NF?

$$\mu^- \rightarrow \nu_\mu + e^- + \bar{\nu}_e$$

$$\nu_\mu \rightarrow \nu_\mu$$

$$\bar{\nu}_e \rightarrow \bar{\nu}_\mu$$

$$\nu_\mu \rightarrow \nu_e \ ?$$

1) Offers multiple channels

2) No beam backgrounds

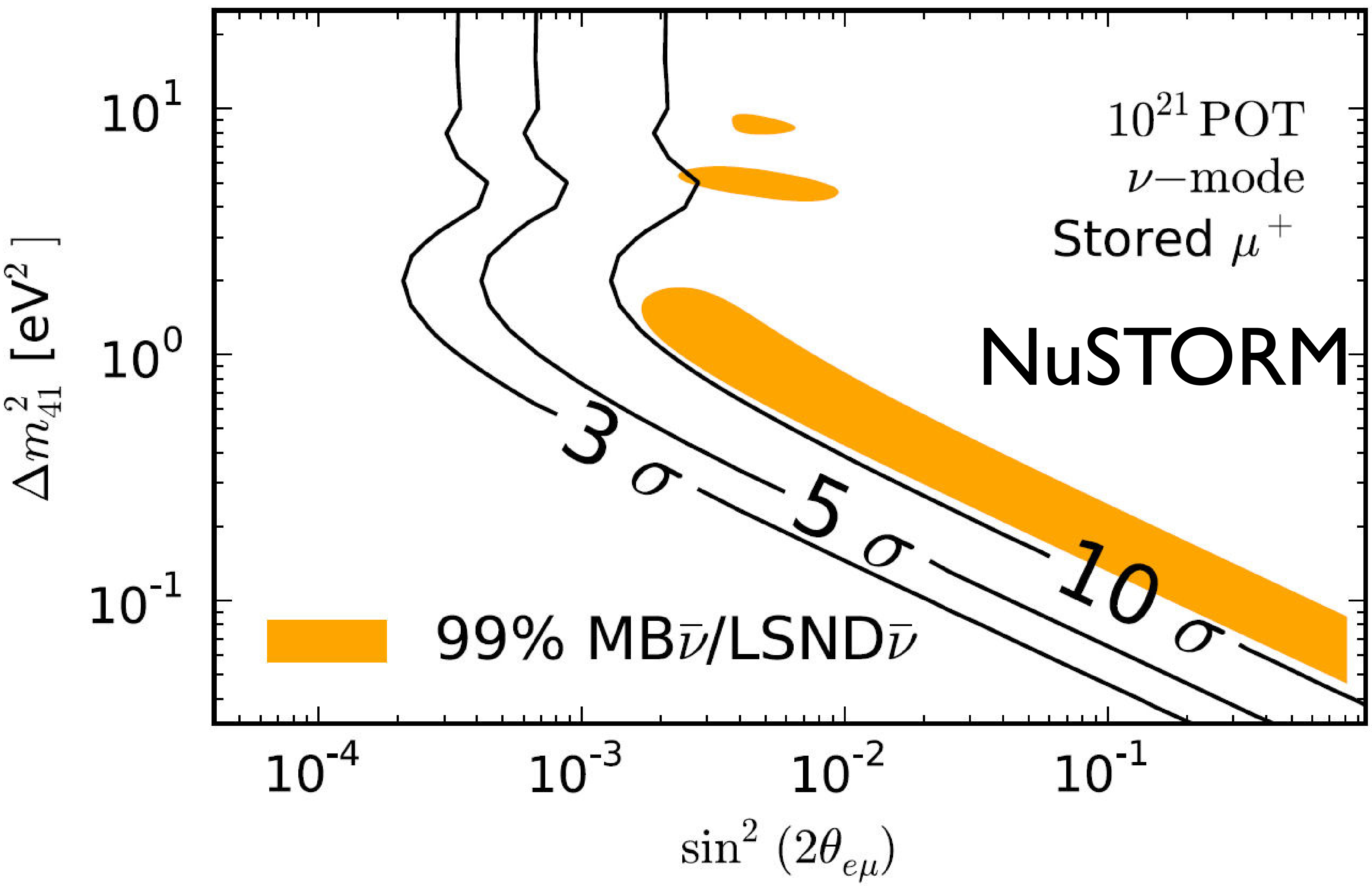
3) Low systematics

4) Great discovery potential and precision

5) Statistically less limited than other facilities

Additional advantages

$$\text{Prob}[\mu \to e] = \sin^2 2\theta \sin^2 \left(\Delta m^2 L/4E\right)$$



Tunnell, Cobb, Bross, 1111.6550 [hep-ph]

Abazajian et al, 1204.5379 [hep-ph]

The concept of a Low Energy Neutrino Factory

The LENF

L=1480 km

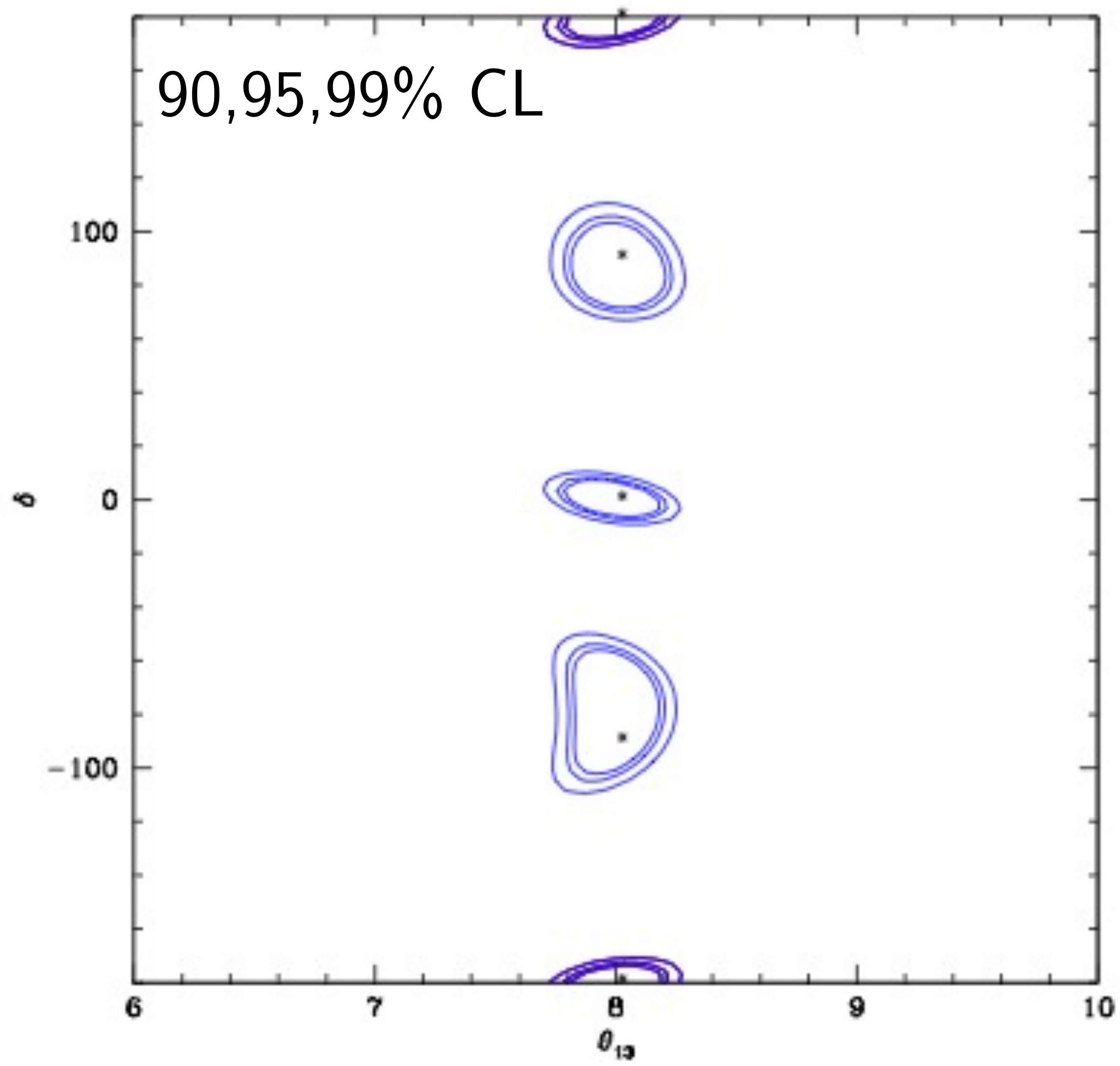
E=4.12 GeV

3x10^{22} kton-decays

(no muon cooling)

100% eff above 0.8 GeV

4 energy bins

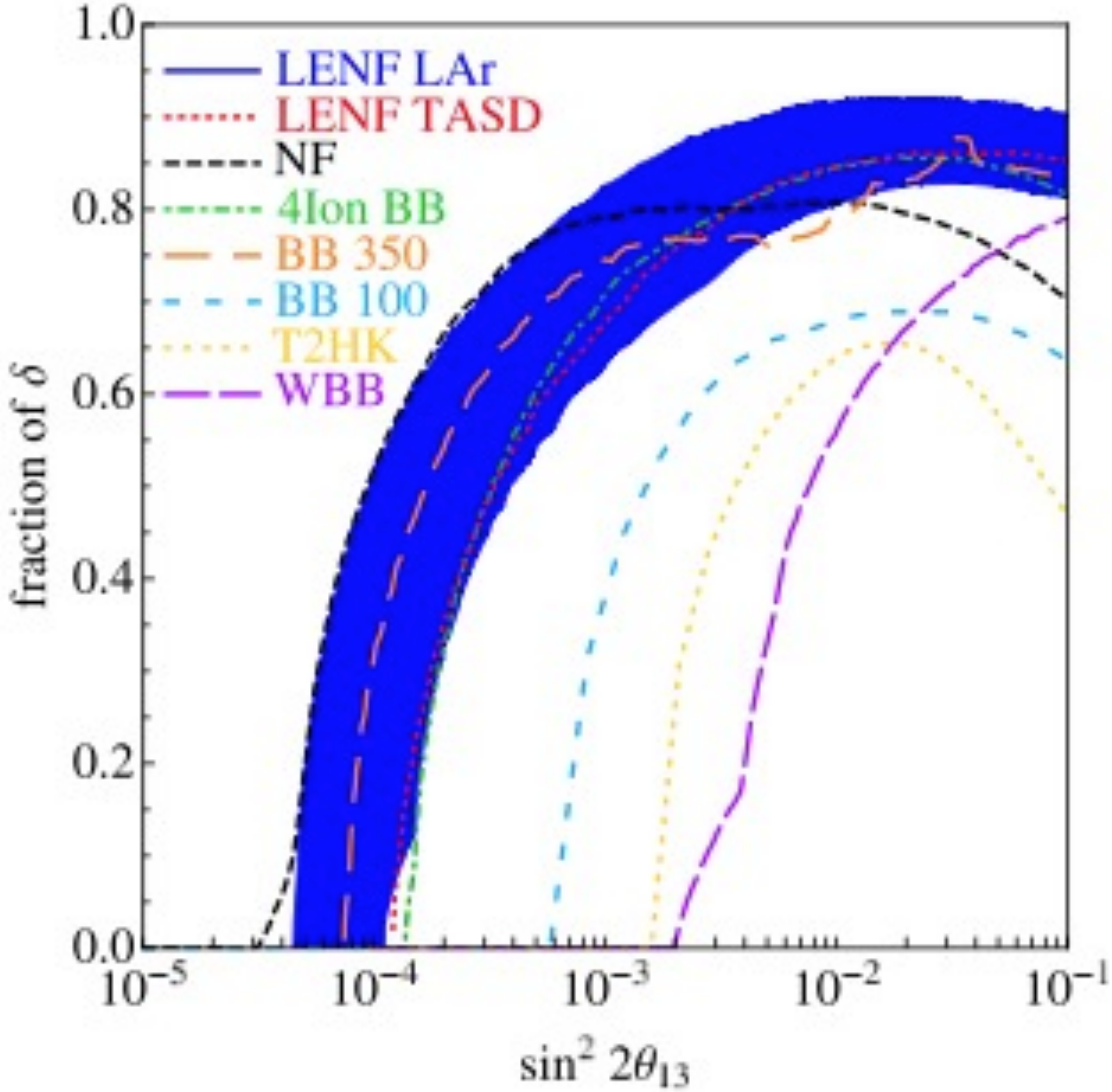


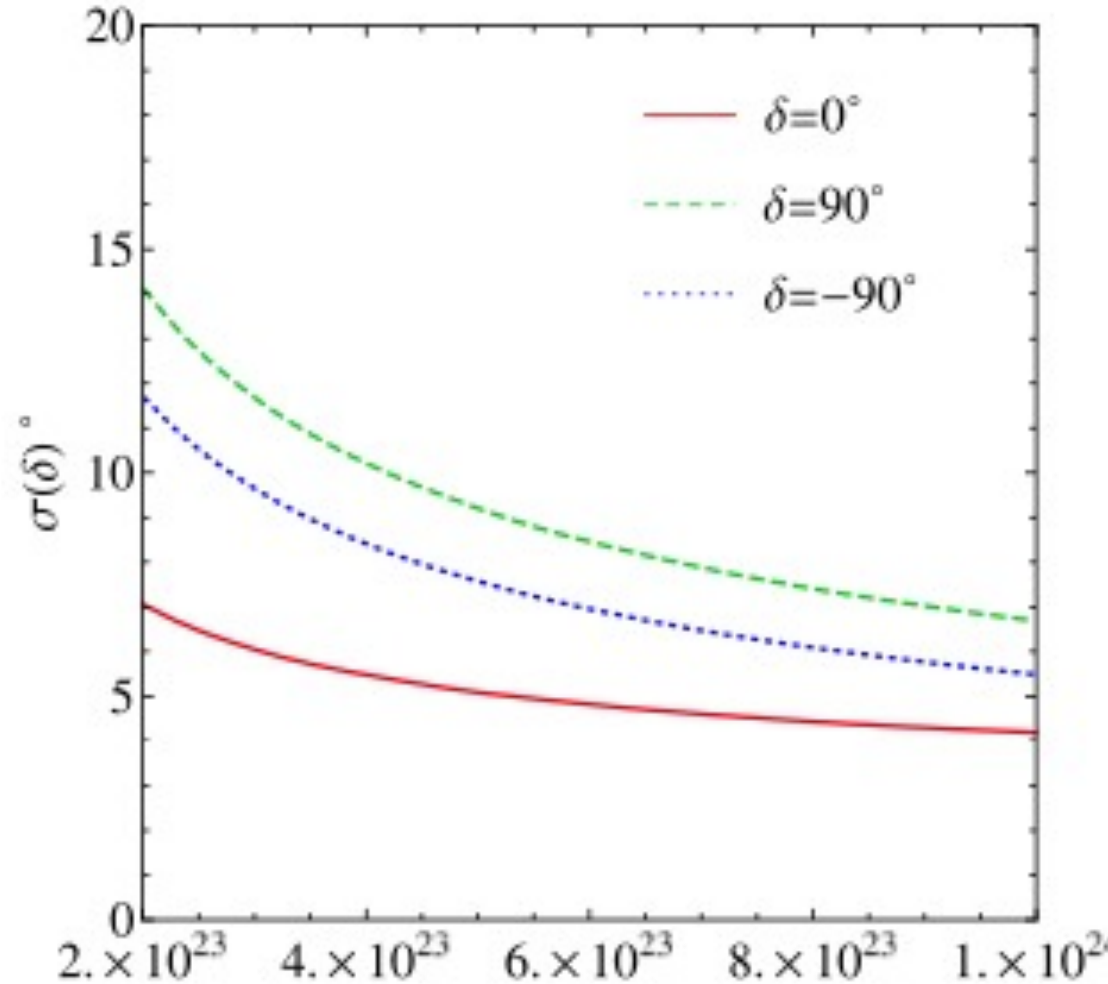
Geer, Mena, Pascoli, hep-ph/0701258

Bross, Ellis, Geer, Mena, Pascoli, 0709.3889 [hep-ph]

Fernández-Martínez, Li, Pascoli, 0911.3776 [hep-ph]

The LENF





Geer, Mena, Pascoli, hep-ph/0701258

Bross, Ellis, Geer, Mena, Pascoli, 0709.3889 [hep-ph]

Fernández-Martínez, Li, Pascoli, 0911.3776 [hep-ph]

L=1300 km

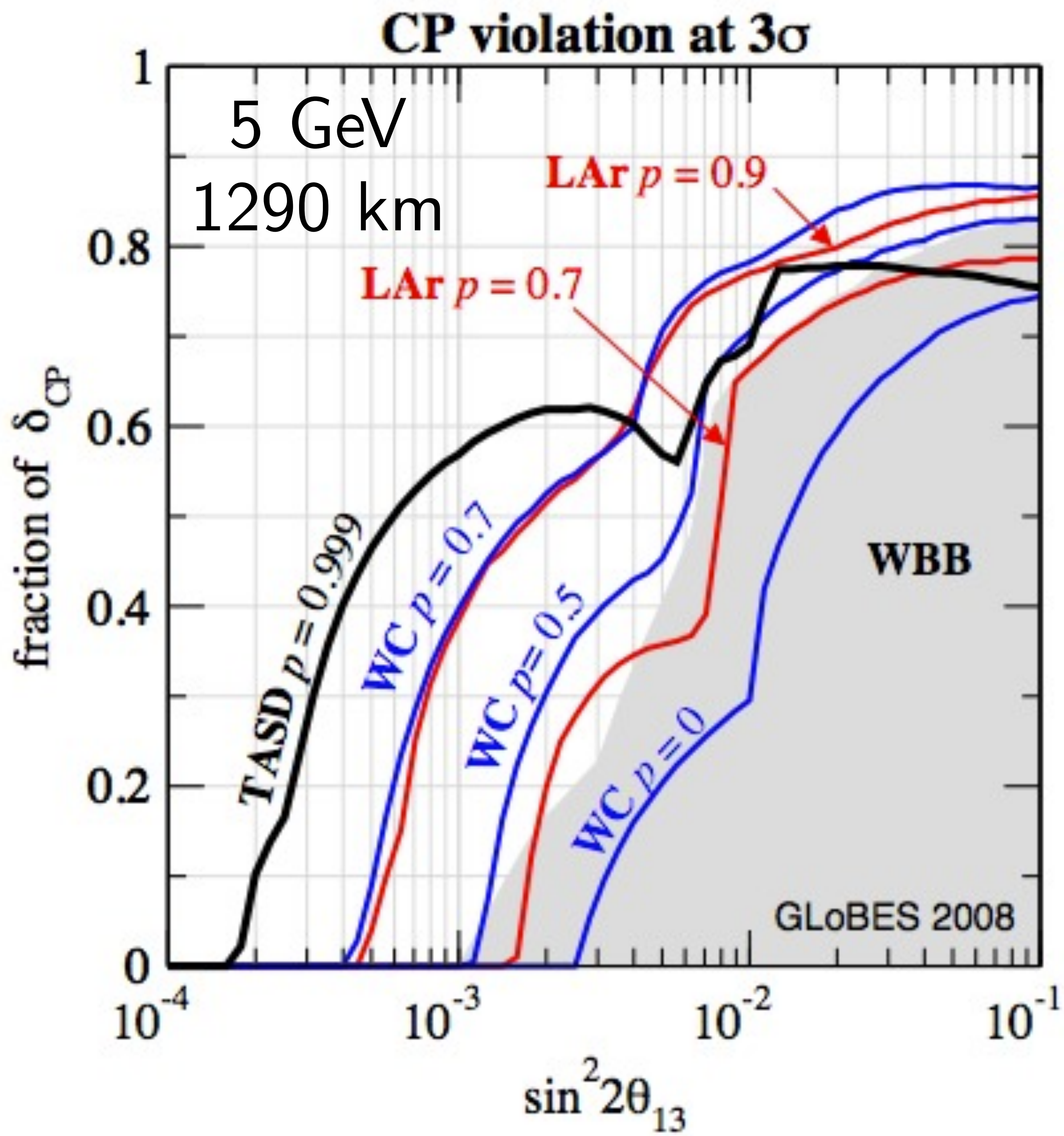
E=4.5 GeV

2.8×10^{23} kton-decays

94 (73)% eff

above (below) 1 GeV

The LENF



Huber, Schwetz, 0805.2019 [hep-ph]

Charge signatures in non-magnetized detectors:

1) μ^- capture in nuclei

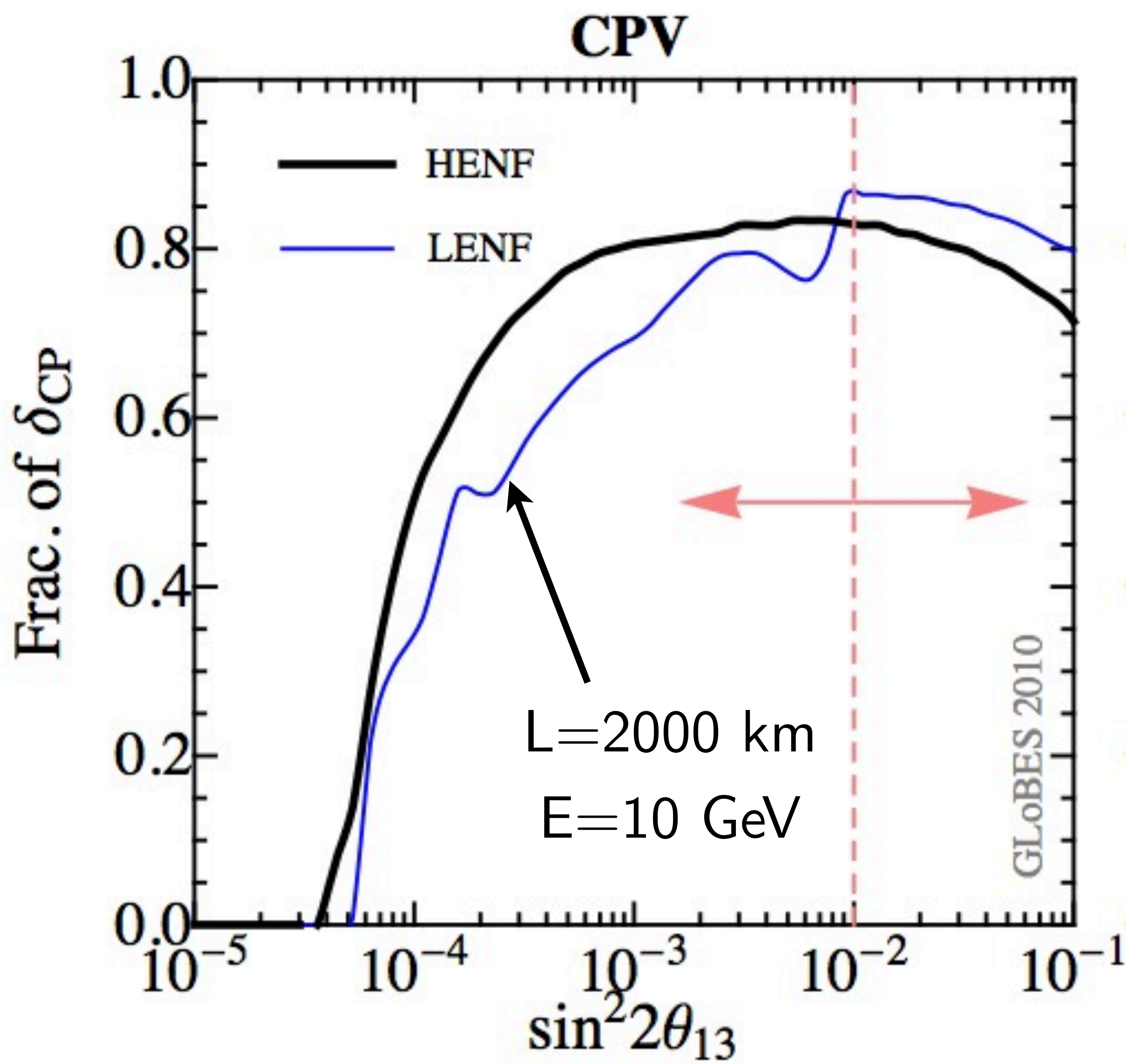
2) different angles between incoming neutrino and outgoing lepton in lab frame for QE events

3) tag protons for neutrinos and neutrons for antineutrinos in QE interactions

The LENF

Latest MIND simulations show that a LENF could also use magnetized iron:

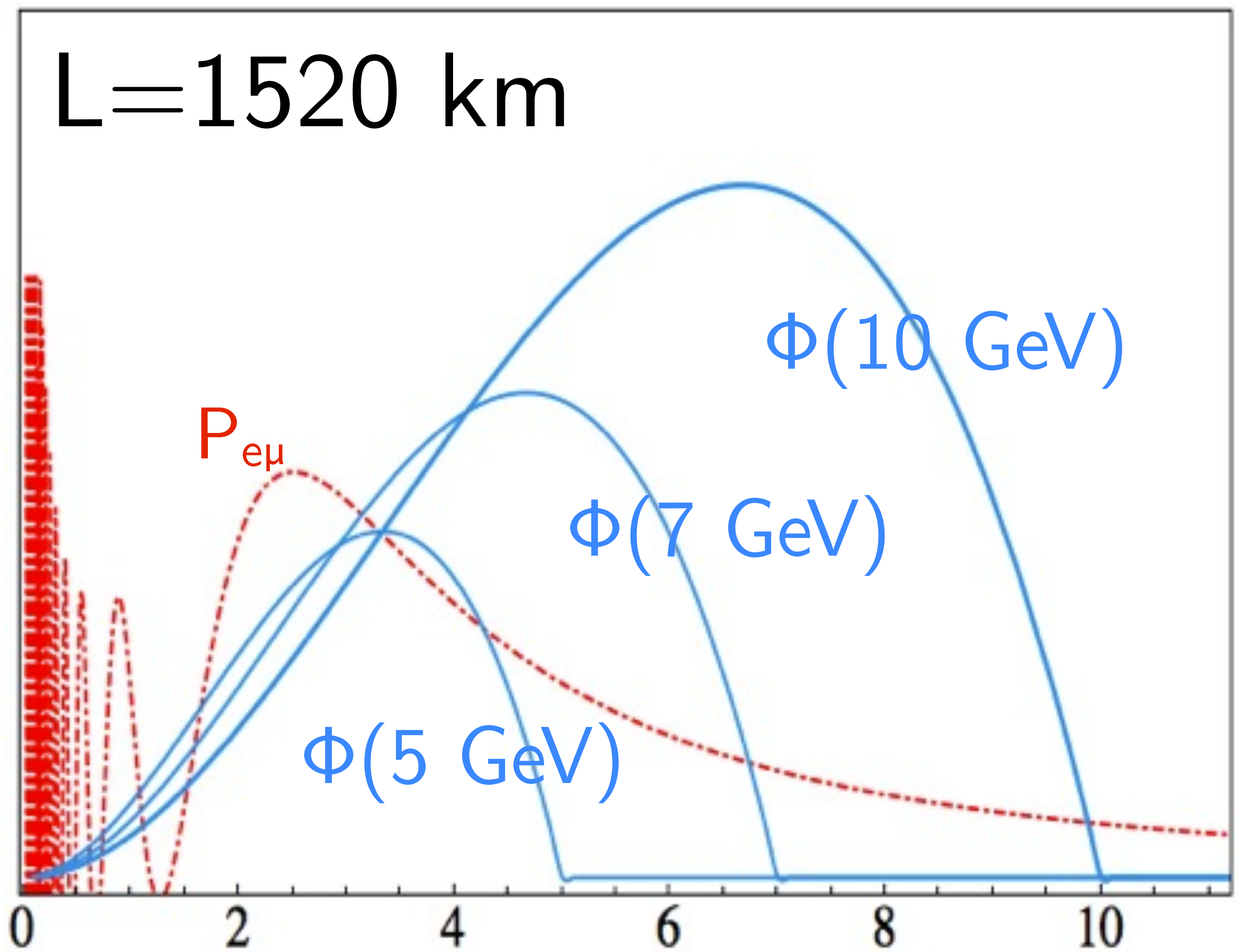
- well-known technology
- can be built on large scale and easily magnetized

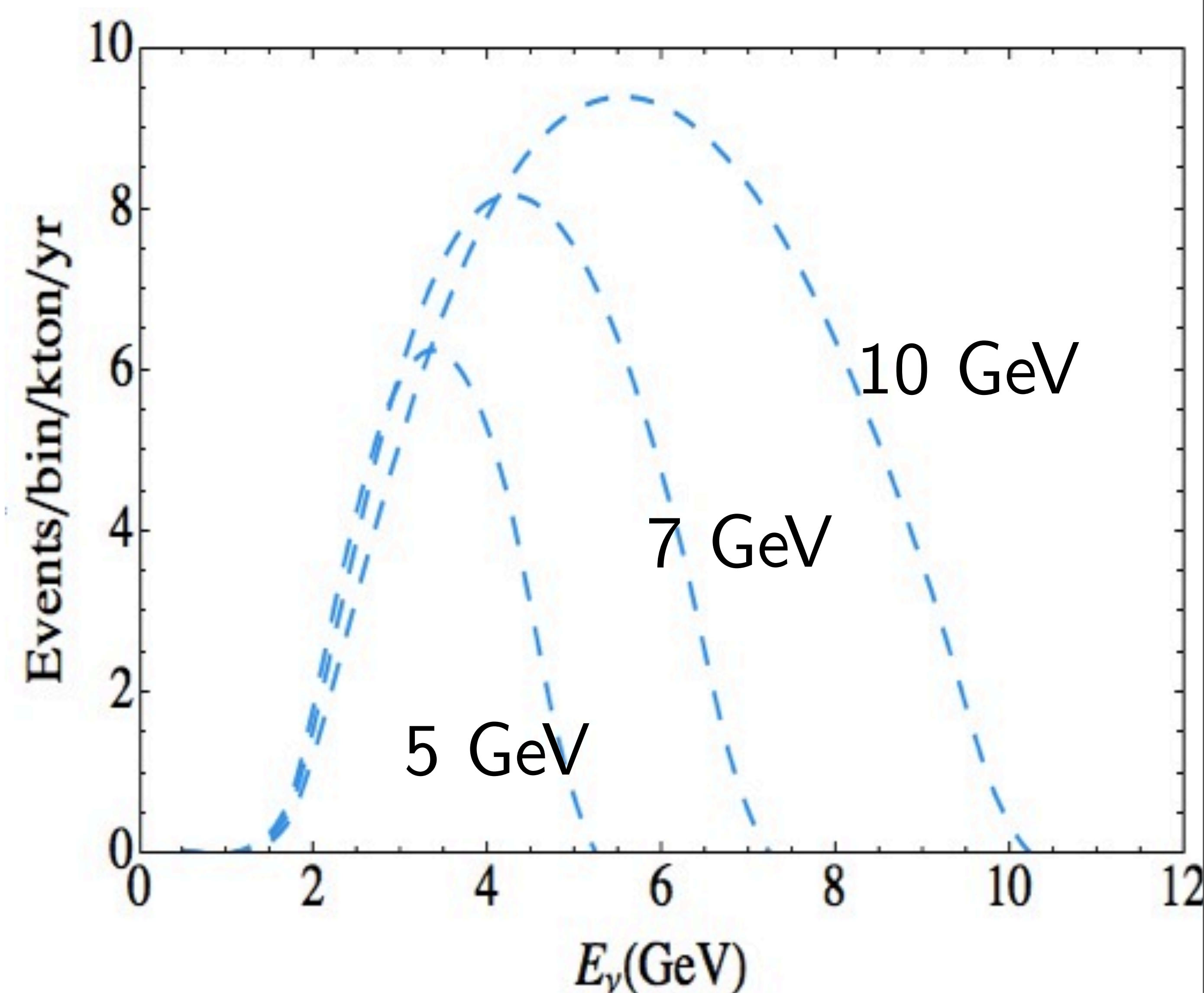


Agarwalla, Huber, Tang, Winter, 1012.1872 [hep-ph]

Cervera, Laing, Martín-Albo, Soler, 1004.0358 [hep-ex]

A setup from RAL to GS





Incremental approach

- The NF at full luminosity (10^{21} muons/yr) relies on a high power proton driver and muon cooling...
  - Muon cooling needed? ($\sim$1.7 less muon decays)
  - 4 MW needed? what could be done with 800 kW?
  - 100 kton detector needed?
  - Huge bg rejection factors (10^{-4}) needed?
- Exposure-thinking: how much can beam/detector requirements be reduced?

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These are equivalent to an order of magnitude in total exposure

Possible detectors

Totally-Active Detector (TAD)

- Considered magnetizable, but at most 30 kton
- High efficiency and energy resolution
- Bin width of 125 MeV
- Bg rejection of 10^{-3} assumed
- NC backgrounds migrated with matrices from LBNE
- Platinum channel can be added (10^{-2} bg rejection assumed)

MIND

- Magnetized, at most 100 kton fiducial
- Migration matrices from 1004.0358 [hep-ex]
- Bin width ranging from 1 to 5 GeV

Mass hierarchy and CPV discovery potentials

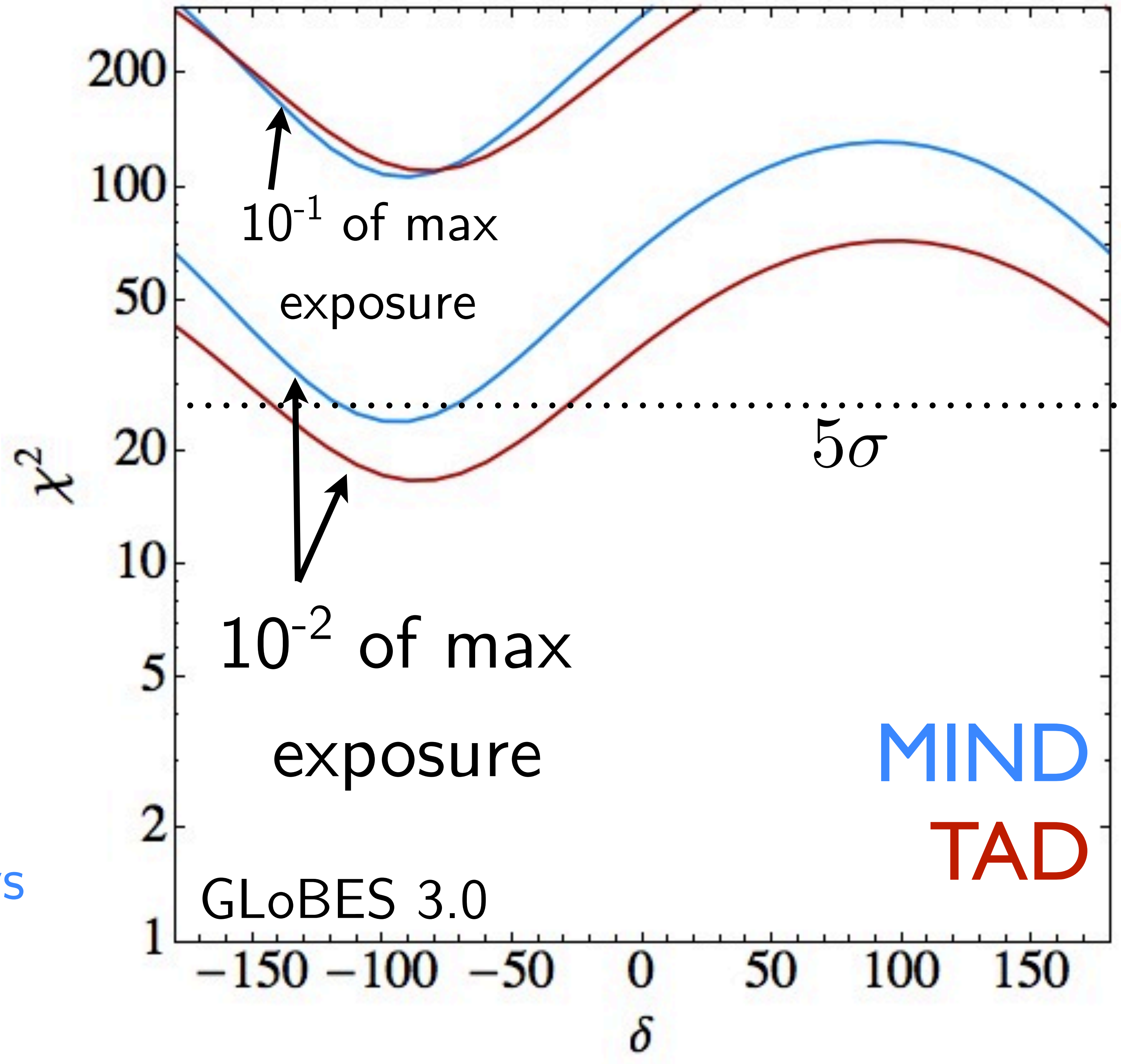
Mass hierarchy

Maximum exposure:

- 5×10^{20} muon decays polarity/yr
- 10 yr
- 2×10^{7} useful sec/yr
- 100 kton for MIND
- 30 kton for TAD

for MIND: $(1\text{-}2) \times 10^{24}$ kton decays

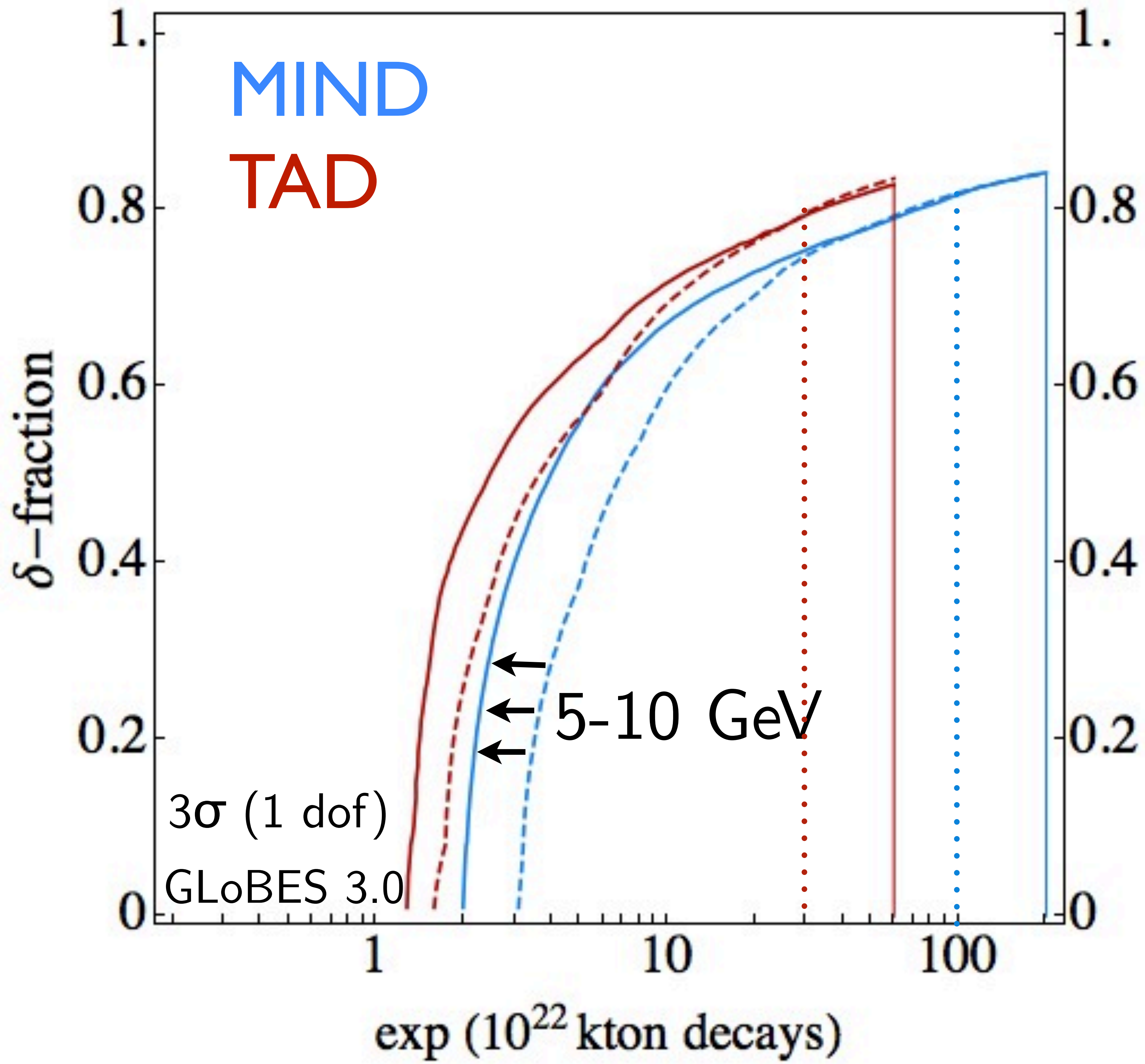
for TAD: $(3\text{-}6) \times 10^{23}$ kton decays



CP violation

Mild dependence on neutrino energy

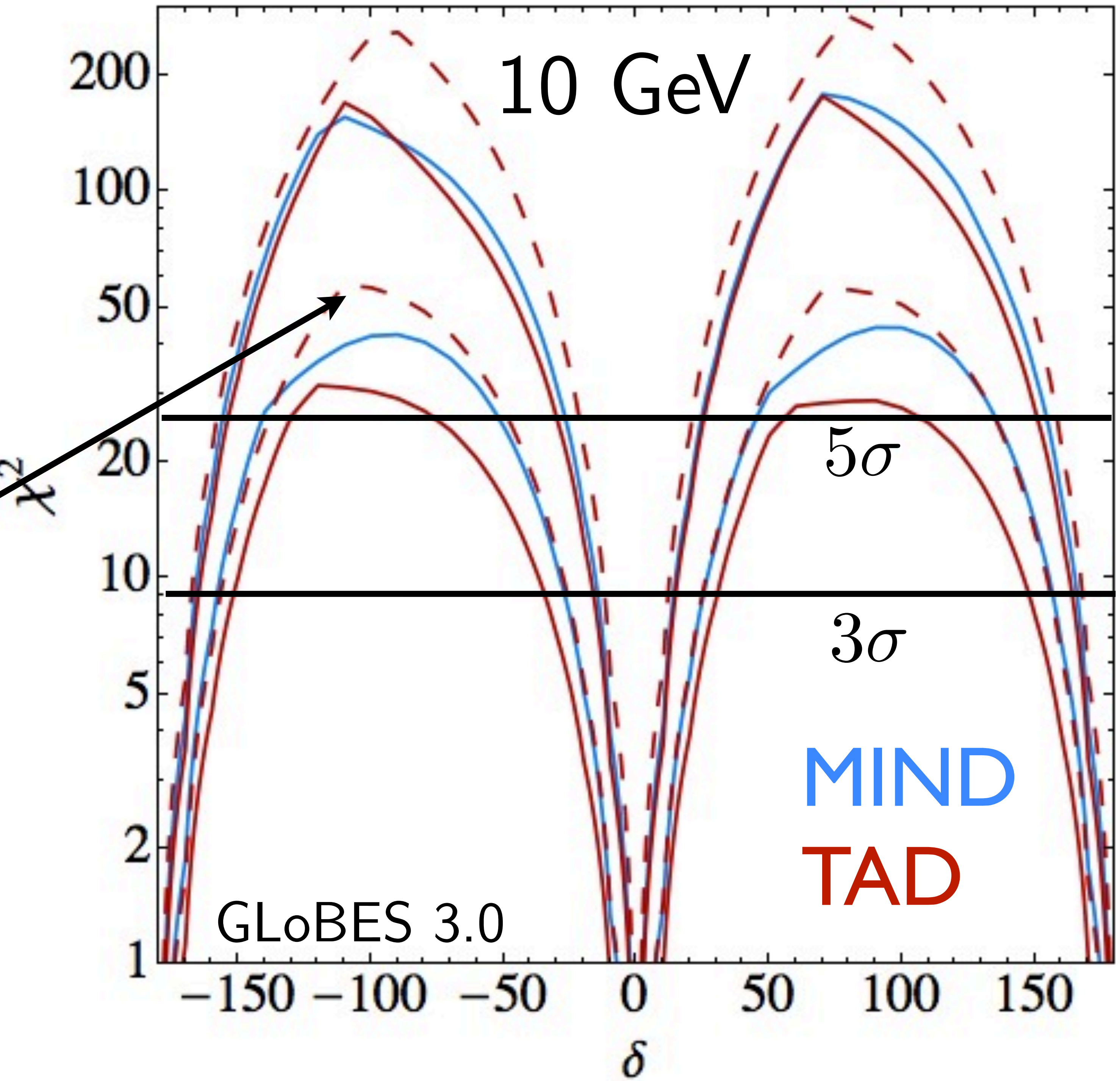
We'll see later that this is not the case for precision, though...



CP violation

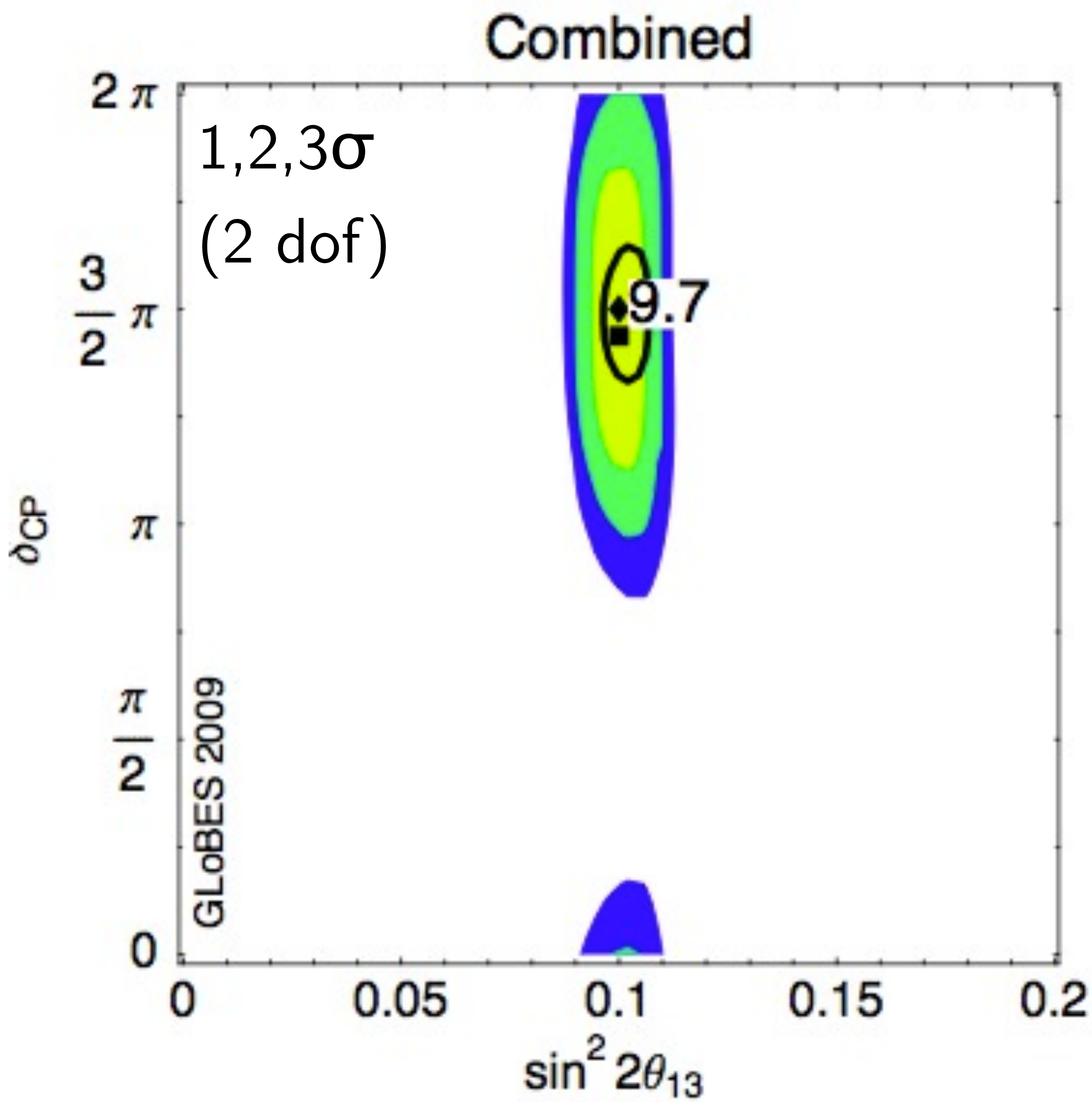
Even reducing the total exposure by an order of magnitude, 5σ still at reach for both detectors

Effect of platinum is non-negligible but noticeable at high CL only

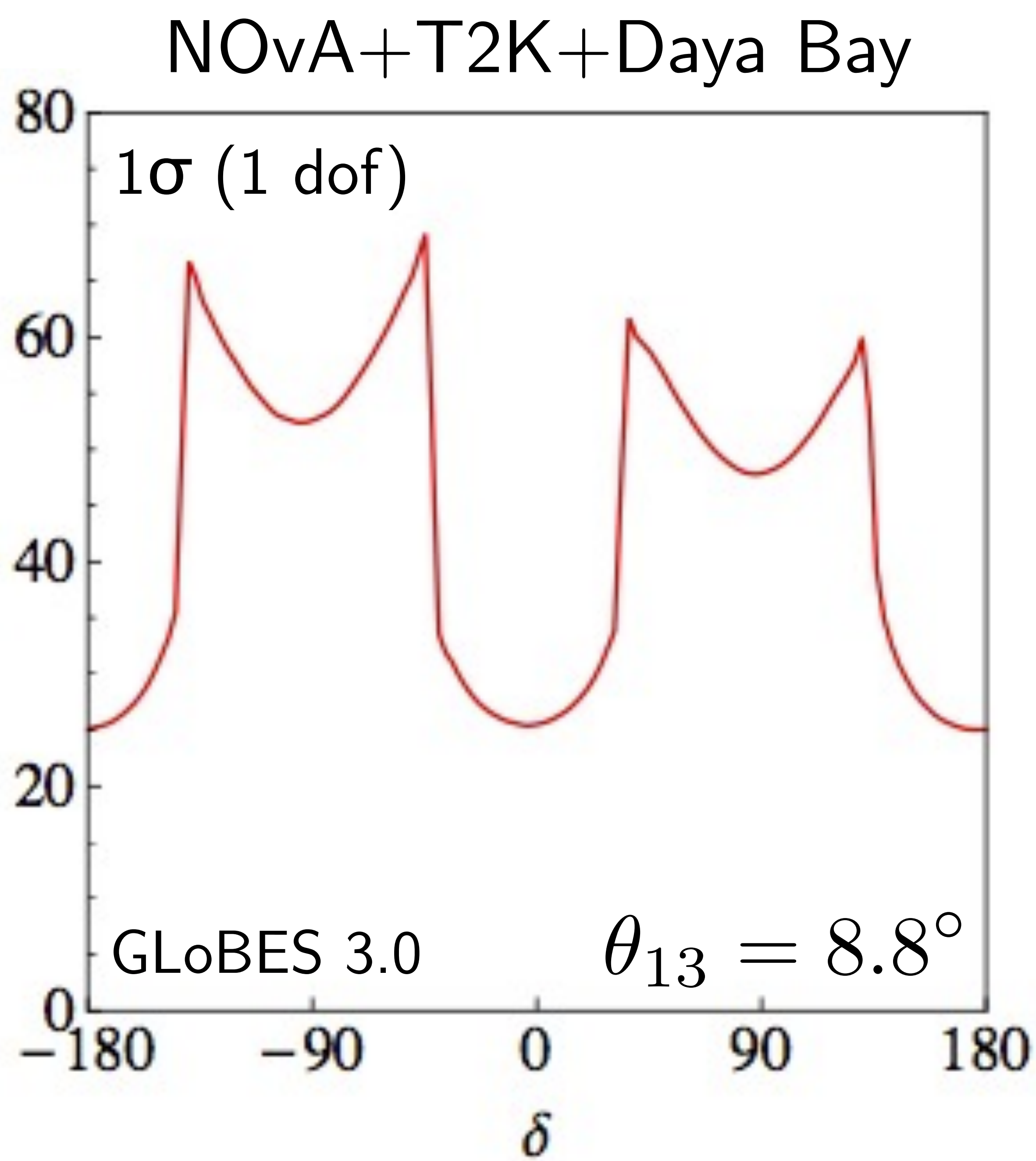


Precision

The starting point

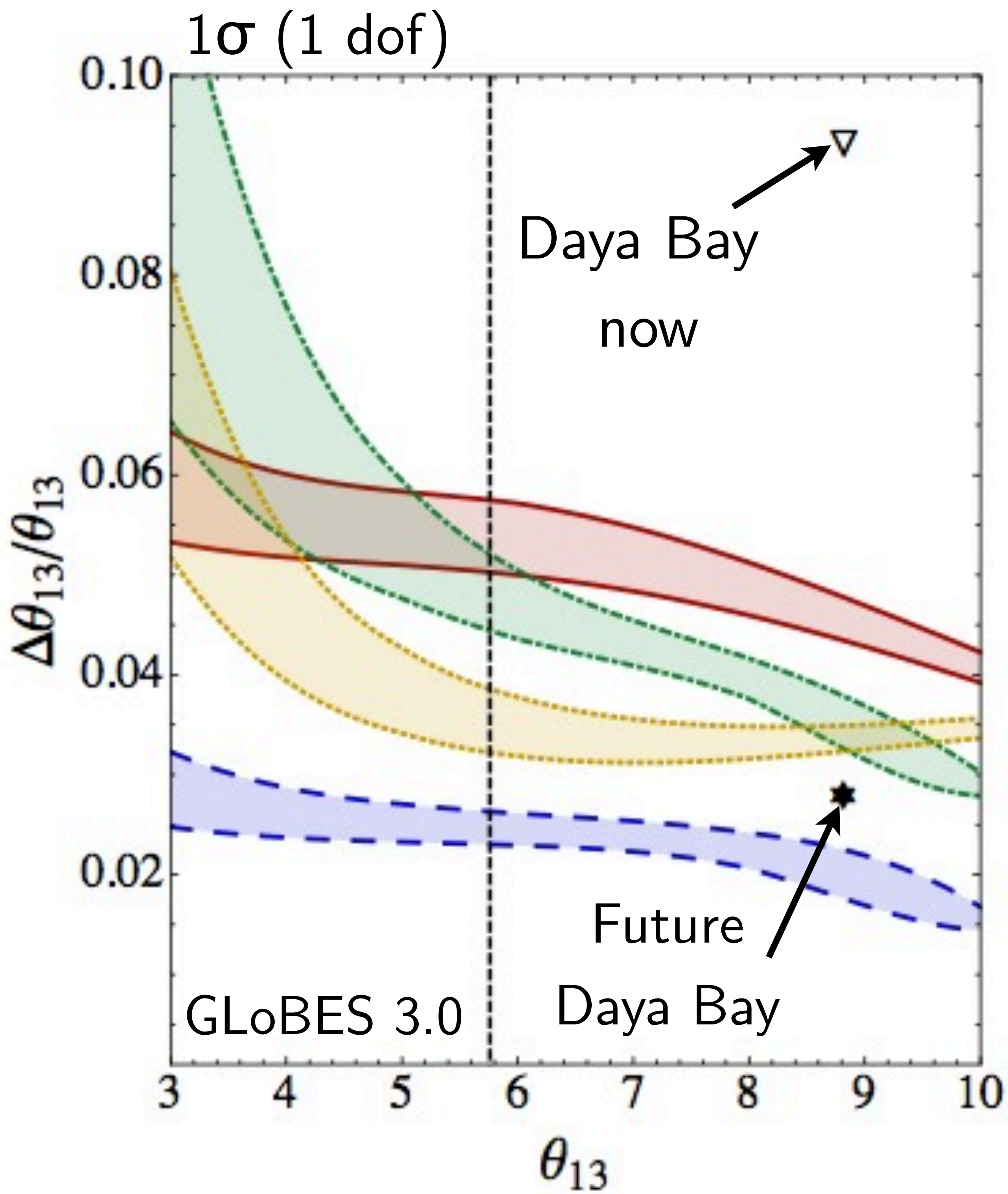


Huber, Lindner, Schwetz, Winter, 0907.1896 [hep-ph]



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

Precision



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

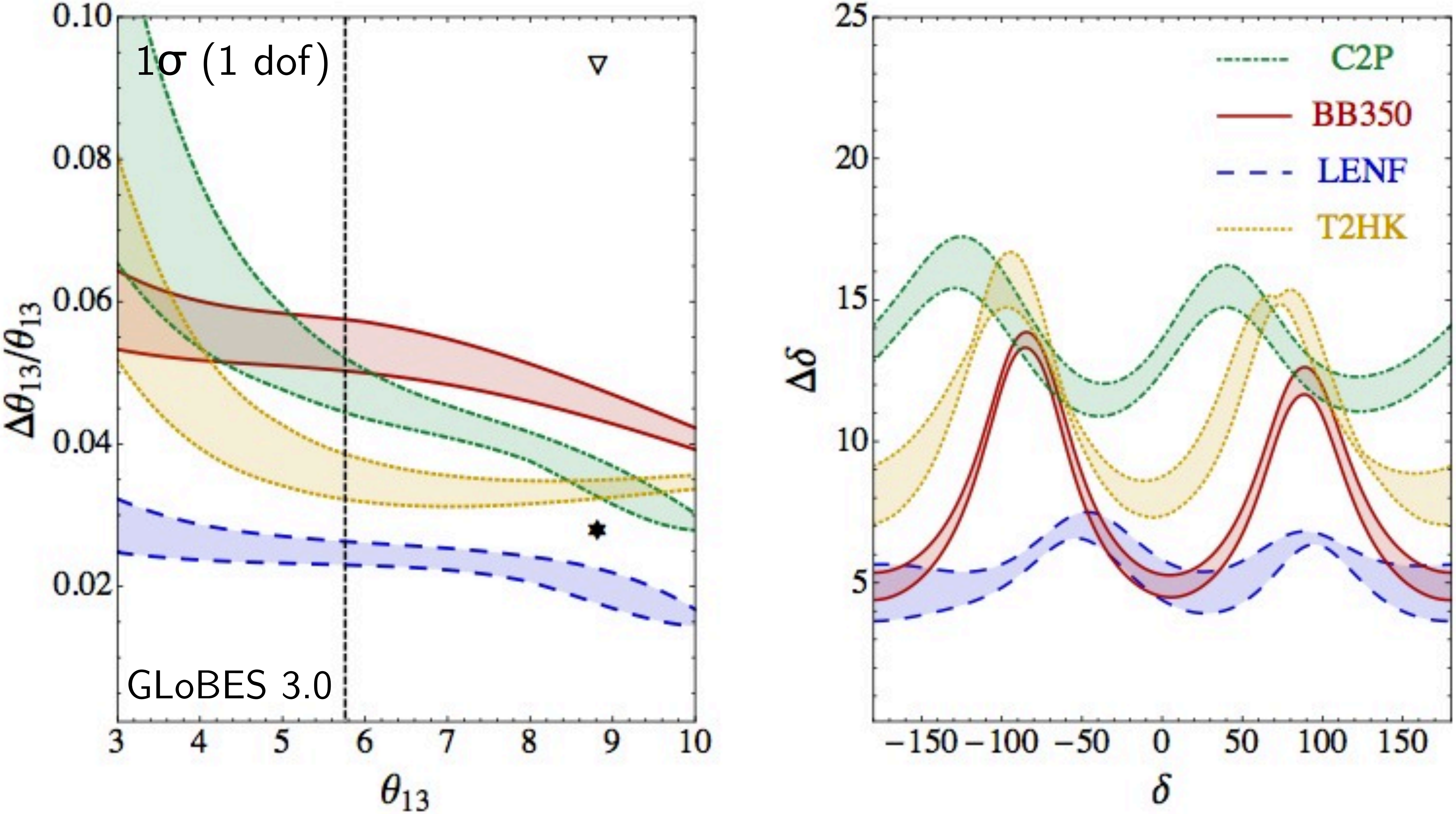
C2P: 800 kW, 100 kton LAr, 2300 km, 5% sys

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

LENF@2000: 1.4x10^{21} μ decays 100 kton MIND, 2000 km, E=10 GeV,2.5% sys

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

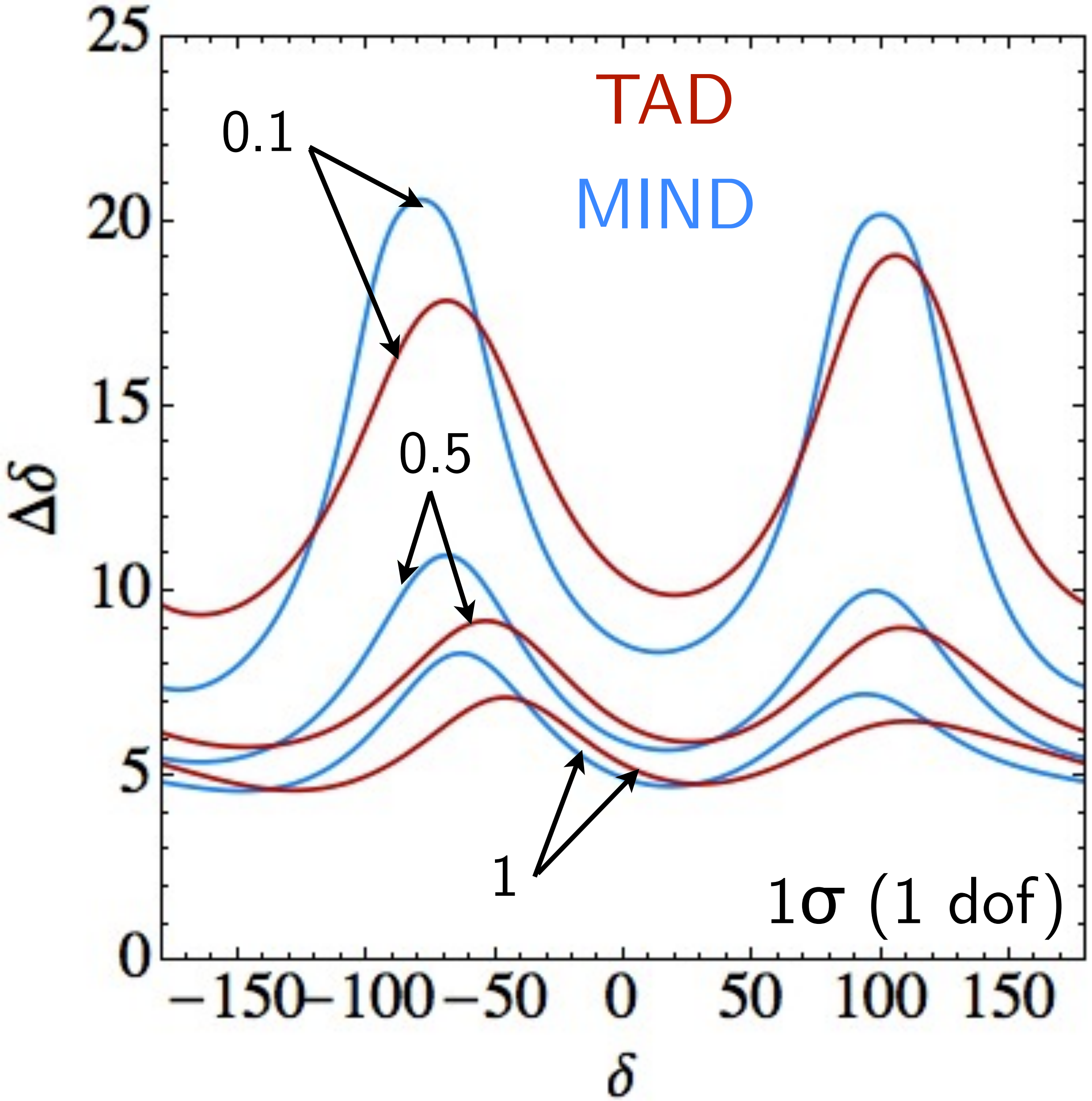
Precision

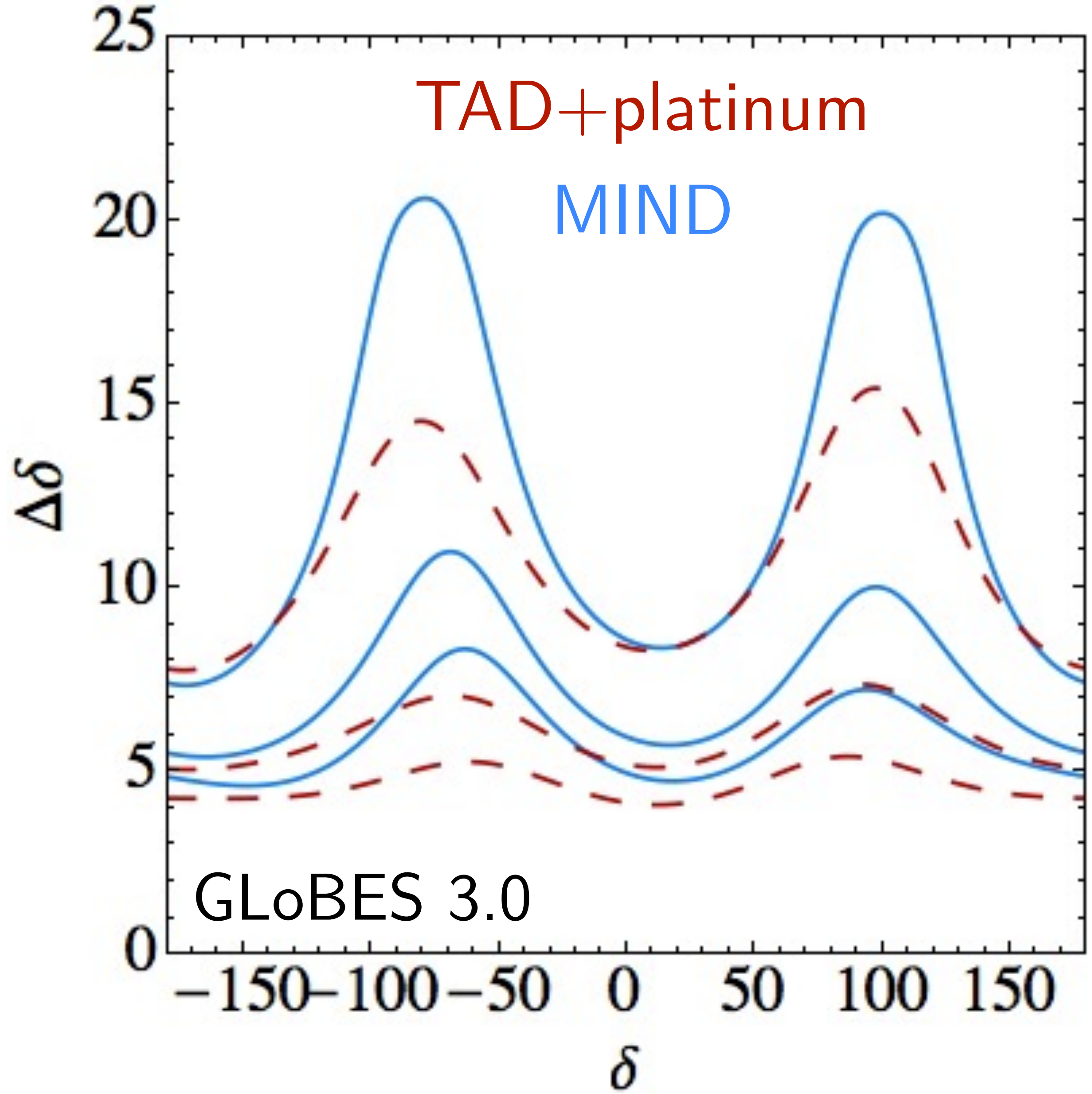


PC, Donini, Fernández-Martínez, Hernández, 1203.5651 [hep-ph]

Precision at the LENF

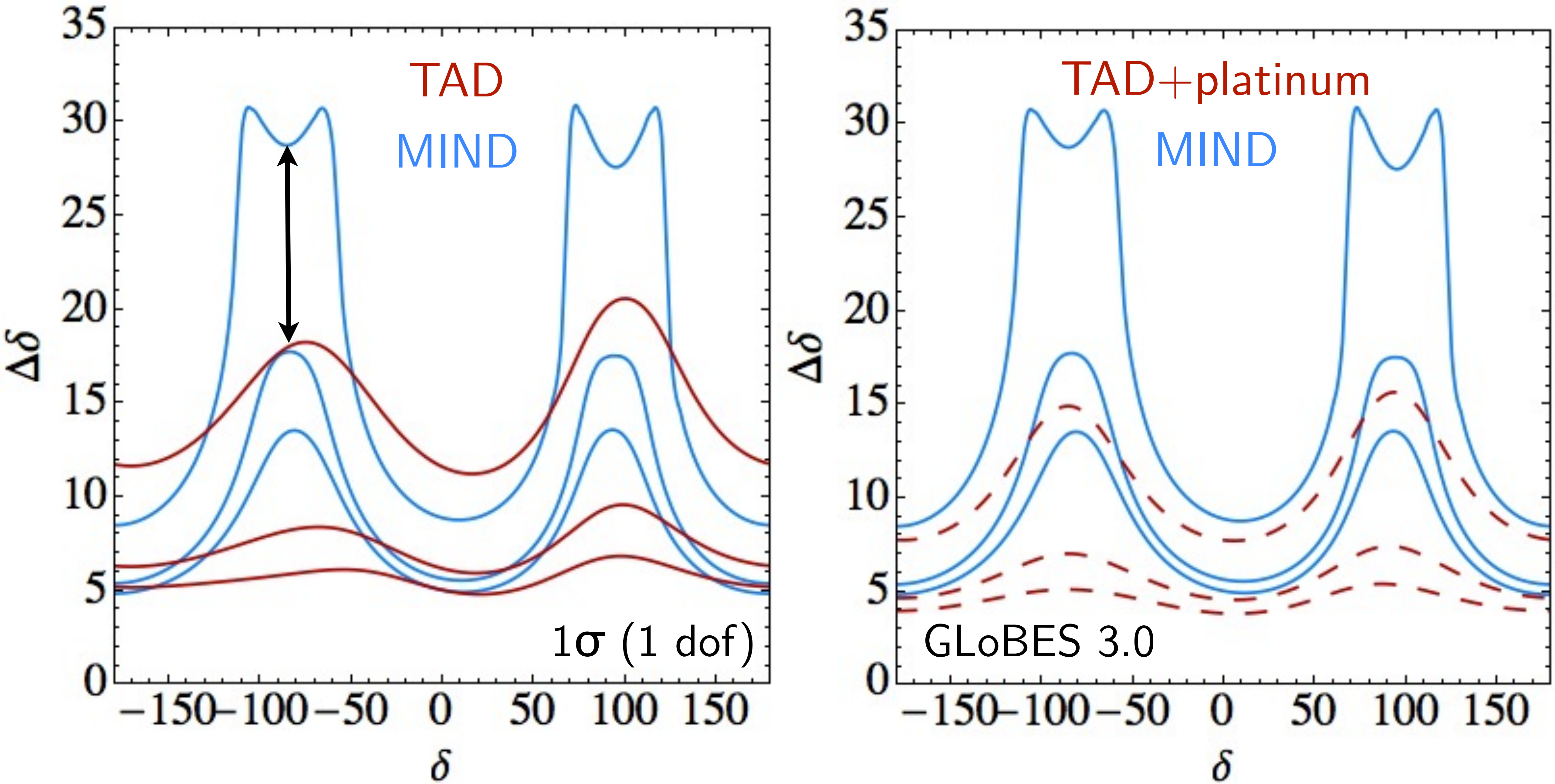
For E=10 GeV and different exposures



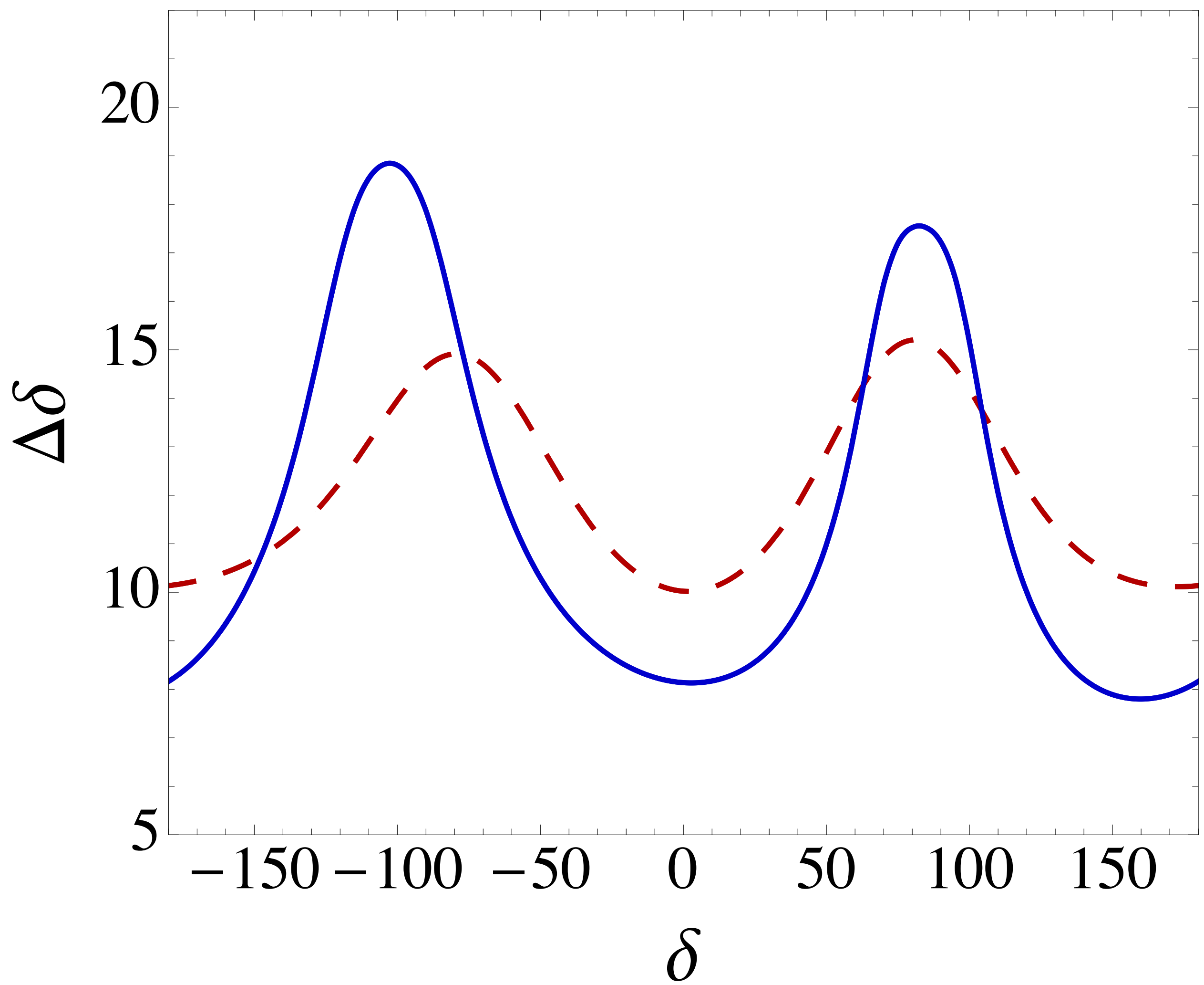


Precision at the LENF

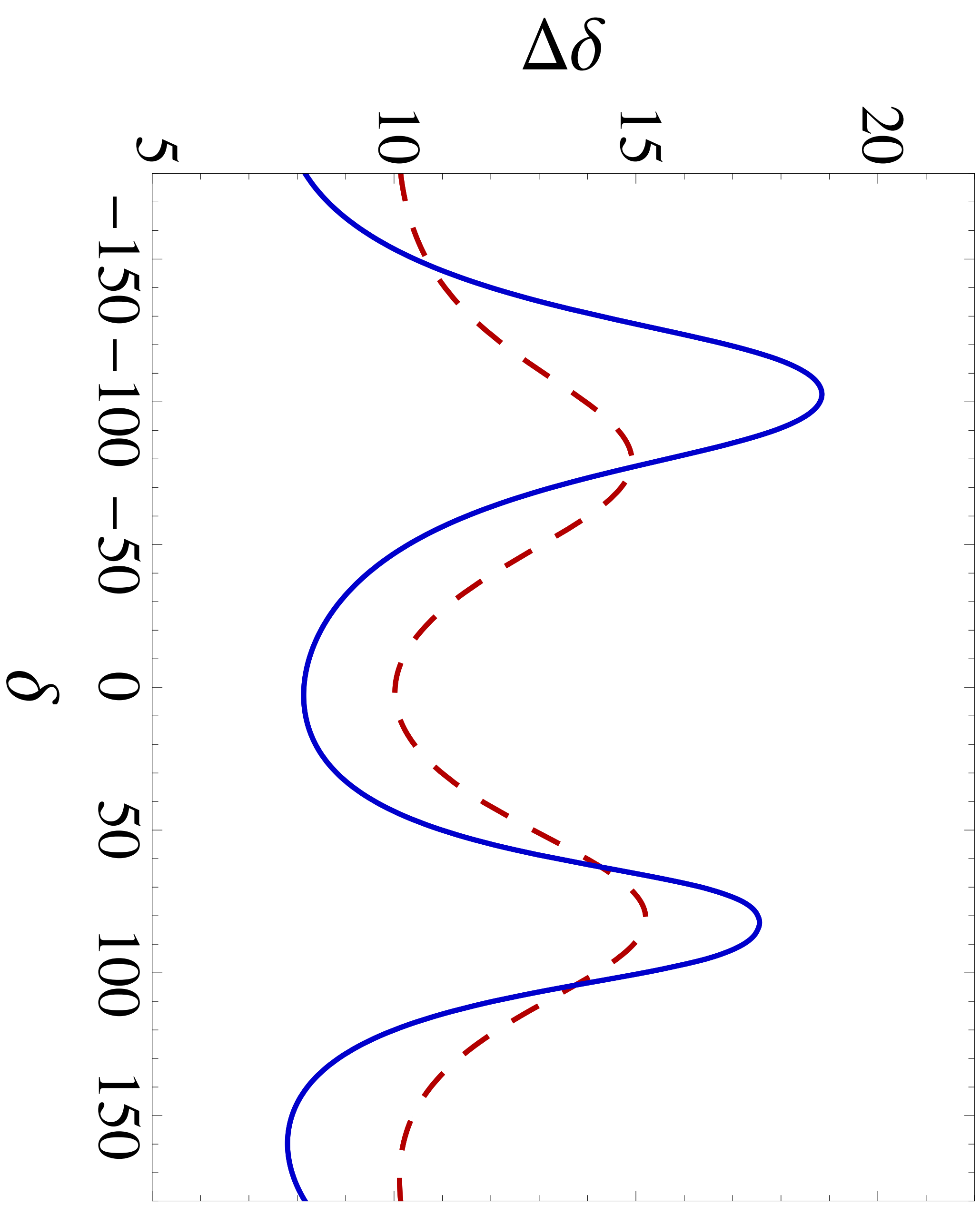
For E=5 GeV and different exposures



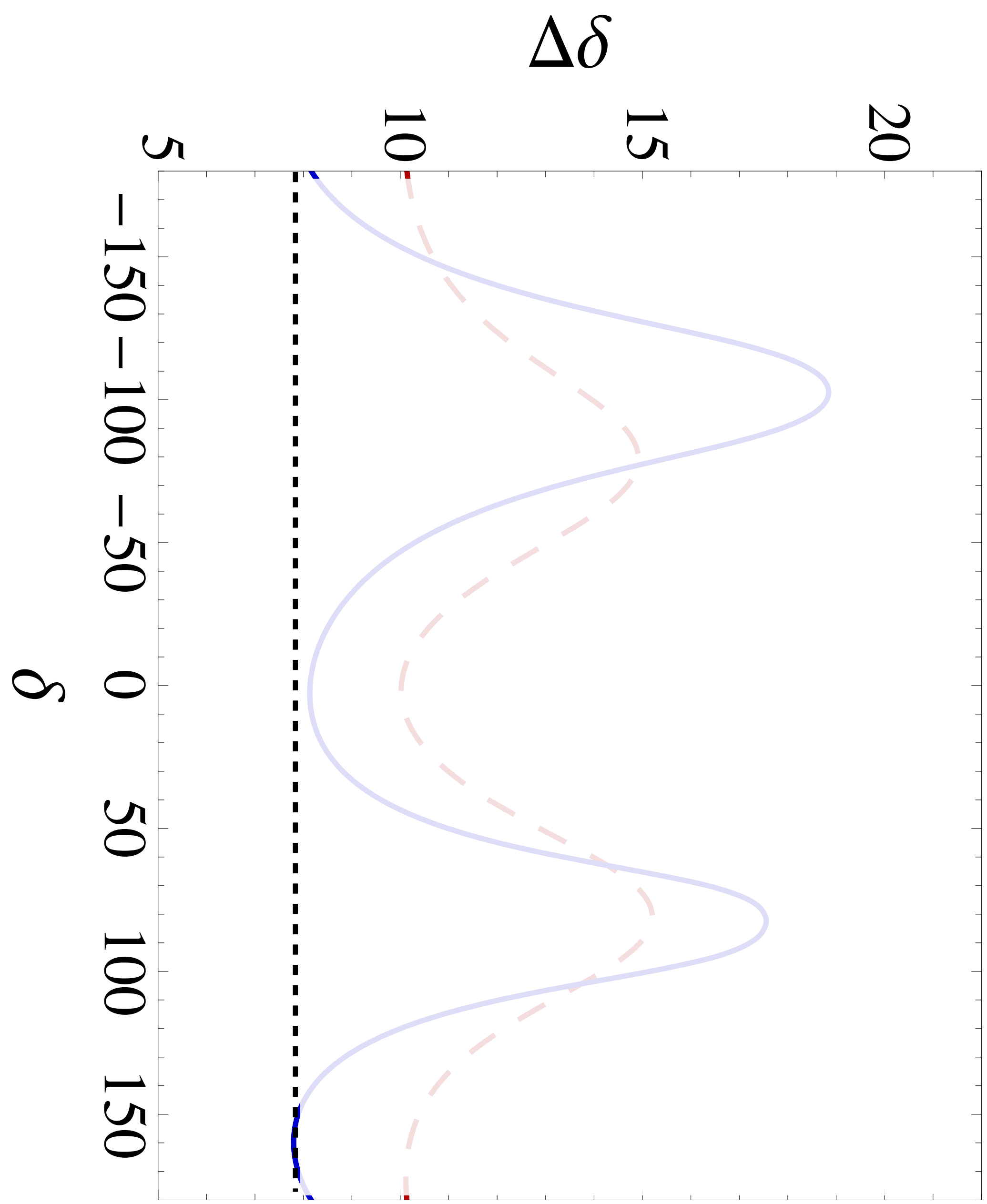
Precision and CP fraction

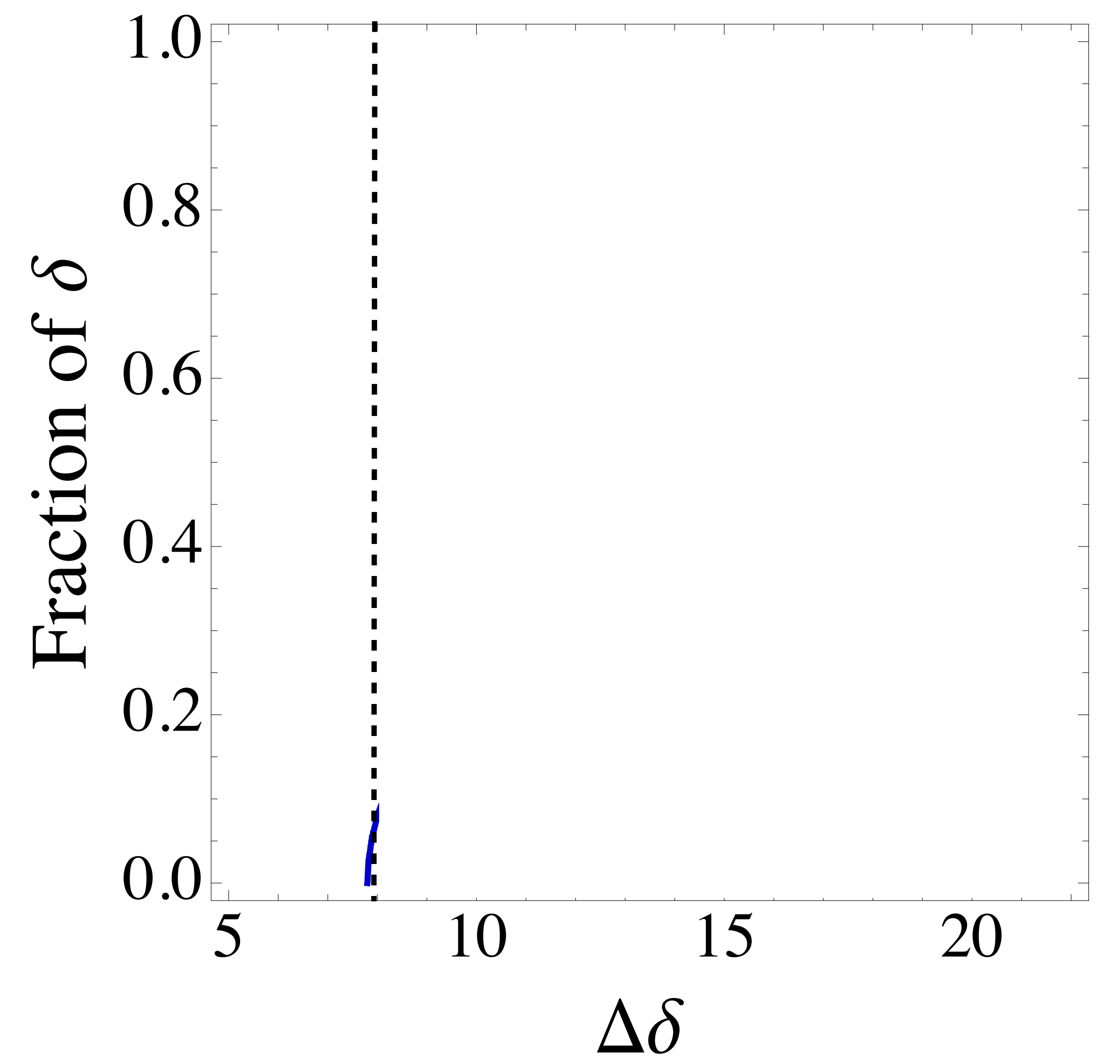


Precision and CP fraction

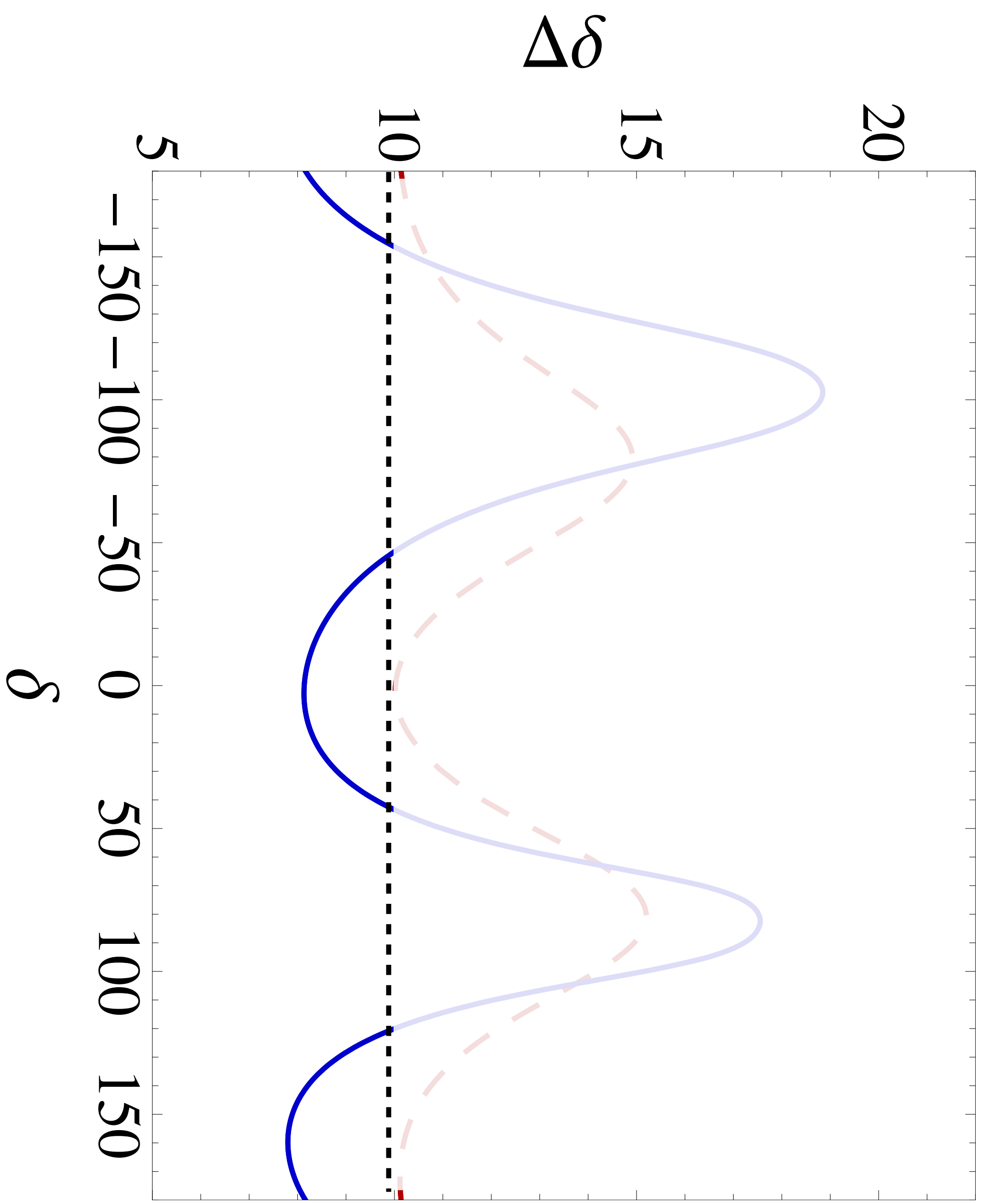


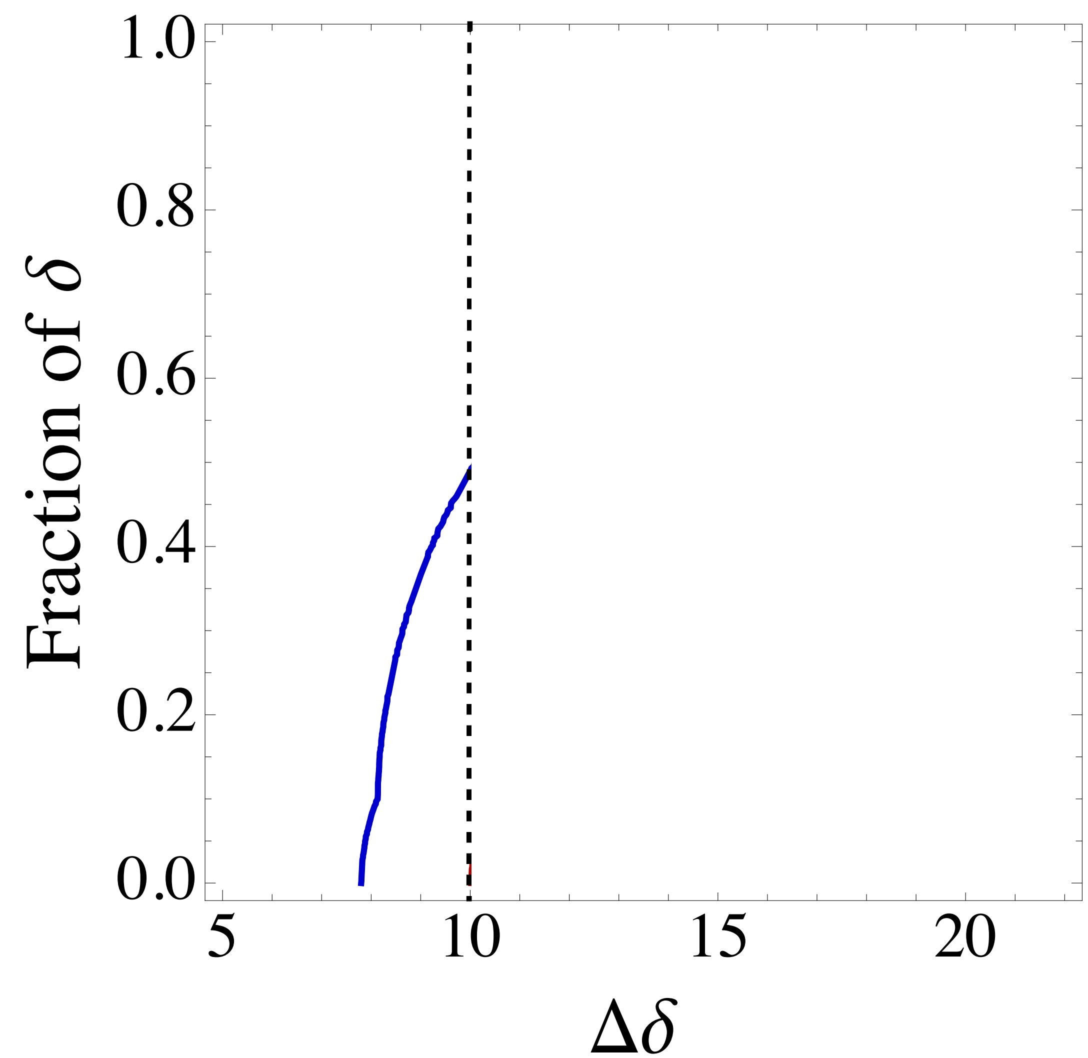
Precision and CP fraction



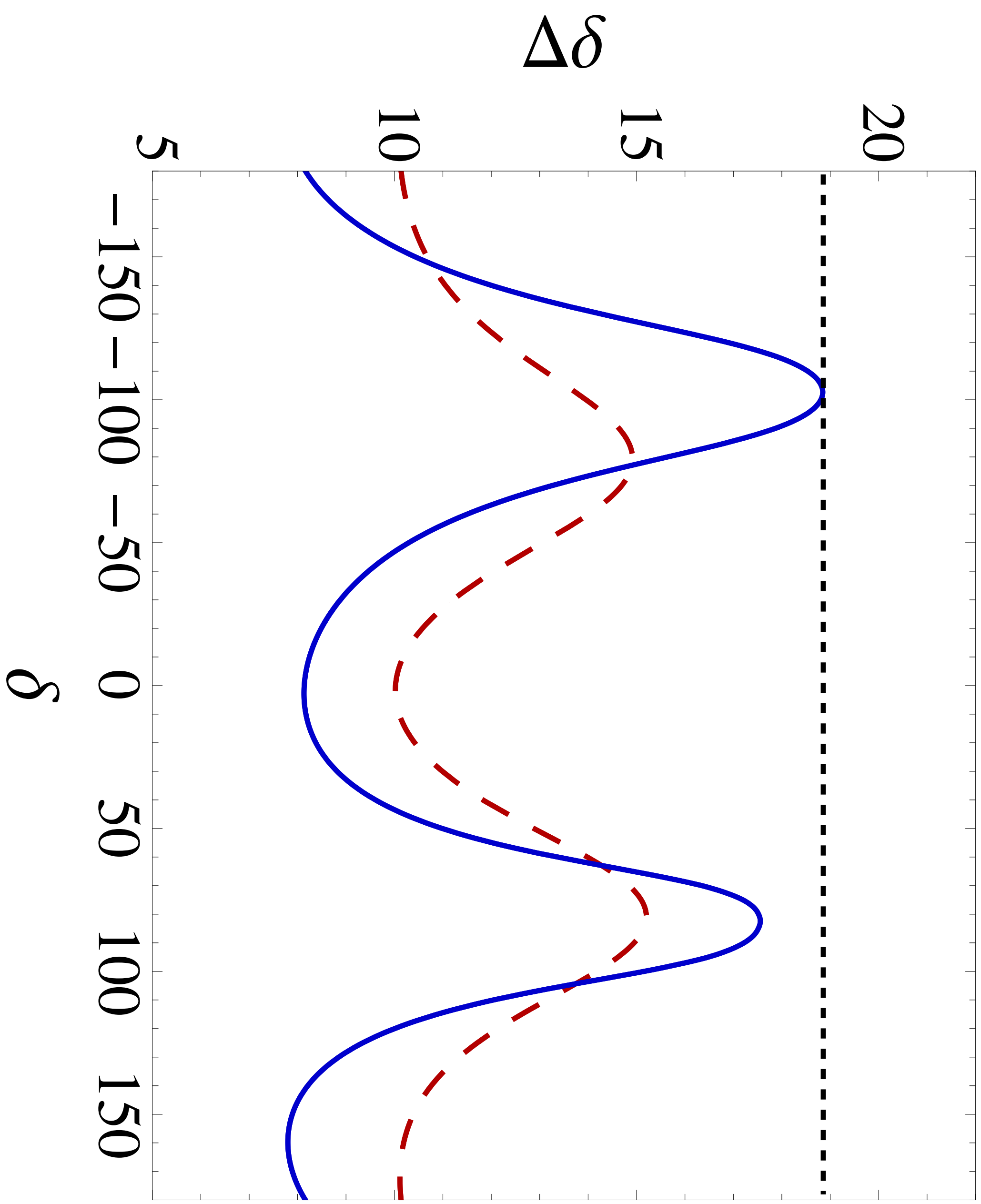


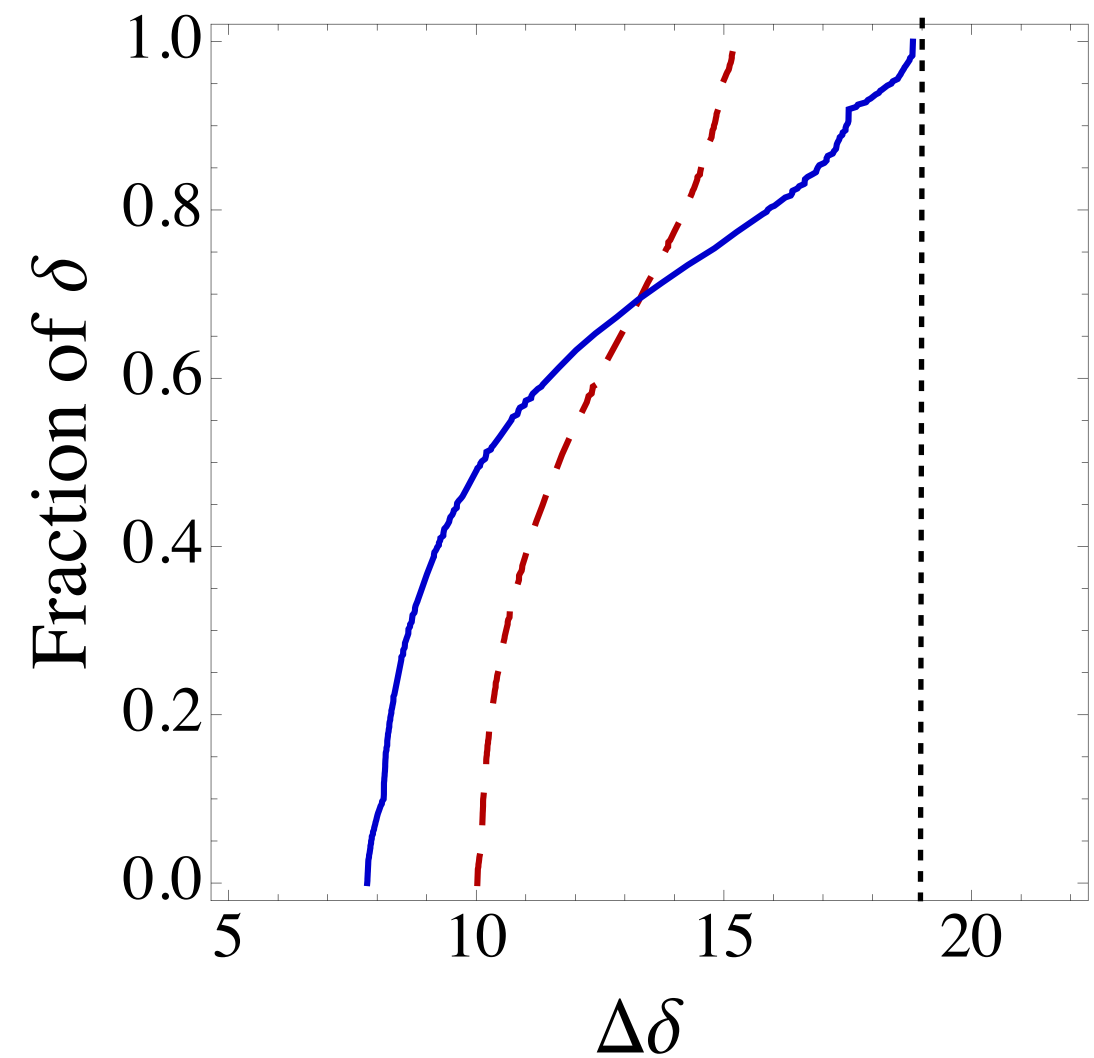
Precision and CP fraction



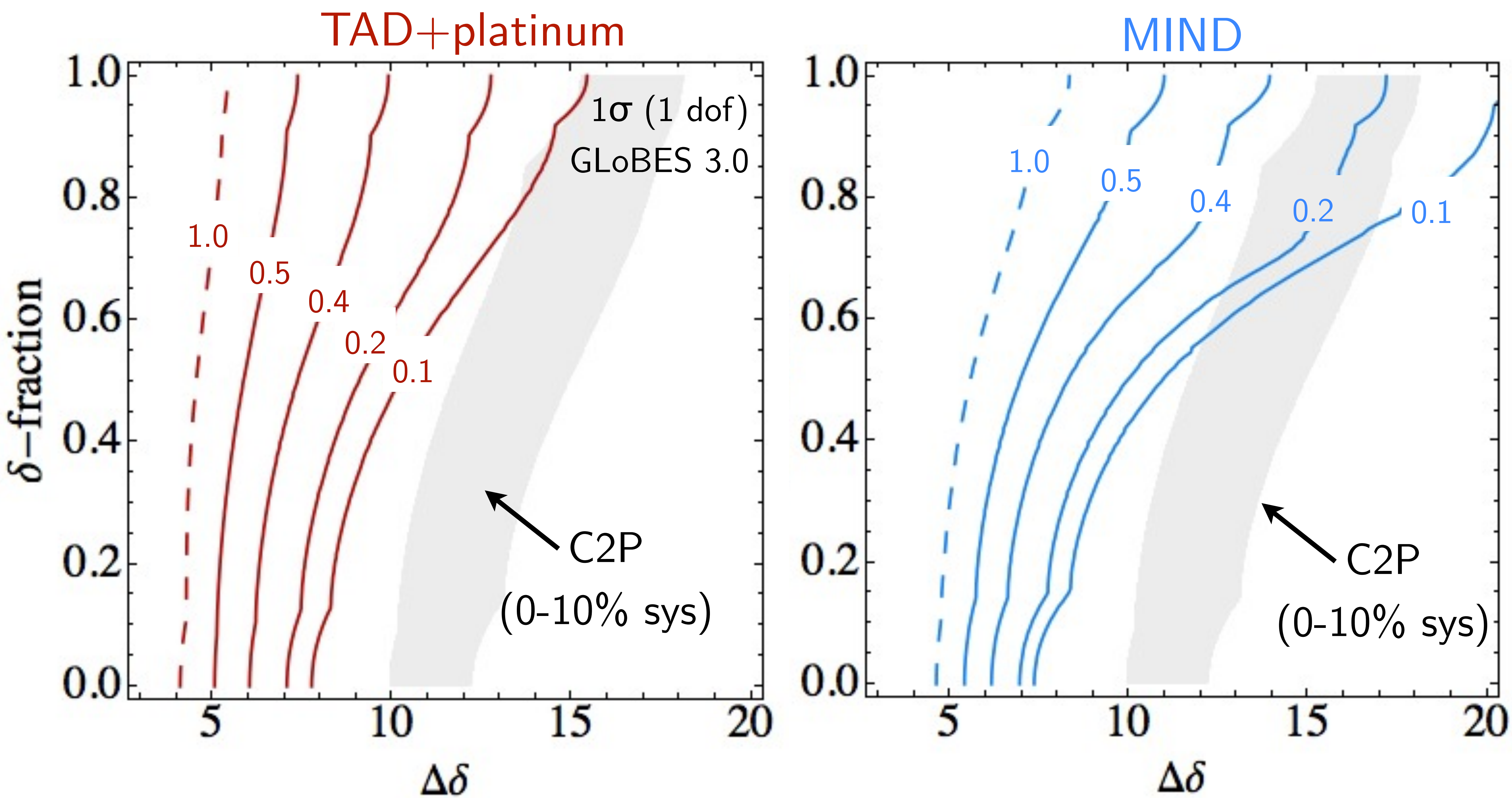


Precision and CP fraction

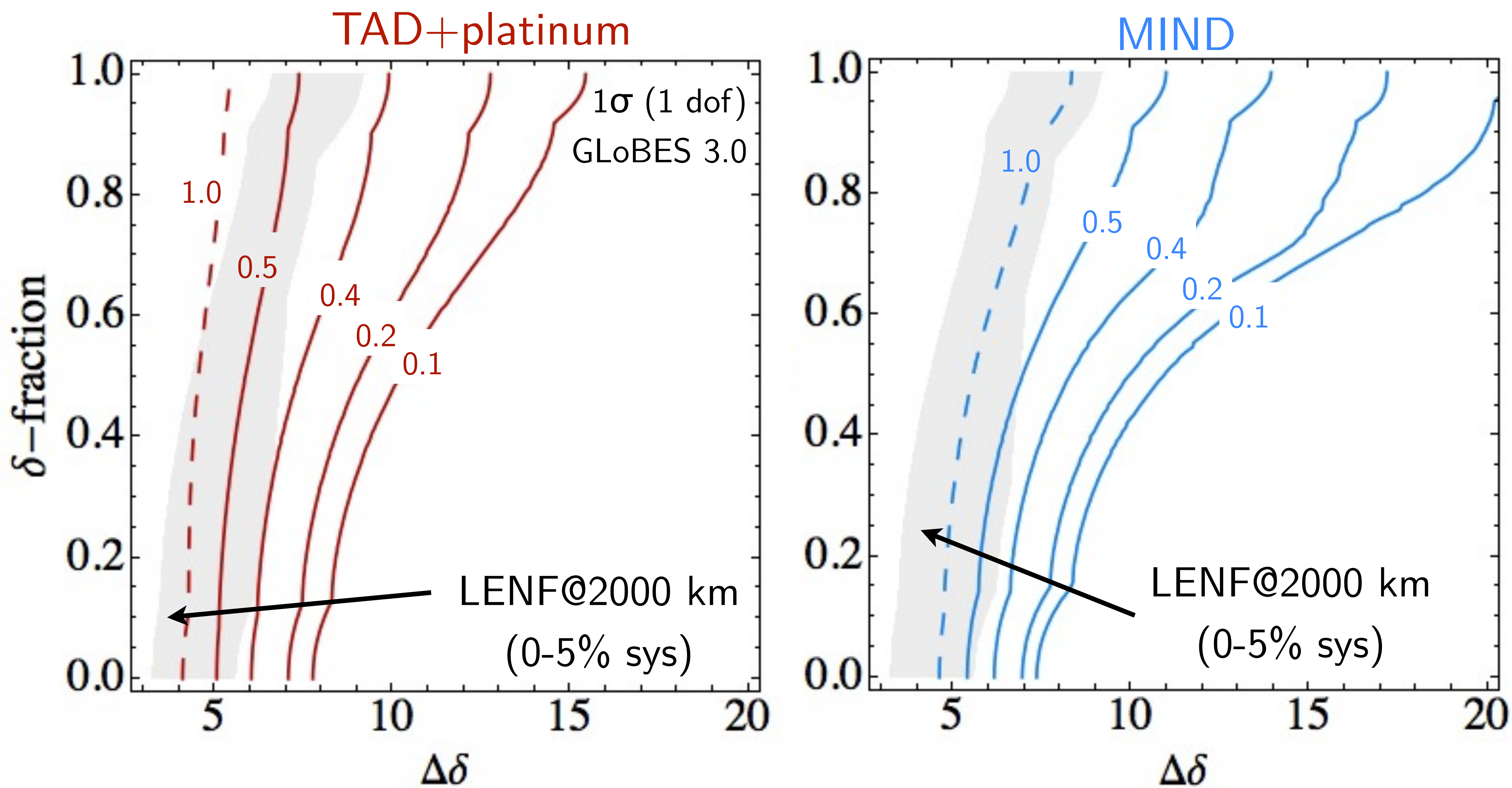




Precision at the LENF



Precision at the LENF



Conclusions

- A LENF from RAL to GS offers an excellent opportunity to study neutrino oscillations
- 10 GeV proves to be much better than 5 GeV even if slightly off-peak, independently of detector technology
- TAD offers better global performance
- A 800 kW NF w/o cooling is significantly better than a long baseline SB with the same power
- If the maximum luminosity can be reached, a NF from RAL to GS is totally comparable to the LENF@2000 (new IDS setup)
- Can we live with larger backgrounds? is magnetization necessary? can we use MIND for low energies?

Backup