Low or High Energy NF?

Patrick Huber

Virginia Tech – IPNAS

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What we want to learn

In neutrino (oscillation) physics the open questions are

- Size of θ_{13}
- $\theta_{23} = \pi/4$?
- Mass hierarchy aka sign of Δm^2
- CP violation
- New physics

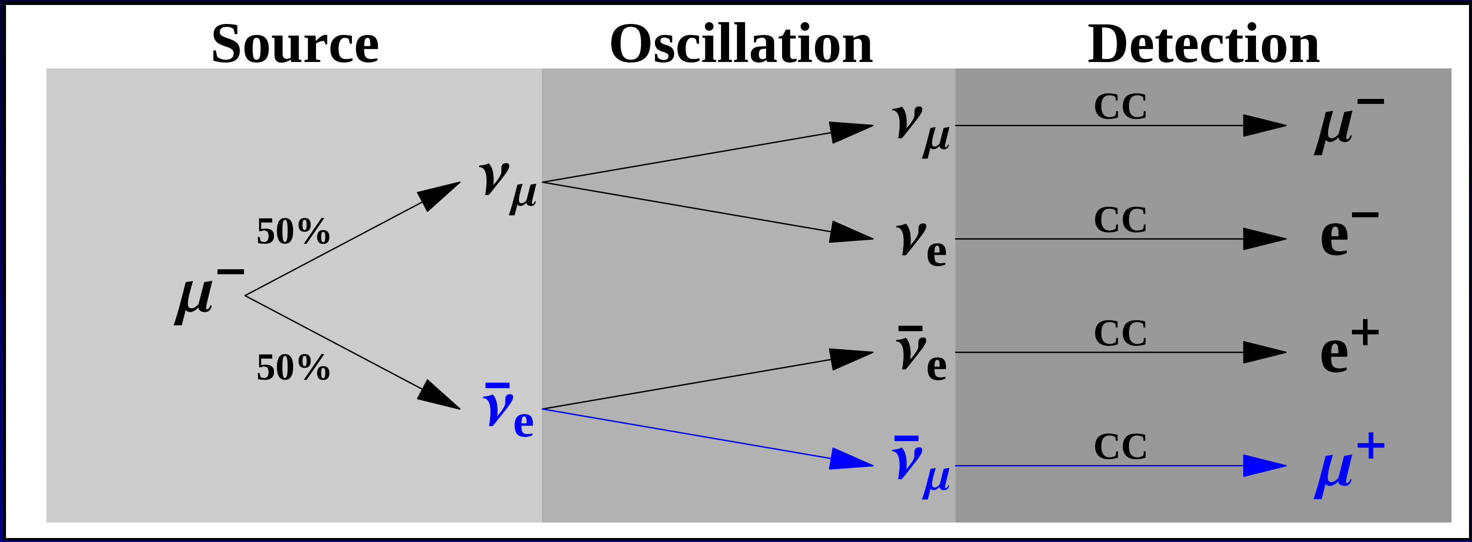
Theory can provide no ordering of these, it depends on the model which one is the most important one.

Oscillations 101

- Size of θ_{13} – $\nu_e \longrightarrow \nu_e$ (reactors) or $\nu_e \longrightarrow \nu_\mu$ or $\nu_\mu \longrightarrow \nu_e$
- $\theta_{23} = \pi/4$? – $\nu_\mu \longrightarrow \nu_\mu$, maybe $\nu_\mu \longrightarrow \nu_\tau$
- Mass hierarchy aka sign of Δm^2 – matter effect, $\nu_e \longrightarrow \nu_\mu$ or $\nu_\mu \longrightarrow \nu_e$
- CP violation $\nu_e \longrightarrow \nu_\mu$ or $\nu_\mu \longrightarrow \nu_e$
- New physics $\nu_e \longrightarrow \nu_\mu$ or $\nu_\mu \longrightarrow \nu_e$ and ν_τ appearance at short distances

Most of these oscillation modes are accessible with a neutrino factory!

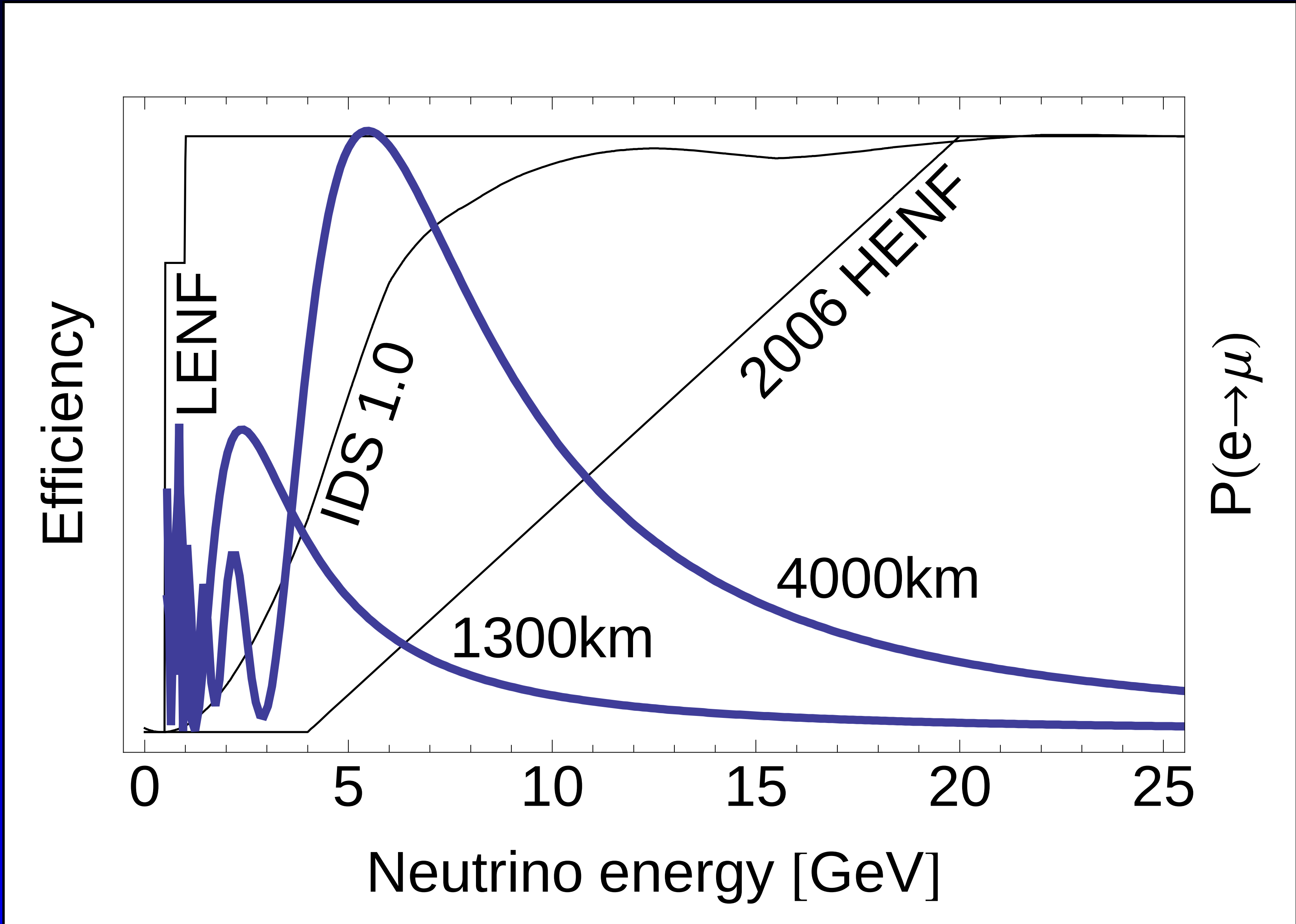
The Signal



This requires a detector which can distinguish μ^+ from μ^- $\Rightarrow$ magnetic field of around 1T

- above 3 GeV – iron calorimeter like MINOS
- below 3 GeV – magnetized, totally active, fine grained scintillator

The Issue


Efficiency
LENF
IDS 1.0
2006 HENF
P(e→μ)
4000km
1300km
0
5
10
15
20
25
Neutrino energy [GeV]

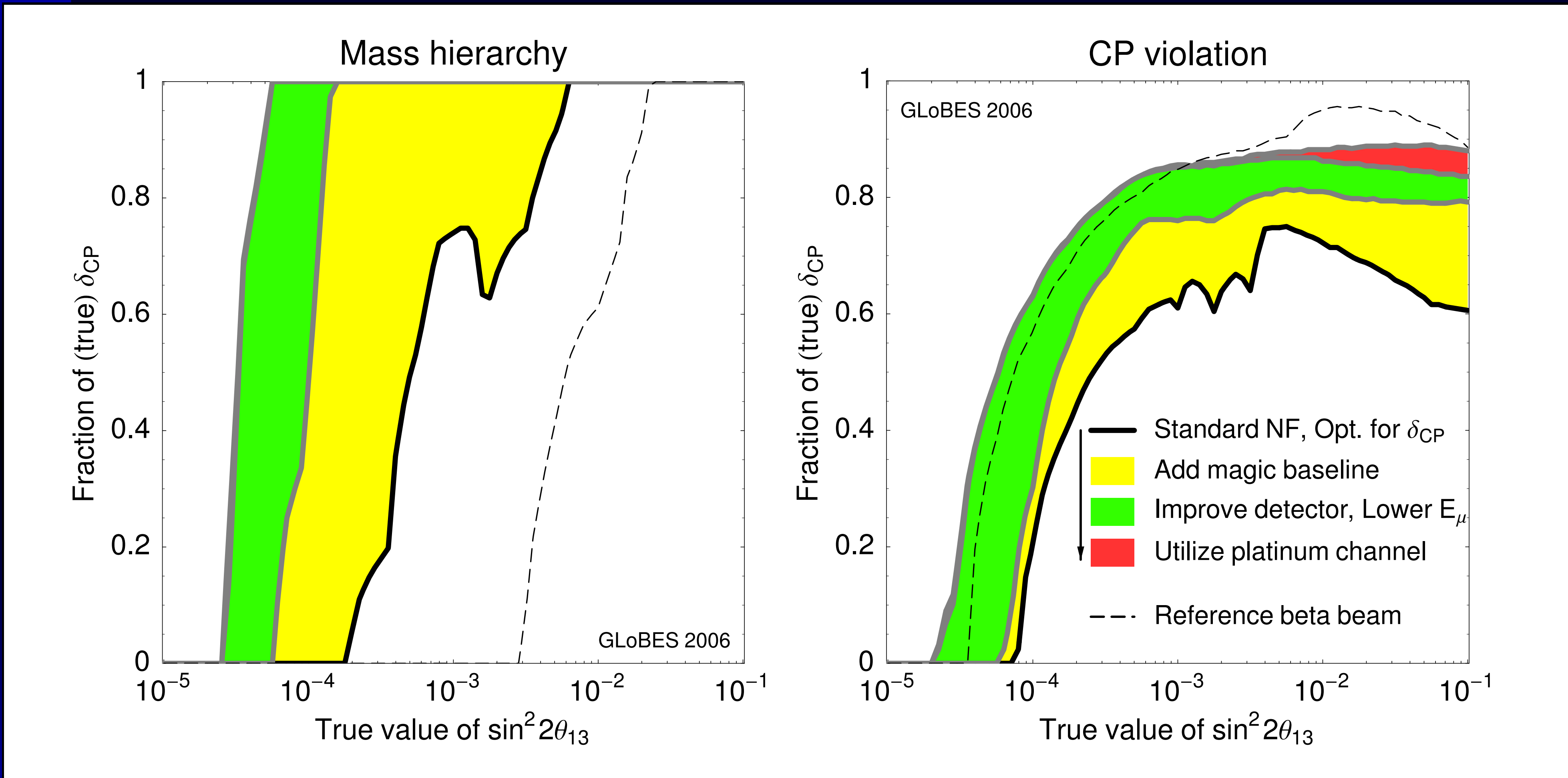
Magnetized iron detector

- iron core magnet
- high target density
- short muon tracks
- most of the detector mass is passive

this results in

- requires a relative long muon track
- puts a severe constraint on the lowest neutrino energy
- mediocre energy resolution
- target mass limited to $\sim 100\,\mathrm{kt}$
- high luminosity, high energy $25\,\mathrm{GeV}$ neutrino source

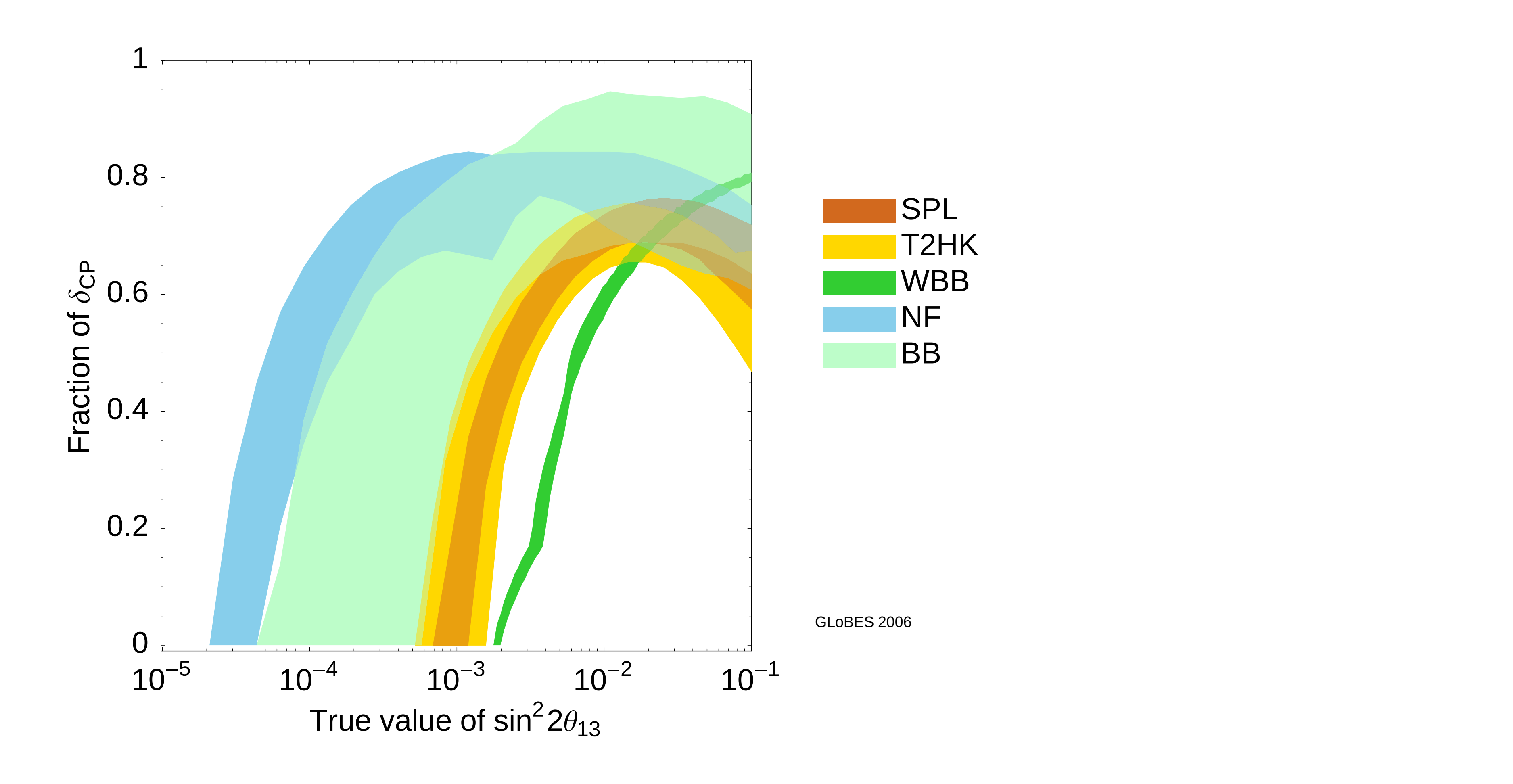
HENF



PH *et al.*, PRD 74:073003,2006.

Re-analysis of detection threshold of MIND led to a reduction in muon energy from 50GeV to 25GeV

HENF



ISS physics report, Rept.Prog.Phys.72:106201,2009.

TASD

- Fully active
- Minerva-like design
- Magnetized

This results in

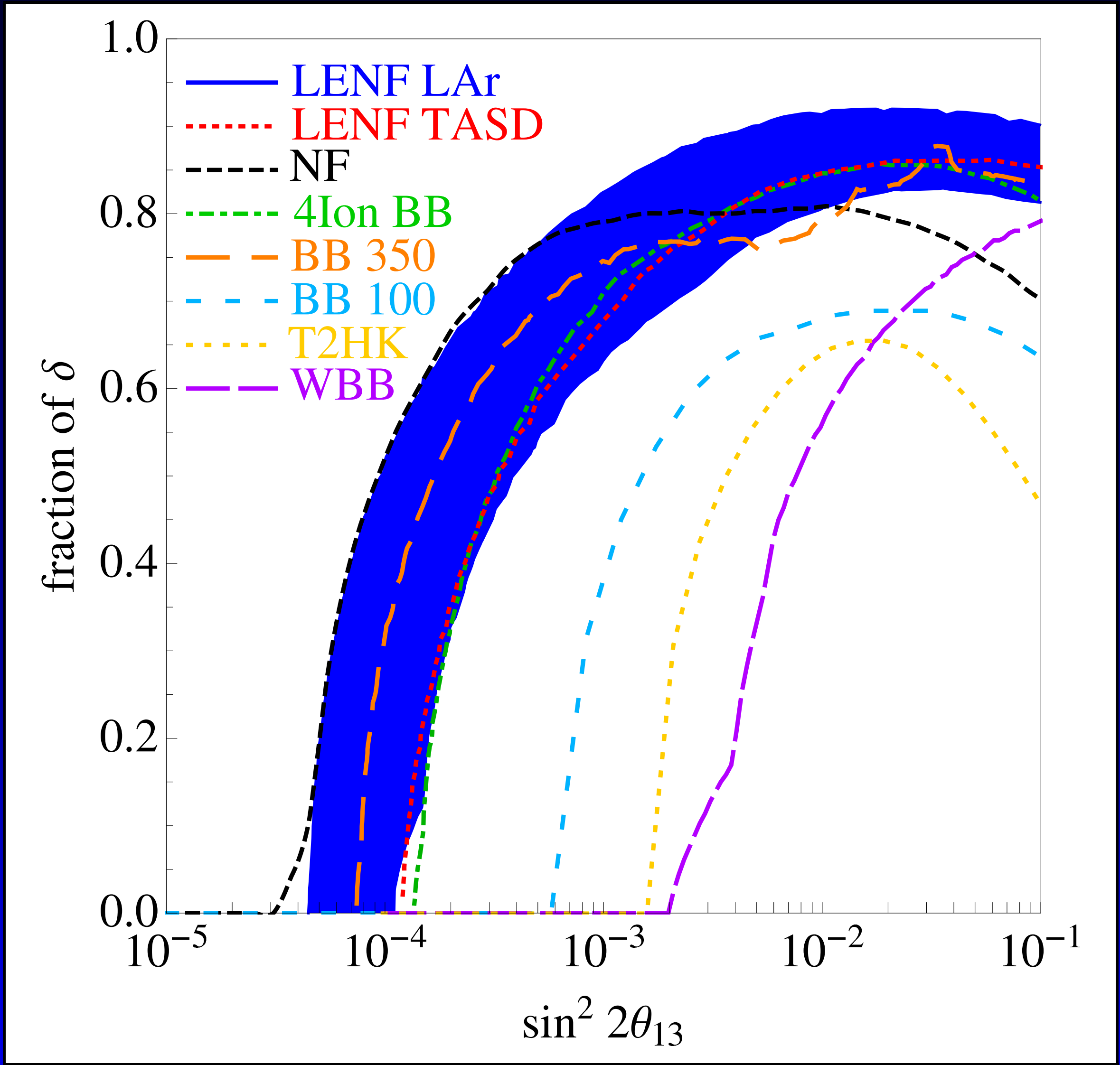
- High efficiency
- Very low neutrino threshold $\sim$0.5 GeV
- Excellent neutrino energy resolution $\sim$10%
- Potential to charge ID electrons

NB A liquid Argon detector could provide the same benefits at a lot less electronics channels (=larger mass)

LENF

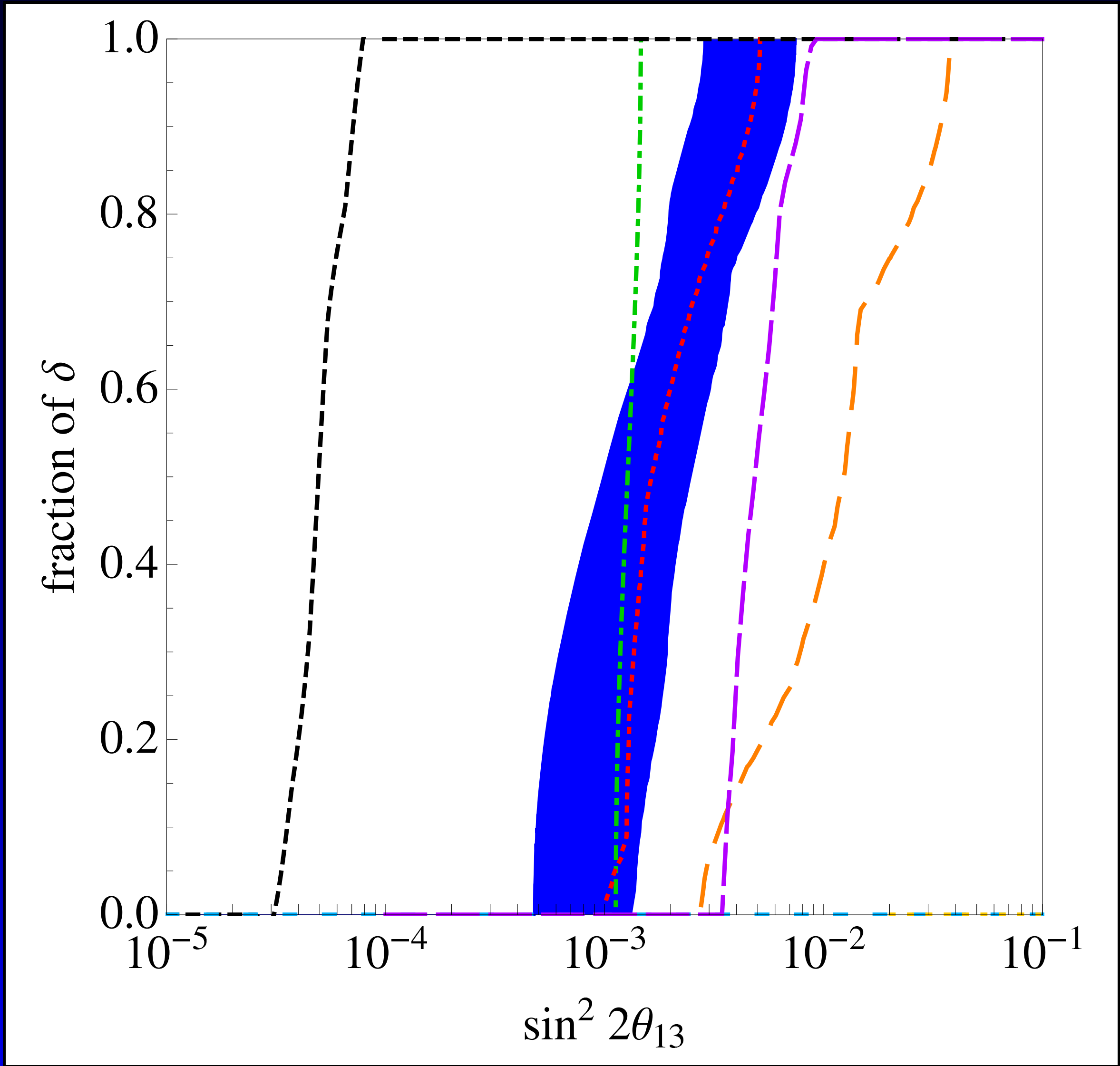
- 20 kt
- efficiencies from Bross *et al.* arXiv:0911.3776v1
- includes platinum channel
- 0.7E21 muons per year and 0.7E21 anti-muons per year
- 4.5 GeV
- 10 years @ 1E7s
- 3 sigma results

LENF – CP



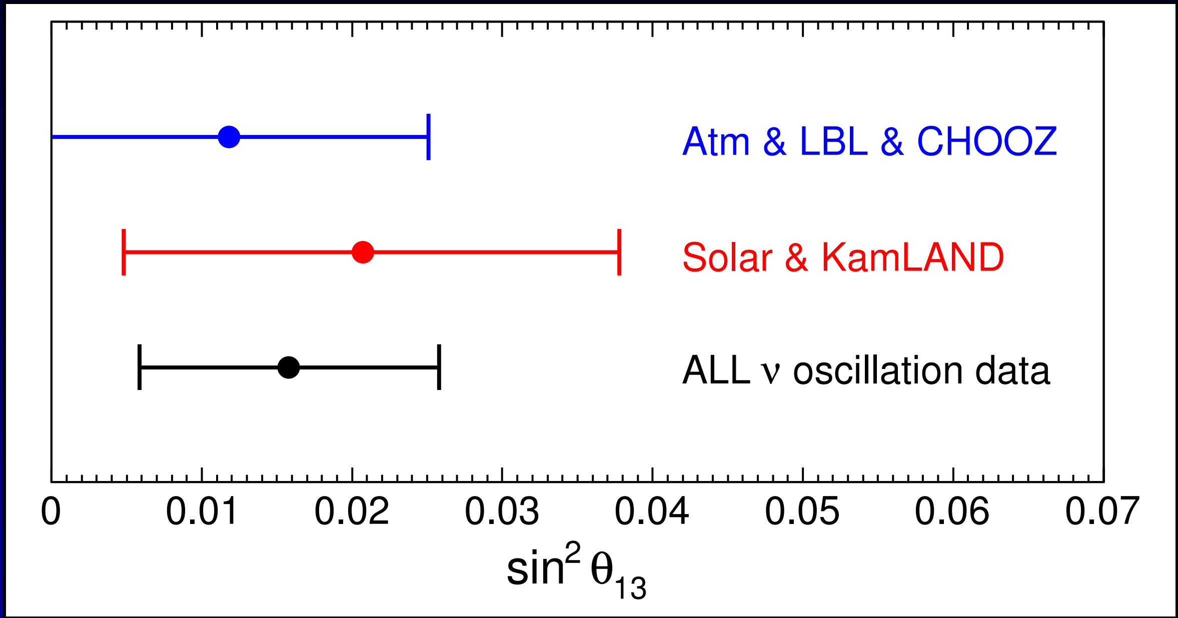
Bross *et al.*, arXiv:0911.3776v1

LENF – mass hierarchy



Bross *et al.*, arXiv:0911.3776v1

Hints for $\theta_{13} \neq 0$



E. Lisi, *et al.*, arXiv:0806.2649.

$\sin^2\theta_{13} = 0.016 \pm 0.010$ or $\sin^2 2\theta_{13} = 0.06 \pm 0.04$

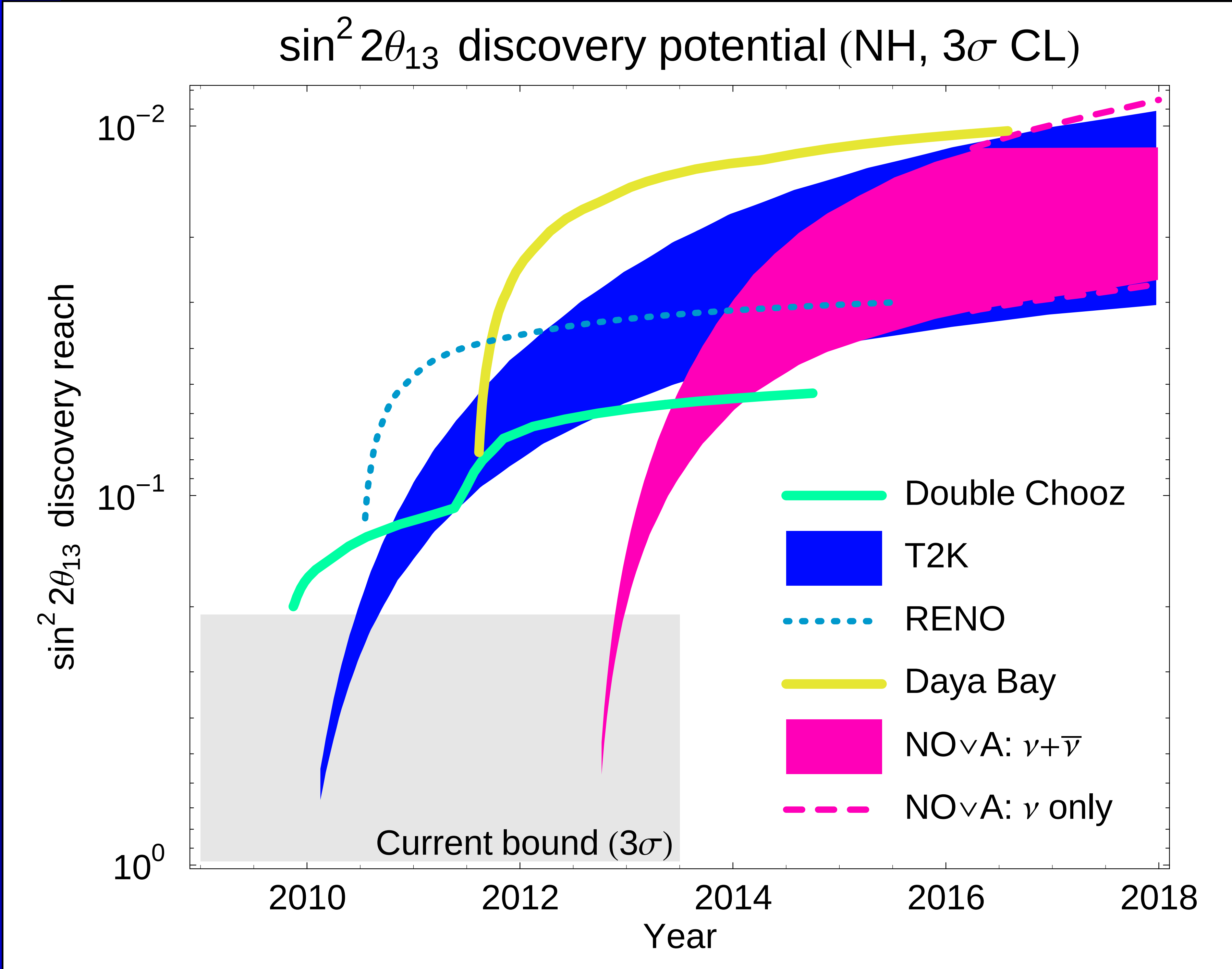
MINOS' first ν_e appearance results

35 events seen vs $27 \pm 5 \pm 2$ expected for $3.14 \cdot 10^{20}$ pot

From hints to the hunt for θ_{13}

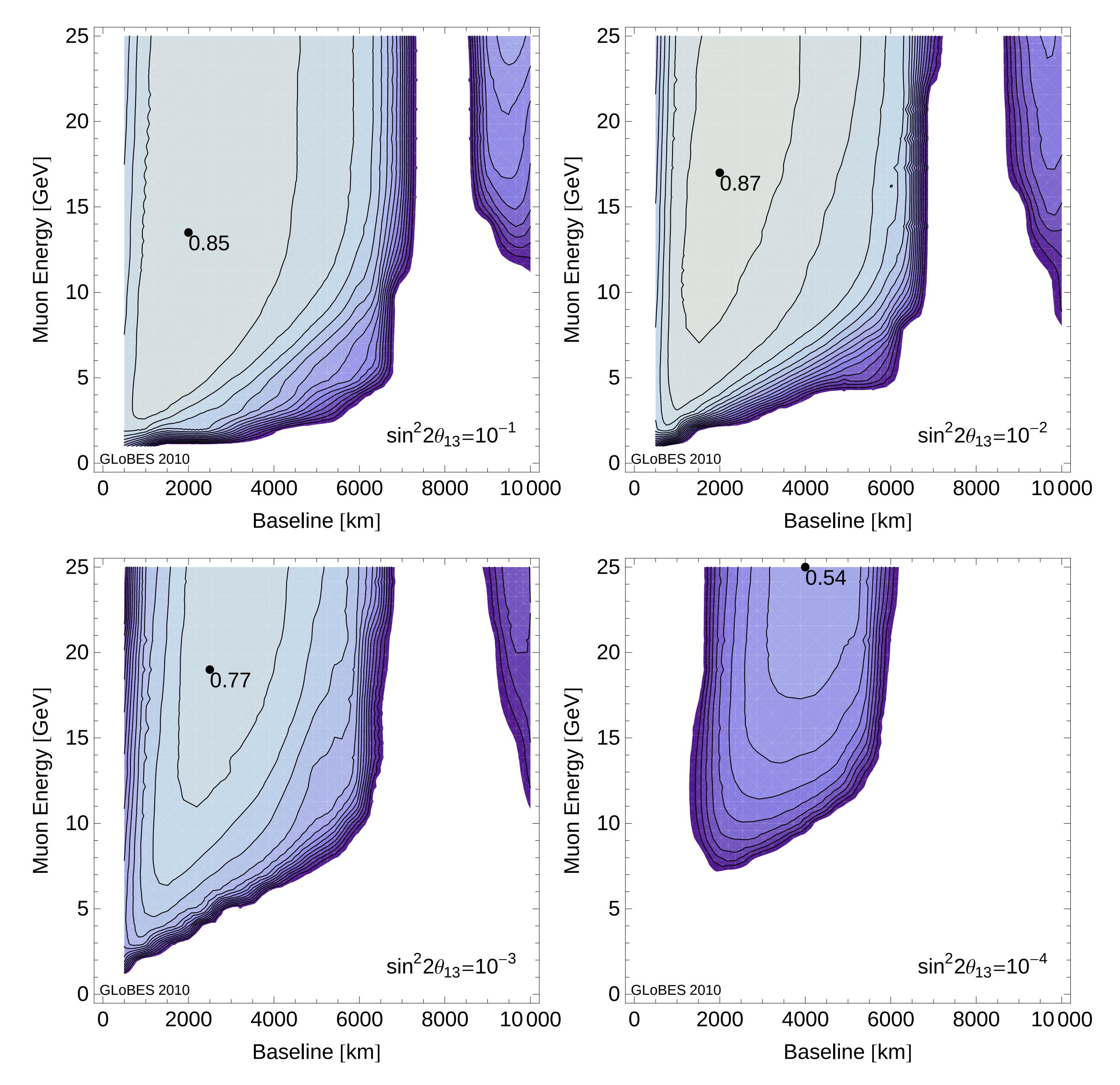
Timeline

- Double Chooz: Start 09/2009, 1.5 yr with FD only, then ND+FD, 5 years total Talk by S. Peeters, NOW 2008
- RENO: Start 06/2010, ND+FD, 5 years Talk by Y. Oh, NOW 2008
- Daya Bay: 7/2011 all modules, Talk by R. McKeown, CIPANP 09
- T2K: 09/2009 - 12/2012: 0 MW - 0.75 MW linear, neutrinos only Talk by H. Kakuno, NOW 2008
- NOvA: 08/2012 - 01/2014: 2.5 kt - 15 kt linear,1/2 neutrinos & 1/2 antineutrino Talk by M. Messier, ICHEP08



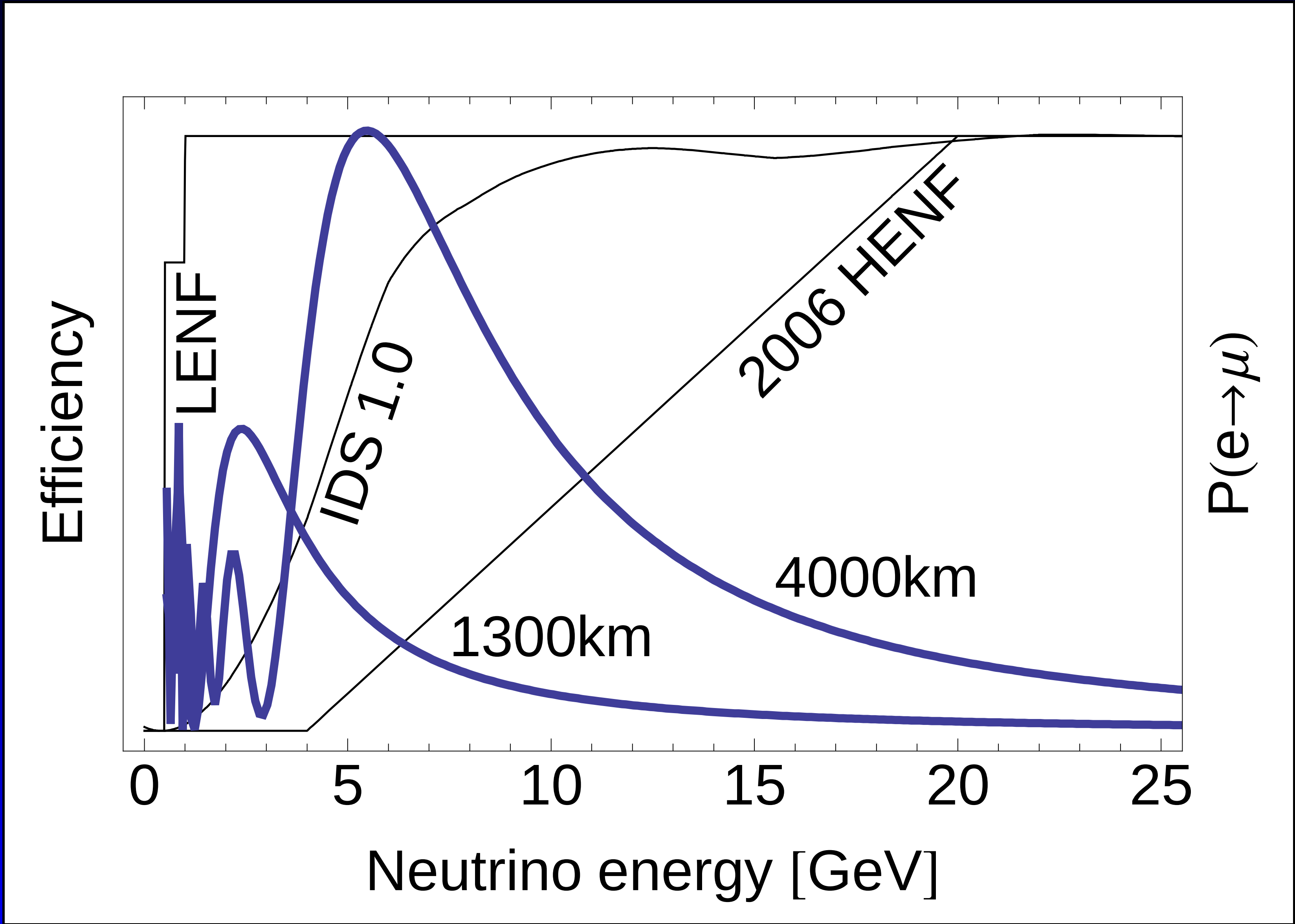
PH, M. Lindner, T. Schwetz, W. Winter, JHEP 0911:044,2009.

HENF or LENF?



Muon Energy [GeV]
Baseline [km]
0.85
$\sin^2 2\theta_{13}=10^{-1}$
GLoBES 2010
0.87
$\sin^2 2\theta_{13}=10^{-2}$
0.77
$\sin^2 2\theta_{13}=10^{-3}$
0.54
$\sin^2 2\theta_{13}=10^{-4}$
0
5
10
15
20
25
2000
4000
6000
8000
10 000

The Issue



Efficiency
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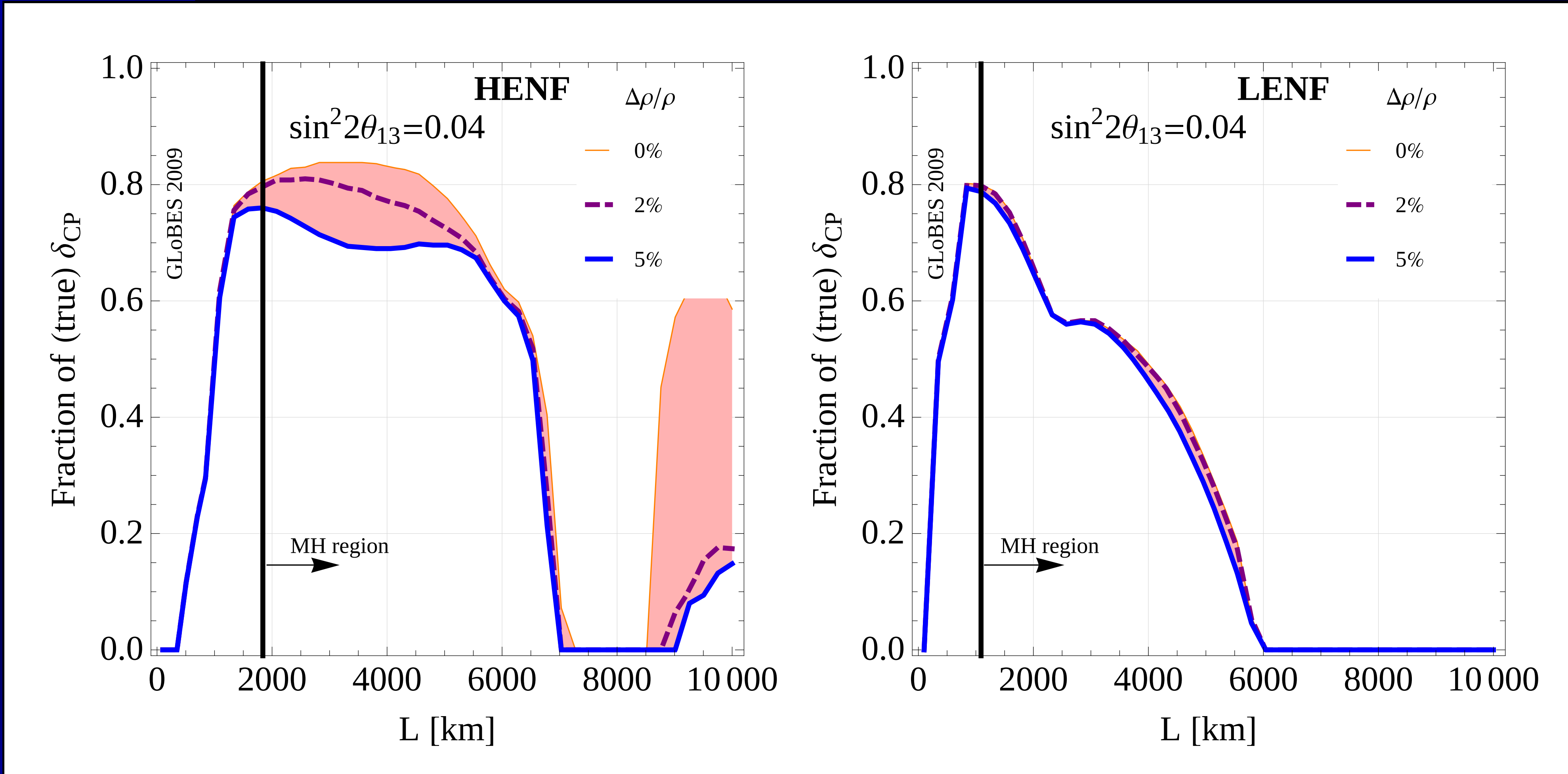
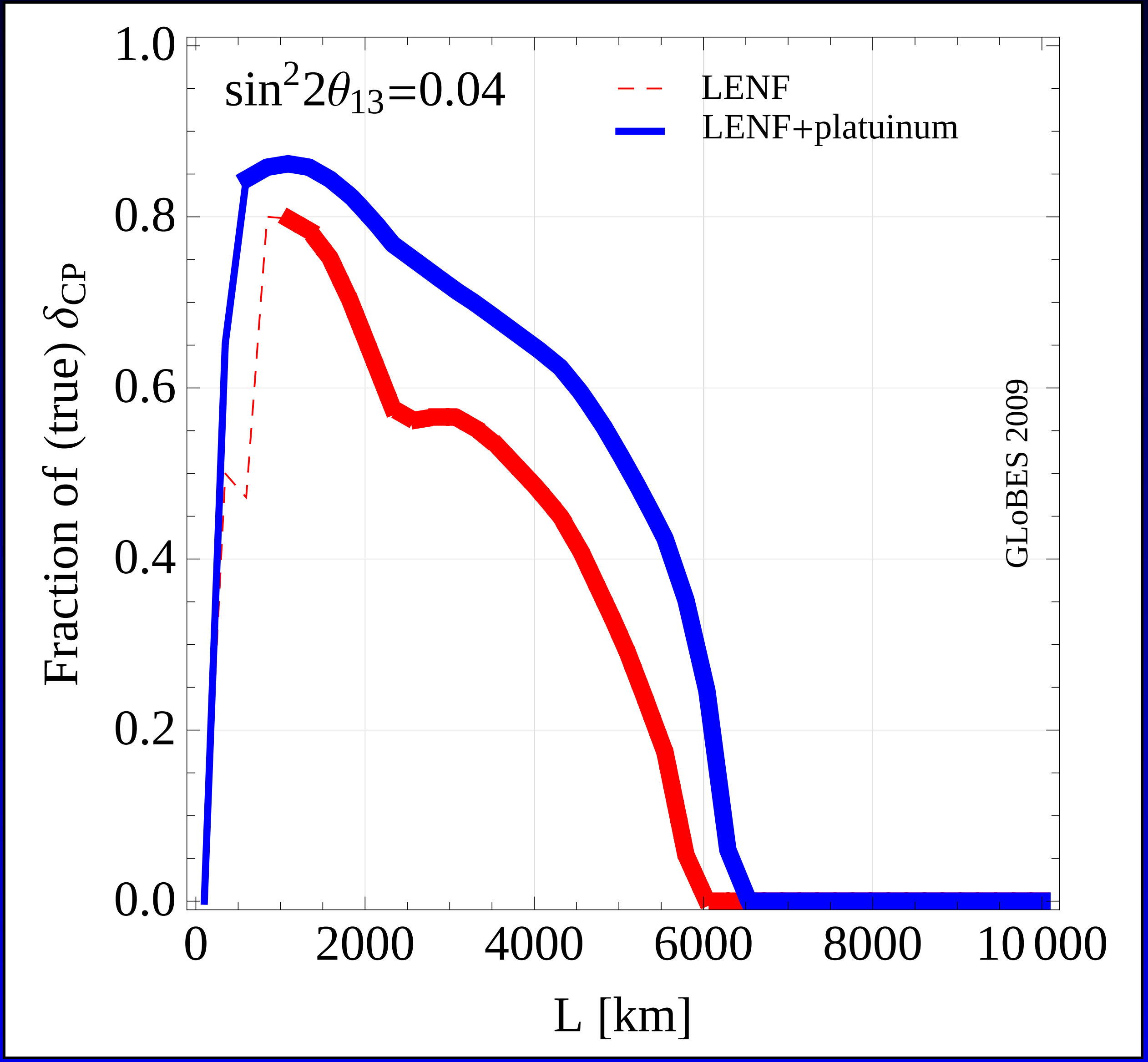
Neutrino energy [GeV]

Matter density



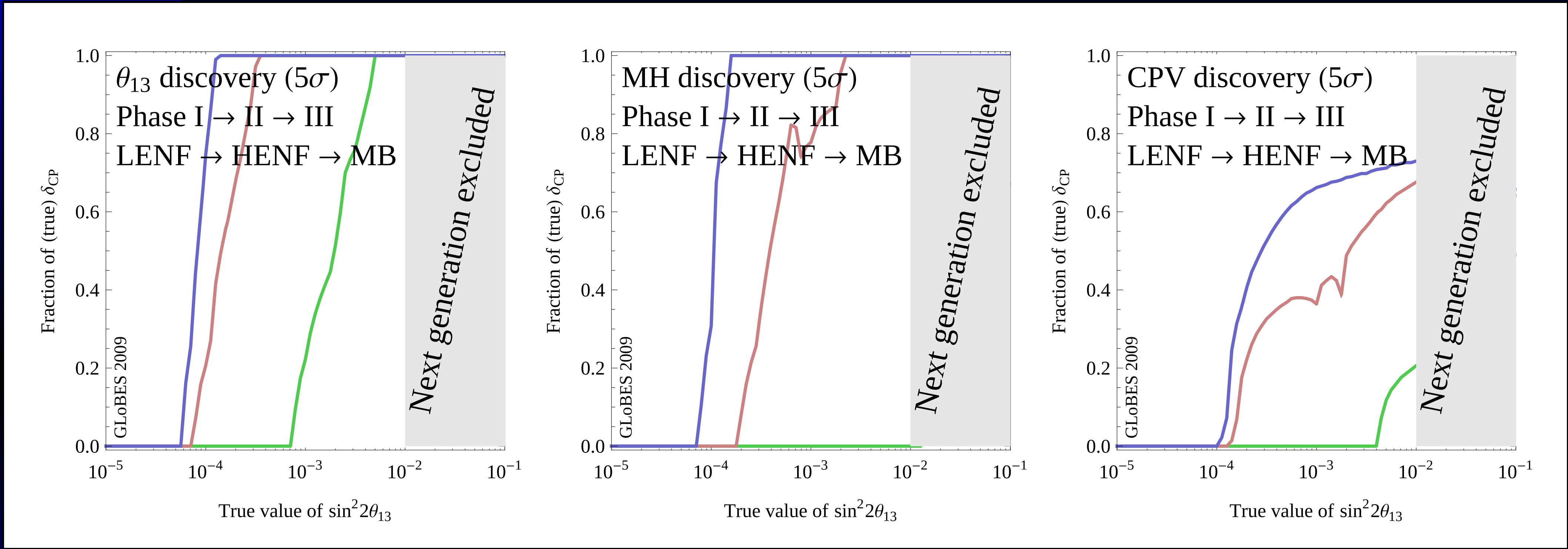
Tang and Winter, arXiv:0911.5052v1.

Platinum



Tang and Winter, arXiv:0911.5052v1.

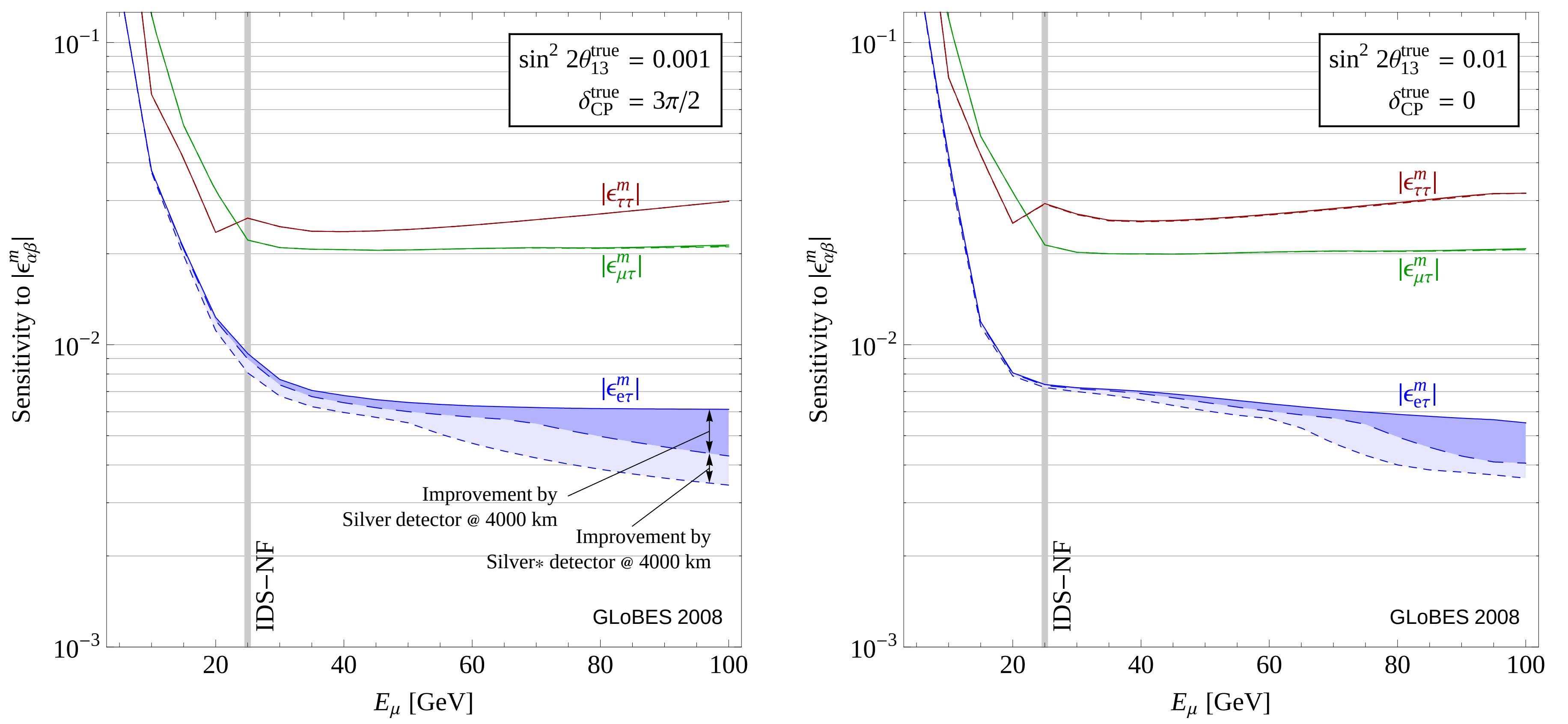
HENF and LENF!



Tang and Winter, arXiv:0911.5052v1.

- LENF
- Upgrade to 25GeV and addition of 4000km baseline
- Addition of 7500km baseline

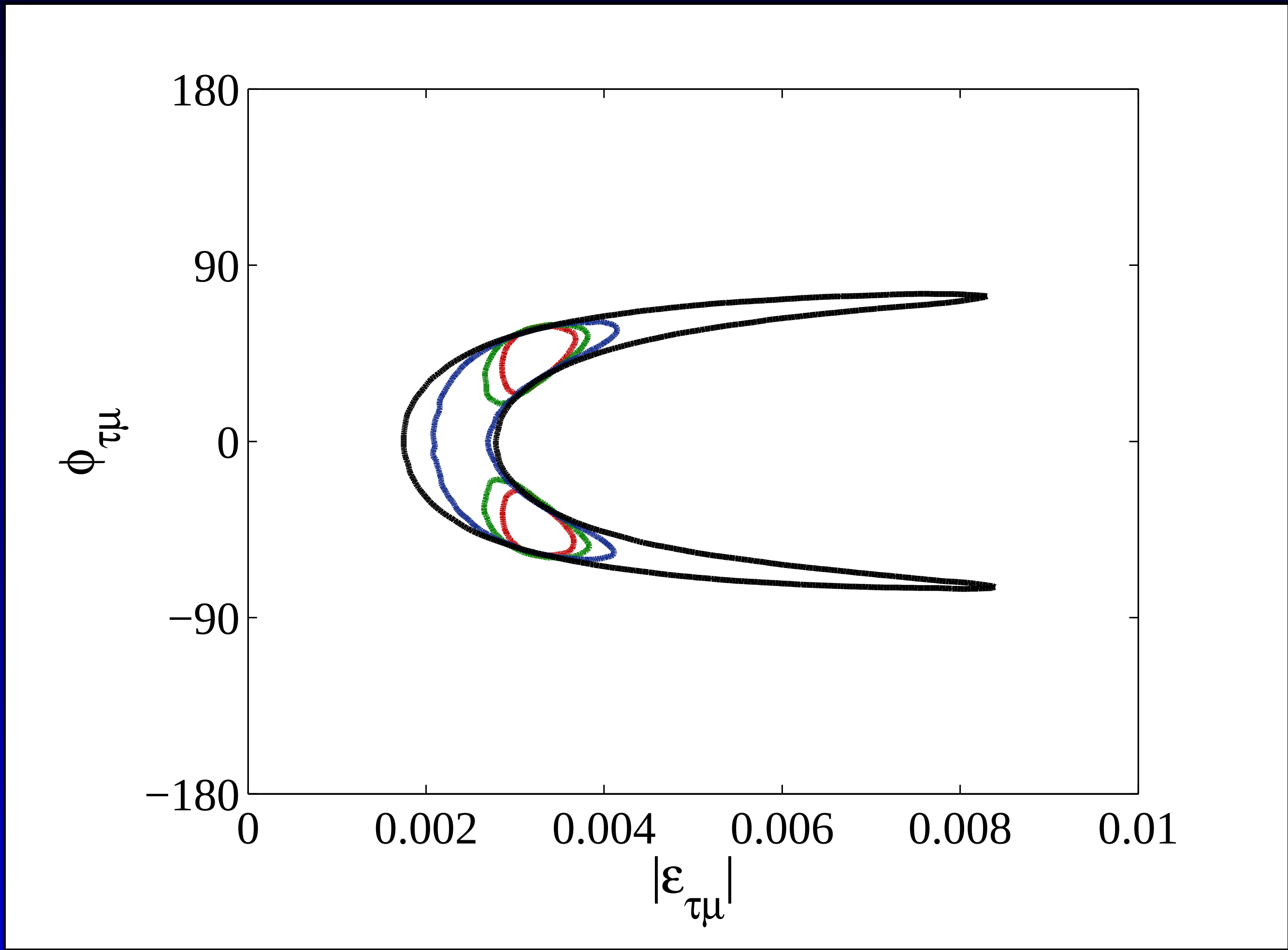
New Physics



Kopp, Ota, Winter, PRD78:053007,2008

High energies are crucial!

New Physics



Antusch *et al.*, PRD80:033002,2009

Large (!) near detector is crucial!

Summary

HENF vs LENF discussion is driven by

- boundary conditions (*e.g.* FNAL-DUSEL distance)
- detector technology
- Oscillation physics over a large range of the parameter space does not prefer one or the other – a very good detector helps at any energy
- New physics searches require energies significantly above τ-production threshold

It seems that a LENF can be upgraded to higher energies in a straightforward and effective manner