Neutrino Factory sensitivity at large θ_{13}

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The Issue

If $\sin^2\theta_{13} > 0.01$, as hinted by recent data, what are the implications for a Neutrino Factory?

I break this question down into the following more focused questions:

- Will the mass hierarchy have been determined by someone else?
- Are new experiments beyond NOνA and T2K necessary?
- Are superbeams enough?
- Optimization?
- Staging?

θ_{13}

FAPP θ_{13} will be known to very high accuracy

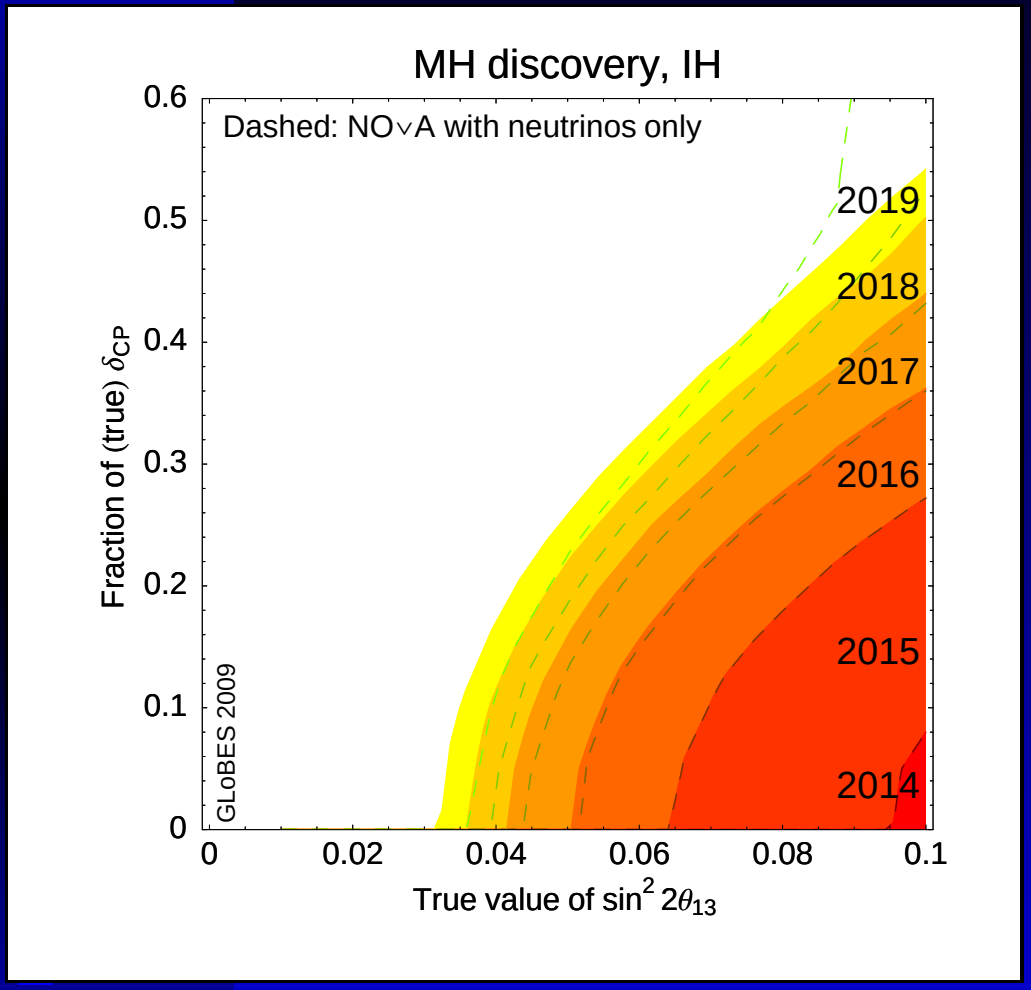
If the current hints are true, θ_{13} will be accurately measured by Double Chooz, RENO, Daya Bay and T2K within a year or so

At $\sin^2 2\theta_{13} = 0.1$ the measurement error at T2K will be 10%

At $\sin^2 2\theta_{13} = 0.1$ the measurement error at Daya Bay will be <5%

Can beams improve this result?

Mass hierarchy

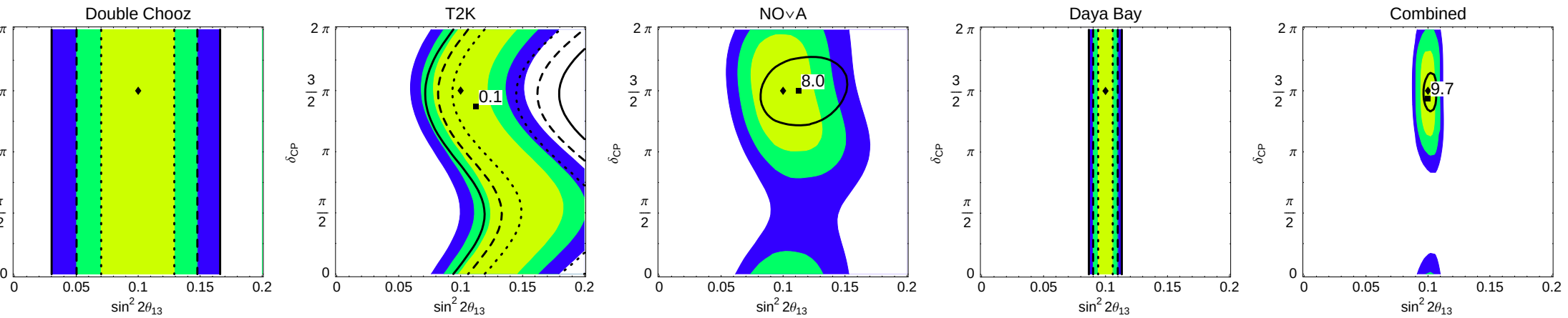


90% CL, combines T2K, NOνA, Daya Bay, Double Chooz and RENO At this CL MINOS and T2K have discovered $\theta_{13} \neq 0$!

At $3\,\sigma$ this plot would be essentially empty!

PH, M. Lindner, T. Schwetz, W. Winter, JHEP 11 044 (2009), arXiv:0907.1896.

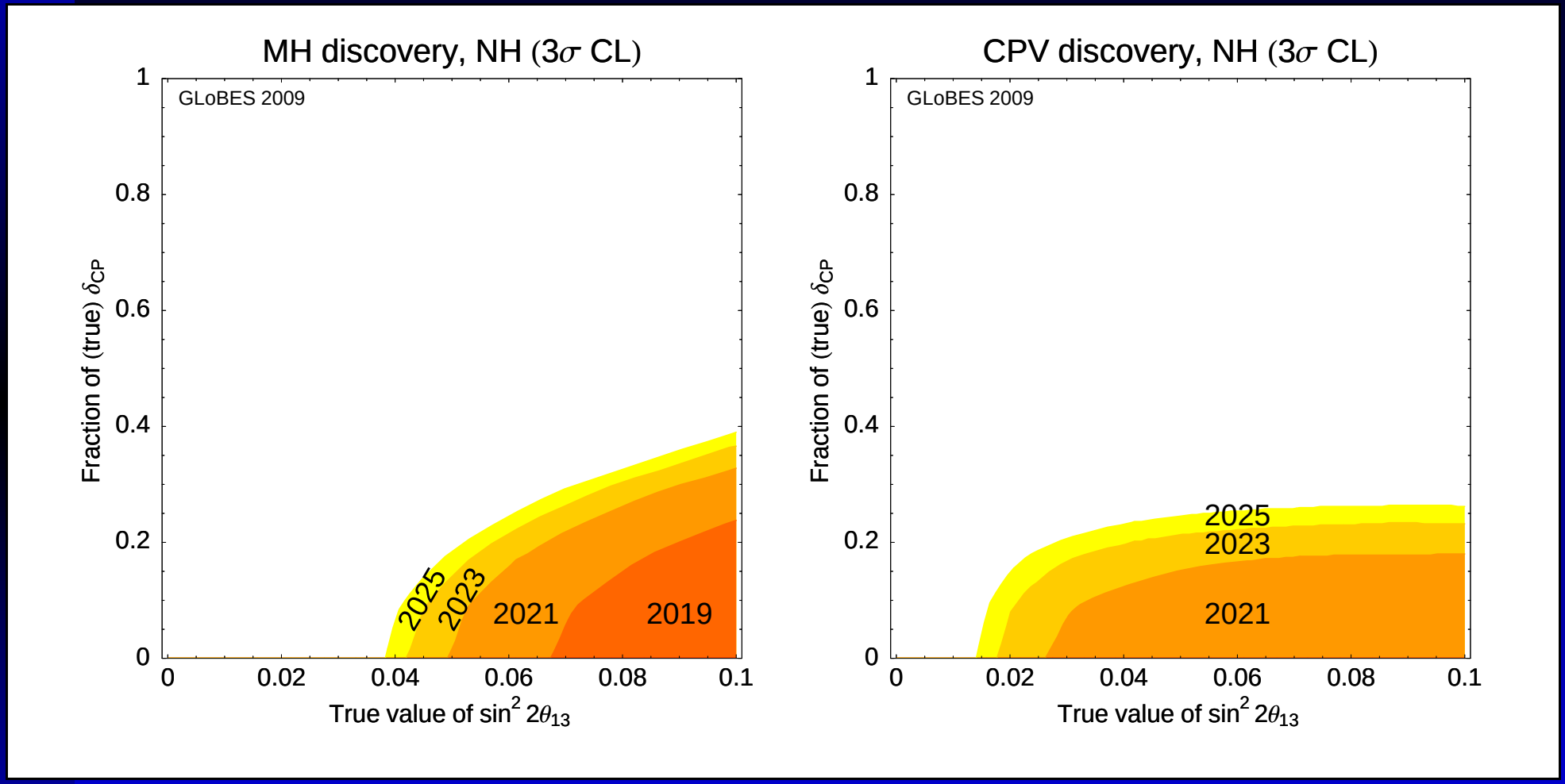
CPV without new experiments?



PH, M. Lindner, T. Schwetz, W. Winter, JHEP 11 044 (2009), arXiv:0907.1896.

Barely reaches $3\,\sigma$ for mass hierarchy, and this is the most favorable δ_{CP}!

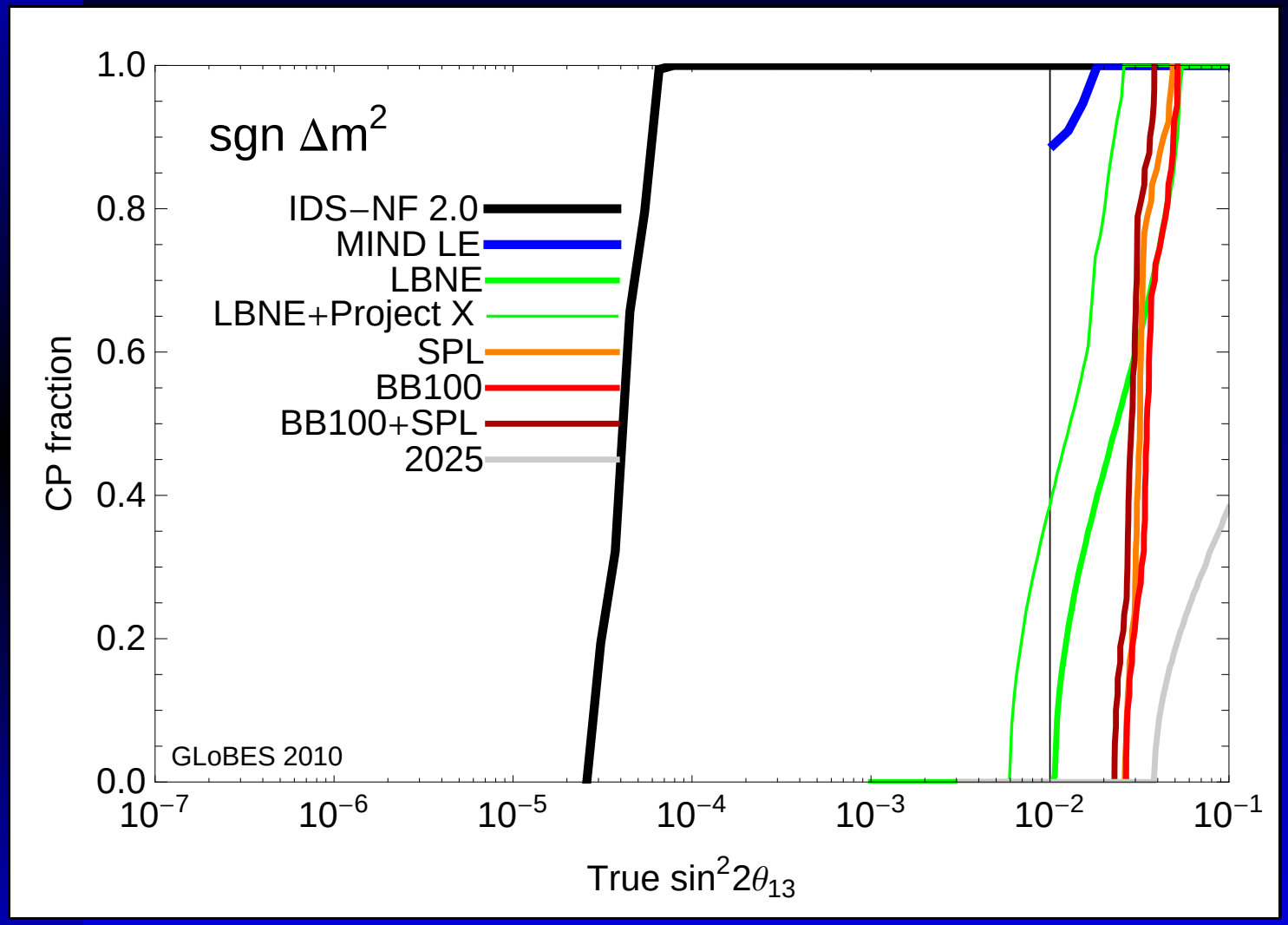
CPV without new experiments?



PH, M. Lindner, T. Schwetz, W. Winter, JHEP 11 044 (2009), arXiv:0907.1896.

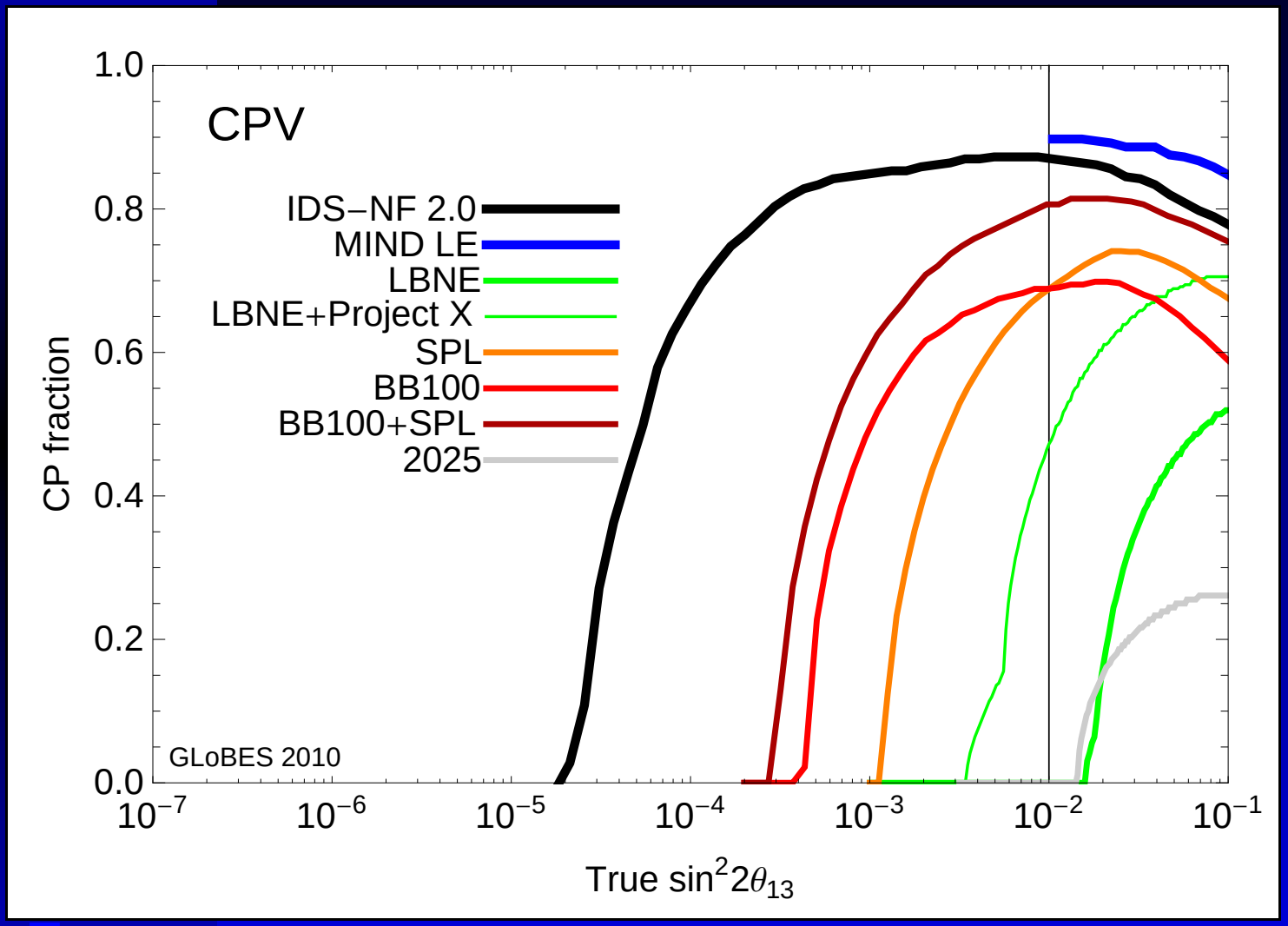
Includes Project X and T2K running at 1.7 MW.

Are superbeams enough?



Mass hierarchy works only at $3\,\sigma$ in the upper half of the current indications.

Are superbeams enough?

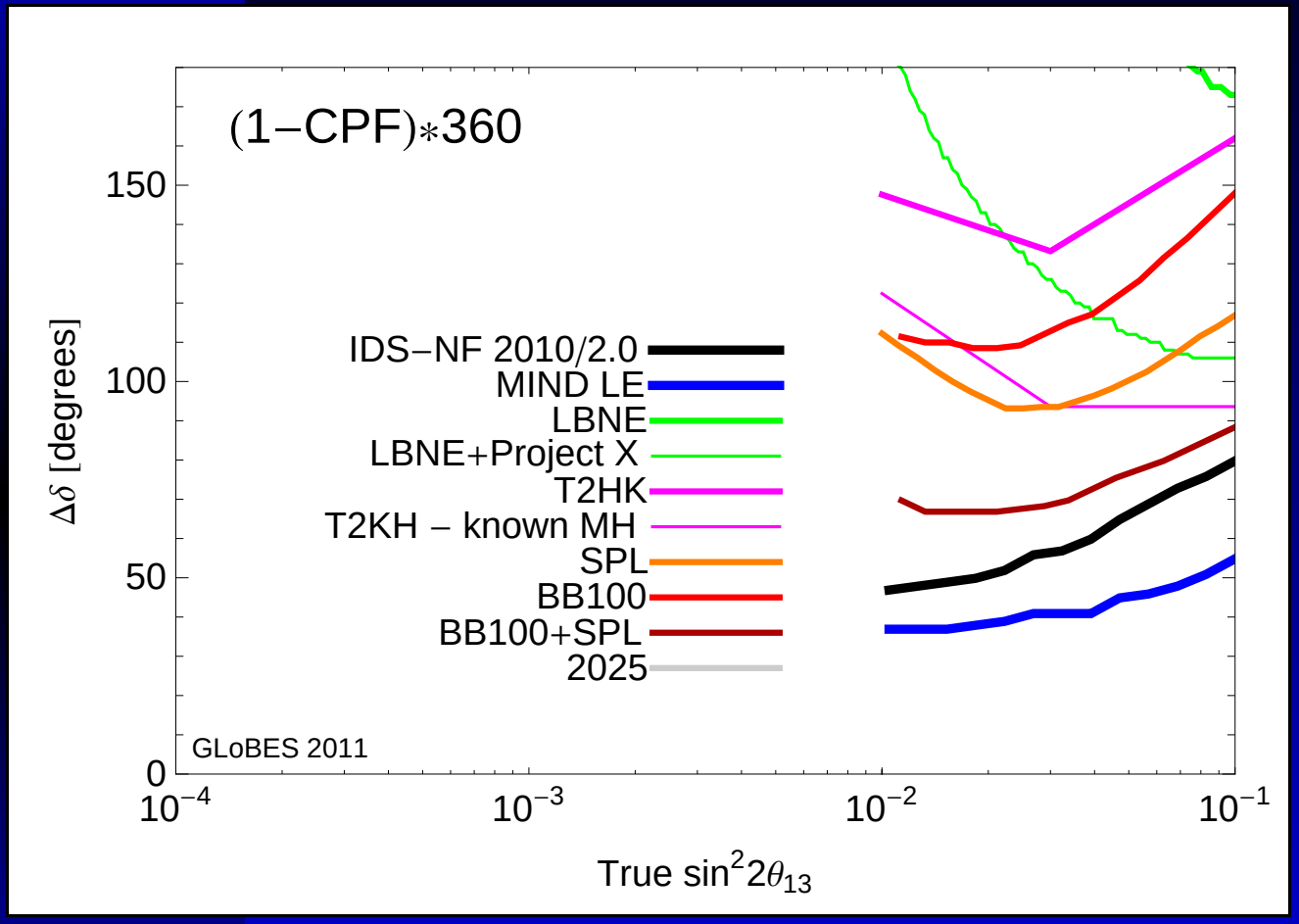


SB reach CPF of 0.7-0.75
NF reaches CPF of 0.85-0.9

MIND LE – 100 kt
MIND at 2000km and 10GeV

NF still best for **all** values of θ_{13}!

Are superbeams enough?



$\Delta\delta \simeq 1-\mathrm{CPF}$

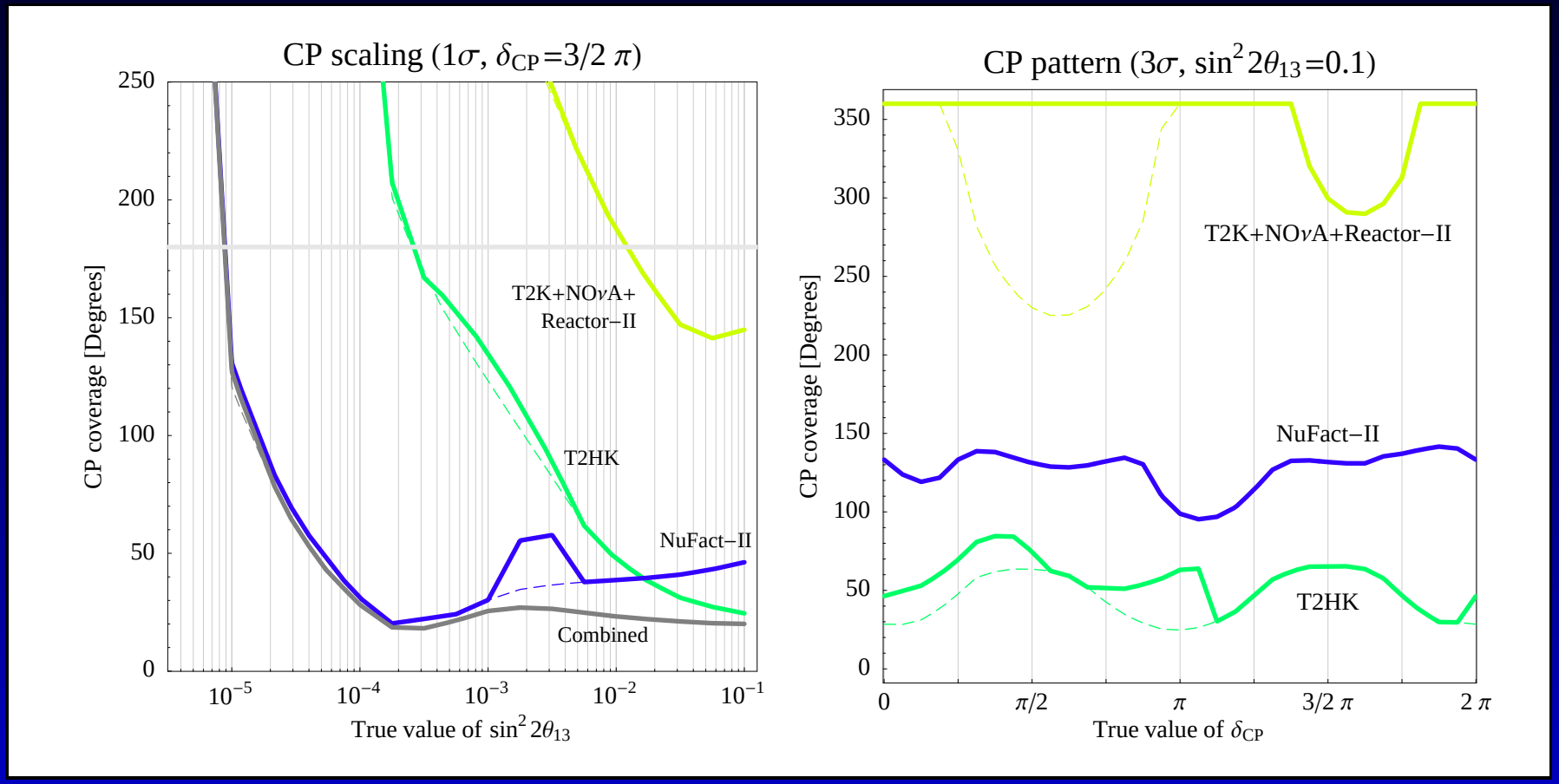
SB $\Delta\delta = 90^\circ - 120^\circ$

NF $\Delta\delta = 40^\circ - 52^\circ$

T2HK taken from K. Abe *et al.*, arXiv:1109.3262

This requires a more detailed analysis …

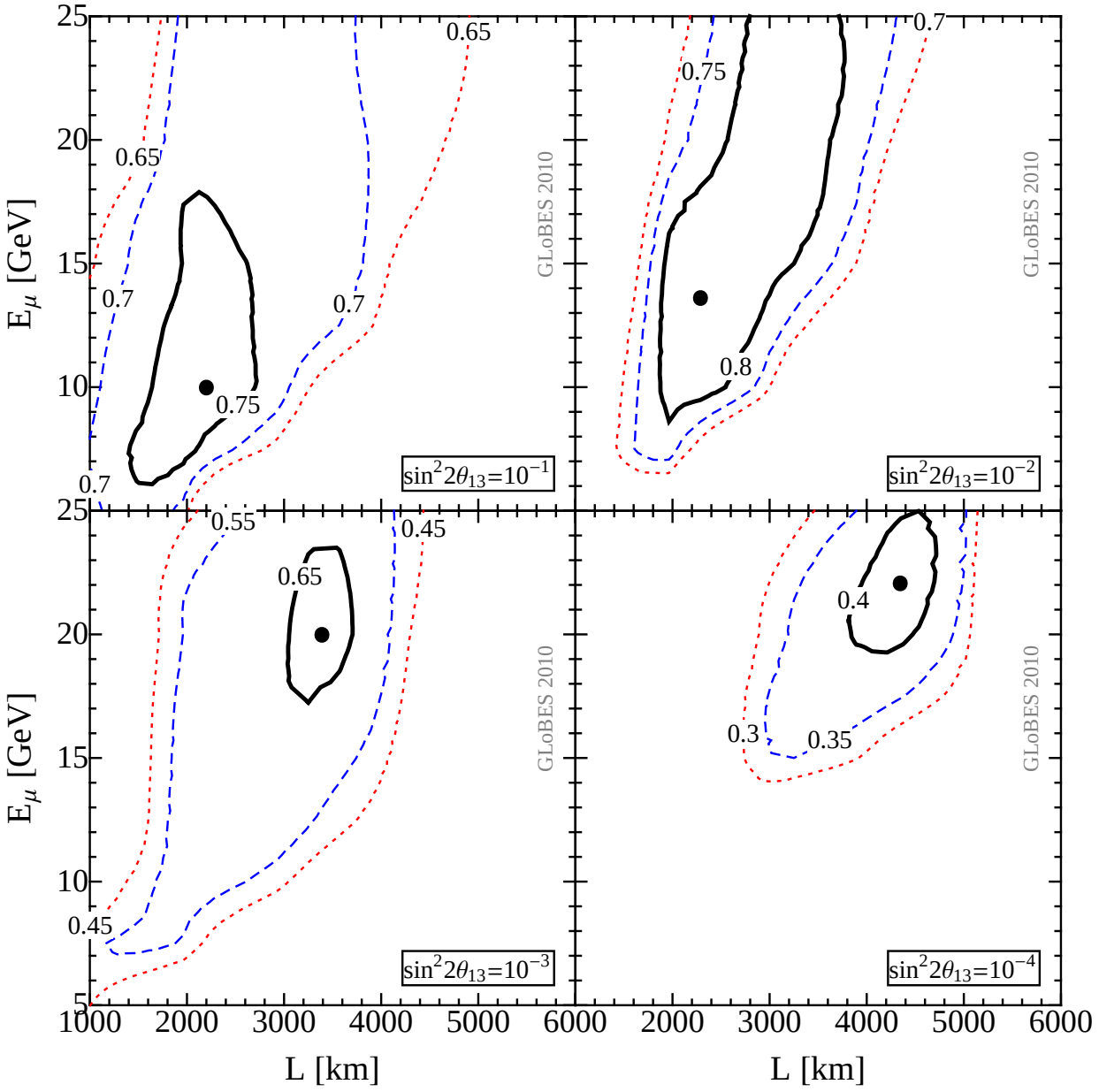
CP precision



PH, M. Lindner, W. Winter JHEP 05 020 (2005).

This is an example using a 50GeV NF with 20GeV detection threshold, needs to be updated.

Optimization – one baseline

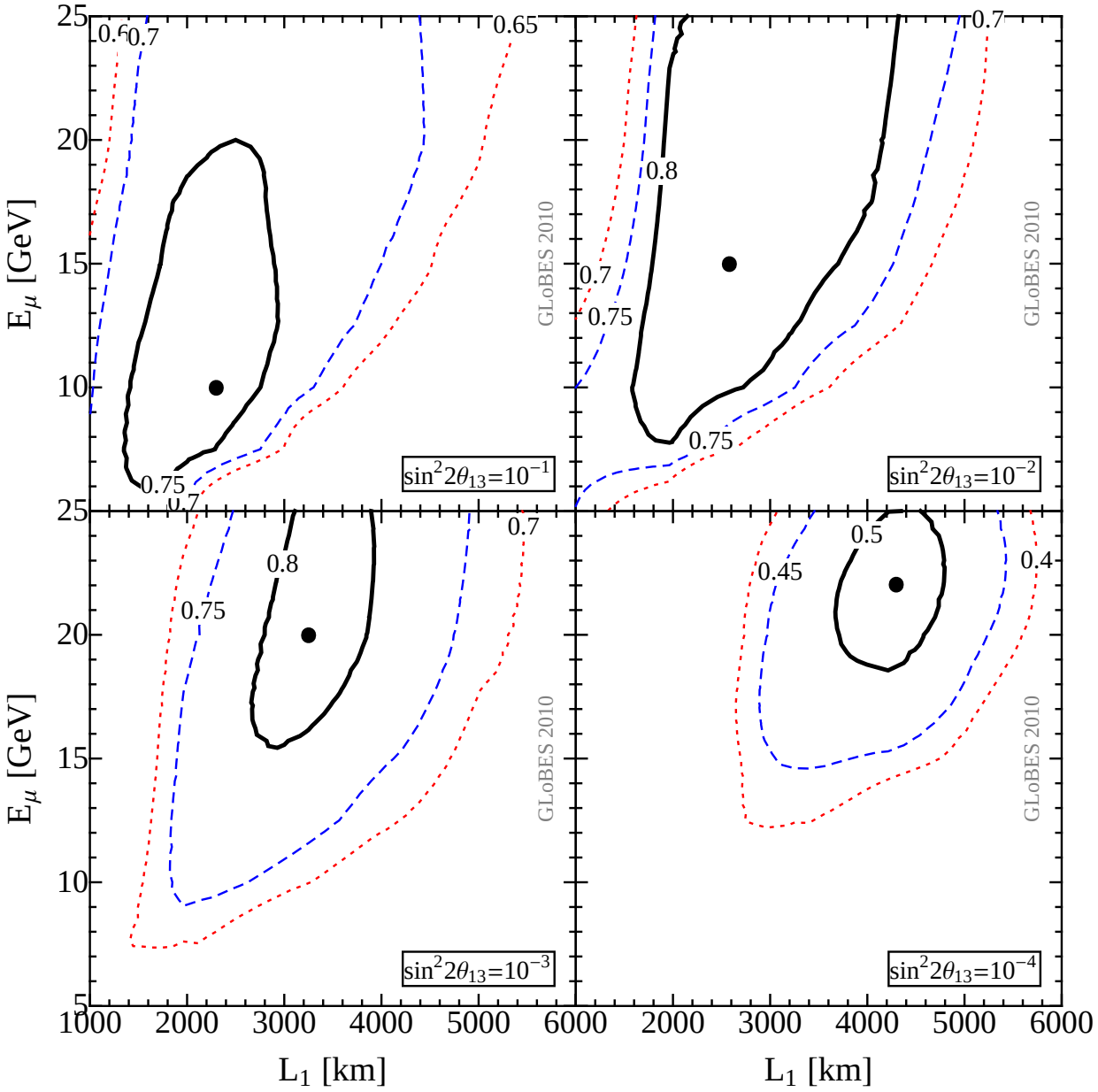


At large θ_{13}, using MIND and one baseline, optimum is at 2200-2300 km and 10-14 GeV.

CPF 0.77-0.84

S. Agarwalla, PH, J. Tang, W. Winter JHEP 1101 120 (2011).

Optimization – 2nd baseline?



At large θ_{13}, using MIND and one baseline, optimum is at 2300-2600 km and 10-15 GeV.

CPF 0.77-0.84 – identical to one baseline setup

Only 1 baseline needed!

S. Agarwalla, PH, J. Tang, W. Winter JHEP 1101 120 (2011).

Staging

Traditional staging scenarios evolve from low energy, 1 baseline setups to high energy, 2 baseline setups.

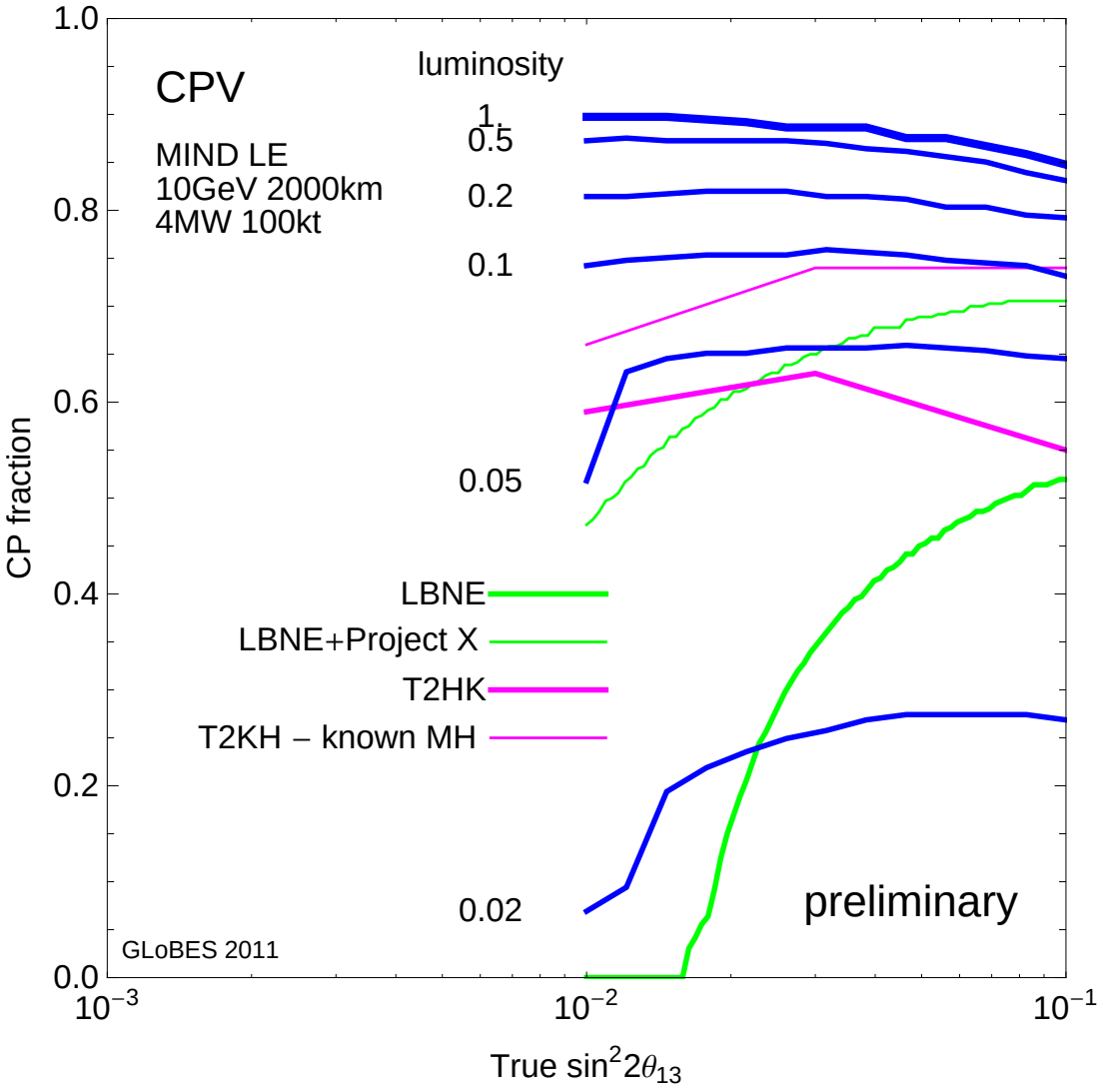
e.g. J. Tang, W. Winter, Phys.Rev. D81 (2010) 033005.

At large θ_{13}, we only want low energy and 1 baseline!

Remaining degrees of freedom

- Luminosity
- Detector technology
  - iron vs fully active
  - magnetized vs non-magnetized

Staging – luminosity



1/20-1/10 of luminosity
- NF as good as the best SB

1/50-1/20 of luminosity
- NF on par with LBNE

$\Rightarrow$ Start somehwere between 1/50 and 1/20 and work your way to full luminosity

Staging – luminosity

Assume 1/25 of the default luminosity, gains split equally between detector and accelerator

- proton beam power of 4 MW $\rightarrow$ 800 kW
- fiducial mass of MIND of 100 kt $\rightarrow$ 20 kt

This opens new possibilities

- Maybe horns instead of solenoids can be used
- Maybe existing proton infrastructure can be used
- Maybe 20 kt of LAr can be magnetized

LBNE + Project X cost about \$2 billion – can we make a 1/25th-luminosity NF for a similar price?

Summary

Comparison with SB

- Will the mass hierarchy have been determined w/o new experiments? – not likely (requires Project X)
- Are SB likely to discover CPV – yes, provided they are truly super (which LBNE is not)
- Can SB do precision measurements – not obvious
- Can NF do significantly better – YES

Consequences for NF

- MIND LE optimal at large θ_{13}
- 1/25th of the luminosity is sufficient for an entry level facility to match the capabilities of SB

Open questions

PPEG & Detector WG

- Study precision
  - Systematics modeling including near detector
  - Select (or develop) performance indicators
  - Optimize for large θ_{13}
- Compare with precision of other facilities

Accelerator WG

- Alternative proton beam scenarios, e.g. 120 GeV
- 1 MW targets
- 5-10GeV muon beam

How cheap and fast can a 1/25th-luminosity NF be?