# Physics Case for 5 GeV Neutrino Factory


Patrick Huber

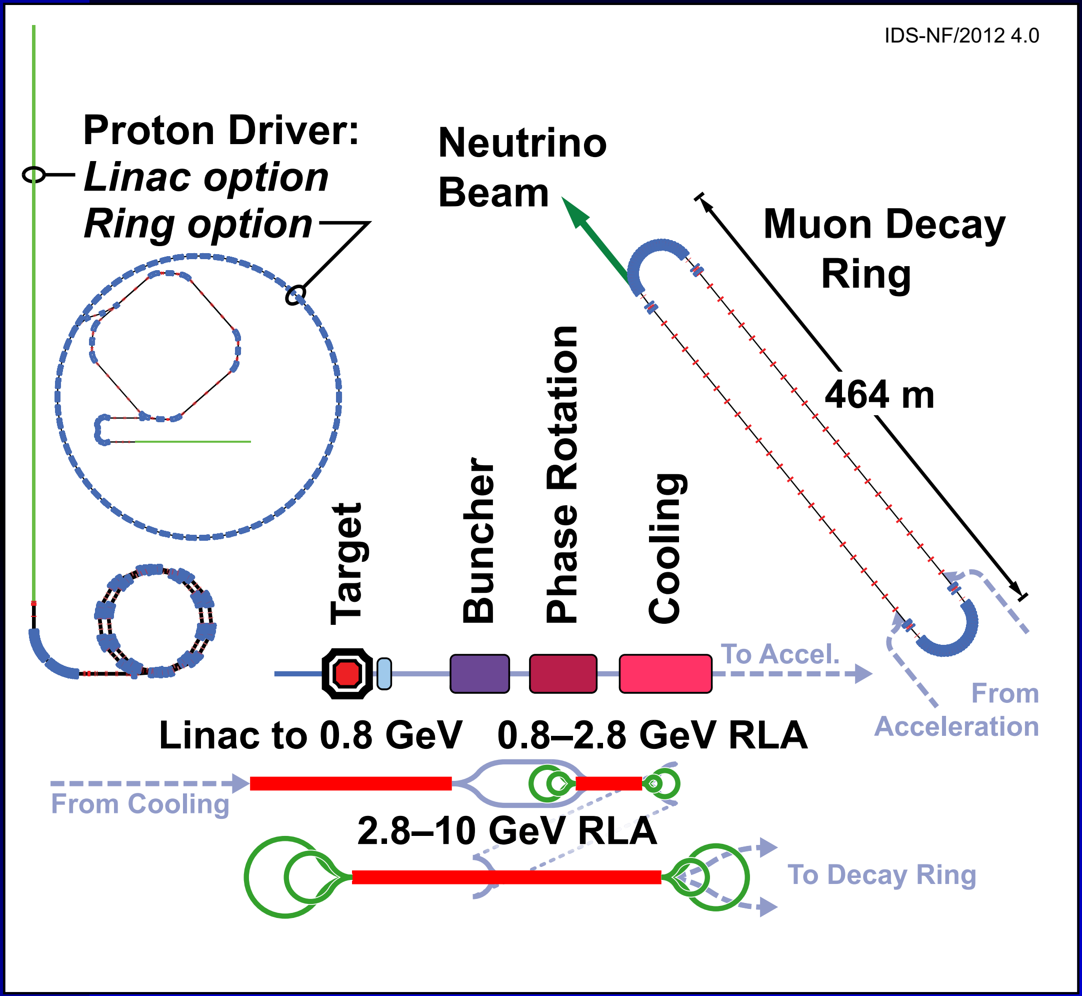
Center for Neutrino Physics at Virginia Tech



MAP 2014 Winter Meeting

December 3-7, 2014, SLAC

# Baseline neutrino factory




10 GeV muon energy

1E21 useful muon decays per straight and polarity, in 1E7 s

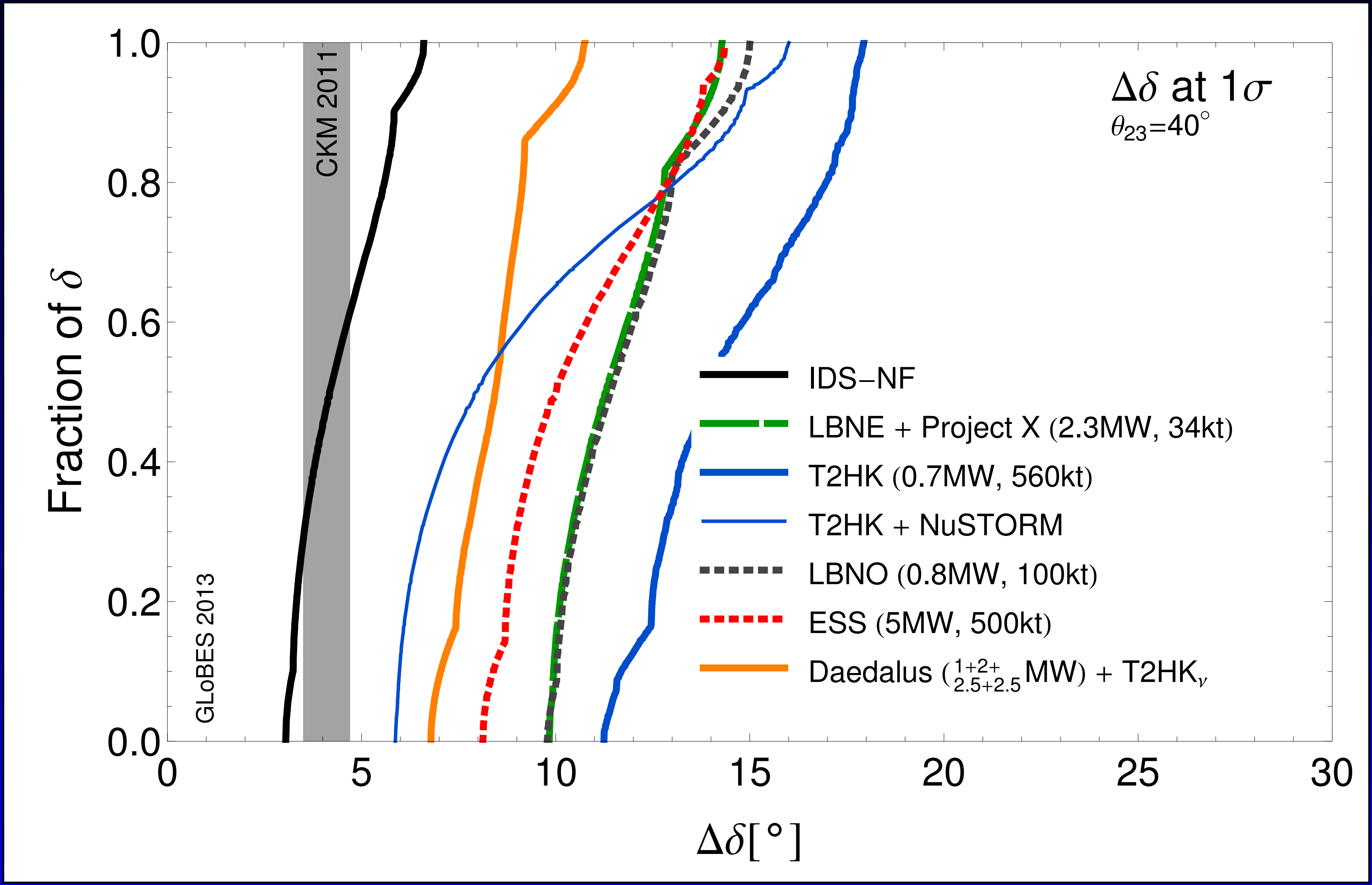
2 000 km baseline

100 kt magnetized iron detector (MIND)

Based on a 4 MW proton driver, which would have become available as part of Project X phase IV, *i.e.* in the 2030s

Difficult to identify synergies with LBNF.

# NF performance




IDS-NF (4MW, 100kt), corresponding to $10^{21}$ useful muon decays p.a.

# An entry level neutrino factory?

In order to maximize synergies with the existing program, MASS identified the following questions

- Can a neutrino factory work at 1 300 km baseline?
- Are there better detector choices?
- What is the minimum number of muon decays needed?

The answers to those questions are interrelated, many options have been studied, one possible scheme has been introduced in Christensen, Coloma, PH, PRL **111** 061803 (2013).

# NuMAX

NuMAX – NeUtrinos from Muon Accelerators compleX

- 1 300 km baseline implies a beam energy of 5 GeV
- 5 GeV beam energy makes liquid argon a very attractive detector choice
- Magnetized liquid argon allows the detection of $\bar{\nu}_e$ and $\nu_e$

As a result proton driver beam power of 1 MW and a detector mass of 10 kt yield already good physics sensitivities.

# Detector choices

A detector suitable for a 5 GeV NuMAX beam should have

- good efficiency down to 2 GeV neutrino energy
- a magnetic field – for muon charge ID
- fine granularity – for electron neutrino interactions

Possible detector systems

- Totally Active Scintillator Detector (TASD) with magnetic field – simulation studies exist
- Liquid argon TPC (LAr) with magnetic field – needs a simulation study

Also, Magnetized Iron Detector (MIND) with a larger mass may be used.

# Detector assumptions

TASD

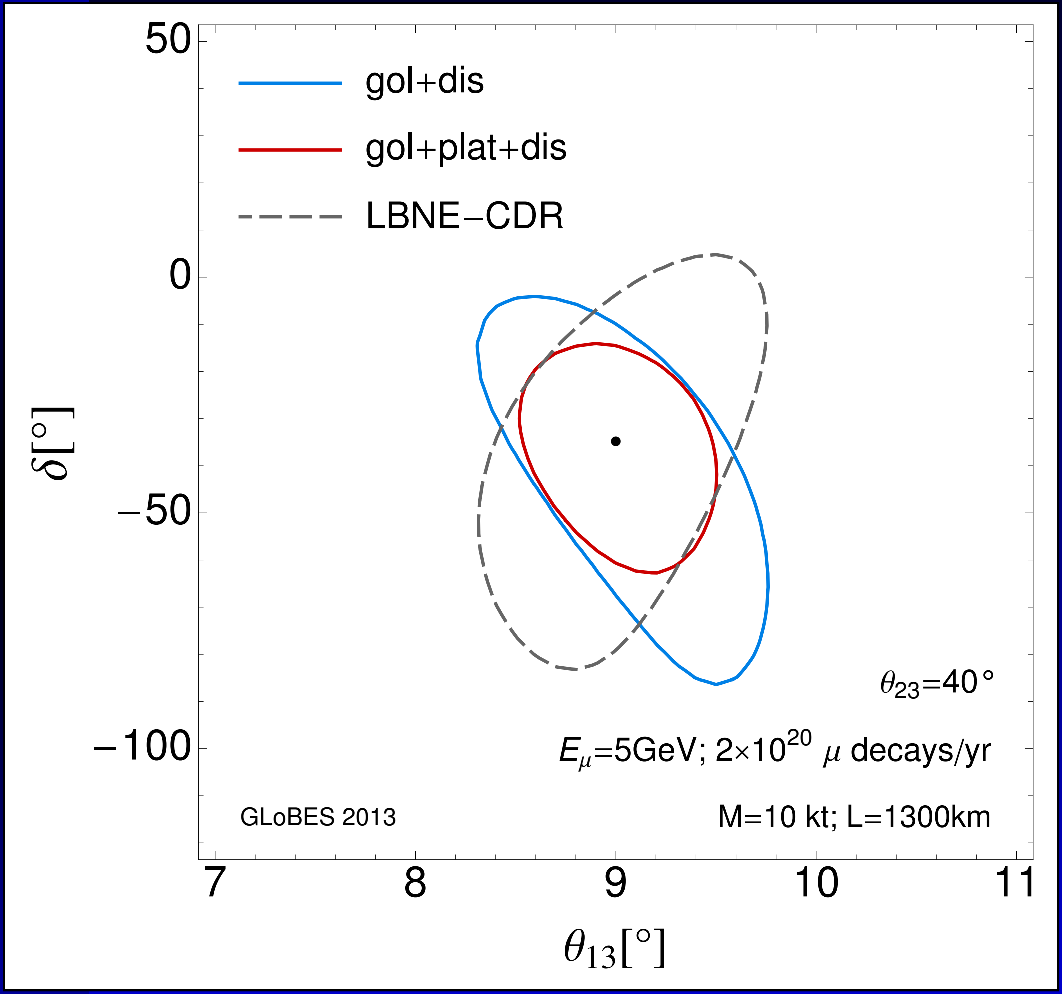
| Channel | Effs. | $\tau$ Rej. | NC/CID/FID Rej. | $\Delta E/E$ |
|---|---|---|---|---|
| $\nu_\mu$ app. | 73%-94% | 0% | 99.9% | $0.2/\sqrt{E}$ |
| $\nu_e$ app. | 37%-47% | 0% | 99% | $0.15/\sqrt{E}$ |
| $\nu_\mu$ dis. | 73%-94% | 0% | 99.9% | $0.2/\sqrt{E}$ |

Magnetized LAr

| Channel | Effs. | $\tau$ Rej. | NC/CID/FID Rej. | $\Delta E$ |
|---|---|---|---|---|
| $\nu_\mu$ app. | 80% | 0% | 99.9% | $0.2/\sqrt{E}$ |
| $\nu_e$ app. | 80% | 0% | 99.9% | $0.15/\sqrt{E}$ |
| $\nu_\mu$ dis. | 80% | 0% | 99.9% | $0.2/\sqrt{E}$ |

$\nu_\tau$ backgrounds included

# The Platinum channel

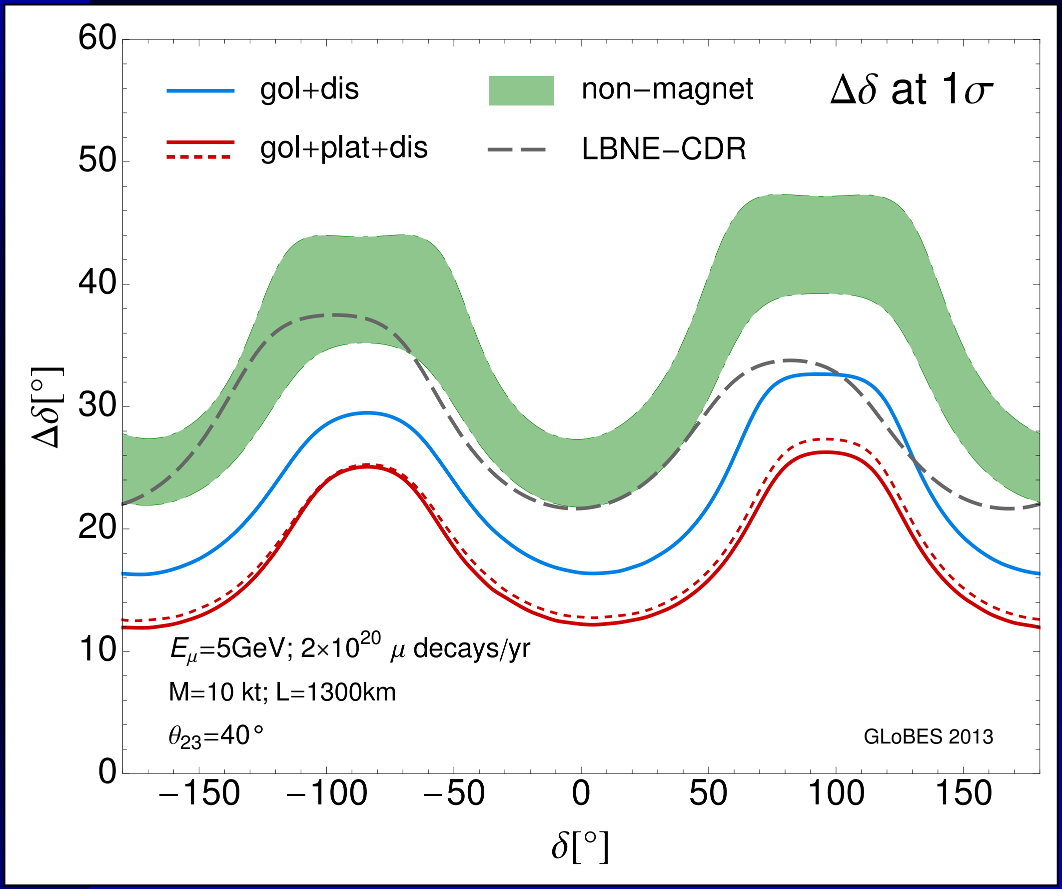



The $\nu_\mu \to \nu_e$ channel is the CPT conjugate of the $\bar{\nu}_e \to \bar{\nu}_\mu$ channel

As a result matter effects effectively cancel

This has been known for quite a while, but the effect is only relevant for large $\theta_{13}$

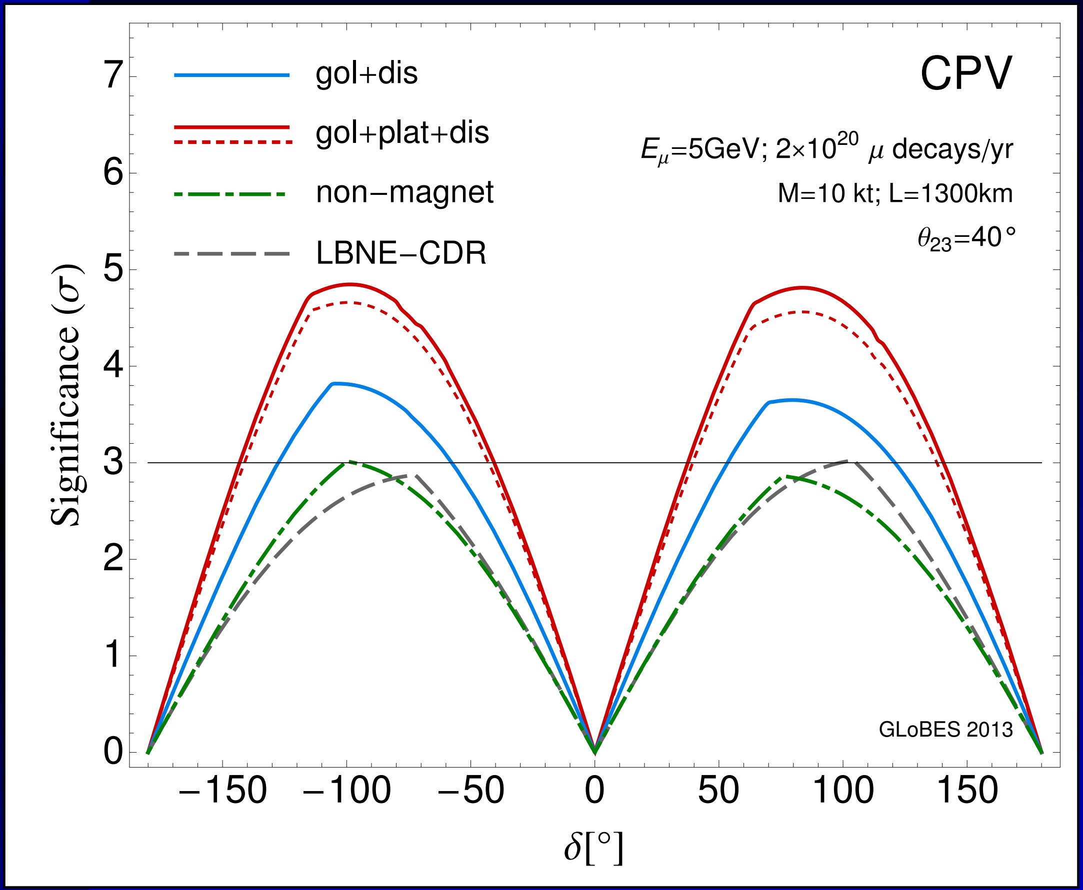
# CP precision




Solid line – magnetized LAr
Dashed line – magnetized TASD

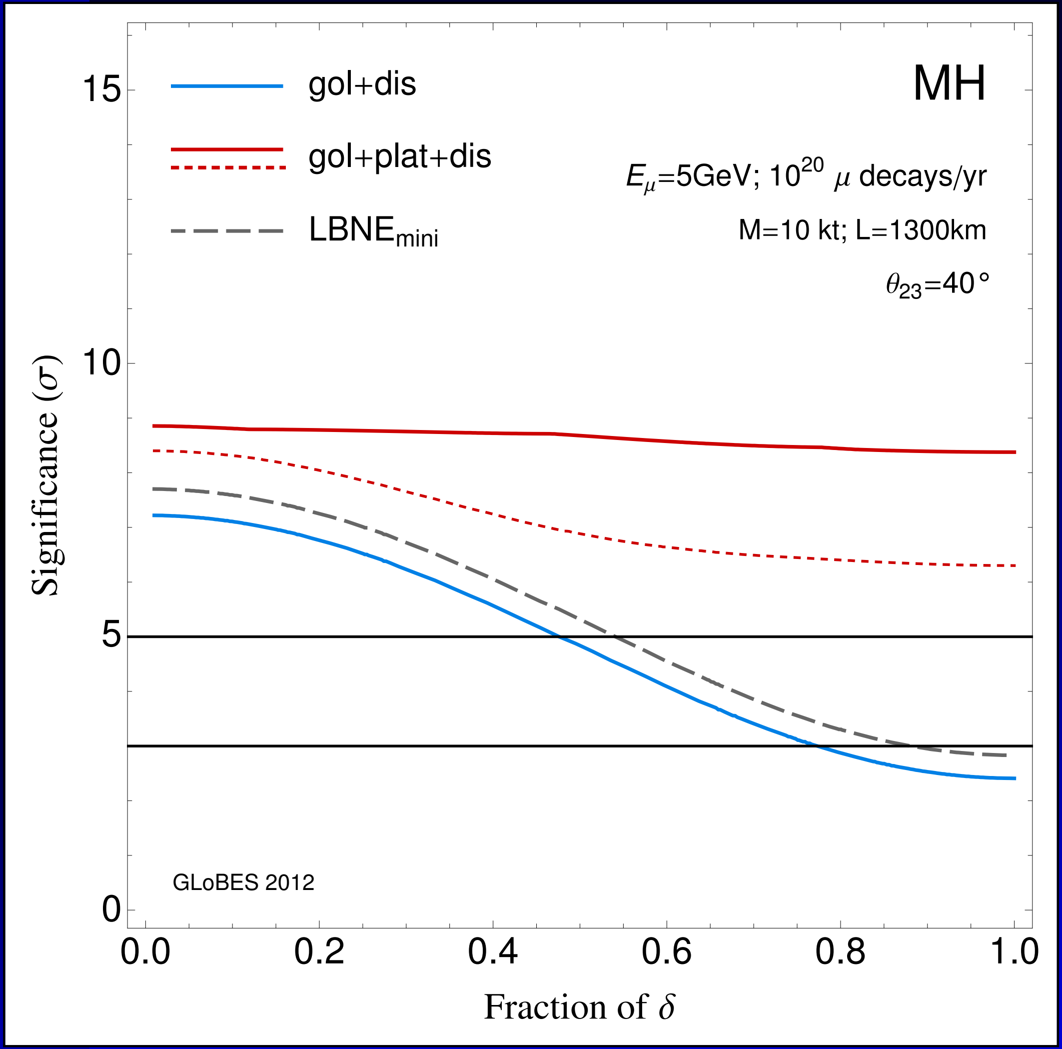
The obtainable precision is everywhere better than LBNE10 by about 9 degrees (1/3)

# CP violation




Significant advantage for CP violation

# Mass hierarchy




Same for mass hierarchy, clear advantage

# Remarks

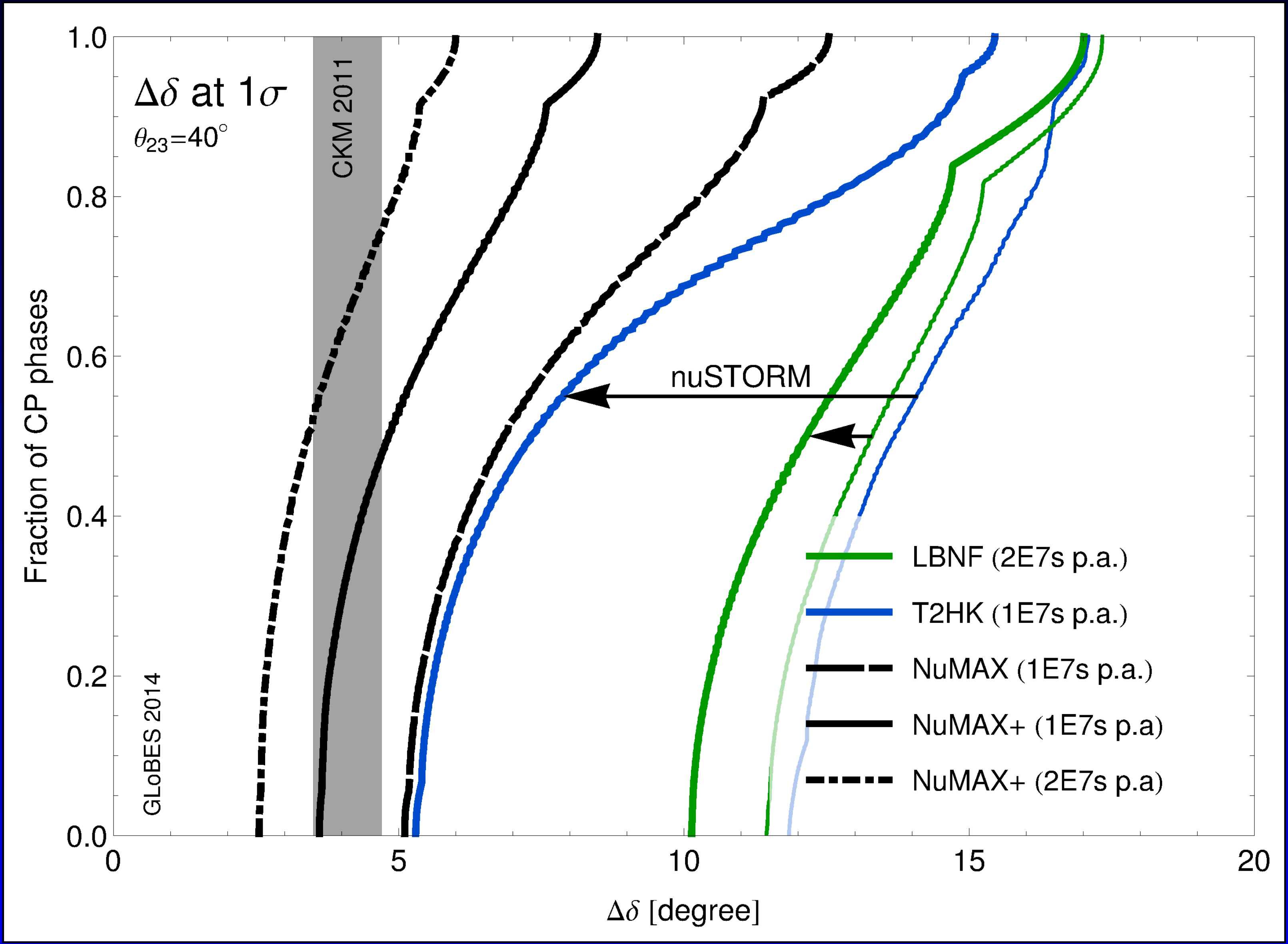
NF detectors probably have to be underground because of large duty factor.

4-6 GeV muon energy works also, shallow optimum around 5 GeV.

A full NF would be a 5 GeV machine, maybe with a larger LAr detector – performance en par with IDS-NF baseline – no energy or baseline staging.

Muon based neutrino beams, NuSTORM and NuMAX, can deliver virtually systematics-free measurements for both short and long-baseline physics – path to unique levels of precision.

# NuMAX performance



# Next steps. . .

- Need to verify magnetized LAr performance – since there is no reconstruction software we may resort to a hand scanning study. MicroBooNE experience indicates that we need about 10-20 man-weeks.
- Monte Carlo production, according to LarSoft collaboration, not a big problem, needs about 1 man-week of additional software development

# Summary

- Full NF – best performance of all technologies
- NuMAX addresses many of the issues of the full NF in terms of timeliness and synergy with LBNE
- NuMAX starts at 1% of full NF exposure $\rightarrow$ incredible upgrade potential, basically systematics free
- The evolution from NuSTORM over NuMAX to NuMAX+ provides unparalleled capabilities for high precision measurements at both short and long baselines, due to virtual absence of beam systematics.