CP violation reach in the next decade and beyond

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CP violation

Like in the quark sector mixing can cause CP violation

$$P(\nu_\alpha \to \nu_\beta) - P(\bar{\nu}_\alpha \to \bar{\nu}_\beta) \neq 0$$

The size of this effect is proportional to

$$J_{CP} = \frac{1}{8} \cos\theta_{13} \sin 2\theta_{13} \sin 2\theta_{23} \sin 2\theta_{12} \sin\delta$$

but the asymmetry

$$\frac{P(\nu_\alpha \to \nu_\beta) - P(\bar{\nu}_\alpha \to \bar{\nu}_\beta)}{P(\nu_\alpha \to \nu_\beta) + P(\bar{\nu}_\alpha \to \bar{\nu}_\beta)} \propto \frac{1}{\sin 2\theta_{13}}$$

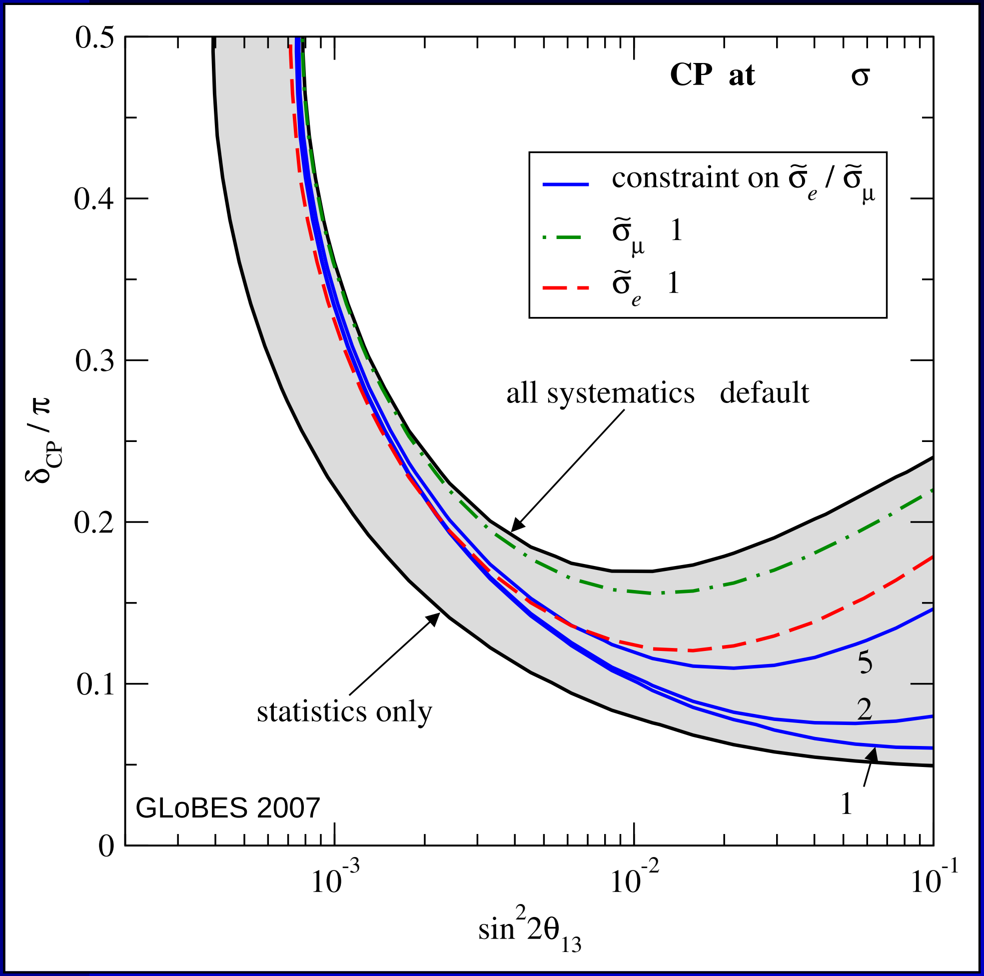
The experimentally most suitable transition to study CP violation is $\nu_e \leftrightarrow \nu_\mu$.

Consequences for experiments

- need to measure 2 out of $P(\nu_\mu \to \nu_e)$, $P(\bar{\nu}_\mu \to \bar{\nu}_e)$, $P(\nu_e \to \nu_\mu)$ and $P(\bar{\nu}_e \to \bar{\nu}_\mu)$
- need more than 1 energy and/or 1 baseline
- large θ_{13} implies small CP asymmetries
$\Rightarrow$ need for small systematics

Ultimately, the combination of large exposure $\gg 100\,\mathrm{kt\,MW\,yr}$ with percent-level systematics will be needed – see Ken's talk.

ν_e/ν_μ x-sections

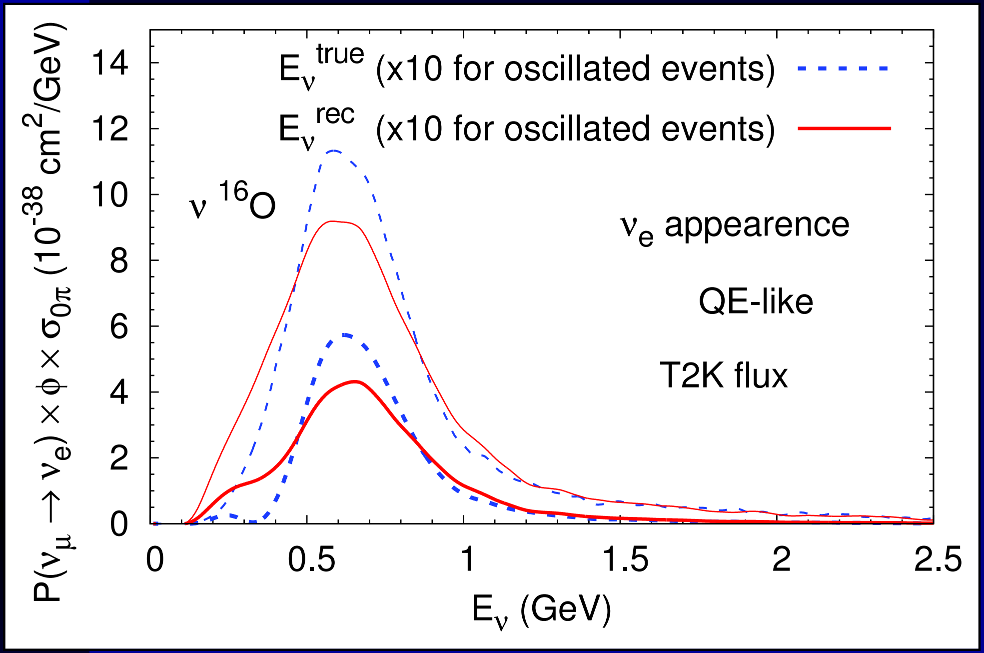


PH, M. Mezzetto, T. Schwetz
arXiv:0711.2950

Appearance experiments using a (nearly) flavor pure beam can not rely on a near detector to predict the signal at the far site!

Large θ_{13} most difficult region.

QE energy reconstruction



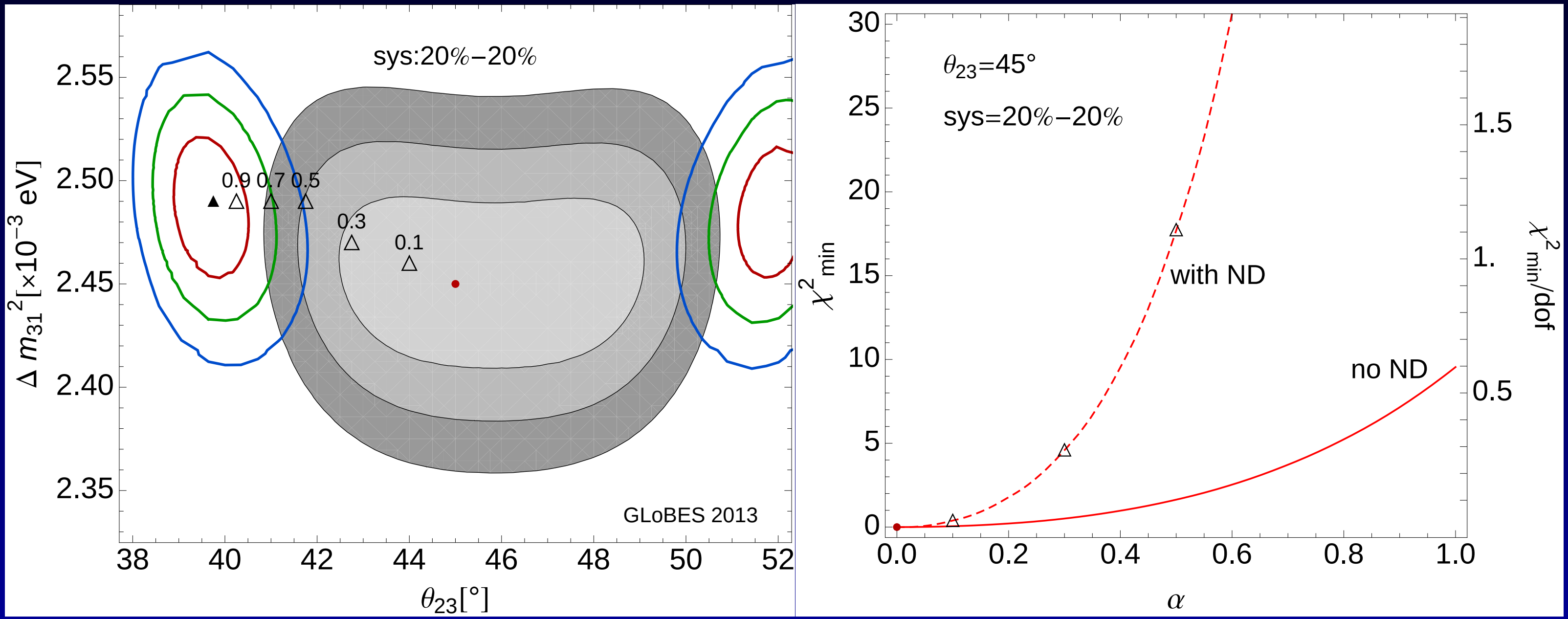
Lalakulich, Mosel, arXiv:1208.3678.

Nuclear effects change the relation between true neutrino energy and lepton energy

Inferring the CP phase from QE spectrum seems quite difficult

Not obvious that near detectors alone can solve this problem.

Nuclear effects



arXiv:1307.1243

$$N_i^{\text{test}}(\alpha) = \alpha \times N_i^{QE} + (1-\alpha) \times N_i^{QE-like}$$

where $\alpha = 0$ corresponds to perfectly know nuclear effects and $\alpha = 1$ to entirely unknown nuclear effects in the fit.

CP precision and systematics

We specifically simulate near and far detectors

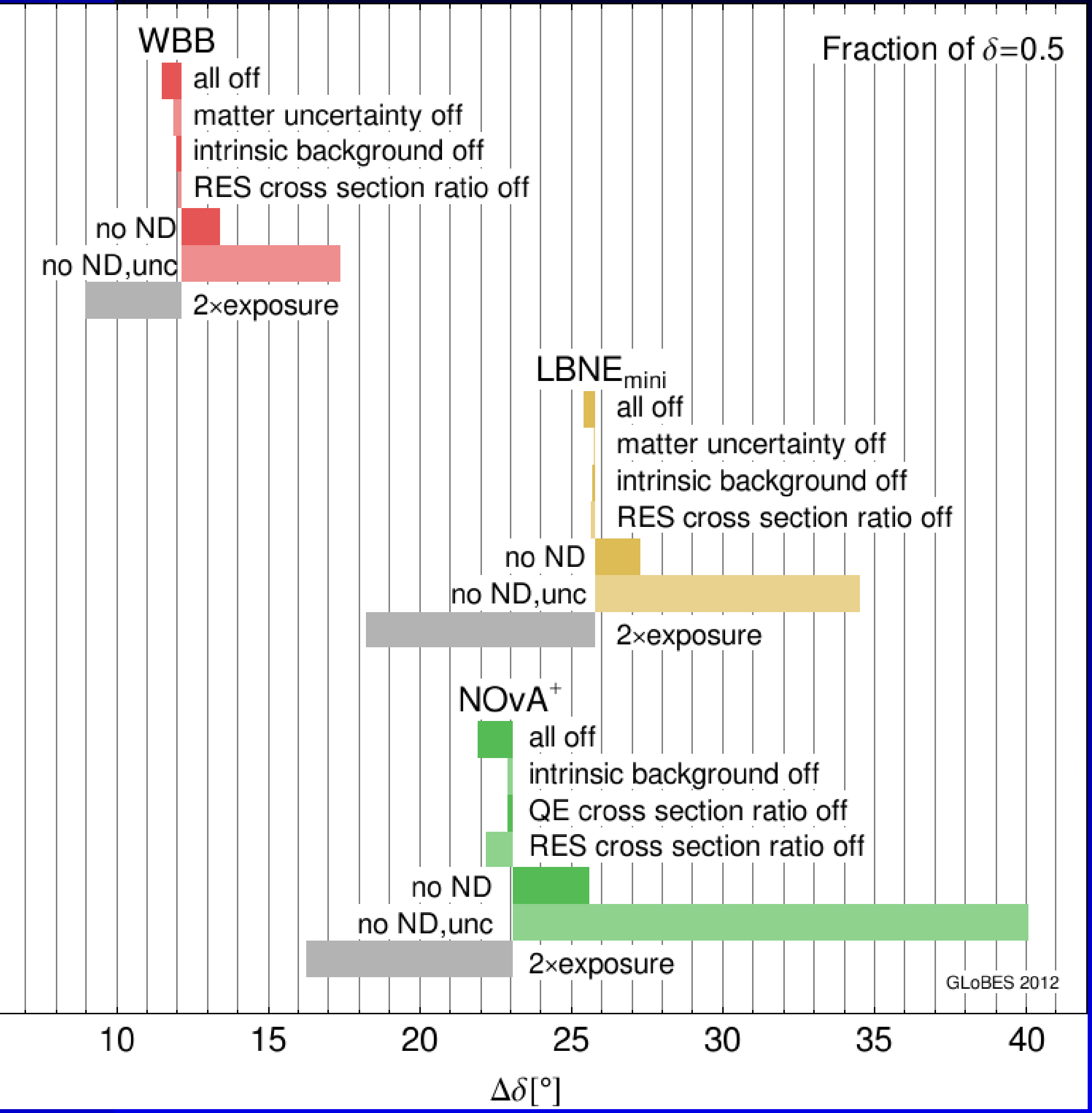
We use common assumptions for all experiments on

- cross sections split into QE, RES and DIS for each flavor and neutrinos and antineutrinos
- cross section ratios between e and μ flavors for QE, RES and DIS and neutrinos and antineutrinos
- fiducial volume and near/far extrapolation errors

We use experiment type specific errors for

- fluxes
- beam backgrounds
- detector backgrounds

Systematics I



Nuclear effects NOT included

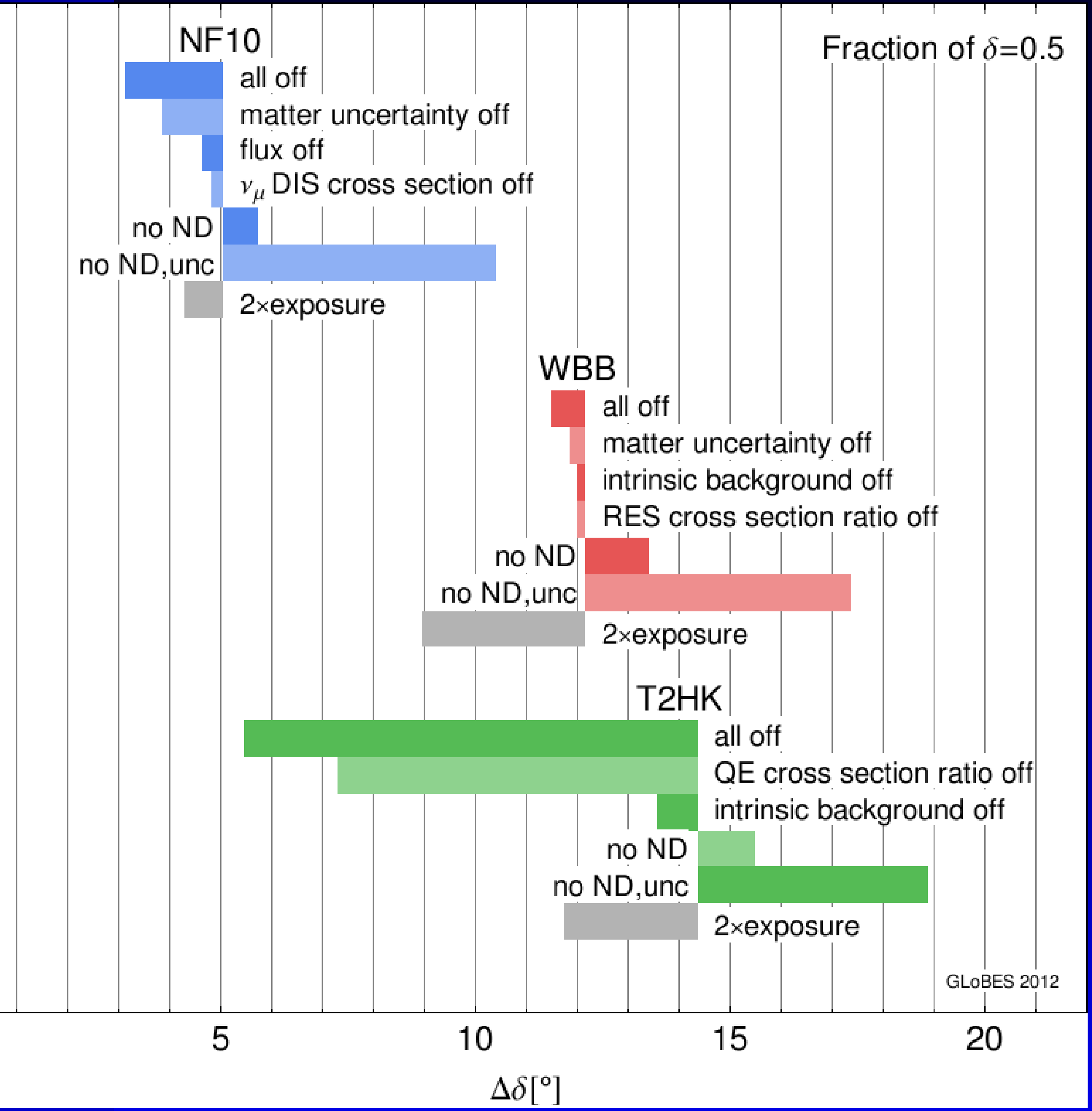
Near detector crucial for new physics searches

NOvA$^+$ higher risk from systematics

Current $\Delta\delta$ is 30-35° Fogli *et al.*, 2012

arXiv:1209.5973

Systematics II

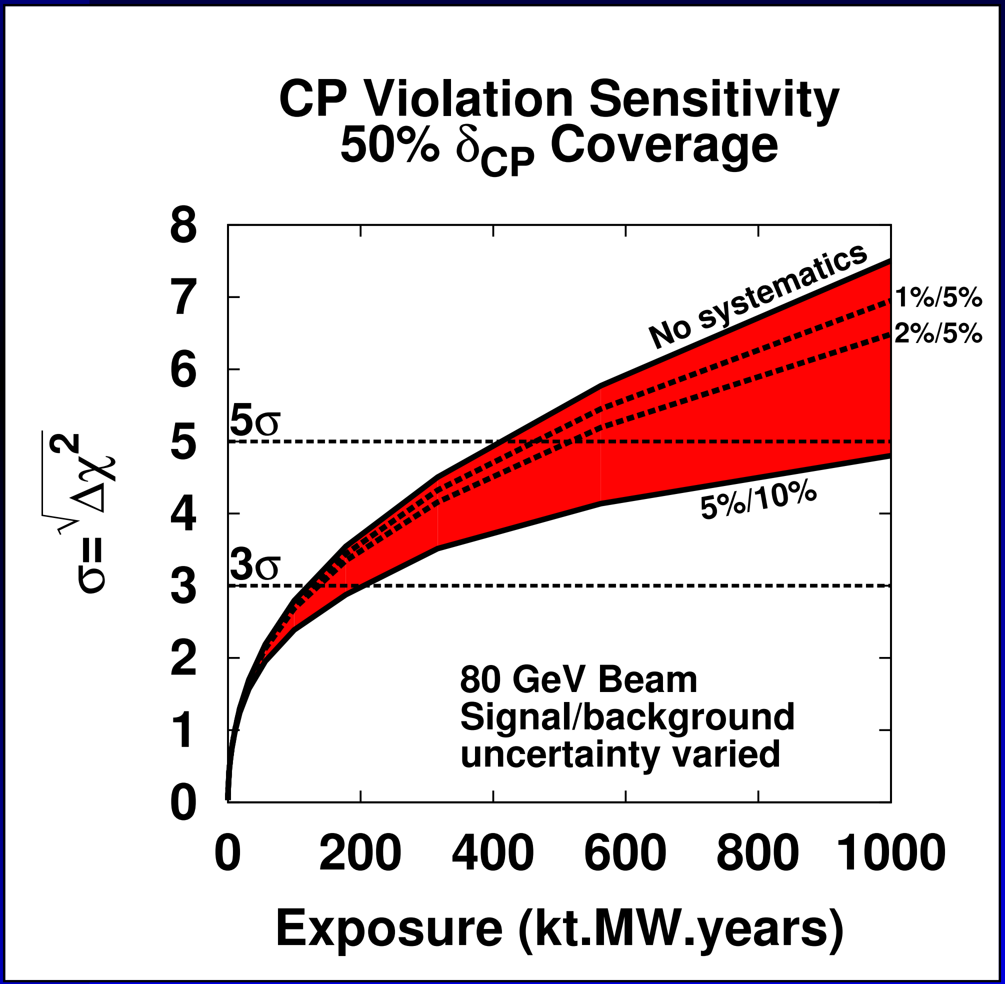


Disappearance data can play the role of near detector if three flavor framework is assumed

Scaling with luminosity is strongyl affected by systematics

arXiv:1209.5973

Luminosity scaling

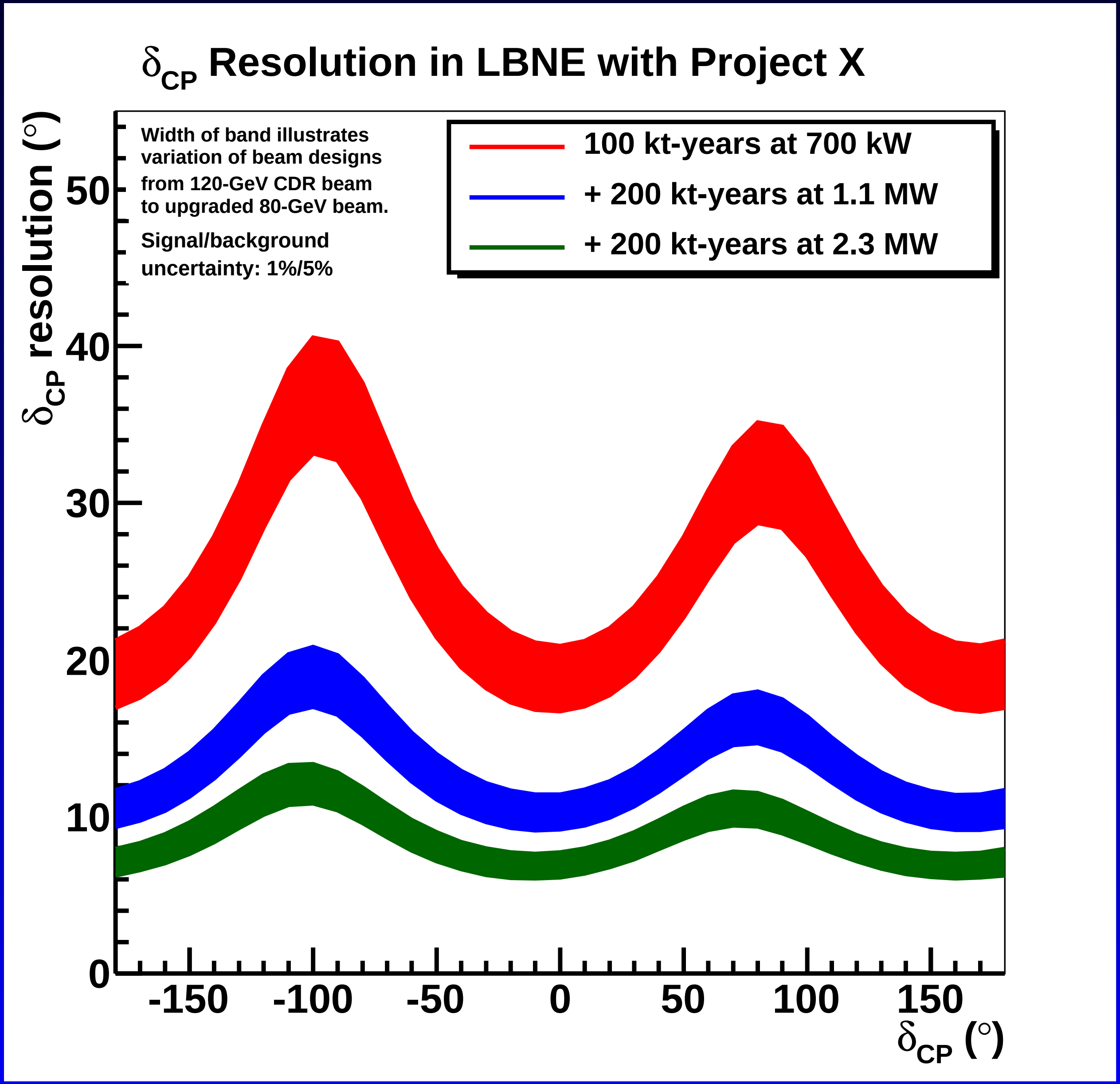


arXiv:1307.7335

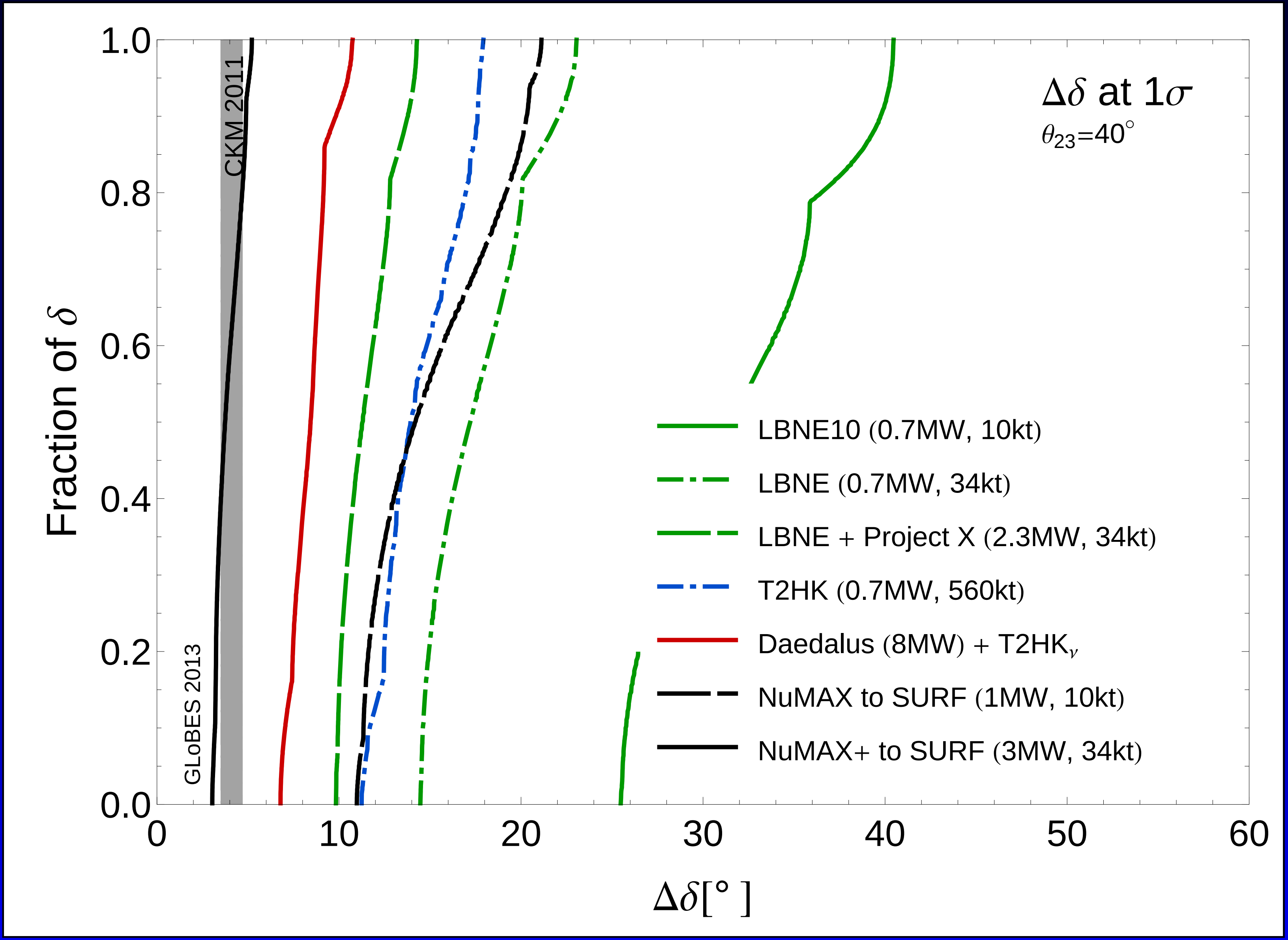
Extrapolating super-beam performances beyond several 100 kt MW years is entirely dependent on the assumptions on systematics!

LBNE10 – 70 kt MW yr
LBNE – 238 kt MW yr
LBNE + Project X – 782 kt MW yr
T2HK –3920 kt MW yr
NuMAX+ 34kt – 1020 kt MW yr

LBNE – CP sensitivity



Comparison of CP sensitivities



Summary

- New facilities are indispensable to fully exploit the discovery of neutrino oscillation
- LBNE10, LBNE and LBNE + Project X provide a staged program to discover CP violation with increasing reach.
- LBNE, in particular, together with Project X is competitive in performance
- Eventually systematics issue, which currently are not well understood, will limit the sensitivity of pion-decay based beams