The Low Energy Neutrino Factory

Tracey Li

In collaboration with: Alan Bross, Malcolm Ellis, Steve Geer, Enrique Fernández-Martínez, Olga Mena and Silvia Pascoli

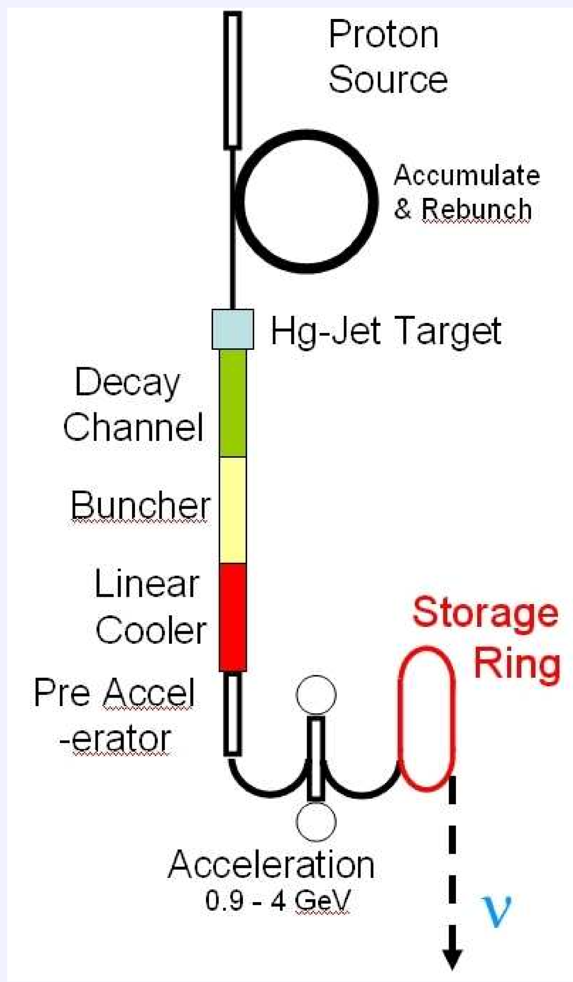
The low energy neutrino factory is a potential next-generation long baseline experiment. We introduce the experiment and assess its physics reach in terms of standard oscillation parameters and non-standard interactions.

Baseline: $L = 1300$ km, $E_\mu = 4.5$ GeV, flux = 1.4×10^{21} useful decays/ year/ polarity, running time = $10 + 10$ years.

Detector: Either a 20 kton totally active scintillating detector (TASD) or a 100 kton liquid argon (LAr) detector:

	TASD	Conservative LAr	Optimistic LAr
Energy threshold	0.5 GeV	0.5 GeV	0.5 GeV
Efficiency of ν_μ ($\bar{\nu}_\mu$) detection	73% for E $<$ 1 GeV, 90% for E $>$ 1 GeV	80%	80%
Efficiency of ν_e ($\bar{\nu}_e$) detection	37% for E $<$ 1 GeV, 47% for E $>$ 1 GeV	80%	80%
Systematics	2%	5%	2%
Energy resolution - QE (non-QE) events	10% (10%)	5% (20%)	5% (10%)
Background for ν_μ ($\bar{\nu}_\mu$) detection	1×10^{-3}	5×10^{-3}	1×10^{-3}
Background for ν_e ($\bar{\nu}_e$) detection	1×10^{-2}	0.8	1×10^{-2}

[Geer, Mena, Pascoli, ‘A low energy neutrino factory for large θ_{13}’; Bross, Ellis, Geer, Mena, Pascoli, ‘Neutrino factory for both large and small θ_{13}’; Ankenbrandt, Bogacz, Bross, Geer, Johnstone, Neuffer, Popovic, ‘Low-energy neutrino factory design’; B. Fleming - private communication reported in hep-ph/0703029]



[Bross]

Oscillation probabilities

A magnetized TASD or LAr detector will give us access to the golden ($\nu_e \to \nu_\mu$, $\bar{\nu}_e \to \bar{\nu}_\mu$) and platinum ($\nu_\mu \to \nu_e$, $\bar{\nu}_\mu \to \bar{\nu}_e$) channels. These channels are sensitive to θ_{13}, δ, sign[Δm^2_{31}] and the NSI parameters $\varepsilon_{e\mu}$ and $\varepsilon_{e\tau}$:

$$P_{\nu_e \to \nu_\mu} = s^2_{213} s^2_{23} \sin^2\left(\frac{\Delta m^2_{31} L}{4E} - \frac{AL}{2}\right) + s_{213} \alpha s_{212} s_{223} \frac{\Delta m_{31}{}^2 L}{2EA} \sin\left(\frac{AL}{2}\right) \sin\left(\frac{\Delta m^2_{31} L}{4E} - \frac{AL}{2}\right) \cos\left(\delta - \frac{\Delta m^2_{31} L}{4E}\right) + \alpha^2 c^2_{23} s^2_{212} \left(\frac{\Delta m^2_{31} L}{2EA}\right)^2 \sin^2\left(\frac{AL}{2}\right) \quad \leftarrow \text{standard oscillation}$$

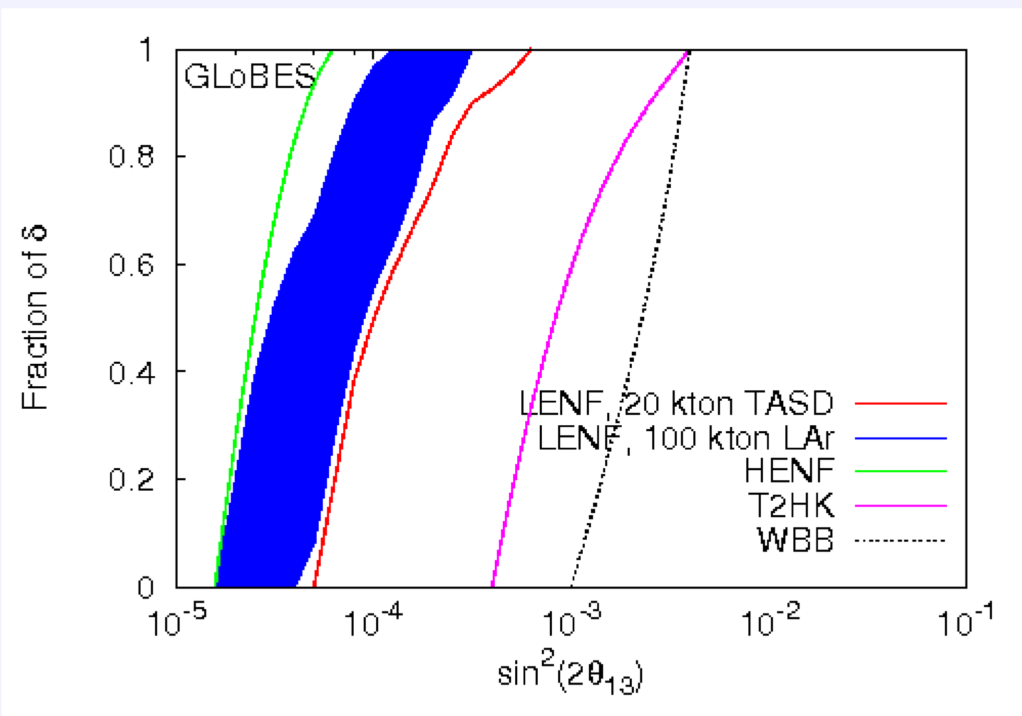
$$- 4\varepsilon_{e\tau} s_{213} c_{23} s^2_{23} \sin\left(\frac{AL}{2}\right) \sin\left(\frac{\Delta m^2_{31} L}{4E} - \frac{AL}{2}\right) \cos\left(\delta + \phi_{e\tau} - \frac{\Delta m^2_{31} L}{4E}\right) + 4\varepsilon_{e\tau} \alpha s_{212} c^2_{23} s_{23} \sin\left(\frac{AL}{2}\right) \sin\left(\frac{\Delta m^2_{31} L}{4E} - \frac{AL}{2}\right) \cos\left(\phi_{e\tau} + \frac{\Delta m^2_{31} L}{4E}\right) + 4\varepsilon^2_{e\tau} c^2_{23} s^2_{23} \sin^2\left(\frac{AL}{2}\right) \leftarrow \text{non-standard interactions} \sim \varepsilon_{e\tau}$$

$$- 4\varepsilon_{e\mu} s_{213} c^2_{23} s_{23} \sin\left(\frac{AL}{2}\right) \sin\left(\frac{\Delta m^2_{31} L}{4E} - \frac{AL}{2}\right) \cos\left(\delta + \phi_{e\mu} - \frac{\Delta m^2_{31} L}{4E}\right) - 4\varepsilon_{e\mu} \alpha s_{212} c^2_{23} s_{23} \sin\left(\frac{AL}{2}\right) \sin\left(\frac{\Delta m^2_{31} L}{4E} - \frac{AL}{2}\right) \cos\left(\phi_{e\mu} + \frac{\Delta m^2_{31} L}{4E}\right) + 4\varepsilon^2_{e\mu} c^2_{23} s^2_{23} \sin^2\left(\frac{AL}{2}\right) \leftarrow \text{non-standard interactions} \sim \varepsilon_{e\mu}$$

[Cervera, Donini, Gavela, Gomez Cándenas, Hernández, Mena, Rigolin, ‘Golden measurements at a neutrino factory’; Kopp, Ota, Winter, ‘Neutrino factory optimization for non-standard interactions’; Gago, Minakata, Nunokawa, Uchinami, Zukanovich Funchal, ‘Resolving CP Violation by Standard and Nonstandard Interactions and Parameter Degeneracy in Neutrino Oscillations’]

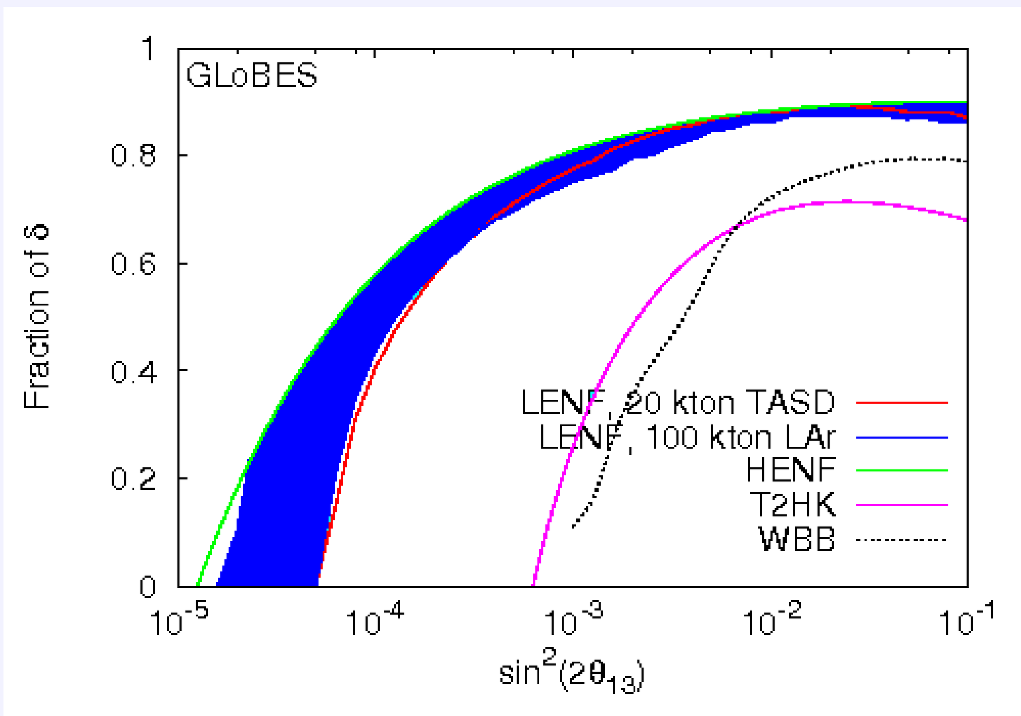
Sensitivity to standard oscillation parameters

θ_{13} discovery potential (3σ):



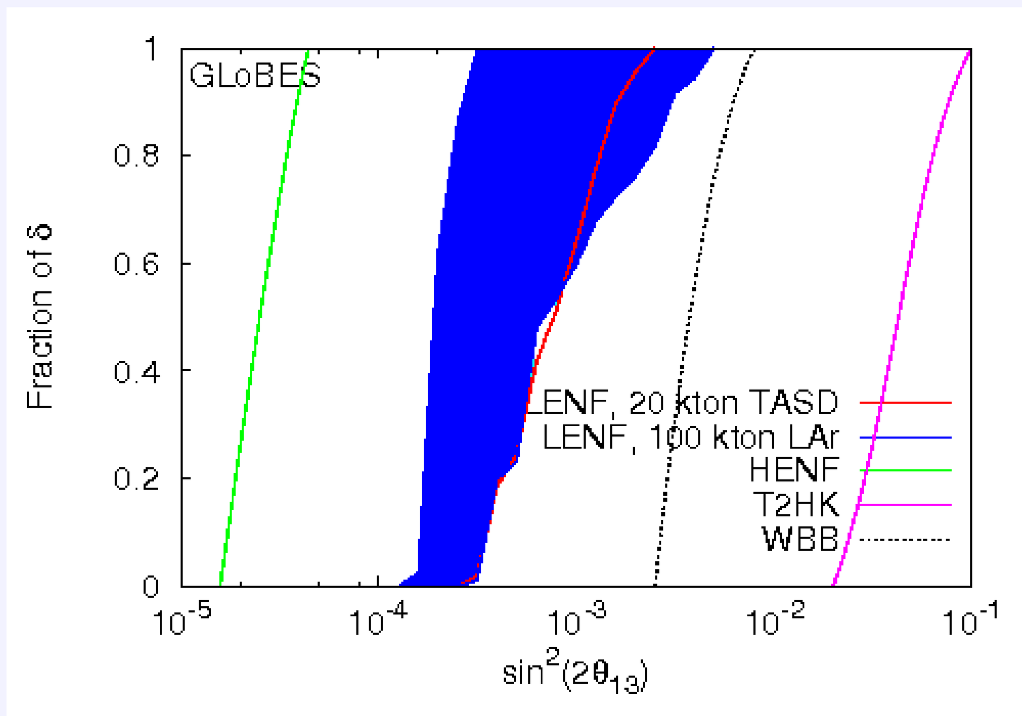
LAr: sensitive to θ_{13} for $\sin^2(2\theta_{13}) \gtrsim 10^{-5}$.
TASD: sensitive to θ_{13} for $\sin^2(2\theta_{13}) \gtrsim 10^{-4}$.

CP discovery potential (3σ):



LAr: competitive with HENF for all θ_{13}.
TASD: competitive for $\sin^2(2\theta_{13}) > 10^{-3}$.

Hierarchy sensitivity (3σ):



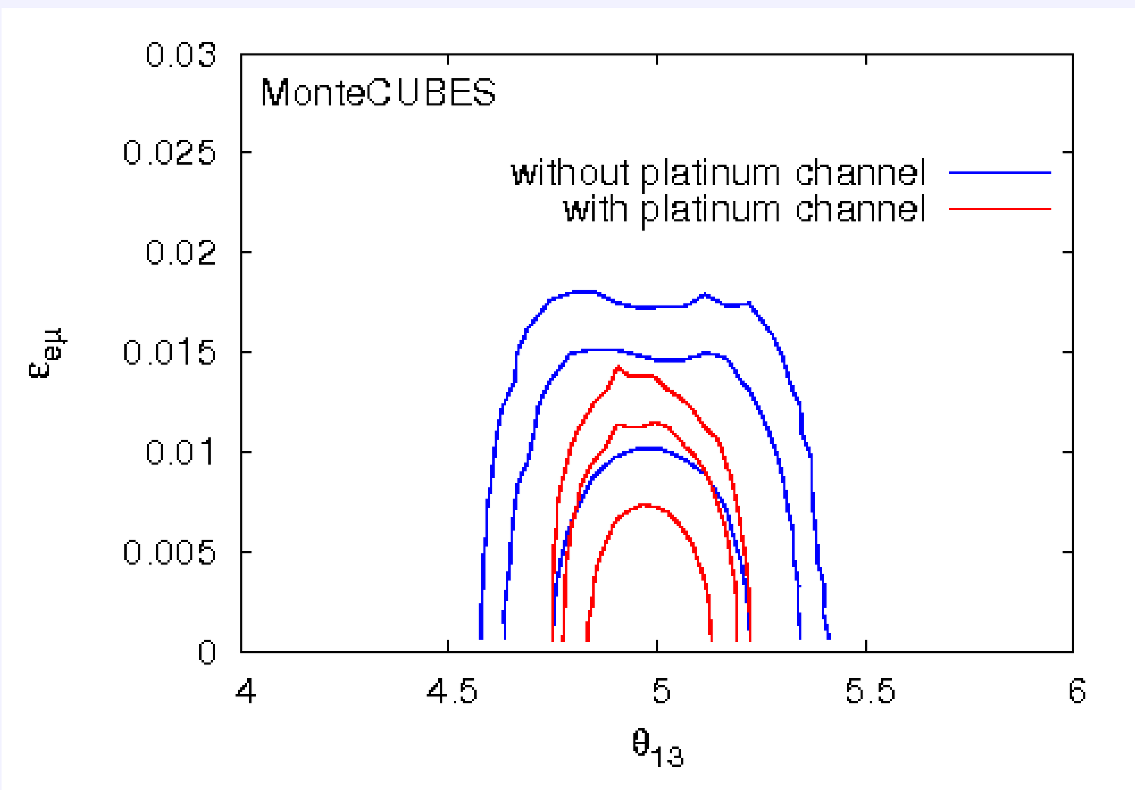
Hierarchy sensitivity limited by baseline, but LENF performs well due to high statistics.

[Huber, Lindner, Winter, ‘Simulation of long baseline neutrino oscillation experiments with GLoBES’; Huber, Kopp, Lindner, Rolinec, Winter, ‘New features in the simulation of neutrino oscillation experiments with GLoBES 3.0’; The ISS Physics Working Group, ‘International scoping study of a future Neutrino Factory and super-beam facility’; Barger, Huber, Marfatia, Winter, ‘Which long-baseline neutrino experiments are preferable?’]

Sensitivity to non-standard interactions (work in progress)

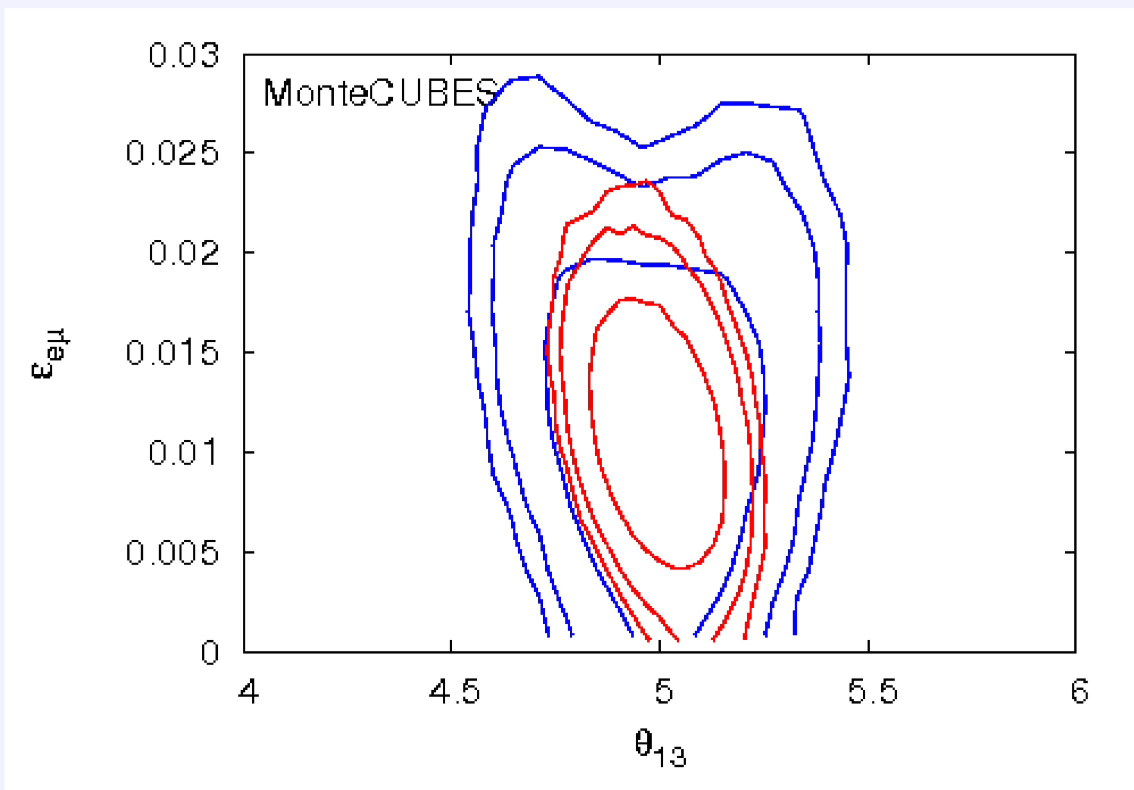
The LENF is sensitive to $\varepsilon_{e\tau}$ and $\varepsilon_{e\mu}$ (more sensitive to $\varepsilon_{e\mu}$ because of constructive interference between the NSI terms). The platinum channel is particularly powerful in maximising the sensitivity.

$\varepsilon_{e\mu} = 0$ ($\theta_{13} = 5°$, $\delta = 0$, $\phi_{e\tau} = 0$):



Can constrain $\varepsilon_{e\tau}$ to be $\lesssim 10^{-2}$ at 95% confidence. (Current bound is $\sim 10^{-1}$).

$\varepsilon_{e\mu} = 0.01$ ($\theta_{13} = 5°$, $\delta = 0$, $\phi_{e\tau} = 0$):



For $\varepsilon_{e\mu} = 0.01$, can exclude $\varepsilon_{e\mu} = 0$ at $\sim 90\%$ confidence.

[Blennow, Fernández-Martínez, ‘Neutrino oscillation parameter sampling with MonteCUBES’; Biggio, Blennow, Fernández-Martínez, ‘General bounds on non-standard neutrino interactions’]

Conclusions

An optimised low energy neutrino factory using either a TASD or LAr detector has remarkable sensitivity to the neutrino oscillation parameters θ_{13} and δ, for $\sin^2(2\theta_{13}) > 10^{-4}$, and to the mass hierarchy for $\sin^2(2\theta_{13}) > 10^{-3}$. The unique combination of golden and platinum channels is particularly useful in maximising the experimental sensitivity to non-standard interactions, specifically $\varepsilon_{e\mu}$ and $\varepsilon_{e\tau}$.

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