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The Low Energy Neutrino Factory

Tracey Li
IPPP, Department of Physics, Durham University, Durham, DH1 3LE, United Kingdom

Abstract
The low energy neutrino factory is a potential next-generation long-baseline oscillation experiment. Here we introduce the experiment and assess its sensitivity to both standard oscillation parameters and non-standard interactions.

1 Introduction

The primary aim of next-generation long-baseline neutrino oscillation experiments is to determine the values of the unknown oscillation parameters θ_{13}, δ and sign[Δm^2_{31}]. In [1] a novel low energy version of the neutrino factory [2] with a baseline of ~ 1000 km was proposed, exploiting the rich oscillation spectrum at energies below ~ 5 GeV. Here we summarize the results of recent optimisation studies of the low energy neutrino factory [3], showing that an optimized setup can have excellent sensitivity to the standard oscillation parameters and can also place competitive bounds on non-standard interactions.

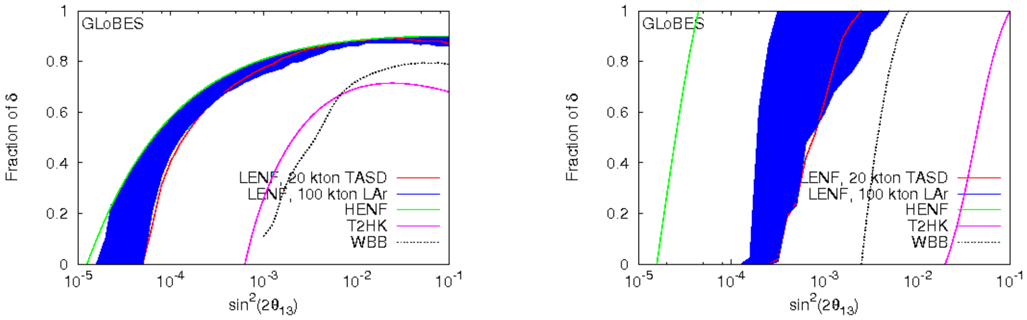
2 Experimental setup

Full details of the experiment can be found in [3]. We have studied a setup having a baseline of 1300 km with a beam capable of delivering 1.4×10^{21} useful muon decays per year [4] per polarity, running for 10 years. For the detector we have considered two possibilities: a 20 kton totally active scintillating detector (TASD) or a 100 kton liquid argon (LAr) detector, both of which would be magnetized. These detectors would be capable of detecting and identifying the charges of both electrons and muons, providing access to multiple oscillation channels: the ν_μ ($\bar{\nu}_\mu$) disappearance channels, the ν_μ ($\bar{\nu}_\mu$) appearance channel (the *golden* channel [5]), and also, uniquely, the ν_e ($\bar{\nu}_e$) appearance channel (the *platinum* channel).

The parameters describing these detectors are shown in Table 1 (see [3] for more details). To accommodate the fact that work on large-scale LAr detectors is still in the preliminary stages, we consider a range of detector parameters; the conservative values are taken from [6] and the optimistic values are the same as those we estimate for the TASD.

Table 1: Parameters describing the 20 kton TASD and a 100 kton 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}



(a) CP discovery potential

(b) Hierarchy sensitivity

Fig. 1: Comparison of the a) 3σ CP discovery potential and b) 3σ hierarchy sensitivity of the low energy neutrino factory with a 20 kton TASD and 100 kton LAr detector, the high energy neutrino factory, T2HK, and the wide-band beam.

3 Results

Measurement of the *golden* [5] and *platinum* channels, together with their CP conjugates, provides sensitivity to the oscillation parameters θ_{13}, δ and sign$[\Delta m^2_{31}]$. These channels are also sensitive to non-standard interactions (NSIs) which can be parameterized by $\varepsilon_{\alpha\beta}$ (see e.g. [7]), which descibe the rate of the transition $\nu_\alpha \to \nu_\beta$. In particular, the golden and platinum channels have leading order sensitivity to the parameters $\varepsilon_{e\mu}$ and $\varepsilon_{e\tau}$. The probability for the golden channel, including NSI contributions, can be found in [7].

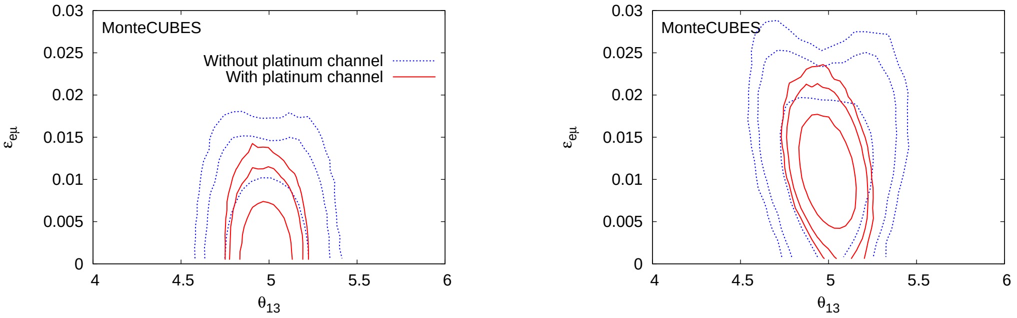
3.1 Sensitivity to standard oscillation parameters

We have used the GLoBES software package [8] to simulate the experimental configuration described in Section 2, presenting the CP discovery potential (ability to exclude $\delta = 0$ or π) and sensitivity to the mass hierarchy (ability to correctly identify the mass hierarchy) in Fig. 1 as a function of $\sin^2(2\theta_{13})$ and in terms of the CP fraction (the fraction of all δ values for which the measurement can be performed). In addition to the low energy neutrino factory with both a liquid argon detector (shown by the solid band) and a TASD (the line close to the right-hand edge of the LAr band), we also show the sensitivities of the high energy neutrino factory [9] (left-most line), T2HK [9] (right-most solid line) and the wide-band beam [10] (dashed line). We use the same oscillation parameters as in [11] and have chosen to assume a normal hierarchy in all our simulations. We have used the exact oscillation probabilities, taking into account matter effects, and have marginalized over all parameters.

It can be seen that a low energy neutrino factory with an optimistic LAr detector has sensitivity to CP violation comparable to that of the high energy neutrino factory, for all values of θ_{13}. A TASD also performs competitively for $\sin^2(2\theta_{13}) \gtrsim 10^{-3}$. The sensitivity to the mass hierarchy is not as competitive, but is still an order of magnitude better than that of the wide-band beam which uses the same 1300 km baseline. This remarkable performance is due to a combination of high statistics and good background rejection, together with an intermediate length baseline wich allows for a clean measurement of CP violation whilst still allowing for the mass hierarchy to be determined for $\sin^2(2\theta_{13}) \gtrsim 10^{-3}$.

3.2 Sensitivity to non-standard interactions

Here we show the sensitivity of the low energy neutrino factory to the NSI parameter $\varepsilon_{e\mu}$, produced using the MonteCUBES software package [12]. We illustrate how the platinum channel enhances the sensitivity of the experiment, by showing the 68%, 90% and 95% allowed regions in the $\theta_{13} - \varepsilon_{e\mu}$ plane, both with the platinum channel (solid lines) and without (dashed lines), for the case of $\varepsilon_{e\mu} = 0$ (Fig. 2a) and $\varepsilon_{e\mu} = 0.01$ (Fig. 2b). The current bound on $\varepsilon_{e\mu}$ is $O(1)$ [13]; from Fig. 2a it can be seen that the



(a) $\varepsilon_{e\mu} = 0$

(b) $\varepsilon_{e\mu} = 0.01$

Fig. 2: 68%, 90% and 95% allowed regions in the $\theta_{13} - \varepsilon_{e\mu}$ plane, for scenarios with and without the platinum channel, for true values of a) $\varepsilon_{e\mu} = 0$ and b) $\varepsilon_{e\mu} = 0.01$.

low energy neutrino factory could improve upon this. From Fig. 2b it can be seen that $\varepsilon_{e\mu} = 0$ could be excluded at $\sim 90\%$ confidence if $\varepsilon_{e\mu} \sim 0.01$.

4 Conclusions

An optimized low energy neutrino factory using either a TASD or LAr detector has remarkable sensitivity to the CP violating phase, 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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