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Role of higher order maxima of oscillation probabilities at long baseline neutrino experiments

NF Topical Groups:

■ (NF1) Neutrino oscillations; ■ (NF3) Beyond the Standard Model ; ■ (NF5) Neutrino properties

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Abstract:
Most of the long baseline neutrino experiments are planned to exploit the first oscillation maximum of the $\nu_\mu \to \nu_e$ probability (i.e. $L/E \simeq 500\ km/GeV$) and the neutrino flux is typically tuned to be peaked at a value of energy corresponding the first oscillation maximum for a given baseline. The location of the dominant phase term in the probability dictates the value of energy since the present unknowns are expected to be best extracted by using that combination of E and L. In the present proposal, we plan to elucidate the role of higher oscillation maxima in answering the unresolved puzzles in neutrino physics. We plan to consider the case of standard interactions as well as the situation when new physics effects are turned on.

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The idea of neutrino oscillations among the three light active neutrino flavours has been rewarded with a Nobel prize in 2015. The parameters entering the neutrino oscillation framework have been measured to a fairly good precision (see the global fit analyses [1;2]). The best-fit values and 3σ range of neutrino mass and mixings deciphered from oscillation data. Yet, there are some open questions in the standard mass-induced oscillation framework. These include the question of neutrino mass hierarchy (sign of Δm^2_{31}), the value of the CP violating phase (δ) and determining the correct octant of θ_{23}.

Determination of neutrino mass hierarchy would allow us to get closer towards determining the underlying structure of the neutrino mass matrix by being able to discriminate between theoretical models giving rise to neutrino masses [3]. Alongwith the CP violation phase δ, it impacts the effectiveness of leptogenesis scenario which can explain the matter-antimatter asymmetry of the Universe [4].

The next generation neutrino oscillation experiments would allow us to precisely determine the known parameters and determine the remaining unknowns in the neutrino oscillation formalism. The long baseline neutrino experiments are designed such that the desirable physics outcome is achieved. Typically, the optimal combination is for a value of baseline (L) and energy (E) for which $P_{\mu e}$ has its first peak. This is referred to as the *first oscillation* maximum. Typically, for shorter baselines, the higher oscillation maximas are unaccessible as the energies at which these occur are too small. For longer baselines, it may be possible to access the information from the second (and higher) oscillation maxima.

A promising future experiment is the Deep Underground Neutrino Experiment (DUNE). Neutrino beam will be produced at Fermilab and will travel 1300 km to a liquid Argon (LAr) far detector placed at an on-axis location at Sanford Underground Research Facility (SURF). The primary aim of DUNE is to address the question of CP violation and identify the neutrino mass hierarchy [5–7]. A wide-band neutrino beam originating from the Fermilab proton complex is considered for DUNE. A systematic evaluation of optimal baseline for discovery of CP violation, determination of the mass hierarchy and resolution of the θ_{23} octant in a long baseline oscillation experiment was carried out by Bass et al. [8] and it was concluded that for achieving unambiguous measurement of these parameters, one needed a baseline atleast of the order of 1000 km. It was further shown from the asymmetry plot that CP measurement was better achieved in the vicinity of second oscillation maximum irrespective of the mass hierarchy and results for sensitivities to standard three flavour oscillation parameters were presented. The authors had considered two detector types - Water Cherenkov (WC) and LAr and performed the study for the erstwhile LBNE.

In this proposal, we plan to utilize optimal beam tunes to explore the precise role of first and higher order oscillation maxima. The standard beam tune used in almost all the studies connected with DUNE sensitivities is derived from 80 GeV proton beam energy and this is well-suited to optimize signal from the first oscillation maximum. The neutrino beam at the second maxima is generated using a 3 MW 8 GeV proton beam which could be generated by the PIP-III superconducting linac option [9]. We also address the issue of extraction of intrinisic CP violation using the two beams and show that the second oscillation maximum helps in resolving the ambiguity in CP phase measurement.

The issue of separation of intrinsic contribution from the extrinsic contribution was addressed in [10;11] and a useful observable to disentangle the two contributions was used utilising the fact that matter contribution gets approximately cancelled if we consider

$$\delta(\Delta P^{CP}_{\mu e}) \quad = \quad \Delta P^{CP}_{\mu e}(\delta = \pi/2) - \Delta P^{CP}_{\mu e}(\delta = 0)$$

Using this observable, we next depict an oscillogram to separate the intrinsic contribution from the extrinsic contribution in Fig. 1. From the figure, it's clear that the second oscillation maximum is the ideal choice for the extraction of the intrinsic CP violation.

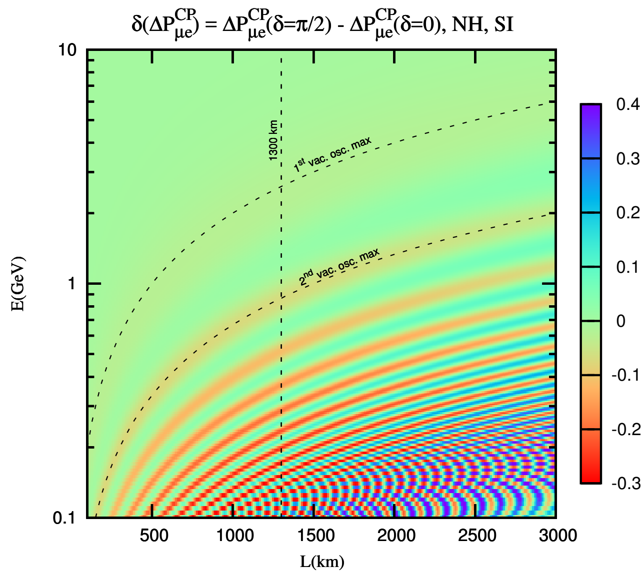

Figure 1: Oscillogram depicting separation of the intrinsic CP contribution from the extrinsic CP contribution.

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