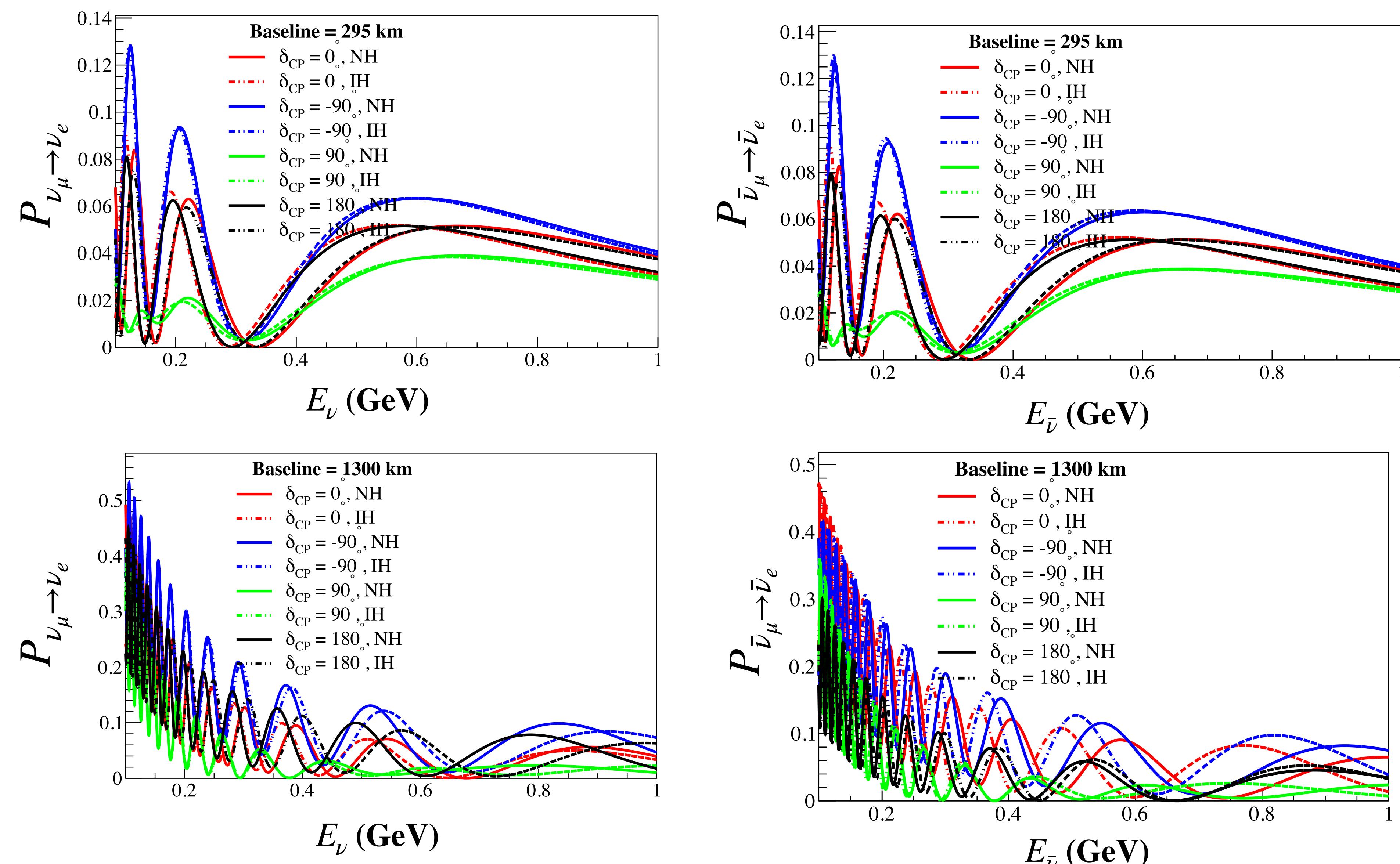


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## Introduction

- Current long-baseline (LBL) neutrino experiments are designed to probe  $\delta_{CP}$  and mass hierarchy in regions where there is no  $\delta_{CP}$ -mass hierarchy (MH) ambiguity.
- A study on sub-GeV atmospheric neutrinos showed hierarchy independence in measuring  $\delta_{CP}$  [1]
- In this study, we explore the possibility of obtaining  $\delta_{CP}$  independent of MH at sub-GeV energies in accelerator based LBL experiments.
- We study oscillated events binned in the final state lepton energy ( $E_\ell$ ) and direction ( $\cos \theta_\ell$ ) produced in CC  $\nu$  and  $\bar{\nu}$  interactions.



Neutrino and antineutrino oscillation probabilities at 295 km and 1300 km for various values of  $\delta_{CP}$  and for normal (NH) and inverted (IH) hierarchies.

## Event generation

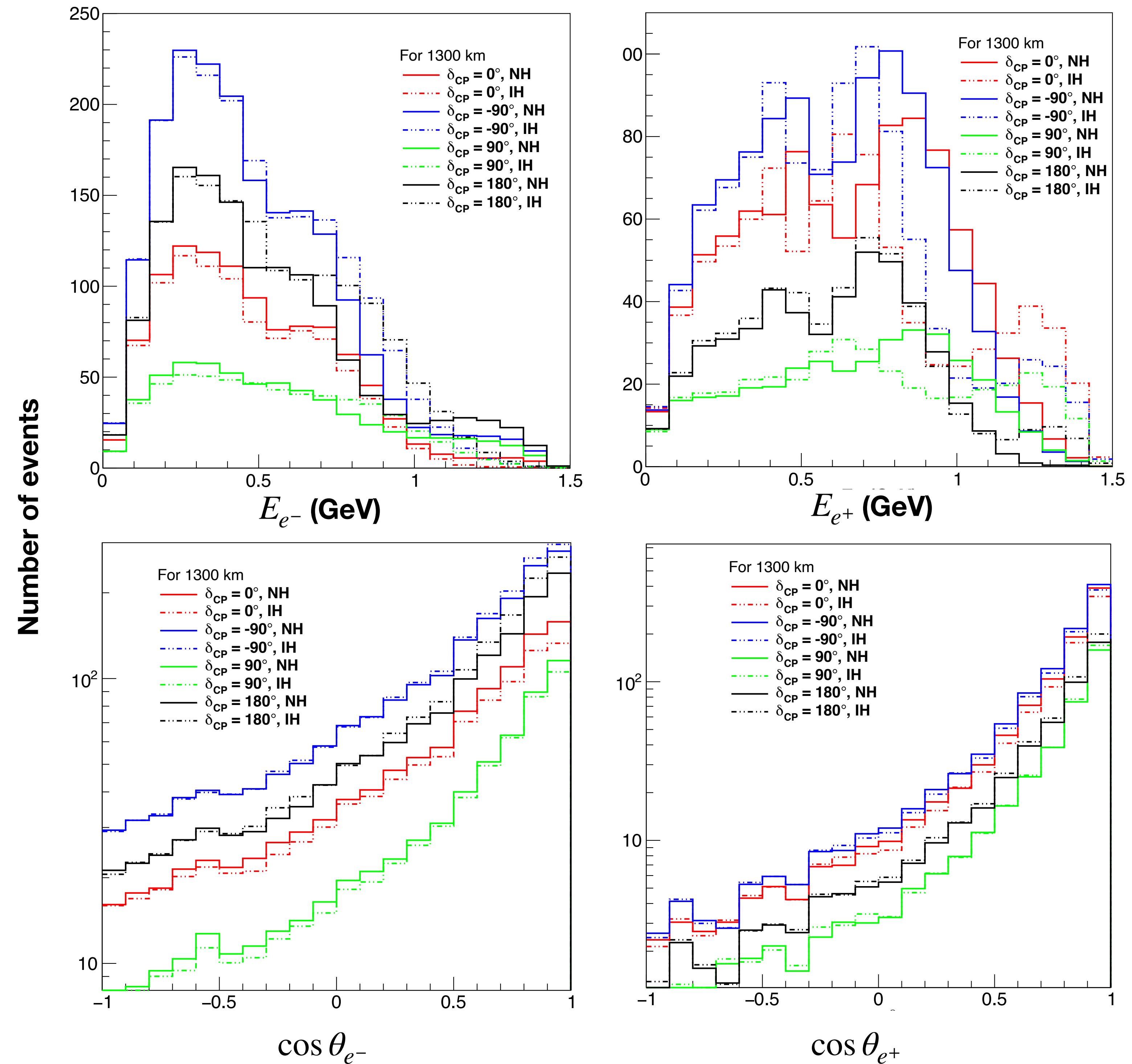
- We use NuWro [2] to generate (anti)neutrino interactions on an isoscalar (Fe) target. A uniform neutrino energy distribution is used for event generation and  $\nu_e(\bar{\nu}_e)$  events are weighted by  $P_{\nu_\mu \rightarrow \nu_e}(P_{\bar{\nu}_\mu \rightarrow \bar{\nu}_e})$  oscillation probabilities.
- For the current analysis, only charged current (CC) interactions are selected. We assume a detector with perfect resolutions and efficiencies and also, that  $\nu_e, \nu_\mu, \bar{\nu}_e$  and  $\bar{\nu}_\mu$  can be separated from one another.

→ Oscillated  $\nu_e$  and  $\bar{\nu}_e$  events are binned in outgoing  $e^-(e^+)$  energy (top pad) and direction (bottom pad).

→ A selection cut of  $E_\nu < 1.5$  GeV is applied for these events.

Taken from [nu-fit.org](http://nu-fit.org) [3]

Parameter	Value
$\delta_{CP}$	$0^\circ, \pm 90^\circ, 180^\circ$
$\theta_{12}$	$33.46^\circ$
$\theta_{23}$	$49.25^\circ$
$\theta_{13}$	$8.585^\circ$
$\Delta m_{21}^2$ (eV <sup>2</sup> )	$7.42 \times 10^{-5}$
$\Delta m_{3\ell}^2$ (eV <sup>2</sup> )	$2.51 \times 10^{-3}$



## Conclusions

- Between 0.1 to 0.6 GeV, we see a clear separation between event spectra for different  $\delta_{CP}$  values for  $\nu_e$  and below 0.4 for  $\bar{\nu}_e$ . For  $E_{e^+} > 0.4$  GeV,  $\bar{\nu}_e$  spectrum requires further investigation.
- For neutrinos, there is clear separation for  $\cos \theta_{e^-}$  in [-1, ~0.7) and reasonable separation from (0.7, 1]. For antineutrinos, there is clear separation for  $\cos \theta_{e^+}$  in [-0.6, 0.7].

## Way Forward

- The next step is to check this result on a realistic flux and with other baselines.
- Then we will obtain sensitivity to  $\delta_{CP}$  by performing a  $\chi^2$  analysis.

## Reference

- [1] D. Indumathi, S. M. Lakshmi, and M. V. N. Murthy, *PRD*100, 115027 (2019)
- [2] T. Golan, J.T. Sobczyk, J. Zmuda, *Nucl.Phys.Proc.Suppl.* 229-232 (2012) 499
- [3] Evan Esteban *et al.* *JHEP* 09 (2020) 178

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