Effect of sterile phases on degeneracy resolution capabilities of NOvA (ID 46)

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Abstract

In sterile neutrino (3+1) parameterisation, we observe that sterile phases (δ_{14}, δ_{24}) are always together in oscillation probability, even when the MSW effect is considered. We see that the difference between the sterile phases has a more dominating effect over event rates compared to small variations due to changes in individual values. In this work, we show the value of sterile phase difference($\delta_{14} - \delta_{24}$), least effects the parameter degeneracy resolution of δ_{13}, θ_{23} at NOvA. We find the value of sterile phase difference that will give a greater chance at sterile neutrino discovery.

Introduction

- LSND and MiniBooNE have experimental results which could be interpreted as due to a new neutrino with a mass ∼1 eV.
- As the LEP experiment limits no: of active neutrinos flavors to 3, the new neutrino must be a sterile (No weak interaction) neutrino.
- Sterile neutrino introduces new parameters to be measured which increases the degrees of freedom and will affect degeneracy resolution capabilities of detectors.

(3+1) Sterile Neutrino Model

- We worked on one sterile neutrino model (3+1). The 3+1 model parameterisation is

$$U_{PMNS_{3+1}} = R_{34}(\theta_{34})\tilde{R_{24}}(\theta_{24}, \delta_{24})\tilde{R_{14}}(\theta_{14}, \delta_{14})U_{PMNS_3}. \quad (1)$$

- We see that addition of one sterile neutrino introduces 3 new mixing angles and 2 new CP-phases.
- Measuring these new parameters is important for the study of sterile neutrinos.
- Short baseline(SBL) experiments give good bounds on sterile mixing angles, while long baseline (LBL) experiments explore CP phases. Combining both give us better measurements.
- $P_{\mu e}$ for LBL experiments in 3+1 model is expressed as sum of the four terms

$$P_{\mu e}^{4\nu} \simeq P_1 + P_2(\delta_{13}) + P_3(\delta_{14} - \delta_{24}) + P_4(\delta_{13} - (\delta_{14} - \delta_{24})). \quad (2)$$

- The first two terms give ordinary CP violation, the last two terms of equation, give the sterile CP phase dependence terms.
- Here we observe that δ_{14} and δ_{24} are always together in form of $\delta_{14} - \delta_{24}$. That implies that in vacuum case, individual values of δ_{14} and δ_{24} do not matter, only the difference $\delta_{14} - \delta_{24}$ matters as shown in below figure 1.

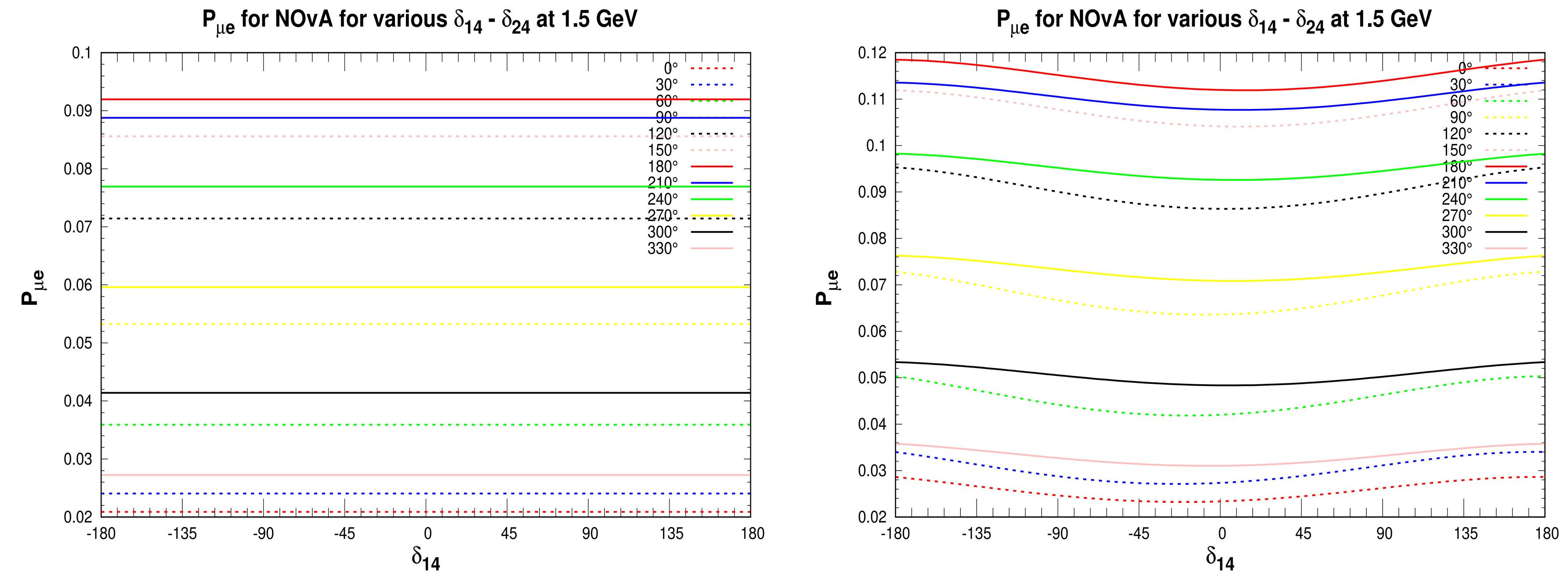

Figure 1: $P_{\mu e}$ for NOvA for various $\delta_{14} - \delta_{24}$ at 1.5 GeV for vacuum case(left) and matter case (right).

- We plotted bands for different $\delta_{14} - \delta_{24}$ values while changing the individual values of δ_{14} and δ_{24} in figure 2 . We observe small variations due to individual values of δ_{14} and δ_{24} at all energies.

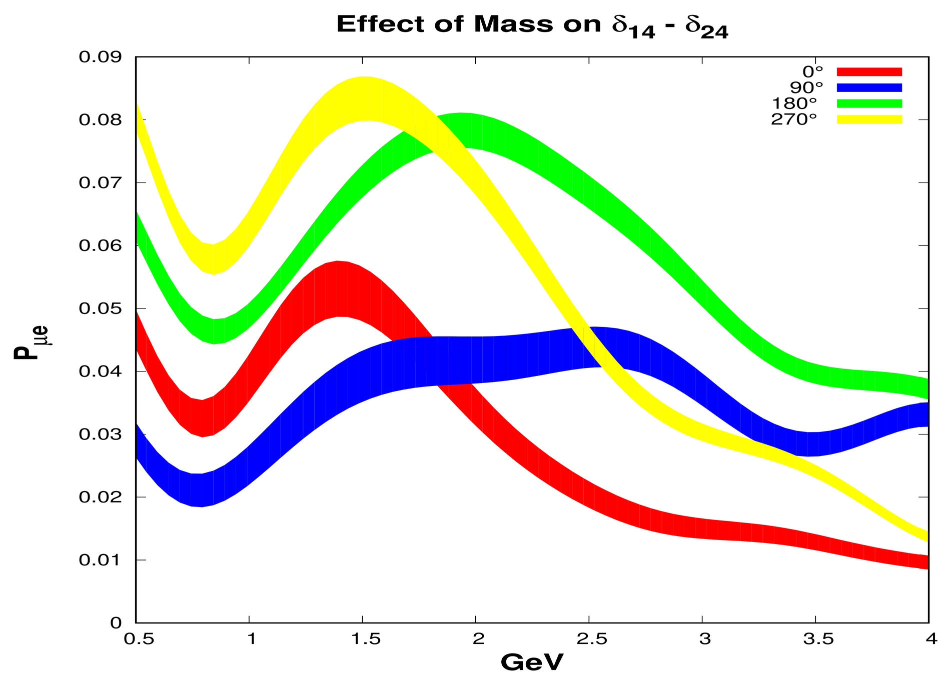

Figure 2: $P_{\mu e}$ for NOvA under matter effects for different energies

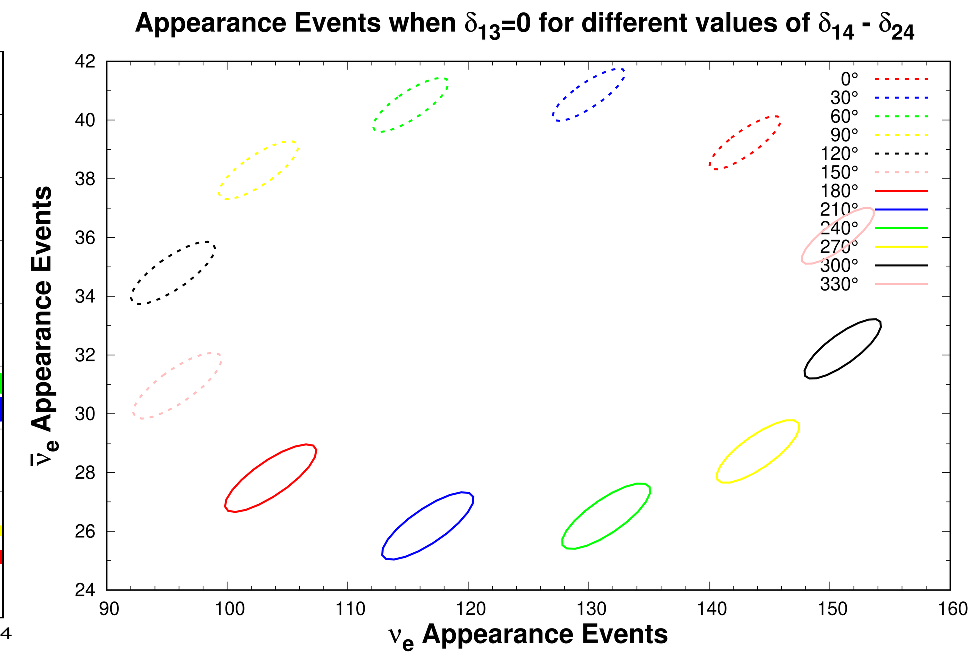

Figure 3: Bi-event plot when $\delta_{13} = 0$ for different values of $\delta_{14} - \delta_{24}$

- Small variations due to individual values of δ_{14} and δ_{24} is found proportional to θ_{34} as shown in figure 3. This implies we cannot measure individual values of δ_{14} and δ_{24} if θ_{34} is too small.
- Even after considering matter potential, we see that difference of (δ_{14} and δ_{24}) has dominating effect over event rates compared to small variations due to individual values δ_{14} and δ_{24}.

Results

- We used GLoBES (General Long Baseline Experiment simulator [1, 2] to simulate the data for NOvA.
- In this work, we try to see which value of ($\delta_{14} - \delta_{24}$) , least effects the parameter degeneracy of resolution of δ_{13}, θ_{23}.
- We use latest NOvA Best fit values [3] as true values for this analysis
- For sterile mixing angles, we take upper bounds given in NOvA neutral current analysis paper. [4]

$$\theta_{14} = 10°; \theta_{24} = 20.8°; \theta_{34} = 31.2°$$

- We explore allowed regions in $\sin^2\theta_{23}$-δ_{13} plane from NOvA simulation data with different runtimes and different values of δ_{14} and δ_{24} considering latest NOvA results as true values.
- We plot test values for both NH-HO and NH-LO, of 3 and 3+1 neutrino models for NOvA[3+3] run-time.

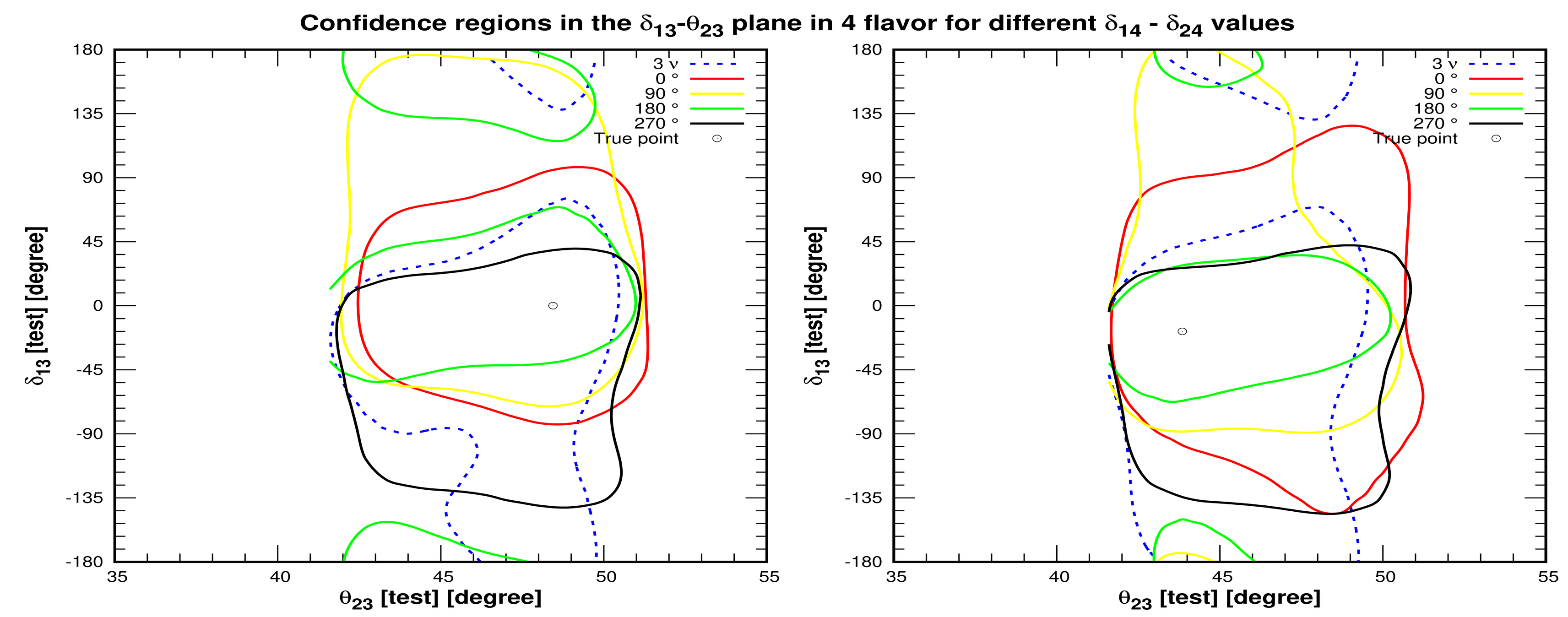

Figure 4: The contours of this figure are plotted for 90% C.I regions. We take NH-HO (NH-LO) as true values for left(right) case.

- We see that for both NH-HO and NH-LO case, δ_{14} - δ_{24} = 180 has highest sensitivity to parameter degeneracy.

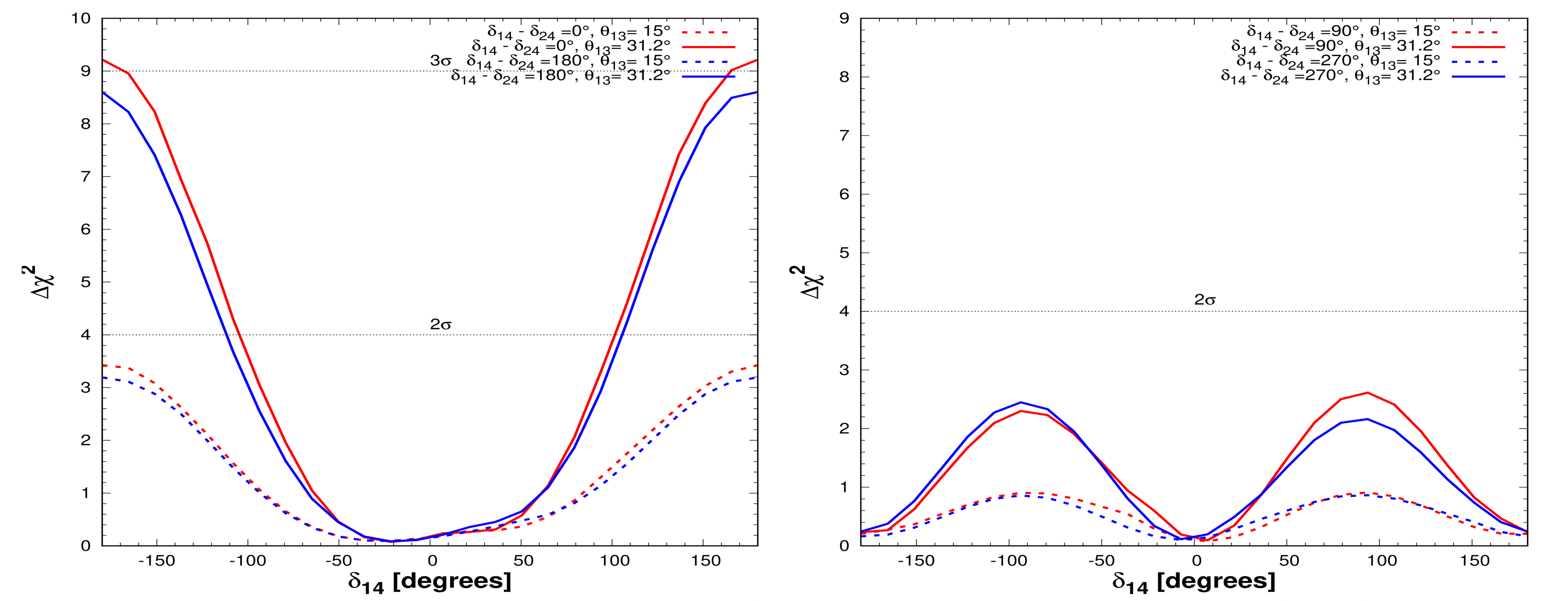

Figure 5: Measurement capacity of δ_{14} for different values of θ_{34} and $\delta_{14}-\delta_{24}$

Conclusion and Future Work

- We find highest sensitivity to parameter degeneracy when δ_{14} - δ_{24} = 180 for both NH-HO and NH-LO case.
- We find that we cannot measure individual values of δ_{14} and δ_{24} if θ_{34} is too small.
- More work is needed to be done to include different run-times of NOvA experiment.

References

[1] P. Huber, M. Lindner and W. Winter, Comput. Phys. Commun. 167, 195 (2005),[hep-ph/0407333].

[2] P. Huber, J. Kopp, M. Lindner, M. Rolinec and W. Winter, Comput. Phys. Commun. 177, 432 (2007),[hep-ph/0701187].

[3] M. A. Acero *et al.* [NOvA Collaboration], Phys. Rev. Lett. **123**, no. 15, 151803 (2019) doi:10.1103/PhysRevLett.123.151803 [arXiv:1906.04907 [hep-ex]].

[4] P. Adamson *et al.* [NOvA Collaboration], Phys. Rev. D **96**, no. 7, 072006 (2017) doi: 10.1103/PhysRevD.96.072006 [arXiv:1706.04592 [hep-ex]].

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