

Measurement of CP Violation in Presence of New Physics

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ABSTRACT: In this analysis we observe the role of extra CP phase δ_3 (due to the presence of sterile neutrino) coming from new physics involved in appearance probability, in imposing constraint on the “standard” three active neutrino phase δ_{CP} . The presence of this phase should be taken into account while planning the future neutrino experiments, aiming towards the measurement of δ_{CP} .

KEYWORDS: three active neutrinos, sterile neutrino, new CP phase, appearance probability.

I. INTRODUCTION

The phenomenon of neutrino oscillation can be described with the help of six parameters; three mixing angles $\theta_{12}, \theta_{13}, \theta_{23}$; two mass square differences $\Delta m_{21}^2, \Delta m_{31}^2$ and Dirac CP phase δ_{CP} . Amongst the above mentioned six parameters, roughly all the parameters leaving the sign of Δm_{31}^2 and δ_{CP} have been measured with high accuracy [1][2]. The next generation neutrino experiments are aiming to pin down the undetermined neutrino oscillation parameters. The T2K experiment gave the first hint of non zero value of the phase [3].

The CP violating signatures in any neutrino oscillation experiment can be analyzed by looking at CP asymmetry, defined as $\Delta P_{CP}^{\alpha\beta} = A_{\alpha\beta}^{CP} = P_{\alpha\beta} - P_{\overline{\alpha\beta}}$ for $\alpha \neq \beta$ where $P_{\alpha\beta}$ and $P_{\overline{\alpha\beta}}$ are neutrino and antineutrino oscillation probability in vacuum. As we know that neutrino oscillation probability changes when neutrinos pass through the earth matter, due to the extra matter potential felt by the electron neutrinos on their way. In long baseline neutrino oscillation experiments, where matter effects play significant role, induces fake CP violation, since the earth matter itself is CP asymmetric [4][5].

Several anomalous experimental signatures have surfaced during the few past decades which require new physics to be interpreted. One possible explanation to such anomalous signals can be addition of light sterile neutrinos [6]. These new neutrino states assumed to have no weak interactions and are associated with light neutrino of masses of order 0.1-10 eV. Inclusion one sterile neutrino along with three active neutrinos define the minimal parameter space [7]. The upcoming and ongoing neutrino experiments are focusing towards imposing tight bounds on such violations [8][9].

II. RELATED WORK

NEUTRINO OSCILLATION FORMALISM IN PRESENCE OF STERILE NEUTRINO

The parameterization scheme selected in this work is:

$$U = U_{34}(\theta_{34}, 0)U_{24}(\theta_{24}, 0)U_{14}(\theta_{14}, 0)U_{23}(\theta_{23}, \delta_3)U_{13}(\theta_{13}, \delta_2)U_{12}(\theta_{12}, \delta_1) \quad (1)$$

The difference in neutrino oscillation probability for golden channel is developed using formalism developed by Kimura, Takamura and Yokomakura [10][8]

$$\Delta P_{CP}^{\mu e} =$$

$$4c_{13}c_{14}^2c_{24}s_{13}s_{23}s_{14}s_{24}\sin(\delta_2 - \delta_3)\frac{4e}{(\Delta_e - \Delta_{31})}\sin\Delta m_{31}^2\frac{L}{2E} + 4c_{13}c_{14}^2c_{24}s_{13}s_{23}s_{14}s_{24}\sin(\delta_2 - \delta_3)\frac{4s_{31}^2}{(\Delta_e - \Delta_{31})4e}\sin 2\Delta_e \quad (2)$$

In the above probability equation δ_2 is standard three neutrino CP phase and δ_3 is CP phase due to new physics.

The value of oscillation parameters used in our analysis are

$$\theta_{23} = 45^\circ, \theta_{13} = 8^\circ, \theta_{12} = 34^\circ, \Delta m_{21}^2 = 8 \times 10^{-5}, \Delta m_{31}^2 = 2.5 \times 10^{-3}, \delta_2 = \pi/2, \theta_{14} = 6.7^\circ, \theta_{24} = 3.3^\circ, \theta_{34} = 6.3^\circ$$

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The value of new phase δ_3 is varied between 0 to $\pi/2$.

III. SIMULATION TOOL AND RESULT

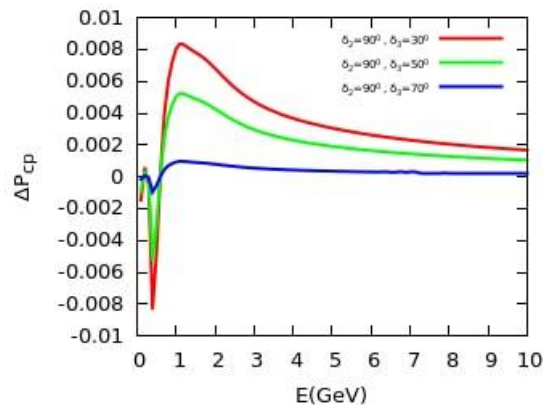


Fig. 1: The above plot shows the variation in with neutrino energy. The phase δ_2 is kept fixed at $\pi/2$

while the new phase δ_3 have three values : red line $\delta_3 = 30^\circ$, green line $\delta_3 = 50^\circ$, blue line $\delta_3 = 70^\circ$

GloBES simulation package is designed to simulate long base line and reactor neutrino oscillation experiments[11][12]. It contains comprehensive abstract experiment definition using which we can completely define the experiments as accurate as possible. On the other hand it uses C- library to process the neutrino oscillation results i.e rate vectors and chi square.

Using GloBES software package we have observed the impact of new CP phase δ_3 on the measurement of three neutrino CP phase δ_2 . The neutrino oscillation probability equation which can be used to estimate the signature of CP violation in a given setup is mentioned in Equ. 2. This difference in probability for golden channel is estimated using parametrization defined in Equ. 1. Using the same parametrization we can develop neutrino oscillation probability difference for all appearance and disappearance channel. For the golden channel we find that the probability depends on both the phases and if the new phase δ_3 is not it will effect our estimation for δ_2 .

In an attempt to observe the impact of new phase we have fixed the value of δ_2 at maximum and allowed new phase to attain any value between 0 to $\pi/2$. From the Fig. 1 we can observe difference in probability changes for different selected values of new CP phase. These changes are large enough and cannot be ignored while doing three neutrino oscillation physics.

IV. CONCLUSION

We have made an attempt to look at the impact of any new CP phase on CP violation prediction in three neutrino framework[13][14][15]. Sterile neutrinos are introduced to justify the anomalous results observed by the neutrino experiments. The extra phase introduced by sterile in the golden channel is assumed as new CP phase. The above results depends on the present constraints on sterile angles. The impact introduced by new phase is large enough and indicates that constraining the new physics parameters (here, sterile mixing angles) will improve the results.

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