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Study on T-Violation in CPT violating and CPT conserving Lorentz Invariance Violation for DUNE

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Introduction

In the context of neutrino oscillation, T-violation, or time-reversal violation, refers to the violation of a fundamental symmetry called time-reversal symmetry (T-symmetry) in neutrino behavior. According to CPT theorem, CP violations are inextricably linked to T violations. Previous works on T violations are largely related under the consideration of matter effect, NSI and sterile nature of neutrino. These symmetry violations are fundamentally related to complex couplings in lagrangian. Lorentz invariance violations(LIV) in SME (standard model extension) also have complex coupling nature in the lagrangian of neutrino. Perturbation in neutrino Hamiltonian produced due to SME can be written as [?]

$$h_{\text{LIV}} = 1/E \cdot [(a_L)^\mu p_\mu - (c_L)^{\mu\nu} p_\mu p_\nu], \quad (1)$$

where p_μ is the four-momentum, $(a_L)^\mu$ are CPT (charge, parity and time reversal) violating LIV (Lorentz invariant violation) coefficients having dimension of energy, and $(c_L)^{\mu\nu}$ are dimensionless CPT-even LIV coefficients. We have study the role of LIV induced T-violation in sidereal variation[?]. the study is focused on T-violation in the presence of CPT-violating and CPT conserving LIV. We found that the Relation Between CP violation (CPT) and T violations (TV) are different in case of matter induced CPT-violation and LIV induced CPT-violation.

For 2-flavour case, T symmetry always conserves. but in case of 3-flavor T-symmetry could violate. In case of CPT conservation:

$$\Delta P^{CP} = \Delta P^T. \quad (2)$$

But in the scenario of CPT-violation, this relationship do not hold. As LIV could be of either nature (CPT-violating if $a^\mu \neq 0$, CPT-conserving if only $c^{\mu\nu} \neq 0$) [?]. LIV is non-isotropic if $\mu, \nu \neq 0$. This non-isotropic nature of LIV causes the sidereal effect [?]. Sidereal Effect is dependency of neutrino probability on the absolute rotation of earth axis in the frame a distant star. Since in equation 1, perturbative hamiltonian is function of momentum, it makes hamiltonian direction dependent. This dependency is inferred as sidereal effect. This dependency of hamiltonian on sidereal time can be further written as

$$\begin{aligned} (h_{\text{LIV}})_{\alpha\beta} = & (C)_{\alpha\beta} + (A_s)_{\alpha\beta} \sin(\omega T) + \\ & (A_c)_{\alpha\beta} \cos(\omega T) + (B_s)_{\alpha\beta} \sin(2\omega T) + \\ & (B_c)_{\alpha\beta} \cos(2\omega T) \end{aligned} \quad (3)$$

for the details of amplitude terms $(C)_{\alpha\beta}$, $(A_s)_{\alpha\beta}$, $(A_c)_{\alpha\beta}$, $(B_s)_{\alpha\beta}$ and $(B_c)_{\alpha\beta}$ please look at [?].

Result and Discussion

For this study we have focused on DUNE experiment. DUNE have baseline length of 1300 km, and first oscillation maxima lies on 2.5 GeV. We have done calculation of probability for both vacuum and matter case. In matter case we have assumed constant density of $\rho = 2.5$, so there could be no T-violation due to matter effect.

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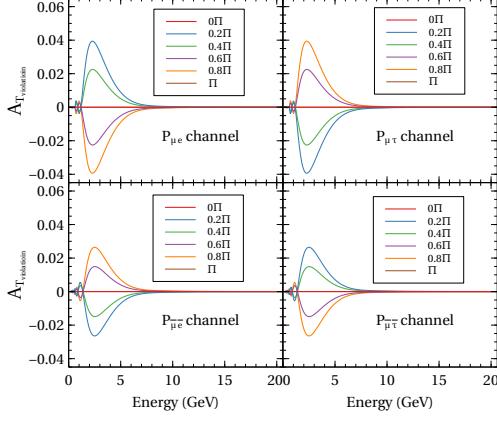


FIG. 1: T-Violation in Neutrino Oscillation due to the complex nature of LIV parameter $c_{e\mu}^{TX}$. Here we have use $|c_{e\mu}^{TX}| \times 10^{-23}$

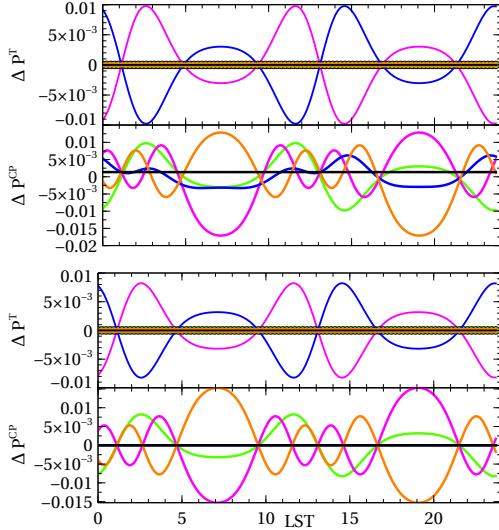


FIG. 2: (TOP: Matter),(Bottom: Vaccume) T-Violation and CP violation in Sidereal variation in the case $a_{e\mu}^X = 5 \times 10^{-22}$, at $E = 2.6$ GeV.

Fig. 3 shows a that.

We have draw the δP^T and δP^{CP} with sidereal time. results shows that presence of matter effect play very significant role in correlation between δP^T and δP^{CP} in the terms of

change in shape change. In case of vaccume the effect of CPT violating and CPT conserving LIV shows same effect for δP^T and δP^{CP} and relation of equation 2 holds. But in case of matter this relation do not hold.

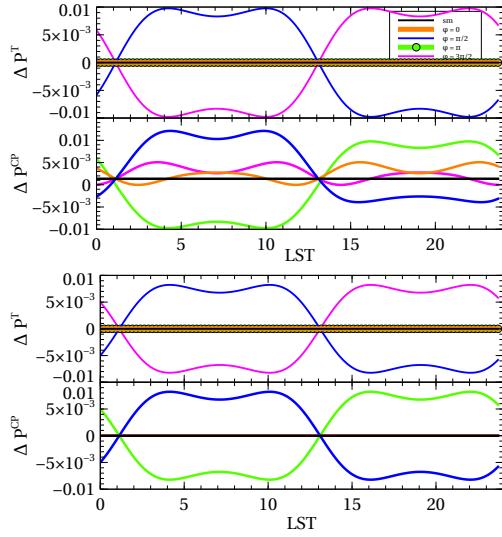


FIG. 3: (TOP: (TOP: Matter),(Bottom: Vaccume) T-Violation and CP violation in Sidereal variation in the case $c_{e\mu}^{TX} = 5 \times 10^{-23}$, at $E = 2.6$ GeV.

Future work

We are looking to obtain equation which can explain how internal CPT (LIV induced) and external CPT (matter induced) works for relation between CP and T violation

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References

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