Study of non-isotropic Lorentz Invariance Violation for NOνA in disappearance channel

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Introduction

The Standard Model (SM) of particle physics is a remarkable framework for describing the fundamental characteristics and interactions of particles. Its validity has been tested in many experiments and culminated by the discovery of the Higgs boson at the LHC. Lorentz invariance is one of the fundamental symmetries, serving as the pillar of SM. Lorentz Invariance has been well established in low energy world. But there are several theories(Stochastic space-time foam, quantum loop gravity, string theory etc.), which allow the violation of Lorentz symmetry at a high energy scale [1]. As neutrino oscillation shows the failure of the standard model, it sets a stage to challenge the Lorentz Symmetry. In this work, we consider the non-isotropic model for Lorentz Invariance Violation (LIV), which states that the vector Lorentz field has a preferred spatial direction and negative vacuum expectation mass.

In a broader sense, the extended Standard Model Lagrangian [2] can be written in the following general form:

$$\mathcal{L}_{\rm LIV} = -(a_L)^{\mu}\bar{\psi_L}\gamma_{\mu}\bar{\psi_L} - (c_L)^{\mu\nu}\bar{\psi_L}\gamma_{\mu}\partial_{\nu}\bar{\psi_L}, \quad (1)$$

where $(a_L)^{\mu}$ are CPT breaking LIV coefficients having dimension of energy, and $(c_L)^{\mu\nu}$ are dimensionless CPT-even LIV coefficients. This langrangian introduces a LIV perturbation in neutrino hamiltonian having direction dependencies as follows :

$$(h_{\rm LIV})_{\alpha\beta} = (C)_{\alpha\beta} + (A_s)_{\alpha\beta}\sin(\omega \mathrm{T}) + (A_c)_{\alpha\beta}\cos(\omega T) + (B_s)_{\alpha\beta}\sin(2\omega \mathrm{T}) + (B_c)_{\alpha\beta}\cos(2\omega \mathrm{T}) \quad (2)$$

where ω is Earth's sidereal frequency and T is the sidereal time, which describes how Earth is aligned with respect to a sidereal star in the Sun-centered frame. Amplitudes $(C)_{\alpha\beta}$, $(A_s)_{\alpha\beta}$, $(A_c)_{\alpha\beta}$, $(B_s)_{\alpha\beta}$, and $(B_c)_{\alpha\beta}$ may be described in terms of LIV coefficients and energy [3].

NOνA Experiment: Overview and Simulation

NOνA experiment is long baseline neutrino experiment with baseline of 810 km, consisting of two identical functioning detectors such as near detector(ND) and far detector(FD). Detectors are exposed to the intense neutrino beam coming from Fermilab. We have simulated the disappearance channel for NOνA using GLoBES [4], with suitable modifications. For the detector configuration, ADEL file is taken form the reference [5]. Running time for the NOνA is assumed as 10 years in the neutrino mode with POT value 10×10^{20} POT/year. The target mass of FD have been taken 14 kTon and the energy window is taken from 1.0 GeV to 3.5 GeV. For $\nu\mu$ disappearance channel, the signal consists of 80% of numuCC events with the contamination of 0.15% of numuNC background events. The standard oscillation parameters, which are used in the simulation are tabulated in the table[I]

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TABLE I: The standard oscillation parameters which are used in this work

Parameter	Value
θ_{12}	$33.48°$
θ_{13}	$8.5°$
θ_{23}	$45.0°$
δ_{cp}	$30.0°$
$\triangle m^2_{21}$	$7.55 \times 10^{-5} eV^2$
$\triangle m^2_{31}$	$2.50 \times 10^{-3} eV^2$

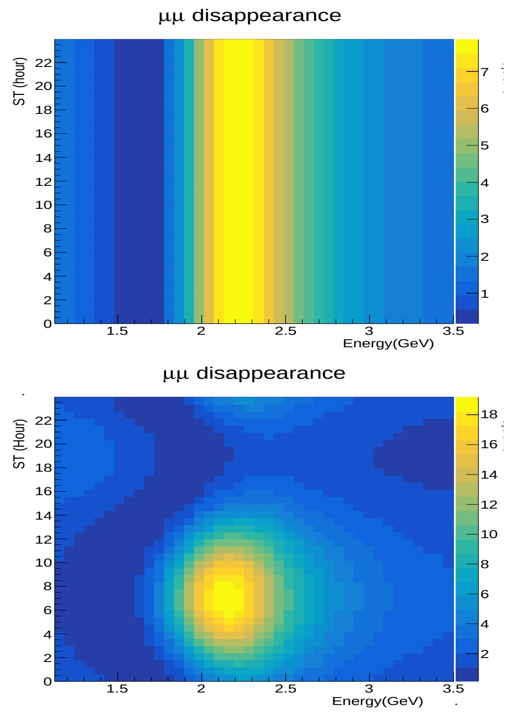

FIG. 1: Figures are showing $\mu\mu$ disappearance channel. The upper one is for the standard case whereas bottom one is for the LIV case with parameter $a^X_{\mu\tau} = 6.6 \times 10^{-23}$ GeV. Figure unfold the event distribution for 2D bin of energy(Gev) and sidereal time(Hour).

Results and discussions

Fig. 1 clearly reflects that in the case of LIV(bottom) we will observe lesser events than the standard case(top) in the disappearance channel due to impact of the LIV parameter $a^X_{\mu\tau}$. Suppression in the maximum event count is also observed. This could lead that NOνA far detector is highly sensitive for the non-isotropic LIV parameters.

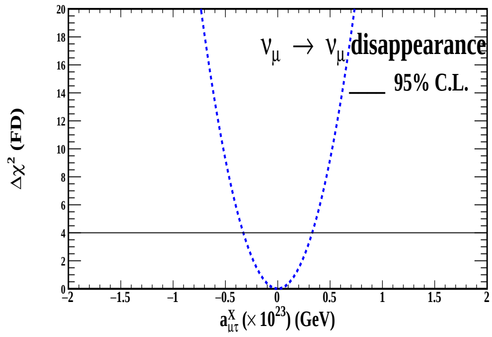

FIG. 2: Expected Senstivity for the Lorentz-violating parameter $a^X_{\mu\tau}$ of NOνA . The dashed horizontal line specifies 95% confidence limit.

Senstivity for the Lorentz-violating parameter $a^X_{\mu\tau}$ is presented in Fig. 2 for the NOνA where we have plotted the corresponding $\triangle\chi^2$. Currently the best limit for $a^X_{\mu\tau}$, given by IceCube experiment [6] at 3σ level is
$-1.8 \times 10^{-23} \leq a^X_{\mu\tau} \leq 1.8 \times 10^{-23}$

From the Fig. 2, we can derive a new limit with 95% confidence limit for $a^X_{\mu\tau}$ as
$-3.29 \times 10^{-24} \leq a^X_{\mu\tau} \leq 3.29 \times 10^{-24}$
We may conclude that, given the configuration of this study, NOνA can offer a better constraint on the LIV parameter.

Acknowledgments

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