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Constraining Lorentz Invariance Violation with Future Long-Baseline Experiments

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Unified theories such as string theory and loop quantum gravity allow the Lorentz Invariance Violation (LIV) at the Planck Scale ($M_P \sim 10^{19}$ GeV). Using an effective field theory, this effect can be observed at low energies in terms of new interactions with a strength of $\sim 1/M_P$. These new interactions contain operators with LIV coefficients which can be CPT-violating or CPT-conserving. In this work, we study in detail how these LIV parameters modify the transition probabilities in the next-generation long-baseline experiments, DUNE and Hyper-K. We evaluate the sensitivities of these experiments in isolation and combination to constrain the off-diagonal CPT-violating ($a_{e\mu}$, $a_{e\tau}$, $a_{\mu\tau}$) and CPT-conserving ($c_{e\mu}$, $c_{e\tau}$, $c_{\mu\tau}$) LIV parameters. We derive approximate compact analytical expressions of appearance ($\nu_\mu \to \nu_e$) and disappearance ($\nu_\mu \to \nu_\mu$) probabilities in the presence of these LIV parameters to explain our numerical results. We explore the possible correlations and degeneracies between these LIV parameters and the most uncertain 3ν oscillation parameters, namely, θ_{23} and $\delta_{\rm CP}$. We find that for non-maximal values of θ_{23} ($\theta_{23} \neq 45^\circ$), there exist degenerate solutions in its opposite octant for standalone DUNE and Hyper-K. These degeneracies disappear when we combine the data from DUNE and Hyper-K. In case of no-show, we place the expected upper bounds on these CPT-violating and CPT-conserving LIV parameters at 95\% C.L. using the standalone DUNE, Hyper-K, and their combination. We observe that due to its access to a longer baseline and multi-GeV neutrinos, DUNE has a better reach in probing all these LIV parameters as compared to Hyper-K. Since the terms containing the CPT-conserving LIV parameters are proportional to neutrino energy in oscillation probabilities, Hyper-K is almost insensitive to the CPT-conserving LIV parameters because it mostly deals with sub-GeV neutrinos.

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