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Exploring Earth's Matter Effect in High-Precision Long-Baseline Experiments

A detailed understanding of Earth's Matter effect is inevitable to correctly analyze the data from the upcoming high-precision long-baseline experiments to resolve the remaining fundamental unknowns such as neutrino mass ordering, leptonic CP violation and precision measurements of the oscillation parameters. In this paper, for the first time, we explore in detail the capability of Deep Underground Neutrino Experiment (DUNE) to establish the matter oscillation as a function of $\delta_{\rm CP}$ and θ_{23} by excluding the vacuum oscillation. We find that DUNE is sensitive to Earth's matter effect at more than 2σ C.L. irrespective of the choice of the oscillation parameters. The relative 1σ precision in the measurement of line-averaged constant Earth matter density ($\rho_{\rm avg}$) for maximal CP-violating choices of $\delta_{\rm CP}$ is around 10% to 15% depending on the choice of neutrino mass ordering. If $\delta_{\rm CP}$ turns out to be around -90° or 90° , the precision in measuring ρavg is better in DUNE as compared to what are achievable from the Super-K atmospheric data, combined data from Solar and KamLand, and full exposure of T2K and NOνA. We also observe new interesting degeneracies among $\rho_{\rm avg}$, $\delta_{\rm CP}$, and θ_{23} and notice that the present uncertainty in $\delta_{\rm CP}$ dilutes more the measurement of $\rho_{\rm avg}$ compared to θ_{23} . To lift these degeneracies, we incorporate the prospective data from the upcoming Tokai to Hyper-Kamiokande (T2HK) and T2HK with a second detector in Korea (T2HKK) experiments. With a relatively shorter baseline and high statistics at first oscillation maximum, T2HK offers unprecedented sensitivity to establish genuine CP violation and to measure $\delta_{\rm CP}$, whereas in the T2HKK setup, the second detector in Korea with a roughly four times longer baseline is more sensitive to Earth's matter effect and provides crucial information on $\delta_{\rm CP}$ working at second oscillation maximum. We explore interesting complementarities among these possible setups and find that the combined data from DUNE and T2HKK can establish Earth's matter effect at more than 5σ C.L. irrespective of the choices of mass ordering, $\delta_{\rm CP}$, and θ_{23}.

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