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Quantum Fisher Information as a Probe of Parameter Sensitivity in Long-Baseline Neutrino Oscillations

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We investigate Quantum Fisher Information (QFI) as a measurement-independent measure of parameter sensitivity in three-flavor neutrino oscillations. Focusing on the $\nu_\mu \to \nu_e$ appearance channel, we evaluate the QFI for the leptonic CP-violating phase $\delta_{\rm CP}$, the atmospheric mixing angle θ_{23}, and the atmospheric mass-squared difference Δm^2_{31} as functions of the baseline-to-energy ratio (L/E) using the latest NuFit-6.0 global-fit parameters.

Our results reveal distinct sensitivity patterns for the three oscillation parameters. The QFI for $\delta_{\rm CP}$ and θ_{23} exhibits two maxima corresponding to the first and second oscillation maxima, whereas the QFI for Δm^2_{31} shows a single broad maximum at intermediate L/E. The corresponding sensitivity hierarchy indicates that Δm^2_{31} can be determined with the highest intrinsic precision, followed by θ_{23} and $\delta_{\rm CP}$. We further find that these QFI profiles are robust against current variations in the global-fit oscillation parameters.

Our study demonstrates that QFI provides a useful quantum-information framework for identifying the optimal L/E regions for oscillation parameter estimation and for assessing the fundamental precision limits of current and future long-baseline neutrino experiments.

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