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Quantum Estimation Perspective on Neutrino Oscillation Measurements

Quantum estimation theory provides a powerful framework to quantify the ultimate precision with which neutrino oscillation parameters can be inferred. In this work, we use the Quantum Fisher Information (QFI) to study the information content associated with the leptonic CP phase δ_{CP} in long-baseline experiments and the solar parameters Δm_{21}^2 and θ_{12} in reactor and solar neutrino experiments. For T2K and NO ν A, we compare the intrinsic QFI of neutrino states with the event-level Fisher information obtained from reconstructed spectra, showing that present measurements extract only a limited fraction of the available quantum information, with reduced efficiency near maximally CP-violating regions. For reactor and solar neutrinos, we show that coherent reactor evolution allows flavor measurements to approach the QFI bound, while solar neutrinos lose the phase-based contribution due to matter effects and decoherence. Consequently, solar experiments are intrinsically more sensitive to θ_{12} than to Δm_{21}^2 . Our results provide a unified information-theoretic perspective on the precision limits of neutrino oscillation experiments.

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