Abstract

The phenomena of entanglement and the nonlocal features of quantum correlations were initially introduced to elegantly abase the opponents of quantum mechanics. However, owing to the development of the quantum information science, these quantum mechanical features have to be reassessed and to be elevated as resources that may be exploited to achieve tasks that are not possible within the realm of classical physics. Along these lines, quantum resource theories provide the framework to study and quantify these quantum effects, develop new protocols for its detection, and identify processes that optimize its use for a given application. Due to weakly interacting nature, the system of oscillating neutrinos can maintain quantum coherence over a long distance, which can be detected in long baseline experiments. Hence, neutrinos can prove to be promising candidates for various quantum information tasks. Also, the correlation measures used in our analysis can reveal important information about several open problems present in the neutrino sector, which makes this a dual study, important for both neutrino physics and quantum information theory.

We study various facets of nonclassicality, quantified by spatial quantum correlations such as flavour entropy, geometric entanglement, Mermin and Svetlichny inequalities, in the system of three flavour neutrino oscillations in the context of ongoing accelerator neutrino experiments NOνA and T2K and upcoming experiment DUNE. We find that various witnesses show sensitivity to the mass-hierarchy problem and CP violation in neutrino physics. In order to test the efficiency and feasibility of neutrinos for QIP tasks, we also incorporated effects of new physics. For this study, we have chosen a measure of quantum coherence, the characteristic element of quantum mechanics which enfolds the defining features of the theory. The new physics effects are incorporated in a model-independent way within the framework of effective field theory, where higher dimensional operators (dimension-6) are added to the Standard Model (SM) Lagrangian. We show that the SM interaction provides favourable conditions for quantum information tasks for normal mass ordering, whereas new physics favours inverted ordering for such tasks. Also, we investigated the variation of coherence and mixedness encapsulated in the neutrino-system under the action of quantum decoherence. It is also interesting to see the features of quantum correlations in the effect of gravitational Zeeman-splitting, causing neutrino-antineutrino oscillations. Another interesting quantum mechanical phenomena, the *geometric phase* has been studied in neutrino system in the context of experiments T2K, NOνA and reactor neutrino experiments such as Daya Bay and RENO. It is seen that for neutrino experimental facilities where the geometric phase can complete one cycle, all the phase curves corresponding to different values of CP violating phase, converge to a single point, called the cluster point. There are two distinct cluster points for positive and negative signs of Δ_{31} (large mass-squared difference). Thus the geometric phase can contribute to our understanding of the neutrino mass hierarchy problem.