Abstract

The Standard Model (SM) is an ensemble of electromagnetic, weak, and strong forces in particle physics. Neutrinos, in the SM, are chargeless, spin-half particles, called fermions, that come in three flavours: electron neutrino (ν_e), muon neutrino (ν_μ), and tau neutrino (ν_τ). In SM, neutrinos are massless. The Super-Kamiokande (SK) experiment from Japan discovered the experimental proof of neutrinos' mass in 1998, and the Sudbury Neutrino Observatory (SNO) from Canada confirmed it in 2002. The observation of non-zero neutrino mass is explained by the neutrino oscillation phenomenon. Neutrino Oscillation is described by a 3×3 unitary matrix, widely known as Pontecorvo-Maki-Nakagawa-Sakata (PMNS) matrix. PMNS matrix connects the three flavors with three mass eigenstates ν_1, ν_2 and ν_3 of masses m_1, m_2 and m_3 respectively. The matrix is commonly parameterized by three mixing angles (θ_{12}, θ_{13} and θ_{23}), one CP-violating phase δ_{CP} and two Majorana phases (ρ_1 and ρ_2). However, the Majorana phases have no effect in neutrino ocillations. Neutrino oscillation is measured by comparing the flux of neutrinos of one flavour produced to that of neutrinos of another flavour observed in a detector separated by a distance (called the baseline) from the source. The probability of oscillation of neutrino from one flavour to another is dependent on mass-squared differences (Δm^2_{21} and Δm^2_{31}), the neutrino energy, the baseline and the density of the matter passed through by the neutrino, besides the four parameters of the PMNS matrix.

Although a few percent precision measurements of three mixing angles and two mass-squared differences have been achieved, a complete picture of neutrino oscillation is yet to be understood. There are at least three unknowns, which the ongoing and upcoming neutrino oscillation experiments plan to address in the next decades. The *first* unknown is CP violation (CPV) in the leptonic sector. Despite a recent hint of maximal CPV from the δ_{CP} measurement by the T2K experiment, it requires higher statistics to establish whether CP is violated or not. The *second*

unknown is the neutrino mass hierarchy (MH), which refers to the order of the three mass eigenvalues of neutrino mass eigenstates. Whether the MH is normal ($m_1 < m_2 < m_3$) or inverted ($m_3 < m_1 < m_2$) is still a question. While the recent measurements from individual experiments mildly favor the former, the efforts for fitting jointly multiple neutrino data samples show that the preference to the normal MH becomes less significant. Thus, more neutrino data is essential to shed light on the neutrino MH. The *third* unknown on the list is the octant of mixing angle θ_{23}. Whether θ_{23} is exactly equal to $45°$, in the lower octant (LO, $\theta_{23} < 45°$) or in the higher octant (HO, $\theta_{23} > 45°$) is of interest to pursue. Moreover, besides resolving these unknowns, the precision measurements of the oscillation parameters for a unitary test of the leptonic mixing matrix are among the major targets of the ongoing and future neutrino oscillation experiments.
In this thesis, we explore the propects of achieving these unknowns in light of three terrestrial neutrino oscillation experiments: the extended run of Tokai-To-Kamioka (T2K-II) and NuMI Off-axis ν_e Appearance (NOνA-II), as well as the reactor-based medium baseline (R-MBL) experiment Jiangmen Underground Neutrino Observatory (JUNO). The work explores the physics reach for the targets by around 2027, when the 3rd generation of the neutrino experiments starts operation, with a combined sensitivity of the three experiments. It is shown that a joint analysis of these three experiments can conclusively determine the neutrino mass hierarchy. Also, at certain values of δ_{CP}, it provides closely around a 5σ confidence level (C.L.) to exclude CP conserving values and more than 50% fractional region of *true* δ_{CP} values can be explored with a statistical significance of at least a 3σ C.L. Besides, the joint analysis can provide unprecedented precision measurements of the atmospheric neutrino oscillation parameters and a great offer to solve the θ_{23} octant degeneracy in the case of non-maximal mixing.

Keywords: Neutrino oscillations; mass hierarchy; leptonic CP violation; octant degeneracy; maximal mixing; terrestrial experiments.