Chapter 6

Conclusion and Future Scopes

In this thesis, the propects of determining the neutrino mass hierarchy, exploring leptonic CP violation, resolving of θ_{23} octant degeneracy and precision measurements of oscillation parameters θ_{13}, θ_{23}, δ_{CP} and Δm^2_{31} are studied, 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).

Firstly, we describe the specifications of the above three neutrino oscillation experiments. We describe the experiments using updated information on fluxes, signal and background efficiencies, and systematic errors. We discuss the simulation technique adopted to study the physics potential of the experiments. We present our results on the event spectra for the selected ν_e ($\bar{\nu}_e$) appearance and ν_μ ($\bar{\nu}_\mu$) disappearance channels for T2K-II and NOνA-II, and $\bar{\nu}_e$ disappearance channel JUNO.

We present our neutrino oscillation analysis based on the simulated data. We present the results on the MH determination and the CPV sensitivity of the above experiments. A joint analysis of JUNO with the A-LBL experiments, NOνA-II and T2K-II, shows a great boost in the MH determination. This is expected since a joint analysis will break the parameter degeneracy between δ_{CP} and the sign of

Δm^2_{31}. Due to the parameter degeneracy among $\delta_{\rm CP}$, the sign of Δm^2_{31}, θ_{13}, and θ_{23} in the measurement with the A-LBL experiments, we also expect that the MH determination depends on the value of θ_{23}. The results conclude that the *wrong* mass hierarchy can be excluded at greater than 5σ C.L. for all the *true* values of $\delta_{\rm CP}$ and for any value of θ_{23} in the range constrained by experiments. We find out that in the paper *Scientific Reports volume 12, Article number: 5393 (2022)* by A. Cabrera *et. al.*, the authors address a similar objective. While their qualitative findings are consistent with our studies, there may still be numerical differences need to be understood. The CPV sensitivity is shown as a function of the *true* value of $\delta_{\rm CP}$ for both MH options: (a) MH is *known*, or (b) MH is *unknown*. The result shows that whether the MH is *known* or *unknown* does not affect on the joint analysis of the three experiments because the MH-δ_{CP} degeneracy is uplifted. It can be seen that the sensitivity to CP violation is driven by T2K-II and NOνA-II. Contribution of the R-SBL neutrino experiment is significant only at the region where $\delta_{\rm CP}$ is between 0 and π and when the MH is not determined conclusively. At $\delta_{\rm CP}$ close to $-\pi/2$, which is indicated by recent T2K data, the sensitivity of the joint analysis with all considered experiments can reach approximately the 5σ C.L..

We also studied the resolution of the θ_{23} octant and the precision measurement of the oscillation parameters in T2K-II, NOνA-II and JUNO. The 3σ C.L. allowed region of $\sin^2\theta_{13}$-$\delta_{\rm CP}$ obtained with a joint analysis of the T2K-II and NOνA-II is compared to that of the present constraints as in NuFiT 4.1. Both JUNO alone and a combined sensitivity of the T2K-II and NOνA-II experiments can reach a sub-percent-level precision on the atmospheric mass-squared splitting Δm^2_{31}. A comparison with such precision may provide a very good test for the PMNS framework. A capability to solve the θ_{23} octant in case the mixing angle θ_{23} is not maximal is also discussed. The θ_{23} octant resolving power can be enhanced significantly when combining T2K-II and NOνA-II data samples, particularly the θ_{23} octant can be determined at 3σ C.L or higher if $\sin^2\theta_{23}$ is ≤ 0.46 or ≥ 0.56.

Finally, we would like to emphasize that the joint analysis in reality is expected to be more complicated than what we have done. Many systematic sources must be taken into account for each experiment, and for a joint analysis, the correlation of systematic errors among experiments is important for extracting precisely the oscillation parameters. However, we affirm that the above conclusions are still valid since the measurement uncertainties, particularly for CP violation and the neutrino mass hierarchy, are still dominated by statistical errors.

Although the picture of neutrino oscillation is concrete, yet, far from complete and requires collaborative efforts. To resolve the octant degeneracy, combined sensitivity studies of data from ongoing and upcoming atmospheric neutrino experiments such as SuperKamiokande, IceCube, PINGU, HyperKamiokande and KM3NeT along with accelerator-based and reactor-based neutrino experiments, as well as exploiting second oscillation maxima at longer baselines like DUNE, P2O and ESSνSB can be realised. It is imperative to consider the dependence and correlation of systematic errors while performing joint analysis of different neutrino oscillation experiments. Precisely measuring the six oscillation parameters gives us a window to directly test the unitarity of the PMNS matrix. To observe the effect on the presently unresolved issues which we have covered in this thesis, non-standard neutrino oscillation phenomena, such as NSI, the sterile hypothesis, and neutrino decay, if any, can be taken into consideration.