Project Proposals

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Phenomenology with a Light Sterile Neutrino:

How many neutrino species are there? Do sterile neutrinos exist? Are three-flavour oscillations enough? These issues have taken centre stage due to some anomalous results from short-baseline (SBL) neutrino oscillation experiments (such as LSND, MiniBooNE), which seem to hint towards high $\Delta m^2 \sim 0.1$–10 eV^2 oscillation. This Δm^2 is too large to be explained with only three active neutrinos, and so oscillations involving sterile neutrinos are proposed which do not couple to W and Z bosons. In this project, we will first study the theory of neutrino oscillation with three active neutrinos and one light eV-scale sterile neutrino and derive all the relevant neutrino oscillation probabilities in the so-called 3+1 scheme. Then, we will discuss the recent results from SBL experiments which hint towards active-sterile oscillation and we will see how the oscillation probabilities in 3+1 scheme can address these results. Next, we will study the impact of this light sterile neutrino in upcoming neutrino oscillation experiments and neutrino-less double beta decay searches.

Addressing Neutrino Mass Ordering in Neutrino Oscillation Experiments:

The solar mass-squared difference ($\Delta m^2_{21} \equiv m^2_2 - m^2_1$) is required to be positive to explain the observed energy dependence of the electron neutrino survival probability in solar neutrino experiments. But, the current oscillation data cannot decide whether the atmospheric mass splitting ($\Delta m^2_{31} \equiv m^2_3 - m^2_1$) is positive ($\Delta m^2_{31} > 0$) or negative ($\Delta m^2_{31} < 0$). The first possibility gives rise to the neutrino mass pattern: $m_3 > m_2 > m_1$, known as normal ordering (NO) and for the second possibility, we have $m_2 > m_1 > m_3$, labelled as inverted ordering (IO). Knowing the ordering of the neutrino masses is one of the fundamental unsolved issues in neutrino physics, which can dictate the structure of the neutrino mass matrix, and hence could give vital clues towards the underlying theory of neutrino masses and mixing. In this project, we will study in detail the issue of neutrino mass ordering and will learn how the Earth matter effect in neutrino oscillation can play an important role to resolve this issue. Towards the end, we will also discuss how the upcoming India-based Neutrino Observatory (INO) experiment is going to determine the neutrino mass ordering using the atmospheric neutrinos.

Addressing Leptonic CP-violation in Neutrino Oscillation Experiments:

Determining the value of the Dirac CP phase, $\delta_{\rm CP}$ and to explore the possibility of CP-violation in the leptonic sector (if $\delta_{\rm CP}$ differs from both 0° and 180°) have emerged as the top most priority in the field neutrino oscillation physics. A substantial amount of CP-violation in the lepton sector may point towards the possibility that neutrinos are involved in generating the observed matter-antimatter asymmetry in the universe dynamically. In this project, we will first study the role of the Dirac CP-phase, $\delta_{\rm CP}$ in three-flavor neutrino oscillation probability and the possible correlations and degeneracies that it may have with the other oscillation parameters. Then, we will explore how the information on neutrino and antineutrino oscillation probabilities can help us to extract information on leptonic CP-violation. In three-flavor scenario, besides the genuine CP-violation caused by $\delta_{\rm CP}$, we also have fake CP-violation induced by Earth matter which causes hindrances in extracting the information on leptonic CP-violation. We will also study this issue in detail under this project.

High-Precision Measurement of the Atmospheric Mixing Angle (θ_{23}):

Another recent and crucial development related to neutrino oscillation parameters is the hint of non-maximal θ_{23} from the global fits of world neutrino data, which indicate towards two nearly degenerate solutions for 2-3 mixing angle: one $< 45^\circ$, termed as lower octant (LO), and other $> 45^\circ$, denoted as higher octant (HO). Accurate measurement of θ_{23} and the resolution of its correct octant (if it turns out to be non-maximal) are also very important issues that need to be addressed in the current and next generation neutrino oscillation experiments. These informations will provide crucial inputs to the theories of neutrino masses and mixings. In this project, we will first learn the role of atmospheric mixing angle (θ_{23}) in appearance and disappearance oscillation channels. Then, we will investigate in detail the features of $\delta_{\rm CP}$-octant of θ_{23}-mass ordering degeneracies in $\nu_\mu \to \nu_e$ oscillation channel with the help of analytical expressions. Then, we will perform some numerical simulation to quantify the physics reach of currently running and upcoming oscillation experiments to precisely measure the value of θ_{23}.