Towards the first evidence of the CP symmetry violation in the lepton sector using the T2K and Hyper-Kamiokande experiments

PhD 2022-2025

Laboratoire Leprince-Ringuet (CNRS/Ecole polytechnique)

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The oscillations of neutrinos were first discovered only 20 years ago, when the Super-Kamiokande collaboration observed the disappearance of atmospheric neutrinos. In less than two decades, the physics of neutrino oscillations has been the fertile field for tremendous progresses and opened a new era: it would allow to measure the CP asymmetry in the leptonic sector through neutrino oscillations, and with it, to possibly explain the asymmetry between matter and antimatter that is currently observed in our Universe.

This PhD proposes to directly tackle this question using the T2K experiment, which is the pioneer experiment in this domain. T2K is a Long-Baseline neutrino oscillation experiment located in Japan. Its main goal is the precise measurement of the (muon) electron neutrino and antineutrino (dis-)appearance. Through these measurements, T2K is measuring the ν oscillation parameters with increasing precision and is providing first indications about neutrino Mass Hierarchy (MH) and CP violation phase (δ_{CP}) in the ν sector. The excellent results reported by T2K have motivated a second phase of the experiment, T2K-II, that will start in 2022 for 5 years and aims at establishing CP violation at 3σ level. In order to improve T2K-II performances, and in view of the incoming Hyper-Kamiokande experiment (construction has started in 2020), an upgrade of the near detector of T2K is ongoing.

This upgrade aims to refine knowledge of neutrino interactions, which are critical inputs for the study of neutrino oscillation, not only in T2K but even more for future experiments (DUNE, Hyper-Kamiokande) aiming at precise determination of MH and δ_{CP}. The T2K collaboration is presently playing a leading role also in this field. With the upgrade of ND280, designed to enable a detailed characterization of the outgoing nucleons and pions, down to very low threshold, new exciting results are expected in the next years. Including new samples with hadron information to the oscillation analysis, will allow to reduce the systematic errors, and thus improve the precision of the oscillation parameters for T2K-II.

The successful PhD candidate will work on the analysis of the T2K data with the ND280 and ND280 Upgrade detectors, and propagate the near detector fit results all the way to produce the upgrade neutrino oscillation result. He/she will focus on the integration of the new ND280 upgrade samples in the oscillation analysis framework, and evaluate the corresponding experimental systematic uncertainties on the measured oscillation parameters. The extraction of near detector constraints must be deeply modified to include the information of outgoing detected protons and neutrons, which are completely missed in the present T2K analysis. The candidate will be able to evaluate the impact not only on T2K-only data, but also on the joint analysis of the T2K accelerator and Super-Kamiokande atmospheric neutrinos. This joint fit has the potential to highly improve the current constraints on MH and CP violation compared to T2K-only. But, it is now limited due to very premature treatment of the cross-section model uncertainties.

Through her/his work on the T2K ND280, the candidate will be able to highly improve the cross-section model uncertainties in this joint fit, and will ultimately participate in providing the world-best constraint on CP violation in the lepton sector. This activity will guarantee a major visibility of the student not only within the T2K collaboration, but also at the whole neutrino community level.
The student will also work on the commissioning of the ND280 upgrade detector (which will be installed in 2022), contributing to the calibration of the SuperFGD electronics.

She/He will be encouraged to present the results in international relevant conferences, so as to offer her/him the rare opportunity to work side-by-side with experimentalists and theoreticians, in an international community that is growing up around this major topic of high energy physics.

Finally, the student may study the prospects and perspectives of the oscillation analysis in the gigantic future Hyper-Kamiokande, the next generation of neutrino observatory to be built in Japan until 2027.

Laboratory team: Laboratoire Leprince-Ringuet, Ecole polytechnique – Neutrino group
The neutrino group in LLR has been created in 2006 by Michel Gonin, as the first historical group in France to work on the world-leading neutrino experiments in Japan. Since then, the group has joint the unique T2K experiment, which has first discovered the neutrino appearance, as well as provided the very first hints of violation of the leptonic CP symmetry. Since 2016, the group has also joined the Super-Kamiokande experiment, and have built a strong leadership inside regarding the DSNB neutrino detection and phenomenology.
The group is composed of 6 permanent researchers and 3 PhD students, who has unique expertize in both high energy (CP violation, mass-hierarchy issue etc.) and low energy neutrinos (Supernovae, solar or reactor neutrinos). In the context of the proposed thesis, the two contact members are respectively leading the T2K cross section and oscillation analysis working groups. The group is also involved in the development of the readout electronics for the upgrade of ND280. Finally, the group is strongly engaged in the P2IO Flagship project, BSMnu, regrouping all the major neutrino actors in the Paris-Saclay/IPP perimeter. All these aspects will guarantee full support and guidance to the PhD student, as well as a unique expertize.

Frequent travels to Japan (collaboration meeting, data taking, ND280 upgrade commissioning) are also expected.