First evidence of the CP symmetry violation and impact on matter-antimatter asymetry in the Universe

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The oscillations of neutrinos were first observed 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 position proposes to directly tackle this question using a complementary approach based on an experimental analysis and supported by a phenomenological study focused on low energy leptogenesis.

The matter-antimatter asymmetry in the Universe has been a long-standing and one of the deepest open question in modern physics. Over the last decades, several mechanisms has been explored in order to bring a definitive answer to this question, from static asymmetry to baryogenesis. Among the surviving scenarios, the so-called leptogenesis mechanism may be the most promising : it predicts that the matter/antimatter asymmetry is generated from an original asymmetry between lepton and anti-lepton behaviour at high energy. This behaviour may be induced by a high energy CP violation phase, or be directly generated by the low energy CP violation phase of the neutrino oscillation matrix, PMNS. In this context, a precise determination of the neutrino oscillation parameters, and in particular, of the low energy CP violation (δ_{CP}), will allow us to constrain this scenario for the very first time. The successful candidate will work a significant amount of her/his research time in order to understand and develop these low energy leptogenesis models in order to extract the key observables that would be measurable at low energy. Depending on her/his achievements, the candidate could also work on extension or alternative of the existing models, which may bring new connections between the low energy CP violation and the matter-antimatter asymmetry.

In parallel, in order to constrain and determine the correct models, the project proposes to use the T2K and Super-Kamiokande experiments, which are the pioneer experiments in this domain. These experiments have already provided first mild but promising constraints on δ_{CP} . The experimental aspect of this project relies on two key goals:

1. Reach the very first evidence (3σ) on CP violation in the lepton sector developing and using a joint analysis between accelerator and atmospheric neutrinos detected by the Super-Kamiokande detector. The candidate will reflect this new world-leading measurement of δ_{CP} to constrain the leptogenesis scenarios.
2. Evaluate the potential of the future Hyper-Kamiokande detector to constrain the leptogenesis scenarios the candidate and the group would have chosen.

Given this dual approach, this project request the successful candidate to have a solid knowledge of quantum field theory as well as a strong motivation to work also on both the theoretical aspects of QFT and the experimental aspects of the T2K, Super-Kamiokande and Hyper-Kamiokande experiments. Based on her/his preference, the candidate would also be able to contribute to the development of a new reconstruction algorithm for the Super and Hyper-Kamiokande detectors, based on Deep Learning infrastructure (GCN). Finally, the door is also open to more instrumental activities by joining the effort to calibrate the Front-End electronics of Hyper-Kamiokande for which the LLR laboratory is in charge of developing a calibration testbench.

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 expertise 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 topic, the two contact members are leading the Hyper-Kamiokande reconstruction effort, as well as the T2K oscillation analysis working groups. Moreover, the group is collaborating with the LLR software engineers as well with the ILANCE laboratory (located in Japan) in order to build a strong leadership in Machine-Learning based algorithms.

Frequent travels to Japan and CERN (working at ILANCE, collaboration meeting, data taking …) are also expected.