Joint France-Japan PhD thesis proposal

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Title: **Neutrino-nucleus cross sections at the T2K ND280-Upgrade detector**

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**University of Tokyo: Masashi Yokoyama**

T2K is a long-baseline neutrino oscillations experiment, taking data in Japan. T2K has been the first experiment to detect the appearance of electron neutrinos and is currently searching for CP violation in the lepton sector by measuring appearance probabilities of neutrinos and antineutrinos.

At a given baseline the oscillation probability depends on the energy of the neutrinos and the largest source of uncertainty is due to the modeling of the neutrino cross-sections that needs to be used in order to infer the neutrino energy from reconstructed quantities. In general, each kind of neutrino interaction (quasi-elastic, multinucleon excitations, pion production, …) is described by one or more cross-section models that have to be tuned on data.

In T2K this is done by using a multi-purpose magnetized near detector, ND280, able to select samples of neutrinos and anti-neutrino interactions.

ND280 is currently being upgraded with a new set of detectors. The Upgrade will consist in replacing one of the sub-detectors, the P0D, the most upstream inner detector of ND280, with two horizontal TPCs and a horizontal fully active carbon target in the middle (Super-FGD). Six Time-Of-Flight (ToF) planes will be installed around the TPCs and the Super-FGD. The upgrade is expected to be installed in Summer 2022 and start taking data in Fall 2022.

The ND280 Upgrade will allow to reconstruct with better efficiency muons produced in neutrino interactions (while with the current detector configuration only muons parallel to the beam direction are reconstructed with good efficiency) and the hadronic part of the interaction, largely reducing the threshold for the reconstruction of protons and pions.

The careful description of the hadronic part will help to better reconstruct the energy of the neutrinos and to shed light on the nuclear processes on-going when neutrinos interact with nuclei. This work will be crucial not only to reach the physics goals of the phase II of T2K but also for the next-generation long baseline neutrino oscillation experiment, Hyper-K that has just started construction and is expected to start data taking in 2027. ND280 will be one of the near detectors of Hyper-K and the ND280 Upgrade is expected to provide inputs to oscillation analyses and cross-section modeling also in Hyper-K.

The proposed PhD thesis will be centered around the ND280 upgrade project that is currently coordinated a researcher from LPNHE (Claudio Giganti) and was previously coordinated by a researcher at University of Tokyo (Masashi Yokoyama). The PhD candidate will work under the supervision of Marco Martini and Claudio Giganti in France and of Masashi Yokoyama during his/her stay in Japan.

Sharing common expertise between French and Japanese groups will guarantee full support and guidance to the PhD student who will spend a significant fraction of time at the University of Tokyo, thus profiting from exciting and stimulating environment of both laboratories.

The first year will be devoted on investigations and developments of neutrino cross-section models. In particular the student will work under the direction of Marco Martini, one of the authors of a microscopic theoretical cross-section model which in these last ten years predicted and reproduced with success all the measured neutrino cross-sections at the T2K energies in different channels (like CC0π, CC1π, CC inclusive) and which, as first, raised the crucial role of multinucleon excitations in neutrino scattering. Unfortunately, this excitation channel is as crucial (in particular for the neutrino energy reconstruction) as difficult to treat without approximations. As a consequence, the predictions by the different theoretical models of the cross sections in this channel are different from each other in size and shape. Differences may appear also in the one pion production channel related to the treatment of pionless Delta resonance decay. The student will analyze the analogies and the differences of the several models implemented in the Monte Carlo used by T2K and will investigate the best strategy to test, constrain and eventually improve these models (in particular the one developed by M. Martini and collaborators) in several exclusive channels in connection with the new information in terms of leptonic and hadronic final state variables that will be provided by the imminent ND280-Upgrade measurements.

During the second year of the PhD thesis, once the ND280 Upgrade data will be available, the student will be responsible for the selection of neutrinos interactions at superFGD with at least one proton in the final state as well as of the interactions with one proton and one pion final states. The student contribute to the estimation of the systematics uncertainties of the new detectors, will develop the analysis tools needed to measure neutrino cross-sections, and will work on the comparison of these data with the cross-section models.

The third year will be devoted to the finalization of the analysis, to the inclusion of the tuned cross-section models in the T2K oscillation analyses and, of course, to the timely preparation of the PhD manuscript.

In parallel, the student will participate to the installation, commissioning, and calibration of the ND280 Upgrade detectors at J-PARC and it is expected that he/she will spend significant amount of time at Tokai, in the context of the CNRS funded international thesis.