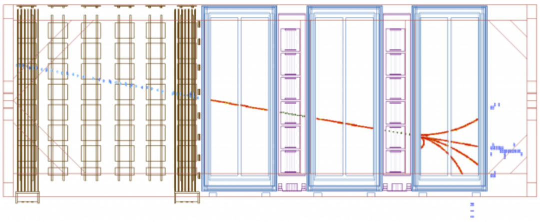
Abstract for the general public

According to the Standard Model, the theory describing elementary particles and their interactions, matter consists of two groups of particles, quarks and leptons, organised in the three so-called generations. Each generation consists of a pair of quarks and one charged and one neutral lepton. The quarks build e.g. well-known protons and neutrons. The charged leptons are the electron, muon and tauon, and the neutral leptons are the electron neutrino (ν_e), muon neutrino (ν_μ) and tauon neutrino (ν_τ). Each of these particles has its antimatter counterpart.

Neutrinos are the lightest and most abundant elementary matter particles. According to the Standard Model, they undergo only weak interactions (the interaction which causes e.g. the nuclear beta decay, in which a neutron decays into a proton, electron and electron antineutrino). This causes neutrinos to interact very rarely, making them difficult to detect and study, but at the same time enables them to travel unimpeded from the farthest and/or the most inaccessible parts of the Universe, providing information about their sources and processes of their production, such as Supernova explosions, nuclear fusion in the core of the Sun and other stars, or the decays of radionuclides inside Earth. Thus, neutrinos are the most mysterious of the known particles and their properties have not yet been fully and consistently described. The non-zero mass of neutrinos is a fact which goes beyond the Standard Model. They are the only elementary matter particles which may be Majorana particles, i.e. particles which are their own anti-particles. There are also indications that the asymmetry between the behaviour of neutrinos and antineutrinos may be strong enough to result in the production, at the beginning of the existence of the Universe, of an excess of matter with respect to the antimatter that now forms our Universe. If the number of particles of matter and antimatter was exactly the same, they would annihilate with each other, i.e. they would disappear, leaving only energy in the form of photons.

Neutrinos oscillate, i.e. a neutrino of one type (e.g. muon neutrino) can change into a neutrino of a different type (e.g. electron neutrino) while propagating through space. To study this phenomenon, physicists have to use intense sources of neutrinos and large detectors, to compensate for the fact of their weak interactions with matter. One of the world-leading neutrino oscillation experiments is the T2K (Tokai to Kamioka) experiment. An intense muon neutrino or antineutrino beam is produced at J-PARC in Tokai on the east coast of Japan. After 280 m, the beam goes through a set of near detectors. One is ND280, which measures the beam's properties before oscillations and study neutrino interactions. After another 295 km, the distance corresponding to the first oscillation maximum, the beam passes through the Super-Kamiokande far detector, where the muon neutrino or antineutrino disappearance and electron neutrino or antineutrino appearance are measured. The matter-antimatter asymmetry in the neutrino sector is measured by the asymmetry between the appearance probability of electron neutrinos and that of electron antineutrinos.



Interaction registered in the ND280 detector [Credit: the T2K experiment, http://t2k-experiment.org]

Currently, T2K is heading towards phase II of the experiment (T2KII), in which the intensity of the neutrino beam will be increased and the near detector ND280 will be modernised to detect neutrino interaction products with greater accuracy, hence improving our understanding of neutrino interactions and modelling them with better precision. The successor to the T2K experiment will be the Hyper-Kamiokande (HK) experiment, which will use the same neutrino beam and near detectors, but the 5 times larger far detector than the present one. The T2KII and HK experiments are scheduled to start in 2023 and 2027, respectively.

The project is related to the upgraded ND280 detector. The planned work will include the safety and the integration of new sub-systems into the existing experimental facilities, the development of the software needed to detect and identify different types of particles produced by interacting neutrinos, and finally the study of different types of neutrino interactions. This effort is needed to understand better how neutrinos interact, to verify whether neutrino interaction models are correct, and improve them if necessary. This knowledge is essential for measuring neutrino oscillations, including matter-antimatter asymmetry, with the desired precision. All this is needed to check in T2KII at the 3σ confidence level (99.7%), and to finally confirm in HK at the 5σ level (99.99994% confidence), whether the matter-antimatter symmetry in neutrino oscillations is conserved or violated.