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The Upgrade of the T2K ND280 Detector

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Abstract. The Tokai to Kamiokande (T2K) experiment is a long-baseline neutrino experiment taking data since 2010. The neutrino beam is detected on two sites, the near detector complex close to the neutrino production point, and Super-Kamiokande in a distance of 300 km. The ND280 detector is one of the near detectors and has the purpose to characterize the beam before oscillation as also the measurement of interaction cross sections. Both is crucial to reduce the systematic uncertainties. To improve the latter further, the T2K collaboration decided in 2016 an upgrade of ND280 which includes the installation of a novel scintillator tracker, two time projection chambers and a time of flight system. This upgrade, in combination of an increase of the neutrino beam power from currently 500 kW to 1.3 MW, will roughly increase the statistics by a factor 4 and reduce the systematic uncertainties from 6% to 4%. The new subdetectors are currently being assembled and will be installed in 2022. The upgraded ND280 will also serve as near detector of the next generation long-baseline neutrino oscillation experiment Hyper-Kamiokande.

1. Introduction

The Tokai to Kamiokande (T2K) [1] experiment is a long-baseline neutrino oscillation experiment located in Japan. A highly pure muon (anti-)neutrino beam is produced at the accelerator complex J-PARC, situated at the east coast of Japan, and detected at two detector complexes: the near detector complex 280 m away from the production point and in a distance of almost 300 km by the water Cerenkov detector, Super-Kamiokande (SK) [2]. T2K is using an off-axis neutrino beam configuration, meaning that the neutrino beam is not pointing directly towards SK but with an angle of 2.5° in respect to the axis J-PARC/SK. The advantage of this configuration is that the neutrino beam energy has a narrow peak at the optimal energy of 600 MeV. The near detector complex contains several detectors to characterize the neutrino beam. The two most relevant are the on-axis detector INGRID [3] and the off-axis detector ND280 which upgrade plans will be presented in this article.

T2K has been the first experiment to detect the appearance of electron neutrinos in a muon neutrino beam [4] and is now searching for CP violation in the leptonic sector by precisely measuring appearance probabilities of neutrino and antineutrinos [5]. Such measurement requires both, larger statistics and a good understanding of systematic uncertainties.

In order to improve both, an upgrade of the T2K Near Detector, ND280, is being conducted and is expected to significantly reduce the impact of systematic uncertainties on T2K oscillation

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[1] on behalf of the T2K collaboration

analyses and, more in general, to improve the current knowledge of neutrino cross-section models.

2. The ND280 Detector

The ND280 detector consists of several subdetectors which are installed in the previous UA1 magnet operated at 0.2 T. The central part can be divided in two sectors, one optimized for neutral current interactions, the π_0 (P0D) detector, and a sector optimized for charged current interactions consisting of two fine grain detectors (FGDS) based on scintillator bars acting as neutrino target between 3 time projection chambers (TPCs). All three detectors are surrounded by an electromagnetic calorimeter (ECAL). A side muon range detector (SMRD) is integrated in the return yoke of the magnet. ND280 is shown in figure 1 and see [6] for details.

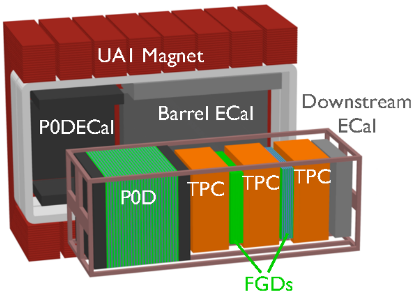

Figure 1. Layout of the current ND280 detector.

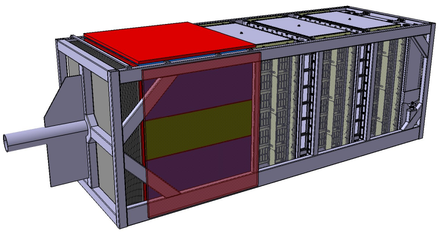

Figure 2. The upgraded ND280 detector (ECAL and magnet not shown).

This configuration has some drawbacks: As shown in figure 3 the detector is optimized to detector muons leaving the vertex in the forward direction, while the efficiency for high angle and backwards going muons is very low. In addition, the detection threshold for protons is relatively high with 500 MeV/c, the detector is not sensitive to neutrons and the identification of out of fiducial interactions, e.g. neutrino interactions in the magnet, is not optimal.

For this reason, the T2K collaboration decided to upgrade ND280 resulting in combination with the upgrade of the beam power from currently around 500 kW to 1.3 MW [7] in the future increasing the statistics by a factor 4 and reducing the systematic uncertainties from currently 6% to around 4%.
For the upgrade, the P0D detector will be substituted by 3 new subdetectors:

- A super fine grain detector (SuperFGD) which instead of bars consists of scintillating cubes traversed by 3 wavelength shifting (WLS) fibers
- Two high angle TPCs installed below and above the SuperFGD
- 6 time of flight (ToF) panels surrounding the SuperFGD and the TPCs hermetically

A detailed description of the ND280 Upgrade can be found in [8] and a sketch in figure 2.

3. SuperFGD

The SuperFGD is a novel concept for a scintillator tracker. The classical approach is to use layers of scintillator bars in which each layer provides either the x or the y coordinate resulting in two independent 2D views of the events. Consequences for the track reconstruction are that

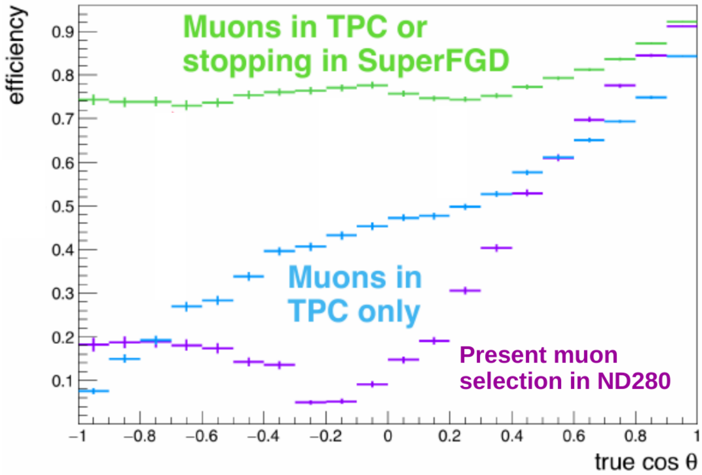

Figure 3. The muon detection efficiency as function of the cosine of the azimuth angle: in magenta for the current ND280 and in green for the upgraded ND280.

tracks along one of the bars (high angle) and short tracks from low energetic particles have a low reconstruction efficiency. For the SuperFGD optically isolated scintillator cubes, each of 1x1x1 cm^3, are used. In total 2.1 million cubes were produced by UniPlast (Russia) for the final detector of size 192x182x56. The optical isolation is achieved by exposing the cubes to an acid bath which yields a highly reflective outer layer of about 100 μm thick. The assembly procedure is described in [8]. For the light detection, the fiber is coupled on one side to a MPPC from Hamamatsu while on the other side a light calibration system is installed allowing to calibrate regularly every single MPPC. The MPPCs are then readout by an electronics developed for this purpose with an excellent timing information (Fig.4). The three views provide a full 3D event reconstruction allowing a significant lower detection threshold. The whole SuperFGD concept was tested with several prototypes in various testbeam campaigns using charged particles and neutrons (Fig.5. Results from the charged particle data can be found in [9].

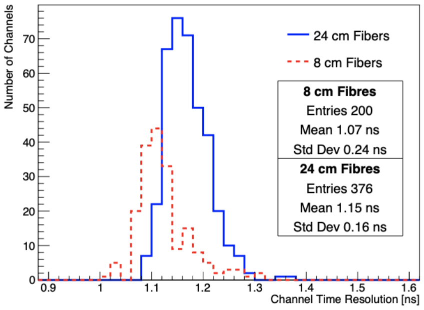

Figure 4. Time resolution measured using the charged particle data taken during a CERN testbeam campaign. The used prototype had a size of 24x8x48 cm.

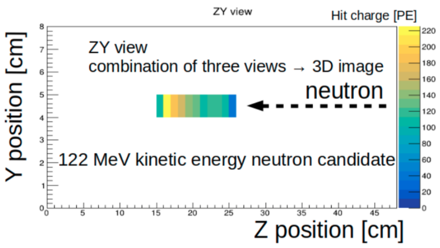

Figure 5. Event display of a neutron event recorded during a testbeam at the Los Alamos facility.

4. HA-TPCs

Two new TPCs will be built for the upgrade each with an overall size of 1865x2000x820 mm^3. A single TPC will be assembled from two halves and a separated cathode (figure 6). A module frame with 8 cut outs will conclude the openings. Eight resistive Migromegas modules (ERAM) will installed in each module frame. ERAM is a novel Micromegas technology in which an insulator with a high surface resistivity is placed between the metal mesh and the readout pads. The resistive layer spreads the charge over several readout pads allowing to achieve a significantly better point resolution, especially for short drift distances. Several prototypes were built and tested for both, the field cage and the ERAM modules using cosmics and testbeams. figure 7 shows one of the events recorded at an electron beam at DESY (Germany). Detailed performance studies can be found in [10] demonstrating that the requirements in respect of dE/dx and point resolution will be fulfilled.

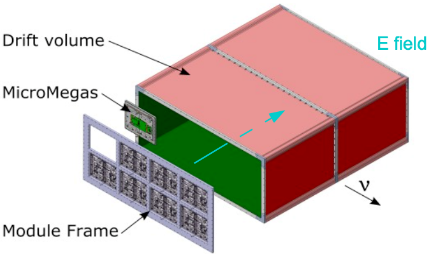

Figure 6. Schemtaics of the TPC: The TPC consists of two halves, a separated cathode, a module frame and 8 ERAM modules.

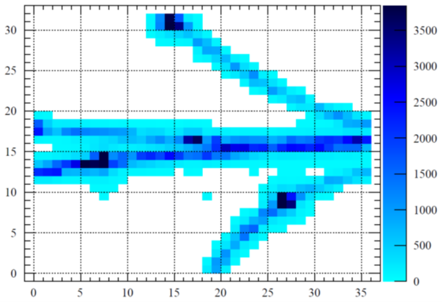

Figure 7. A multi-track event taken at the electron beam at DESY (Hamburg). The maximal drift distance was 15 cm for these tests and the charge spread is achieved thanks to the ERAM concept.

5. ToF

The third subdetector is the ToF system which consists of 6 large panels of 2.5x2.3 m^2 and surroundes the SuperFGD and both TPCs. Its main function is to measure the direction of the particles by measuring the time difference between the SuperFGD and the ToF panels. Each panel consists of 20 scintillator bars which are readout at both sides by MPPCs. This configuration allows an position independent point resolution of 150 ps as shown in testbeam studies [11].

6. Conclusions and Outlook

The near detector of T2K is currently undergoing an important upgrade which in combination with the beam upgrade will increase the statistics by a factor 4 and reduce significantly the systematic uncertainties. This will allow to establish CP violation at 3σ level for a significant fraction of the possible δCP values. The three new subdetectors are currently produced, assembled and tested before installation in ND280 in the second half of 2022 aiming on first data taking in the Japanese fiscal year 2022 (ending 31st of March 2023). An simulated event display is shown in Fig.8.

The upgraded ND280 will also serve as near detector for the next generation neutrino long-baseline oscillation experiment Hyper-Kamiokande and will be crucial to exploit its full physics potential [12].

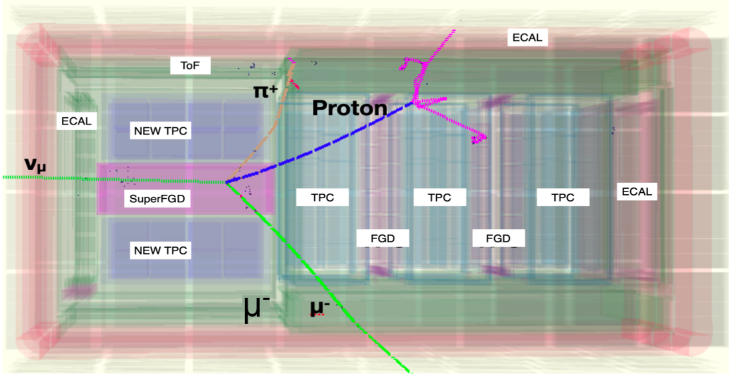

Figure 8. Simulated CC1π in the upgraded ND280 detector.

Acknowledgments

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