T2K: ND280 Status, Progress, and Plans

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Abstract.
T2K(Tokai to Kamioka) is an off-axis long baseline (295 km) neutrino oscillation experiment designed to search for $\nu_\mu \to \nu_e$ appearance. The neutrino beam is generated using 30 GeV protons from the J-PARC facility at Tokai, Japan. The Near Detector(ND280) is located in J-PARC and the Far Detector, Super-Kamiokande, in Kamioka, Japan. Presented is a summary of the status and plans of the Near Detector suite.

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INTRODUCTION

The T2K experiment (Tokai to Kamioka) at J-PARC is part of the next generation exploration of neutrino mixing phenomena. In the current picture of three generation neutrino oscillations two of the three mixing angles $\theta_{12}(\sim 34^\circ)$ and $\theta_{23}(\sim 45^\circ)$, have been determined as have the two independent mass differences, $\Delta m^2_{23}(\approx 2.5\times 10^{-3} eV^2)$ and $\Delta m^2_{12}(\approx 8\times 10^{-5} eV^2)$. The next generation of experiments will attempt to determine the size of the remaining unknown mixing angle θ_{13}.

There are two approaches to measuring θ_{13}. Reactor experiments can directly constrain θ_{13} through $\bar{\nu}_e$ disappearance. Long-baseline experiments such as T2K will search for ν_e appearance in a ν_μ beam. The dominant term in the $\nu_\mu \to \nu_e$ vacuum oscillation probability is given by

$$P(\nu_\mu \to \nu_e)_{vac} \approx \sin^2\theta_{23}\sin^2(2\theta_{13})\sin^2(1.27\Delta m^2_{13}L/E)$$

The current best limits for θ_{13} require that long-baseline experiments be sensitive to small ν_e appearance probabilities. The tools required to perform a long-baseline ν_e appearance search are an intense proton source, a massive far detector, an off axis beam to reduce beam ν_e contamination uncertainty, and a careful measurements of beam flux and backgrounds using a suite of near detectors.

The main T2K goal is to improve sensitivity to θ_{13} by an order of magnitude over the current best limit from the CHOOZ experiment[1]. The estimated sensitivity for 8.3×10^{21} protons on target(POT) is $\sin^2 2\theta_{13} > 0.008$ at 90% CL, for a CP violating phase $\delta = 0$ and $\Delta m^2 = 2.5\times 10^{-3}\mathrm{eV}^2$. T2K can also also improve substantially on oscillation parameters in the $2 \to 3$ sector. The precisions expected are $\delta(\Delta m^2_{23}) \sim 10^{-4}\mathrm{eV}^2$ and $\delta(\sin^2\theta_{23}) \sim 0.01$.

DESCRIPTION OF EXPERIMENT

The J-PARC neutrino beam is aimed toward the off-axis detectors at an angle of 2.5° off the beam axis. The resulting beam spectrum is peaked at $E_\nu \sim 750 MeV$. As a result, background from the ν_e beam and NC feed-down from high energy neutrinos is greatly suppressed. The existing SuperKamiokande 50 kton water Cerenkov located 295 km away is used to detect the oscillated neutrinos. The ND280 site, 280m from the beam source, houses a suite of detectors needed to measure the beam flux and ν_e appearance backgrounds.

Beamline

Protons are extracted from the J-PARC 30 GeV main ring in six bunches (to be increased to eight) to the neutrino beam-line's graphite target at a cycle time of 3.5 seconds. A schematic of the beam-line is shown in Figure 1. The proton beam generates pions from the target. These pions are then focused by three magnetic horns operated at 250-kA (to be increased to 320-kA). Almost all of the pions decay in the decay volume into muons and muon neutrinos. All particles other than neutrinos are absorbed by the beam dump. The expected ν_e contamination from this beam-line configuration, at oscillation maximum, is expected to be 0.4%. The neutrino beam is monitored by the on-axis INGRID (Interactive Neutrino GRID) detector and the ND280 off-axis detector.

Near Detector(ND280) Suite

ND280 is shown in Figure 1. INGRID has seven vertical and horizontal modules interleaved with planes of iron and segmented scintillator. The primary purpose of

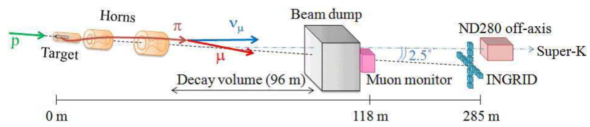

FIGURE 1. Schematic view of the off-axis T2K neutrino beam-line and the near detector suite(ND280).

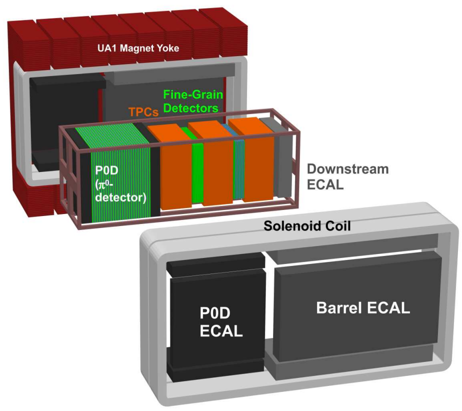

FIGURE 2. Schematic of off-axis ND280 Detectors.

the INGRID is to monitor the beam profile and stability using neutrino interactions. The ND280 off-axis detector (see Figure 2) is a hybrid detector designed to provide measurements of the ν_μ spectrum and the dominant $\sin^2 2\theta_{13}$ backgrounds from the ν_e beam contamination and neutral current π^o production. Initially the statistical errors will dominate but the systematic errors will become important at approximately total POT of 2×10^{21}.

The off-axis sub-detectors include the upstream "Pi-Zero Detector" (P0D) which has alternating scintillator planes and water target modules. It is optimized to measure the neutral current π^o production background in water. Downstream of the P0D are two fine grained detectors(FGD) used as active neutrino targets. The momentum of the produced muons are measured using three interleaved time projection chambers(TPCs) instrumented with MicroMegas. The TPCs also measure $\frac{dE}{dx}$ and are used for particle identification and will measure ν_μ and ν_e beam fluxes. Surrounding these inner-detectors are electromagnetic calorimeters (ECAL) used to measure energy of particles that exit the sides of the P0D and FGD. In addition the entire suite of off-axis detectors are placed inside a 0.2T field produced by the recycled UA1 magnet from CERN. The magnet is instrumented with planes of scintillator called the SMRD (Side Muon Range Detector). The SMRD is used to veto neutrino interaction magnet events, detect wide angle muons from inner detector neutrino interactions, and to trigger on cosmic rays events for calibration. Other than the TPCs all detectors use Hamamatsu Multi-Pixel Photon Counters(MPPCs)[2] as their photo-sensors and is the first large scale (∼30,000 channels) use of these devices in an HEP experiment. The failure rate during the first run was less than 0.1%.

Super-Kamiokande(far) Detector

Super-Kamiokande is a 50-kt(22.5-kt fiducial) mass ring-imaging water Cherenkov detector. It is located in the Kamioka mine at a depth of 2,700-m water equivalent. The detector consists of two optically separated concentric cylindrical regions. The J-PARC beam timing and synchronization is achieved by means of a GPS system with a timing resolution of 26ns.

Super-K distinguishes muons and electrons by analyzing the sharpness of the Cherenkov ring edges. The probability of misidentification of muons as electrons is $< 0.1\%$ for T2K neutrino energies. Therefore, the signal can be clearly seen by selecting one-ring electron-like events in CCQE samples. Possible signal background events can result from high-y CC ν_μ interactions that produce a π^0 and NC π^0 events ($\nu_\mu + N \rightarrow \pi^0 + N'$). In general the π^0can be identified by two electron-like rings from its decay into two photons. However, if one of the photons is missed, the event will mimic the signal. Therefore a major goal of the off-axis near detectors is to measure this background.

PRELIMINARY RESULTS

The first neutrino physics run was January-June, 2010; an integrated POT of 3.35 $\times 10^{19}$ was collected. The average continuous power was $\sim 50kW$ with trial shots up to $100kW$. All detectors except for the barrel ECAL (installed in Fall, 2010) were operational. Experimental lifetimes for Super-K and ND280 were $>$99% and $>$96% respectively.

As a result of this exposure 23 fully contained events were observed in the Super-K fiducial volume. The timing of these events with respect to the six beam bunches is shown in Figure 3 and clearly shows the expected correlation and is consistent with the GPS timing resolution. The stability of the beam was monitored by the INGRID detector as a function of time and a plot covering the full run period is shown in Figure 4. The requirement that the variation of beam center be less than $\pm 28.5cm$ $(\pm 1mr)$ was met. Thousands of neutrino interactions where observed in the off-axis detectors with dead channel counts less than 0.4%. The event timing distribution for FGD interactions is shown in Figure 6 and shows a clear cor-

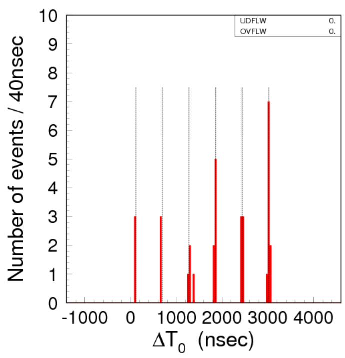

FIGURE 3. Times of Super-K events (in red) superimposed over expected beam bunch timing.

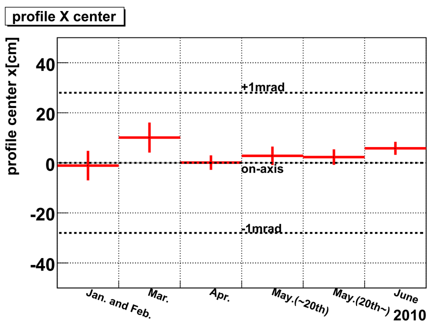

FIGURE 4. Beam center, X projection, as function of time during the 2010 physics run.

relation with the expected six beam bunches. An example interaction originating in the P0D is shown in Figure 5.

CROSS SECTIONS

The most precise oscillation measurement comes from a solid cross section determination in ND280 as an important cross check of backgrounds. ND280 will provide

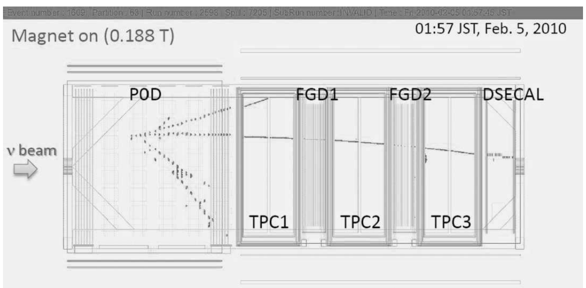

FIGURE 5. North side view of neutrino interaction originating in P0D from 2010 physics run.

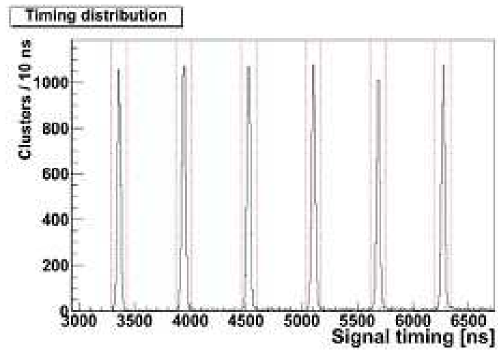

FIGURE 6. Distribution of FGD event time stamps overlaid on expected bunch timing(red vertical bands).

many cross section measurements for ν_μ of about 750 MeV energy. At this energy, the quasielastic and pion production reactions have the largest rates. With simple cuts, the P0D and FGD produce a few $\times 10^5$ quasielastic events and few x 10^4 events in each of a number of 'regular' pion production channels for accumulation of 10^{21} POT (expected in the next $\sim$ 3 years). The number of coherent pion production events is smaller by more than a factor of 10. Data taken in the first run period has a few thousand events in the high rate reactions. Present efforts are focussed on tracking and reconstruction of charged particles and π^0's and beam flux measurements. Various beam monitors are expected to produce measurements with about 20% systematic error for the upcoming run.

SUMMARY AND FUTURE PLANS

T2K is a high intensity off-axis long-baseline neutrino experiment designed to study $\nu_\mu \to \nu_e$ oscillations. The ND280 detectors are required to maximize physics reach and sensitivity. The first physics run period was from January untill June of 2010. All installed detectors worked as designed. A second run is scheduled to commence in November 2010 with a goal of $150 kW \times 10^7 sec$ integrated power by July 2011.

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