Status of the T2K 280m Near Detector

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The Tokai-to-Kamioka (T2K) long-baseline neutrino-oscillation experiment is being prepared for start of operations in Fall 2009. The purpose of T2K is to measure the oscillation parameters from an intense $\nu_\mu$ beam. In order to make precision measurements of $\nu_\mu$ disappearance a new detector complex (ND280) will be used to identify the profile and composition of the neutrino beam near its production site. ND280 will also be used to study important background processes in the measurement of a $\nu_e$ appearance signal at Super-K. We will describe the physics goals and technology choices of ND280.

1. INTRODUCTION

T2K is a long-baseline neutrino oscillation experiment based in Japan. The goal of T2K is to precisely measure the oscillation parameters associated with $\nu_\mu$ disappearance and search for evidence of $\nu_e$ appearance. T2K will use a narrow-band off-axis beam of $\nu_\mu$ generated from the 50 GeV proton synchrotron of the new JPARC facility. The beam will be pointed 2.5$^\circ$ off-axis from the upgraded Super-Kamiokande detector. Using an off-axis beam results in a neutrino energy spectrum that is narrowly peaked at 600-700 MeV, which is near the oscillation maximum for the 295 km baseline from JPARC to Super-Kamiokande.

With an integrated beam intensity of $5 \times 10^{21}$ protons on target, the T2K experiment will be capable of determining the oscillation parameters relevant to the muon neutrino disappearance with a high precision of $\approx 10^{-4}$ eV$^2$/c$^4$ and $10^{-2}$ for $m_{23}^2$ and $\sin^2 2\theta_{23}$, respectively. The measurement of $\nu_e$ appearance in the same data sample is expected to improve the sensitivity to $\sin^2 2\theta_{13}$ by an order of magnitude compared to the current upper limit, reaching $\approx 0.008$ for CP violating phase $\delta_{CP} = 0$.

The oscillation parameter measurements will be derived from measurements of the rates and spectrum of $\nu_\mu$ and $\nu_e$ seen in Super-Kamiokande. However, in order to reach the design sensitivity, we must make precise measurements of the neutrino flux and spectrum before any oscillations have occurred, i.e., measurements near the production site. To this end we are building a new detector facility, called the Near Detector at 280m (ND280 for short). This facility is located at JPARC, at 280 m from the beam target. In what follows we will introduce the ND280 facility, as well as describing the physics goals and detector technologies choices of ND280. We will conclude with the current status and near-term future of ND280.

2. ND280

There are two different neutrino detectors in the ND280 pit. The first of these is INGRID, which is a scintillator-based detector that is centred on the axis of the neutrino beam. This detector is designed to provide rapid feedback to the beamline operations group concerning the flux and position of the neutrino beam.

The second detector is the ND280 off-axis detector, which sits in the direction of Super-Kamiokande, as seen from the average neutrino production point. Figure 1 shows the off-axis detector in more detail. We have re-used the UA1 magnet, which has been refurbished and shipped to Japan. As seen from the diagram, there are five different detection sub-systems in this detector; a set of Time Projection Chambers and four scintillator based sub-detectors.

2.1. Physics Goals of ND280

In order for T2K to succeed, ND280 must provide the following physics input:

• Measurement of unoscillated $\nu_\mu$ flux and spectrum, both on-axis and off-axis (towards Super-Kamiokande).
• Measurement of small $\nu_e$ flux that is intrinsic to beam (0.5% $\nu_\mu$ flux).

• Measurement of differential rates and characteristics of various neutrino interaction modes.

As noted above, the ND280 facility consists of a number of different sub-systems. Different parts of the detector have been optimized in order to make different measurements. Many of the measurements can be made in a complementary fashion with different parts of ND280. In what follows we shall explain two of the different measurements that will be made with ND280. These two examples do not cover the totality of what ND280 can achieve; rather they are merely to give a sense of the measurements that will be performed.

2.1.1. CCQE $\nu_\mu$ Interactions

At the peak energy of the T2K off-axis beam the most probable interaction mode for $\nu_\mu$ is the Charge Current Quasi-Elastic (CCQE) interaction:

$$\nu_\mu + n \rightarrow \mu^- + p.$$  

This is a clean interaction mode to reconstruct, since the initial neutrino energy can be approximately reconstructed from the muon alone. This is the interaction mode that Super-Kamiokande uses for measuring the $\nu_\mu$ flux and spectrum.

The Tracker section of the ND280 detector consists of the three TPCs interleaved with the two FGDs. The Tracker has been optimized for making measurements of CCQE interactions. The FGDs, which provide the target mass for the interactions, are narrow in the beam direction, which means that a large fraction of the charged products from CCQE interactions enter the TPCs. The TPCs will provide excellent tracking and particle identification for charged tracks that enter it and the FGD will provide decent particle identification for shorter tracks that don’t enter the TPC (such as lower energy protons). The Tracker is therefore well-adapted to measuring all the products of CCQE interactions. In addition, the surrounding ECAL will provide information that will allow the rejection of events that might mimic CCQE interactions.

Note that one FGD is all plastic scintillator, but the other FGD interleaves plastic scintillator planes with water planes. The partial-water FGD will allow us to extract the CCQE reaction rates on water, which is important since Super-Kamiokande is a water-based detector.

2.1.2. Neutral Current $\pi^0$ $\nu_\mu$ Interactions

Another important interaction mode is the Neutral Current $\pi^0$ interaction:
Measuremement of the rate of this interaction is crucial, because this mode is an important background for $\nu_e$ measurements at Super-Kamiokande (if one gamma from $\pi^0$ is missed by Super-Kamiokande, then the event looks like a $\nu_e$ interaction). We must therefore carefully measure the rate and characteristics of this interaction. The P0D detector has large target mass and lead radiators, which allows it to efficiently reconstruct EM showers from $\pi^0$. The P0D in combination with the surrounding ECAL will therefore be capable of making clean measurements of Neutral Current $\pi^0$ interactions. Note that the P0D, like the FGD, has a water target to allow the extraction of the relevant reaction rates on water.

3. ND280 TECHNOLOGY CHOICES

3.1. Time Projection Chambers

The three Time Projection Chambers are part of the Tracker section of the ND280 detector. The overview of a single TPC is shown on the left side of Figure 2. Each TPC has two inner drift volumes separated by a central cathode. This is surrounded by an outer box holding CO$_2$ gas that serves as an insulator.

When a charged particle passes through the TPC it will create ionization electrons, which will then drift to the readout planes on the sides of the TPC. Measurement of the drift time, combined with the position of the pad that the electrons drift to, allows for excellent 3D reconstruction of each charged particle. Precise 3D tracking, combined with the 0.2 Tesla magnetic field, results in TPCs that will achieve momentum resolution of better than 10% for particles with momenta below 1 GeV/c.

The T2K TPC uses $\mu$MEGAS modules for the electron amplification and readout. An example of a T2K-TPC $\mu$MEGAS is shown on the right side of Figure 2. The capacity to produce such large $\mu$MEGAS was the result of a significant amount of development work. For electronic readout of the $\mu$MEGAS the TPC group developed a custom ASIC that provides a 511 deep switched capacitor array. The information from this switched capacitor array is digitized, zero suppressed and then transferred off-magnet over a fibre optic link. The data readout is a challenge, because there are $\approx 100,000$ channels of $\mu$MEGAS data for the full TPC. This data readout chain was copied and used by the FGD sub-detector.
3.2. Scintillator Sub-Detectors

Five of the six ND280 sub-detectors use scintillators as the active medium. In general, we use long, thin scintillator bars arranged into layers; sets of layers with different orientations allows for 3D reconstruction of tracks and showers. Scintillation light from the bars is retransmitted by wave-length shifting fibres to photosensors.

The ND280 group has chosen to use Multi-Pixel Photon Counters (MPPCs) for all of our photosensors (≈50,000 required). These particular devices are made by Hamamatsu; but MPPCs are part of a broader family of devices based on arrays of silicon photodiode pixels. Each pixel operates above its breakdown voltage (approximately 70V) and can produce an avalanche of electrons if struck by a photon. An MPPC therefore provides the single photon counting capability and electronic gain of a traditional PMT. An MPPC is superior to a PMT in terms of costs; in addition an MPPC will work well in a magnetic field, meaning we can place our photosensor right inside our detector. The left side of Figure 3 shows an MPPC. Since MPPCs are new devices, the ND280 group has gone through an extensive period of research and testing. We believe that we have a firm understanding of the crucial characteristics of these devices, such as the dependence of the breakdown voltage on temperature and their long-term stability.

In addition to the photosensors, a great deal of other work was involved in the construction of the scintillator based detectors. In particular, extensive effort has been made on the development of the electronics readout of the MPPCs. Most of the sub-detectors used an ASIC called the Trip-T for electronic readout (the Trip-T was originally developed at Fermilab for the D0 experiment); this chip provides time and charge for any discriminated pulses. The right side of Figure 3 shows an example of one of the front-end boards that houses these Trip-T chips; in addition to the electronics readout, these boards also provide the high voltage to the MPPCs, as well as environment monitoring. Approximately 1100 of these boards will be produced.

4. CURRENT STATUS AND CONCLUSIONS

The ND280 group is making rapid progress towards the construction and installation of all sub-detector components. The large pit at JPARC that houses the ND280 facility is now complete and work is progressing on installing all the required services. Refurbishment and transportation of the UA1 magnet is now complete and the magnet is installed in the ND280 pit. By April 2009 the INGRID detector will be installed, in time for the first neutrino events provided by JPARC. All other sub-detectors are in production at this moment and extensive commissioning (including beamline tests) is proceeding for many groups. All sub-detectors will be installed at ND280 by Fall 2009.