

The T2K Experiment

Kate Scholberg, for the T2K collaboration

Department of Physics, Duke University, Durham, NC, 27708

E-mail: schol@phy.duke.edu

Abstract. This talk will describe briefly the physics goals of the Tokai to Kamioka (T2K) experiment, and its current status and prospects.

1. The Quest for θ_{13}

In the current standard three-flavor picture of neutrino oscillations, the neutrino flavor states are related to the mass eigenstates by a 3×3 unitary mixing matrix, the Maki-Nakagawa-Sakata (MNS) matrix. A consequence of this framework is that neutrinos oscillate in flavor as they propagate, with transition probabilities dependent on the differences between the squares of the masses of the states (Δm_{ij}^2), the MNS matrix elements, and the energy of the neutrino. The MNS matrix can be parameterized using three mixing angles, θ_{12} , θ_{23} and θ_{13} , and a CP-violating phase δ (and two Majorana phases, unobservable in oscillation experiments). The first two mixing angles have been measured by solar/reactor and atmospheric/beam oscillation measurements, respectively; the third, θ_{13} , is known to be small from the CHOOZ reactor experiment results[1], which are consistent with atmospheric neutrino oscillation[2] and beam[3, 4] studies. The two mass-squared differences are also known; however the pattern of masses (as well as the absolute mass scale) are unknown. The CP phase is also unknown. The next step for oscillation physics is the measurement of the unknown mixing angle θ_{13} .

Globally, there are two experimental strategies for determining θ_{13} . First, one may look for disappearance of few-MeV reactor $\bar{\nu}_e$ on a \sim km distance scale: several experimental programs are taking this approach[6, 7, 9]. Alternatively, one may look for an appearance signal of ν_e in a GeV ν_μ beam on a few-hundred km distance scale. The first-generation long-baseline beam experiments, K2K[3] and MINOS[4, 5], have searched for non-zero θ_{13} ; to go further requires a higher intensity beam. The next experiments to tackle ν_e appearance are T2K, NO ν A[10], and LBNE[8].

2. The Long Baseline Beam Approach

The ν_e appearance probability is approximated by $P(\nu_\mu \rightarrow \nu_e) \sim \sin^2 2\theta_{13} \sin^2 \theta_{23} \sin^2 \left(\frac{\Delta m_{23}^2 L}{4E_\nu} \right)$, where E_ν is the energy of the neutrino; this expression holds in vacuum for $\Delta m_{23}^2 \gg \Delta m_{12}^2$, and $E_\nu \sim L\Delta m_{23}^2$, $\delta = 0$. The oscillation is driven by the ‘‘atmospheric’’ Δm^2 ; from the known limit on θ_{13} , the appearance amplitude cannot be more than about 7%. Therefore good statistics and a clean sample are both needed to observe an appearance signal of non-zero θ_{13} . For a baseline of \sim 300 km, the first oscillation maximum is at around 600 MeV.

To make a \sim GeV neutrino beam, one accelerates protons, collides them with a target, and focuses the produced mesons forward with magnetic horns; the mesons (primarily pions) are

then allowed to decay in a long pipe via $\pi \rightarrow \mu + \nu_\mu$. The neutrino beam is sampled at a near detector before propagating to a far detector. Two on-axis beam experiments, K2K and MINOS, have already observed long-baseline ν_μ disappearance oscillations[12, 13]. Two next-generation long baseline oscillation experiments, T2K and NO ν A, will improve their sensitivity to oscillations via clever configuration of beam and detector: they will site their detectors slightly off beam axis. According to two-body decay kinematics, at locations few degrees off beam-axis, neutrino energy becomes relatively independent of pion energy. The neutrino spectrum is then more sharply peaked, which allows enhanced flux at the oscillation maximum and reduction of backgrounds from off-peak tails of the spectrum.

3. The T2K Experiment

The T2K experiment[11] is the first off-axis long-baseline neutrino oscillation experiment, employing a high-intensity beam from the J-PARC facility in Tokai (designed eventually to achieve 750 kW beam power) sent to the 22.5 kton fiducial mass Super-Kamiokande (Super-K) water Cherenkov detector 295 km away in Kamioka. The experiment also includes a number of components deployed near the neutrino source for beam characterization: a muon monitor, an on-axis near detector (the INGRID), and an off-axis suite of detectors (the ND280).

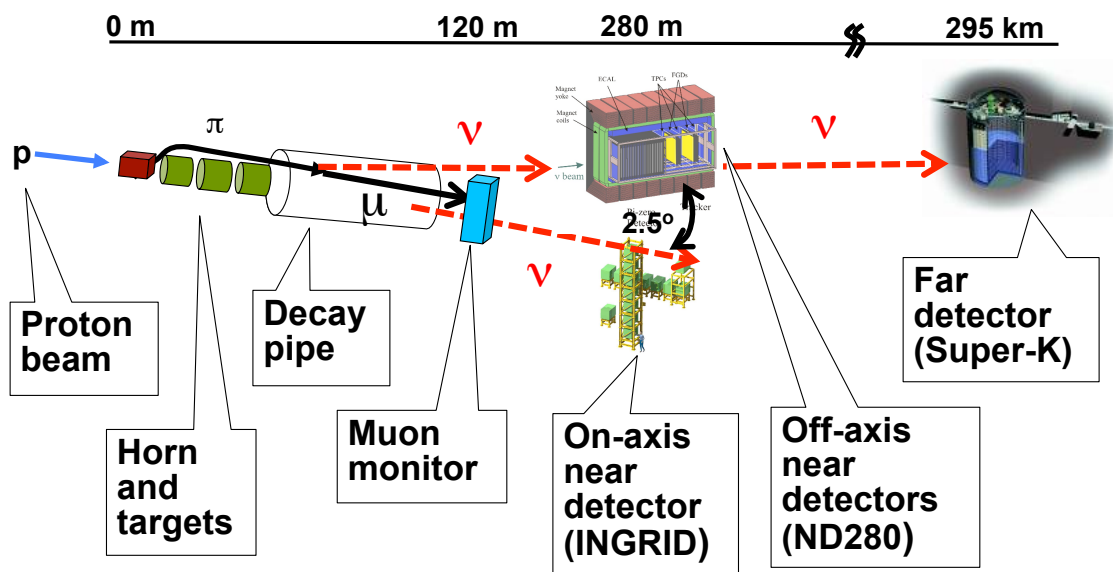


Figure 1. Components of the T2K experiment.

3.1. Neutrino Beamline

Protons for T2K are extracted from the J-PARC 30 GeV main ring proton synchrotron. The neutrino beam target station includes a graphite target and three magnetic horns for parent meson focusing. A muon detector monitors muon flux at 120 m from the target. For the first running period, there were 6 bunches per spill, with spills every 3.5 seconds; the rate has been increased to 8 bunches per 5 μ s spill, and 3.2 seconds between spills. Spills are matched to events at Super-K using GPS timing. The beam energy spectrum peaks at about 600 MeV, which is optimized for oscillation sensitivity.

3.2. Near Detectors

The on-axis detector, the INGRID, comprises an iron target and scintillator active elements, and is used for beam profile monitoring; the first run's results indicated good beam alignment.

The off-axis detector complex at 280 m employs fine-grained trackers inside a 0.2 T magnetic field (provided by the relocated UA1/NOMAD magnet). The off-axis detectors are used for flux normalization, background characterization for oscillation physics, and cross-section studies. Three time projection chambers instrumented with Micromegas are interleaved with two mixed plastic-scintillator/water fine-grained detectors read out by multi-pixel photon counters. (The TPCs were described in more detail in a separate contribution to this symposium.) These tracking detectors are designed to determine ν_e and ν_μ flux and spectrum for extrapolation to Super-K. A "POD" module and downstream and barrel electromagnetic calorimeters are also installed. The POD consists of water target and scintillator planes and is designed for measurement of neutral current π^0 production. Additionally the magnet yoke is instrumented with scintillator detectors. Installation of all near detector components was complete by summer 2010. Please see references [14, 15] for more detailed description of the near detectors and their capabilities.

3.3. Far Detector

The far detector, Super-K[16], has been running as "Super-K-IV" since 2008, with a full complement of 11,000 photomultiplier tubes and completely refurbished electronics. In Super-K, the signature of ν_e appearance is an excess of charged-current quasi-elastic events, $\nu_e + n \rightarrow p + e^-$, in the expected energy range; these interactions manifest themselves in a water Cherenkov detector as single fuzzy rings (electron showers appear fuzzy because electrons scatter and shower, in contrast to ν_μ -induced muon rings which appear sharp). Understanding of backgrounds is critical to the measurement: dominant backgrounds are intrinsic beam ν_e contamination, misidentified μ -like events, and neutral-current π^0 events for which the double gammas from $\pi^0 \rightarrow \gamma\gamma$ are not distinguished from single electron showers.

4. First Data

First beam arrived in 2009, and production running began in early 2010. Over the first running period, through June 2010, stable operation at 50 kW beam power was achieved, and a total of 33×10^{18} protons on target (pot) were delivered (see Fig. 2). The second running period started in November 2010; at the time of this conference contribution, 114 kW had been achieved. The aim is for 150 kW $\times 10^7$ seconds by mid-2011.

The first long-baseline T2K beam event observed in Super-K occurred in February 2010. Beam neutrinos at SK are divided into several subsamples: fully-contained events have light in SK's inner detector (ID) only; outer detector (OD) events have light in SK's outer veto (they can be entering, exiting, or contained in the OD); low energy fully-contained events are selected to search for neutral current nuclear excitation events. During the first running period, 33 fully-contained events were observed in the beam window. The time structure of the observed events is consistent with the beam bunch structure: see Fig. 3. The updated data sample for the second running period has an SK event rate per pot consistent with the first running period.

5. Status and Prospects

T2K construction is complete, and near and far detectors are running well.

The eventual aim of the T2K experiment, for running of 750 kW times (5×10^7 s), is for a sensitivity to $\sin^2 2\theta_{13}$ between $2 - 15 \times 10^{-3}$ (depending on δ and the mass hierarchy) at the current best measured value of Δm_{23}^2 . See Fig. 4.

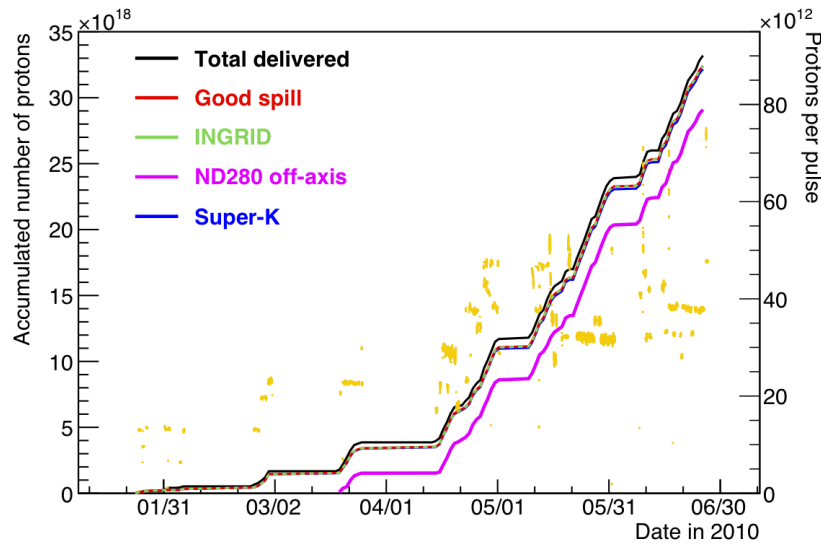


Figure 2. Delivered protons on target for the first T2K running period.

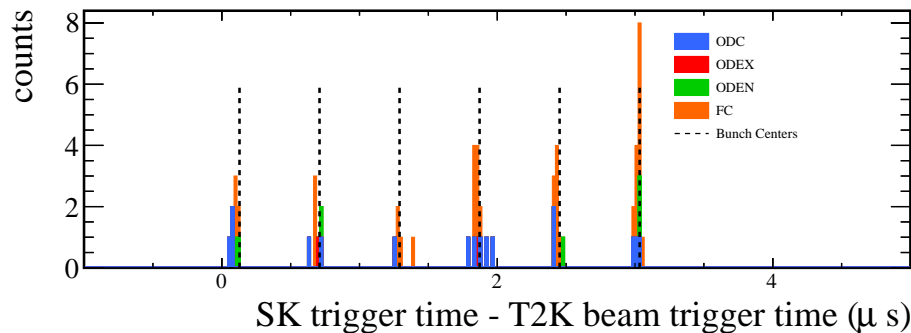


Figure 3. Time difference between the Super-K event trigger and the T2K beam trigger for the first T2K running period for beam events passing neutrino selection cuts. The plot includes different categories of events with light in the OD as well as FC events.

References

[1] M. Apollonio *et al.* [CHOOZ Collaboration], Phys. Lett. **B466**, 415-430 (1999). [hep-ex/9907037].
 [2] R. Wendell *et al.* [Super-Kamiokande Collaboration], Phys. Rev. **D81**, 092004 (2010). [arXiv:1002.3471 [hep-ex]].
 [3] S. Yamamoto *et al.* [K2K Collaboration], Phys. Rev. Lett. **96**, 181801 (2006) [arXiv:hep-ex/0603004].
 [4] P. Adamson *et al.* [MINOS Collaboration], Phys. Rev. Lett. **103**, 261802 (2009) [arXiv:0909.4996 [hep-ex]].
 [5] P. Adamson *et al.* [The MINOS Collaboration], Phys. Rev. D **82**, 051102 (2010) [arXiv:1006.0996 [hep-ex]].
 [6] F. Ardellier *et al.* [Double Chooz Collaboration], [hep-ex/0606025].
 [7] W. Wang [Daya Bay Collaboration], AIP Conf. Proc. **1222**, 494-497 (2010). [arXiv:0910.4605 [hep-ex]].
 [8] <http://lbne.fnal.gov/index.shtml>
 [9] J. K. Ahn *et al.* [RENO Collaboration], [arXiv:1003.1391 [hep-ex]].
 [10] R. E. Ray, J. Phys. Conf. Ser. **136**, 022019 (2008).
 [11] Y. Itow *et al.* [hep-ex/0106019].
 [12] M. H. Ahn *et al.* [K2K Collaboration], Phys. Rev. **D74**, 072003 (2006). [hep-ex/0606032].
 [13] P. Adamson *et al.* [MINOS Collaboration], Phys. Rev. Lett. **101**, 131802 (2008) [arXiv:0806.2237 [hep-ex]].
 [14] <http://www.nd280.org/info>

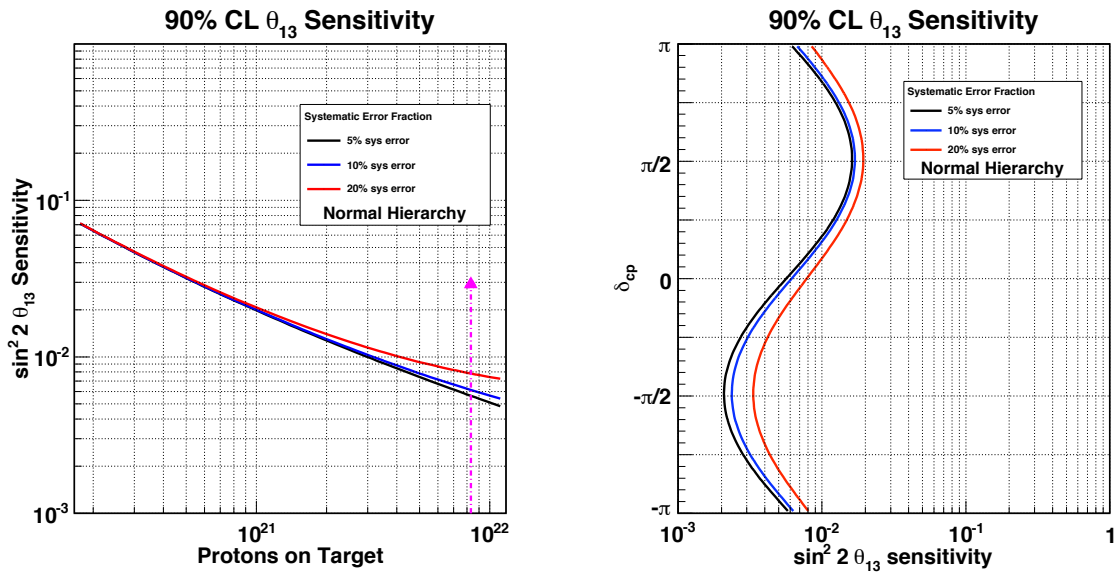


Figure 4. Left: T2K sensitivity to θ_{13} at the 90% confidence level as a function of protons on target. 5%, 10% and 20% systematic error fractions are plotted. The dashed arrow indicates a 5-year run. The following oscillation parameters are assumed: $\sin^2 2\theta_{12} = 0.8704$, $\sin^2 2\theta_{23} = 1.0$, $\Delta m_{12}^2 = 7.6 \times 10^{-5} \text{eV}^2$, $\Delta m_{23}^2 = 2.4 \times 10^{-3} \text{eV}^2$, $\delta_{CP} = 0$, normal hierarchy. Right: T2K sensitivity to θ_{13} at the 90% confidence level as a function of δ_{CP} . Beam is assumed to be running at 750 kW for 5 years, using the 22.5 kton fiducial volume SK detector. 5%, 10% and 20% systematic error fractions are plotted. The following oscillation parameters are assumed: $\sin^2 2\theta_{12} = 0.8704$, $\sin^2 2\theta_{23} = 1.0$, $\Delta m_{12}^2 = 7.6 \times 10^{-5} \text{eV}^2$, $\Delta m_{23}^2 = 2.4 \times 10^{-3} \text{eV}^2$, normal hierarchy.

[15] C. Hearty and E. Mazzucato [T2K/TPC Collaboration], J. Phys. Conf. Ser. **136**, 042036 (2008).

[16] Y. Fukuda *et al.*, Nucl. Instrum. Meth. A **501**, 418 (2003).