The T2K beam line and near detectors

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Abstract. The goal of the Tokai-to-Kamioka (T2K) experiment is to measure the last undiscovered neutrino oscillation parameter θ_{13} and determine precisely the value of θ_{23} and Δm^2_{23}. This proceeding describes the T2K baseline and emphasises on the role of the beam line and near detectors. Performances of the on-axis neutrino beam flux monitor and off-axis neutrino detector system are presented.

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THE T2K EXPERIMENT

Tokai-to-Kamioka (T2K)[1] is a long baseline neutrino experiment aimed to look at $\nu_\mu \rightarrow \nu_e$ oscillations. T2K will use the Proton Synchrotron (PS) beam from JPARC, the new accelerator complex currently being built on the east coast of Japan. A intense 0.75 MW ν_μ beam will be created and directed towards the Super Kamiokande (SK) water Čerenkov detector [2], located 295 km away in the Kamioka mine. The detailed configuration of the experiment is show in Fig. 1. Several beam upgrades are being considered and a beam power of 1.34 MW is expected to be reached by 2012 making T2K the first super-beam neutrino experiment of its generation. To enhance further the measurements, the beam will be sent slightly off-axis ($2-2.5°$) narrowing the energy spread around the peak energy (650 MeV) and decreasing significantly the beam content of other neutrino flavours without compromising the beam flux.
The main goals of T2K are the precise measurement of the oscillation parameters Δm^2 and θ_{23} and the search for a non-zero θ_{13}. An integrated luminosity of 10^{21} proton on target per year will allow for a high statistics measurement of Δm^2 and θ_{23} through the observation of the deficit of ν_μ Charge Current Quasi-Elastic events (CCQE). The sensitivity on $\sin^2\theta_{13}$ is expected to be improved by a factor of ten from the current limit. For both measurements, main uncertainties will come from neutrino beam energy spectrum, cross-section and background measurement. These quantities will be measured before oscillation by a near detector (ND280) and extrapolated at the far detector. The requirements for the systematic uncertainties are :

1. SK ν_e backgrounds is less than 10%
2. ν_μ Event normalisation : 5%
3. Energy scale better than 2%
4. Beam width < 10%
5. Non-QE/QE ratio : 5-10%

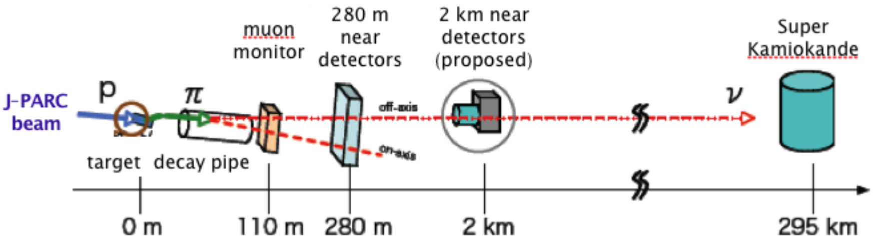


FIGURE 1. A simplified schematic of the T2K baseline. The figure shows the main beam line components, the off-axis configuration of the experiment and the respective distance of near and far detectors.

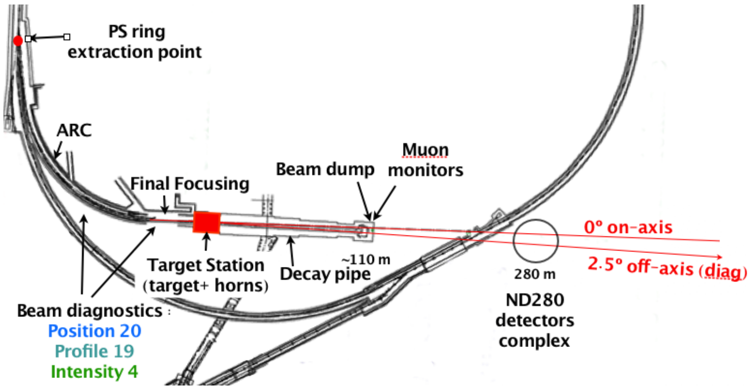


FIGURE 2. Top view of the J-PARC neutrino beam line.

J-PARC NEUTRINO BEAM LINE

The JPARC PS ring has been designed to produce a high intensity 50 GeV proton beam and the current plan is to start with an energy of 30 GeV. The ν_μ neutrino beam is created using the method of producing pions from proton-Carbon reactions. As shown in figure 2, the proton beam is extracted and bent inside the PS ring in the ARC section. The ARC is composed of dual-function, super-conducting magnets ensuring the tight bending of the proton beam in the direction of the target station. A final focusing section instrumented with beam monitors will ensure that the beam is well aligned with the target. The pion production target is a graphite rod, cooled with Helium gas designed to stand the 0.75 MW beam power. Development of a target required for the 1.34 MW beam power upgrade is ongoing. A system of 3 horns focuses the pions to the He gas filled decay pipe. The target will be placed in the first horn to maximise the flux of pions focused. At the end of the decay pipe, a beam dump composed of graphite blocks cooled with aluminium water pipes is installed. All remaining protons, pions and low energy muons will be stopped in the beam dump. The flux of high energy undecayed muons (above 5 GeV) will be monitored by an array of radiation hard sensors (MUMON) located behind the beam dump. This measurement will give the muon beam position and profile on a spill to spill basis.

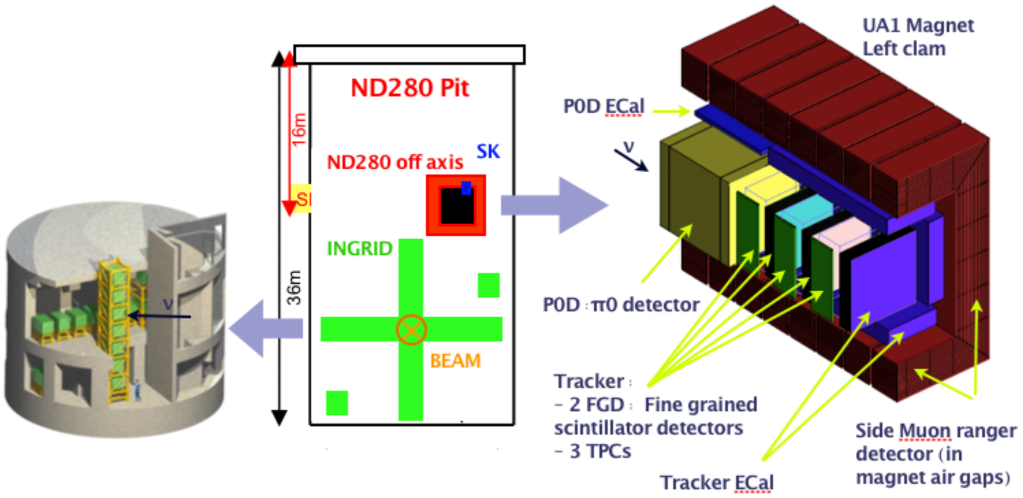


FIGURE 3. A cross-section view of the 280 m pit with schematics of the INGRID on the left and the ND280 on the right. The ND280 right clam of the magnet and associated calorimeter modules is not represented for clarity.

THE 280 M DETECTOR COMPLEX

At a distance of 280 m from the target, the near detectors will perform various measurements of the on-axis and off-axis beam. Figure 3 shows a cut view of the 280 m pit with the respective positions of the on-axis beam monitor (INGRID) and the off-axis detector system (ND280).

The On-axis neutrino beam monitor : INGRID

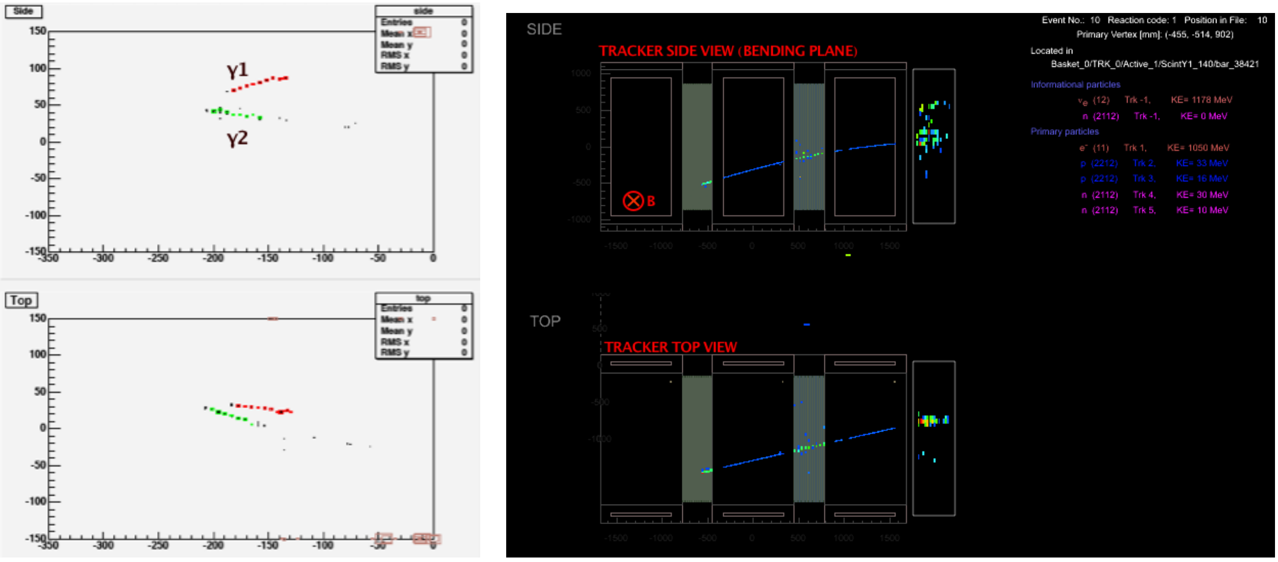
The "Interactive Neutrino GRID" or INGRID tasks are the measurements of the beam direction, intensity and mean energy using neutrino interactions. It is composed of 14 modules forming a "cross" centred on the beam axis with 2 additionnal modules covering bottom left and upper right diagonals. Each module is composed of 11 alternated scintillator planes and thick iron plates (64 cm x 100 cm x 100 cm). Veto planes will be installed on each transverse face of the module. INGRID has been designed to provide sufficient statistics to determine on a day-to-day basis, the beam direction within 1 mrad corresponding to a 2% (14 MeV) shift in the off-axis beam spectrum. It will be able to resolve better than 1 mm beam displacement at the target.

Off-axis near detector : ND280

The ND280 consists of the UA1 magnet and a set of sub-systems installed in the 3.5 m x 3.6 m x 7 m inner region of the magnet. A 0.2 T dipole field will be operated to measure momentum and identify the sign of charged particles from the curvature of the tracks. The detector is divided into two regions : The P0D and the Tracker region (see right schematic in figure 3 for details). Both regions comprise target volume based on scintillators with good resolution on vertex and proton recoil. The total number of scintillator channels is around 50000. Because SK is a water target, a significant fraction of the ND280 fiducial volume (40 to 50%) will be replaced with passive water modules to determine C/$H_2$0 cross-section differences.

P0D region Upstream of the UA1 magnet is located the Pi-zero Detector (P0D). This detector is optimised for measuring the rate of Neutral Current (NC) π^0 events which is the main background for the appearance measurement at SK. It consists of 40 X-Y scintillator bars tracking planes interleaved with thin Lead sheets. The Lead enhances γ conversion close to the vertex allowing for maximum efficiency of π^0 event reconstruction. A coarse calorimeter plane (P0DECAL) is installed around the P0D to catch escaping γ and to tag muons and pions going side ways.
A rate of $1.7x10^4$ NC-1π^0 interactions is expected in the 6 T fiducial mass. According to current simulations a total of 6000 π^0 will be reconstructed per year (see an example of a P0D events Fig. 4 (a)). The P0D will also provide information on inclusive NC/CC production and beam ν_e.

Tracker region Downstream of the P0D is the tracker region composed of 2 fine grained detectors (FGD) acting as active target with 3 Time Projection Chambers (TPC). There is a fine grained calorimeter (Barrel) installed on the inner faces of the UA1 magnet and downstream of the tracker.
The tracker is designed to measure CCQE events and CC-1π events with high purity. The Reconstruction of ν_μ CCQE interaction will give a a precise measurement of the ν_μ energy spectrum before oscillation and will serve as a normalisation for other non-QE events. Around 40000 ν_μ CCQE and 2000 beam ν_e CCQE events are expected per ton of FGD at nominal 5 years exposure. Figure 4 shows a typical ν_e neutrino events in the tracker region. To range out sideways muons, air gaps of the UA1 magnet have been instrumented with scintillator planes (SMRD). The SMRD will also provide a cosmic trigger for calibration purpose. The rate of CC-1π^+ will be measured precisely by combining TPC tracks curvature and PID information from the calorimeter. The tracker will also provide another measurement of NC-1π^0 by reconstructing γ shower in the calorimeter and pointing back to the π^0 decay point.
The expected performance of the Tracker and calorimeter is shown in figure 5. The size of the FGD scintillator bar is 1 cm x 1cm x 2m providing a excellent granularity to reconstruct the interaction hadronic system. It will also provide useful dEdx information to separate proton and pions for small tracks. The TPC will measure the momentum of the charged particle with a resolution better than 10% below 1 GeV and will help distinguishing electron from muon and pion.



(a)

(b)

FIGURE 4. (a) Reconstructed NC-1π^0 events in the P0D. Both γ narrow electromagnetic showers are clearly identified. (b) Simulation of a typical ν_e CCQE events in the tracker region. The interaction has occurred in the first FGD target volume and the outgoing electron can be seen going through the second FGD and TPC and showering in the downstream ECAL.

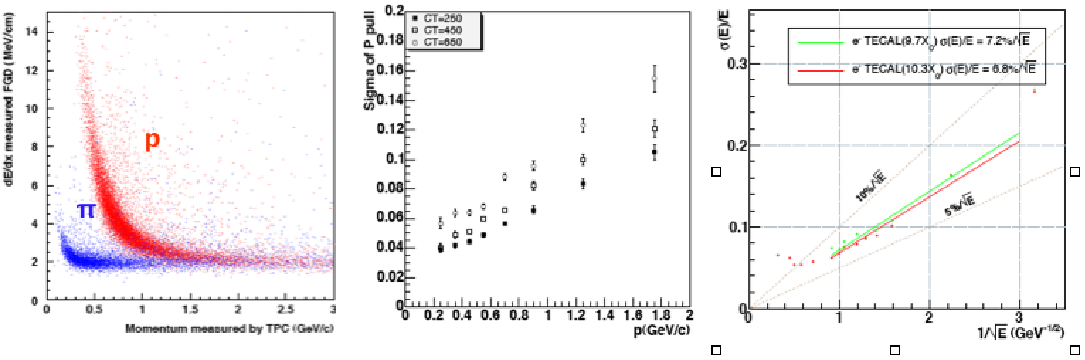


FIGURE 5. On the left, 2D plot of pion and proton TPC track momenta versus dEdx in the FGD. The Middle plot shows track momentum resolution as function of muon momentum in the TPC. Different points corresponds to different value of transverse diffusion coefficient CT. On the right is shown the energy resolution of the tracker calorimeter for electron showers.

REDUCING T2K BEAM UNCERTAINTIES : NA61

Hadron production uncertainties at the target are currently dominating the T2K neutrino beam systematics. The NA61 experiment [3] includes in its program measurements of $p+C$ reactions in the 30-50 GeV energy range of interest for T2K. A plan to study interactions in 3 targets (thin, thick and a copy of the T2K target) using the NA49 setup is proposed. The information gathered will be used to tune the beam Monte Carlo and reduce systematics in the extrapolation of the beam energy spectrum at SK. NA61 has been approved in April and will start data taking at the end of September.

2 KM COMPLEX PROPOSAL

To complement the T2K baseline, a near detector complex at 2 km is proposed. It consists of a smaller version of the SK water Čerenkov detector combined with a muon ranger and a LAr detector. One of the advantage of a measurement at 2 km is that the neutrino beam flux is almost identical to the far detector (within ± 5%). Additionnal measurements at 2 km will reduce further the beam systematics and will also greatly help to test the prediction given by the combined measurements of ND280 and NA61 before extrapolating the beam flux and backgrounds rate at SK.

SCHEDULE

The construction of the JPARC facility started in 2004. The construction of the near detector pit has started this summer and the UA1 magnet is expected to arrive in april 2008. The installation and commissioning of the ND280 will be completed at the end of 2009. The start of T2K is scheduled for April 2009 and will run for 5 years.

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