The contribution of Near Detectors to the T2K neutrino measurements

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Abstract. The T2K long baseline experiment located in Japan is dedicated mainly to constrain or measure the $\theta_{13}$ neutrino mixing angle by searching for the electron neutrino appearance at Super Kamiokande in a pure muon neutrino beam produced at JParc 295 km away. The beam recently started on time in April 2009. Near detectors are situated 280 m from the primary target. One is on axis and a second one is situated off axis with an angle of 2.5 degrees in the direction of Super Kamiokande. They are essential to study the different systematic errors which have to be well known for the $\theta_{13}$ determination. This paper reviews the overall status of the near detectors and their role in the understanding of systematics.

1. The T2K experiment

T2K (Toaki to Kamiokande) is a long baseline neutrino experiment in Japan aiming to study several neutrino parameters. A muon neutrino beam is produced at JParc accelerator located in Tokai and sent in the direction of Super Kamiokande (SK) 295 km downstream. The first goal of T2K is to measure or constrain the $\theta_{13}$ mixing angle by studying the $\nu_\mu \rightarrow \nu_e$ oscillation (electron neutrino appearance). It will also be possible to measure the ”atmospheric parameters” $\theta_{23}$ and $|\Delta m^2_{23}|$ with a very good precision by studying the muon neutrino disappearance. The muon neutrino beam is produced by 30 GeV protons sent on a carbon target. The resulting hadrons (pions and kaons) decay mainly into a muon and a muon neutrino. Electron neutrinos can be produced by other decay channels and secondary interactions. The amount of tau neutrino is negligible. A complete description of the beamline can be found in [1].

The muon neutrino beam is sent in the direction of SK with an off axis angle of 2.5 degrees. The off axis angle decreases the neutrino flux but provides several advantages thanks to the kinematics of a 2-body decay:
- The muon neutrino energy is peaked to 700 MeV corresponding to the maximum oscillation probability along the 295 km distance.
- The high energy tail and the $\nu_e$ beam component are strongly reduced.

The expected fluxes at SK of muon neutrinos and oscillated $\nu_\mu \rightarrow \nu_e$ strongly depend on the off-axis angle. This angle, in addition to other parameters like fluxes and cross sections, has therefore to be known very precisely in order to limit the systematic errors. The following section presents the needs and means of T2K concerning systematics and their measurement. The Two near detectors located 280 m from the primary target will play a crucial role in this task. A detailed description of the near detectors is given in section 3.
2. Systematic errors and sensitivities to neutrino parameters

Thanks to its features detailed in section 1, T2K can achieve competitive sensitivities after 5 years running [1]:

- $\sin^2(2\theta_{13}) < 6 \times 10^{-3}$ at 90% C.L. if systematic errors are less than 10%.
- $\Delta(\sin^22\theta_{23}) \approx 10^{-2}$ and $\Delta(\Delta m^2_{23}) \approx 10^{-4}$ at 90% C.L. if systematic errors are kept below statistical errors.

The different sources of systematics can be studied thanks to different means:

- The near/far ratio (calibration of fluxes at SK with respect to near detectors) depends on the off-axis angle but also on hadronic production and hadron decays. This point is studied by the NA61 experiment at CERN [2]. Their goal is to reach 2 or 3% error for the near/far ratio.
- The energy calibration can be done thanks to SK-IV data analysis with cosmic events and $\pi^0$ mass measurements. A 2% precision is presently achieved.
- Off-axis angle, fluxes and cross-section of signal and background events will be studied with the near detectors, described in the next section.

3. The role of near detectors in systematic error measurements

The T2K near detectors, located 280 m from the primary target in a 25 m deep pit, are represented on figure 1. They play the main role in systematic error measurements.

![Figure 1. Sketch of T2K near detectors: Left, on axis INGRID. Right, off axis ND280.](image)

INGRID is a cross-shaped detector made with seven horizontal and seven vertical modules composed by iron plates interleaved with X-Y plastic scintillator planes. INGRID is on axis and aims to measure the off axis angle with a precision better than 1 mrad. The complete installation and cabling was finished in August 2009 and the commissioning with neutrino beam will start in October. Moreover, as can be seen on figure 1, two off-axis modules will be added by 2011 in order to estimate the azimuthal symmetry of the beam. Also, a movable module without iron, called proton-module, will be installed in the front of the horizontal modules. It will discriminate between the different hadronic final states and quasi-elastic interactions, and will give a more precise measurement of the vertex positions.

The ND280 detector is located off axis in the direction of SK and is composed of several sub-detectors dedicated to the measurement of neutrino fluxes and different neutrino cross-sections.
- The UA1 magnet is surrounding all sub-detectors. Its C-shape iron elements are instrumented with muon range detectors made of plastic scintillators. It will be possible to measure the muon energy with 10% resolution.

- The first sub-detector located upstream the neutrino beam is called \( \pi^0 \)-detector (POD). It is made of lead foils and scintillator planes interleaved with water tanks. It will measure the \( \pi^0 \) production in neutrino interactions on water, which corresponds to the main background of the electron neutrino appearance at SK.

- Downstream the POD is located the tracker. It is composed of three TPC interleaved with two fine grained detectors (FGD) made of plastic scintillator bars. The TPC will separate electrons and muons using dE/dX, also providing energy measurements. The FGD will distinguish quasi-elastic events from multihadronic states which constitute a huge background for the "atmospheric parameters" measurement. Moreover the most upstream FGD is filled with water allowing to measure cross-sections like in SK. Finally the tracker will be able to study several cross-sections (CCQE, NC1\( \pi \), CC1\( \pi \)) and measure neutrino fluxes.

- The ECAL detector is located downstream and on the top of the POD and the tracker. It is composed of scintillator bars interleaved with lead sheets. The part surrounding the POD acts as a \( \gamma/\mu \) tagger for large angle tracks escaping the POD. The part around the tracker will reconstruct electromagnetic showers with their energy and improve the electron/muon identification.

Table 1 summarises the near detector contributions to the systematic error measurements in T2K. All the near detectors will be installed and instrumented by the end of the year 2009 in order to take neutrino data early 2010.

**Table 1.** Near detector contributions to the systematic error measurements in T2K.

| Source of systematic error | Required performances | Actual achievable performances | Principal means |
|---------------------------|-----------------------|--------------------------------|-----------------|
| off-axis angle            | 1 mrad                | <1mrd                         | INGRID         |
| CCQE \( \nu^e_{\text{beam}} \) event flux | 10%                   | 5%                            | TPC+ECAL       |
| CCQE \( \nu_{\mu} \) event flux | 5%                    | 4%                            | TPC+Magnet     |
| QE/Non-QE ratio (\( \nu_{\mu} \) events) | 5-10%                 | 10%                           | TPC+FGD        |
| Number of \( \pi^0 \) events | 10%                   | 10%                           | POD+ECAL       |

4. Conclusion
The T2K experiment will measure several neutrino mixing parameters with competitive sensibilities and precisions. To achieve these performances, the near detectors will study and measure systematic errors in order to keep them below 10% for \( \theta_{13} \) study and under statistical errors for "atmospheric parameter" measurements. The full set of near detectors will be installed and instrumented in the pit by the end of 2009 and precise measurements will be performed during the first year of data taking. First physic results are expected by summer 2010.

References
[1] Hayato Y et al. 2003 Letter of intent Neutrino Oscillation Experiment at JHF
[2] Posiadala M 2009 Status of the NA61 (SHINE) experiment at CERN (preprint hep-ex/09013332)