THE SMRD SUBDETECTOR AT THE T2K NEAR DETECTOR STATION*

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(Received May 27, 2010)

The T2K long-baseline neutrino oscillation experiment is running in Japan. The primary goals of the T2K are measurement of the mixing angle θ_{13}, and precise measurements of the mixing angle θ_{23} and of the mass difference Δm^2_{23}. The installation of the near detector complex was completed and first data were already registered. This article presents operation of the Side Muon Range Detector, a component of the Off-Axis near detector. Detector concept and implementation are presented, followed by a description of cosmic muon track reconstruction algorithm and finally current status.

PACS numbers: 29.40.Mc, 85.60.Gz

* Presented at the Cracow Epiphany Conference on Physics in Underground Laboratories and Its Connection with LHC, Cracow, Poland, January 5–8, 2010.

1. Introduction

The T2K (Tokai to Kamioka) experiment [1, 2] is a second generation long-baseline neutrino oscillation experiment located in Japan. The goals of the T2K are measurement of the neutrino mixing angle θ_{13} (sensitivity for $\sin^2 2\theta_{13} > 0.006$) and precise measurement of the mixing angle θ_{23} and of the mass difference Δm^2_{23} ($\delta(\sin^2 2\theta_{23}) = 0.01$ and $\delta(\Delta m^2_{23}) = 10^{-4}$ eV^2). The T2K Off-Axis ν_μ beam is generated with the 30 GeV proton synchrotron at the J-PARC facility (Japan Proton Accelerator Research Complex). The beam direction is inclined 2.5 degree with respect to the direction of the far detector — Super-Kamiokande (SK), located 295 km away. This beam allows the measurement of the oscillation parameters with the neutrino energies of $500 \div 700$ MeV, which gives the oscillation maximum at the SK.

The near detector complex, ND280 [3, 4], is designed to measure the property and interaction cross-sections of the ν beam before its oscillation. It is located 280 m downstream from the hadron production target. The ND280 consists of two parts:

- The On-Axis detector (INGRID), placed on the beam axis, allowing direct measurement of the direction and of the profile of the ν beam.
- The Off-Axis detectors (Fig. 1), placed on the direction to SK, for the measurement of the neutrino beam flux, energy spectrum, flavor contents and neutrino cross-sections. These detectors are placed inside the UA1 magnet, which provides horizontal uniform magnetic field of 0.2 T for the Off-Axis detectors.

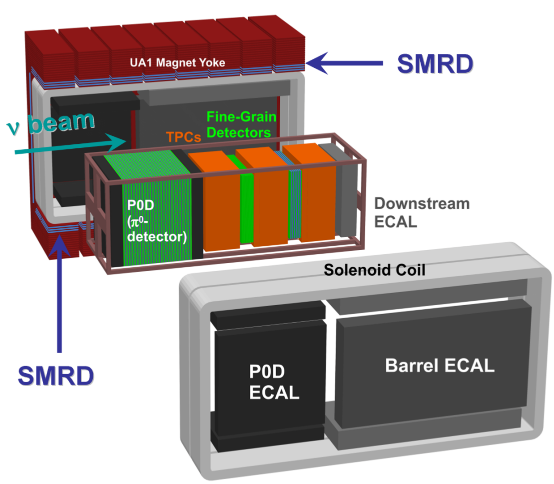

Fig. 1. ND280 Off-Axis detector.

2. Side muon range detector

2.1. Detector concept and implementation

The side muon range detector (SMRD) is one of the components of the Off-Axis detector. The goals of SMRD are:

1. Energy measurement of muons generated in charged current neutrino interactions;
2. Identification of backgrounds from beam neutrino interactions in the magnet yokes and in the walls of the experimental hall;
3. Generation of cosmic ray trigger signals for the calibration of inner detectors.

The SMRD is designed as a multi layered structure made of plastic scintillation counters and iron yokes of the UA1 magnet. Each magnet yoke is made of sixteen 48 mm iron plates with 17 mm air gaps between them (Fig. 2(a)). The scintillation counters (Fig. 2(b)), grouped into modules using aluminum H-profiles (Fig. 2(c)), are placed inside the gaps and fixed using phosphorus-bronze springs[1] (Fig. 2(a)). The number of counters for the horizontal modules is four and for the vertical ones is five. Each module is equipped with two temperature sensors[2], placed on opposite sides. There are 3 layers of the scintillators per magnet yoke, with the 3 downstream yokes equipped with 1 to 3 additional vertical layers (making a total of 4 to 6 vertical layers).

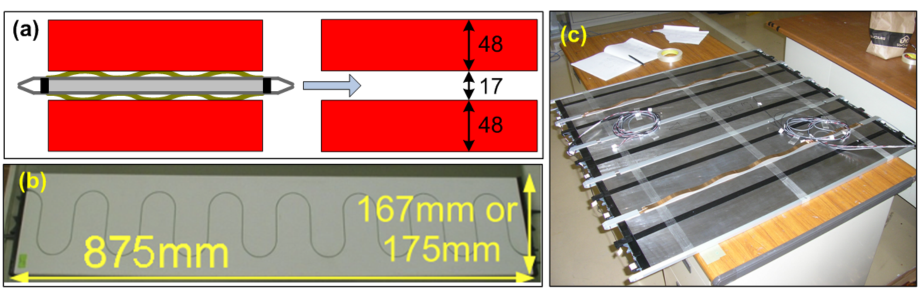

Fig. 2. (a) Module fixing inside the magnet yokes; (b) SMRD counter with a wavelength shifting fiber; (c) Vertical SMRD module.

The counters[3] are made from Polystyrene based scintillator, with a reflective coating made by etching the outer surface using chemical agent and subsequent fixing of the diffuse film [5]. The dimensions of individual coun-

[1] Phosphorus content is 0.3%.

[2] DS18B20, 1-Wire bus, manufactured by Maxim-Dallas Semiconductor.

[3] Produced by extrusion at Uniplast company in Vladimir, Russia and assembled at INR RAS.

ters are $875 \times 175 \times 7\,\mathrm{mm}^3$ and $875 \times 167 \times 7\,\mathrm{mm}^3$ for vertical and horizontal ones, respectively. A total of 2008 counters have been installed. The optical signal is extracted from the scintillator slab using Kuraray Y11 [6] wavelength shifting fiber (1 mm diameter), placed in an S-shaped groove (Fig. 2(b)). The readout is performed with two 667 pixel, $1.3 \times 1.3\ \mathrm{mm}^2$ Hamamatsu MPPCs, [7,8] attached to both ends of the fiber and working in coincidence mode. The light yield was found to be 25 to 50 p.e./MIP, resulting in MIP detection efficiency better than 99% [9]. The spatial resolution was measured as 6.1 ± 0.8 cm, derived from signal timing [10]. Due to the fact that the photosensors used are relatively new and, to date, have not been used on such a large scale, an extensive testing has been performed[4], which revealed good sensor quality. A description of one of these tests can be found in [11]. A system for on-line monitoring has also been developed, allowing for realtime data analysis — currently only MPPC gain and dark count rate are checked, based on channel histograms, but the work is on-going to extend the system to allow readout of temperature data, displaying per-channel history, threshold calculation and monitoring the quality of physics data.

2.2. Cosmic muon track reconstruction

First level of the track reconstruction is the estimation of the actual hit times and positions in the scintillator slabs. Photosensor signals are considered as hits if they are in the time coincidence (23 ns time window) and above the amplitude threshold of 4.5 p.e. Actual hit position along the WLS fiber direction is calculated from the time difference dt of the signals on both ends of the slab. Bayesian estimate is used with the following assumptions:

1. uniform prior distribution of the hit positions in the scintillator slab;
2. Gaussian likelihood of measured dt, based on scintillator slab tests performed before the installation. Actual hit time is calculated according to the estimated hit position.

Simple reconstruction was proposed for cosmic muon data. Straight line is fitted to the hits reconstructed in the first stage; PCA (Principal Component Analysis) technique is used. Example of reconstructed muon track is shown in Fig. 3(a). The distribution of the zenithal angle of the reconstructed cosmic muon tracks was compared to the Monte Carlo simulation. A very good agreement was achieved as shown in Fig. 3(b).

[4] The sensors have been measured independently at INR Moscow, Luisiana State University and Warsaw University of Technology.

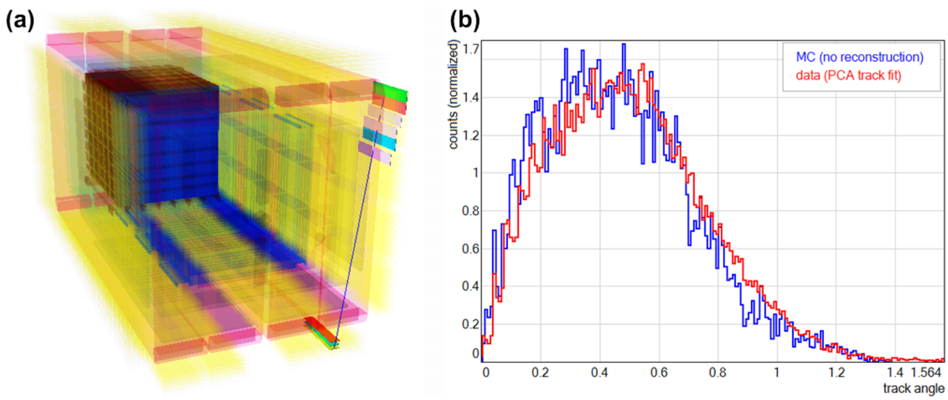

Fig. 3. (a) Example of the cosmic muon event — fired scintillators and track fit are shown. (b) Comparison of the distributions of the zenithal angle for cosmic muons: one curve shows the angle of the muon entering the magnet (no reconstruction procedures are applied) for the simulated data, the other one shows the reconstructed track angle for the real data.

2.3. Current status

The detector has been installed in July 2009 and fully commissioned. Only few broken channels were found (some of them already repaired) and more than 99.8% of all 4016 channels function correctly. Data acquisition works and first cosmic muon tracks were already reconstructed. Currently, main efforts concentrate on detector calibrations, development of an on-line monitoring system and a cosmic muon trigger — both simulation and setting up the trigger itself. Preliminary data show that the cosmic trigger simulation and real data agree well. Also, different reconstruction approaches are being pursued for beam events.

3. Summary

T2K long-baseline neutrino oscillation experiment is currently running in Japan. The description and current status of one of the components of the Off-Axis near detector — the Side Muon Range Detector has been presented. The detector is fully operational and first cosmic muon tracks were already registered and reconstructed. Current efforts concentrate around detector calibrations, an on-line monitoring system, a cosmic trigger and reconstruction of muon tracks (both cosmic and beam related).

This work is partially supported by the Polish Ministry of Science and Higher Education, grant number 35/N-T2K/2007/0.

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