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# Scintillator counters with WLS fiber/MPPC readout for the side muon range detector (SMRD) of the T2K experiment


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**Abstract**

The T2K neutrino experiment at J-PARC uses a set of near detectors to measure the properties of an unoscillated neutrino beam and neutrino interaction cross-sections. One of the sub-detectors of the near-detector complex, the side muon range detector (SMRD), is described in the paper. The detector is designed to help measure the neutrino energy spectrum, to identify background and to calibrate the other detectors. The active elements of the SMRD consist of 0.7 cm thick extruded scintillator slabs inserted into air gaps of the UA1 magnet yokes. The readout of each scintillator slab is provided through a single WLS fiber embedded into a serpentine shaped groove. Two Hamamatsu multi–pixel avalanche photodiodes (MPPC's) are coupled to both ends of the WLS fiber. This design allows us to achieve a high MIP detection efficiency of greater than 99%. A light yield of 25-50 p.e./MIP, a time resolution of about 1 ns and a spatial resolution along the slab better than 10 cm were obtained for the SMRD counters.

# 1 Introduction

The T2K neutrino experiment [1] is a second generation long-baseline neutrino experiment and its primary goal is to measure the unknown neutrino mixing parameter $\theta_{13}$. A muon neutrino beam generated by the 50 GeV (initially 30 GeV) proton synchrotron at J-PARC (Japan Proton Accelerator Research Complex) is directed towards the Super-Kamiokande detector located 295 km away. The complex of near detectors, ND280 [2–4], is designed to measure the properties of the unoscillated $\nu_\mu$ beam and neutrino interaction cross-sections. It is located 280 m downstream from the primary production target and consists of two detectors: the on-axis detector (neutrino monitor) and the off-axis detector. The off-axis detector operates with a magnetic field of 0.2 T using the UA1/NOMAD CERN magnet and consists of a number of sub-detectors (Fig. 1).

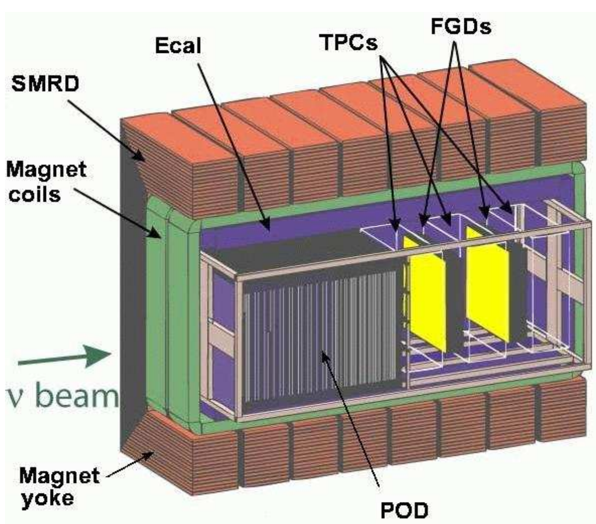


Figure 1: Schematic view of the ND280 detector. One side has been removed for clarity.

In this paper we discuss one of the ND280 sub-detectors - the side muon range detector (SMRD). The principal goals of the SMRD are (1) to measure the muon momentum and angle for charged current quasi-elastic CC-QE reactions to help determine neutrino energy, (2) to identify backgrounds from beam neutrino interactions in magnet yokes and surrounding walls and (3) to provide a cosmic trigger signal for calibration of the inner detectors. As for point (1) the detector is designed to detect lateral muons that are unseen by the inner detectors. According to MC simulation approximately 40% of muons from CC-QE interactions and about 15% of muons from CC non-QE reactions are expected to intersect the SMRD.

A high muon detection efficiency, a highly hermetic layout and long term stability are the main requirements for the detector. The time and spatial resolution of the entire SMRD strongly depend on the DAQ electronics performance. In this paper we will focus mainly on the design and tests of the individual SMRD counters.

## 2 SMRD design

The UA1 magnet yoke consists of 16 C-shaped elements (8 rings). A C-element is segmented into 12 azimuthal sections, each of them is made of sixteen 48 mm thick iron plates with 17 mm air gaps between them. Some of the air gaps are instrumented with the SMRD detectors.

In order to allow for maximum flexibility during the installation process a modular approach was chosen: 4 (horizontal gaps) or 5 (vertical gaps) individual counters are assembled by means of H-profiles to form a SMRD module. The total number of individual counters (including spares) is 2130.

## 3 SMRD individual counters

### 3.1 Design

Polystyrene based scintillator slabs with double-ended WLS fiber readout are used as active elements of the SMRD detector (Fig. 2). A single WLS fiber is glued into a serpentine-routed groove with BC600 Bicron glue [11]. Such a configuration allows us to collect scintillation light uniformly over the entire plastic surface, to obtain a high light yield as well as to minimize the number of photosensors and electronics channels to a pair per a counter.

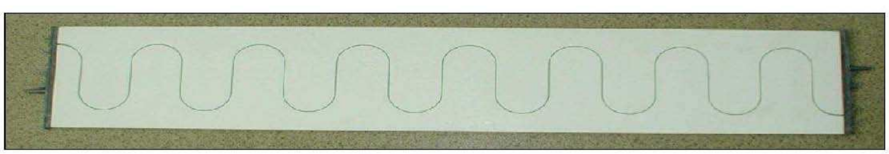

Figure 2: SMRD counter with embedded WLS fiber before wrapping into a stainless steel container.

Molded end-caps are attached to the counter ends to provide a housing for photodetectors and temperature sensors. Hamamatsu 667-pixel MPPC‘s [5–7] are used in the SMRD as photosensors. These multipixel avalanche photodiodes have a sensitive area of $1.3\times1.3$ mm$^2$ and have the advantage of being insensitive to a magnetic field.

To fill the magnet air gaps, scintillator slabs of two sizes have been manufactured: $875\times167\times7$ mm$^3$ for horizontal gaps, and $875\times175\times7$ mm$^3$ for vertical ones.

Extruded polystyrene scintillators have been produced by Uniplast company in Vladimir, Russia. Outer surfaces of a slab are etched, thus resulting in formation of a white diffuse layer which acts as a reflector and has been demonstrated to have an excellent performance. The advantage of this approach is an almost ideal contact of the reflector with the scintillator. Some details of the extrusion technique and the method of etching a scintillator with a chemical agent can be found in Ref. [8]. Extruded scintillators of this type have shown good light yield stability over two years [9].

### 3.2 WLS fibers

The Y11 (150) Kuraray WLS fibers used in the SMRD are of flexible S-type, with double-cladding and 1 mm diameter [10]. Fibers are bent into a serpentine-like geometry, consisting of 7 loops with diameter of 58 mm. The total fiber length is about 2.2 m.

The long term stability of bent WLS fibers was tested with two photosensors MRS APD‘s [12] and a blue LED as a light source. Several 3 m long fiber samples were wound into 7 turns to reproduce the SMRD configuration. A bending diameter of about 60 mm led to an average initial drop in light transmission quality of about 5%, which is in a good agreement with Kuraray data [10]. Light attenuation was measured as the ratio of the light signal at the far fiber end to the signal at the close end. The near end signal served as a reference of LED intensity. A straight fiber of the same length was used to calibrate photosensors. No degradation in light attenuation has been observed over a period of more than a year.

### 3.3 Assembly of SMRD counters

Scintillator slabs with glued WLS fibers and attached end-caps are wrapped into an additional reflector layer of 0.1 mm thick Tyvek paper which increases a light yield by about 15%. Then counters are wrapped into 0.1-0.15 mm thick stainless steel foils in order to have a good protection from light and humidity. Stainless steel has been selected to protect the counters from a possible mechanical damage during installation.

The containers are fixed with DP-490 black epoxy glue and an adhesive tape. The light isolation of assembled counters has been checked by measuring the signal rate for light-on and light-off modes.

## 4 Individual counter performance

The first SMRD prototype was tested at the KEK 12-GeV synchrotron with a 1.4 GeV/c pion beam [13]. In these tests MRS APD‘s were used as photodetectors. A small size beam scanned all of the counter surface. Successive data analysis demonstrated that a light yield (sum of both ends) of more than 12 p.e./MIP results in a detection efficiency of better than 99%.

The performance of the mass-production SMRD counters was measured with cosmic ray muons and MPPC photodiodes using a small $2\times2$ cm$^2$ trigger counter placed at the slab center. The mean light yield was near 40 p.e./MIP (sum of both ends). A high light yield of 40 p.e. corresponded to a timing resolution of about 0.9 ns (Fig. 3). To suppress the timing spread caused by trigger counters we used the $(T_{left} - T_{right})/2$ combination for timing measurements. The corresponding spatial resolution along the slab was about 6 cm rms. A MIP detection efficiency of more than 99.9% was achieved.

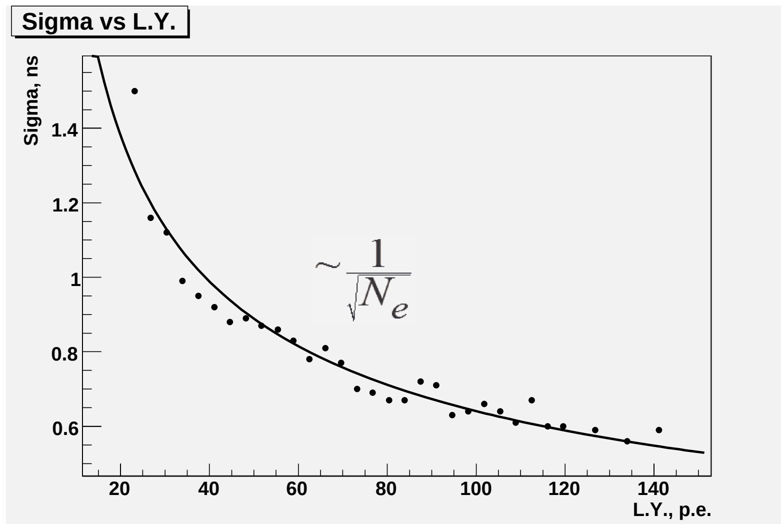


Figure 3: The time resolution after time-amplitude correction versus the light yield for a MIP penetrating the center of the SMRD counter.

## 5 Cosmic muon tests of SMRD counters

Before installation into the UA1 magnet yokes all the counters were tested with cosmic muons. The T2K experiment will collect data for almost ten years, so we have set strict limits to accept a counter for installation. The light yield requirement is more than 25 p.e./MIP for the sum of both ends and at 20 $^{o}$C. The latter value corresponds to expected temperature inside UA1 yokes. According to our measurements the light yield ranges from 25 to 50 p.e./MIP (Fig. 4).

The asymmetry in signal size between ends was required to be less than 10% to guarantee no fiber damage.

## 6 Conclusion

The SMRD muon detector of the near-detector complex of the T2K experiment is described in the paper. Active elements of the SMRD are extruded scintillator slabs with double-ended WLS fibers and MPPC readout. The main feature of the detector is the usage of S-shaped grooves for embedding the fiber. The performance of individual SMRD counters was measured with cosmic ray muons. The measured light yield value was 25-50 p.e./MIP at 20-22 $^{o}$C. This light yield allows us to achieve a MIP detection efficiency $>$ 99%, a time resolution of about 1 ns and a spatial resolution along the slab better than 10 cm.

The first T2K physics run is expected in December 2009.

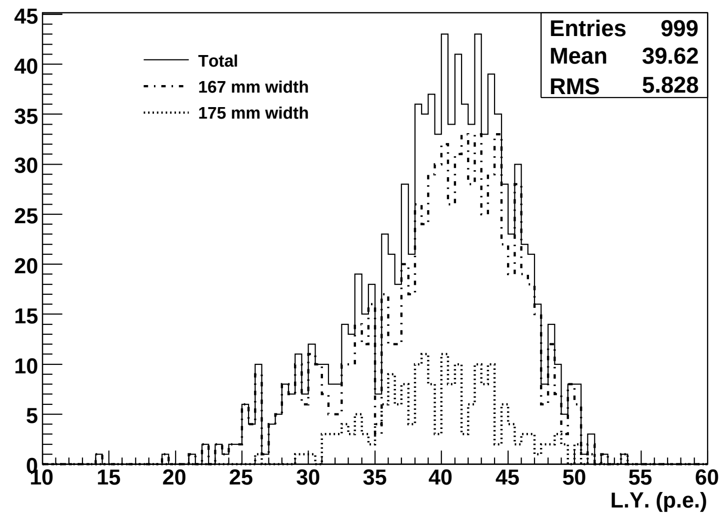


Figure 4: The light yield distribution for about 1000 SMRD counters.

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