PROCEEDINGS OF SCIENCE

The design, construction and testing of Totally Active Scintillator Detector

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Totally Active Scintillator Detector (TASD) for future neutrino experiments is assembled out of 50 module planes of plastic scintillators. The modules are instrumented with one X and one Y plane, with 86 scintillator bars per each plane. The bar size is 0.7x1x86 cm^3. The distance between modules can be varied from 0 to 2.5 cm. Additional components as active detectors or passive material sheets can be inserted between the modules, if required. The bar elements were tested with cosmic rays and the results are reported.

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1. Introduction

The Totally Active Scintillator Detector (TASD) is under construction in the framework of the Neutrino platform at CERN [1]. The detector is developed as a prototype for large-scale neutrino detectors in long baseline neutrino oscillation experiments. A possible implementation for a such detector is shown in Fig. 1. This near detector conceived for the LBNO project consists of a 20 bar argon gas pressure vessel which contains a time projection chamber (TPC) surrounded by plastic scintillator modules.

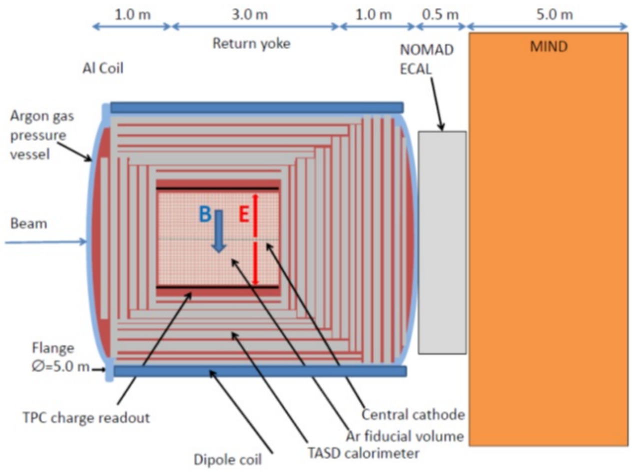


Figure 1: Sketch of the near detector for future neutrino experiments.

The MIND modules are composed of magnetized iron and the long plastic scintillators bars which are read out with wavelength shifting (WLS) fibers. Event reconstruction resides in selecting tracks above the certain threshold in length. Analyzing the vertex allow us to reconstruct the hadronic component of interactions.

In order to characterise the response of the detectors in terms of tracking, electromagnetic and hadronic calorimetry, secondary interactions, the prototype detectors will be built and tested in charged particle beams, see Fig. 2. Tests of a prototype MIND (Baby-MIND) using the TASD scintillator modules are also planned.

2. The TASD prototype design

The TASD prototype detector will be assembled out of 50 plastic scintillator module planes spaced from each other with the variable gap from 0 to 2.5 cm [2]. The whole detector depth can be changed from 75 cm to 200 cm, the active volume is about 1 m^3. Individual module (see Fig. 3) consists of one X and one Y plane, with 86 scintillator bars per each plane. The bar size is 0.7x1x86 cm^3.

In total 9000 bars were manufactured by extrusion of polystyrene based scintillator by Uniplast, a company in Vladimir, Russia. The wide and long extruded slabs of 0.7 cm thick were cut in the bars, then the bars were covered by 30–100 μm thick diffuse reflector using etching of

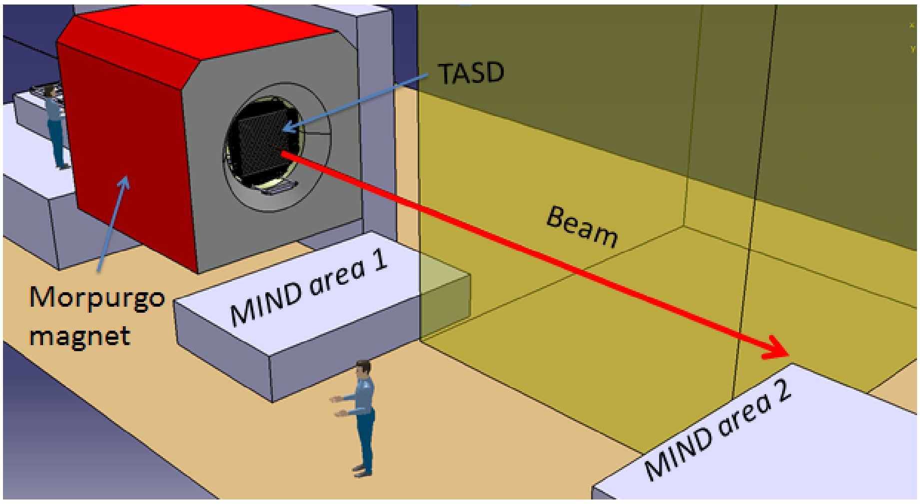
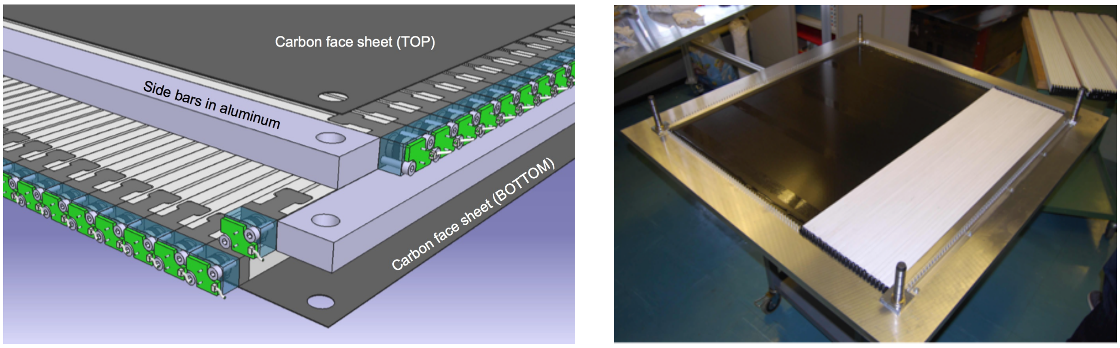


Figure 2: The planned area for the TASD test.



a) b)

Figure 3: Module of the TASD prototype, *(left)*. The assembly of the TASD module, *(right)*.

polystyrene surface with a chemical agent. Details about the extrusion technique and the method of etching a scintillator with a chemical agent can be found in [3, 4] The variations of bar width and thickness were measured during cosmic tests. Size distributions are shown in Fig. 4. The width variation is measured to be $\sigma = 150$ μm. The thickness of the bars varies from 6.8 mm to 7.6 mm.

A groove of 1.1 mm width and 2 mm depth was milled along the bar at INR (Moscow) to glue in a 1 mm diameter Kuraray Y11 multiclad WLS fiber with the embedded in scintillator optical couplers developed specially for this project. Compact connectors were designed and manufactured employing plastic injection moulding at Uniplast. The glue is colorless epoxy cement EJ-500 from Eljen Technology. The WLS fiber is read out at both ends of the bar by SiPM photodiodes, 1x1 mm^2 Hamamatsu MPPCs.

3. Selection of photosensors for the prototype detectors

The first silicon photomultiplier (SiPM) device used on a large scale in high-energy physics experiment was the Hamamatsu MPPC S10362-13-050C instrumenting all scintillator detectors in

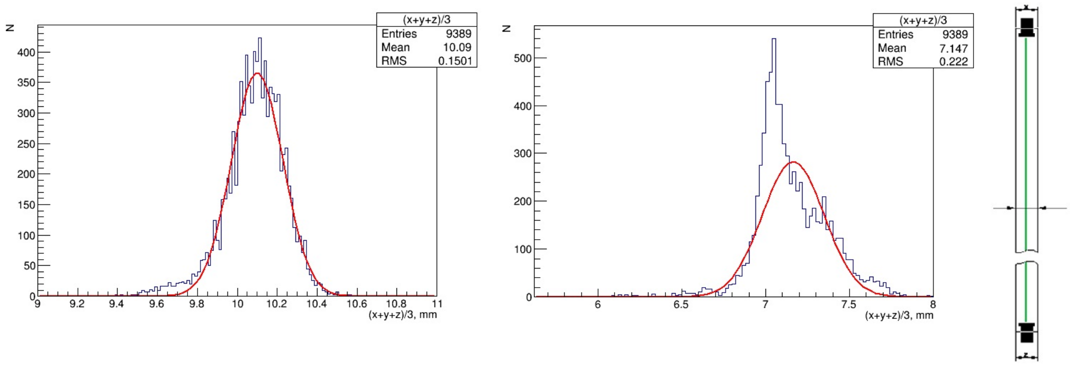


Figure 4: Variation of width (*left*) and thickness (*right*) for the bars.

the ND280 detector complex of the T2K experiment in Japan[5]. The thorough work done in the selection and characterization of photosensors for the T2K experiment served as a solid basis for the selection of photosensors for our prototypes. There are a few SiPM manufacturers with a variety of available commercial products. Table 1 summarizes the characteristics of different SiPMs tested at INR. Finally we decided to use the 1x1 mm^2 low-noise Hamamatsu MPPC S12571-025C (see Table 1) for these detectors.

Table 1: Characteristics of tested photodiodes. MPPC-T2K is S10362-13-050C, MPPC is S12571-025C type.

Parameter	MPPC-T2K [6]	MPPC [6]	ASD-40 [7]	KETEK [8]	SensL [9]
Sensitive area, mm^2	1.3×1.3	1×1	dia. 1.2	1×1	1×1
Number of pixels	667	1600	660	400	848
Pixel size, μm	50	25	40	50	20
Gain	7.5×10^5	5.1×10^5	1.6×10^6	—	—
Dark rate, MHz	≤ 1	≤ 0.1	≈ 3	≤ 1	≤ 2
Bias voltage, V	≈ 70	≈ 68	≈ 47	≈ 33	30
Cross-talk, %	10	25	12	40	10
PDE at 520 nm, %	26	35	11	42	14

4. Tests of the bars with cosmic muons

Each individual bar was tested for light yield at both ends with cosmic rays. A trigger telescope was set up with two large counters installed above and below of the central part of the array of 10 bars. We tested simultaneously 10 bars at one side, then turned over these 10 bars and measured the light yield from opposite ends, i.e the light yields from both bar ends were measured with the same MPPC. Hamamatsu MPPC-T2K (1.3×1.3 mm^2, see Table 1) were used to readout the bars. MPPC signals after preamplifiers were sent to a digitizer CAEN DT5742 with 5 GHz sampling rate, then the charge was calculated by integrating the signal pulse shape and calibrated in the number of photoelectrons (p.e.). The integration time gate was 120 ns. We did not apply the correction for MPPC crosstalk so the absolute light yield shown below is overestimated by 10%. The ambient temperature fluctuated within the range $19-30°$ C during measurements that affected the results.

The average light yield, sum from both ends, of all bars was measured to be 116.5 p.e./MIP without temperature correction. Temperature correction in relation to $T = 22°$C increases the average light yield to 124.2 p.e./MIP. Fig. 5 demonstrates the distribution of the light yields between 9389 bars with and without temperature correction. Light yield asymmetry between the bar ends ewsuremd in the central point of the bars was found to be less than 10%.

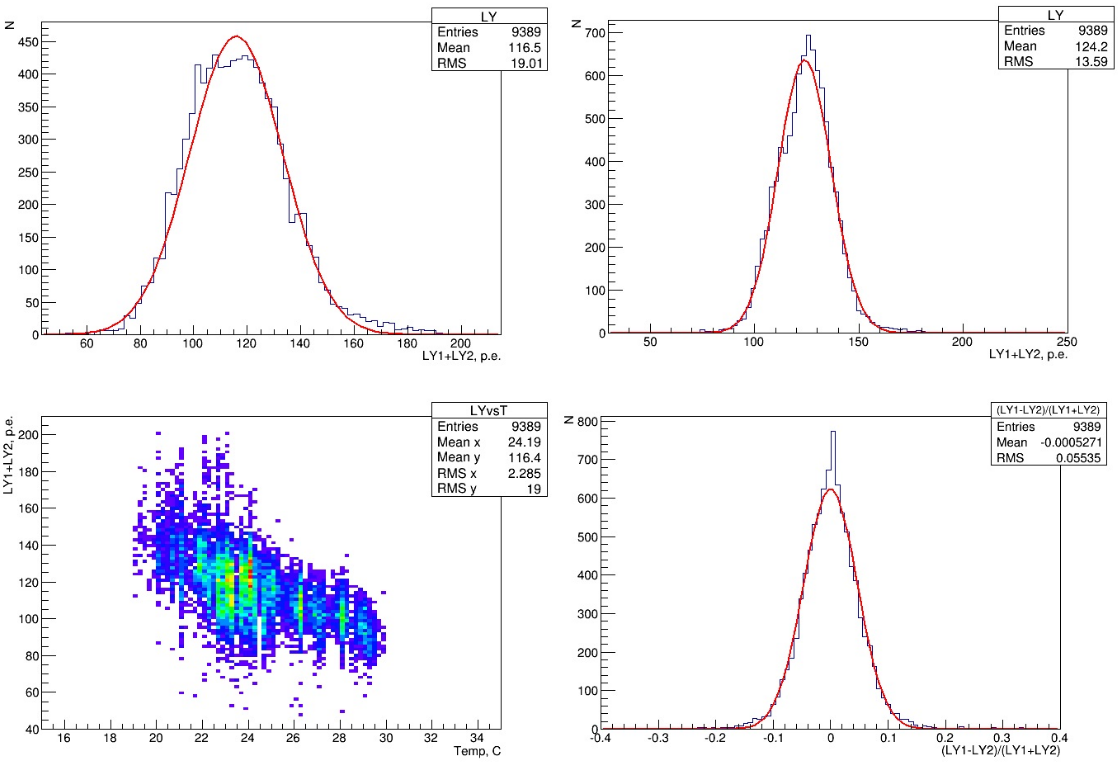


Figure 5: Distribution of light yield (sum from both ends) for 9389 bars: *top left* — without temperature adjustments, *top right* — with temperature correction for reference $T = 22°$C, *bottom left* — temperature variation during measurements, *bottom right* — distribution of the light yield asymmetry between the ends.

5. Cross-talk between the adjacent bars in array

Since the reflector layer over the scintillator surface does not provide light isolation, we investigated the leak of the scintillating light from one bar to neighboring ones in a dense array. The setup for the cross-talk measurement with cosmic rays is shown in Fig. 6. In this configuration, the bars numbered 8, 7, 5, 2 and 9 were used as the trigger counters to select normal incident cosmic muons. The cuts were imposed on signal spectra in the bars 8,7,9 to select the events with high

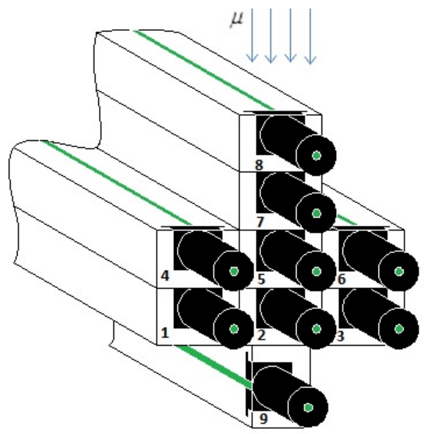


Figure 6: Setup to measure the cross-talk between adjacent bars. The bars numbered 8, 7, 5, 2, 9 are used to select normal incident cosmic particles. The cross-talk is measured between the fired bar 5 and adjacent bars 4 and 6, between the fired bar 2 and adjacent bars 1 and 3.

light yield. The cross-talk is measured between the fired bar 5 and adjacent bars 4 and 6, between the fired bar 2 and adjacent bars 1 and 3. The bar 2 was light isolated with black tape so that we apply it as the reference point of no light leakages in the bars 1 and 3 from the bar 2. Fig. 7

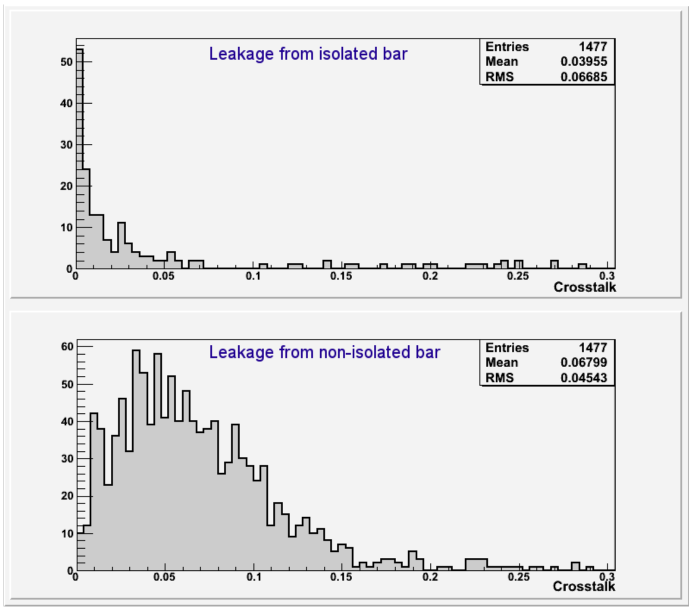


Figure 7: Cross-talk is defined as the ratio of sum of light leakages in both adjacent bars to the light signal in the fired bar. Isolated bar is number 2, non-isolated bar is number 5.

shows the result of cross-talk measurement. The cross-talk is defined as the ratio of sum of light leakages in both adjacent bars to the light signal in the fired bar. One can see that the average light leakage from the non-isolated bar 5 into two adjacent bars 4 and 6 is about 6.8%. It should be noted that events with 15% crosstalk were observed. We have attributed the cross-talk events observed in the isolated bar 2 to accidentals caused mainly by MPPC dark noise.

6. Conclusion

Over 9000 scintillator bars of 0.7x1x86 cm^3 size were manufactured and tested for TASD and Baby-MIND prototype detectors. Hamamatsu MPPCs were used for readout of scintillating signals. The average light yield was measured with cosmic rays to be 124.2 p.e./MIP at $T = 22°$C for sum of both ends. Difference in light outputs between the bar ends does not exceed 10%. We also investigated the effect of optical cross-talk between the adjacent bars. Average light leakage in two neighboring bars was found to be below 7% that is expected to create no problem in charge particle track reconstruction.

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