

The design of the totally active scintillator detector

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Abstract. In the project of Advanced European Infrastructures for Detectors at Accelerators (AIDA), the Institute of Nuclear Research designed and tested the Totally Active Scintillator Detector (TASD). This paper reports the results of design of TASD prototype and outlines requirements for a test beam at CERN to test these, tentatively planned on the H8 beamline in the North Area, which is equipped with a large aperture magnet. TASD consists of 50 modules of plastic scintillators. Each module is instrumented with one X and one Y plane, with 90 scintillator bars per plane. The bar width, height and length are 1.0 cm, 0.7 cm and 90 cm respectively. The distance between modules can be varied from 0 to 2.5 cm. Other components such as active detectors or passive sheets of material can be inserted in these 2.5 cm gaps if required. The full detector depth can therefore be varied from 75 cm to 200 cm and in its compact form, it is 1 m³ in volume. The paper presents measurement results for the TASD elements that included in the prototype elements (measurement of crosscurrents, the light yield of scintillators, and the characteristics of photodiodes).

1. Introduction

The project of Advanced European Infrastructures for Detectors at Accelerators (AIDA) was created to improve the characteristics of modern detectors. That will be useful for high energy density physics investigations [1]. As a part of AIDA, the project of Large Apparatus for Grand Unification, Neutrino Astrophysics, and Long Baseline Neutrino Oscillations (LAGUNA-LBNO) includes design, construction and testing of near and far neutrino detectors [2]. One of the variants of the near detector is presented on the figure 1. As one can see, near detector consisting of a 20 bar argon gas pressure vessel enclosing a time projection chamber (TPC) and surrounding plastic scintillator detector modules. Downstream of this pressure vessel, an electromagnetic calorimeter (ECAL) and magnetized iron neutrino detector (MIND).

The MIND modules consist of magnetized irons, bars of plastic scintillators with wavelength shifting fibers and silicon photo-multipliers as light sensors. MIND detectors are self-calibrating detectors in that the magnetic field provides a measurement of momentum by bending, which can be checked against a momentum measurement by range for those muon events that are fully contained in the detector. Event reconstruction is relatively straightforward and consists in selecting tracks above a certain threshold in length, say 100 cm, and analyzing the vertex, extracting calorimetric information from the vertex to reconstruct the hadronic component of the interaction.



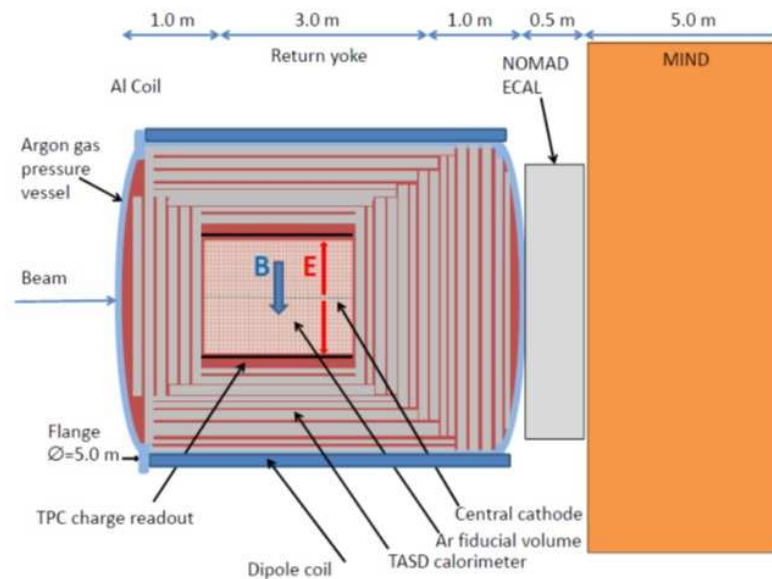


Figure 1. Sketch of the LAGUNA-LBNO near detector.

At present detectors prototypes The Magnetized Iron Neutrino Detector (Baby MIND, figure 2) and Total Active Scintillator Detector (TASD, figure 3) are created, which can be used in the central part of near detector. In cooperation LAGUNA-LBNO Institute of Nuclear Research Russian Academy of Science (INR RAS) are design and testing TASD and Baby MIND, which is the prototype of the 50 tons detector MIND. Assuming minimum ionising muon loses $11.4 \text{ MeV}/(c \cdot \text{cm})$ of steel, 51 plates of 3 cm-thick steel interleaved with 1.5 cm-thick modules of plastic scintillator would contain 2 GeV/c muons. Here c is the speed of light.

In order to characterise the response of the detectors in terms of tracking, electromagnetic and hadronic calorimetry, and the physics of secondary interactions the detectors will be exposed to charged particle beams. The charged particles momentum should be selectable and cover the range 0.5–20 GeV/c. The beam composition should be pions, muons, electrons and sign selected. The rate of particles should be in the range 200–1000 Hz.

2. The TASD prototype.

The TASD detector consists of 50 modules of plastic scintillators [3]. Each module is instrumented with one X and one Y plane, with 90 scintillator bars per plane. The bar width, height and length are 1.0 cm, 0.7 cm and 90 cm respectively. Wavelength shifting fibers Kuraray Y11 are glued in each scintillator. Scintillation signal is register at both ends of the plate by MPPS Hamamatsu, which sensitive area are 1 mm^2 . The distance between modules can be varied from 0 to 2.5 cm. Other components such as active detectors or passive sheets of material can be inserted in these 2.5 cm gaps if required. The full detector depth can therefore be varied from 75 cm to 200 cm and in its compact form, it is 1 m^3 in volume.

A small batch of prototypes has been manufactured by Uniplast based in Vladimir (Russia) and shipped to Geneva for testing. These extruded scintillator slabs are polystyrene-based with 1.5% of paraterphenyl (PTP) and 0.01% of POPOP, similar to the plastics used for the T2K SMRD detector counters. The surface is etched with a chemical agent (Uniplast) to create a 30–100 μm layer acting as a diffusive reflector. Slabs of three different sizes have been manufactured ($895 \times 7 \times 10 \text{ mm}^3$, $895 \times 7 \times 20 \text{ mm}^3$, $895 \times 7 \times 30 \text{ mm}^3$) with 2 mm deep grooves of different

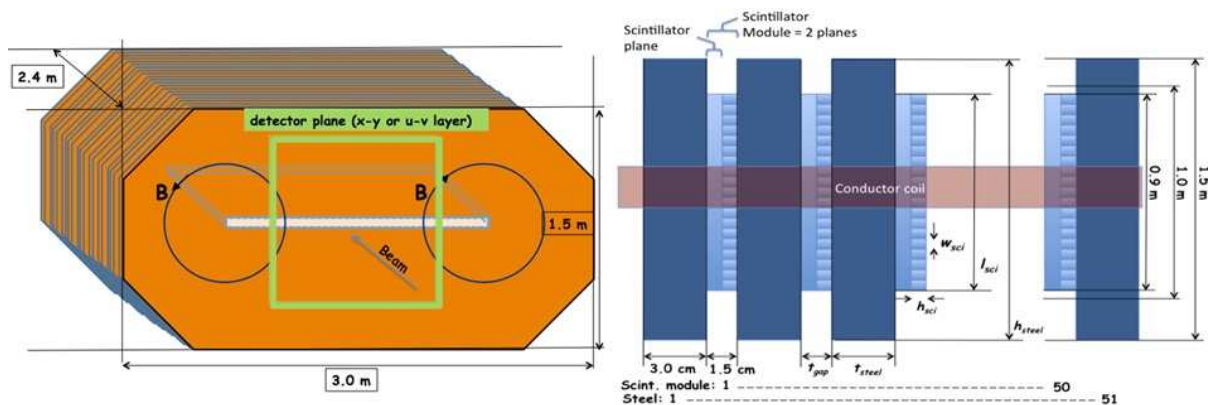


Figure 2. Sketch showing dimensions of the iron slabs and plastic scintillator modules for the baby MIND prototype.

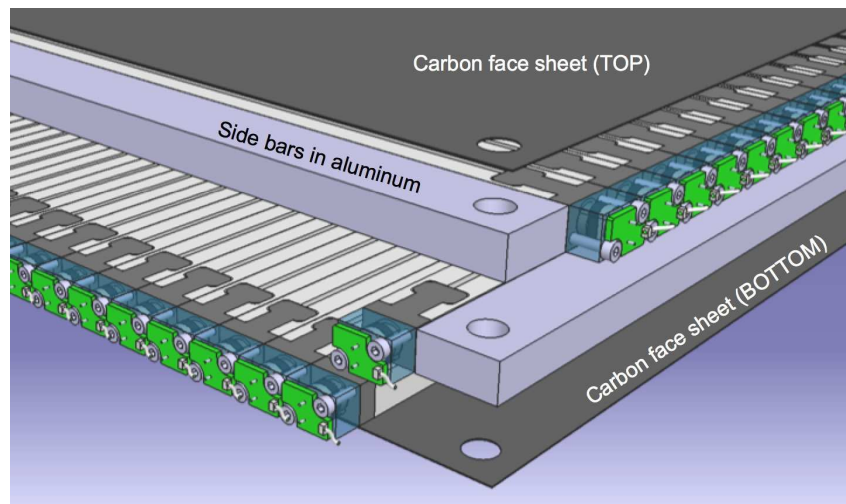


Figure 3. The T ASD prototype.

widths (1.1 mm, 1.3 mm or 1.7 mm) to embed optical fibers of different diameters (figure 4).

The result of using chemical reflector, optical grease and Tyvek reflector:

- 1) $\times 2.5$ the effect of the chemical reflector;
- 2) $\times 1.6$ the effect of the optical grease;
- 3) $\times 1.2$ the effect of the Tyvek reflector.

It is important to note, that at the now moment in the prototype detector is planned to use scintillators without optical grease and Tyvek reflector.

3. Choice of photosensor

The first silicon photomultiplier device used on a large scale in a physics experiment is the Hamamatsu MPPC S10362-13-050C instrumenting all scintillator detectors at the ND280 near detector complex of the T2K experiment [4]. This MPPC consists of 667 pixels, each working in limited Geiger mode with an applied voltage slightly above the breakdown voltage. With the production of a photoelectron in a pixel, a Geiger avalanche is generated, which is then passively

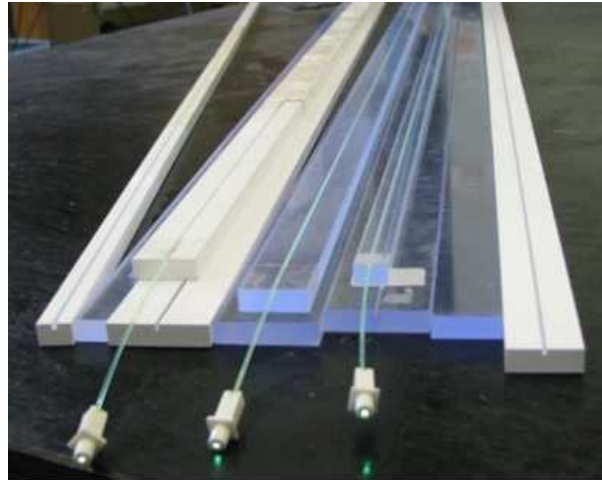


Figure 4. Different geometrics scintillators.

Table 1. Characteristics of tested photodiodes.

Parameter	Unit	MPPC-T2K	ASD-40	KETEK	SensL
Manufacturer reported specifications					
Pixel size	μm	50	40	50	20
Number of pixels	1	667	600	400	848
Sensitive area	mm^2	1.3×1.3	1.2	1.0×1.0	1.0×1.0
Gain	1	7.5×10^5	1.6×10^6	—	—
Dark rate	MHz	≤ 1	≈ 3	≤ 2	≤ 2
Bias voltage	V	≈ 70	30–50	33–50	30
Performance					
Overvoltage	V	≈ 1.4	3.6	4.5	2.7
Dark rate	kHz	900	3630	1250	1960
Cross-talk	%	10	13.4	35	9.7
Pulse shape	—	Good	Good	(long tails)	Good
Peak separation	—	Good	Good	Bad	Bad
Photon detection efficiency	%	25.6	11	26.4	14.2

quenched by a built-in resistor in each pixel. The induced charge is independent of the number of photoelectrons produced, and is directly proportional to the over voltage. In order to operate in the linear regime, where the MPPC output charge is directly proportional to the incoming photons, it is crucial that the total number of photoelectrons remains below the number of pixels in the device. The thorough work done in the selection and characterization of photosensors for the T2K experiment serves as a very good basis for the selection of photosensors for the prototypes. Photosensor design is a fast evolving field. Several manufacturers offer a variety of products. Table 1 lists characteristics and measured performance for a selection of devices from different manufacturers tested at the INR in Russia in 2013.

A good geometrical interface between the SiPM sensitive area and the fiber is a crucial step in achieving good signal transmission efficiency and signal quality. The final connector design and

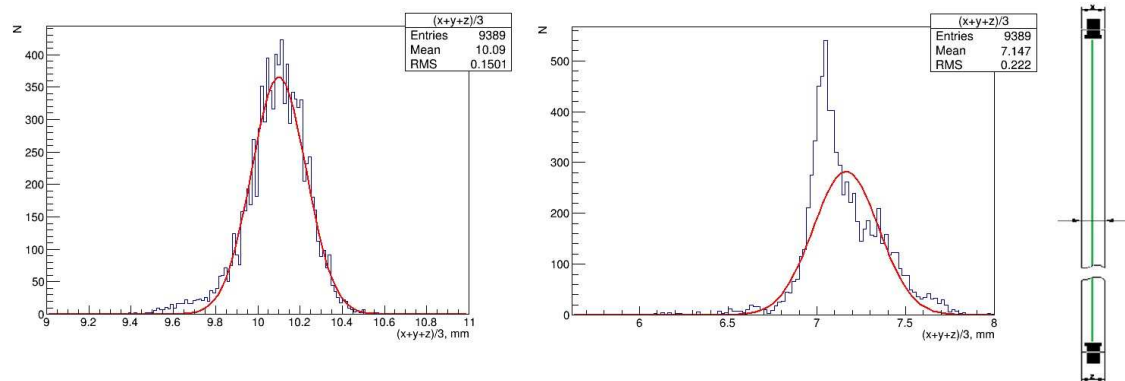


Figure 5. Distribution of measured width and thickness for plastic scintillator bars.

mass production using plastic injection moulding is carried out by the INR. Particular attention will be paid to fiber polishing and assembly stages, where quality assurance must be guaranteed, costs, and schedule controlled.

4. Results of the tests of scintillation counters.

Tests were carried out at INR to determine basic light yield and timing properties. A wavelength shifting fiber (WLS) from Kuraray (200 ppm, S-type) of $d = 1.0$ mm was embedded into the 1.1 mm wide groove with a silicon grease (TSF451-50M) to improve optical contact between the scintillator groove surface and the fiber. Hamamatsu MPPC photosensors (1.3×1.3 mm², 667 pixels, 50×50 μm^2 , gain = 7.5×10^5 , $T = 25^\circ\text{C}$) were connected to both ends of the 1 m long WLS fibers. A cosmic telescope was set up with two trigger counters. Measurements were made at the center of the scintillator slabs. The temperature during testing was $19\text{--}30^\circ\text{C}$. Timing properties were studied for the two-sided readout, combining both ends with the result (t_1 —event time result of bar one end, t_2 —event time result of bar another end): $\sigma((t_1 - t_2)/2) = 0.5$ ns. The timing is mostly determined by the fiber decay constant, $\tau = 12$ ns. On the figure 5, distribution of measured width for all plastic scintillator bars for the chosen width of 10 mm, size distribution was 150 microns. Distribution of measured thickness for plastic scintillator bars for the chosen width of 7 mm, size distribution was 222 microns. These parameters fully meet the requirements of prototypes.

The light yield was measured to be 116.5 photoelectrons at the minimum ionizing pion (p.e./MIP) on average for two photosensor (without temperature adjustments), and 124.2 p.e./MIP with temperature adjustments (figure 6). This result confirms the quality of scintillators, which were produced in Vladimir.

5. Cross-talk

Plastic scintillator bars are placed in contact to each other, for this reason cross-talk is possible (when events from one bar create false events in contiguous bars). Experiment to measure the cross-talk was held in INR (figure 7).

In this experiment, 1 and 3 scintillator bars were in additional Tyvek reflector to close the possibility of light transmission from other bars. Scintillator bars number 2, 5, 7, 8, and 9 were use like trigger counters. Events from 1 and 3, 4 and 6 were recorded (figure 8).

After summation 1 and 3, 4 and 6 we get comprehensive understanding of cross-talk. The results suggest the existence of cross-talk at the level of 7% for scintillator bars w/o additional Tyvek reflector (figure 9).

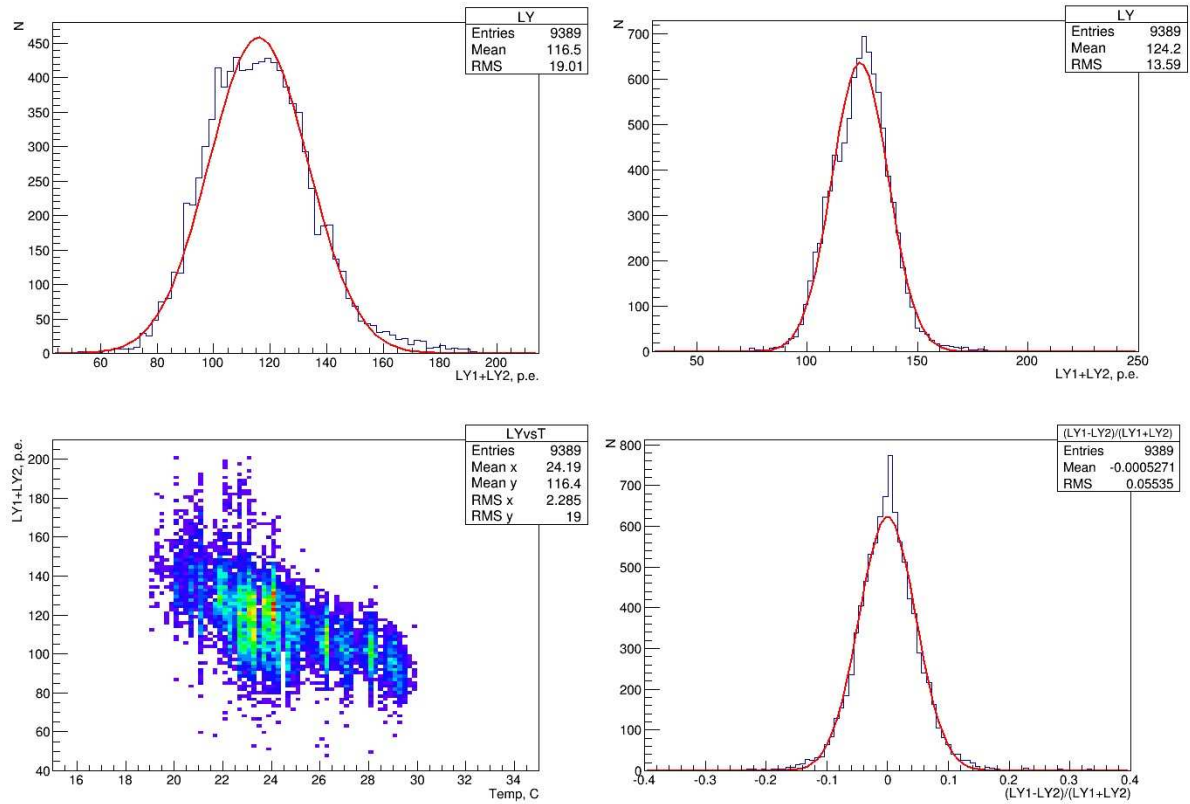


Figure 6. Distribution of measured light yield width (a—without temperature adjustments, b—with temperature adjustments ($T = 22^\circ\text{C}$), c—temperature distribution, d—LY distribution.) and thickness for plastic scintillator bars.

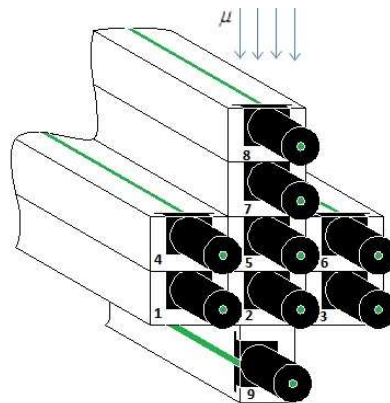


Figure 7. Experimental scheme to measure the cross-talk.

6. Beam request

The test beam is required to deliver electrons, muons and hadrons (pions and protons) in a momentum range between 0.5–5.0 GeV/c with the possibility of extending up to 9 GeV/c [5]. A

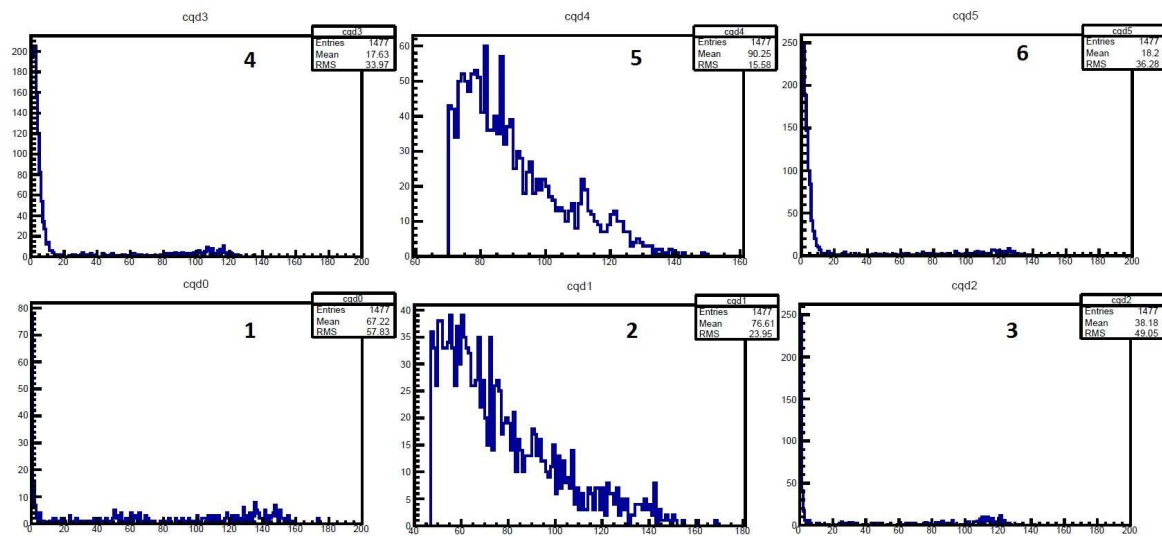


Figure 8. Result of cross-talk experiment. X—analogue to digital converter (ADS) channel, Y—number of photoelectrons

Table 2. Requirements for particles and their momenta. The particle rate here is the rate within a spill, regardless of the spill length, slow extraction is assumed.

Type	Momentum, GeV/c	Rate, kHz	Total	Time est., hour
Electron and muon charge separation, TASD in large aperture magnet				
$e^{+/-}$	0.5, 0.7, 1.0, 2.0, 5.0, (9.0)	1.0	10×10^7	170
$\mu^{+/-}$	0.5, 0.7, 1.0, 2.0, 5.0, (9.0)	1.0	10×10^7	170
Muon charge separation, MIND				
$\mu^{+/-}$	0.8, 1.0, 1.5, 2.0, 5.0, (9.0)	1.0	10×10^7	170
Hadronic shower reconstruction, MIND				
$\pi^{+/-}$	0.5, 0.7, 1.0, 2.0, 5.0, (9.0)	1.0	12×10^7	200
$p^{+/-}$	0.5, 0.7, 1.0, 2.0, 5.0, (9.0)	1.0	6×10^7	100

large aperture magnet such as the MORPURGO magnet installed in the North Area at CERN should be included in the test beam infrastructure. A possible location is the H8 beamline at the North Area (which includes the MORPURGO magnet) but could also be in the East Area which would require the installation of a suitable magnet.

Particle rates presented in table 2 are given as indication, in order to have an idea of the estimated beam time for sufficient statistics, and for an upper limit to be considered in the design of the electronics and data acquisition chains. Significant departures from these values are expected when studies of the beamline in WP8.2 are carried out, especially for low momenta particles. The rate assumed is 1 kHz, with a sample of 10^7 particles for each energy bin and configuration. It is recognized that a sample of 10^6 is probably adequate, in which case we can accept a drop in rate to 100 Hz, whilst keeping the same overall test beam time online, estimated

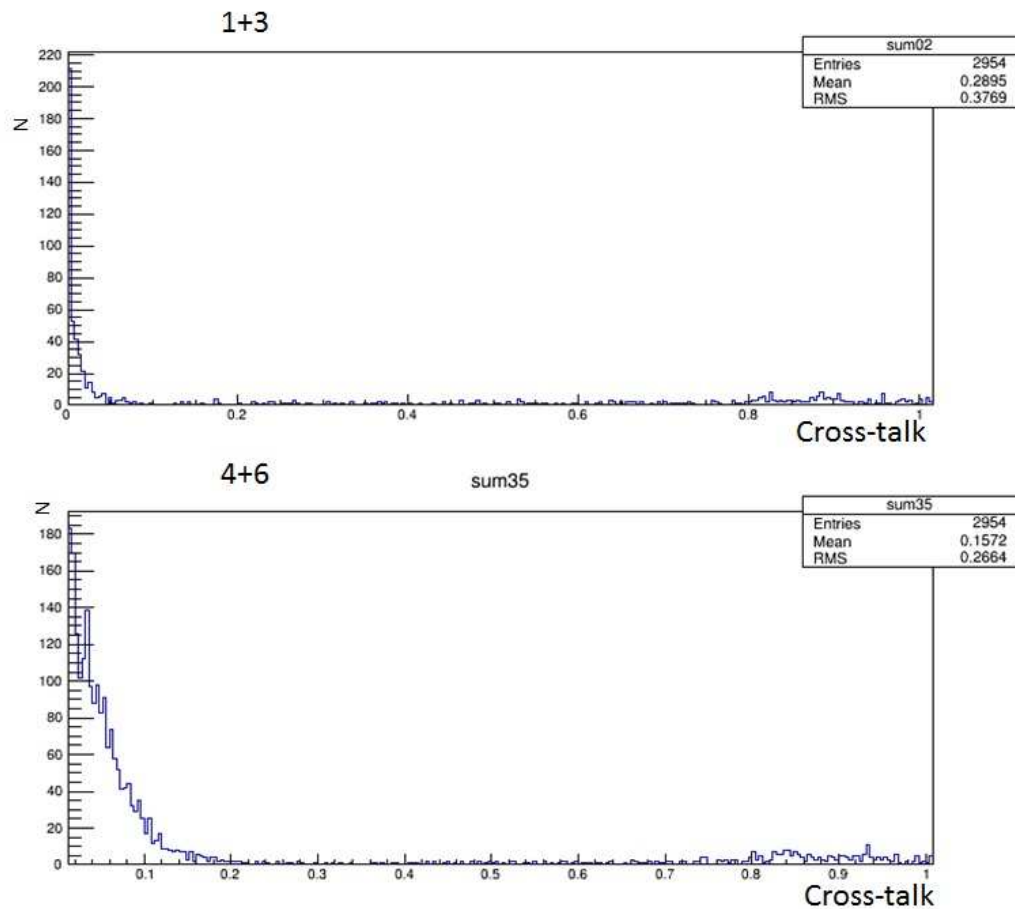


Figure 9. Result of cross-talk experiment. Percent of false events is in contiguous bars (N —number of events).

to be 16 weeks if we make the assumption of 50×10^8 triggers in total at 1 kHz with 50% running efficiency.

7. Conclusions

Scintillator bars were design and produced for T ASD and Baby MIND. The light yield was measured to be 124.2 p.e./MIP ($T = 22^\circ\text{C}$). Distribution of measured width for all plastic scintillator bars for the chosen width of 10 mm, size distribution was 150 microns. Distribution of measured thickness for plastic scintillator bars for the chosen width of 7 mm, size distribution was 222 microns. Timing properties were studied for the two-sided readout, combining both ends with the result 0.5 ns. These parameters fully meet the requirements of T ASD and Baby MIND.

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