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METHODS
OF PHYSICAL EXPERIMENT

Increase in the Light Collection from a Scintillation Strip with a Hole for the WLS Fiber Using Filling Materials of Various Types

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Abstract—The light collection of extruded scintillation strip samples with the help of WLS fibers placed in a longitudinal hole inside of the plates has been measured. The holes are filled with various liquid fillers. Measurements are performed under irradiation by cosmic muons. A method for pumping a liquid filler with a viscosity of more than 10 Pa s into the strip hole with a WLS fiber inside is devised and successfully tested.

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INTRODUCTION

Currently, detectors based on extruded plastic scintillators are essential devices used in most physical experiments in particle physics. One of their advantages is the short signal rise time τ_{rise} equal to several nanoseconds. Another no less significant circumstance is the relatively low cost of the material. Such scintillators are manufactured, as a rule, in the form of long-measuring—up to several meters—plates with different cross sections [1, 2]. The light is normally collected with the help of wavelength shifting (WLS) fibers that absorb the light irradiated by the scintillator material and reradiate it in a range close to the maximum spectral sensitivity of the photoelectric receptor. Frequently, WLS fibers are fastened with an optical adhesive on one of the faces over the entire length of the scintillator [3].

However, a more technologically feasible solution for arranging the fibers is to create extruding scintillators with holes that run inside of the scintillator over its entire length [4, 5]. Normally the diameter of the hole is 2–3 times larger than the diameter of the fiber. In such scintillators the WLS fibers are inserted into the holes and the light from the scintillator is captured by the fibers through an air gap.

When rather long scintillation strips with WLS fibers inserted into the holes are used, the amount of the light that arrives at the photoelectric receptor may appear to be insufficient. Gluing in the fibers inside of the holes can enhance the light collection [4]. The high viscosity and limited application time of the two-component adhesive, however, make the problem of filling the holes difficult to manage. In such a situation, filling the holes in the scintillators with suitable low-viscous liquids or the use of optical adhesives without a hardening compound, which eliminates the condition of the filling time/speed, may be a possible solution. In this article, the results of the tests carried out using various fillers are presented. Fillers of four types were selected, viz., distilled water, aqueous glycerin solution, the Spektr-K-59EN UV curing adhesive with an ultralow viscosity [6], and SKTN-MED grade E low-molecular rubber [7]. The characteristics of the fillers are presented in Table 1. It should be noted that at this stage of research the fillers were chosen without considering their radiation resistance and possible chemical impacts on the scintillator.

EXPERIMENTAL

Instruments and Materials

The tests were carried out using 50-cm long scintillation strips with a triangular cross section—a base of 33 mm and a height of 17 mm—with longitudinal holes 2.6 mm in diameter manufactured in ISMA (Institute of Scintillation Materials), Kharkiv, Ukraine. The strips were manufactured by extrusion molding from polystyrene with the addition of 2% PTP and 0.03% POPOP and simultaneously coated with a reflective titanium oxide (TiO_2) layer. The ends of the samples were polished and coated with a layer of mirror mylar. The doubly-clad WLS Kuraray Y11 (200) fiber 1.2 mm in diameter [8] was used, which was glued in the hole at two ends of the scintillator. To pump the fillers,

Table 1. Characteristics of the fillers used in the work

Filler designation	Distilled water	Aqueous glycerin solution	Spektr-K-59-EN UV adhesive	SKTN-MED grade E low-molecular rubber
Refractive index (20°C)	1.333	1.388	1.460	1.606
Dynamic viscosity, mPa s	1	20	20	10000
Comments		43-% solution		No hardening compound used

threaded holes with plastic plugs were made on the surface (base) of the strips (Fig. 1).

An EMI 9814B photomultiplier with a photocathode 51 mm in diameter was used as a photoelectric receptor. The trigger counters were based on SensL SiPM photomultipliers with a size of 3×3 mm^2 with a scintillator of $20 \times 20 \times 20$ mm^3 (Fig. 2). These counters have output signals in both analog and digital formats.

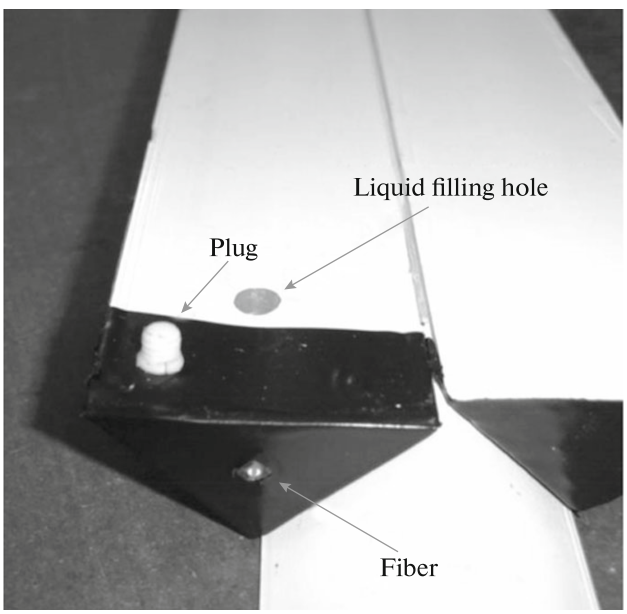

Fig. 1. Scintillation strip samples.

Experimental Conditions

The measurements were performed by comparing the light collection from the same “dry” strips (without fillers) and those filled with a certain liquid under irradiation by cosmic muons. The light was collected only from fibers that had an optical contact with the PMT window through an optical lubricant. Two pairs of counters were used as the cosmic muon trigger, i.e., the spectra were picked up at two points simultaneously (Fig. 3). The scintillators of the trigger counters were adjusted for the center across the strip, thus covering an area of the investigated strip of 20×20 mm^2. The fillers were pumped into the holes in two ways, viz., liquid fillers such as water, glycerin, and the UV curing adhesive were pumped manually through a syringe and the viscous rubber using a compressor and a pressure proportioner (see below).

The amount of the light collected in photoelectrons was assessed by the absolute calibration method [9]. Since the paths of the cosmic muons in the scintillator material are extremely different—from 4 mm to the size of the cathetus of 24 mm for normally incident muons—due to the triangular cross section, the signal wavelength spectrum is wider than that in the case of a rectangular strip (see Fig. 4).

The data-acquisition system (Fig. 5) was implemented in the following way. The signals from two pairs of trigger counters, after passing through the comparator and, in pairs, the coincidence circuit, were accumulated and delivered to the gate generator input. The latter, in turn, generated a signal of a definite duration (a strobe pulse) to a LeCroy 2249W charge-to-digital converter (CDC) input, thus trigger-

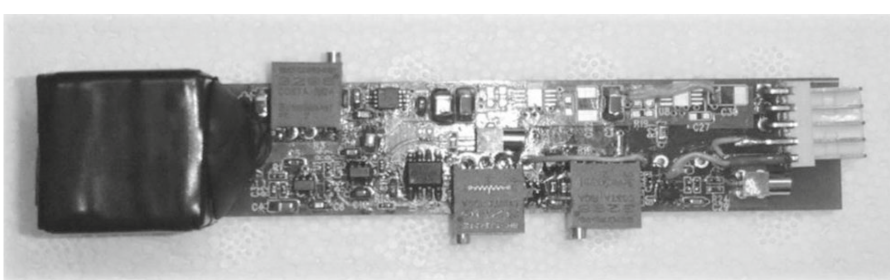

Fig. 2. A SensL-SiPM-based trigger counter.

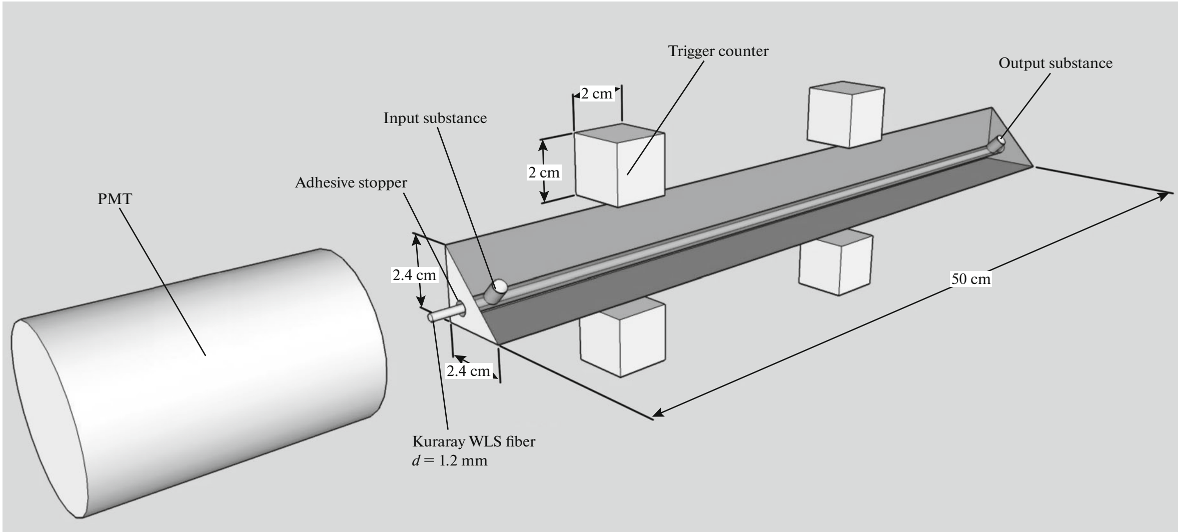

Fig. 3. Schematic arrangement of the components.

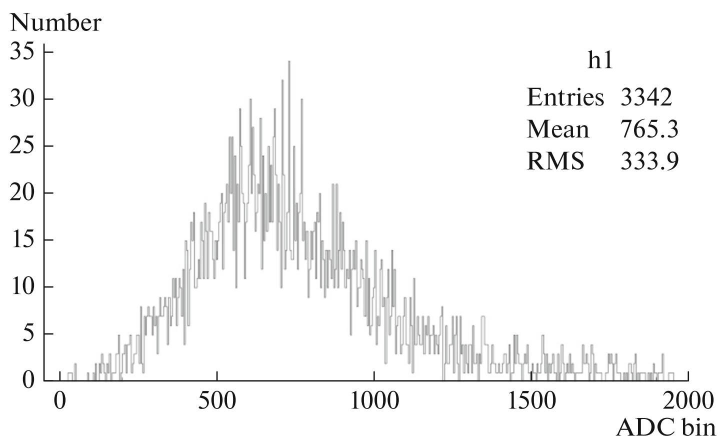

Fig. 4. A typical spectrum of cosmic muons for a triangular scintillation strip.

ing the processing of the signal that arrived from the basic PMT. Simultaneously, the next-signal-entry inhibit was generated. The digitized signals from the CDC were read out by a computer with the input register indicating the activated pair of the trigger counters.

Filler Pumping Methods

As was mentioned above, to pump water, glycerin, and the UV adhesive into the scintillation strip sample, a conventional syringe and a transparent tube were used. The syringe was connected to the first hole and the tube was inserted into the second one and the contents were squeezed out until the liquid started to flow out of the tube. The process was continued until all air bubbles were forced out. Finally, plastic plugs were screwed into the holes.

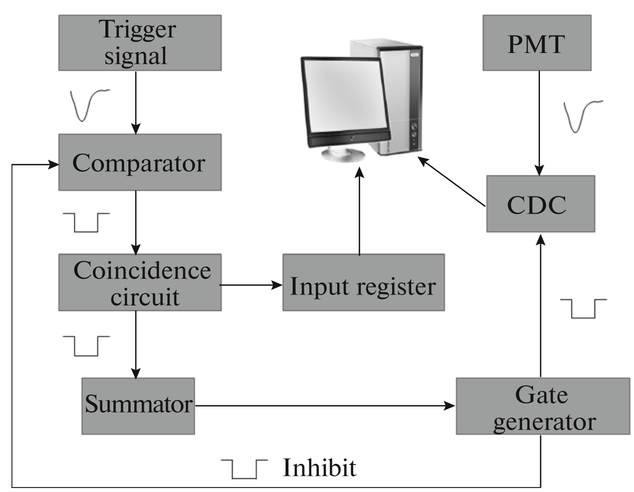

Fig. 5. Data-acquisition system.

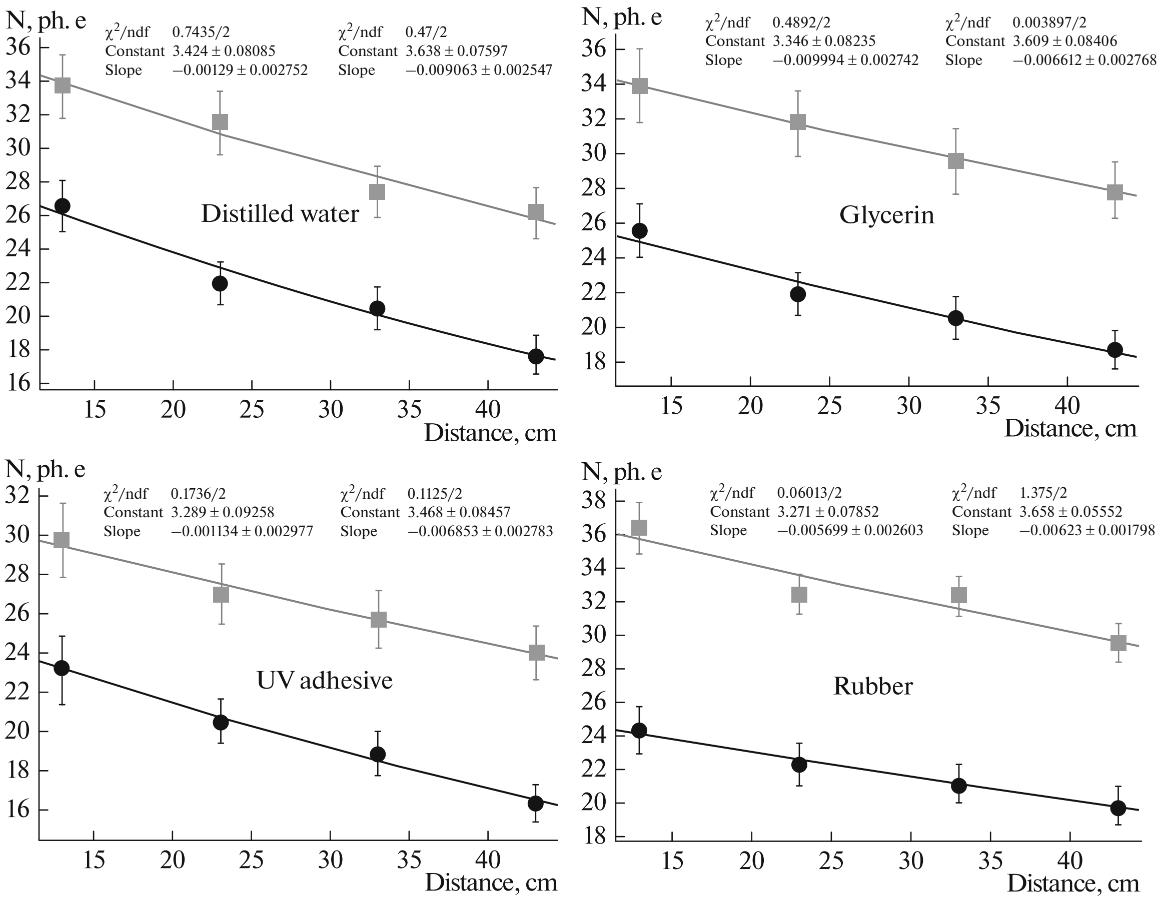

Fig. 6. Light collection from strips with fillers of various types. The circles indicate strips without the filler and the squares indicate the strips with the filler.

Viscous rubber was pumped in through a commercial Fisnar compressor for supplying air to the dosing apparatus [10] and further to the container with liquid rubber. Excess pressure in the dosing apparatus of 0.2 atm was selected experimentally. Under such a low constant pressure, the rubber was slowly pressed out into the tube connected to the hole in the scintillation strip. It took 30 min to fill the hole in the 50-cm strip. Previously, experiments with strip samples without the TiO_2 layer had been conducted. The results showed that the holes were satisfactorily filled without displaying any air bubbles. After being filled with rubber, the holes were sealed by putting a small amount of the hardening compound into both holes.

Table 2. Total light collection gain with regard to each filling material

Filler	Distilled water	Aqueous glycerin solution	SKTN rubber	Spektr UV adhesive
Light collection gain, %	38 ± 6	43 ± 6	50 ± 5	36 ± 6

RESULTS AND DISCUSSION

In Table 2, the final results of enhancing the light collection with regard to each filling material are presented. The measurements were performed in four fixed positions 13, 23, 33, and 43 cm away from the PMT window plane. For every position, a signal spectrum was picked up and the mean value of the photoelectrons was determined by the absolute calibration method. The results of the measurements are presented in Fig. 6. The data were fitted by the function $f(x) = \exp^{p0+p1*x}$.

The data obtained without using the filler are indicated by circles; those obtained using the corresponding filler are shown by squares. The sequence of the diagrams is as follows (from left to right and from top to bottom): distilled water, aqueous glycerin solution, the UV adhesive, and low-molecular rubber.

As a result, all four liquids produced a gain in the light collection of 36–50% compared with a strip without the filler. The largest gain in the light collection produced the SKTN-MED grade E low-molecular rubber indicated by circles.

CONCLUSIONS

Samples of extruded scintillation strips with longitudinal holes and WLS fibers inserted into the holes were tested for enhancing the light collection using various optical filling materials.

Fillers of four types were investigated, viz., distilled water, aqueous glycerin solution, the Spektr-K-59-EN ultralow-viscous UV adhesive, and the SKTN-MED grade E low-molecular rubber.

A method for pumping the filler with a viscosity of more than 10 Pa s into the holes of the strips 2.6 mm in diameter with WLS fibers 1.2 mm in diameter inside was devised and tested. It took 30 min to fill the hole in the 50-cm strip.

Filling the holes in scintillation strips with low-viscous optical liquids, as well as viscous adhesives, e.g., SKTN-MED grade E rubber, without adding hardeners to increase the light collection might be a good alternative to gluing fibers, which is especially difficult in the case of long scintillation strips.

It is shown that the use of various liquid filling materials between the WLS fiber surface and the scintillator material produces a gain in the light yield of 36–50% compared with samples with air gaps.

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