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Research and development of fast-timing large-area thin detector

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We are developing a thin and large-area plastic scintillation counter attached by wavelength shifting fibers for a fast timing detector of good time resolution. It is the most effective to increase the light yield and to reduce the time jitter that the plastic scintillator plate with the polished surface is wrapped by a white-painted box and it is also important that the gap between a wavelength shifting fiber and a groove is filled up with optical grease. Taking uniformity of the light yield into account, we should wrap a plastic scintillator plate by a white-painted box and array wavelength shifting fibers separately rather than concentratedly in a scintillator plate. We have a bright outlook for success in the development of the thin detector with small time jitter and sufficient light yield suitable for the fast timing detector in an air shower array.

1. Introduction

For an air shower array to observe cosmic rays of sub-TeV energy region, it is important to increase the coverage rate of particle-sensitive area to the total array area. For this purpose, it is necessary to enlarge the area of each detector considering the cost performance. Simple enlargement of a plastic scintillation detector used in a current air shower array makes the detector box too huge and time resolution poor. We are developing a thin and large-area plastic scintillation counter attached by wavelength shifting (WLS) fibers for a fast timing detector of good time resolution. The recent results of our development are presented in this paper.

2. Experimental setup

We test a plastic scintillator plate with a WLS fiber [1] as the simplest one. We groove the scintillator plate to embed WLS fiber(s). The wavelength of scintillation light produced in the scintillator plate is converted to a longer wavelength by the WLS fiber embedded in the plate. Converted light is transmitted to a photomultiplier tube (PMT, Hamamatsu R329) by the WLS fiber [2]. The WLS fiber is coupled to the PMT with optical grease (Fig. 1). A signal from the PMT connected to the WLS fiber is digitized using a CAMAC charge ADC module (REPIC RPC-022) and a TDC module (REPIC RPC-061), and readout with a PC.

In this paper, we report recent results using a 200 mm-square and 10 mm-thick plastic scintillator (CI KOGYO, POPOP 0.03%) and a 300 mm-long WLS fiber (Kuraray Y11) with a diameter of 2 mm. First, we measure the light yield of two kinds of WLS fiber, Y11 and BCF91-A (SAINT-GOBAIN). Because the number of photoelectrons of the PMT from Y11 is 1.3 times as large as that from BCF91-A, we adopt Y11. We embed the WLS fiber inside the groove with optical grease as shown in Fig. 1. As a result of a measurement, the light yield is 1.2 times as much as that without optical grease. Figure 2 shows a typical signal waveform converted by the WLS fiber when a cosmic-ray muon penetrates the scintillator plate.

We measure the number of photoelectrons and time jitter when a cosmic-ray muon penetrates through the scintillator under various settings. Prior to the measurement, we confirm that one photoelectron peak corresponds to 0.63 pC in charge by measuring the signal from the PMT that received the light of a LED lit weakly.

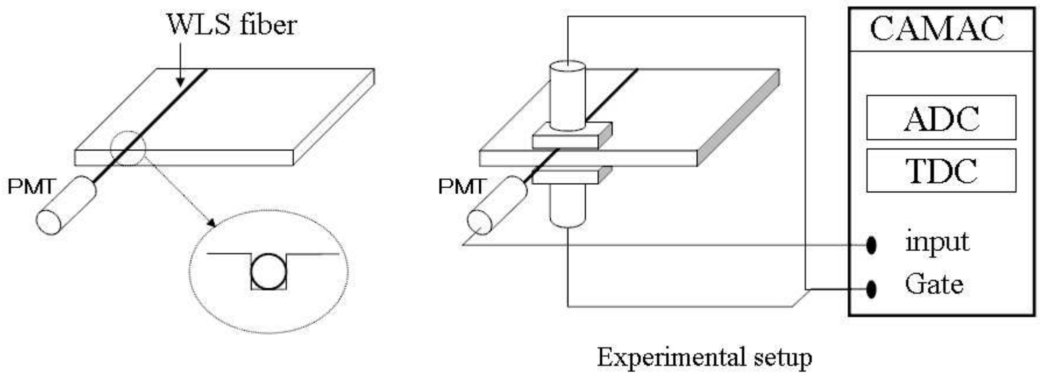

Figure 1. Schematic illustration of the scintillation plate and the WLS fiber system with PMT.

The target scintillator sandwiched with the WLS fiber is placed between two trigger scintillation counters, each of which is 50 mm square and 10 mm thick in size as shown in Fig. 1. The spacing of two trigger counters is 100 mm. Two kinds of trigger location on the scintillator plate are used to measure uniformity of transverse response. First, the two trigger scintillation counters are set just above and just below the WLS fiber (position 1). Second, the two trigger scintillation counters are set to a location away from the WLS fiber by 100 mm perpendicularly (position 2).

A trigger signal is generated when both of the two trigger counters are hit. The TDC is started by the signal of the upper trigger counter, and stopped by the signal from the PMT of the target scintillator plate. We collected 10000 muon events that penetrate through the target scintillator plate at each setting as describe in §3. The mean charge value of the 10000 events divided by 0.63 pC/p.e. is used for the number of photoelectrons to evaluate light yield, and the timing root mean square (RMS) of the 10000 events is used for the time jitter. Figure 3 shows a typical distribution of light yield in number of photoelectrons and time distribution for 10000 muon events. Details are described in §3 and §4.

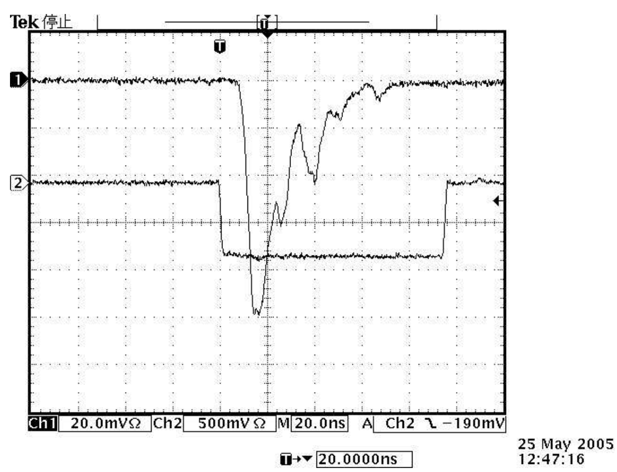

Figure 2. A typical signal waveform converted by the WLS fiber when a muon penetrates the scintillator plate.

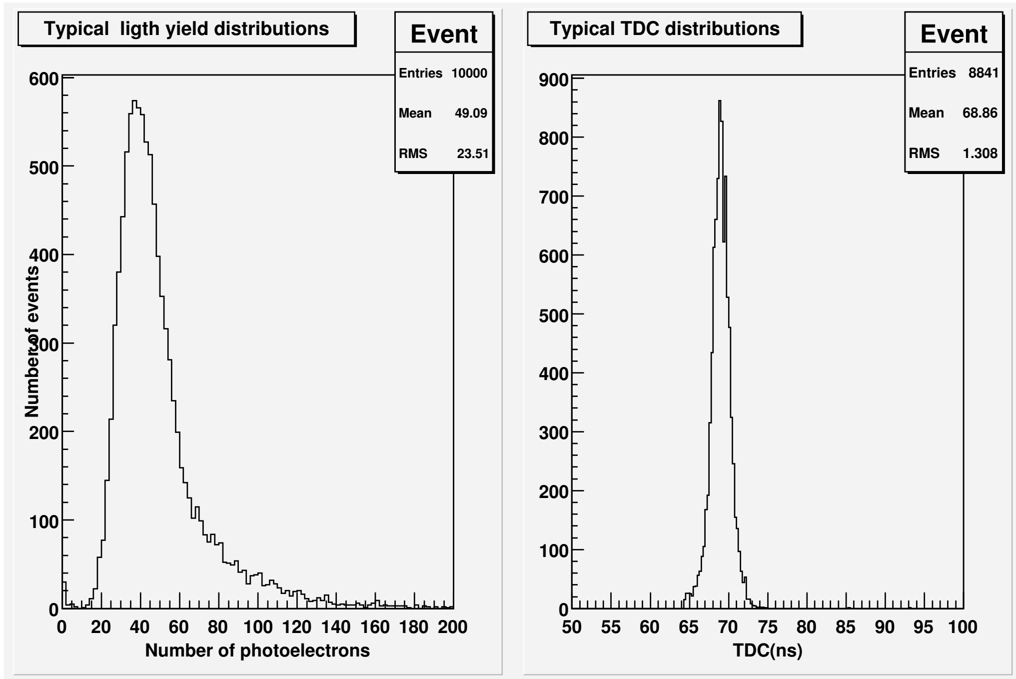

Figure 3. A typical distribution of light yield in number of photoelectrons and time distribution for 10000 muon events.

3. Light yield and time jitter

It is rare that scintillation light enters the WLS fiber directly. In most cases, light enters the fiber after some reflections at the surface of the scintillator plate. In this section, we examine the light yield and time jitter under various settings.

We measure the light yield and time jitter under the polished and sandy cases on the scintillator plate surface, and the scintillator is wrapped up in three cases as follows: black paper, aluminum foil and white-painted box (settings A–D). WLS fiber embedded in the polished scintillator with white-painted box can correct lights most efficiently in settings A to D. We can also see that the time jitter becomes smaller as the light yield increases.

Next, we discuss the number of WLS fibers, embedded per groove of the plastic scintillator plate, dependence of the light yield. Number of the WLS fibers per groove we measure is set to 1, 2, 3 and 4 corresponding to groove depth of 2, 4, 6 and 8 mm, respectively (settings E–H). The WLS fibers in groove are filled up with optical grease. The surface and wrapping condition of the scintillator is the same as setting C. The settings E–H in Table 1 show the number of WLS fibers dependence of light yield and time jitter. The best number of WLS fibers per groove is two considering the cost performance.

4. Transverse uniformity of light yield

In this section we discuss the transverse uniformity of the light yield within the scintillator plate. The light yield depends on a transverse distance between the WLS fiber and the location where a cosmic-ray muon hits the scintillation plate. The ratios of the numbers of photoelectrons ($N^1_{\rm pe}/N^2_{\rm pe}$) are shown in Table 1 under

Table 1. Number of photoelectrons and time jitter under various settings.

				Position 1		Position 2		
Setting	scinti. surface	wrapping	No. of WLSs	No. of p.e. ($N_{\rm pe}^1$)	time jitter (ns)	No. of p.e. ($N_{\rm pe}^2$)	time jitter (ns)	$N_{\rm pe}^1/N_{\rm pe}^2$
A	sandy	black	2	19.3	2.75	5.0	5.47	3.9
B	sandy	aluminum	2	45.7	1.38	13.3	3.32	3.4
C	polished	aluminum	2	56.0	1.31	24.8	1.90	2.3
D	polished	white	2	64.0	1.24	38.0	1.68	1.7
E	polished	aluminum	1	27.1	1.81	14.3	3.10	1.9
F	polished	aluminum	2	56.0	1.31	24.8	1.90	2.3
G	polished	aluminum	3	66.1	1.25	33.7	1.99	2.0
H	polished	aluminum	4	77.0	1.21			

various settings, where $N_{\rm pe}^1$ and $N_{\rm pe}^2$ are the number of photoelectrons when a cosmic-ray muon hits near the WLS fiber (position 1) and away from it by 100 mm (position 2), respectively. Among various conditions of the surface of the scintillator plate and wrapping, polished scintillator plate wrapped by white-painted box (setting D) gives the best uniformity of the light yield. We found that the polished scintillator surface gives better uniformity than sandy one, because the scintillation light does not escape from the scintillator plate to be guided by the total reflection on the polished surface. The results of setting E to H show that it is hardly effective to embed more than one WLS fiber to a groove. Therefore, we think it is better for the uniformity of the light yield to array WLS fibers separately rather than concentratedly in a scintillator plate.

5. Conclusions

It is the most effective to increase the light yield and to reduce the time jitter that the plastic scintillator plate with the polished surface is wrapped by a white-painted box and it is also important that the gap between a WLS fiber and a groove is filled up with optical grease. Taking uniformity of the light yield into account, we should wrap a plastic scintillator plate by a white-painted box and array WLS fibers separately rather than concentratedly in a scintillator plate.

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