Development of fast timing plastic scintillation counter of thin and large area type applying wavelength-shifting fiber

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***Abstract*— We are developing a thin and large-area fast timing plastic scintillation counter by attaching wavelength-shifting (WLS) fiber as air shower detector of the Tibet air shower array. Plastic scintillator of 1 cm thick and a unit of 20 $\times$ 20 cm^2 with 4 WLS fibers of 1 mm diameter was found to give enough light yield and small time jitter of less than 1.5 ns. This performance is sufficient for the requirements of fast timing to detect incident directions of air showers with high resolution. This experimental performance was practically reproduced by the simulation.**

I. 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 area of array. For this purpose, it is necessary to enlarge the area of each detector considering the total cost. A simple enlargement of plastic scintillation detectors used in current air shower arrays makes volumes of detectors too huge and gives poor time resolution. 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. The recent results of our development will be presented in this paper.

II. Experimental

A. Experimental setup

We test a plastic scintillator plate with a WLS fiber [1] as shown in Figure 1. We carved grooves on scintillator plate to embed WLS fibers. 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. 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 read out 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 1600 mm-long WLS fiber (Kuraray Y11) with a diameter of 1 mm. We embed the WLS fiber inside the groove which is filled with optical grease. The surface of plastic scintillator plate was transparency by polished and tightly with which was wrapped with white box painted with VH enamel inside. We measure the number of photoelectrons and time jitter when a cosmic ray muon penetrates through the scintillator plate. Figure 2 shows a typical example of signal waveform generated by single CR muon.

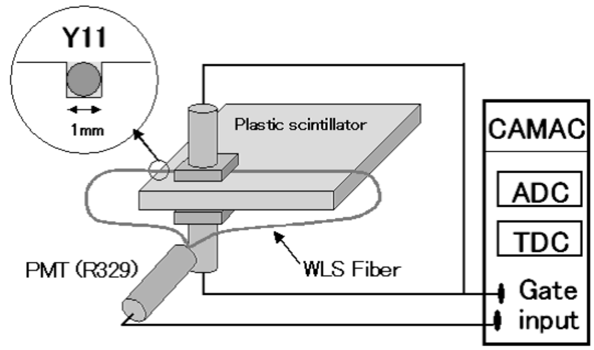

Fig. 1. Schematic illustration of experimental setup

B. Definition of mean photoelectron yield and time jitter

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 is lit weakly with blue light of a LED. The tested scintillator plate is sandwiched by two small trigger scintillation counters of size 50 mm square and 10 mm thick as shown in Figure 1. The spacing between two small trigger counters is 100 mm. Three kinds of location on the scintillator plate are used to measure the positional uniformity of photoelectron yield and timing response for triggers by incidences of cosmic ray muon. The TDC is started by the signal of the upper trigger counter, and stopped by the signal from the PMT of the scintillator plate. We collected 10,000 muon events that penetrate through the scintillator plate under various setting. In order to determine the mean of photoelectron yield given by a muon, we fit the charge distribution for 10,000 muons near the peak with the Landau function[3]. We fit the TDC distribution for 10,000 muons with the Gaussian and defined Sigma as Time jitter.

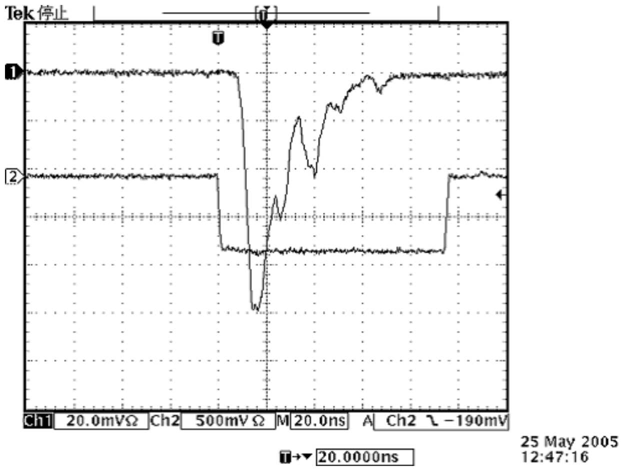

Fig. 2. TUpper curve shows typical signal waveform by a cosmic-ray muon. Lower rectangular waveform shows an ADC gate signal

III. Number of WLS fibers and light yield

We tried a case that the depth of groove is 8 mm and embed 4 WLS fibers of 2 mm in diameter[4]. For this case CR muons which hit the position around the groove gave the mean of photoelectron yield of as twice large as the case of position with distance 10 cm from the groove. Then we increased number of WLS fiber of 1 mm diameter up to five aside (Figure 3). The cosmic ray muon trigger counters were set at positions 1,2,3 as seen in Figure 3. The mean values of detected photoelectron numbers are plotted by closed marks in Figure 4. As increasing the number of fibers, the mean of photoelectron yield increases about 5 at the center of scintillator plate. We can also see that the mean of photoelectron yields at the center of plate (position 3) tends to become higher than ones from the case that the CR muon hit near the fiber (position 1 or 2). The uniformity of photoelectron yield achieved 5 % for the case of 3 WLS fibers and 10 % for the case of 4 WLS fibers.

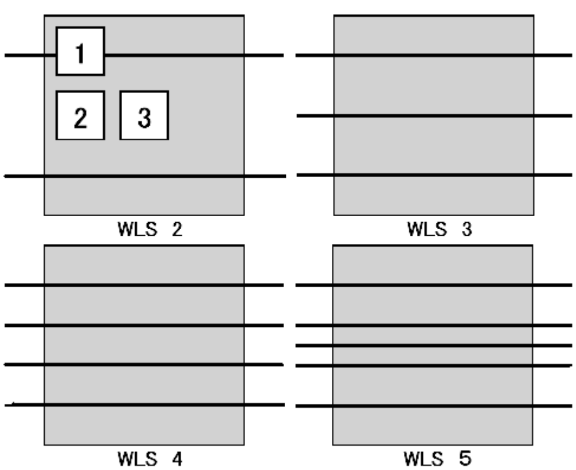

Fig. 3. Top view of test scintillator counters and arrangement of WLS fibers. Signals by cosmic ray muons passing through positions 1, 2, 3 are examined for each arrangement.

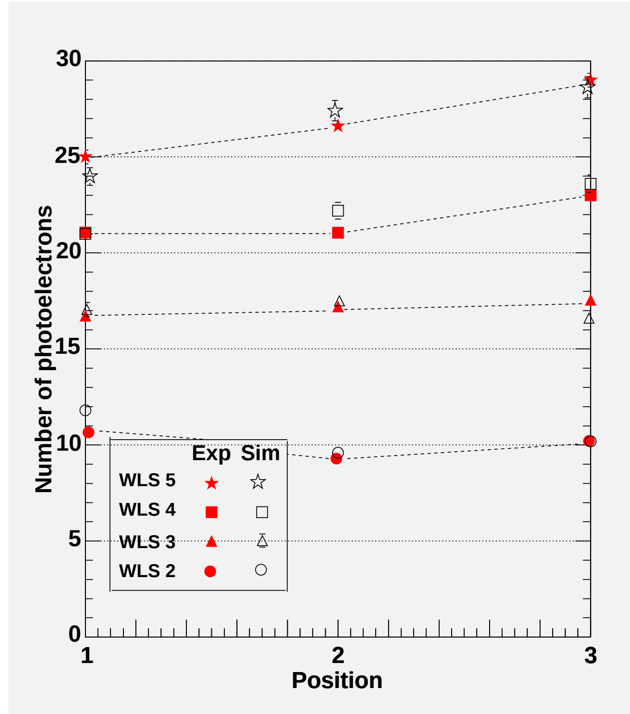

Fig. 4. Mean of photoelectron yield at each position. Closed marks show experimental value and open marks show results of the simulation.

TABLE I

Time jitter at Position 3 for each arrangement.

	WLS 2	WLS 3	WLS 4	WLS 5
Exp - Time jitter [ns]	1.86	1.51	1.22	1.16
Sim - Time jitter [ns]	1.89	1.49	1.28	1.19

Table 1 shows magnitudes of time jitter at position 3. It shows that the time jitter becomes smaller as the number of fibers increase. This is understood by the fact that time resolution of PMT is mainly dependent on the number of photoelectrons per one pulse.

IV. Simulation

To determine the best setup of the number and arrangement of WLS fibers, we made a simulation for mean of photoelectron yields and the time jitter in this detection system using Geant4 (version 4.7.1). Simulated muon events were generated on the same configuration as the experiment. After 1000 cosmic muons fired into the plastic scintillator plate, we counted the number of photons which reached to the end of WLS fibers, and recorded the photon's arrival time for every muon events.

Consequent number of photoelectrons and the generated time were calculated, considering the quantum efficiency of PMT. It was confirmed that simulated the mean of photoelectron yield for cases that CR muon hit the scintillator plate of 20 cm $\times$ 20 cm at positions 1, 2, 3 are well in agreement with the experimental value as shown by closed marks in Figure 4.

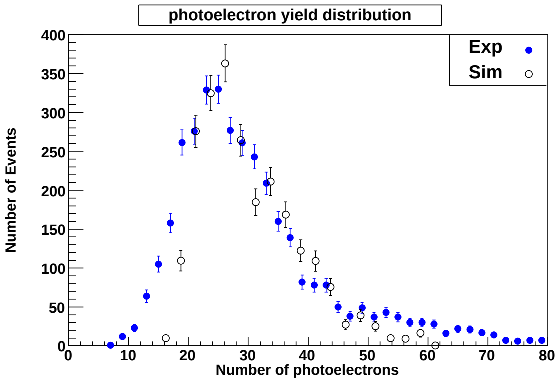

Fig. 5. Detected photoelectron distribution with 4 WLS fibers at Position 3. Open and closed circles indicate experimental data and simulation, respectively.

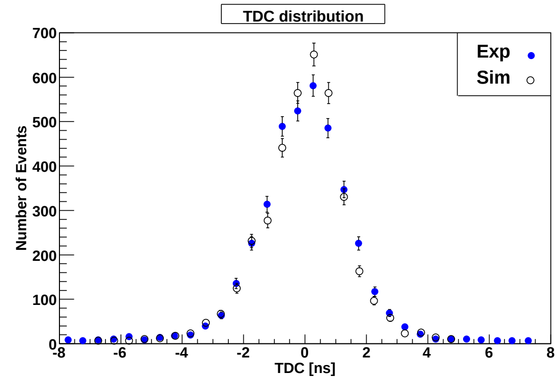

Fig. 7. Time jitter distribution with 4 WLS fibers at Position3. Open and closed circles indicate experimental data and simulation, respectively.

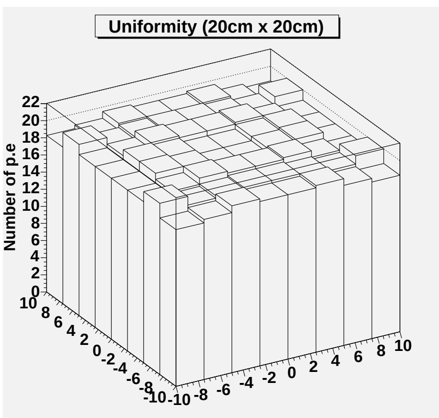

Fig. 6. Uniformity of detected photoelectron in 20 cm x 20 cm unit by the simulation

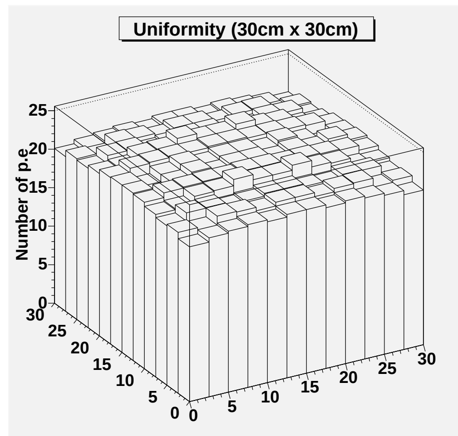

Fig. 8. Uniformity of detected photoelectron in 30 cm x 30 cm unit by the simulation

The simulated distribution of the number of photoelectrons is roughly consistent with experimental data as shown in Figure 5.

As for the information of timing, magnitude of time jitter are presented in Table 1. These value were calculated, considering the time generated first photoelectron and T.T.S(Transit.Time.Spread)[5] of PMT and the time spread of TDC start pulse. The simulated distribution of TDC count is roughly consistent with experiment as shown in Figure 7.
By the result of simulation we confirmed that the number of fibers is preferred to be three or more and intervals between WLS fibers are not over 5 cm respectively for the case of 20 cm $\times$ 20 cm unit. The difference $\pm$ 5 % was achieved for photoelectron numbers beteween cases of CR muons hit the center and a corner of the scintillator plate. Simulation is also done for a case of 30 cm $\times$30 cm plastic scintillator plate in which 6 WLS fibers are embedded with intervals of 5 cm, and uniformity of photoelectron yield was estimated to be $\pm$ 6 %. Figure 6 and 8 show response maps for them. Time jitter of the one unit is estimated to be 1.31 ns in 20 cm $\times$ 20 cm, and 1.42 ns in 30 cm $\times$ 30 cm.

V. Conclusion

Plastic scintillator of 1 cm thick and a unit of 20 $\times$ 20 cm^2 with 4 WLS fibers of 1 mm diameter was found to give enough light yield and small time jitter of less than 1.5 ns. This performance is sufficient for the requirements of fast timing to detect incident directions of air showers with high resolution. This experimental performance was practically reproduced using Geant4 code. Consequently, we can discuss about various setups in a simulation now.

Acknowledgment

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