

Systematic studies of small scintillators for new sampling calorimeter

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Abstract. A new sampling calorimeter using very thin scintillators and the multi-pixel photon counter (MPPC) has been proposed to produce better position resolution for the international linear collider (ILC) experiment. As part of this R&D study, small plastic scintillators of different sizes, thickness and wrapping reflectors are systematically studied. The scintillation light due to beta rays from a collimated ⁹⁰Sr source are collected from the scintillator by wavelength-shifting (WLS) fiber and converted into electrical signals at the PMT.

The wrapped scintillator that gives the best light yield is determined by comparing the measured pulse height of each $10 \times 40 \times 2$ mm strip scintillator covered with 3M reflective mirror film, teflon, white paint, black tape, gold, aluminum and white paint+teflon. The pulse height dependence on position, length and thickness of the 3M reflective mirror film and teflon wrapped scintillators are measured.

Results show that the 3M radiant mirror film-wrapped scintillator has the greatest light yield with an average of 9.2 photoelectrons. It is observed that light yield slightly increases with scintillator length, but increases to about 100% when WLS fiber diameter is increased from 1.0 mm to 1.6 mm. The position dependence measurement along the strip scintillator showed the uniformity of light transmission from the sensor to the PMT. A dip across the strip is observed which is 40% of the maximum pulse height. The block type scintillator pulse height, on the other hand, is found to be almost proportional to scintillator thickness.

Keywords. Calorimeter; scintillator; multi-pixel photon counter; wavelength-shifting fiber.

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1. Introduction

Beam experiments were conducted at the High Energy Accelerator Research Organization, KEK, Japan in 2002 and 2004 [1,2] to evaluate the detector designs for the international linear collider (ILC) calorimeters. The experiments tested a $10 \times 200 \times 2$ mm strip array electromagnetic calorimeter (EMCAL) and a 40×40 mm tile EMCAL. Since the physics at ILC demands an excellent ability to identify and separate showers coming from different particles entering the calorimeter, the

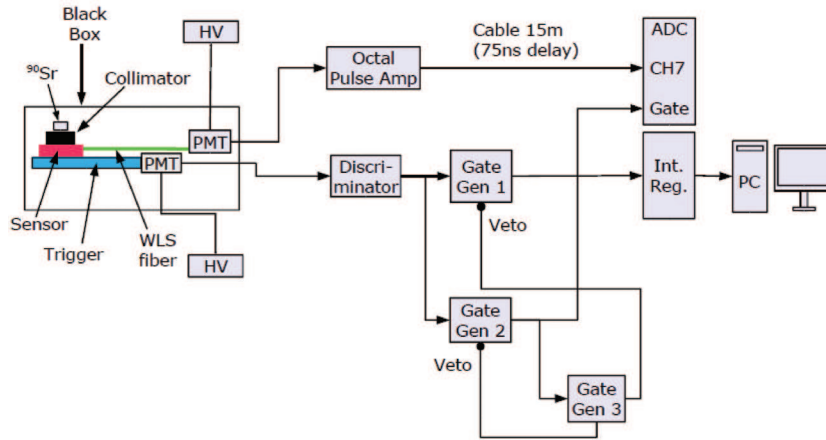


Figure 1. The experimental set up.

recent GLD designs feature finer segmentation calorimeters both in transverse and longitudinal directions [3].

The hadron calorimeter (HCAL) will be composed of 46 layers of strip and tile type scintillators. The multi-pixel photon counter (MPPC) or the silicon photomultiplier (SiPM) will be used and should be directly connected to the wavelength shifting fiber (WLS) at the end of every scintillator. The EMCAL, on the other hand, will be composed of 30 layers of strip scintillators and tungsten absorbers. Each scintillator layer is also placed orthogonal to each other [3]. Optimal results from these type of configurations are still not certain and hence this study aims to determine the optimum size of strip scintillator and the best wrapping reflector for excellent light collection efficiency.

Figure 1 shows the bench test set up. Strontium 90 (^{90}Sr) is used as beta source collimated at 0.5 mm. A $10 \times 80 \times 5$ mm scintillator is utilized as trigger and is directly connected to the Hamamatsu H3164 PMT with -900 V high voltage source while a 16-channel multi-anode PMT Hamamatsu H656810 with HV source of -950 V is used as readout for the sensor through the 20-cm WLS fiber with diameters of 1.0 mm and 1.6 mm. These are all enclosed in a black box to prevent light leaks.

The experiment measured the light yield efficiency of small strip type scintillators 10 mm wide, 2 mm thick and lengths of 40, 60, 80, 120 and 160 mm with seven different wrapping reflectors; 3M radiant mirror film, teflon, black tape, white paint, gold coat, aluminium coat, and white paint + teflon. This study also measures the light yield of 10×10 mm block scintillators whose thickness are 2, 4, 5, 6, and 8 mm.

The pulse height distribution is fitted with 3 functions (Gaussian, Landau and Landau-like [2] functions) and the best fit is used. We first measured the light yield from each $10 \times 40 \times 2$ mm scintillators with different wrapping reflectors and considered the best two reflectors for different lengths of scintillators. The beta source is consistently placed at one point in the scintillator during the ADC measurement for the light yield efficiency. For the strip type, the source point is

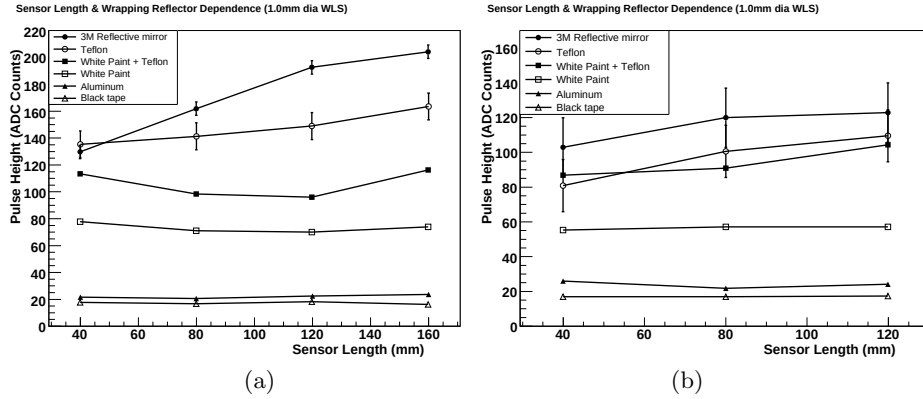


Figure 2. Sensor length and surface covering dependence on pulse height through (a) 1.0 mm Φ WLS fiber and (b) 1.6 mm Φ WLS fiber.

located at 10 mm from the far end (of the PMT) and 2.5 mm from the side. For the block type, the source point is at 2.5 mm from the side and 5 mm from each end.

The measured pulse heights from each strip scintillators are then plotted against the sensor length with different surface coverings. The position dependence along and across the strip scintillators for the best two wrapping reflectors are measured and compared. The block scintillator thickness dependence on pulse height for teflon and 3M radiant mirror film wrapped scintillators are also plotted. Furthermore, the systematic error which may be caused from the uneven or unpolished sensor surface and groove/hole is also determined.

2. Results and discussions

2.1 Bench test

Figure 2 shows the pulse height in ADC counts plotted against the scintillator length. The results show that the 3M radiant mirror wrapping reflector gives the best light yield for both sizes (diameter) of WLS fiber. A trend of slightly increasing pulse height with increasing sensor length is observed for 3M radiant mirror film and teflon wrapped sensors.

Result in figure 3 shows no significant change in pulse height along the length of the strip. This denotes a uniformity of light transmission from the sensor to the PMT.

However, figure 4a reveals a dip at the center of the scintillator which is 40% of the maximum pulse height. This corresponds to the scintillator thickness (300 microns) just below the 1.6 mm Φ fiber (groove). Small peaks are noticeable near the 1.6 mm WLS fiber which shows that more light is collected at points near the fiber. It also shows that the light yield increases about 100% as fiber diameter is increased from 1.0 mm to 1.6 mm for 3M radiant mirror film.

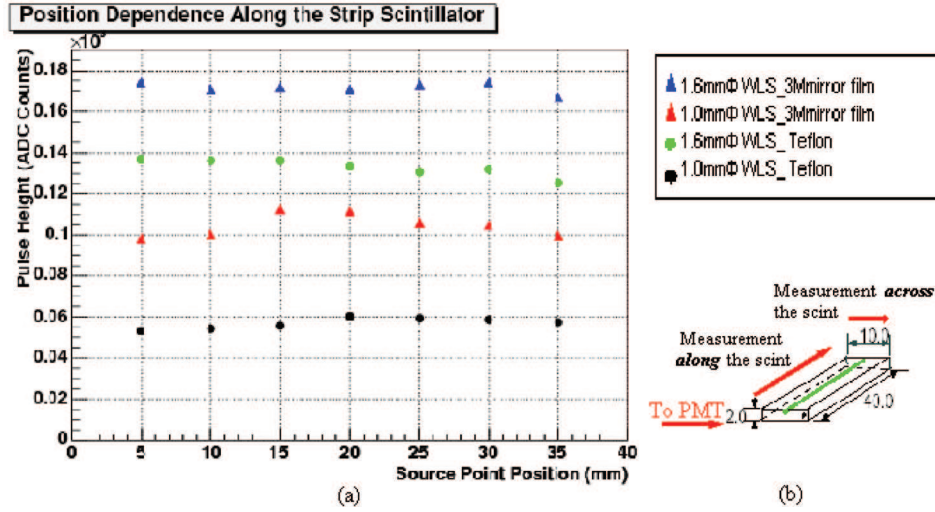


Figure 3. (a) Position dependence on pulse height along the $10 \times 40 \times 2$ mm scintillator and (b) measurement directions.

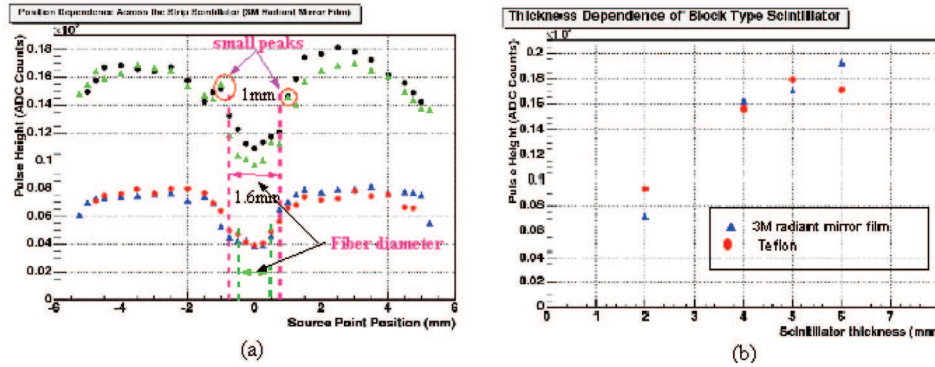


Figure 4. (a) Position dependence on pulse height across the $10 \times 10 \times 2$ mm 3M radiant mirror film wrapped scintillator. (b) Thickness dependence on pulse height of the block type scintillator.

The result in figure 4b shows the thickness dependence on pulse height for the block type scintillator. This reveals that pulse height is almost proportional to the thickness of 3M radiant mirror film wrapped scintillator. It is also observed that the light output of a 6 mm thick 3M radiant mirror film wrapped block scintillator is larger compared to the $10 \times 40 \times 2$ mm scintillator with the same surface covering.

2.2 Simulations vs. bench test

We simulate the pulse height dependence on scintillator length of the three wrapping reflectors, using a C++ program based on a previous simulator for light collection in scintillator strips [4].

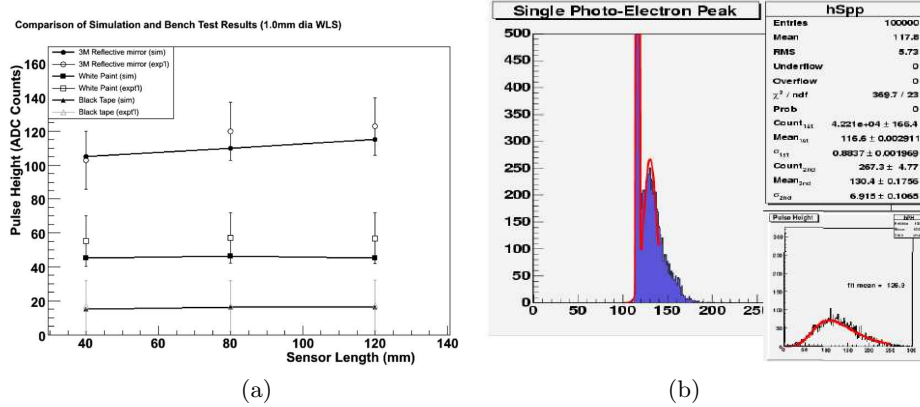


Figure 5. (a) Comparison of simulation and bench test results. (b) The single photoelectron peak and the fitted pulse height (inset).

Figure 5a shows the plotted light yield (in ADC counts) from 3M radiant mirror film, white paint and black tape covered scintillators. This reveals that simulated results (blue lines) are in good agreement with the bench test results.

The single photo-electron peak is determined to identify the number of photons being emitted by the scintillator. The $10 \times 40 \times 2$ mm 3M radiant mirror film wrapped scintillator gives an equivalent of 13.8 ADC counts/photoelectron as shown in figure 5b. The average light yield of the above-mentioned scintillator is 9.2 photoelectrons as shown in the inset.

3. Summary

The 3M radiant mirror film wrapped scintillators showed to have the best light output among the seven types of wrapping reflectors for both sizes of WLS fibers and with a trend of slightly increasing pulse height with increasing lengths. The light yield increases about 100% as fiber diameter is increased from 1.0 mm to 1.6 mm for 3M radiant mirror film. Position dependence along the strip scintillator showed the uniformity of light transmission from the sensor to the PMT for both 3M radiant mirror film and teflon wrapped scintillators. However, a 'dip' is observed at the center of the strip which is dependent to the size of the fiber groove. The block type scintillator's pulse height, on the other hand, is found to be almost proportional to scintillator's thickness. The bench test results are found to be in good agreement with the simulation results.

4. Recommendation

The Monte Carlo simulation of the light transmission for the $10 \times 40 \times 2$ mm strip scintillator wrapped with other reflectors is presently under way to verify and confirm the results of this study. A bench test for the best light yield scintillator

is scheduled soon using the newly introduced compact device called the multi-pixel photon counter (MPPC) or SiPM as read out through the WLS fiber.

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