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Scintillator Hodoscope with a Few Millimeter Position Resolution for Cosmic-ray Test Stand

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A large prototype of the analogue hadron calorimeter (AHCAL) for the International Linear Collider (ILC) was constructed and performance studies in beam are underway. The detection layers of the large prototype are highly segmented into 30×30 mm^2 scintillator tiles. The numerous readout channels had to be tested and calibrated before they were installed to the large prototype. As an efficient tool to calibrate multiple layers simultaneously, a cosmic-ray test stand was newly developed. The test stand composed of a pair of scintillator hodoscopes is designed to determine the cosmic-ray track precisely for detailed tile calibration. Each hodoscope is a square plastic scintillator plate readout with wavelength shifting fibers embedded at 5 mm intervals. It was found that the incident particle position can be reconstructed with a few mm resolution, which is good enough for the cosmic-ray tracking at the test stand. The detection layers were calibrated in the cosmic-ray test stand successfully.

KEYWORDS: ILC, ILD, AHCAL, scintillator, WLS fiber, cosmic-ray

1. Introduction

The International Linear Collider (ILC) is a future electron-positron linear collider to search for new physics. A large technological prototype of the analogue hadron calorimeter (AHCAL) for the ILC was constructed [1]. The prototype contains 38–39 detection layers with the size of 72×72 cm^2, which are segmented into 30×30 mm^2 tiles and each tile is readout individually with a silicon photomultipliers (SiPM).

The large amount of the readout channels had to be tested and calibrated before the detection layers were installed to the prototype. To efficiently test and calibrate the large number of channels, we have developed a cosmic-ray test stand with a pair of high-position-resolution scintillator hodoscopes, which can precisely reconstruct cosmic-ray tracks.

2. Hodoscopes

2.1 Principle

The hodoscope is based on $420 \times 420 \times 6$ mm^2 scintillator plate with wavelength shifting (WLS) fibers embedded at 5 mm intervals. The one-dimensional hit position is reconstructed by the light distribution seen by the fibers as illustrated in Fig. 1. The fibers are embedded in both top and bottom surfaces orthogonally to reconstruct two-dimensional position.

There are 168 fibers on one hodoscope and they are readout from both ends, consequently 336 readout channels are needed for each hodoscope. To reduce the number of channels, the fibers are bundled together every other 16 fibers and readout by one SiPM. Fake hits are periodically generated due to the bundling of the fibers as shown in Fig. 2. To determine the true hit position, we use the hit information from the AHCAL layers under test, which has about 10 mm position resolution by themselves.

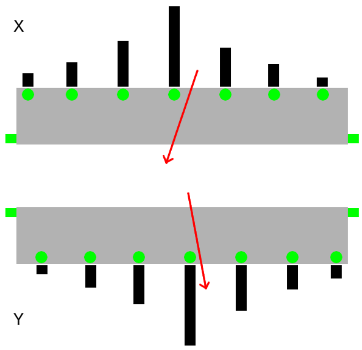

Fig. 1. The hit position can be reconstructed from the light distribution seen by the fibers.

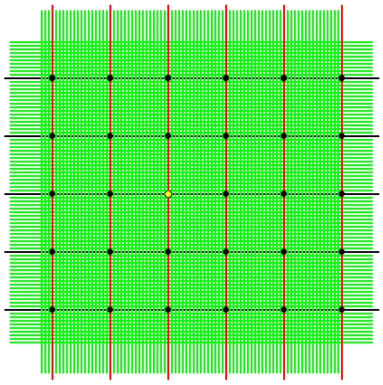

Fig. 2. A number of fake hits generated by bundling the fibers. Yellow point is the true hit and the black points are the fake hits.

2.2 *Construction*

The scintillator plate is made of polyvinyl toluene (PVT)-based EJ-212 (Eljen Technology). Shallow grooves are carved on the top and bottom surfaces of the plate with 5 mm pitch, then WLS fibers (Kuraray Y11, ϕ = 1 mm) are glued in the grooves using optical cement (Fig. 3). The top and bottom surfaces are covered with aluminum mylar to increase light collection efficiency. On the other hand, the four side surfaces are painted black to reduce the reconstruction bias caused by reflection.

Five or six fibers are bundled together as explained in the previous section, then are readout by one SiPM via a bundle holder (Fig. 4, 5).

2.3 *Reconstruction*

Since the 84 fibers in each surface are bundled into 16, the signals from the fibers look periodic. In order to deal with the periodic signal, we relocate the 16 channels onto a virtual unit circle at even intervals and calculated the 2D mean position of the channels each weighted by the signal size. We take the crossing point of the circle and the line joining the weighted mean position and the center of the circle as the reconstructed position in each 16 fiber section.

3. Performance test and commissioning

3.1 *Performance test of the hodoscopes*

The position reconstruction performance of the hodoscopes were tested with collimated beta-rays from ^{90}Sr as Fig. 6.

Fig. 7 shows the signal distribution of the fibers when the radiation source was placed above the fibers around the edge of the hodoscope. The spread of the light distribution is small enough not to reach the next fiber in the same bundle.

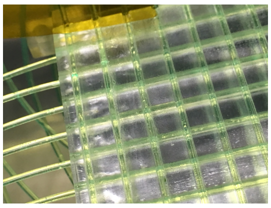

Fig. 3. The WLS fibers were glued in the grooves on the scintillator plate with optical cement.

Fig. 4. Five or six fibers were bundled with a holder.

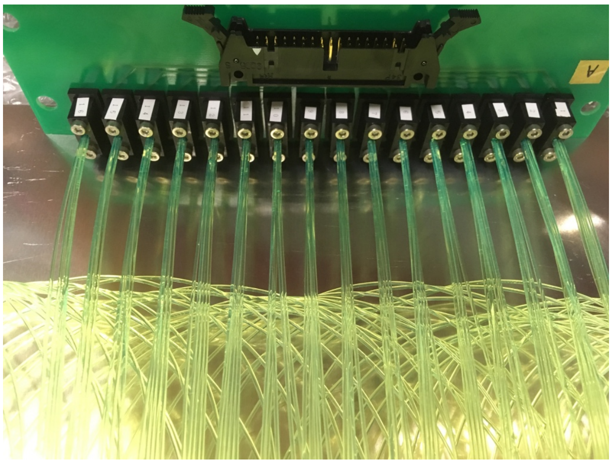

Fig. 5. Each bundle of fibers is readout with one SiPM.

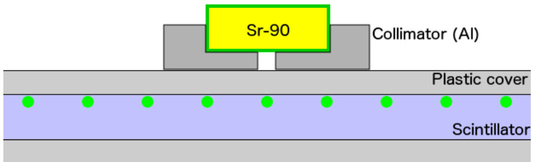

Fig. 6. The test setup of the hodoscopes. The hodoscope was irradiated by collimated beta-rays.

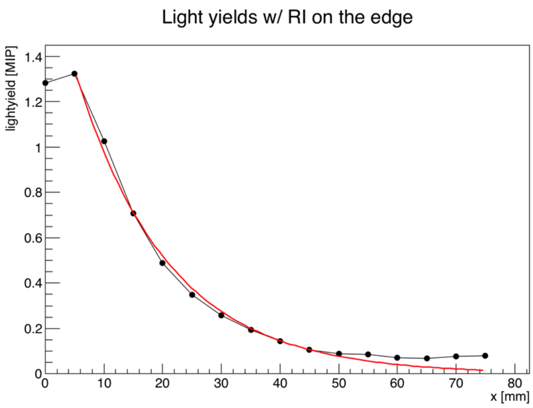

Fig. 7. The signal distribution of the readout channels with a radiation source at the edge of the hodoscope.

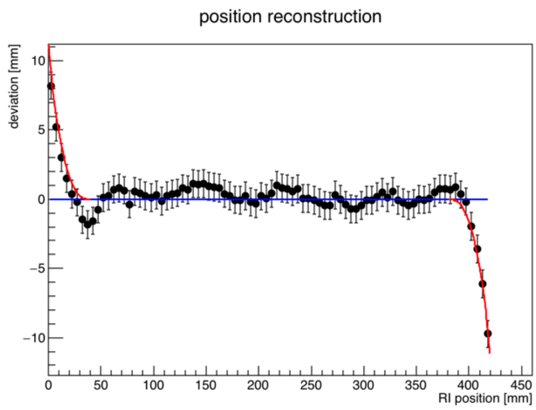

Fig. 8. The difference of the reconstructed position from the true position of the radiation source.

Fig. 8 shows the mean difference of the reconstructed position from the true position. The error bar is largely due to the uncertainty of the positioning of the checking source (~1 mm). There is a large difference at the edge of the hodoscope. The difference is caused by the fact that there is no signal beyond the hodoscope edge and the signal distribution get asymmetric. The difference is corrected according to a calculated function (the red curves in the Fig. 8.)

We could achieve 3–4 mm position resolutions throughout almost all the area of the hodoscopes

(Fig. 9). There are some part with worse position resolutions due to unstable signal from a damaged fiber.

The detailed response was also measured by moving the checking source between two adjacent fibers at 1 mm step to check if there is a reconstruction bias when particles pass through near the fiber. The reconstruction bias was found to be less than 1 mm (Fig. 10).

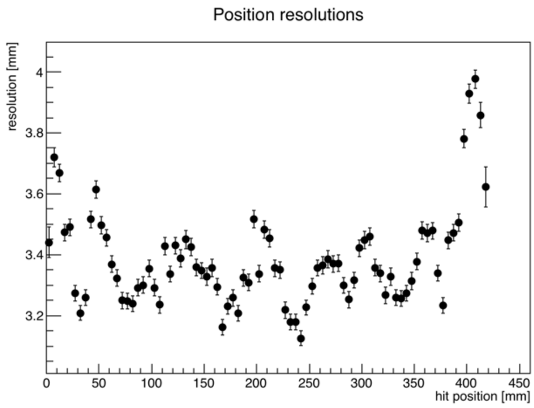

Fig. 9. The position resolution of one hodoscope throughout the whole hodoscope width.

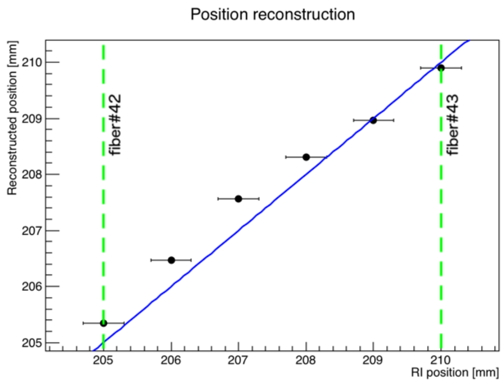

Fig. 10. The reconstructed position against the source position between two fibers.

3.2 Commissioning

The test stand was shipped to DESY, Germany, where the AHCAL large prototype was constructed. The commissioning of the test stand was conducted with a few detection layers. The cosmic-ray track was successfully reconstructed with combining the hit information from the detection layers under test. The test and the calibration were successfully done for all the developed detection layers.

4. Conclusion

The cosmic-ray test stand with a high position resolution was developed for the test and calibration of the large number of detection channels of AHCAL large prototype. The test stand was demonstrated to fulfill the designed position resolution of less than 5 mm at the lab test and it was used for the mass test and calibration of the detection layers. The layers were installed in the prototype and test-beam experiment was successfully operated from May to October, 2018 [2].

Acknowledgement

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References

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