Proc. 5th Int. Workshop New Photon-Detectors (PD18)
JPS Conf. Proc. **27**, 012015 (2019)
https://doi.org/10.7566/JPSCP.27.012015

Study on Granularity Optimization for ILD Hadron Calorimeter

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(Received March 25, 2019)

The CALICE Analogue Hadron CALorimeter (AHCAL) at the International Linear Collider (ILC) is a high-granularity hadron calorimeter based on scintillator tiles readout by MPPCs. Toward the construction of ILC, the AHCAL granularity is being optimized. We have studied mixed configurations of the granularity by using larger scintillator tiles. We first measured the performance of 60×60 mm^2 tile, which is larger than the standard 30×30 mm^2 tile. The uniformity of the response in the tile was found to be quite good although the light yield is reduced by a factor of two compared to the standard 30×30 mm^2 tile, which can be recovered with a larger-area MPPC. A prototype detection layer composed of 144 pieces of 60×60 mm^2 tiles was constructed. The detection layer was added to the AHCAL large technological prototype composed of 38 detection layers with 30×30 mm^2 tiles. The detection layer was successfully tested in test beam experiments at CERN SPS. The measured performance of the detection layer is presented as well as the study on the possible saturation using the test beam data.

KEYWORDS: the International Linear Collider, CALICE, calorimeter, scintillator, MPPC

1. Introduction

The International Linear Collider (ILC) is a future electron-positron linear collider. A center-of-mass energy is 250–500 GeV and extendable to 1 TeV. The International Large Detector (ILD) is one of the two detector concepts proposed for ILC. It consists of a vertex detector, a central tracker, an EM calorimeter, a hadron calorimeter, and a muon detector. ILD adopts the Particle Flow Algorithm (PFA), which reconstructs individual particles using the best suited detectors. By this method, the jet energy resolution is significantly improved. Calorimeters with much higher granularity are required for PFA.

The Analogue Hadron CALorimeter (AHCAL) developed in the framework of the CALICE collaboration [1] is a sampling hadronic calorimeter concept based on steel absorber and scintillator tiles ($30\times30\times3$ mm^3) readout by MPPC (1.3×1.3 mm^2) as active materials. The total number of readout channels in full 48 layers is around 8 million. The AHCAL group constructed a large technological prototype with 38 layers. Each layer is based on four HCAL Base Units (HBUs) on each of which are assembled 144 pieces of 30×30 mm^2 tiles. Each tile is wrapped with ESR film, glued on a HBU and read out individually with a MPPC. It was successfully tested in test beam experiments at CERN SPS. [2] [3]

Toward the construction of ILC, it is necessary to make a more realistic design of the ILD detector. The granularity of AHCAL is now revisited. We are studying mixed configurations of the granularity with larger tiles at different layers. In these configurations, the number of readout channels and ASICs, thus the cost can be reduced. In the previous study [4], 30×30 mm^2 tiles can be replaced with

60×60 mm^2 tiles at latter half of the layers without significant performance degradation. However, the performance of tiles larger than 30×30 mm^2 has not been well tested.

2. Performance of 60×60 mm^2 tile

We measured the light yield and uniformity of the response in the tile using a prototype tile of 60×60 mm^2. The measurements were also done with 30×30 mm^2 tile for comparison. The tile was irradiated by β–rays from ^{90}Sr. The light yield was measured to be 18.2 p.e. on average as shown in Fig. 1. It is about 50% of that of 30×30 mm^2 tile (43 p.e.), but this light yield degradation can easily be recovered by using MPPCs with larger sensitive area. On the other hand, it was found that the 60×60 mm^2 tile has an excellent uniformity in tile response.

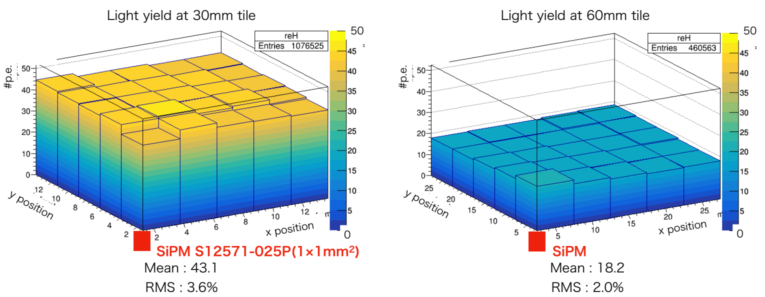

Fig. 1. Measured light yields of 30×30 mm^2 (left) and 60×60 mm^2 (right) tiles

3. Construction of detection layer with 60×60 mm^2 tiles

After the successful demonstration of the good performance of the 60×60 mm^2 tile, a prototype detection layer with 60×60 mm^2 tiles was constructed. MPPCs with an active area of 2×2 mm^2 are used instead of the 1.3×1.3 mm^2 MPPCs as used in the standard detection layer. Hamamatsu Photonics produced a custom MPPC with an active area of 2×2 mm^2, which is a discrete array of four pieces of TSV MPPC (S13615-1025, 1×1 mm^2). Scintillator tiles were produced by injection moulding, which is suitable for large scale production. Four HBUs with 144 pieces of 60×60 mm^2 tiles were assembled as shown in Fig. 2.

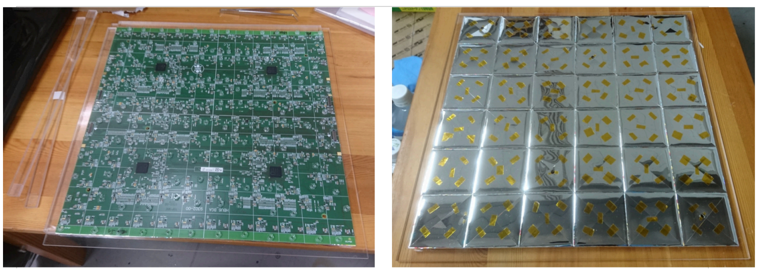

Fig. 2. Completed prototype detection layer with 60×60 mm^2 tiles. Readout electronics side (left) and scintillator tile side (right).

4. Installation to large prototype

The detection layer module with 60×60 mm^2 was added to the large prototype as the 38th layer and tested with muon, electron and pion beam at CERN SPS. Almost all of the configurations were set to be the same as standard layers, but the over voltage of the 2×2 mm^2 MPPCs were set to be lower than the standard 1.3×1.3 mm^2 MPPCs to mitigate possible saturations due to the higher hit multiplicity.

The peaks of photoelectrons were still clearly resolved even with the lower over voltage. Pedestal, MIP and gain calibrations of the 60×60 mm^2 tile module were successfully done like as the standard layer. All channels worked fine and it was found that they have reasonable calibration constants similar to that of $30 \times 30 mm^2$ tile on the standard layer.

5. Saturation

There are two possible types of saturation for the detection layer with larger tiles; one for electronics and the other for MPPC. The current electronics are optimized for 1.3×1.3 mm^2 MPPCs and $30 \times 30 mm^2$ tiles, so saturation of MPPC and ADC would be an issue for 60×60 mm^2 tiles. The 2×2 mm^2 MPPCs have 6,400 pixels, while the 1.3×1.3 mm^2 MPPCs have 2,700 pixels. The number of photoelectrons per MIP is almost the same, but the hit multiplicity can be four times higher because of the larger size. Hence, the MPPCs could be saturated more frequently at the 60×60 mm^2 tiles. SPIROC2E, the ASIC on HBUs has 12 bit ADC. The ADC is saturated at its maximum count of 4095.

The MPPC and ADC saturations were observed only for the highest energy pions of 350 GeV, as shown in Fig. 3. The ADCs are saturated only for 0.08% of tile hits. The bump at 3500–4500 ADC counts is caused by the MPPC saturation. However, it should be noted that 350 GeV is much higher than the energy expected at the real experiment with $\sqrt{s}$=250–500 GeV. Therefore, these saturations will not be an issue.

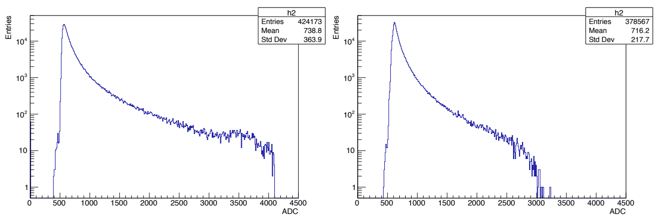

Fig. 3. ADC distributions of 60×60 mm^2 tile module (left) and standard module (right) for 350 GeV pion.

6. Study on mixed granularity using test beam data

There was only one 60×60 mm^2 tile module at the backwards of the large prototype. We simulated the response of 60×60 mm^2 tile in different shower depths by combining hits from 2×2 adjacent 30×30 mm^2 tiles. This ganging technique allows us to study mixed granularity with any combination of 30×30 mm^2 and 60×60 mm^2 tiles.

The larger tile would suffer larger saturation especially near the shower maximum where the hit energy density is expected to be higher. The hit energy distribution is, therefore, evaluated at different depths in the shower profile by the ganging technique. The response of the 60×60 mm^2 tile module was successfully reproduced by ganging tiles, as shown in Fig. 4. The imaginary tile response without saturation can be studied as shown in Fig. 5. This technique allows further study on mixed granularity.

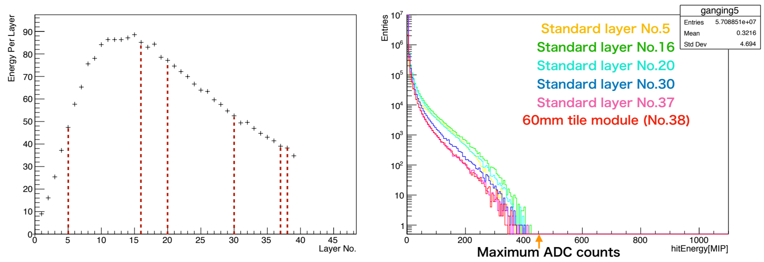

Fig. 4. The right plot shows the distributions of the MIP–equivalent energy of single hit for 80 GeV pions for the standard layers with the simulated 60 mm tiles by the tile ganging at different depth in the shower profile as shown in the left plot. The distribution of the 60 mm tile module at layer 38 is also shown for comparison.

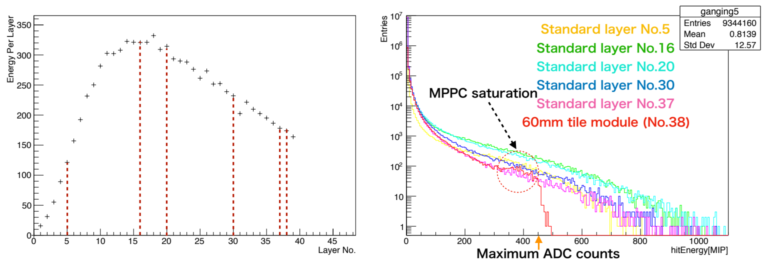

Fig. 5. Shower profile (left) and the ganging tile distributions of standard layers (right) for 350 GeV pions.

7. Summary

As a part of the granularity optimization for AHCAL, the mixed granularity configuration with larger scintillator tiles for outer layers looks a viable option for cost reduction. A good performance of single 60×60 mm^2 tile was demonstrated and a prototype detection layer with 60×60 mm^2 was constructed. The prototype module was installed into the AHCAL large prototype, and successfully tested in test beam experiments at CERN SPS. Slight saturations for ADC and MPPC were observed only at 350GeV pion, although it will not be an issue at the experiment of $\sqrt{s}$=250–500 GeV ILC. We developed a new technique of ganging tile hits to simulate larger tile hits using test beam data, which will allow extended studies on the mixed granularity.

Acknowledgements

We are grateful for the support by DESY FLC group as the host laboratory. This work supported by JSPS KAKENHI Grant Number JP17H02882.

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