Conference Paper

Tests of scintillator tiles for the technological prototype of highly granular hadron calorimeter

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Abstract

A new technological prototype of the highly granular hadron calorimeter for future collider experiments is being developed by the CALICE collaboration. The proposed baseline design of active elements considers scintillator tiles with a silicon photomultiplier readout. The light yield and uniformity of response of two tiles with dimple geometry from different producers were measured. The technology proposed for the ILD detector was used: each tile was individually wrapped in the reflecting foil and the SiPm was coupled directly to the dimple side of the scintillator tile. The measured response to minimum ionizing particle is almost twice better for BICRON408 scintillator than for polystyrene-based scintillator, while the estimated uniformity of response is better for the polystyrene-based scintillator tile produced by injection molding.

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1. Introduction

The development of highly granular calorimeters for future collider experiments is being performed by the CALICE collaboration. A set of tests of electromagnetic and hadron calorimeter prototypes with unprecedented granularity was carried out during the successful test beam campaign in 2006–2012 and the proof of principle and reliability of the particle flow approach was demonstrated on the real data [1, 2]. Now the construction of new technological prototype of scintillator-SiPm-based hadron calorimeter is in progress. The main goal of these efforts is to test the new technologies of tile-SiPm couplings and demonstrate the scalability of embedded electronics, calibration approaches and working modes. The choice of tile design with the direct coupling of a

SiPm without wavelength-shifting fiber is motivated by the mass production requirements, to guarantee a real time-scale for the assembling of hadron calorimeter from about 8 million tiles for the ILD detector on the future International Linear Collider [3]. Different tile geometries were tested [4–7] and the tile design with the dimple on the tile big face was chosen, which provides both the suitability to mass production and appropriate uniformity of response. In this study, two tiles with dimple design from different materials were tested to compare their light yield and uniformity of response to minimum ionizing particles (MIP).

2. Tile design and experimental setup

The highly granular hadron calorimeter of the ILD detector for future lepton collider experiments is designed to be a sampling calorimeter with projective geometry with respect to interaction point. The active layers assembled from scintillator tiles are interleaved by steel absorber plates. The tile sizes are 30x30 mm^2 in the transverse plane and 3 mm in depth in the longitudinal direction. Each tile has a dimple on one of the big faces and is individually wrapped in reflecting foil. Silicon photomultipliers will be soldered on the embedded electronics plate and coupled directly to the dimpled surface of each tile. The dimple geometry is chosen to achieve the uniformity of response in the absence of the wavelength-shifting fiber. We have tested two tiles of this design from the samples produced for the CALICE technological prototype.

2.1. Tile characteristics

The first tile is made from BICRON408, which is the polyvinyltoluene-based scintillator. The second tile is made from polystyrene with p-terphenyl (2%) and POPOP (0.01%) and produced by injection molding at the Uniplast factory in Vladimir. The sizes of both tiles are 30x30x3 mm^3 in x, y and z directions respectively. Both tiles have dimples in the center of one of the big faces. The radius of the dimple is 4.5 mm and its depth is 1.6 mm. The tiles are wrapped in foil (3M™ Enhanced Specular Reflector), which is an ultra-high reflectivity, mirror-like optical enhancement film. The wrapping has a hole in the center over the dimple to hold a SiPm and an additional hole for calibration purposes. The photo of the tile with dimple is shown in figure 1 together with the foil prepared for wrapping.

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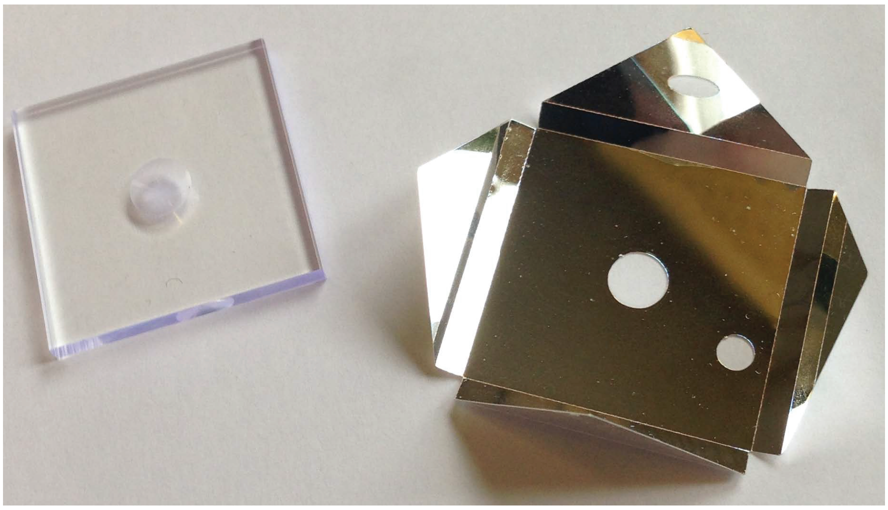

Figure 1: Photo of the scintillator tile with dimple (left) and wrapping foil (right).

2.2. Experimental setup

The experimental setup consists of a moving stage and a fixed plane. The moving stage allows precision scanning along the xy-plane and holds the beta-radioactive source (^{90}Sr) and trigger tile, electrons from the source are emitted along z axis. The measured wrapped tile is placed on the fixed plane. The small board, which holds SiPm, is placed on top of the tile, so that the SiPm is centered in the hole of the wrapping foil. The SiPm from KETEK with 2.2×2.2 mm^2 window and 12,100 pixels was used to measure both tiles. The measurements were performed using the same SiPm working mode (overvoltage). The uncertainty of the vertical position of SiPm window with respect to the dimpled face of the tile was ∼100 micron.

The source and trigger tile are placed above and below the measured tile, respectively. The trigger tile is readout by another silicon photomultiplier in the threshold mode with the threshold set to ∼0.5 MIP. Electrons from the source, which reach the trigger tile have energies from ∼1.5 to 2.28 MeV and can emulate the minimum ionizing particles. The scan step in xy-plane was 1.5 mm in both directions and the scanned area was ∼35.0×35.0 mm^2 to guarantee the coverage of tile surface. The measurement at each step was limited either by the maximum number of triggered events set to 2000 or by time limit, which was set to 10 seconds per point. The measured amplitude in units of ADC are saved in ASCII file at each scan step.

3. Results

The resulting saved samples contain both signal events from source electrons and pedestal events produced by noise of the trigger SiPm. The total number of triggered events is shown in figure 2 for one of the tiles. The smaller number of events collected for the central part of the tile is due to the fact that this part is shadowed by the SiPm electronic board and wires and therefore requires longer time to collect the same amount of data, which exceeds the time limit of 10 s mentioned above. The scan area covers ~35.0×35.0 mm^2 and consists of 23×23 points. Figure 3 shows the measured spectra at one of the points near the center of the tile. The left peak on figure 3 corresponds to pedestal events, while signal events lie above 200 ADC. Therefore, to select signal events and reject pedestal, the cut of 200 ADC is applied to the measured amplitude. To find the position of the tile on the scanned area, we calculate the number of signal events at each point after the cut applied. The corresponding map with number of signal events is shown in figure 4.

3.1. Identification of tile position

The following algorithm was developed to found the position of the tile with the size $N \times N$ points within the measured area of $M \times M$ points ($N < M$). One can expect that outside the tile edges pedestal events dominate in the measured spectra. The number of signal events after cut is calculated over the range, corresponding to $N \times N$ points, this region being sliding within the measured area. The range, which contains the maximum number of signal events is assumed to be the real tile position. The found tile boarder for our measurements with $N = 20$ and $M = 23$ is shown in figure 4.

3.2. Fitting algorithm and extraction of MPV

For the points, which belong to the identified tile, histograms of the response to MIP at each scan position were filled and fitted to extract the most probable value (MPV). A two-step Gaussian fit was performed in the range of $\pm$1.5 r.m.s. from the mean of the measured spectrum. Figure 5 shows an example of the response spectrum of signal events for the scan position near the center of the tile. The result of two-step Gaussian fit is shown with the red curve, which parameters can be found in the legend. The mean of this Gaussian function is taken as an MPV for the particular point. The fit is not performed for the spectra with number of entries less than 50 and these points

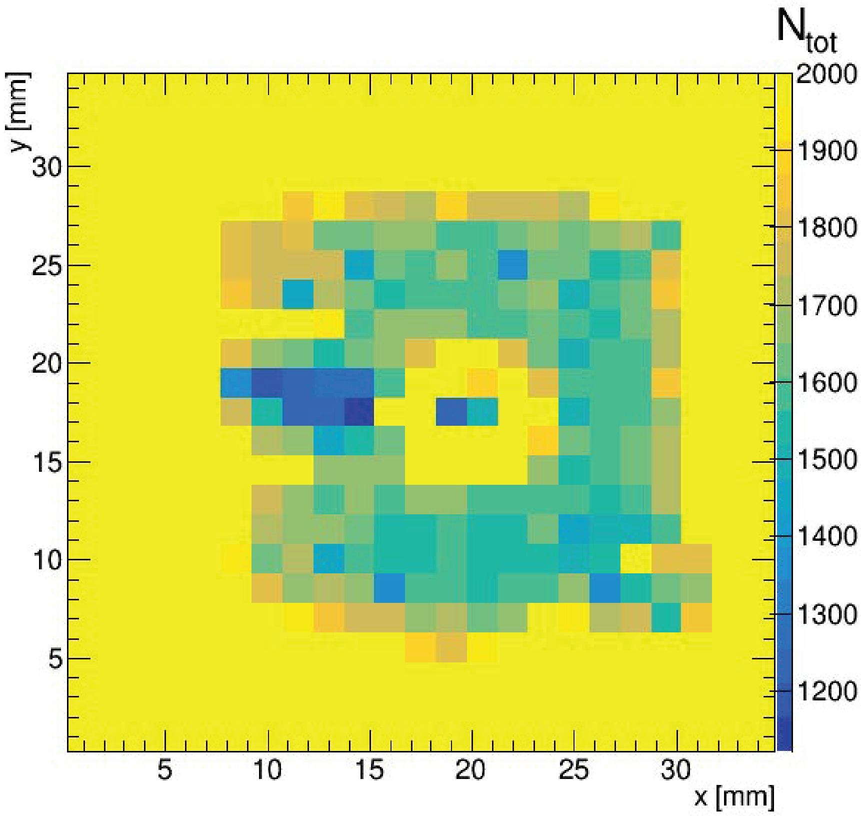

Figure 2: Total number of events within the scanned area measured for BICRON408 tile.

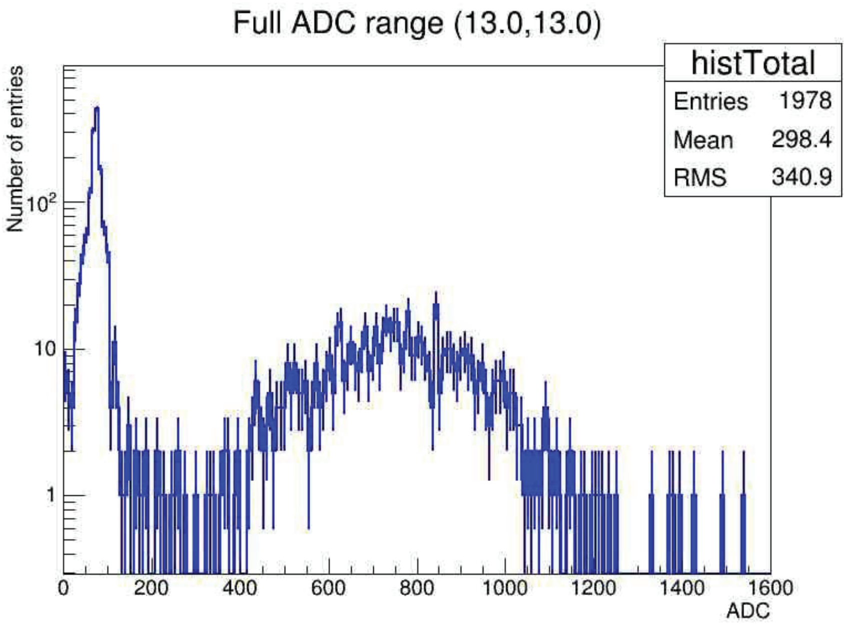

Figure 3: Example spectrum of response to minimum ionizing particles measured in the central part of the BICRON408 tile.

are not taken into account in the estimates of uniformity. The statistical uncertainty of the most probable values extracted from the fit is ~2%.

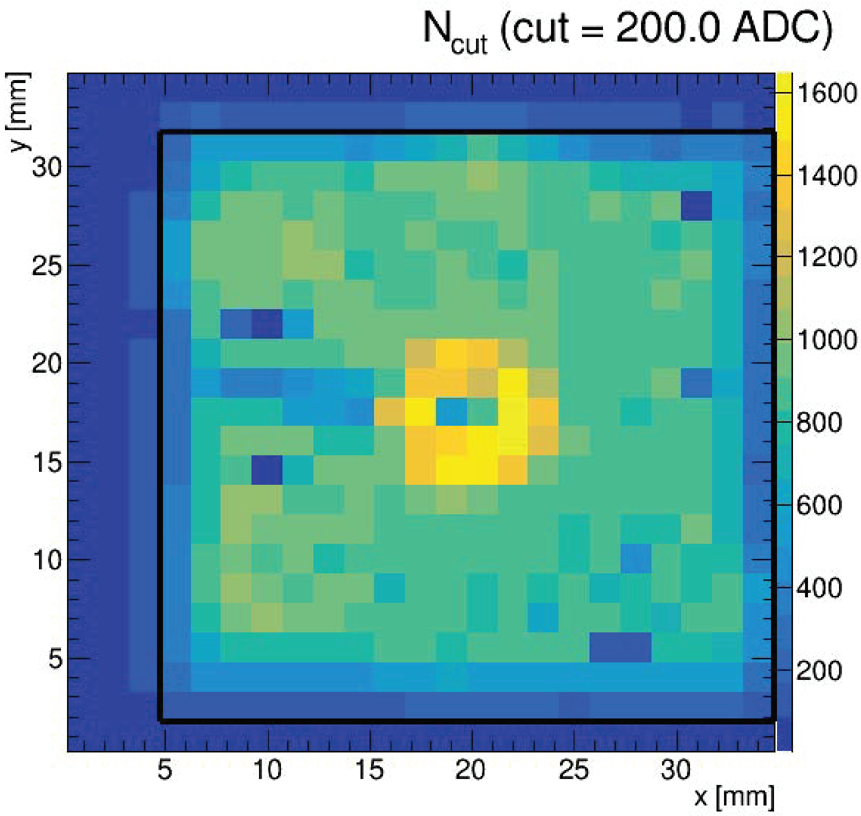

Figure 4: Number of measured signal events with the 200-ADC cut on the amplitude for the BICRON408 tile. The identified tile boarders are shown with black lines.

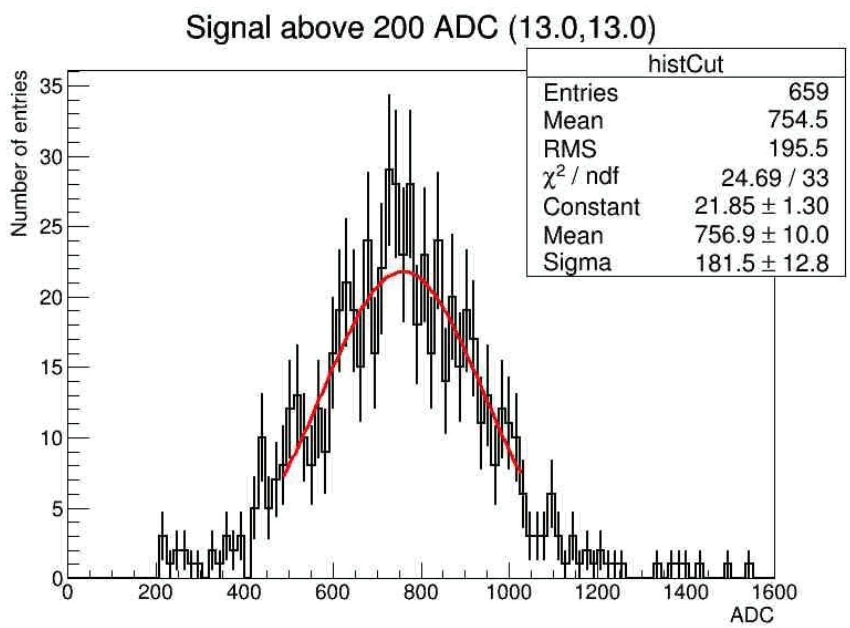

Figure 5: Example spectrum of response to minimum ionizing particles measured in the central part of the BICRON408 tile. The cut on amplitude at 200 ADC is applied. The red curve shows the result of the fit with Gaussian function.

3.3. Uniformity estimates

The results of scan over the BICRON408 tile are shown in figures 6 and 7. A map with the extracted most probable values at each point with the scan step of 1.5 mm is presented in figure 6. Figure 7 shows the fit quality. The average response, $\langle R \rangle$, and its standard deviation, ΔR, are calculated over all non-empty entries in the map. The nonuniformity of response is estimated as a ratio $\Delta R/\langle R \rangle$.

The results of nonuniformity estimates for both types of tiles and two scan step options are shown in table 1. As the same SiPm in the same working mode was used for both measurements, the temperature conditions are the main source of systematic uncertainty. The conservative estimate of the uncertainty due to temperature variations is ~5% for average response to MIP and does not affect the uniformity comparisons. To estimate the effect of scan step size, the measurements at the neighbor steps are merged to get coarser grid with the step size of 3.0 mm. Though such a merging helps to increase histogram statistics near the tile edges, the coarser scan step naturally leads to the underestimation of the level of nonuniformity as can be seen from the results presented in the table.

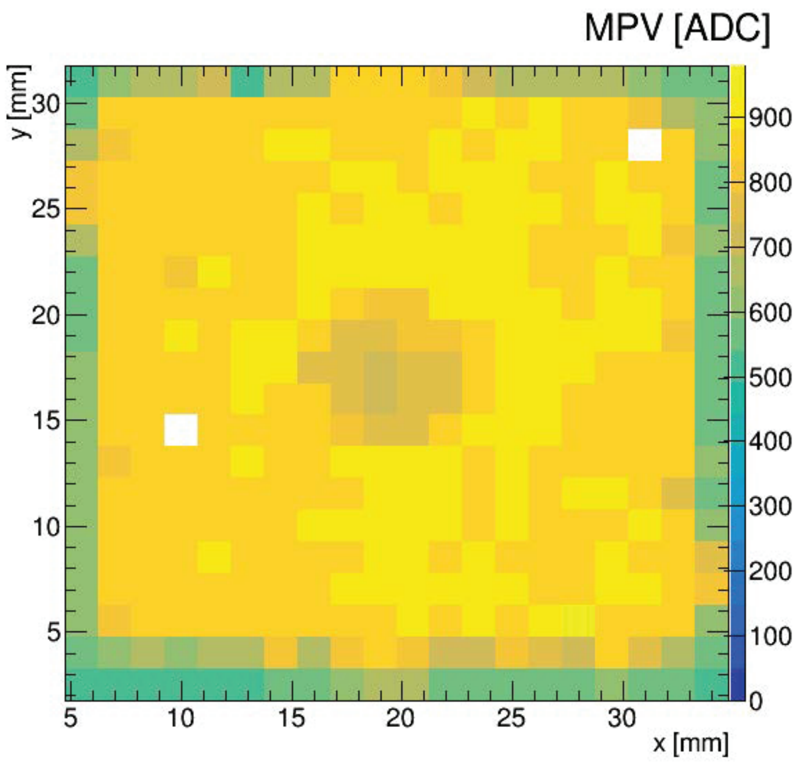

Figure 6: Most probable values of response to MIP extracted for the BICRON408 tile.

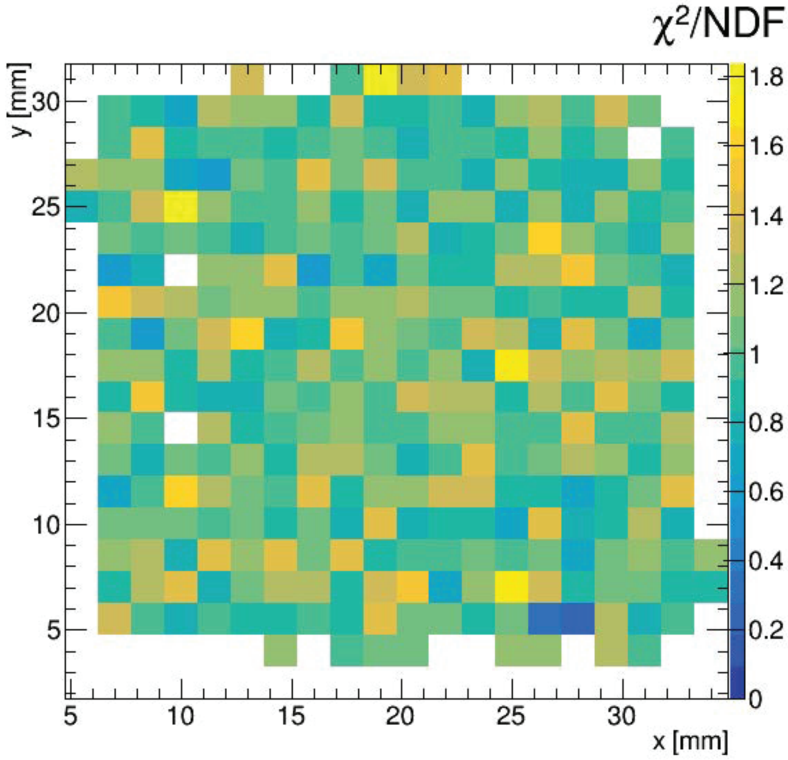

Figure 7: Quality of fits in terms of χ^2/NDF for the fit of response for BICRON408 tile.

Table 1: The average MPV of response to minimum ionizing particles and nonuniformity of the measured scintillator tiles.

Scintillator material	Scan step [mm]	Average MPV [ADC]	Nonuniformity
BICRON408	1.5	812±41	0.14
	3.0	827±41	0.10
Polystyrene-based	1.5	423±21	0.09
	3.0	428±22	0.07

4. Conclusion

The measurements of uniformity were performed for the scintillator tiles with dimple design and SiPm readout produced for the technological prototype of the CALICE highly granular hadron calorimeter. The tile from BICRON408 shows twice higher level of response to MIP but worse uniformity than the polystyrene-based tile.

Acknowledgments

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References

[1] Adloff C *et al.* [CALICE collaboration] 2010 *JINST* **5** P05004 (*arXiv*:1003.2662 [physics.ins-det])

[2] Adloff C *et al.* [CALICE collaboration] 2011 *JINST* **6** P07005 (*arXiv*:1105.3417 [physics.ins-det])

[3] Behnke T (ed.) *et al.* 2013 The ILC TDR - Volume 4: Detectors *arXiv*:1306.6329

[4] Simon F and Soldner C 2010 *Nucl. Instrum. Meth.* A **620** 196 (*arXiv*:1001.4665 [physics.ins-det])

[5] Blazey G *et al.* 2009 *Nucl. Instrum. Meth.* A **605** 277-81

[6] Abu-Ajamieh F *et al.* 2011 *Nucl. Instrum. Meth.* A **659** 348-54

[7] Bobchenko B *et al.* 2015 *Nucl. Instrum. Meth.* A **787** 166-8