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Optimization of the light yield properties from scintillator tiles read out directly by silicon photomultipliers

B Bobchenko[1,2], M Chadeeva[1,2], M Danilov[1,2], D Mironov[1,2], V Rusinov[1,2] and E Tarkovskiy[1,2]

[1] Institute for Theoretical and Experimental Physics, Moscow, Russia
[2] National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Kashirskoe highway 31, Moscow, 115409, Russia

E-mail: dima.mironov@cern.ch

Abstract. The research of the light yield from the scintillator tiles with direct readout by silicon photomultipliers (SiPM) has been performed. The tile size is $30 \times 30 \times 3$ mm^3 as planned for the AHCAL of the ILD at the ILC. The different tile geometries were studied. The uniformity of light yield has been optimized and one geometry has been selected. The results are compared to the studies on the same topic, performed by another groups.

1. Introduction

The International Linear Collider is one of the proposed e^+e^- accelerators to further study the properties of the Higgs boson and to search for the dark matter particles. [1] The proposed center of mass energy at the ILC is from 250 GeV to 1 TeV. To achieve a very high energy resolution, which is required for the physics goals, the Particle Flow Approach [2, 3, 4] has been invented. It exploits the possibility to measure the energy of charged particles inside jets in the tracker with the precision much higher, than it is achievable in the calorimeter. The PFA suggests to subtract the energy in the calorimeter, which can be assigned to charged tracks, and consider the rest as an energy of the neutral fraction of the jet. To exploit the possible efficiency of the PFA a very high granularity of the calorimeter is a key requirement. The Analogue Hadron Calorimeter (AHCAL) is on of the projects of such a calorimeter for the ILD detector project at ILC. It is assembled from the scintillator tiles, read out by silicon photomultipliers (SiPM). The transverse tile size has been optimized considering the efficiency of the energy reconstruction and is 30×30 mm^2. The currently proposed tile thickness is 3 mm.

The physics prototype of a highly granular calorimeter was built in 2006 by the CALICE collaboration. It was assembled from 7608 square tiles [5] of different sizes. The big faces were held between two highly reflective foil mirrors and the edges were mated using special chemical treatment. The green wavelength-shifting (WLS) fiber has been used in every tile to collect the light and guide it to the SiPM and increase the efficiency of the detection. The recent development of the SiPMs with increased efficiency and sensitivity to blue light gave a possibility to get rid of the WLS fiber still achieving the required light yield. This vastly reduces manpower needed for the manufacturing and costs of assembly. However, if the SiPM is just placed next

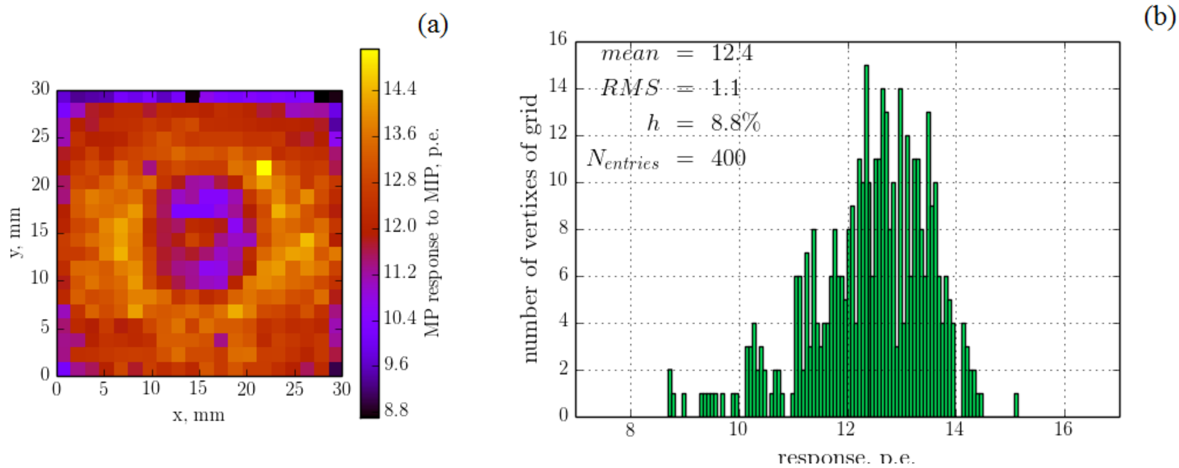

Figure 1. (a) Dependence of the response to MIP in photoelectrons on the beam position in the XY-plane with the optimal geometry[8]. (b) The distribution of the MP responses to MIP in the optimal geometry.

to a flat tile, the response has very big spatial nonuniformity, which affects the calorimeter resolution. To achieve the uniformity of the response, which will allow the required resolution, the dimple design has been introduced in [6]. The goal of this study is the optimization of the geometry of the readout and measurement of the properties of the optimal one.

2. Dimple concept

The minimum ionizing particle (MIP) produces the same amount of light independently of the impact position, when crossing the flat tile. The light which is emited in front of the SiPM has twice higher probability to reach the photodector. To improve the uniformity, one can reduce the mean light emission from MIP in the tile center by reducing the scintillator thickness there by making a dimple in the scintillator in front of the SiPM. In our study the paraboloid dimple is used to optimize the light collection uniformity. The dimple shape is parametrized by its depth d and radius at the tile face r.

The surface mounted SiPM can be plunged into the dimple. This allows using SiPMs soldered directly to the mirrored PCB without introduction of any special electrical connectors.

3. Nonuniformity characterization

To measure the nonuniformity, a rectangular lattice in XY-plane has been used, which is parallel to the big tile face. The SiPM response spectrum to β-particles flying through each vertex of the lattice has been measured. Electrons from ^{90}Sr source were used to simulate a minimum ionising particle (MIP). The response spectrum at each XY-point has been fitted with a Gaussian function around the peak of the distribution. The obtained Gaussian mean, which is close to the most probable (MP) value of the spectrum, has been considered to be the response to a MIP at the given beam position with a correction from [7]. Example of the dependence of this value on the beam position in the XY-plane for the optimal geometry is shown in figure 1a. The distribution of the MP responses to MIP in the optimal geometry is shown in figure 1b. It makes sense to characterize it by the mean M and the spread RMS and take the ratio $h = \frac{RMS}{M}$ as a measure of the response nonuniformity. It allows getting the rough estimate the additional relative error in energy introduced by the nonuniformity as $\frac{h}{\sqrt{N}}$, where N is the number of tiles affected by a shower.

In 2006 WLS-fibered tiles have been tested in a proton beam. When calculating an average using 2 mm lattice, nonuniformity measure h is $\approx 7\%$ with 2 mm scan step and $h \approx 10\%$ with 1 mm step with effective beam size of 1 mm [9].

4. Experimental setup

The dimples have been milled on the big face (30×30 mm^2) using the 3-dimensional engraver with the precision of 10 μm.

The ^{90}Sr source and trigger tile are moved in the XY-plane along the tile big face. The beam direction is along Z axis. The tile is laid down on its big flat face on the fixed mirrored table and covered by a mirror with a hole in the center, in which the SiPM is placed. The surface of the SiPM can be at the mirror level or several millimeters higher or lower. The beam diameter is about 1.3 mm.

In the response conversion to photoelectrons per MIP the 20% SiPM crosstalk and MIP simulation by β-particles have been taken into account.

5. Test of light focusing hypothesis

In the previous note we have used a SiPM from KETEK [10] with 2.2×2.2 mm^2 window and 12100 pixels. It gave us a mean MP response of 12.5 photoelectrons. To test the hypothesis of the focusing of the light we have tried another SiPM from KETEK with 1.2×1.2 mm^2 window and 576 pixels. The surface decrease is 2.8 times, while the observed light yield decrease was only 1.7 times. The nonuniformity increased not significantly from $h = 7.6\%$ to $h = 10.1\%$.

The study of the effect of properties of the surface in front of the SiPM has been performed. No significant differences in light yield have been observed between the initial option (just after milling), polished one and one mated with a hard sandpaper.

6. Test of Mainz geometry

The group from the University of Mainz performed similar studies[11]. They use another scintillator, wrap their tiles with the laser cut 3M ESR foil and use a SiPM from Hamamatsu with 1.3×1.3 mm^2 window and 2668 pixels. Their tiles show the response of 19 photoelectrons per MIP even with a cheaper type of the scintillator. They proposed another measure of nonuniformity H, which is the fraction of the surface, where the response is deviated from the mean response by less than 5%. Below we make the comparison for both the measures h and H. To make a crosscheck with our results the dimples have been milled with a geometry proposed by the University of Mainz in tiles from the scintillator we use. The edges have been mated using special chemical treatment. On our setup with our 1.2×1.2 mm^2 SiPM they show the response of 5.4 photoelectrons per MIP, which is less than the response in our optimal geometry. For Mainz geometry we see the peak of the response in the tile center as in [11]. The nonuniformity value we measure for their tiles is $h = 32\%$, which is significantly higher than any other h value of tiles with dimple and is comparable to $h \approx 40\%$ of flat tiles. We measure H to be $H = 13\%$ for the tiles with their geometry and $H = 28\%$ for our configuration.

7. Conclusion

The direct readout of scintillator tiles with SiPMs is a possible and feasible option for high-granularity calorimetry. The particular geometry to be selected depends on the scintillator material.

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