Directly Coupled Tiles as Elements of a Scintillator Calorimeter with MPPC Readout

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Abstract

We present results on the direct i.e. fiberless coupling of scintillator tiles to Multi-pixel Photon Counters (MPPC). The fiberless option has the potential of simplifying the assembly and construction of a finely-segmented scintillator-based calorimeter with MPPC readout. In this paper we show detailed studies on the response and uniformity of directly coupled tiles and describe our concept for an Integrated Readout Layer (IRL).

Key words: Scintillator, Calorimeter, Direct coupling, MPPC, Integrated readout layer
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1 Introduction

It is clear that for the International Linear Collider (ILC) to fulfill its physics potential, multi-jet final states must be exceptionally well measured. In particular, excellent jet and missing energy resolution will be critical for the discovery and characterization of new physics as well as for precision tests of the Standard Model (SM). Particle-flow algorithms (PFAs), which allow for the optimal use of the information available in the event; tracker momenta for charged particles and calorimetric measurements for photons and neutral

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hadrons, are a promising means to achieving these goals. This however requires individual reconstruction of showers in a jet which, in turn, implies a fine transverse and longitudinal segmentation of the calorimeter system.

A finely-segmented scintillator-based hadron calorimeter which capitalizes on the marriage of proven detection techniques with novel photo-detector devices is an ideal candidate for such a calorimetric system. PFA simulations indicate that tile sizes of 9 cm^2 or smaller are required. Such a hadron calorimeter will therefore consist of millions of channels and require a high degree of integration. The first steps towards this integration have already been facilitated by the small size and magnetic field immunity [1] of the MPPCs. The photo-conversion occurs right at the tile thus obviating the need for routing of long clear fibers [2]. Similar considerations apply to the presence of wave-length shifting (WLS) fibers inside the tiles which couple it to the photo-detectors.

Significant simplification in construction and assembly can ensue if the MPPCs can be coupled directly to the scintillator tiles. Equally importantly, the total absence of fibers would offer greater flexibility in the choice of the transverse segmentation while enhancing the electro-mechanical integrability of the design.

In what follows we evaluate the feasibility of directly coupled square and hexagonal tiles as elements of a hadron calorimeter with MPPC [3] readout through studies of response, uniformity and cross-talk for tiles which are 5 mm thick and 9 cm^2 in area. Based on these studies our concept for an Integrated Readout Layer (IRL) is described. Note that while our research has been motivated by hadron calorimetry for an ILC detector, the results have relevance to high granularity scintillator/crystal electromagnetic and hadronic calorimetry for any detector.

2 Direct Coupling: Uniformity of Response

The uniformity of response with respect to the particle impact position was measured, for directly coupled tiles, with the setup shown in Fig. 1. The Sr^{90} source sitting on top of the tile irradiated it at right angles through a collimator opening of 0.8 mm. A fraction of the scintillation light generated inside the tile is captured by the photodetector which sits below the tile. No fibers are used to guide the light to the photodetector. The sensor packaging can either be in physical contact with the tile or separated from it with an air gap. Hamamatsu MPPC S10362-11 series were used as the photo-detectors. These are 1 mm^2, pixellated solid-state photo-diodes operating in the limited Geiger-mode. The response of the MPPC was measured with a Keithley 6485 pico-ammeter as the source was moved across the surface of the tile.

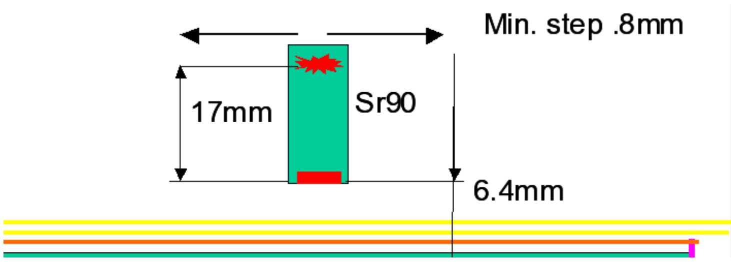

Fig. 1. Tile uniformity scan schematic (not to scale).

2.1 Flat Tile

The response of a 9 cm^2 and 5 mm thick, directly coupled square tile as a function of the source position is shown in Fig. 2. 'Flat' refers to the fact that neither of the square faces of this tile have been modified in any way (as will be discussed in the next section). Since these are current-mode measurements, low magnitude and high stability of the dark current is of vital importance. For the MPPC S10362-11 series used, the dark current is a factor of ten lower than the signal, making uniformity measurements in the current mode a sensible exercise. Since the MPPC dark current is temperature dependent, the ambient room temperature was maintained to within 0.2° C. Repeated control measurements of the dark current exhibited stability to within 1%. The Sr^{90} source was attached to a precision, LabView controlled x-y motion table. From the scan, a large non-uniformity can be observed across the face of the tile with the response near the sensor position being a factor of 2.5 times higher compared to the plateau at the sides.

2.2 Concave Tile

In order to reduce the non-uniformity of the response, a concave tile (see Fig. 3) was machined from EJ200 cast scintillator. The concavity was produced by rotating the tile and the machine cutter at the same time. The tile was rotated in the horizontal plane while the cutter was rotated in the vertical one. This ensured that there was no point of zero rotation on the tile that could serve as a point source. The speed of cutting and the available cooling were adjusted so as to avoid melting the scintillator material which can drastically increase its opaqueness. Tiles with different depths of concavity were produced and then tested. It was found that for tiles with area 9 cm^2 and thickness 5 mm, 60%

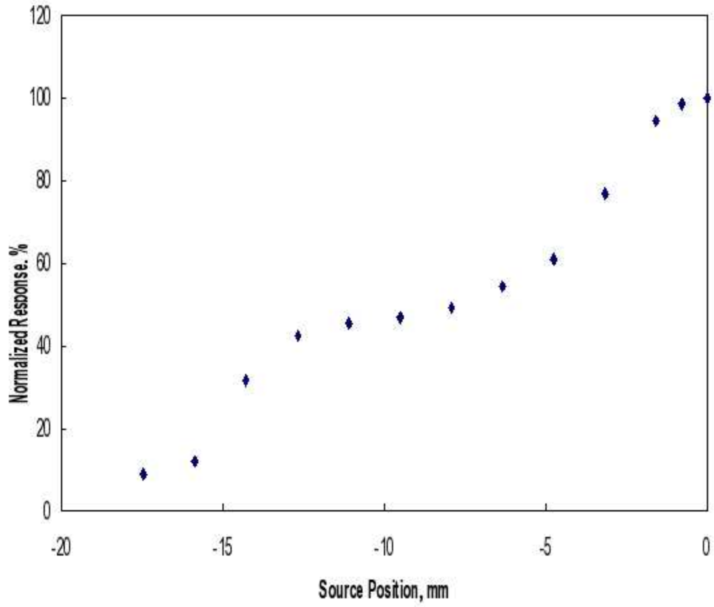

Fig. 2. Response uniformity for a square flat tile as a function of the distance from its center where the sensor is located.

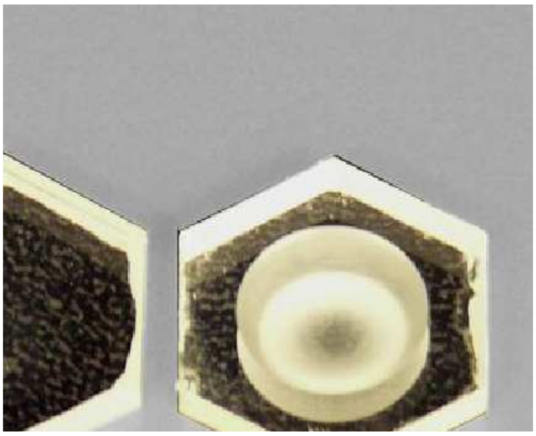

Fig. 3. Hexagonal flat (left) and concave tiles (right)

concavity is optimal i.e. the maximum depth of the sphere cut out from the scintillator material was ≈ 3 mm.

The response for such a tile as a function of the source position is shown in Fig. 5. For these measurements the concave face of the tile was placed on Tyvek [4] (which had an opening in the middle for the photodetector), the flat face

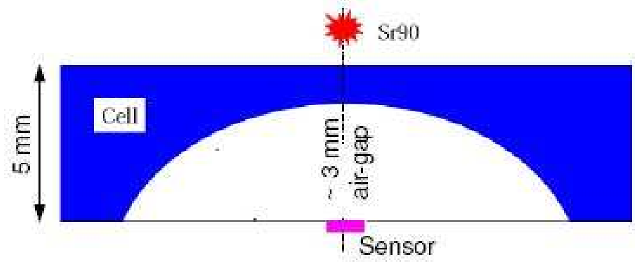

Fig. 4. Concave tile uniformity scan schematic (not to scale).

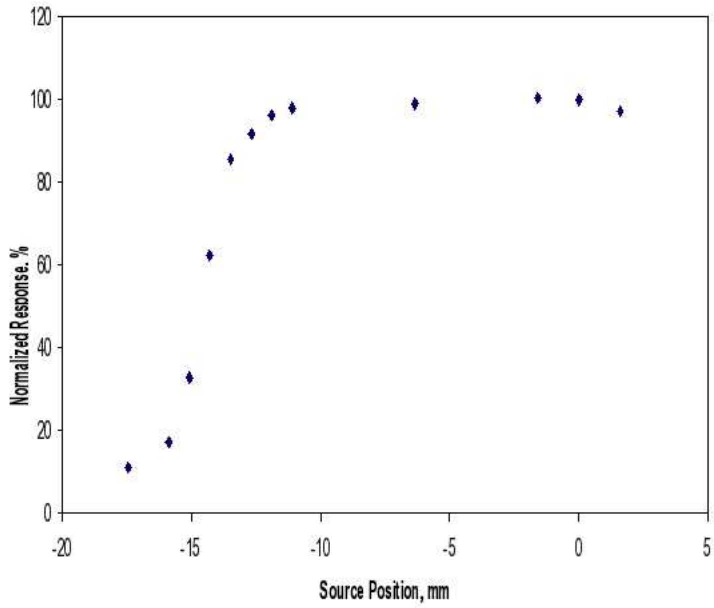

Fig. 5. Response uniformity for a square concave tile.

was covered with VM2000 mirror film [5] while the sides were painted white using EJ510 paint from Eljen Technologies [6]. This reflector treatment is the same as used for the flat tile scan. The photodetector sat in a hemispherical air-gap with its ceramic package flush with the flat surface of the concave face (see Fig. 4). It is clear that good uniformity of response can be obtained for a directly coupled concave tile (see Fig. 5). Similar scans were done for 9 cm^2 hexagonal tiles (see 2-dimensional scans in Figs. 6 and 7). For these, the concavity prescription is carried over without modifications from the square tiles indicating the robustness of the procedure.

The details of how the response, across the face of the tile, changes as its concavity is altered can be seen in Fig. 8. As we progressively cut into the tile its uniformity as a function of the source position improves as the response in the center of the tile decreases while that at the edges increases. The response, in the vicinity of the photo-detector, decreases as the tile presents less material to the incident particles. The air-gap introduced between the sensor and the

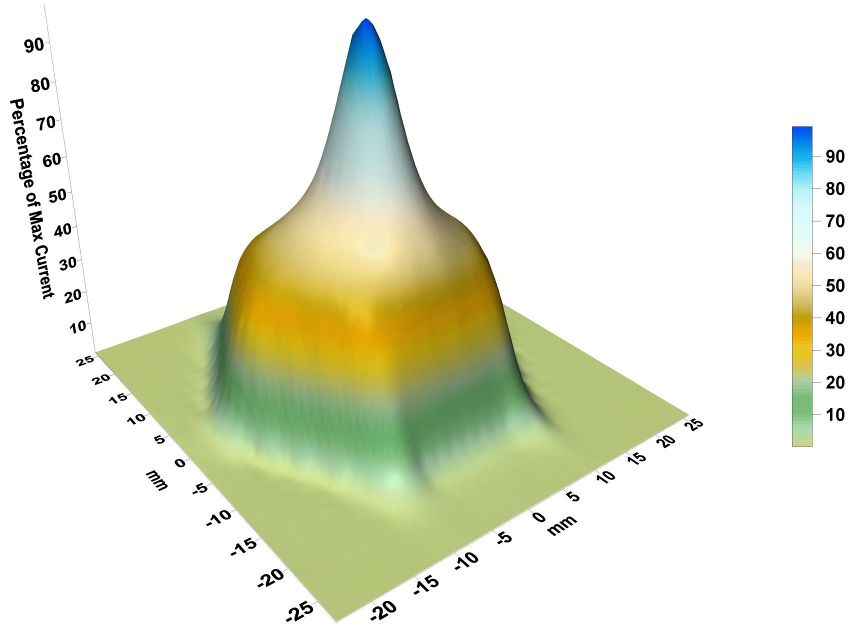

Fig. 6. Response uniformity for a hexagonal flat tile.

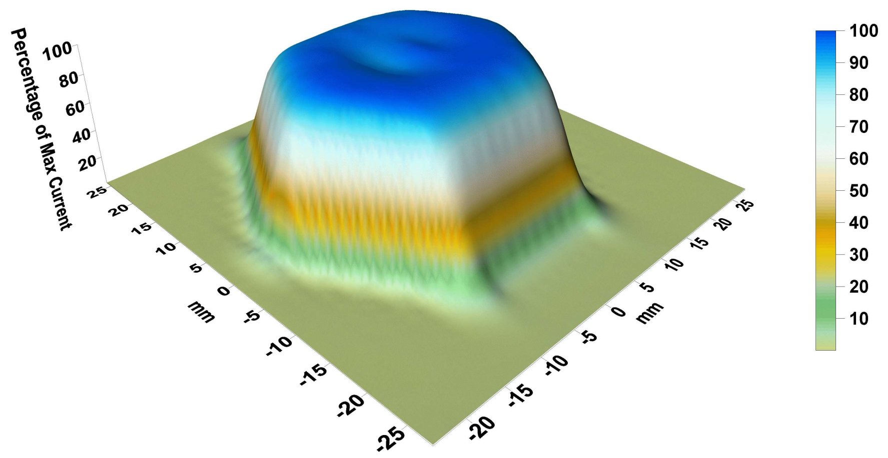

Fig. 7. Response uniformity for a hexagonal concave tile.

scintillator also plays an important role. Consider first the case of the particle incident close to the sensor position. It is reasonable to conclude that most of the excess response observed for this case as compared to an edge incidence is due to photons refracting into the sensor within the space of a few reflections. The introduction of distance between the point of refraction at the scintillator boundary and absorption at the sensor, through the air-gap, implies that a smaller fraction of the refracted photon flux will make it to the MPPC. The

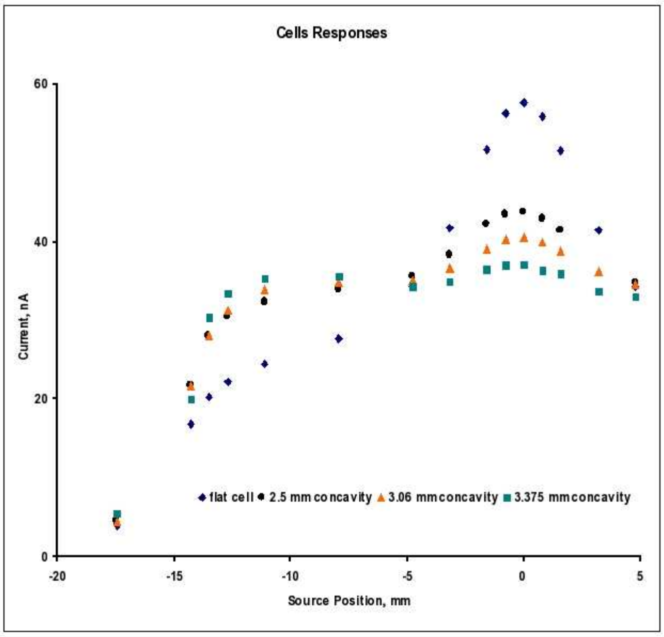

Fig. 8. Response uniformity of a square tile with different depths of concavity

effect goes in the opposite direction for light generation at the edges since the air-gap opens up the field of vision of the sensor, improving the probability of the shallow-angle photons to intersect it.

3 Direct Coupling: Light Yield

Having established the excellent uniformity of response for concave tiles we next examined their adequacy of response. This was done by measuring the response of the 5 mm thick directly coupled square tiles, with 3 mm concavity, to cosmic ray muons. The concave tile was placed between two trigger counters which were 10 cm apart. The trigger counters were 3 cm x 3 cm scintillator tiles which had Kuraray Y-11 [7] WLS fibers embedded in them. The output from the trigger tiles was sent to a coincidence logic which triggered the data acquisition system once a 30 mV threshold was satisfied for both the counters within a 50 nsec window.

The response of a directly coupled concave tile to cosmic muons can be seen in Fig. 9. A Landau distribution well separated from pedestal can be seen. Based on the calibrations available from the MPPC single photoelectron spectra we observe $\approx$ 10 photoelectrons when using a S10362-11-50C device.

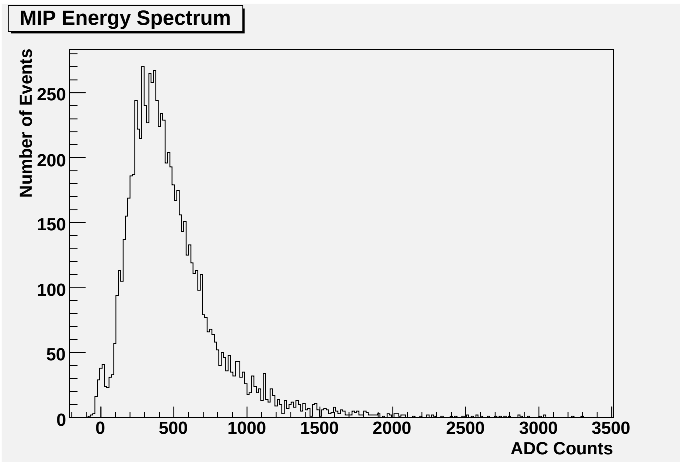

Fig. 9. Response of a directly coupled concave tile to cosmic ray muons.

4 Integrated Readout Layer

Directly coupled tiles make the design of a multi-million channel scintillator calorimeter entirely plausible. The very large number of readout channels can, however, still pose a significant challenge in the form of complexity and cost of signal transport, processing and acquisition. The development of an integrated readout layer comprised of the scintillator, photodetector and front-end electronics is crucial in carrying the calorimeter design forward. To this end, we propose to have a printed circuit board (PCB) inside the detector which will support the scintillator tiles, connect directly with the silicon photodetectors and carry the necessary front-end electronics and signal/bias traces (see Fig. 10). The photodetectors are surface mounted on the PCB and are directly coupled to the tiles. Such a board has been fabricated and is now undergoing testing. The tiles (square or hexagonal) can either be placed individually with the help of alignment pins or can be fabricated in the form of a mega-tile (see Fig. 11) which needs only two pins to align the whole array. Since the double-rotation technique is not readily extensible to an array, a burr ball bit installed at a 45° angle was used to obtain a uniform concave surface for the tiles inside the array. A response uniformity comparable to the double-rotation technique, used for individual tiles, is obtained. Efforts are underway to further simplify the fabrication of such mega-tiles by using injection molding techniques.

5 Summary and Conclusions

Fiberless or direct coupling can significantly enhance the scalability and flexibility of a scintillator-based calorimeter. The performance of directly coupled scintillating tiles was studied and found to be very encouraging. Directly cou-

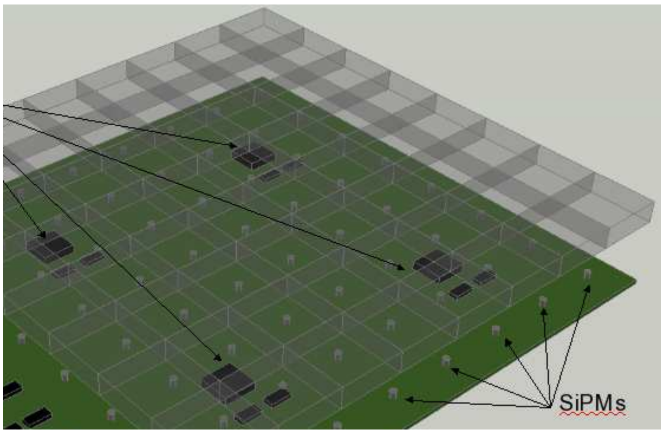

Fig. 10. Integrated readout layer concept.

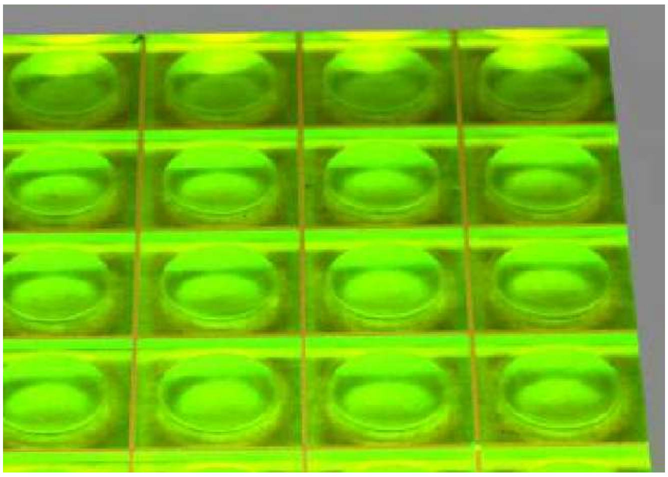

Fig. 11. Array (mega-tile) of 5 mm thick, 9 cm^2 concave square tiles with two alignment holes.

pled concave tiles give adequate response while exhibiting good uniformity of response. They are thus promising as elements of any scintillator calorimeter requiring fine segmentation. We have begun to exploit this potential in its specific application to a hadron calorimeter for the ILC detector. The result is the development of an integrated readout layer which is now undergoing testing.

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[7] Kuraray America Inc., 200 Park Avenue, NY 10166, USA.