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# Modular design for narrow scintillating cells with MRS photodiodes in strong magnetic field for ILC detector

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**Abstract**

The experimental results for the narrow scintillating elements with effective area about 20 cm$^2$ are reported. The elements were formed from the single piece of scintillator and were read out via wavelength shifting (WLS) fibers with the Metal/Resistor/Semiconductor (MRS) photodiodes on both ends of each fiber. The count rates were obtained using radioactive source $^{90}$Sr, with threshold at about three photoelectrons in each channel and quad coincidences (double coincidences between sensors on each fiber and double coincidences between two neighboring fibers). The formation of the cells from the piece of scintillator by using grooves is discussed, and their performances were tested using the radioactive source by measuring the photomutiplier current using the same WLS fiber. Because effective cell area can be readily enlarged or reduced, this module may be used as an active element for calorimeter or muon system for the design of the future electron–positron linear collider detector. Experimental verification of the performance of the MRS photodiode in a strong magnetic field of 9 T, and the impact a magnet quench at 9.5 T are reported. The measurement method used is described. The results confirm the expectations that the MRS photodiode is insensitive to a strong magnetic field and therefore applicable to calorimetry in the presence of magnetic field. The overall result is of high importance for large multi-channel systems.


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## 1. Introduction

The challenging goal of the future international electron-positron linear collider detector is to get about $30\%/\sqrt{E}$ jet energy resolution, or better. Nowadays, an energy flow algorithm is the most promising way; however, it demands highly granulated (up to 1 cm$^2$) sampling hadron calorimeter. Because of large cost, a digital approach is under investigation for use in hadron calorimetry. The electronics for a digital hadron calorimeter should be less expensive than for an analog one. The active medium can be gas [1,2] or solid, e.g., small scintillation cells [3] or scintillator strip [4]. For millions of cells, the small area of the active element creates assembly issues, dead zones and edge effects that significantly reduce the efficiency of registration (smaller the area, longer the perimeter and, consequently, larger the edge effects).

Because an energy flow algorithm demands a separation of charged particles from the neutral ones, entire detector assembly should be able to function in a magnetic field of at least 4–5 T. The algorithm will benefit from higher fields, especially if the total volume of the detector will be smaller. This requires that the detection method used should not exhibit sensitivity to the magnetic field presence. In a case of silicon photodetectors, we were able to verify their performance in the largest magnetic field strength available to us. A scintillator-based modular design of small active elements that are insensitive to the magnetic field presence

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is an approach to the cost effective digital hadron sampling calorimeter for the future International Linear Collider (ILC) and is a goal of the article.

We have tested a long narrow scintillating element with effective area about 20 $cm^2$ using optical readout via wavelength shifting (WLS) fibers and miniaturized photodetectors. A set of those elements can be combined with another layer perpendicular to its orientation, thereby creating the space resolution of about 1 $cm^2$ or better. Such elements, flexible in length and width, combine naturally in a set of ten or more, drastically reducing the amount of dead zones and edge effects, and providing space for the small-sized photodetectors that are insensitive to strong magnetic field, like Metal/Resistor/Semiconductor (MRS) photodiode [5,6], and on-board electronics assembly similar to that in Ref. [7], which may include amplifiers, discriminators, logic units, etc. In this way, usage of clear fiber can be avoided completely, WLS fibers are used in the minimum amount and fiber routing problems are avoided. In the future, scintillating elements can be produced by extrusion process [8]. This note reports on the first promising indication for the similar cell performance with machining grooves that were tested using $^{90}$Sr radioactive source by measuring current and rate. In this paper, we have also reported the performance of MRS photodiode in the presence of strong magnetic field (i.e., the dependence of output amplitude, area and rise time on the field and the possible damaging effects of a magnet quench on the sensor). This test extends measurements to 9 T, exceeding earlier measurements carried out at lower fields (4.4 T) [6].

## 2. General modular design considerations

The main idea behind the work done is to create a module-based self-triggering and self-sufficient detector part with an area resolution of about 1 $cm^2$ or less, flexible in length and width, that already consists of several cells, fibers, photodetectors and necessary on-board electronics. The ideas tested in this paper are: creation of the cell-like elements and their possible optical separation within solid scintillator piece using grooves, use of miniature solid-state photodetectors (MRS) to read out the WLS fibers, and then the performance of quad coincidence schema for the neighboring fibers of the formed cells. To avoid MRS high dark noise rate, rather high threshold (more than three photoelectrons (PE)) was used for each photodiode. By moving the radioactive source across the cells, with MRS sensors being in coincidence schema, the optical width of the cell was measured. The direct coincidences realized between both WLS fibers on each side of the cell were similar to that in Ref. [7].

## 3. Descriptions and schematics for modular design test

### 3.1. Three implemented cell formation geometries

Because the depth of a sampling hadron calorimeter for future electron–positron linear collider detector [3] is about only 1 m, the gaps for active elements should be small. For the scintillator-based hadron calorimeter, the thickness of about 5 mm is both reasonable and available from extrusion process [8]. Moreover, the 10-cm-wide strips are available and can be co-extruded with up to ten holes [8]. The distance between the co-extruded holes can be adjusted to 10 mm.

The following tests were performed using scintillator with machined grooves, not co-extruded holes, just to verify the concept and the possibility of optical cell separation using coincidence of neighboring photodetectors. For those reasons we did not perform any optimization of the machined grooves. The inter-groove distance was chosen to be 10 mm as both the distance available from co-extrusion process, and to provide space resolution about 1 $cm^2$ that is desirable for digital calorimetry. The inner diameter of the machined grooves was defined by a beat diameter nearest to outer diameter of the WLS fiber—1.2 mm. The 1.2 mm outer diameter for WLS fiber was chosen because it provides larger signal than 1.0 mm outer diameter WLS fibers even in case of 1 $mm^2$ photodetector active area. The tests on alignment of the fiber with the sensor were conducted earlier [9]. Each MRS sensor used in this test had an interface that provided sensor-fiber alignment.

As bases for described further three cell formation geometries by using grooves, 20 cm × 10 cm × 5 mm extruded scintillator pieces [8] were used. Initial pieces were solid, i.e. they did not contain any co-extruded features like holes, etc. In order to optically separate the cells from each other, the following types of grooves were milled through the strips with a computer-controlled machine (THERMWOOD) at Fermi National Accelerator Laboratories (FNAL) Lab8: "key" grooves on the one side (Fig. 1a), "key" grooves on both sides—in alternating fashion (Fig. 1b), and "key" grooves on the one side and separation grooves on the other (Fig. 1c). The schematics and dimensions of the "key"-shaped groove and rectangular separation groove are given in Fig. 1d. Each cell formed between two neighboring "key" grooves is 1 cm wide and 20 cm long.

### 3.2. MRS photodiode description

The MRS photodiode is a multi-pixel solid-state device with every pixel operating in the limited Geiger multiplication mode. A resistive layer on the sensor's surface accomplishes avalanche quenching. The devices used were of round shape and had ~1000 pixels per 1.1 mm diameter photosensitive area, with the quantum efficiency (QE) of the device reaching ~25% at 500 nm [10]. MRS photodiodes are non-sensitive to the magnetic field [6]. The result of test using field values up to 9 T is reported later in this paper. Because the MRS gain is not high, we need to use an amplifier before a discriminator with a minimal threshold of 30 mV.