PROPERTIES OF SCINTILLATOR STRIP WITH WAVELENGTH SHIFTING FIBER AND SILICON PHOTOMULTIPLIER

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The detector consisting of the 200x2.5x1cm^3 plastic scintillator strip, the wavelength shifting (WLS) fiber and two novel photodetectors called Silicon Photomultipliers (SiPMs) has been constructed and tested. Light yield and light attenuation measurements are presented. More than 13 photons are detected by two SiPMs placed at the fiber ends for cosmic ray particles at normal incidence. This provides >99% efficiency with a small noise rate. SiPM has several advantages over photomultipliers. It is not sensitive to magnetic field and hence light transportation is not required. Its gain is determined easily by observing peaks corresponding to different number of fired SiPM pixels. It is cheaper than one channel in multichannel photomultiplier. A possibility to use such a new technique in the muon systems or calorimeters with tracking information is demonstrated.

1. Introduction

Use of plastic scintillator with WLS fiber and multichannel photomultiplier for detection of charged particles is a well established and reliable technique (see, e.g. [1]). However this method has some disadvantages:

- photomultiplier can not operate in magnetic field. So one has to use clear fibers to guide light to photodetectors placed outside magnetic field and light loss in long fibers is inevitable.
- assembly of hundreds or thousands fibers in bundles to be attached to PMTs is not easy and creates problems when exchange or disassembly of fibers is needed
- conventional PMTs require HV in 1000 V range (cables, safety …etc)

In this work we used a novel solid state photodetector Silicon photomultiplier (SiPM) [2] which is free from these drawbacks. Due its small size a SiPM may be embedded into scintillator without noticeable loss of efficiency. There is no need to use clear fiber for light transportation. It is insensitive to magnetic field (has been tested up to 4T field). Operational voltage of a SiPM does not exceed several tens volts.

2. Properties of the Silicon Photomultiplier

The SiPM is the matrix of 1024=32x32 independent silicon photodiodes (pixel) operating in Geiger mode. The total area covered by diodes is 1 mm^2. Each diode is connected to a common bus via a quenching resistor of the order of few hundred kΩ. A reverse bias voltage of 40-60 V is applied to pixels. If bias voltage exceeds the breakdown voltage then the Geiger discharge starts when a free charge carrier appears in the p – n junction depletion region. The resulting output signal is $Q_{pixel} = C_{pixel} \times (V_{bias} - V_{breakdown})$. Typically C_{pixel} ~ 50 fF and $\Delta V = V_{bias} - V_{breakdown} \sim 3$ V yielding $Q_{pixel} \sim 10^6$ electrons. When several pixels are fired then the sum signal is proportional to the number of fired pixels because characteristics of all diodes are very similar. This is illustrated in Fig.1b where SiPM response spectrum is shown. SiPM is illuminated by weak flashes of a light emitting diode (LED). The spectrum has peak structure. Each peak corresponds to the number of fired pixels, so there is an excellent possibility to find the SiPM gain from LED spectrum. Due to finite number of pixels saturation effects should be taken into a when number of detected photons is comparable with number of pixels.

The SiPM photodetection efficiency depends on the value of overvoltage ΔV and light wave length. Typical value of efficiency is 10-15% for the green light. It is product of silicon photoefficiency (~80%), efficiency of Geiger avalanche development (~60%) and geometry efficiency (~35%). There is an interpixel cross talk which may reach 30% - this limits possible gain. SiPM has a significant noise of about 2 MHz at ~0.1 pixel level. However the noise rate drops fast with increasing threshold. The drop rate is determined mainly by interpixel cross talk. The SiPM is a very fast device – the discharge development time is less than 1 nsec.

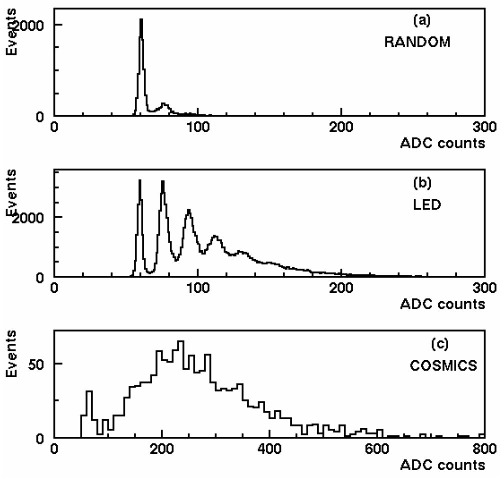

Figure 1. Response of SiPM to various trigger

3. Test of scintillator strip

3.1. *Experimental set-up*

Figure 2 shows schematically the set-up. The detector was a 200 x 2.5 x 1 cm^3 strip with 2.5 mm deep groove in the middle of the strip. The scintillator was produced by "Uniplast" company in Vladimir, Russia by extrusion technique from the granulated polystyrene with two dopants (0.01% of POPOP

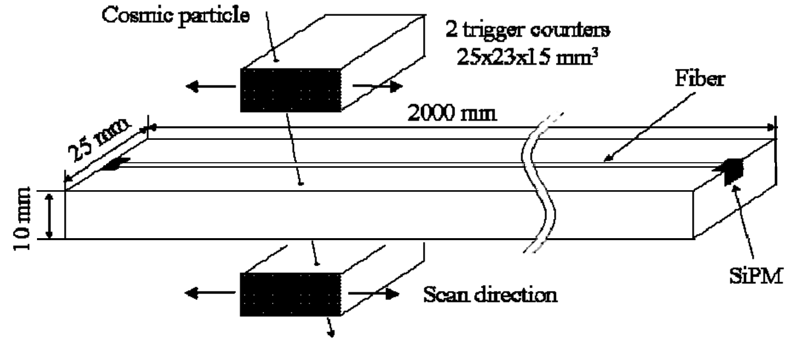

Figure 2. Schematic view of the experimental set-up.

VLS

fiber of 1 mm diameter placed in the groove. Two SiPMs were attached to the fiber at both fiber ends. The gap between sensitive SiPM surface and fiber was 200 µ. The scintillator was wrapped in 3M Superradiant VN2000 foil. Signals from SiPM were integrated by LeCroy 2249A ADC with the gate of 120 ns .

There were two trigger counters of 23 x 25 mm above and below the tested strip. Moving them along the strip one might test strip response at various distances from strip end. Due to angular spread the mean value of cosmic particles path length in the strip is 10% larger than strip thickness. This was taken into account during data analysis.

3.2. *Data analysis*

During a run we collected SiPM response distributions for different triggers – one for trigger from cosmic particles, another – for LED light and the third one for random trigger. This is illustrated at Fig. 1. We determined the SiPM gain from the LED spectrum. It was equal to the distance between adjacent peaks. After that we expressed the MIP response in pixels. To estimate the light yield of the detector for the minimum ionizing particles we used the maximum of Landau distribution. The average value is approximately 1.1 times larger than position of the maximum due to Landau tail. We did not correct result for this value in order to be conservative in our estimates of detector performance. In order to convert the number of fired pixels into number of detected photons the response of each SiPM was divided by factor taking into account the inter pixel cross talk. This factor was equal to 1.43 and 1.28 for the left and right SiPMs, correspondingly. The obtained values were divided by 1.1 because of inclined tracks selected by trigger counters. The number of detected photons at normal incidence is plotted at Fig. 3, where the sum signal is shown as well. The minimal value of sum signal is equal to 13.7 for the position of trigger counters in the strip center. One may see that light transportation from the far end attenuates the light by about factor of 2. The sum signal is uniform in the 13% limit.

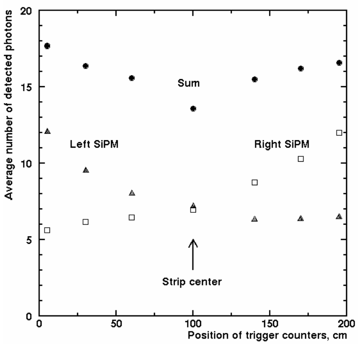

Figure 3. Average number of detected photons for normally incident cosmic particles vs position of trigger counters.

In case of Poisson distribution with mean value of 13.6 detected photons the 98% efficiency is reached when the threshold is set to 7 photons. In order to determine the threshold in terms of fired pixels the simple modeling was done. We simulated response for each SiPM equal to 6.8 detected photons distributed according to Poisson law. Then number of fired pixels was calculated by

Table 1. Data of strip response at various positions of trigger counters.

x-coordinate, cm	5	30	60	100	140	170	195
Number of cosmic trigger	270	607	199	645	199	517	142
Number of cosmic events $A_{sum} < 9$	0	4	3	11	1	5	0
Non-efficiency, %	0.	0.7	1.5	1.7	0.5	1.0	0.
Number of random trigger, x10^3	6.4	13.3	3.9	12	4.4	12	3.2
Number of random events $A_{sum} > 8$	3	9	7	6	1	11	4
Noise probability, x10^{-4}	5	7	18	5	2	9	12

multiplying of number of detected photons after simulation of cross talk value. Then the width of single photoelectron peak from LED spectrum was added to have the final SiPM response. It turned out that one might have more than 98%

efficiency if sum response was larger than 8 pixels. This was checked with data. As the data were taken with inclined tracks we had to increase the threshold by factor 1.1. Numbers of cosmic triggers and number of events with $A_{sum} < 9$ are given in the Table 1. One may see that for all data the detector non-efficiency is less than 1%.

In order to estimate the noise rate at the threshold ≥ 8 pixels we used the spectra obtained with random trigger. Number of random trigger and number of events with amplitude higher than 8 pixels are also given in the Table 1.

All runs data gave $1.7*10^{-4}$ noise probability with 120 ns gate width. The noise rate may be reduced if one uses for SiPM pulses coincidence faster electronics.

4. Conclusions

The detector consisting of 200 x 2.5 x 1 cm3 plastic scintillator, the WLS fiber and two novel photodetectors (SiPM) has been tested. Such kind of detectors may be used in muon systems. It has high efficiency and low noise rate as compare with resistive plate chambers often proposed as muon detector. The SiPM has similar gain and efficiency as the traditional photomultiplier. Despite Contrary to vacuum photomultipliers the SiPM can operate in magnetic field, its small size allows incorporate it into scintillator body, SiPM operational voltage does not exceed several tens volt. The light collection efficiency may be increased by gluing of a fiber into the groove [3].

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