Development of a scintillation detector with a photosensor based on matrices of silicon photomultipliers

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Abstract. Scintillation detector with matrices of silicon photomultipliers (SiPM) as multi-channel photosensors is under development. The use of SiPM matrices gives a possibility to do a snapshot of glowing track of charged particle traversing a scintillator. The snapshots of the events inside the scintillator were taken for the two SiPM matrices arrangements. The comparison characteristics of snapshots for these arrangements are presented.

1. Introduction

A charged particle traversing a scintillator induces scintillation along its track. At each point of the track the produced light is emitted isotropically. The use of SiPM matrices (with appropriate optical collector) gives, in principle, a possibility to do a snapshot of this glowing track [1]. This technique has the obvious advantages. Firstly, the snapshot of glowing track of the particle gives a possibility to determine the direction of the particle. Secondly, there is a possibility to measure the energy release along the track of particle. It is expected that the proposed method of detecting particles may be useful in the creation of new large detectors to neutrino astrophysics and geophysics.

In this paper we present prototype of the scintillation detector with SiPM matrices ArrayC-60035-64P-PCB as multi-channel photosensors. Plastic scintillator has a size of $50\times59\times59$ mm^3. The matrix ArrayC-60035-64P-PCB consists of 64 SiPMs (8×8) SiPMs, each of them has size of 6×6 mm^2 and consists of 18 980 micropixels [2]. It sould be noted that the contamination of the matrix by gamma-active impurities is low enough and comparable with that for low background PMTs [3]. Multichannel data acquisition system for the detector is based on VME interface [4]. Four QDC V792AC allow to digitize signals from 128 SiPMs.

Two variants of scintillation detector were considered. In the first variant both matrices are placed on the surface of the plastic scintillator (figure 1). In the second variant an optical system with Fresnel lens was used (figure 3).

2. Detector with matrices placed on the surface of the plastic scintillator

In this variant of the detector – with matrices are located directly on the surface of the plastic scintillator – linear size of the matrix must be equal to linear size of the scintillator bar (figure 1).

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The optical grease was used for optical contact between matrix and scintillator.

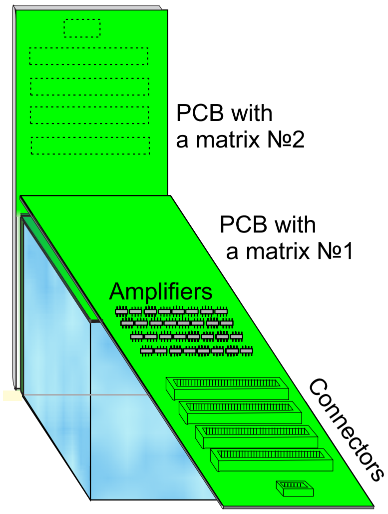

Figure 1. Detector with matrices placed on the surface of the plastic scintillator.

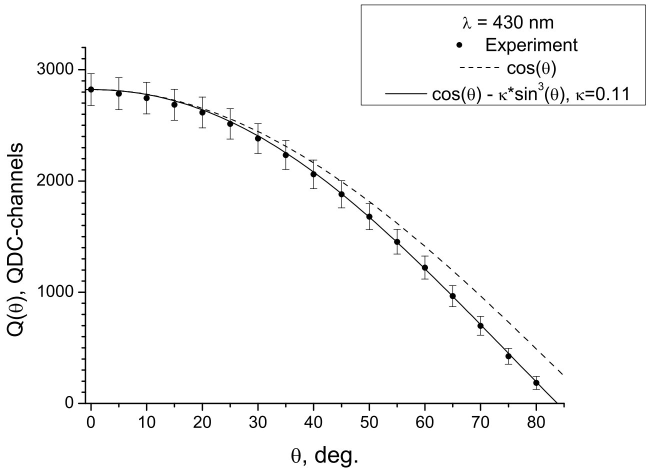

Figure 2. Charge of the SiPMs pulses vs. the angle of incidence of the light beam for wavelength of 430 nm.

The effective area of a silicon photomultiplier depends on the angle of incidence θ of the light beam according to the law $\cos\theta$. If quantum efficiency of the silicon photomultiplier depends on the angle of incidence then one can expected that charge distribution of the SiPMs pulses will not be scaled according to the same law. The experimental verification of this assumption has been performed for three wavelengths: 470 nm, 430 nm and 400 nm. To create a parallel beam of uniform density the LED has been removed from the matrix on 340 mm. The LED emitter was operated in the regime of low flux of light. In this regime less than 2% of the total number of pixels of the SiPMT were simultaneously in operation. Measuring the charge of pulses of the SiPM in response to the LED pulses was conducted for different angles of incidence photons at the same radiated power. The results of the measurements for wavelengths of 430 nm are shown on figure 2. The experimental data for all three wavelengths have tangible difference from cosinusoidal law. They are fitting by function $cos(\theta) - \kappa \times sin^3(\theta)$. Values of κ depend on wavelength, they are 0.07, 0.11 and 0.11 for, correspondingly, wavelengths 470 nm, 430 nm and 400 nm.

Amplitude calibration of the detector is performed by means of cosmic ray muons. To this effect the energy deposition spectrum in the scintillator bar and spectra on the number of photoelectrons for each SiPM have been calculated. Most probable value of energy deposition from cosmic ray muons for used scintillator bar is 10.5 MeV. Calculated spectra by the number of photoelectrons for all SiPMs of the matrix viewed the scintillator from above are shown on figure 3. One can see that for the calibration of the detector the dependence of charge of the SiPM pulses on the angle of the photon incidence must be considered.

Example of the snapshot for such kind of detector is shown on figure 4. The surface of each SiPM on the snapshot is shaded from black to white depending on magnitude of the measured signal. The numbers represent the measured values and include pedestals of QDC channels.

3. Detector with optical system

The design of the scintillation detector with optical system on the base of Fresnel lenses is shown on figure 5. The Fresnel lenses of A4 format with threefold magnification are used. These lenses

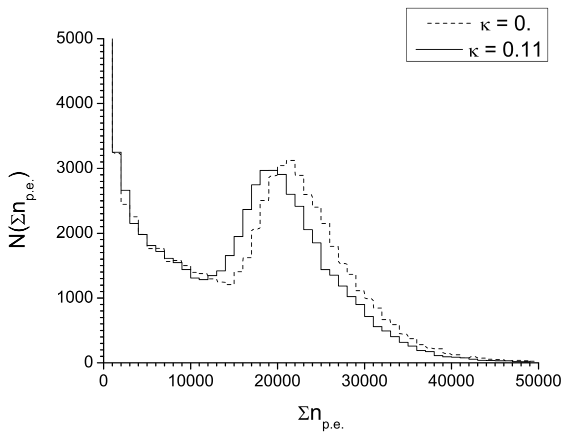

Figure 3. Calculated spectra by the number of photoelectrons for all SiPMs of the matrix viewed the scintillator from above.

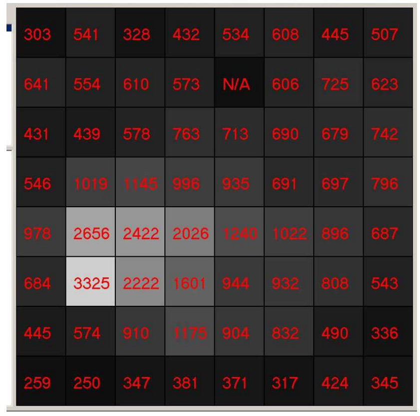

Figure 4. Example of the snapshot taken by matrix placed horisontally on the surface of the scintillator.

made from optical acrylic. Matrices are located on the doubled focal lenght from the center of scintillator bar. Two Fresnel lenses are used for each projection to reduce of the focal lenght and, therefore, to reduce the size of whole detector.

Though the optical system decrease the amplitude of signal such kind of detector allows to obtain well-defined snapshots of the events inside the scintillator. Example of the snapshot for two projection (H - horizontal, V - vertical) is shown on figure 6.

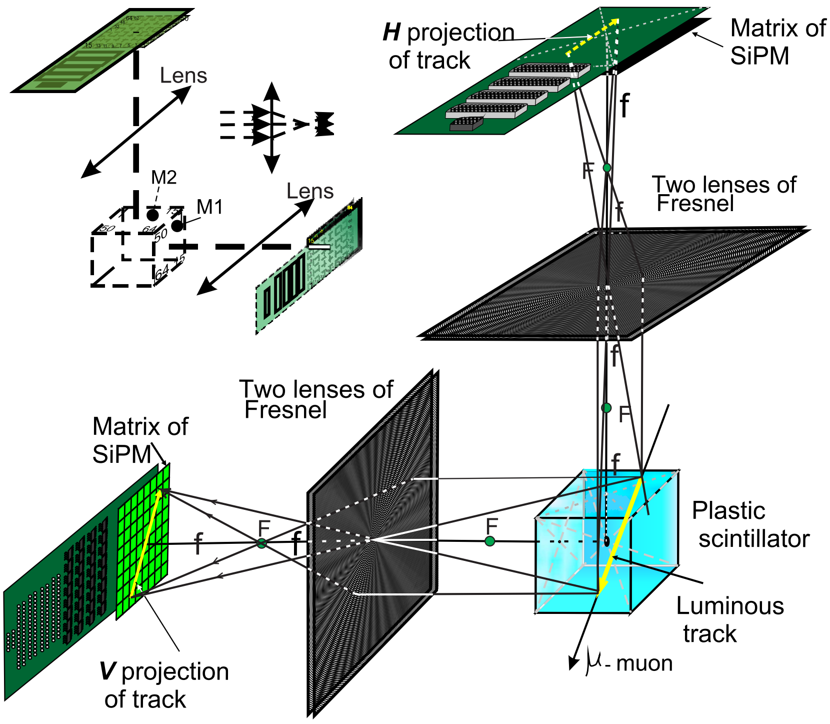

Figure 5. Detector with optical system based on the base of Fresnel lenses.

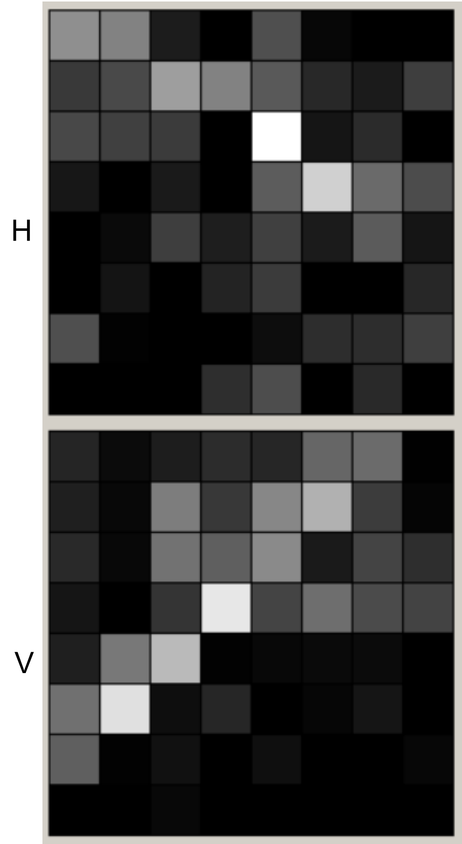

Figure 6. Example of the snapshot for two projection: H - horizontal, V - vertical.

4. Conclusion

Different types of scintillation detectors with a photosensors based on SiPM matrices are under development now. The SiPMs matrix attached to a plastic scintillator can be used both: for the selection of events in separate parts of the scintillator bar and for taken of snapshot of events inside the scintillator. Such kind of detector has obvious size limit, because linear size of the matrix must be equal to linear size of the scintillator bar. The use of the optical system removes this restriction and allows to take well-defined snapshots of the events inside the scintillator. It is quite natural that the details of optical system of the detector must depend on scintillator dimensions and scientific problems. As an example, for large scintillator dimensions and optical system based on Fresnel lenses the size of whole detector can be unacceptably large. In this case an optical collector using optic fibers can significantly reduce the size of whole detector.

Acknowledgments

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