MODERN ASTRONOMY: FROM THE EARLY UNIVERSE TO EXOPLANETS AND BLACK HOLES

Liquid scintillation detector based on an acrylic sphere and silicon photomultiplier matrices

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Abstract. This paper presents the results of applying the matrices of silicon photomultipliers (SiPMs) as multichannel photodetectors for the scintillation detectors based on a liquid scintillator. We consider the possibility of using the SiPM matrices with an appropriate optical collector to obtain an image of the luminous tracks of charged particles passing through a scintillator. Such a method allows one to obtain an image of an event inside the scintillator volume, the analysis of which makes it possible to separate different classes of events. It is expected that the proposed particle detection technique may be useful in the creation of new large detectors for neutrino astrophysics and geophysics. The detector is an acrylic sphere with a diameter of 500 mm, filled in with a liquid scintillator. The scintillator is viewed through an optical collector based on two Fresnel lenses with two matrices of 64 SiPMs. The paper describes the data collection system and the detector design, we also demonstrate a three-dimensional image of a recorded event.

Keywords: instrumentation: detectors; techniques: image processing

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1 Introduction

Silicon photomultipliers (SiPMs) and Fresnel lenses have already been used in the design of scintillation detectors. The Mini-EUSO telescope, launched in 2019, has Fresnel lenses and vacuum photomultiplier tubes in its design as well as the SiPMs matrices (Battisti et al. 2023). The Gamma-400 space observatory under development also explores the possibility of detecting the photons from a scintillator by focusing them through a Fresnel lens onto a SiPM (Runsto et al. 2019).

For our detector, the task is to obtain a snapshot of an event when a particle passes through the scintillator substance in order to derive an additional parameter to the measurement of the energy released for further analysis and classification of the event. It is also of interest to study the possibility of recording tracks of rare events, which may become in demand in the development of new large detectors for neutrino astrophysics and geophysics. The prospects for the application of the new technique in the Baksan Large Volume Scintillation Detector are indicated in Petkov (2016).

2 Detector design

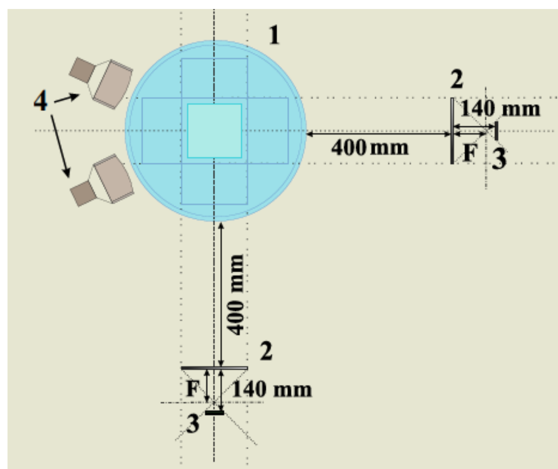

Fig. 1. Detector design (top view): 1—acrylic sphere, 2—Fresnel lens, 3—SiPM matrix, 4—vacuum photomultiplier XP4500B.

The detector has small dimensions: the diameter of the acrylic sphere is 500 mm, which is convenient for designing the mounting structure for matrices and Fresnel lenses as well as for developing the calibration and processing techniques.

The acrylic sphere is filled with a scintillator developed at the Institute for Nuclear Research of the Russian Academy of Sciences and remaining one of the best in the world in terms of such characteristics as the scintillation output, short illumination time, and stability of the scintillator (Voevodskii et al. 1970). The SiPM matrices ARRAYJ-60035-64P-PCB of the Irish company SensL were selected as photodetectors, their maximum sensitivity (420 nm) coincides with the maximum of the photon emission spectrum of our scintillator.

The optical collector of the detector has two Fresnel lenses. Two matrices of SiPMs are arranged orthogonally. The total working volume to view is close in shape to a cube with a face of 17 cm. The volume is highlighted in Fig. 1 in the center of the sphere. The measurements of the volume viewed by the matrix for this geometry of the optical collector were carried out using a probe with a LED mounted on it. We were recording the positions of the LED in the volume of the sphere when the image of the LED was still falling onto the edges of the matrix. The description of the measurements is given in Dzaparova et. al. (2021).

The working volume of the detector is viewed by two Photonics XP4500B vacuum photomultipliers. A trigger is generated by the coincidence of the photomultiplier anode signals with the set threshold. The next step in improving the detector design is to add a third matrix to the data acquisition system. For this purpose it was necessary to create a program for constructing three-dimensional images of recorded events. This approach to visualize the registered events is useful for the analysis even when there are only two matrices in the data acquisition system.

3 The data acquisition system and measurement results

The MDU3-GI64X2 data acquisition system from AiT Instruments consists of two 64-channel boards of 12-bit charge-to-digital converters. The data acquisition system can operate from an external trigger and can use different options for generating an internal trigger. A flat micro-coaxial cable assembly connecting the MDU3-GI64X2 input connector to a preamp board creates an interference-proof channel for transmitting analog signals. The control of the unit and data collection are implemented via the USB 3.0 interface.

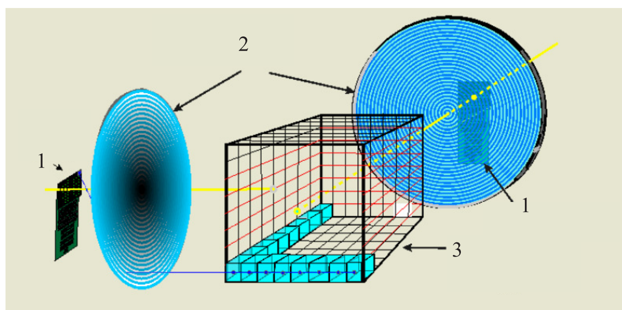

Fig. 2. The working volume of the detector divided into 512 cubes by two SiPM matrices.

The data processing program for constructing three-dimensional events based on the measurements is working in test mode: so far with data from two matrices—128 channels. Having the two projections obtained by the matrices, one can build the third projection. The viewed working volume in this case will be divided into 512 cubes (Fig. 2). Each SiPM of the first matrix detects photons from eight cubes of the corresponding SiPM row of the second matrix, then vice versa the measured values in the row of the first matrix are determined for each SiPM of the second matrix. Thus, the program determines the coordinates and brightness of the SiPM cubes for the entire working volume of the detector.

The brightness of some cubes in event visualization is not always uniquely determined and requires the use of assumptions (before including the third matrix in the data acquisition system). Figure 3 shows a three-dimensional image of a registered event.

Fig. 3. Three-dimensional image of the registered event.

The size of the ARRAYJ-60035-64P-PCB, 8×8 SiPM matrices, is 5.04×5.04 cm^2, and the area of the working volume cube face facing the matrix is 17×17 cm^2. Thus, the cube face area is 11 times larger than the area of the matrix. It is assumed that after connection of the third matrix, the parameters of the optical system will remain the same for the time being, in order to simplify testing both the event visualization program and the optical system.

4 Summary

Necessary conditions have been created to connect three SiPMs matrices to the data acquisition system. A trigger for the measurements is generated by the coincidence of the anode signals from the vacuum photomultipliers with the set threshold. The construction for the installation of the third matrix has also been prepared. Further increase in the number of matrices included in the data acquisition system while reducing the volume viewed by a matrix requires creation of another calibration system both to obtain an image at the required scale and to verify the accuracy of the location of the matrices in the detection system.

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