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Assembly and test of prototype scintillator tiles for the plastic scintillator detector of the High Energy Cosmic Radiation Detection (HERD) facility

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Abstract. Satellite experiments for gamma-ray and cosmic-ray detection employ plastic scintillators to discriminate charged from neutral particles in order to correctly identify gamma-rays and charged nuclei. The High Energy Cosmic Radiation Detection (HERD) facility will be among these experiments, to be installed onboard the future Chinese Space Station (CSS), to detect cosmic-rays and gamma-rays up to TeV energies. The plastic scintillator detector (PSD) will consist of scintillator tiles or bars coupled to Silicon Photomultipliers (SiPMs). To discriminate gamma-rays from charged particles and measure the ion charge up to iron nuclei a wide dynamic range is required, from few tens up to thousands of photoelectrons. We have equipped a plastic scintillator tile prototype with SiPMs produced by Hamamatsu and AdvanSiD and coupled their analog signals to the DT5550W board based on the CITIROC ASIC, produced by CAEN SpA. The CITIROC ASIC allows both the formation of a fast trigger with a configurable threshold and the digitization of analog waveforms after a preamplification and shaping stage along two paths with different gain settings. The performance of our prototype will be shown.

1. Introduction

The High Energy cosmic Radiation Detection (HERD) facility is an international space mission that will be installed on the Chinese Space Station currently being assembled (see Fig.1) and

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will be operative by the end of 2027. The main goals of HERD are: the precise measurements of the cosmic-ray spectrum and composition up to the knee energy, the precise measurement of the cosmic-ray electron/positron spectrum and of their anisotropy up to 10 TeV, the monitoring and survey of the high-energy gamma-ray sky, the search for signals from dark matter annihilation products. The instrument will be surrounded by a plastic scintillator detector (PSD), which will be used to discriminate charged from neutral particles, to correctly identify gamma-rays and nuclei [1]. Currently two configurations are being studied for the PSD geometry, respectively based on scintillating bars and tiles. Several tests and R&Ds are ongoing; hereafter we will illustrate the tests based on the second option.

Usually, scintillators are read out using photomultiplier tubes (PMTs), requiring high operation voltages (order of kV) and making them unpractical to be operated on satellites. However, new developments in the field of Silicon Photomultipliers (SiPMs) are confirming that they can be suitable for the detection of fast light signals, with lower power consumption and with very good sensitivity to low numbers of photons. Several tests are studying the scintillators coupled to the SiPMs, to be used for future missions such as e-Astrogam [2], AMEGO [3], and HERD [4]. In recent years some tests of scintillators coupled to SiPMs were already performed, exploring this possibility also for different applications.

Figure 1: Artist's view of the Chinese Space Station.

2. Setup description and measurements

A $10 \times 10 \times 0.5$ cm^3 BC-404 plastic scintillator tile has been used, equipped with three PCB mounting Hamamatsu SiPMs (see Fig. 2), which has a light yield of 68% of Anthracene and peak emission at 408 nm. The photon detection efficiency (PDE) peaks at 420 nm, matching the BC - 404 emission, with a maximum value of 43% which is reached at 5 V of over-voltage. Two of the three PCB have been equipped with 3 SiPMs S14160-3015ps with a 3×3 mm^2 area, while the other one has been equipped with 3 SiPMs S14160-1315ps with a 1×1 mm^2 area. All SiPMs have cells of 15 μm size. The scintillator tile has been polished and wrapped tyvek sheet (250 μm thick) that has been black-painted on one side and left white on the other. The signals have been acquired with the CAEN DT5550W [5] board CITIROC ASIC [6]. The entire setup was placed in a dark box, see Fig.3.

We have performed two kind of tests one with a ^{90}Sr beta emitter radioactive source, moving it with 1 cm steps along the X and Y axes, as is illustrated in Fig. 4 and the other one acquiring cosmic-rays. Two amplification channels were available on the amplification boards, one with a gain 10 times larger than the other. We labelled these channels as High Gain (HG) and Low Gain (LG). Also we labelled three DAQ channels: Channel 16 (Ch16) referred to the trigger and connected to the PCB equipped with SiPMs S14160-1315ps placed on the right side; Channel 17 (Ch17) and Channel 18 (Ch18), used to perform measurements, respectively connected to the PCB equipped with SiPMs S14160-3015ps placed on the left and on the top side, respectively.

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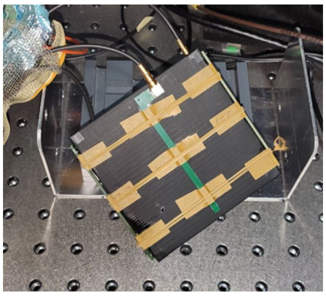

Figure 2: 3 PCB placed on the PSD are visible, one on the top and the others on the two opposite sides.

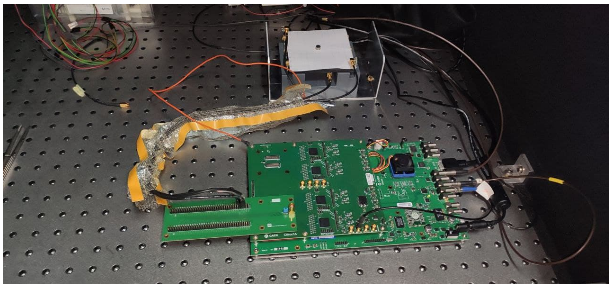

Figure 3: Picture of the experimental setup.

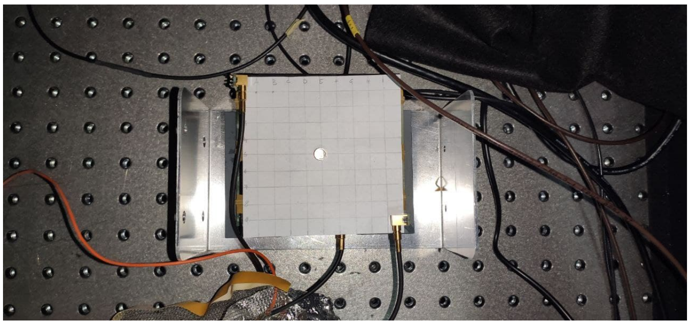

Figure 4: ^{90}Sr radioactive beta-particle source placed on PSD.

3. Data analysis and Results

We triggered on the PCB equipped with S14160-1315ps both in the cosmic-ray and in the ^{90}Sr source tests. The cosmic-ray and the ^{90}Sr ADC charge distributions in the low gain case referred to the acquisitions with the PCB placed on the tile side (Ch17) and on the top (Ch18) are shown in Figs. 5 and 6. In the case of the ^{90}Sr radioactive source tests, are referred to a measurement in which the source was placed in the position in which $X = 4\ cm$ and $Y = 3\ cm$. The charge distributions in the case of ^{90}Sr measurements are characterised by a tail on the right, that is less evident with respect to the case of cosmic-rays as expected. In Figs. 7 and 8 are shown the mean value of the measured spectra for top and side positions of the SiPMs respectively. The number of photons increases when the source position is close to the SiPMs. We see that side SiPMs show a more uniform response with respect to the top ones.

4. Conclusions

HERD is a new generation detector for gamma-rays and charged cosmic-rays which will be operated onboard the Chinese Space Station starting from 2027. The HERD PSD needs to have a very high detection efficiency for the charged cosmic-rays, which represent the main background for the identification of gamma-rays, and a very great capability in identifying charged nuclei. The future HERD space mission will employ SiPMs instead of classical PMTs to read out the scintillator light in order to exploit their smaller sizes and lower power consumption.

Optimization of the PSD performance can be achieved by choosing the best PSD geometry and by optimizing the electronics. Several tests are planned in order to improve the tile assembly procedure, including various kind of wrapping and couplings to SiPMs, and to study different

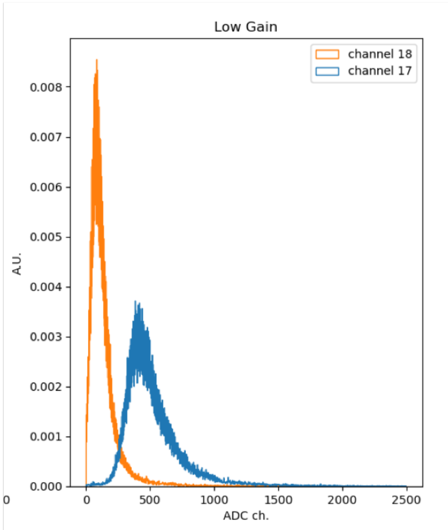

Figure 5: Cosmic-ray distributions.

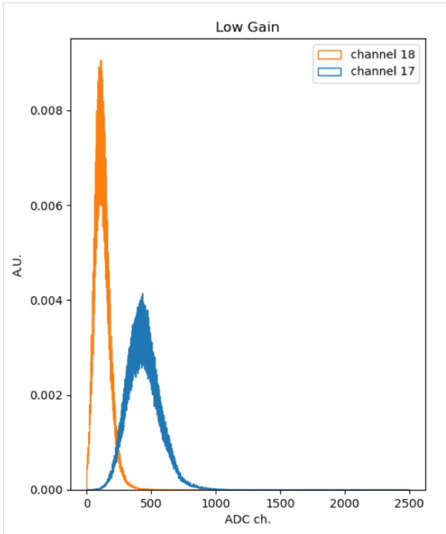

Figure 6: ^{90}Sr radioactive source distributions.

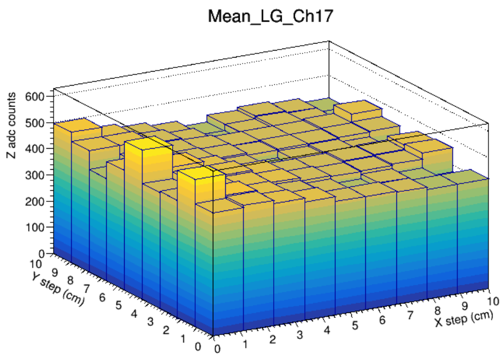

Figure 7: Photon count map for Ch17 in the low gain case, placing the source on the left side.

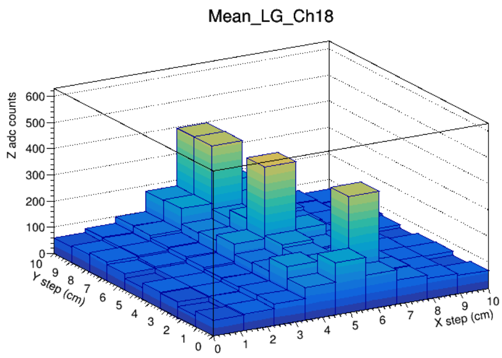

Figure 8: Photon count map for Ch18 in the low gain case, placing the source on the top.

tile shape and SiPM configurations.

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