IL NUOVO CIMENTO **44 C** (2021) 101
DOI 10.1393/ncc/i2021-21101-y

Communications: SIF Congress 2020

Simulation and tests of HEPD-02 scintillator prototypes

A. Contin(1)(2), M. Lolli(2), A. Oliva(1)(2), F. Palmonari(1)(2), M. Pozzato(2), and Z. Sahnoun(2)(*), on behalf of the CSES-Limadou Collaboration

(1) *University of Bologna - Bologna, Italy*
(2) *INFN, Sezione di Bologna - Bologna, Italy*

received 15 January 2021

Summary. — The High-Energy Particle Detector (HEPD-02) on board of the China Seismo-Electromagnetic Satellite (CSES-02) is a second-generation particle detector aimed to measure particle precipitation due to short-time perturbations in the radiation belts caused by solar and terrestrial phenomena. It consists of two trigger planes one above and the other below the tracker module and a range calorimeter surrounded by a veto system. HEPD-02 should be able to measure particle flux and energy spectrum in a wide range of energies. In this paper simulations and tests of HEPD-02 trigger paddle prototypes are discussed.

1. – Introduction

The China Seismo-Electromagnetic Satellite (CSES-02) is a Chinese-Italian space mission [1,2] dedicated to monitoring of electromagnetic field, plasma and particle fluxes variations in the near-Earth space. Its main goal is the study of the correlation of particle bursts (fast increase in count rate) with the occurrence of strong seismic events, but it has also the capability to study the perturbations due to solar and cosmic phenomena. The High-Energy Particle Detector (HEPD-02) [3] developed by the Italian collaboration (also called Limadou) is one of the instruments on board the CSES-02. It is composed of two segmented trigger planes above and below a solid-state detectors tracking system, followed by a range calorimeter combining plastic and crystal scintillation counters. Finally, five plastic scintillator panels covering the sides and the bottom are used to detect particles escaping from the calorimeter and background particles entering from the sides. HEPD-02 will measure particle fluxes and energy spectra in the range 3–100 MeV for electrons and 30–200 MeV for protons. The trigger counters define the acceptance of the calorimeter. The top layer also determines the detector's energy threshold. The thinner the layer, the lower is the threshold. With the prospect of lowering the threshold, a dedicated study was performed to characterize the light output and efficiency of thin counters. In this paper, the results of the experimental test and simulation of two prototypes of plastic scintillators considered for the top trigger layer are presented.

(*) Corresponding author. E-mail: `sahnoun@bo.infn.it`

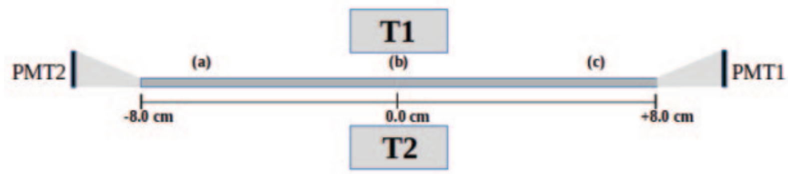

Fig. 1. – Sketch of the experimental setup used to test the trigger paddle prototypes in three different positions: (a) toward PMT2 (−6.0 cm from center), (b) at the center of the paddle (0.0 cm), and (c) toward PMT1 (+6.0 cm).

TABLE I. – *Most probable number of photoelectrons for minimum ionising particles (cosmic muons).*

Position (cm)	2 mm counter		3 mm counter	
	PMT1	PMT2	PMT1	PMT2
−6.0 (a)	10.6 ± 1.5 p.e.	32.1 ± 3.6 p.e.	22.0 ± 4.7 p.e.	50.2 ± 7.1 p.e.
0.0 (b)	16.5 ± 1.5 p.e.	16.5 ± 2.3 p.e.	30.1 ± 5.4 p.e.	31.0 ± 5.4 p.e.
+6.0 (c)	36.5 ± 2.9 p.e.	8.7 ± 1.4 p.e.	50.0 ± 7.0 p.e.	21.0 ± 4.6 p.e.

2. – Experimental test

The top trigger plane is made of five paddles of EJ-200 plastic scintillation counters. Each counter is read out by two photomultiplier tubes (Hamamatsu R9880U-210) on opposite sides to improve the uniformity of light collection. These photomultipliers are coupled to the paddle via light guides, designed in order to match both the shape of the scintillator bar and the aperture of the phototube to optimise the light collection. Two prototypes of plastic scintillator counters, 30 mm $\times$ 160 mm with thickness 2 mm and 3 mm, respectively, were tested under cosmic muons. These paddles were wrapped in mylar and coupled through trapezoidal light-guides to the Hamamatsu R9880U-210 photomultiplier tubes, named PMT1 and PMT2. Two counters (T1 and T2), one above and the other below the paddle, covering a 30 mm $\times$ 30 mm surface area were used in coincidence to trigger a digital oscilloscope used to record the PMT signal. These trigger counters were moved together along the length of the paddle, in order to collect data at the center and at both ends. A sketch of the experimental setup is shown in fig. 1. The recorded signal from PMT1 and PMT2 could then be integrated over time to retrieve the number of photoelectrons (p.e.) collected, considering an estimated PMT gain $\sim 1.2 \cdot 10^6$, at 850 V, and a 50 Ω resistance. For both prototypes, the photoelectrons are collected by each phototube for three muon incident positions (a), (b) and (c) in fig. 1, namely toward PMT2 (−6.0 cm from center), at the center of the paddle (0.0 cm) and toward PMT1 (+6.0 cm), respectively. The most probable number of photoelectrons, obtained from a Gauss-Landau fit of the photoelectrons distribution, is reported in table I. From these results it appears that both prototypes are efficient in revealing minimum ionising particle.

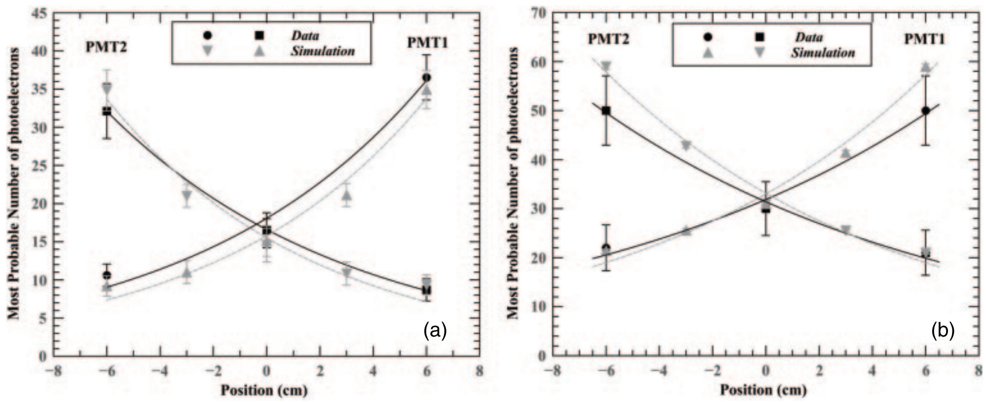

Fig. 2. – The most probable number of photoelectrons obtained from simulation compared to experimental data for 2 mm (a) and 3 mm (b) thick prototypes. Black squares and circles are for experimental data. Light grey up and down triangles are simulation data.

3. – Simulation

A Monte Carlo simulation of the response of the 2 mm and 3 mm thick plastic scintillator paddles was performed using the GEANT4 toolkit [4]. The light guides are simulated as acrylic glass (PMMA), 20 mm long, with a 30 mm $\times$ 2 (3) mm surface area at the scintillator's end and a 12 mm $\times$ 12 mm surface area at the PM end. In the simulation, the phototube is implemented as a sensitive photocathode surface with a 8 mm diameter immediately behind a borosilicate entrance window of 1 mm thickness. The physical properties of the materials, the light emission spectrum of EJ-200 plastics and the photon to electrons conversion (quantum) efficiency were included in the simulation. The reflectivity of the wrapper was taken to vary from ~ 0.92 to 0.93 in our spectral range and was adjusted to best match the experimental results. For each event, the energy released in the plastic scintillator and the number of photoelectrons produced on each photocathode all along with the arrival times and wavelengths of the primary photons are registered.

The simulation was run for a vertical beam of minimum ionizing muons uniformly distributed on the scintillator surface. Results were then compared to experimental data, see fig. 2(a) and fig. 2(b) for the 2 mm and 3 mm counters, respectively. The simulation shows a reasonable agreement with experimental data. An additional parameter that shows the efficiency of light collection is the near/far ratio, that is the ratio of the number of photoelectrons collected by a PMT for muons incident at the closest position, to that collected for muons incident at the farthest position from the same PMT. For the 2 mm counter this ratio was found to be $\sim$ 3.4–3.7 from experimental data while it is $\sim$ 3.7 from simulation. In the case of the 3 mm counter, the simulation gives a near/far ratio around 2.7–2.8 whereas the experimental value is 2.2–2.4.

Spatial resolution. – The Monte Carlo simulation allows us also to better study the performances of the scintillator counters and their spatial and temporal resolution. For example, one estimator that can be used to measure the particle impact point along the counter is the ratio of the difference between the number of photoelectrons seen by each pmt to their sum, $(p1 - p2)/(p1 + p2)$, $p1$ being the number of photoelectrons collected on PMT1 and $p2$ the one collected on PMT2. In fig. 3(a) the correlation between the

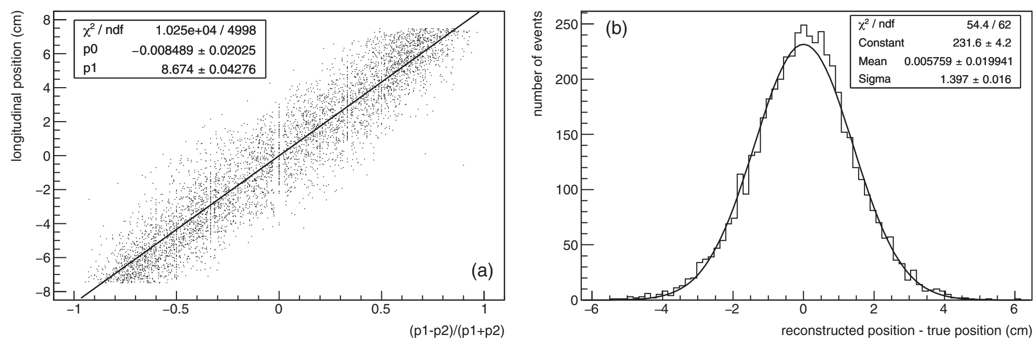

Fig. 3. – Spatial resolution of the 2 mm thick scintillator paddle as given by simulation. (a) Longitudinal position as a function of the photoelectron number. (b) Distribution of the difference between the reconstructed and real positions.

muon impact position along the paddle and the ratio estimator is shown for the 2 mm counter. A linear fit of the real impact position as a function of the ratio could give a valuable parametrization to reconstruct the hit position from the number of collected photoelectrons. For the 2 mm counter, the difference between reconstructed and real position shows a Gaussian distribution with a sigma resolution of ~ 1.4 cm, see fig. 3(b). Not shown here, the results for the 3 mm counter are similar to those for the 2 mm counter with a Gaussian spatial resolution of about ~ 1.3 cm.

4. – Conclusions

Two prototypes of trigger counters 2 mm and 3 mm thick were tested under cosmic muons. The number of photoelectrons collected was found to be sufficient to ensure a good detection efficiency for low-energy electrons and protons for both prototypes. A Geant4 Monte Carlo simulation of these counters was implemented and tuned on experimental data. It showed that the two counters have a similar efficiency and spatial resolution. This allowed to guide the LIMADOU Collaboration in the choice for the 2 mm thick trigger counters, thus reducing the lower-energy threshold of the experiment in comparison to the first-generation HEPD-01 detector, which has thicker counters, enlarging the experiment energy range.

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This work was supported by the Italian Space Agency in the framework of the agreement between ASI and INFN "Accordo Attuativo 2020-32.HH.0 Limadou Scienza".

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