

# The Plastic Scintillator Detector for the HERD experiment

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Future satellite experiments for cosmic-ray and gamma-ray detection will employ plastic scintillators to discriminate gamma-rays from charged particles and to identify nuclei up to Iron. The High Energy Cosmic Radiation Detector (HERD) facility will be one of those new experiments and will be installed onboard the Chinese Tiangong Space Station (TSS). The main goal of the HERD experiment is to detect charged cosmic-rays up to PeV and gamma-rays up to hundreds GeV. The plastic scintillator detector (PSD) surrounds the inner detectors from five sides. For energies above a few GeV a high detector segmentation is required in order to avoid the back-splash effect, due to the interaction between the high energy particles and the innermost calorimeter [1]. Each PSD basic element (bar or tile) is coupled to several Silicon Photomultiplier (SiPMs) for the scintillation light detection. In 2021 we have performed a beam test campaign to test all the subdetectors of HERD experiment at CERN PS and SPS. We tested two different PSD prototypes, one with a long bar geometry and the other with a squared tile geometry. In both prototypes two scintillating materials (BC-404 and BC-408) were used. Both the prototypes were equipped with SiPMs of two different sizes (MPPC S14160-3050 and S14160-1315) and they were read-out with CAEN Citiroc-based board DT5550W. In this work we will describe the PSD design and show beam test results.

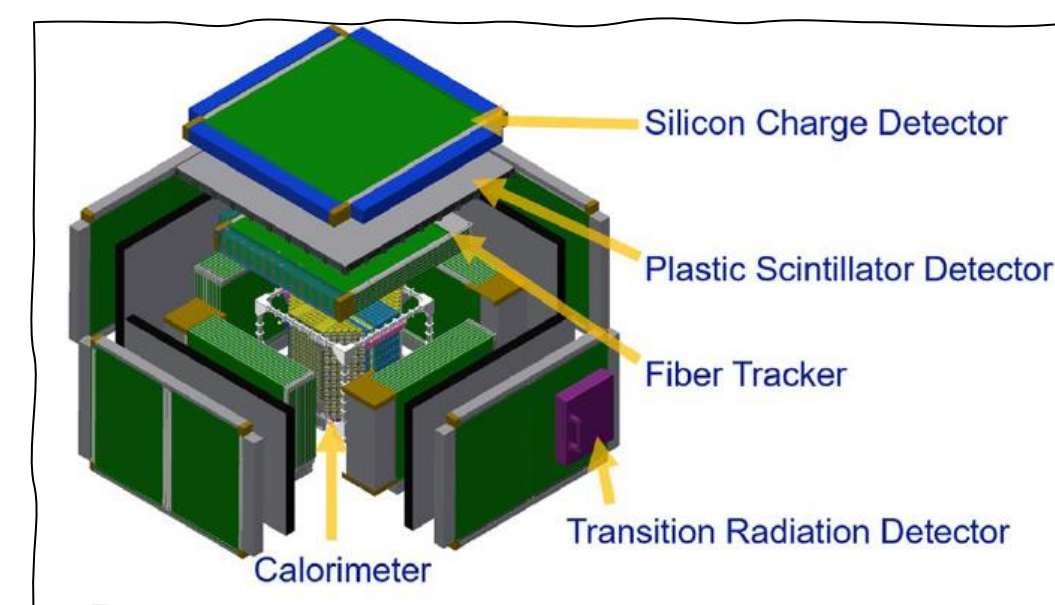
## The HERD facility onboard the Chinese Tiangong Space Station (TSS)

The Higher Energy cosmic Radiation Detection (HERD) facility is an international space mission that will be operative on the Chinese Space Station currently being assembled (see Fig.1) that will be operative by the end of 2027. The HERD current design (see Fig.2) consists of five sub-detectors. The innermost layer one is a 3D imaging calorimeter (CALO), made up of 7497 cubic LYSO crystals with a size of  $3 \times 3 \times 3 \text{ cm}^3$  and shaped as an octagonal prism. Each sensitive face of the CALO is equipped from the outermost to the innermost with silicon charge detector (SCD), a plastic scintillator detector (PSD) and a fiber tracker (FIT). Additionally, a transition radiation detector (TRD) is located on one of the lateral faces.



**Fig.1** A rendering of the Tiangong Space Station in its current construction state as of March 2022, with the Tianhe core module in the middle, Tianzhou at two ends and the Shenzhou at the nadir.

HERD sub-detector	Description	Aim
CALO	The HERD core is 3D, homogeneous, isotropic and finely-segmented calorimeter	Energy reconstruction and e/p discrimination
FIT	The CALO is surrounded by Fiber trackers (FiTs)	Trajectory reconstruction, charge identification
PSD	The CALO and the FIT are covered by Plastic Scintillator Detector (PSD)	Charged reconstruction, gamma identification
SCD	The silicon charge detector (SCD) is the outermost detector	Charge reconstruction
TRD	A Transition Radiation detector (TRD) will be located on the lateral side	Calibration of CALO response for TeV protons



**Fig.2** Scheme of HERD facility with the five sub-detectors. From the innermost to the outermost: CALO, FIT, PSD, SCD and TRD.

## The Plastic Scintillator Detector (PSD)

The primary goal of the PSD is to implement the trigger of low energy gamma-ray events from 0.5 to 10 GeV. The secondary goal of the PSD is to perform the offline high energy gamma-ray identification and provide a redundant charge measurements of cosmic ray nuclei.

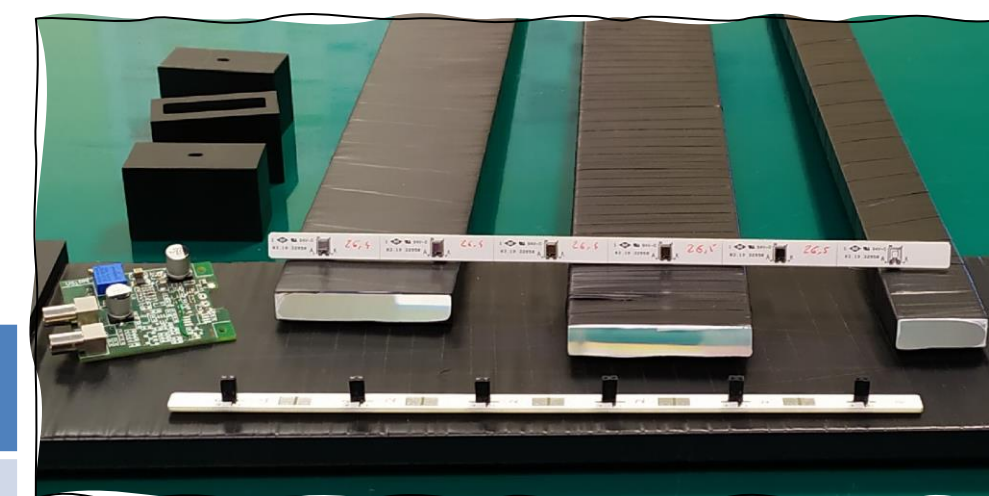


**Fig.3** PSD Tile segmented option ( $10 \times 10 \times 0.5 \text{ cm}^3$ )

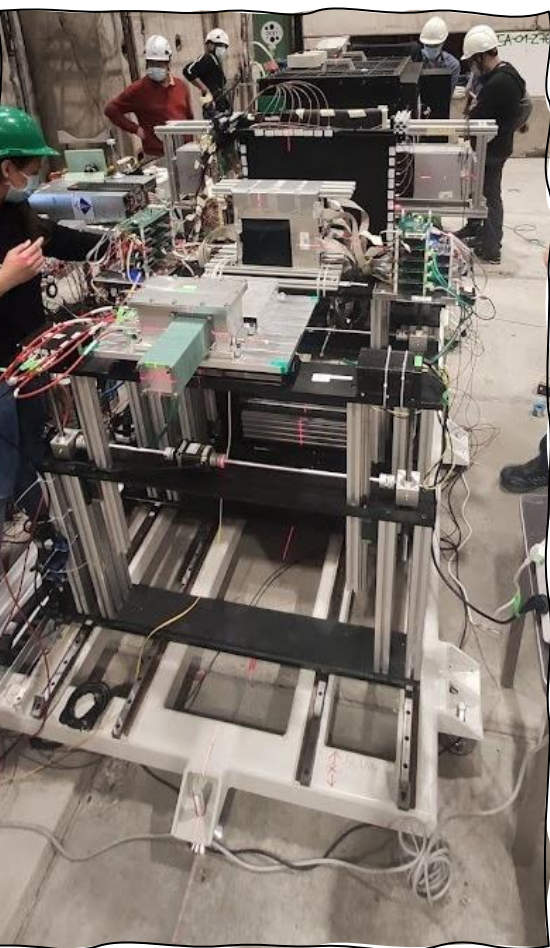
PSD Requirements:

- Must be highly segmented to reduce self-veto signals from back-splash effect
- High efficiency for charged particle identification
- Good energy resolution and frontend readout with high dynamic range for charge measurement
- Low power consumption for space application
- SiPMs read-out with two different possible geometries (Tile Fig. 3 or Bars Fig. 4)

PSD geometry	Description	PRO	CONS
TILE	Two layer of tiles to increase nuclei identification power	High segmentation reduces back-splash effect	Higher number of readout channels
BAR	Two layer, one per view, each layer made by two staggered sub layers	Fewer readout channels	Higher back-splash contamination



**Fig.4** PSD bar segmented option ( $50 \times 5 \times 0.5 \text{ cm}^3$ )



**Fig.6** HERD full sub-detectors test during CERN 2021 beam test campaign.

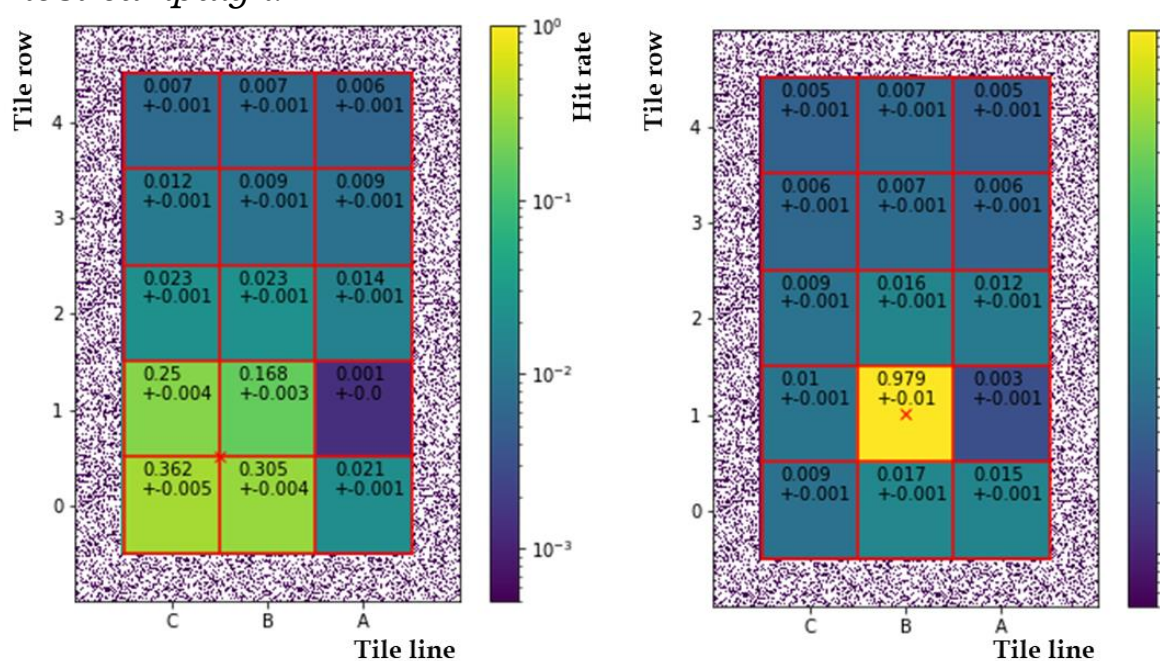
## CERN beam test campaign

A beam test was conducted at CERN in 2021. For the first time, a scaled prototype ( $\sim 50 \text{ cm} \times 50 \text{ cm}$ ) of both PSD concept designs were tested under the beam along with the other HERD sub-detector prototypes (Fig 6 and 7). The tile PSD prototype consisted in a single layer of 20 plastic scintillator tiles organized in an array of  $4 \times 5$  elements (each one  $10 \times 10 \times 0.5 \text{ cm}^3$ ). The tiles, wrapped with a 150um thick sheet of black/white Tyvek, were read out by two PCBs, each one embedding 3 analogue-summed SiPMs. In the prototype, two readout options for tiles were adopted. Different SiPMs (MPPC S14160-3050 and S14160-1315) and different materials (BC-4504 and BC-408) were used for performance comparison. The bar PSD prototype was made out of 50 cm long bars with trapezoidal cross section ( $45^\circ$  angle). Two thickness values (1 cm and 0.5 cm) and two scintillator materials (BC-404 and EJ-204) were used. All the bars were read out by means of PCBs housing 2 analogue-summed SiPMs (MPPC S14160-3050) for each side of the bar. The prototype consisted of 2 overlapped layers of bars, respectively arranged along X and Y axes. With this configuration, the beam is identified by intersection of two bars. Both tile and bar prototypes adopted the same read-out system, based on the CAEN Citiroc-based board DT5550W.

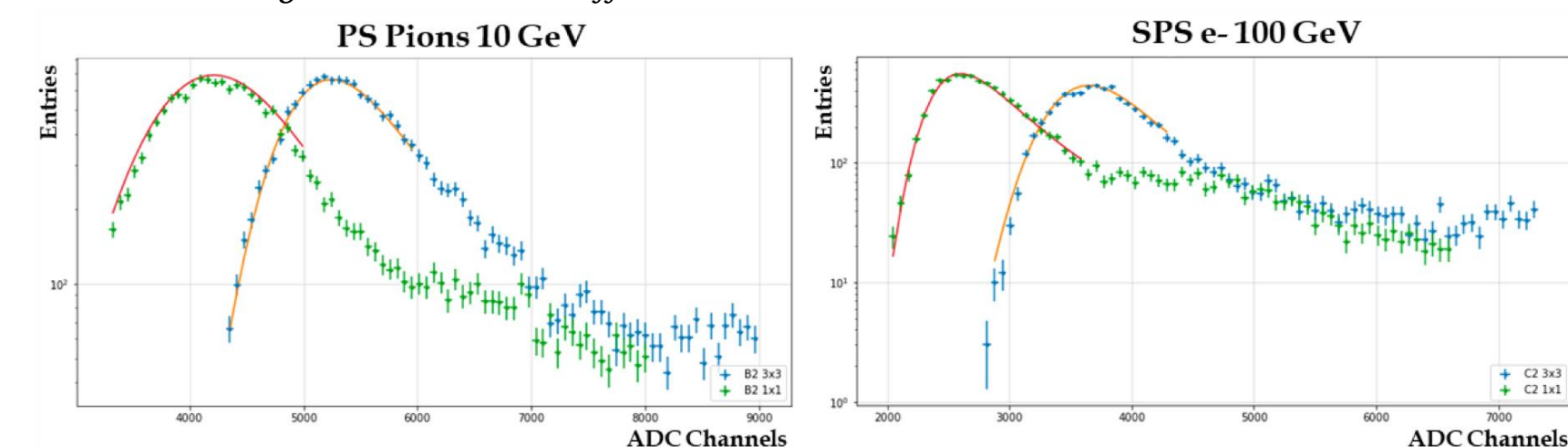
## Beam test results

Fig.8 shows two examples of hit maps obtained at CERN PS (Proton Synchrotron) using a 10 GeV pion beam. The colors and the number shown are the fraction of events acquired with respect to the number of main triggers. The hit is recorded when the signal amplitude is larger than  $1/3$  of the MIP one and the event is detected by both the SiPMs PCBs. The right figure shows the hit rate when the beam hits the center of a single tile (B1) and the left figure when the beam hits the corner of 4 different tiles (C0, C1, B0 and B1). These maps were produced to study the noise contamination in tiles neighboring the fired one. This value, as shown, is about 1% in the neighbor tiles of the fired one (probably due to non-collimated particle in the beam), but it is less than 0.5% in the all the other ones. Fig.9 shows the signal acquired for MIPs in tile B1 (Fig. 8 can be used as reference) exposed to 10 GeV pions beam (LEFT) and 100 GeV electrons (RIGHT). These measurements were carried out to study the uniformity of response in the same tile when different type of particle hits the same tile.

Fig.10 (RIGHT) shows the bar PSD hit map reconstructed from experimental data collected at SPS (Super Proton Synchrotron) using 350 GeV proton beam centered at the intersection of B9 and B15. As expected, most of the hits are detected in the bars in which the beam is centered on. In order to evaluate the signal shape and its dependency on hit position along the bar, the prototype was moved to the relevant position beforehand identified to get a meaningful scan of the bar, the trend of signal amplitudes follows the expected behavior due to light attenuation in the scintillator (exponential-like curve as shown in Fig.11). The light yield of 2 different scintillator material (EJ-204 and BC-404) operated at similar condition in the PSD prototype was also measured at SPS by means of a proton beam. There is no evidence of pronounced differences.



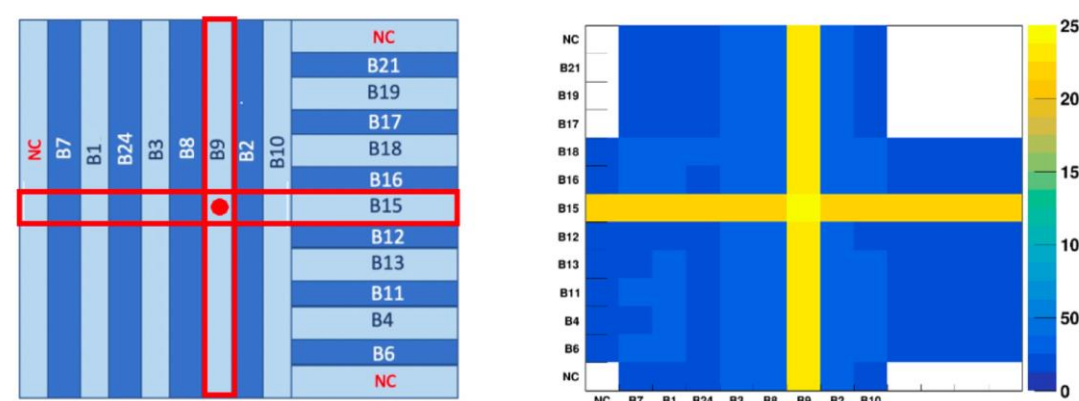
**Fig.8** Fraction of events acquired with respect to the number of main triggers for 10 GeV pions beam. LEFT: the beam is centered at the intersection of 4 tiles. RIGHT: the beam impinges in the center of tile B1. The hits are recorded when the signal amplitude is larger than  $1/3$  of a MIP signal and it is simultaneously detected and generated in two different PCB boards.



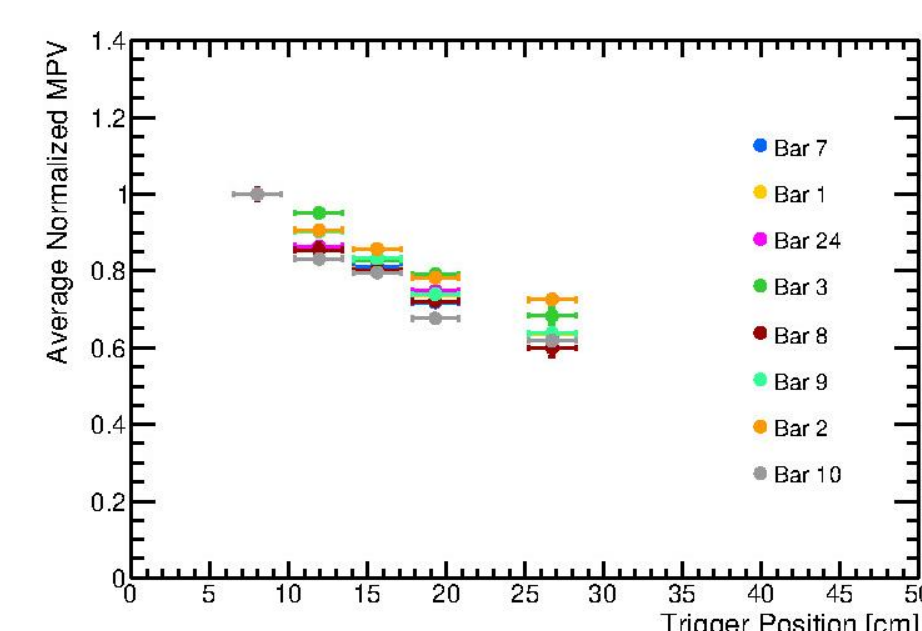
**Fig.9** Referring to Fig.8, the signal acquired in tile B1 (BC-408 material) exposed to 10 GeV pions beam (LEFT) and 100 GeV electron beam (RIGHT). The signals were fitted with Langaus function.

## Conclusion

We have conducted a beam test campaign at CERN in 2021 to study the first PSD scaled prototype in the framework of the HERD international space mission comparing different PSD segmentation, scintillating material and SiPMs redout obtaining useful data for the final decision in the PSD construction and future test planning.



**Fig.10** LEFT: Prototype layout with beam (red dot) centered in bars B9 and B15. RIGHT: The hit map reconstructed from experimental data collected with proton beam, confirming that most of the hits are detected by these 2 bars.



**Fig.11** Vertical trapezoidal bars ( $50 \times 3 \times 0.5 \text{ cm}^3$ ) from the CERN bar prototype, readout by 2 SiPMs/side (Hamamatsu) in OR. The figure corresponds to the light attenuation behavior inside each single bar with respect to the trigger position