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# The scintillating-fiber tracker (FIT) of the HERD space mission from design to performance

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The High Energy cosmic-Radiation Detection facility (HERD) will be a calorimetric experiment on board the China Space Station. Starting from 2027, HERD will perform the first direct measurement of cosmic rays in the PeV region and the gamma-ray full-sky survey from 100 MeV. The detector will be equipped with a scintillating-fiber tracker (FIT) read out with silicon photomultipliers. A miniature of a FIT sector, called MiniFIT, was designed, built and tested with particle beams at CERN. The FIT design, together with the design and physics performance of MiniFIT will be presented in this contribution.

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## 1. The HERD experiment

The High Energy cosmic-Radiation Detection facility (HERD) will be a space-borne experiment for the direct detection of charged cosmic rays and gamma rays. Installed on board the China Space Station (CSS) in 2027, HERD will be taking data for at least 10 years [1]. With HERD we will search for the annihilation and decay products of dark matter in the electron+positron energy spectrum and anisotropy from 10 GeV to 100 TeV and in the gamma-ray energy spectrum; we will measure the energy spectrum and composition of cosmic nuclei from proton to iron up to a few PeV/nucleon and we will perform a wide field-of-view monitoring of the $\gamma$-ray sky from 100 MeV. HERD consists of five subdetectors (Fig. 2): a 3D homogeneous, isotropic, deep (55 radiation lengths and 3 nuclear interaction lengths) calorimeter (CALO) [2], made of approximately 7500 LYSO cubes with an edge length of 3 cm. The top side and the four lateral sides of CALO are instrumented with the scintillating-FIber Tracker (FIT), described in more detail in the next section, the Plastic Scintillator Detector (PSD) [3] which will be used in the trigger logic as VETO detector for charged particles when $\gamma$-ray selection is needed and as charge-measurement detector for the nuclei identification, the Silicon Charge Detector (SCD) [4] which will provide an independent measurement of the absolute value of the charge before any charge-change interaction could occur. The Transition Radiation Detector (TRD) [5], installed on one lateral side, will calibrate the response of CALO to high-energy hadronic showers.

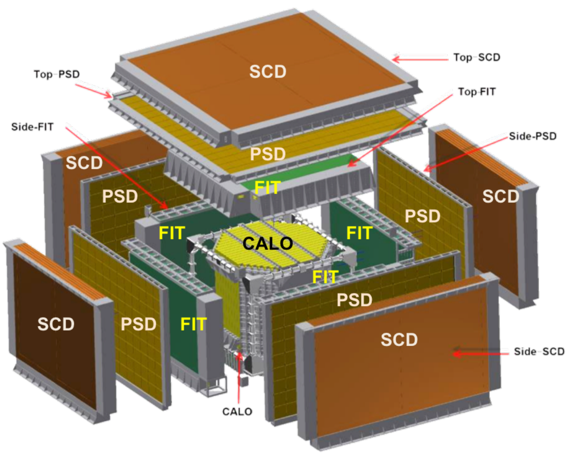


**Figure 1:** Exploded view of the HERD detector. The core subdetector is the calorimeter (CALO), surrounded on the top and the four lateral sides with a sector of the scintillating-FIber Tracker (FIT), the Plastic Scintillator Detector (PSD) and the Silicon Charge Detector (SCD).

## 2. The scintillating-fiber tracker (FIT)

The HERD scintillating-FIber Tracker (FIT) aims at reconstructing the trajectory and the absolute charge value (|Z|) of the traversing charged cosmic paticles. In addition, it will enhance the low-energy gamma-ray conversion in electron and positrons pairs and reconstruct the tracks of the created electrons and positrons. FIT consists of four lateral and one top sectors, each composed of seven tracking planes for seven independent position measurements. Each tracking plane consists of

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two layers of FIT modules measuring the two orthogonal spatial coordinates. A module includes one scintillating-fiber mat and three silicon photomultiplier (SiPM) arrays to read out the scintillation light induced by the charged particles hitting the mat. The mat is made by stacking six layers of fibers. The fibers, manufactured by Kuraray (type SCSF-78MJ), have a round section with an average total diameter of 250 μm with a polystyrene core surrounded with two claddings. The mat width is 97.8 mm to match three Hamamatsu S13552-10 SiPM arrays. The array, customized by Hamamatsu Photonics, is made of 128 SiPMs. Each SiPM has 3 749 (23 × 163) pixels with a pitch of 10 μm. Every SiPM array is mounted on a small printed circuit board (PCB) screwed to the end-pieces of the fiber mat. The three PCBs are connected to the main body of the front-end board through one flexible cable each. On the back side of the SiPM PCB is mounted a PT100 thermal sensor, to allow for the correction of the bias voltage according to the temperature. In this configuration, FIT has 225 792 read-out channels. The FEBs used so far for all the FIT module prototypes are equipped with six VATA64HDR16.2 ASICs that will be replaced by six BETA-64 ASICs [6]. The latter is a customized ASIC with a dynamic range large enough to enable the charge measurement up to $|Z| = 26$.

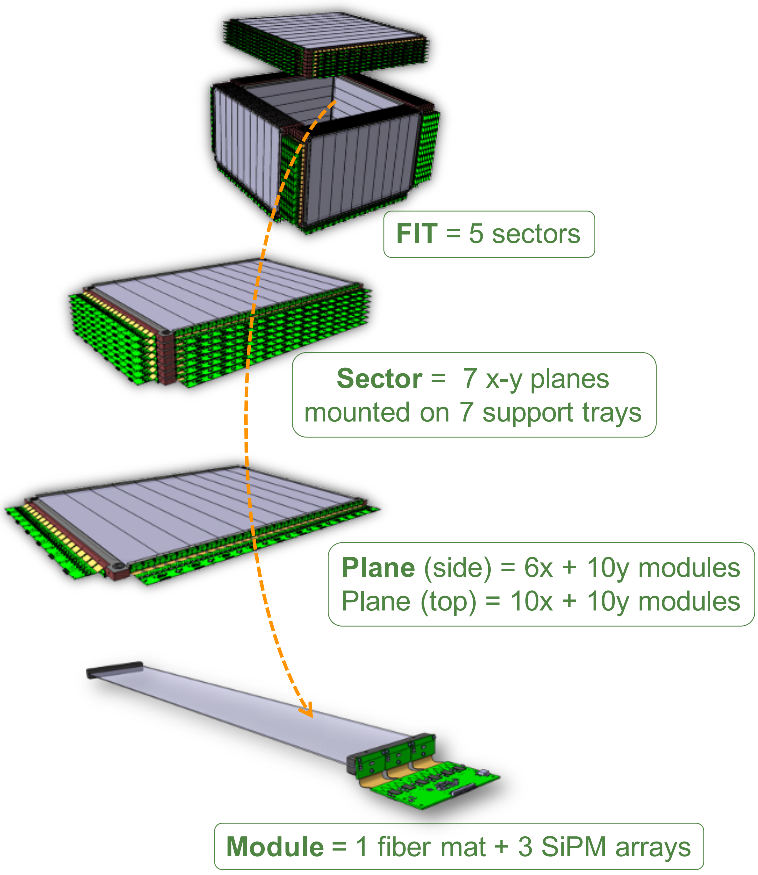


**Figure 2:** Sketch of FIT, the scintillating-fiber tracker of the HERD experiment.



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## 3. MiniFIT

A miniature of a FIT sector, called “MiniFIT” was designed and tested at CERN in order to evaluate its response to a beam of particles with different charges. As a FIT sector, it consists of 7 support trays equipped with 7 tracking planes for 7 independent measurements of the position and 14 measurements of the absolute value of the charge of a traversing charged particle. The tracking layers are made of 4 FIT modules with a fiber mat of about 40 cm length. The expertise gained in the development of MiniFIT is of immense technical importance for the production and assembly of the large scintillating-fiber tracker (FIT) of the future HERD space mission. The production and quality assurance process of MiniFIT spanned four months, from July to October 2022. We also established a quality assurance protocol for the manufactured fiber mats which includes an optical scan conducted with a commercial scanner to verify the position of each fiber in the mat. Additionally, the light-yield of the mat is measured using a calibrated read-out system and a $^{90}$Sr source.

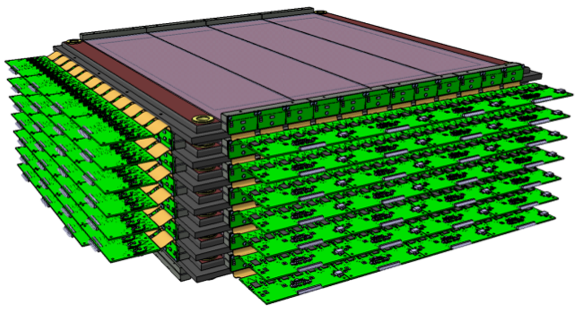

**Figure 3:** Sketch of MiniFIT.

## 4. MiniFIT performance

MiniFIT was commissioned at CERN in November 2022 with a fragmentation-ion beam. Eight tracking modules ($x_0$ to $x_3$ and $y_0$ to $y_3$) were read out. The inner modules ($x_2$ and $y_2$) are used to infer the resolution of the position measurement along $x$ and $y$ respectively, since they have the smallest track extrapolation error. The residual is defined as the difference between the projected hit position ($x_{\text{fit}}$) and the measured hit position ($x_{\text{hit}}$). The former is the position estimated by the 3-point linear fit of the hit positions measured with the other modules ($x_0$, $x_1$ and $x_3$ or $y_0$, $y_1$ and $y_3$). The residual distribution is fitted with the sum of two Gaussian functions. The spatial resolution is defined as the standard deviation of the narrowest Gaussian function ($\sigma_1$). Fig. 4 shows the distribution of track-hit residuals for the modules $x_2$ and $y_2$. The position resolution of MiniFIT equipped with 4 x-y tracking planes is $< 35$ µm for normal incident helium nuclei. Fig. 5 shows the charge distribution of the reconstructed nuclei (beam composition). With the VATA front-end electronics, MiniFIT is able to identify nuclei with charge $|Z| = 7$. FIT should be able to identify nuclei up to iron ($|Z| = 26$). To comply with this requirement, the new BETA-64 ASIC, with a larger dynamic range, has been developed by ICCUB-Barcelona.



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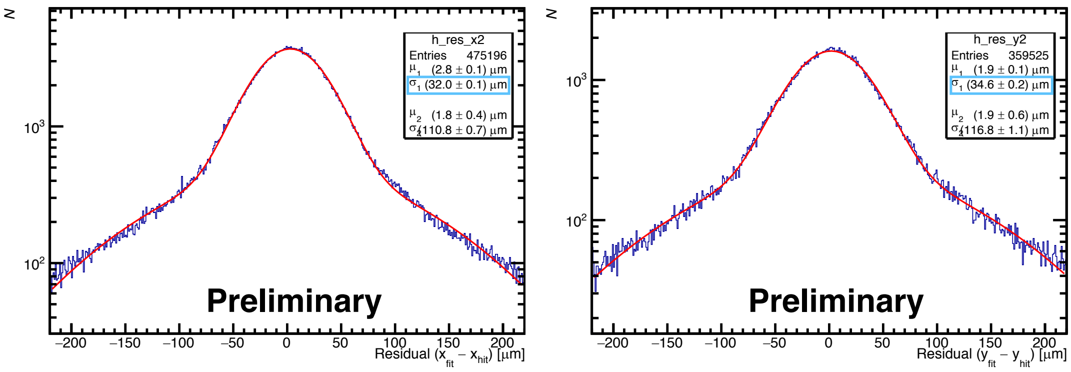


**Figure 4:** The track-hit residual distributions for helium candidates for internal layers ($x_2$ and $y_2$) fitted with double-Gaussian distributions. As the estimate of the position resolution we use the width of the narrowest Gaussian function ($\sigma_1$).

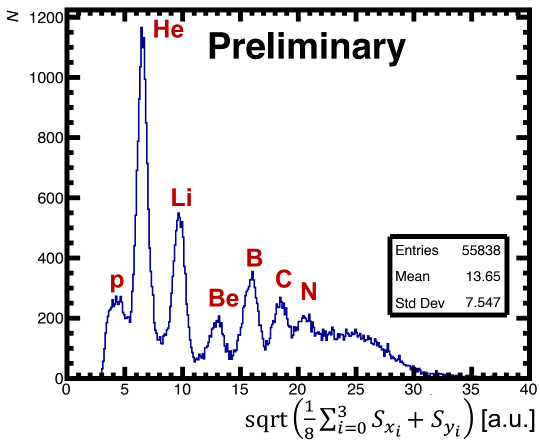


**Figure 5:** Distribution of the all-module ($4x + 4y$) mean square root cluster integral for the reconstructed tracks.

## 5. Conclusions

FIT is the scintillating-fiber tracker of the HERD space mission. It serves for the track reconstruction of the charged cosmic particles crossing the detector, for the conversion of low-energy gamma rays and for a redundant measurement of the particle charge. We designed a scaled-down FIT sector, called MiniFIT. MiniFIT demonstrated the tracking and charge measurement capabilities of FIT. The position resolution for normal incident helium nuclei is < 35 μm. In the next future, we will test MiniFIT with updated boards hosting the new BETA-64 ASICs which will enable the measurement of high-charge nuclei up to the iron.



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