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# FIT: the scintillating fiber tracker of the HERD space mission

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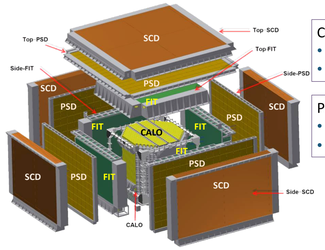
EPFL

## The HERD experiment

The High Energy cosmic-Radiation Detection (HERD) facility will be one of the future astronomy missions on board the China's space station (CSS). Planned to be operational from 2027, for more than 10 years.




CALO: CALOrimeter
- Energy measurement
- Electron/proton separation

**FIT: FIber Tracker**
- **Track reconstruction**
- **Low energy γ ray conversion (γ → $e^+$ $e^-$)**
- **Charge measurement (|Z|)**

PSD: Plastic Scintillator Detector
- Charge measurement (|Z|)
- γ ray identification

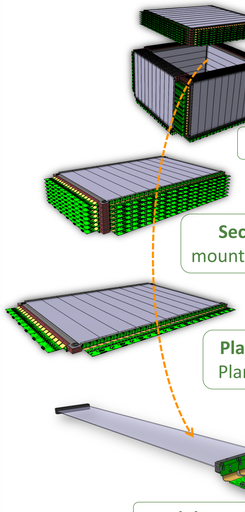
SCD: Silicon Charge Detector
- Charge measurement (|Z|)

TRD: Transition Radiation Detector
- Energy calibration of TeV nuclei

Goals:
- Indirect search for dark matter, in the energy spectrum and anisotropy of electrons+positrons from 10 GeV to 100 TeV and in the γ-ray spectrum from 500 MeV to 100 TeV;
- Measurement of the energy spectrum and the composition of cosmic rays (protons and heavier nuclei up to iron) from 30 GeV to a few PeV;
- Monitoring of the γ-ray sky from 500 MeV.

| | |
|---|---|
| **Energy range ($e^{\pm}$/γ)** | 10 GeV – 100 TeV |
| **γ low energy range** | 100 MeV – 10 GeV |
| **Energy range (nuclei)** | 30 GeV – 3 PeV |
| **Angular resolution ($e^{\pm}$/γ)** | 0.1° @10 GeV |
| **Charge resolution (nuclei)** | 10 % – 15 % for Z = 1 – 26 |
| **Energy resolution ($e^{\pm}$/γ)** | 1 % @200 GeV |
| **Energy resolution (γ)** | 20 % @100 GeV - PeV |
| **$e^{\pm}$/p separation power** | > $10^{-6}$ |
| **Geometric factor ($e^{\pm}$)** | > 2 $m^2$sr @200 GeV |
| **Geometric factor (p)** | > 1 $m^2$sr @100 GeV |

## The FIber Tracker (FIT)



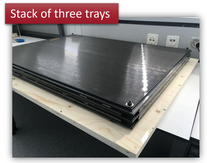
**FIT** = 5 sectors

**Sector** = 7 x-y planes mounted on 7 support trays

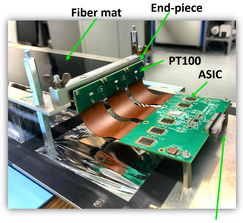
**Plane** (side) = 6x + 10y modules
Plane (top) = 10x + 10y modules

**Module** = 1 fiber mat + 3 SiPM arrays

Stack of three trays



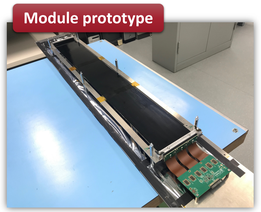
Tray: two carbon fibre sheets (0.6 mm thick) with Al honeycomb core (20 mm thick)




The present design uses six **VATA64HDR16.2** ASICs → **BETA (β)** ASICs.
Power consumption: **9 mW/ch** → **0.3 mW/ch.**

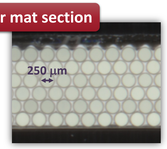
## The FIT module: the fiber mat

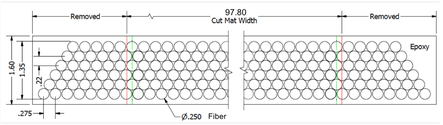
Module prototype



- Fiber mat: 6 layers of fibers
- Fiber type: **KURARAY SCSF-78MJ**
  - round section with, diameter = 250 μm
  - peak emission at λ: 450 nm
- Titanium dioxide coating to avoid cross-talk between fibers
- Mat width ≅ 97.80 mm to match 3 SiPM arrays

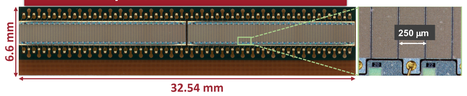
Fiber mat section




## The FIT module: the Silicon Photomultiplier (SiPM) array

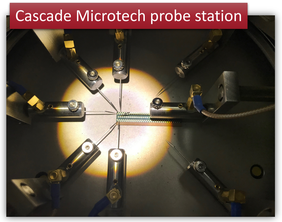
SiPM array S13552-10 from Hamamatsu

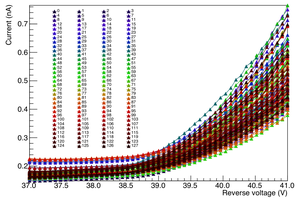


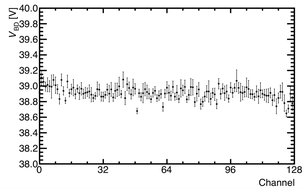

| | At 25 °C |
|---|---|
| **Breakdown voltage ($V_{BD}$)** | 33 V - 43 V |
| **Operational voltage ($V_{OP}$)** | $V_{BD}$ + 6.5 V |
| **Gain at $V_{OP}$** | 2.3 x $10^5$ |
| **Photon detection efficiency at $V_{OP}$** | 15 % |
| **Temperature coefficient** | $dV_{BD}/dT$ = 34 mV/°C |

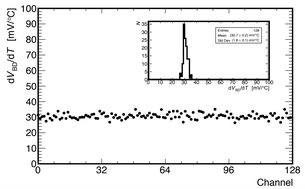
- SiPM array: 2 chips with 64 channels
- Channel size: 230 μm × 1630 mm
- Pixel size: 10 μm × 10 μm
- 23 x 163 pixels/channel
- Gap between channels: 20 μm → pitch: 250 μm
- Gap between chips: 220 μm
- 105 μm epoxy resin on top

Cascade Microtech probe station





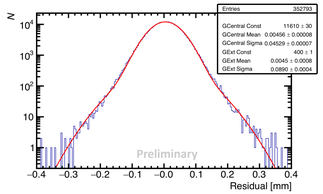




## Performance of a FIT module

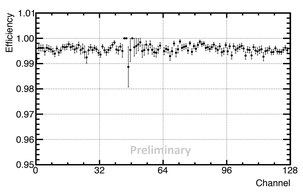
Proton beam test results

### Position residual distribution




Spatial resolution = (45.0 ± 0.1) μm
(taking into account the external beam telescope resolution)

### Hit detection efficiency




Mean efficiency = 99.6 %

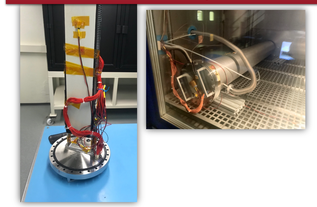
Nuclei beam test results

**Charge resolution for nuclei heavier than p**

| Z | $\mu_z$ | $\sigma_z$ | $\sigma_z/\mu_z$ |
|---|---|---|---|
| **2** | 1.99 | 0.31 | 15 % |
| **3** | 3.07 | 0.40 | 13 % |
| **4** | 4.01 | 0.51 | 12 % |

## Space Qualification Process

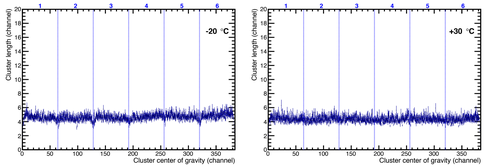
FIT module in a vacuum cylinder inside a thermal chamber



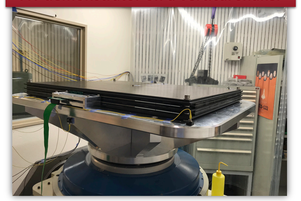


- Vacuum cylinder (5 × $10^{-6}$ mbar)
- Chamber temperature set from -20 °C to 30 °C, with steps of 10 °C.
- Scintillators placed on top and bottom of the chamber, to have cosmic triggers.

- The cluster length distribution is uniform and independent of the temperature.
- This is a sign of the mechanical stability between the fiber mat and the SiPM arrays.




FIT demonstrator on a vertical shaker



A demonstrator, composed of three trays has been produced:
- Top and bottom trays are equipped on one side.
- The central tray is equipped on both sides.
- Each layer is equipped with 4 scintillating fiber modules, the remaining modules are made of fishing lines.
- The trays, the modules and the front-end electronics have survived the tests.

## Outlook

- Irradiation tests of the SiPM arrays.
- Beam test at CERN of a prototype made of several FIT modules to test the tracking performance.
- Vibration tests on horizontal plane and thermal vacuum test of the demonstrator.