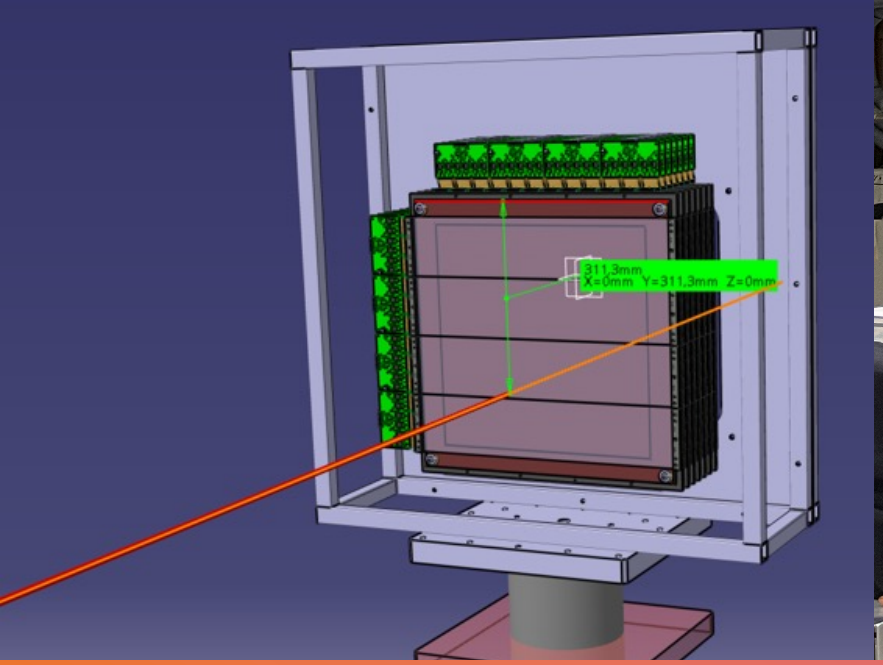


MiniFIT, the small-scale version of the HERD tracking system, from design to performance

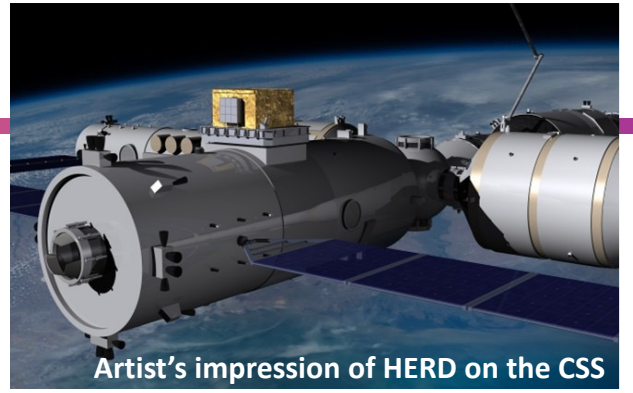
Chiara Perrina for the HERD Collaboration (Chiara.Perrina@epfl.ch)

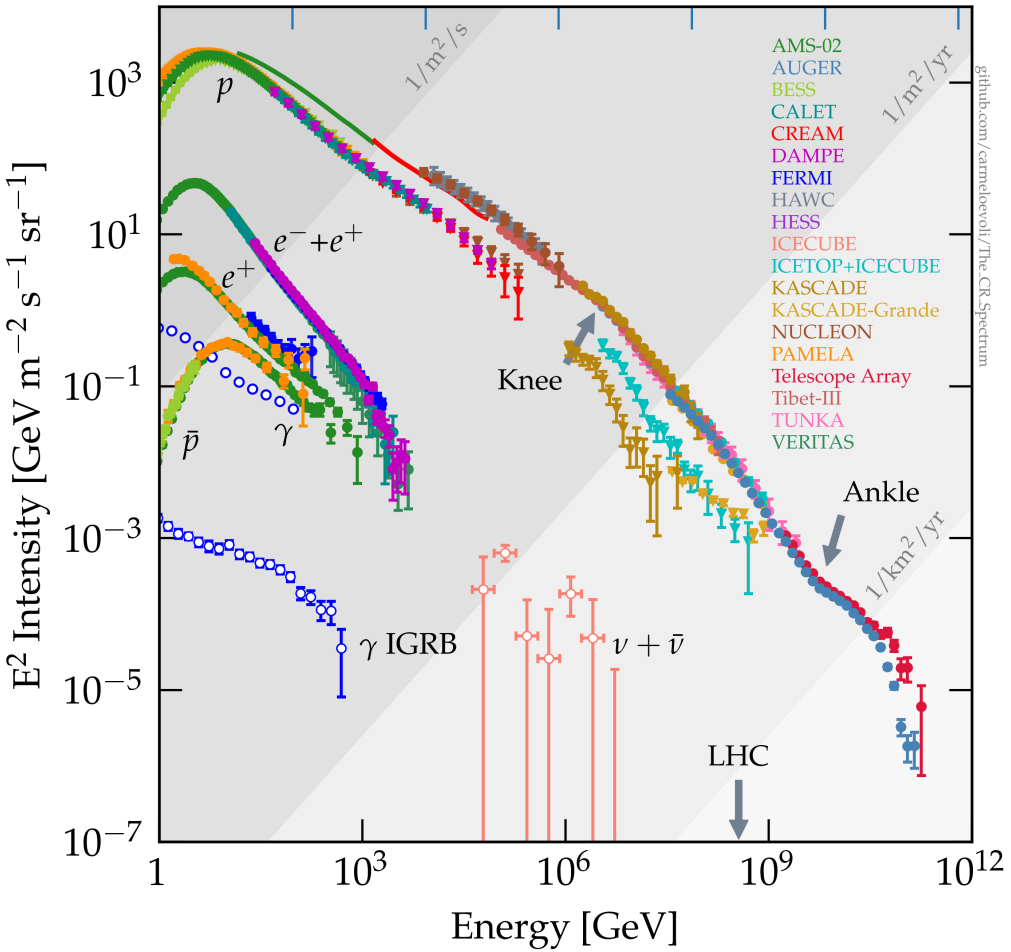
Annual Meeting of the **Swiss Physical Society** – September 13, 2024

EPFL Swiss National Science Foundation ⟨SPS⟩ swiss physical society

HERD

- **The High Energy cosmic-Radiation Detection facility (HERD) will be the next experiment for the detection of cosmic rays in space.**
- HERD will be launched and installed onboard the China Space Station (CSS) in 2027, operational for at least 10 years.


Artist's impression of HERD on the CSS

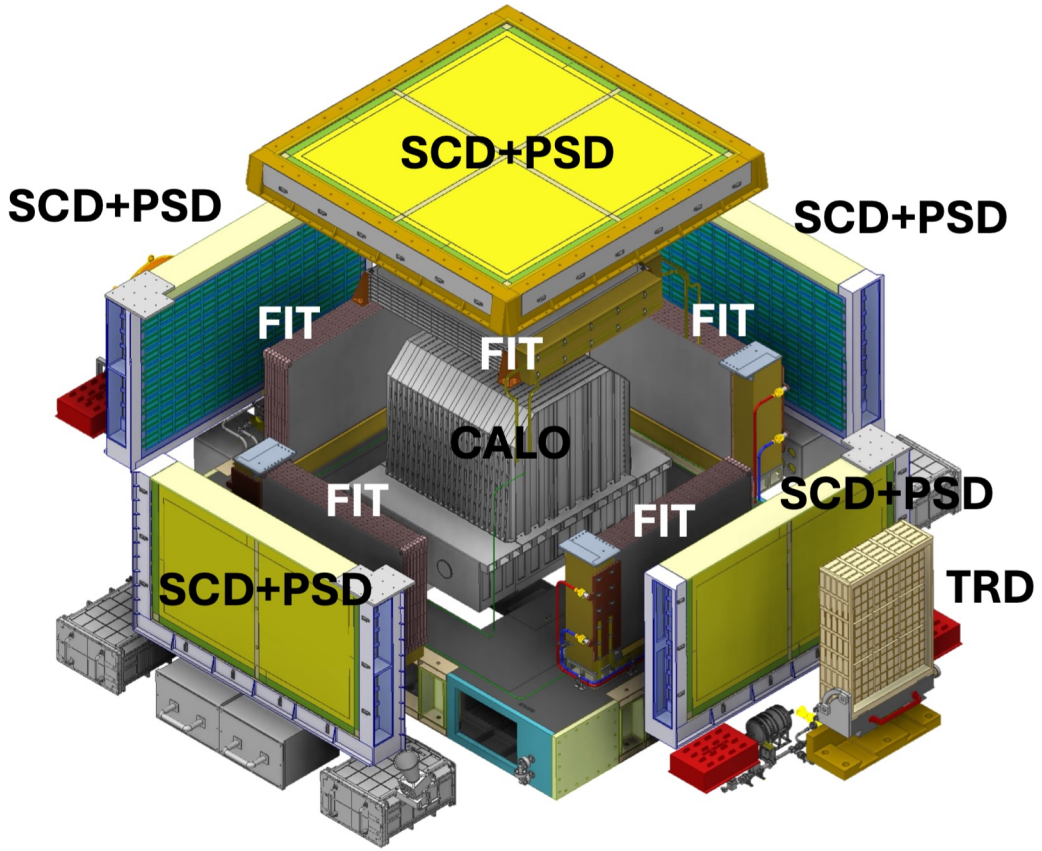


→ Extend the energy range: **nuclei to PeV/n, $e^- + e^+$ and γ rays to 100 TeV**

- Deep calorimeter: 55 X_0 (current max: 31 X_0 of DAMPE)
- **Large acceptance:** > 2 $m^2 sr$ (current max: 0.02 $m^2 sr$ of DAMPE)
  - "Isotropic" design with a central 3D calorimeter + other subdetectors on 5 sides.

The HERD detector

Needed: **particle identification**, **energy** and **direction** measurements.



https://doi.org/10.1051/epjconf/202328001008

HERD needs a large-area tracker.
Operation in space requires compactness, modularity, low power consumption, low material and cost budgets.

CALO: CALOrimeter (55 X_0)

- **Energy** measurement
- e.m./hadronic separation

FIT: FIber Tracker (5 sides)

- **Track** reconstruction
- **Charge** measurement (|Z|)
- Low-energy γ–ray conversion (γ → e^+ e^-)

PSD: Plastic Scintillator Detector (5 sides)

- **Charge** measurement (|Z|)
- γ–ray identification (fast veto < 200 ns)

SCD: Silicon Charge Detector (5 sides)

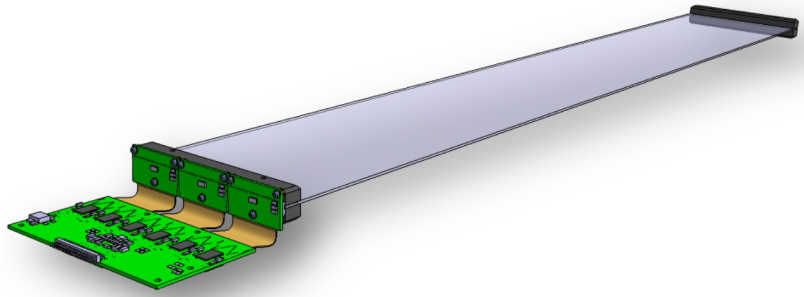
- **Charge** measurement (|Z|)
- Track reconstruction

TRD: Transition Radiation Detector (1 side)

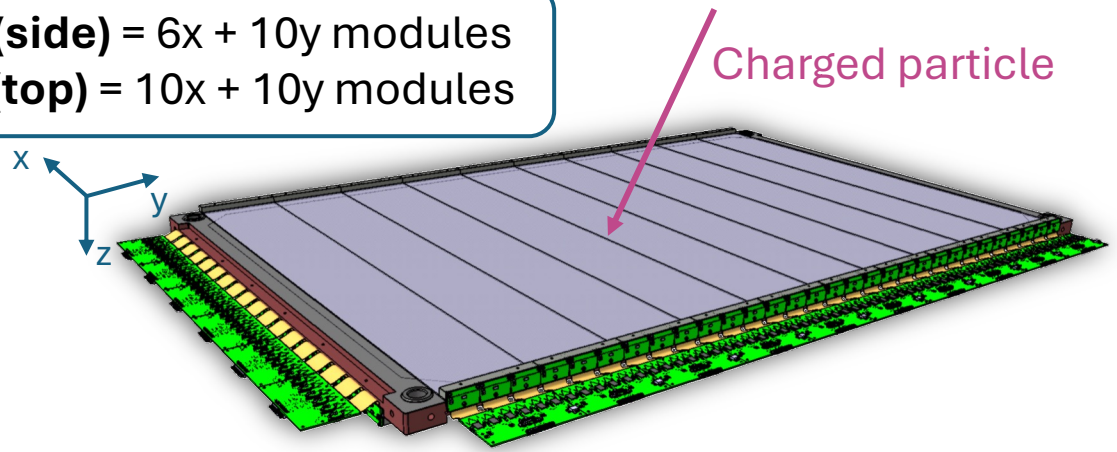
- Energy calibration of CALO for TeV nuclei

FIT: modular high-resolution tracker for application in space

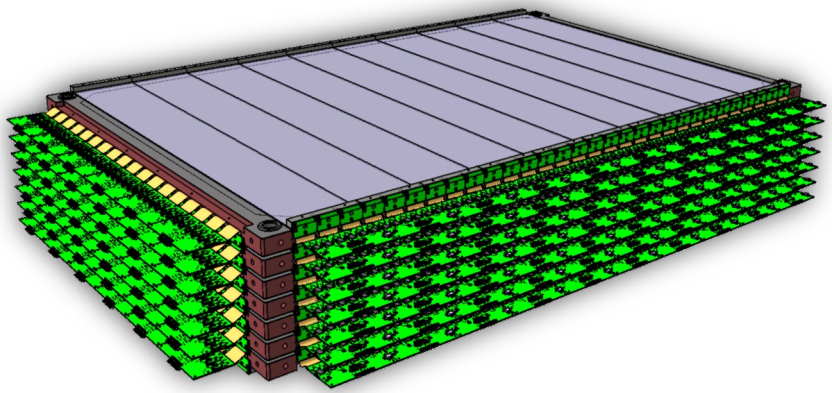
FIT Module = 1 fiber mat + FEB with 3 SiPM arrays



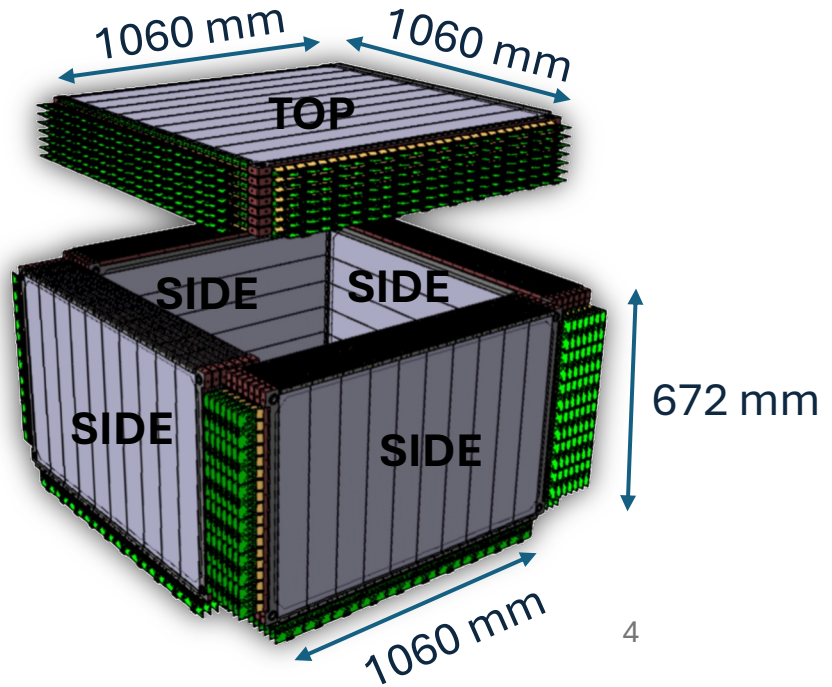
FIT Plane (side) = 6x + 10y modules
FIT Plane (top) = 10x + 10y modules



FIT Sector = 7 x-y tracking planes



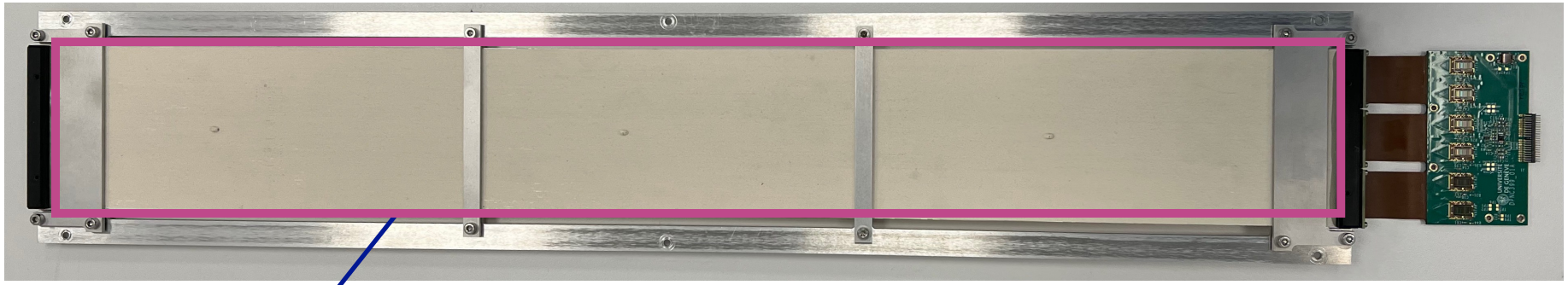
FIT = 5 sectors



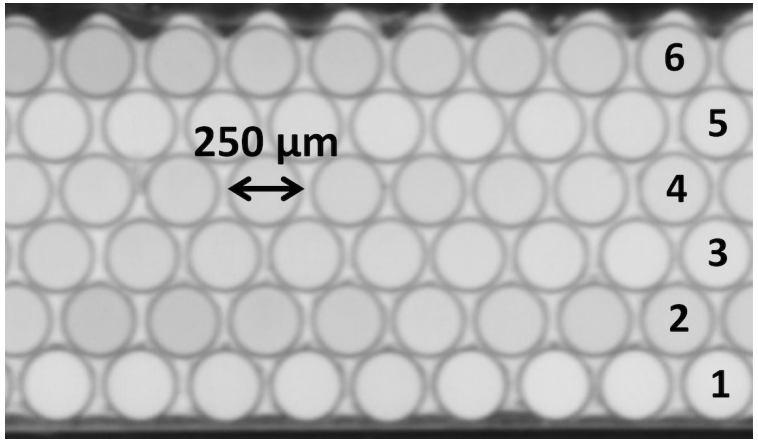
Tray: **two** 0.3 mm **sheets of carbon fiber** reinforced polymer (CFRP) with 20 mm thick **core of aluminum honeycomb**

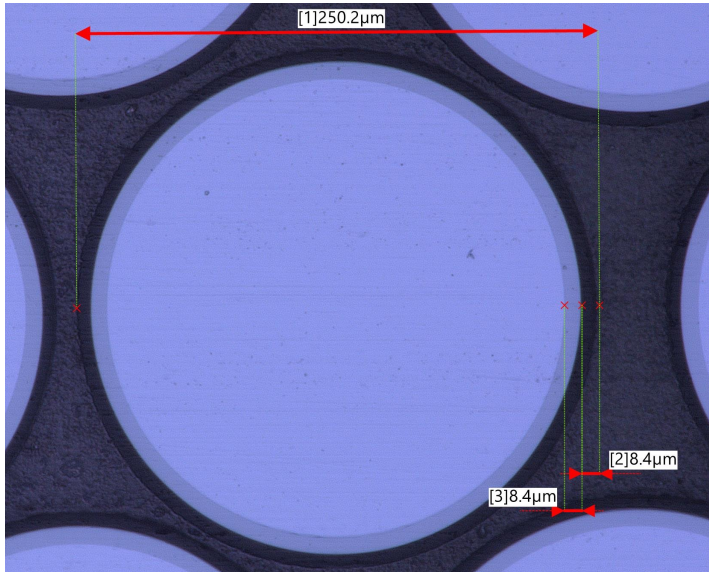
https://doi.org/10.22323/1.395.0067

FIT module: the fiber mat



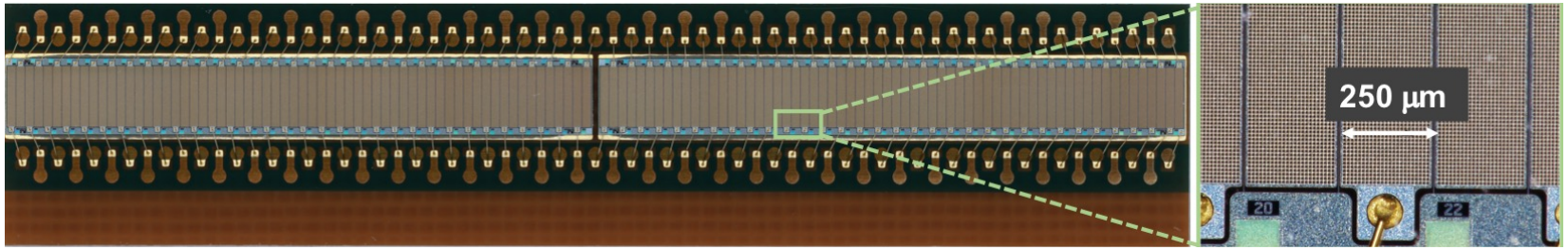
- Design of LHCb SciFi
- Fiber mat: **6 layers of fibers**
- Fiber type: KURARAY SCSF-78MJ
  - round section, diameter = **250 µm**
  - Peak at 450 nm
- Mat width ≅ 97.8 mm to match 3 SiPM arrays



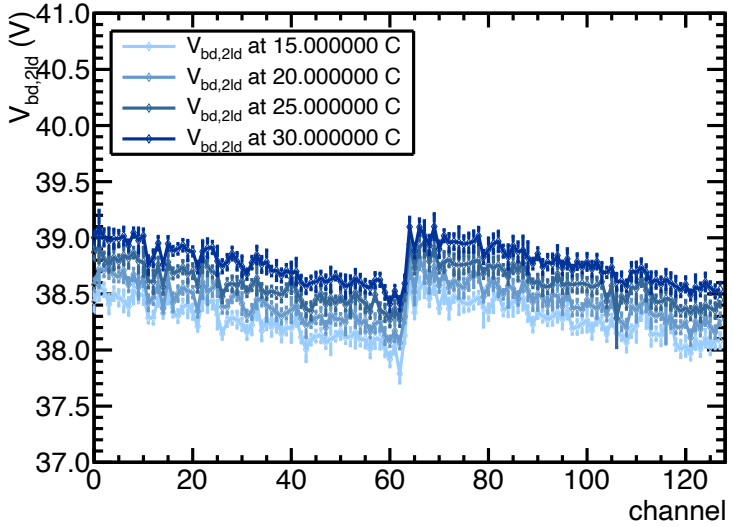


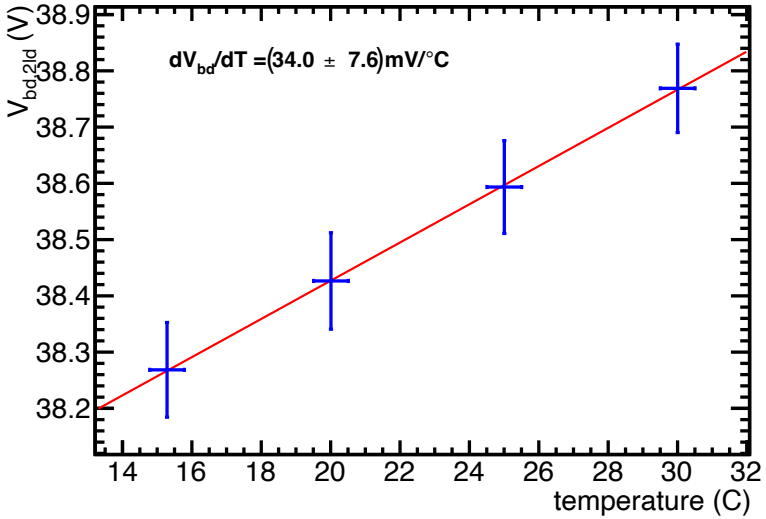
FIT module: the SiPM arrays

- Hamamatsu array: 2 chips with 64 SiPMs
- 23 x 163 pixels/SiPM
- **Pixel pitch: 10 μm**
- SiPM size: 230 μm × 1630 μm
- **SiPM pitch: 250 μm**

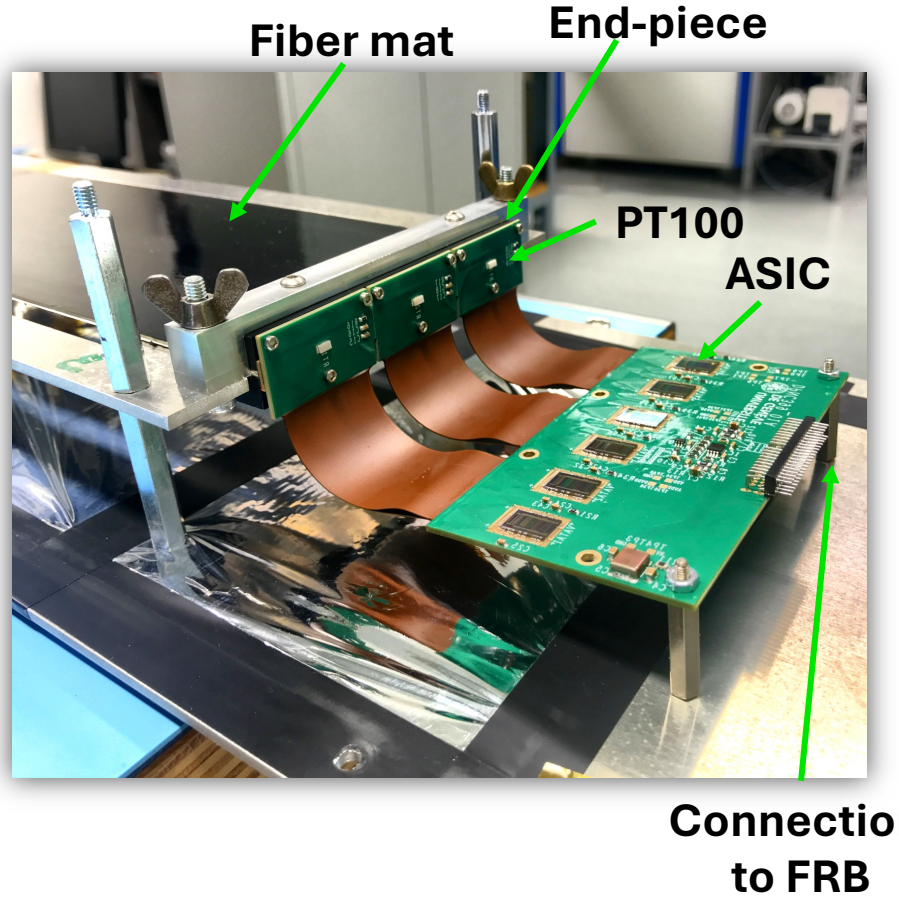


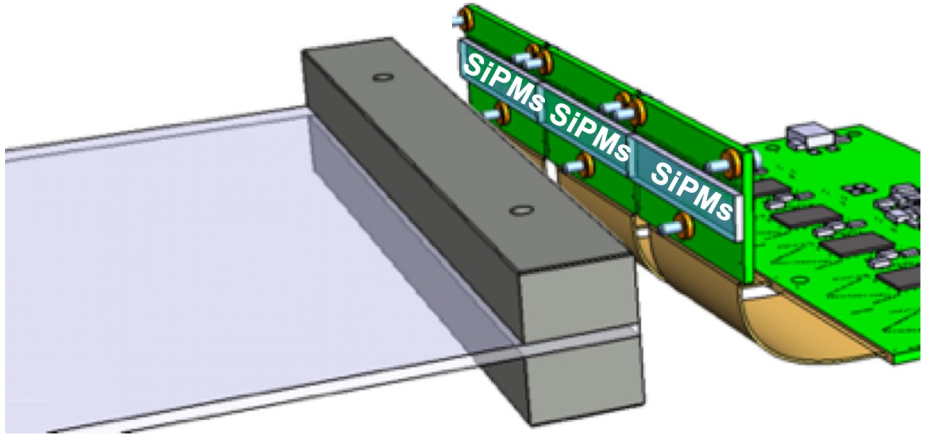
- Breakdown voltage @25 °C: 38 V to 39 V
- Overvoltage: 6.5 V
- Temperature coefficient: ~ 30 mV/ °C

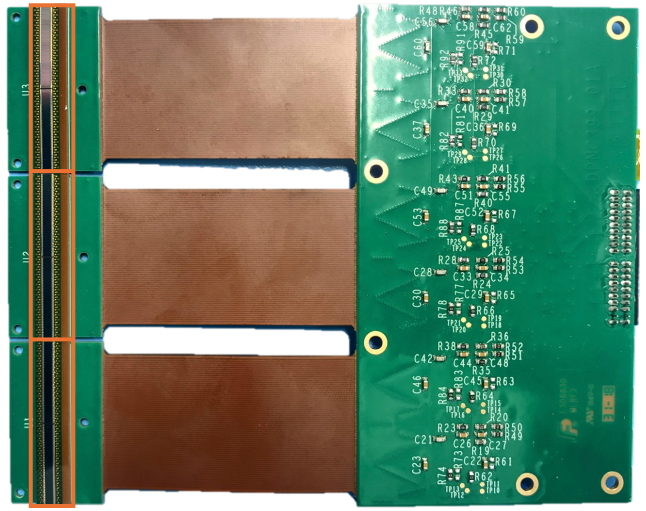




FIT module: the front-end board (FEB)

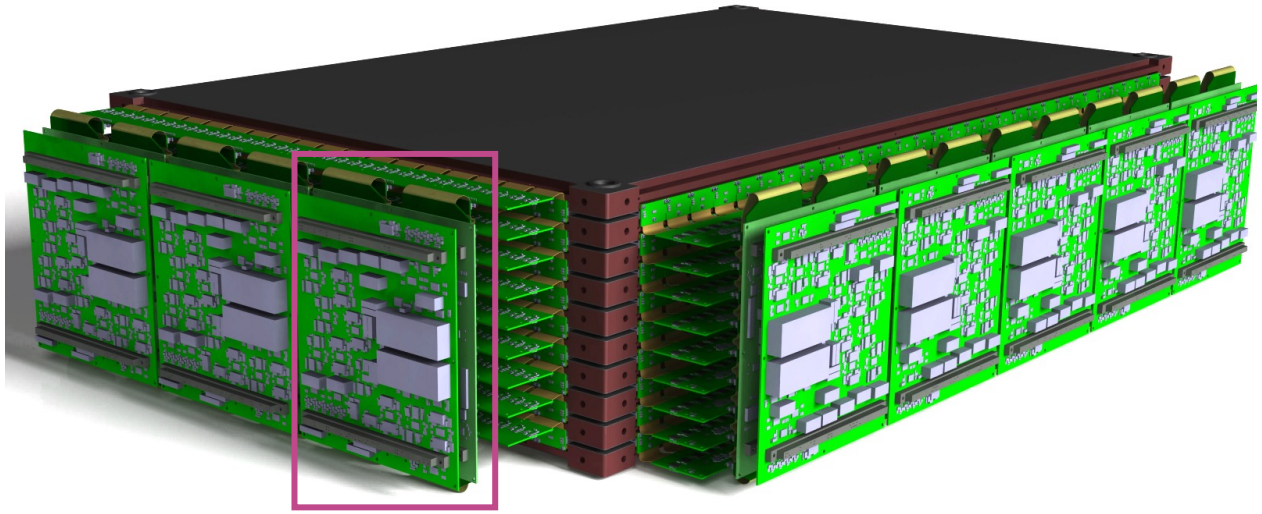




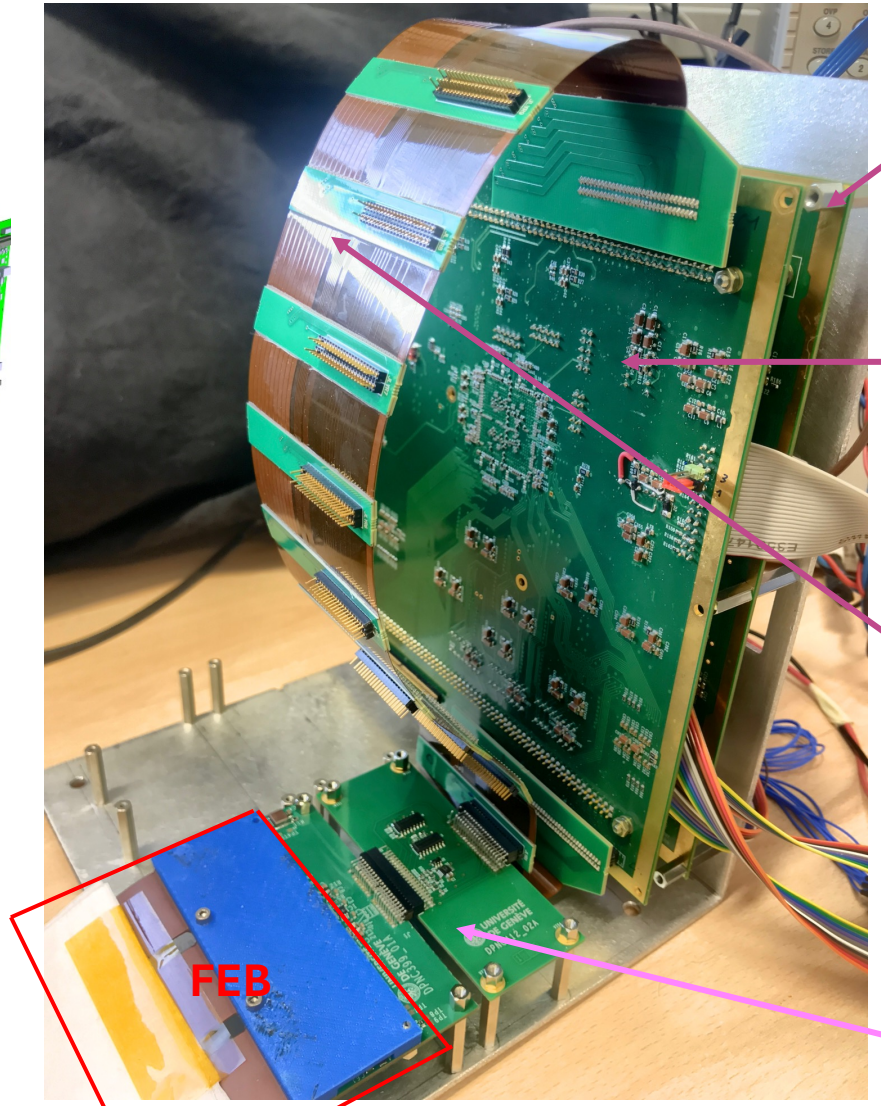


- The ASICs in the picture are **VATA64HDR16.2** (by IDEAS) (**9 mW/channel**)
- They will be replaced by the **BETA ASICs** (**1 mW/channel** & includes the ADC) developed by the Institute of Cosmos Sciences of the University of Barcelona

FIT Read-out Board (FRB)



FRB: FIT Read-out Board



Power board for the power supply distribution to the FEBs

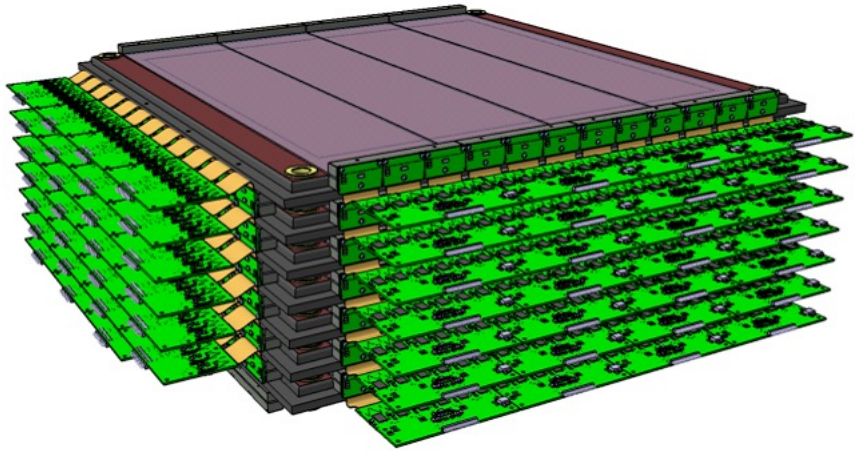
Logic board for the DAQ and communication with higher levels of DAQ

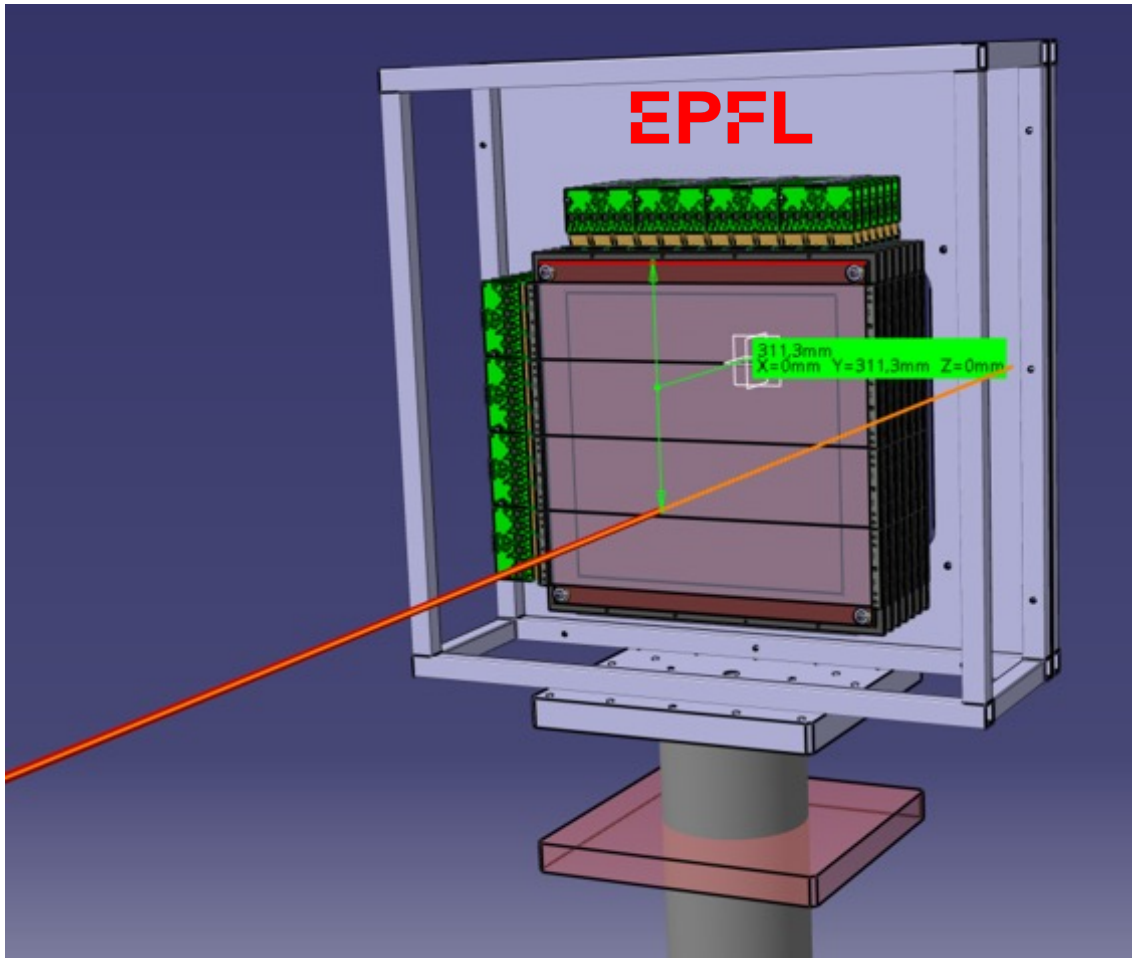
Flex for interconnection with 7 FEBs

ADC board

MiniFIT

The miniature of a FIT sector.





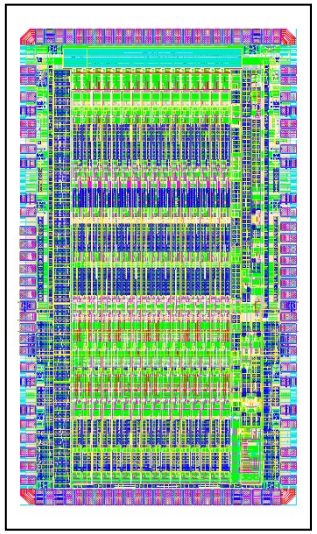
Layout:

- 7 x-y tracking planes
- 4 x + 4 y FIT modules per tray
- Fiber-mat length: 40 cm.

Goals:

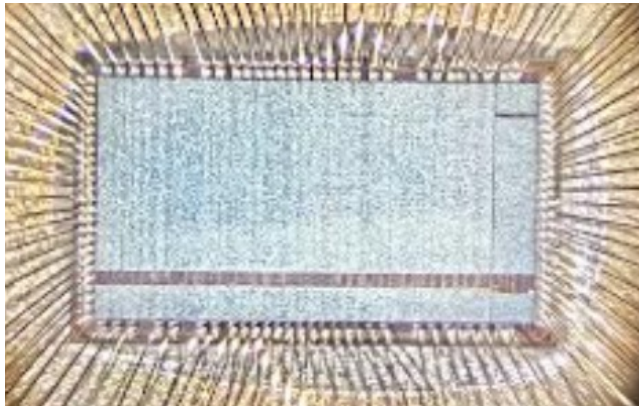
- Test the **tracking** capability of FIT
- Test the **charge measurement** capability of FIT
- Test the BETA ASIC

BETA ASIC



- ✓ Channels: 64 (PSD version: 16 ch)
- ✓ Event rate: 10 kHz with ADC @ 50 MHz
- ✓ Configurable preamplifer gain: 4 bits
- ✓ Tunable shaping time: 230 ns to 1.5 us
- ✓ Trigger output: < 250 ps time resolution

- ✓ **Single photon resolution**: **SNR > 5 for 10 µm pixel**
- ✓ On chip ADC: Wilkinson 11 bit + 1bit (path sel)
- ✓ **High Dynamic Range: 15 bit (no saturation for > 3800 fired pixels)**
- ✓ **Dual path: automatic gain switching**
- ✓ Slow Digital Control : I2C
- ✓ **Power Budget : < 1 mW/ch**



First version of BETA ASIC: BETA-16

ICCUB

https://doi.org/10.22323/1.444.0085

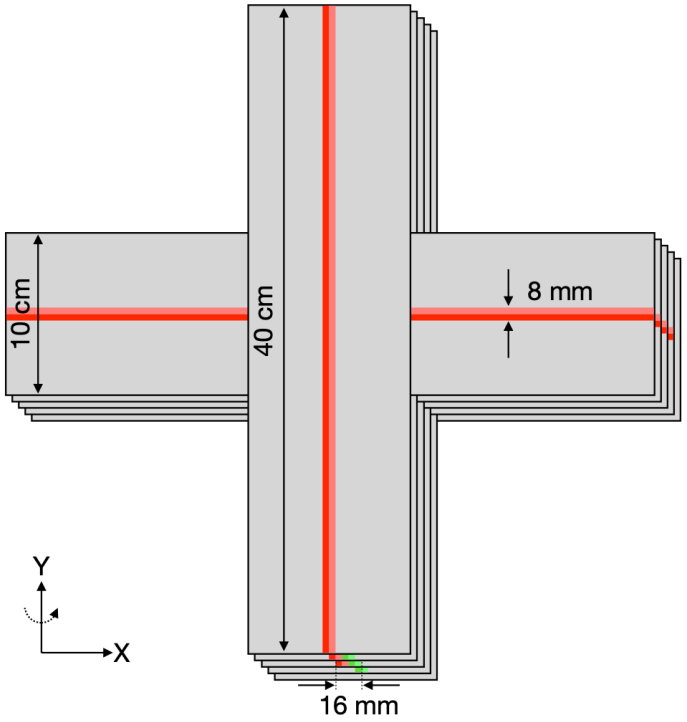
MiniFIT @beam test 2023

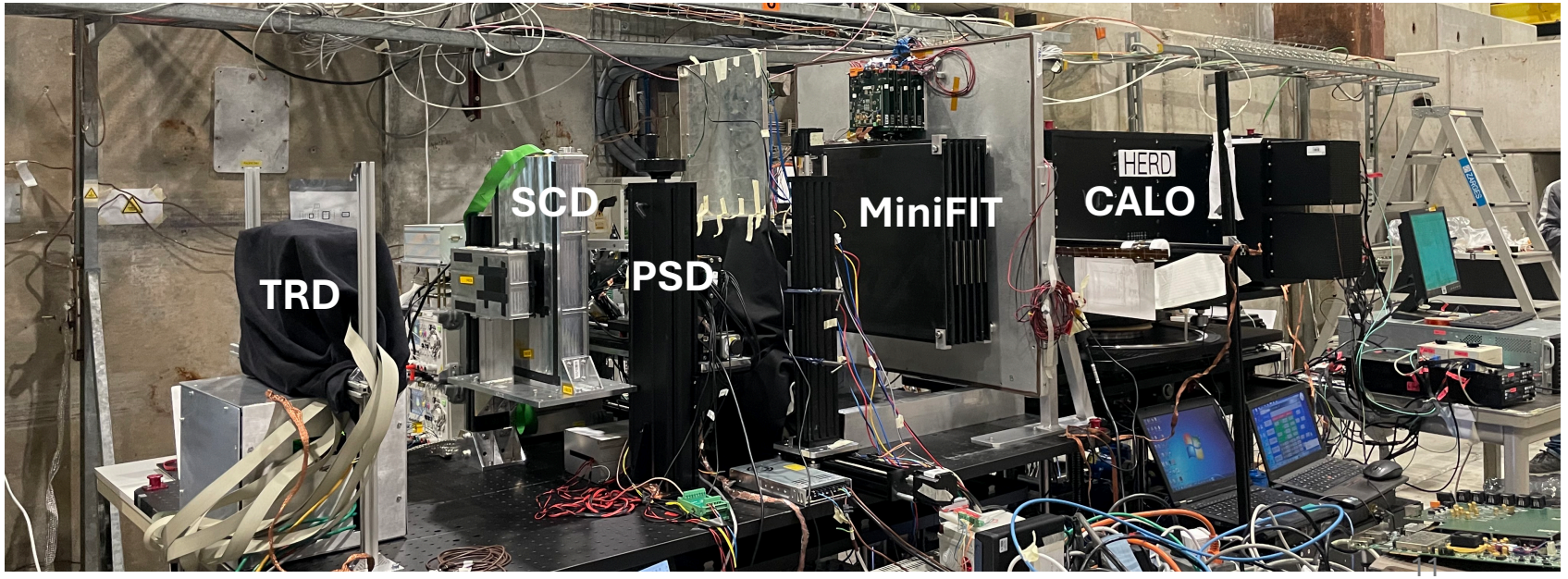
MiniFIT @CERN SPS, Fall 2023

- 4 x + 4 y tracking modules
- **Fragmentation ion beam** (330 GV/c) created with a beam of lead nuclei (379 GV/c) hitting a 40 mm thick beryllium target.

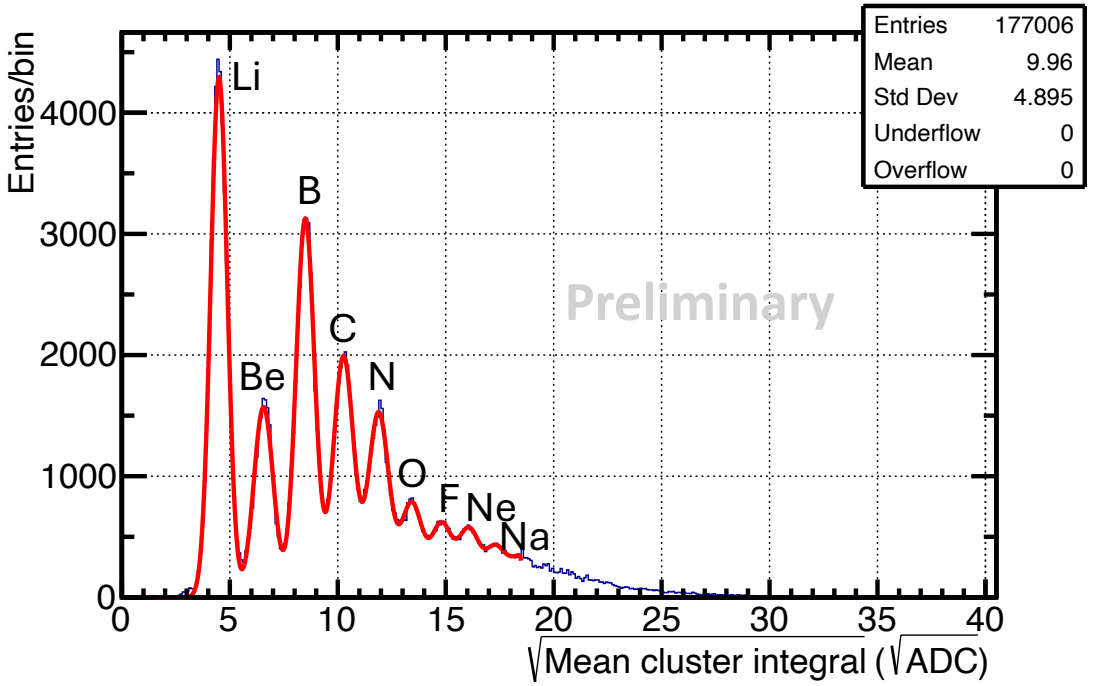
Test electronic boards developed at

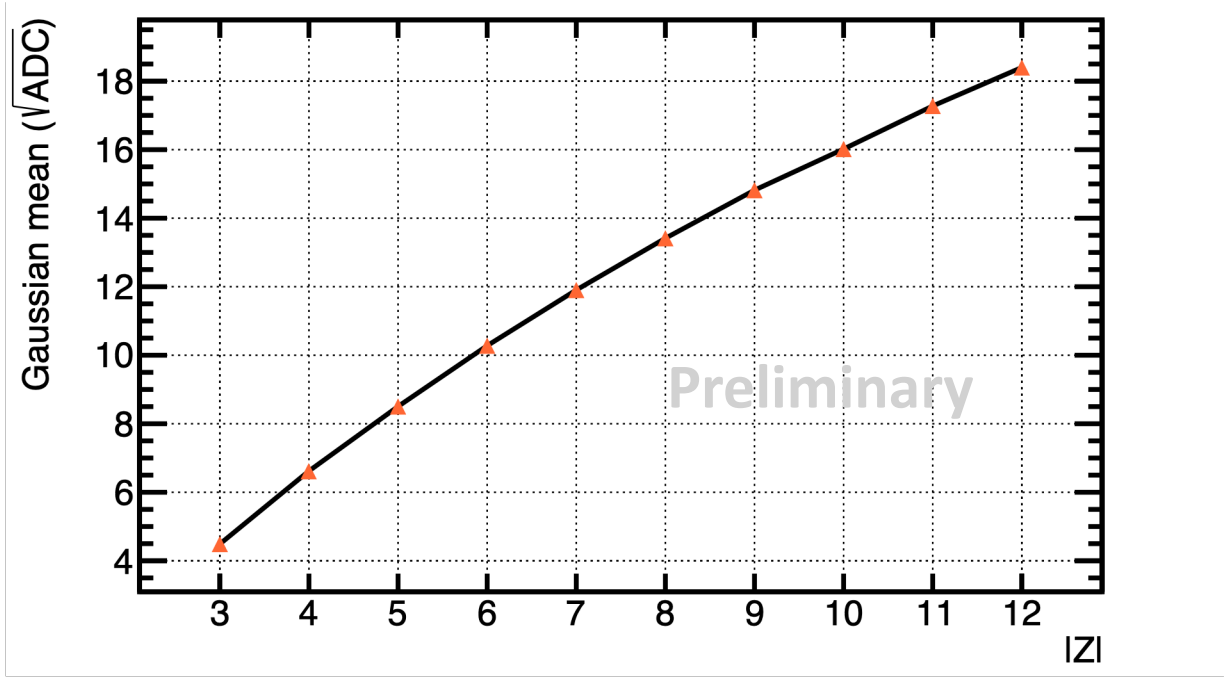
IFAE
Institut de Física d'Altes Energies





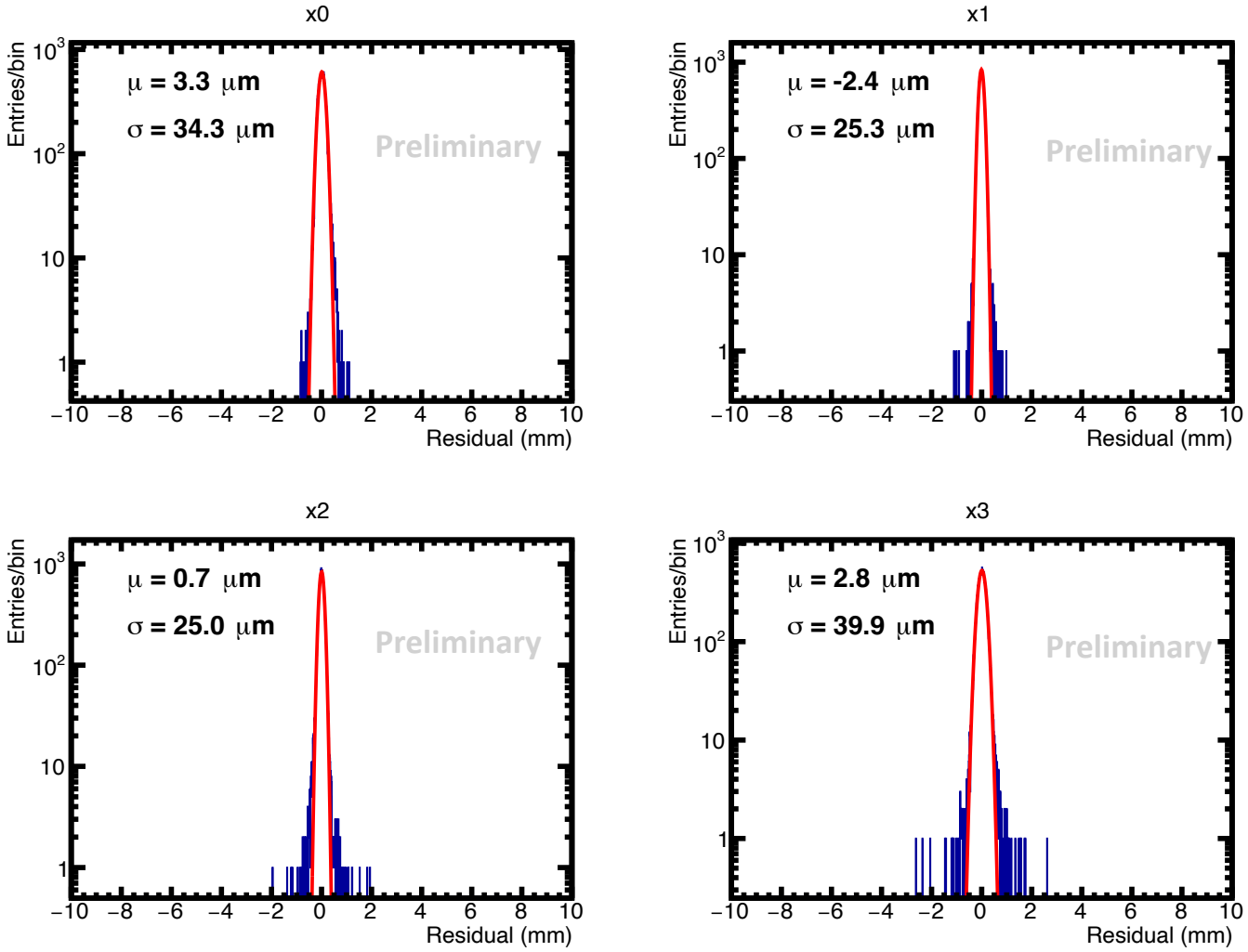
MiniFIT charge measurement



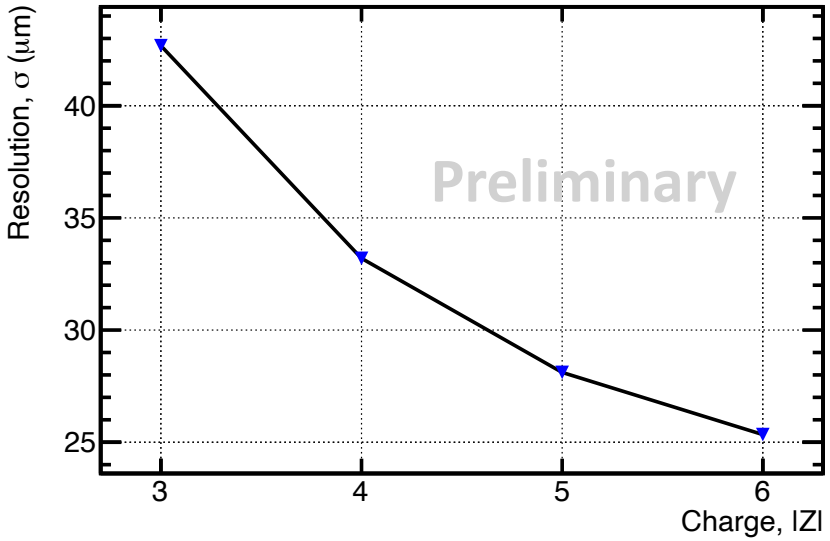


MiniFIT position resolution

Carbon (Z = 6)



Module x1

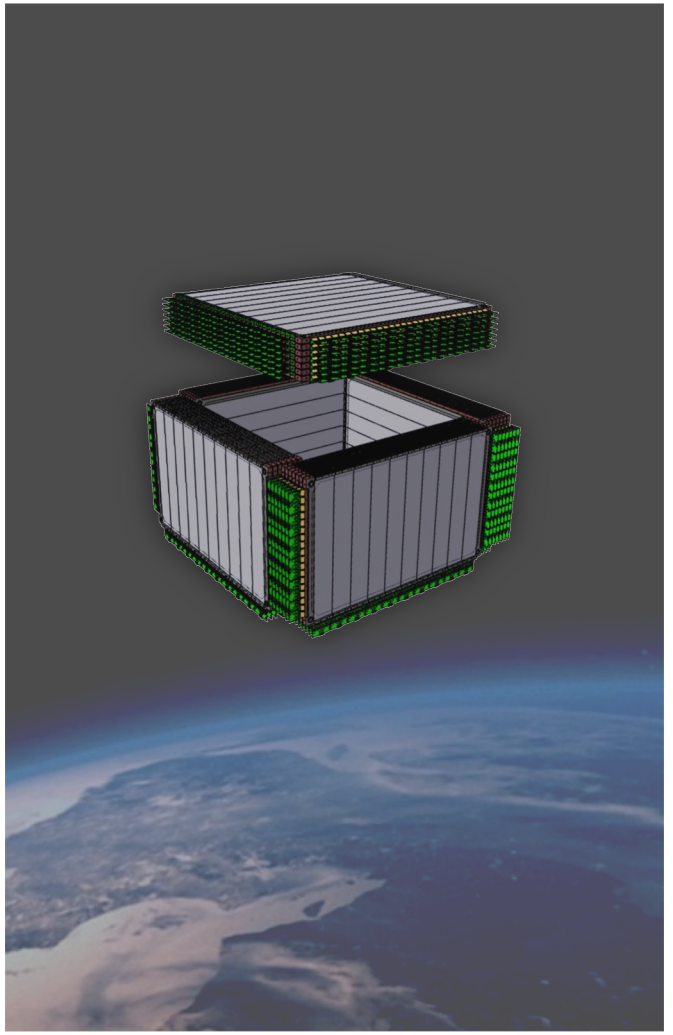


The inner modules (x1 and x2) are used to infer the **position resolution** along x, since they have the smallest track extrapolation error.

$$\text{Residual} \equiv x_{\text{fit}} - x_{\text{hit}}$$

Conclusions and outlook

- FIT is a modular high-resolution tracker well suited for future space-borne experiments requiring large-area tracking systems.
- **Position resolution of MiniFIT equipped with 4 x-y tracking planes is < 44 μm for normal incident particles.**
- MiniFIT demonstrated the charge measurement capability of FIT. Additional studies are ongoing to enlarge the measurement to higher charges.
- We will test MiniFIT in November 2024 at CERN SPS with updated test boards hosting the new BETA-64 ASICs.
- We are updating the FEB design to host the BETA-64 ASICs.



Not in this talk:

- Space qualification of FIT (publication soon)
- Monte Carlo studies demonstrate that FIT meets HERD requirements: angular resolution ~ 0.1° for gamma rays > 10 GeV (https://pos.sissa.it/444/691/)
- SiPM irradiation at Universidad Tecnológica Nacional (Facultad Regional Buenos Aires) (IEEE paper approved for publication)


Annual Meeting of the
Swiss Physical Society
9 - 13 September 2024, ETH Zürich
in collaboration with
CHIPP, SGN, SSPh, Departement Physik - ETH Zürich
Photo: © ETH Zürich/ Kuster Frey

Thank you!

HERD with current space-borne experiments

Experiment	Energy (e/γ)	Energy (p)	Calorimeter thickness (X_0)	Angular res. @ 100 GeV (deg)	$\Delta p/p$ (e/γ) @ 100 GeV	$\Delta p/p$ (protons) > 100 GeV	e/p ID	e acceptance (m^2sr) @ 200 GeV	p acceptance (m^2sr) @ 100 GeV
Fermi-LAT (2008)	< 0.1 GeV – 300 GeV	30 GeV – 10 TeV	8.6	0.1	10%	40%	10^3	1	< 0.28
AMS-02 (2011)	1 GeV – 1 TeV	1 GeV - 2 TeV	17	0.3	2%	20%	$10^4 – 10^5$	0.05	0.16
CALET (2015)	1 GeV – 10 TeV	50 GeV – 60 TeV	27	< 0.2	2%	30%	10^5	0.1	0.042
DAMPE (2015)	5 GeV – 10 TeV	40 GeV – 300 TeV	32	0.2	< 1.5%	25 - 35%	> 10^5	0.3	0.02
HERD (2027)	10 GeV – 100 TeV 0.5 GeV – 100 TeV (γ)	30 GeV - PeV	55	0.1	< 1%	20%	> 10^6	3	> 2