

FIT: a high-resolution scintillating-fiber tracker with SiPM readout for future space applications

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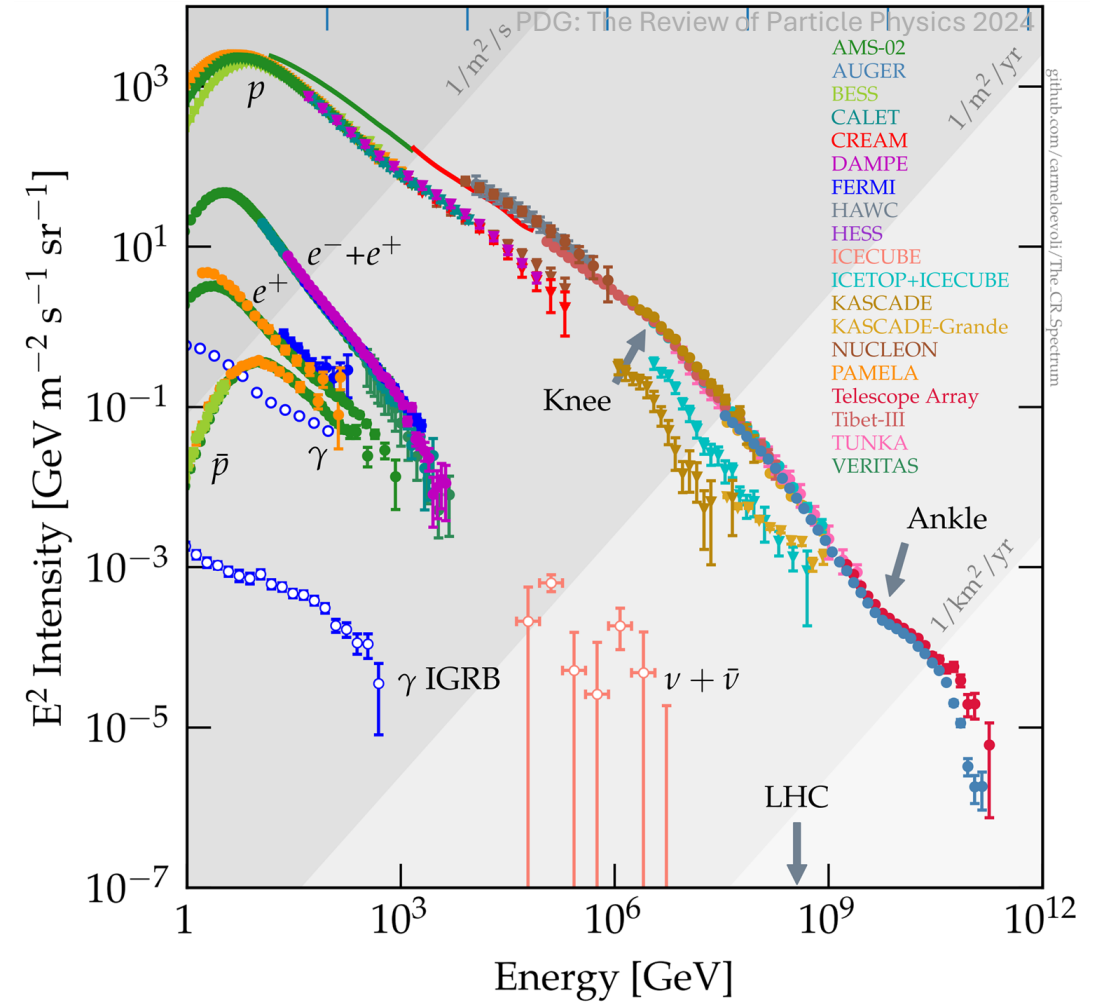
on behalf of the FIT working group

Institute of Physics, EPFL, Switzerland

Laboratory of Cosmic Particles

Cosmic Rays

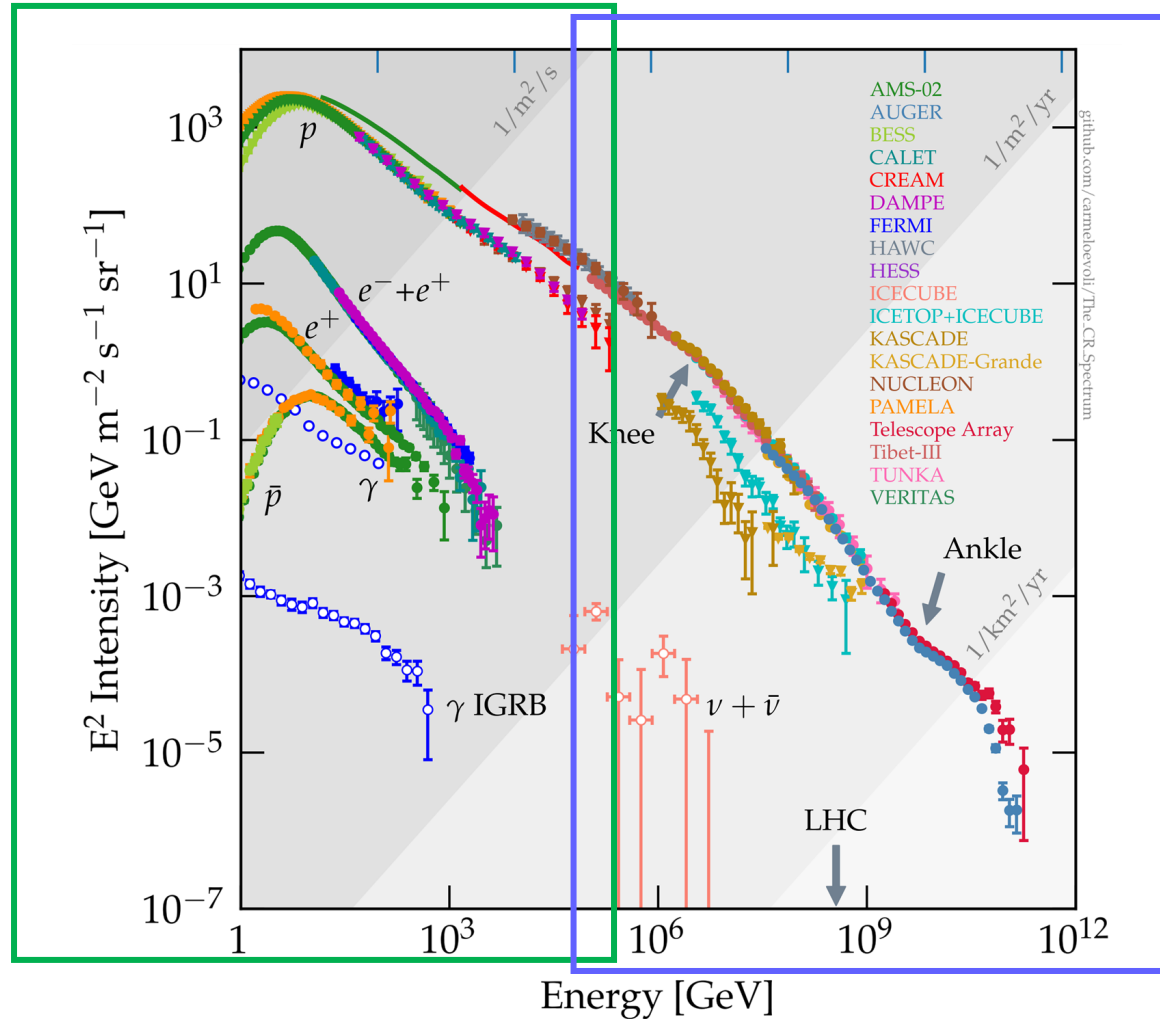
- Cosmic rays are energetic elementary particles (mostly protons) and atomic nuclei.
- Important to help us understand extreme astrophysical objects and processes such as their acceleration and propagation mechanisms.



Cosmic-ray detection

Direct detection

- Detection on top of atmosphere with balloons (CREAM) or in space on stations (AMS-02) or with satellites (DAMPE).
- Accurate composition measurements.
- Limited in energy (small detector acceptance).



Indirect detection

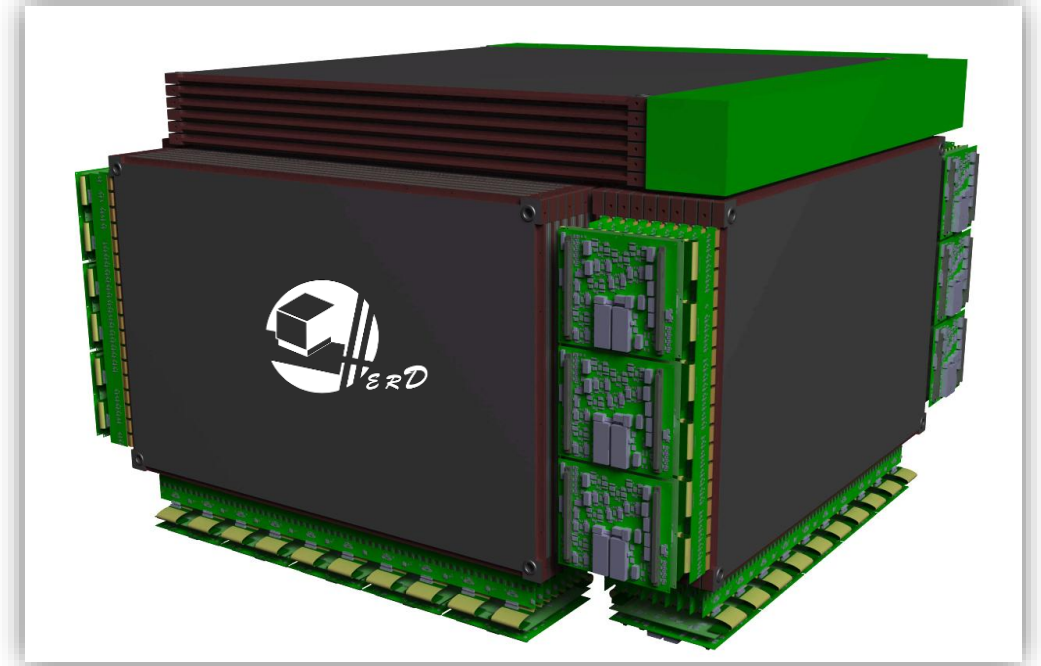
- Ground-based experiments (Pierre Auger Observatory).
- Particles produced in showers from CRs interacting with the atmosphere.
- Very high energetic events, larger detector acceptance.
- Complex charge composition, larger systematics.

Trackers in space missions

New-generation space-borne experiments require
large-area trackers

Space operations differ from ground experiments as the systems must satisfy stronger constraints:

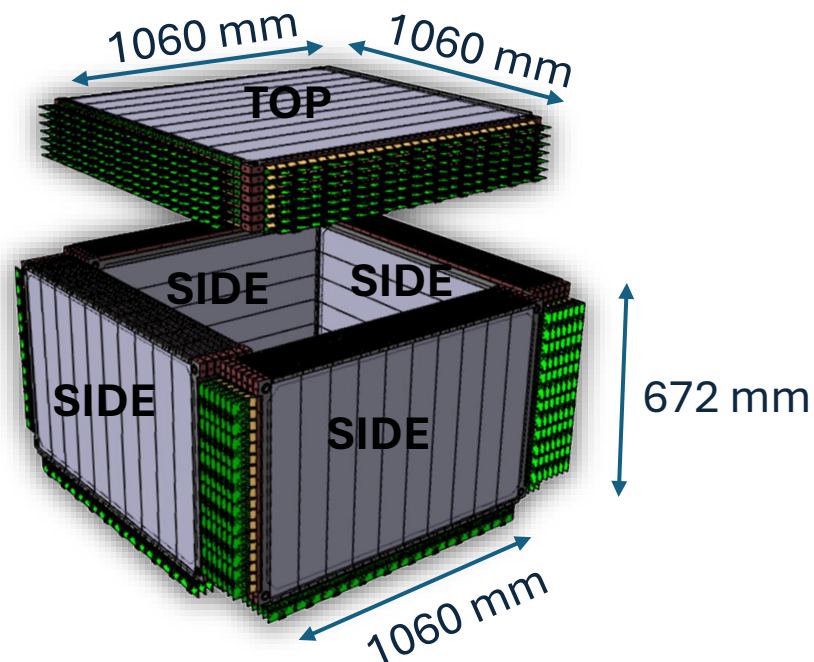
- Compactness
- Modularity
- Low-power consumption
- Low cost
- Measurement redundancy
- Mechanical stability



The scintillating fiber tracker (FIT)

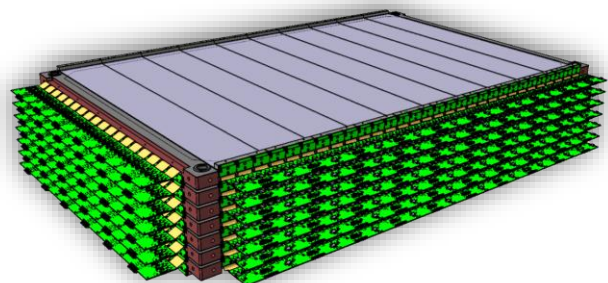
FIT = 5 sectors

- Track reconstruction
- Charge measurement ($|Z|$)
- Low-energy γ -ray conversion ($\gamma \rightarrow e^+e^-$) and track reconstruction of produced e^+e^-



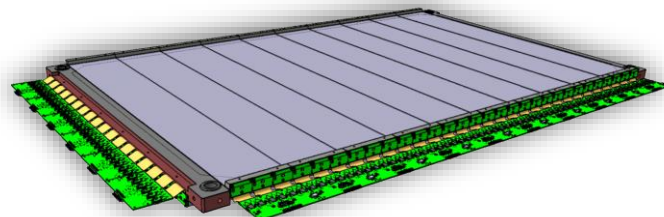
Tray of 0.3 mm sheets of carbon fiber reinforced polymer (CFRP) with 20 mm thick core of aluminum honeycomb.

FIT Sector = 7 X-Y tracking planes



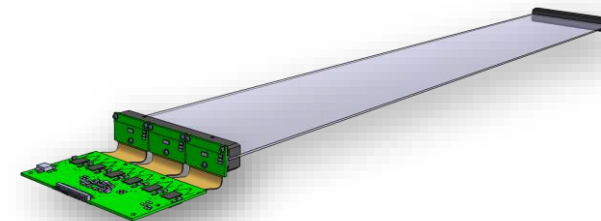
Kimberly Keyser

FIT Plane = 2 layers (X-Y coordinates), made of fit modules

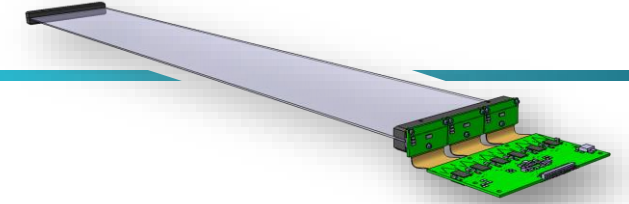
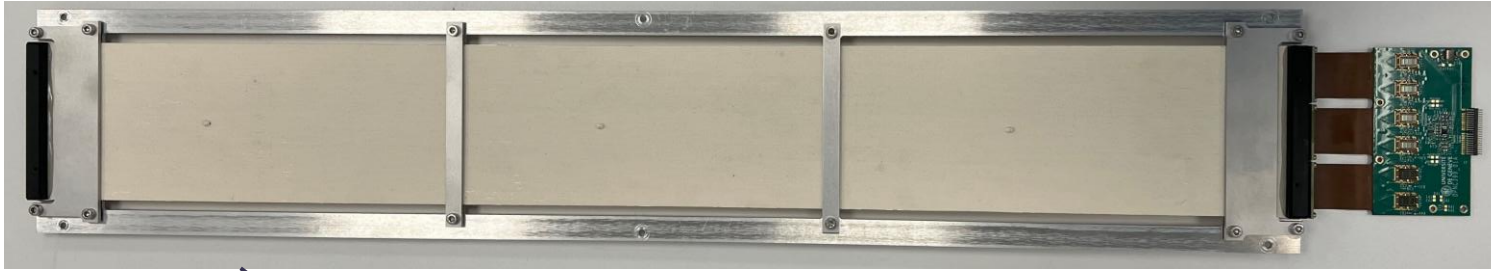


ICNFP 2025

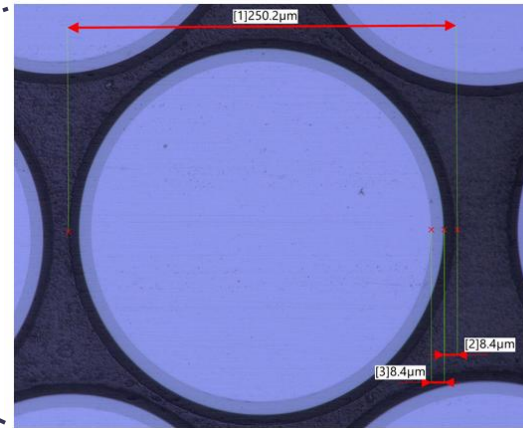
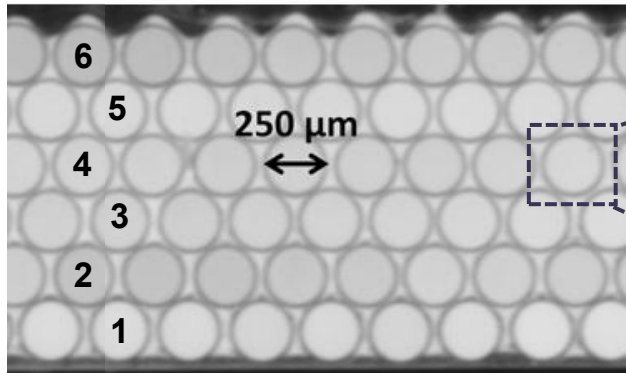
FIT Module = 1 fiber mat + 3 SiPM arrays with FEB



FIT module : the fiber mat



Design of LHCb SciFi (Upgrade I)



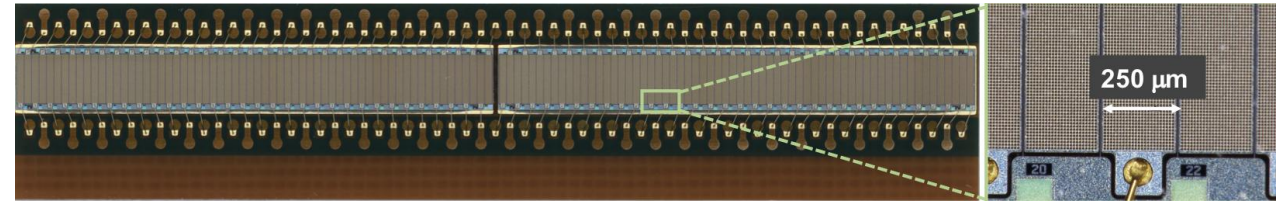
Fiber type: KURARAY SCSF-78MJ

- round section,
- diameter = 250 μm,
- Dual cladding,
- Peak at 450 nm.

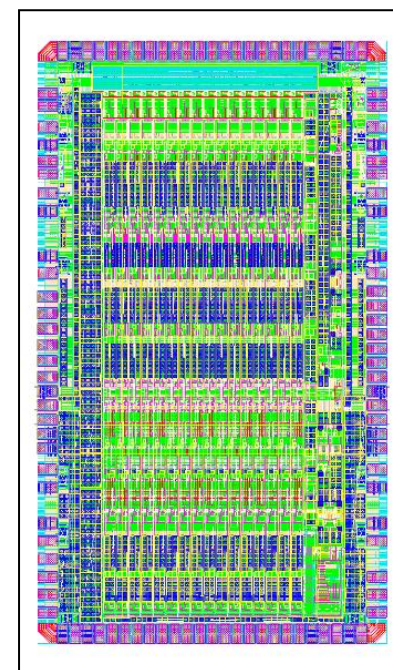
- Fiber mat: 6 layers of fibers
- Mat width \cong 97.8 mm to match 3 SiPM arrays.

SiPMs in FIT

- Hamamatsu array: 2 chips with 64 SiPMs
- 23×163 pixels/SiPM = **3749 pixels/SiPM**
- Pixel pitch: $10 \mu\text{m}$
- SiPM size: $230 \mu\text{m} \times 1630 \mu\text{m}$
- **SiPM pitch:** $250 \mu\text{m}$
- Breakdown voltage at $25 \text{ }^\circ\text{C}$: 38 V to 39 V
- Temperature coefficient: $\sim 30 \text{ mV/ }^\circ\text{C}$
- Overvoltage: 6.5 V
- **Fill factor:** $\sim 30\%$
- **Photodetection efficiency:** 15% at 450 nm

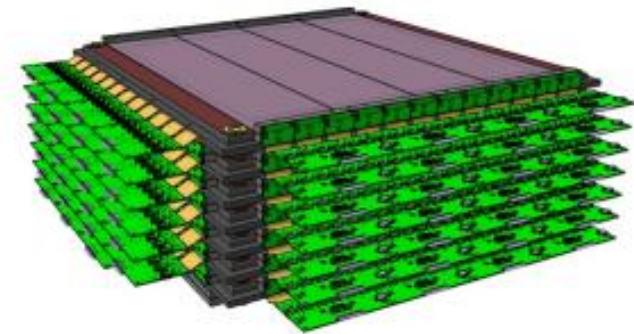
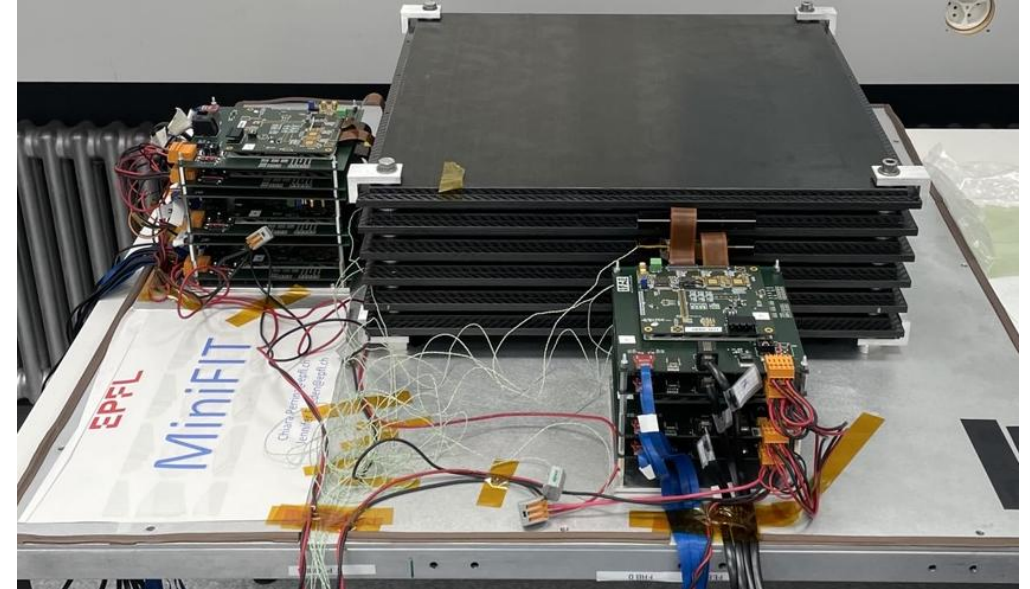


- **Channels:** 64 (tested version 16)
- **Event rate:** 10 kHz with ADC @ 50 MHz
- **Configurable preamplifier gain:** 4 bits
- Tunable shaping time: 230 ns to 1.5 μ s
- Trigger output: < 250 ps time resolution
- **Single photon resolution:** SNR > 5 for 10 μ m pixel
- **On chip ADC:** Wilkinson 11 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/channel



MiniFIT

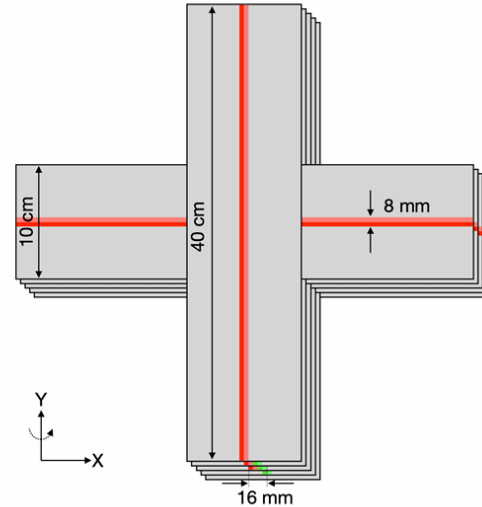
- The miniature of a FIT sector.
- 7 tracking planes, 4-X + 4-Y FIT modules per plane.
- Fiber-mat length: 40 cm.
- Goals :
 - Test the tracking capability of FIT,
 - Test the charge measurement capability of FIT,
 - Test the BETA ASIC.



MiniFIT at CERN : beam test November 2024

Beam Test at Super Proton Synchrotron (SPS) CERN.

- 4-X and 4-Y tracking planes
- Fragmentation ion beam (330 GV/c) created with a beam of lead nuclei (379 GV/c) hitting a 40 mm thick beryllium target.

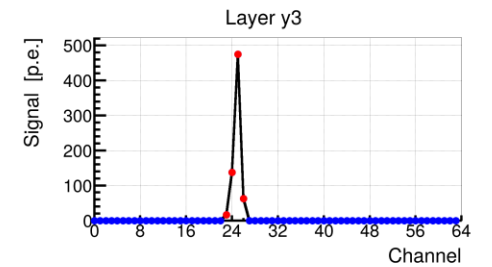
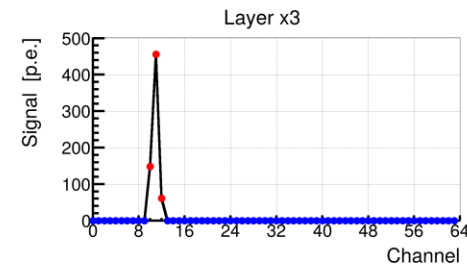
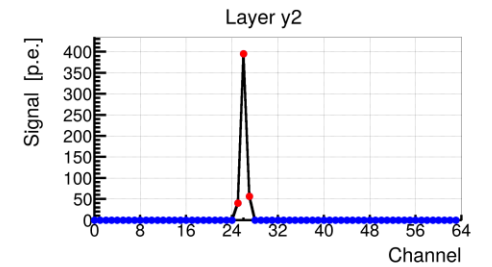
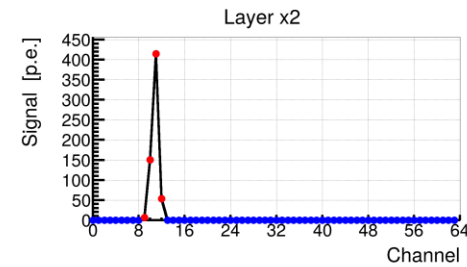
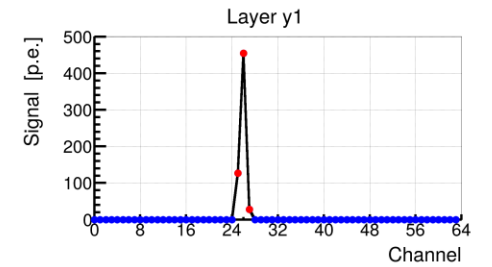
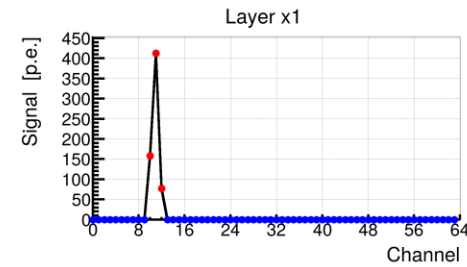
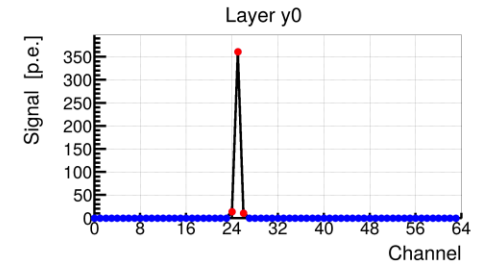
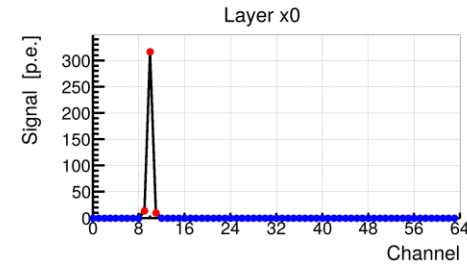


Test electronic boards developed at



Track reconstruction

- Used Low gain data → focus on high charge.
- Trigger : 3 in a row.
- Only select clean events : one cluster per layer on every layer.
- Clustering and track reconstruction algorithms developed and applied.



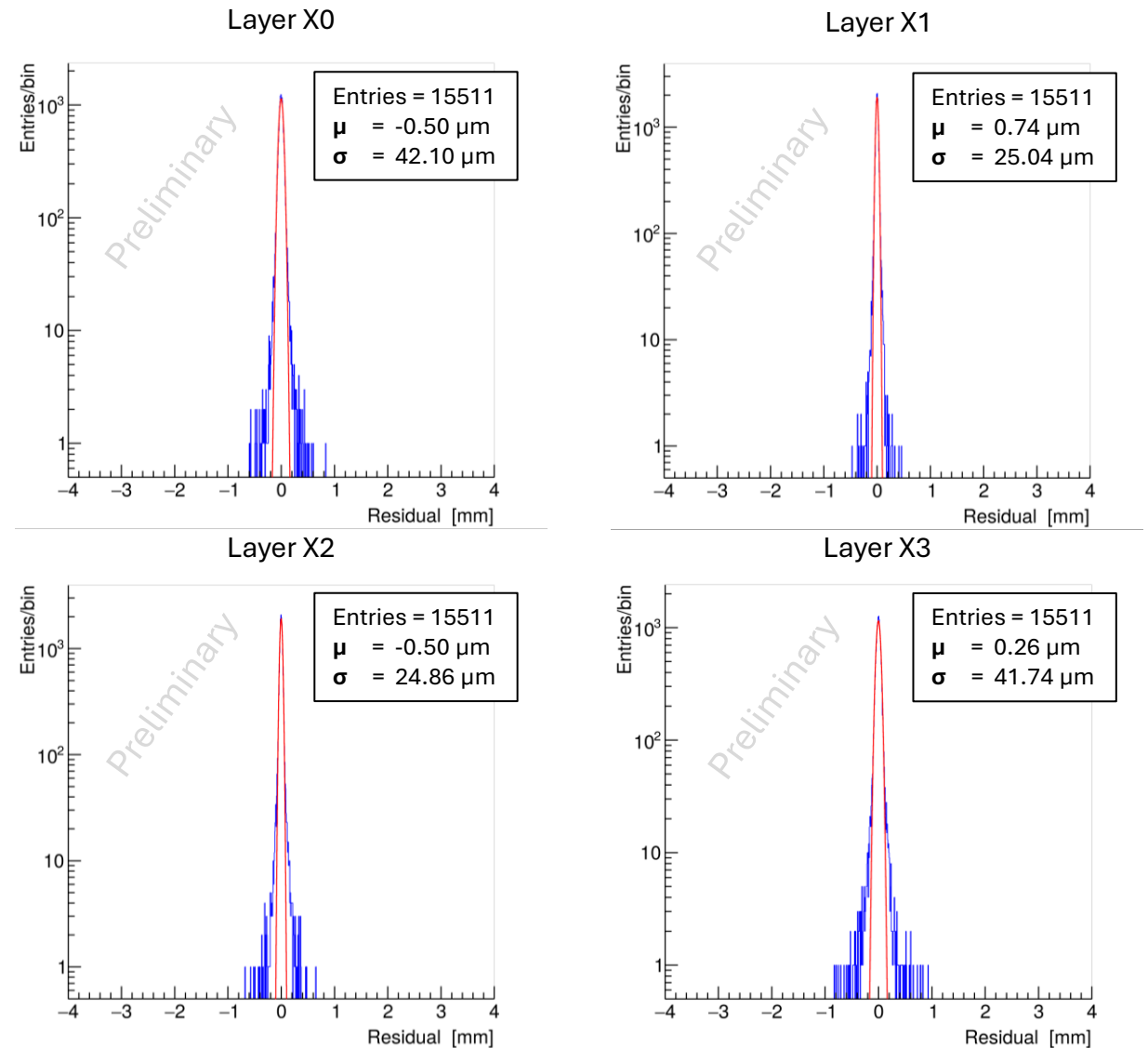
MiniFIT position resolution

- Compute for each charge separately
- Take 3 layers, to compute a track fit and estimate x_{fit} on the remaining layer.
- Estimate the position residual:

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

- The inner layers are used to estimate the position resolution since they have the smallest extrapolation error.

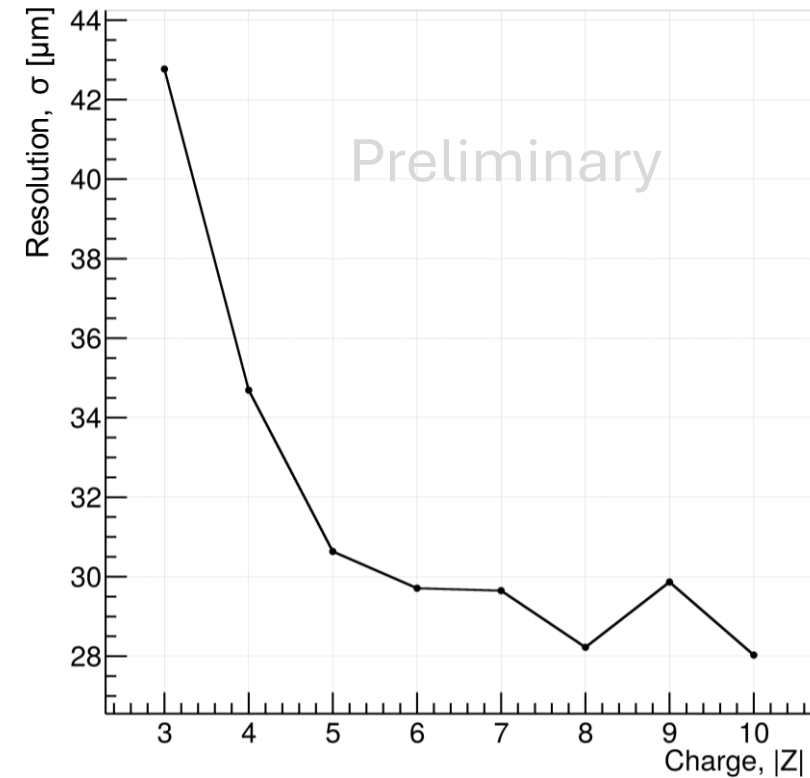
Carbon, $Z = 6$



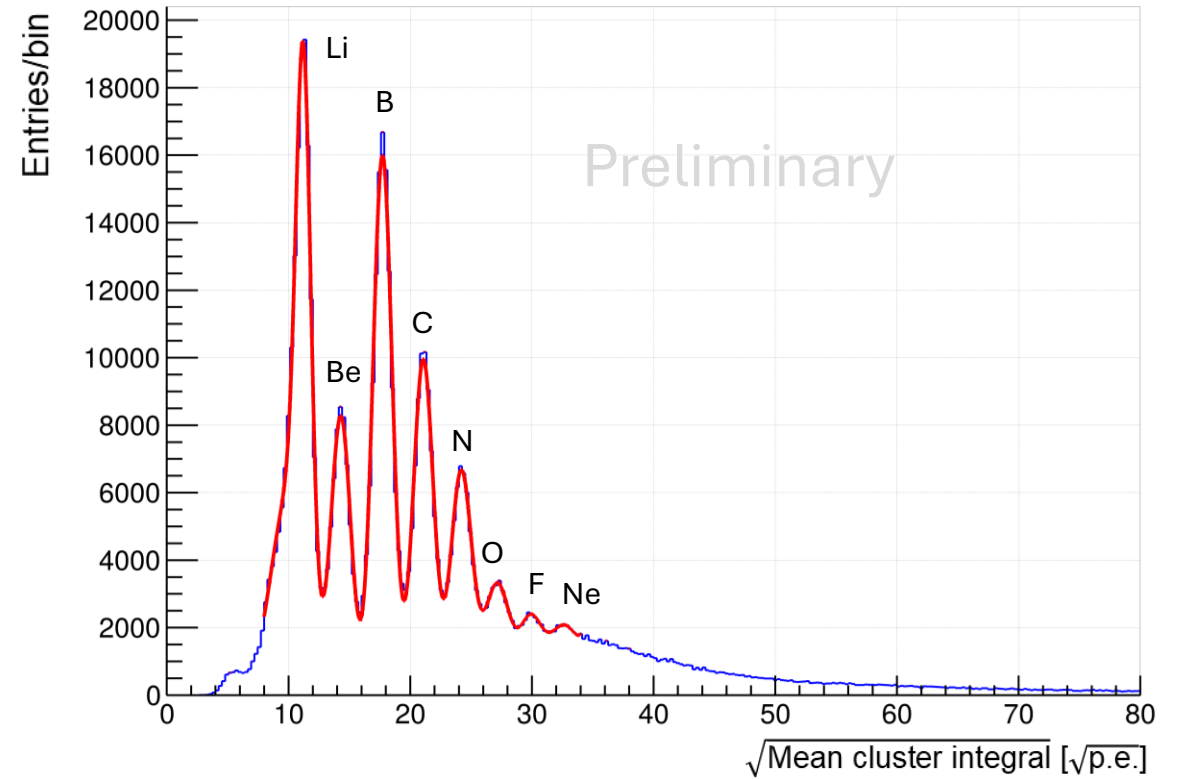
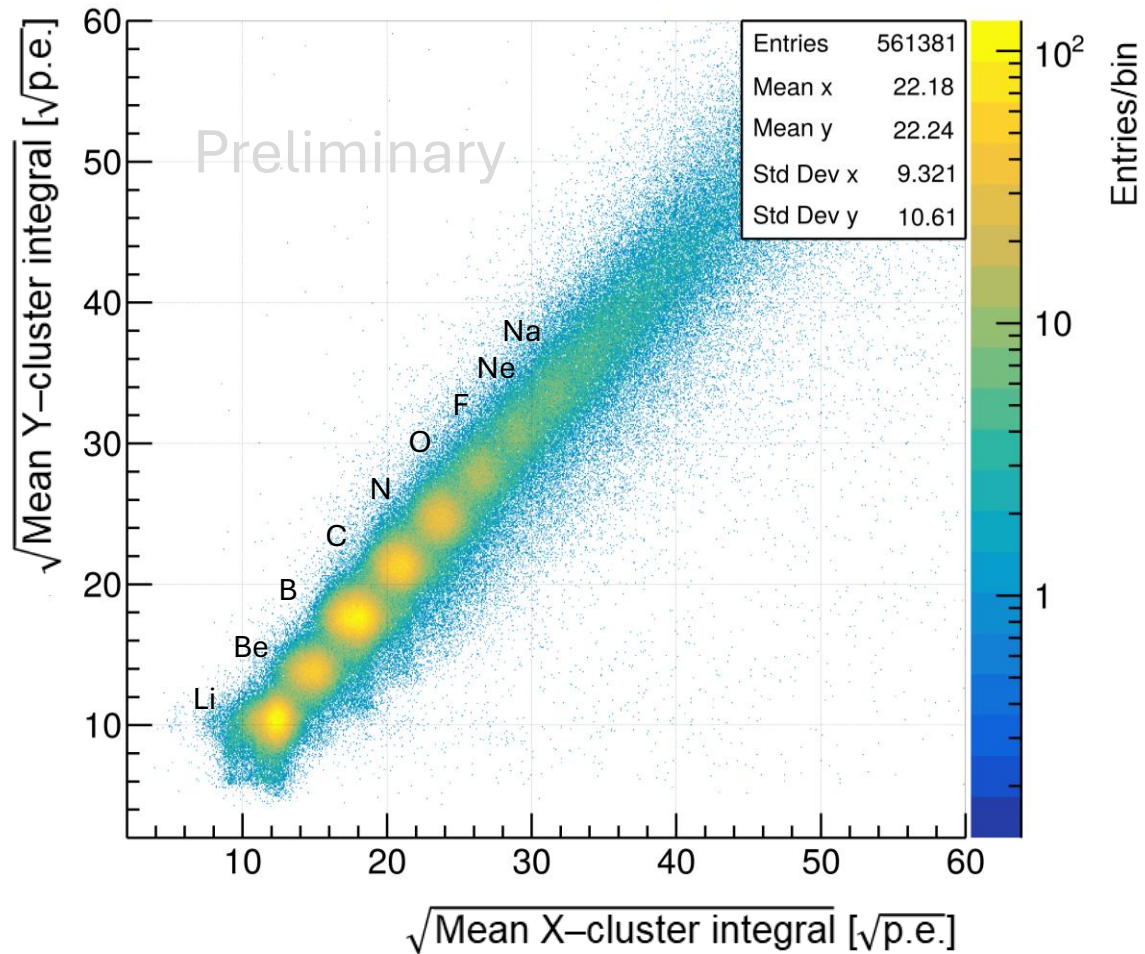
MiniFIT position resolution as a function of the charge

Position resolution better than $44\ \mu\text{m}$ for charge $|Z| > 2$.

Layer Y2

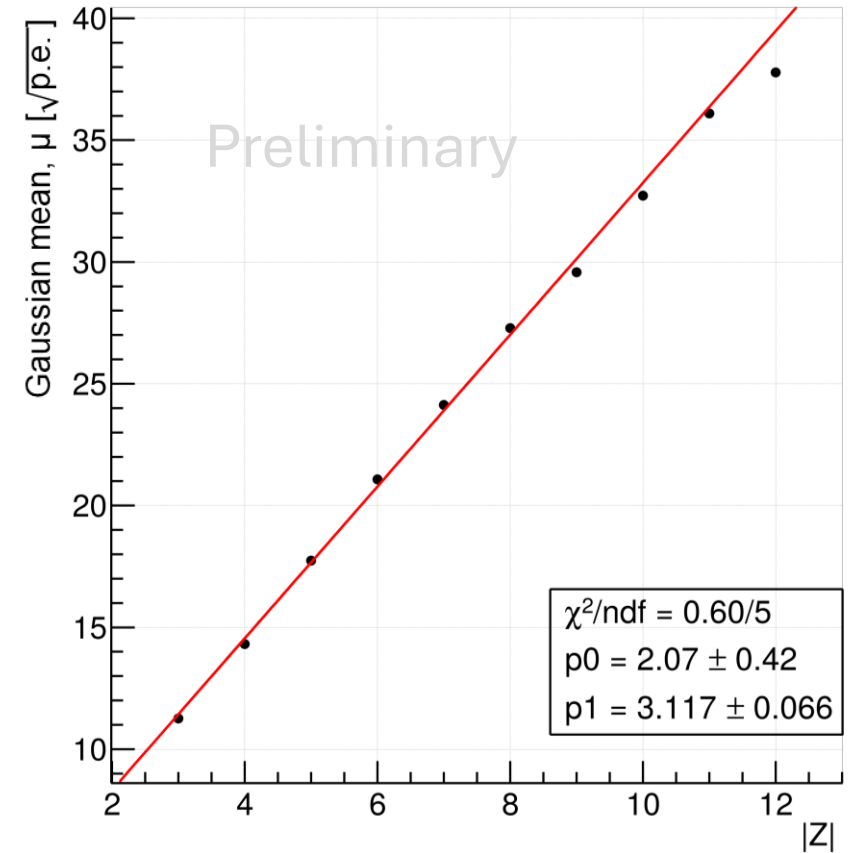


Charge distribution



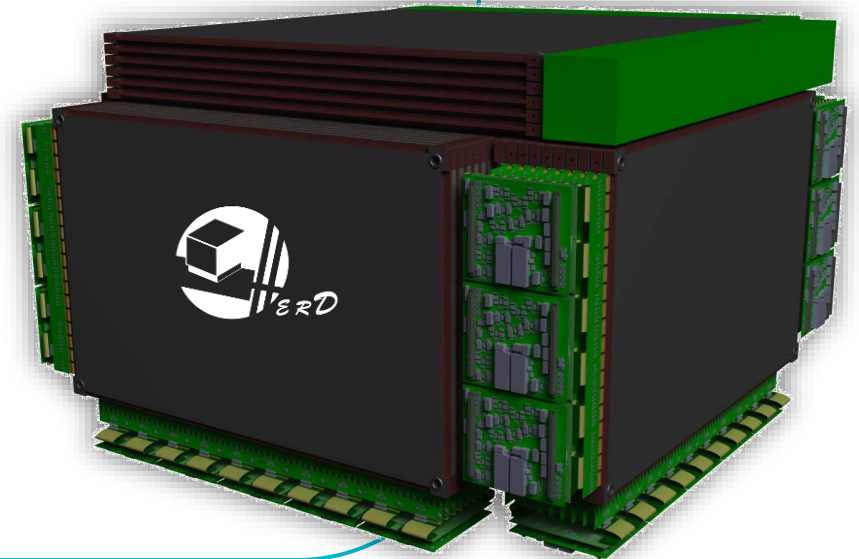
Charge measurement

- Charge resolution better than 10% for $|Z| > 2$
- Linear fit very good, more statistics required to include higher charge.
- Saturation effects from the fibers must be included (Birks' law).



Conclusions

- FIT is a modular high-resolution tracker developed for large-acceptance space-borne experiments focused on the detection of charged cosmic rays, gamma rays and the search for dark matter.
- MiniFIT developed to test the FIT performances in terms of charge and position resolution.
- Charge resolution better than 10% for charge $|Z| > 2$.
- Position resolution better than $44 \mu\text{m}$ for charge $|Z| > 2$.
- Next :
 - Further analysis with larger dataset,
 - High-gain data analysis (Proton and Helium),
 - Incident angle analysis,
 - Test the new BETA-64 ASIC.





Thank you !