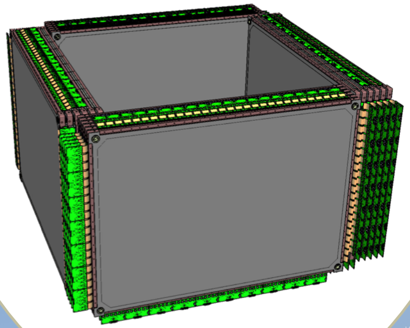
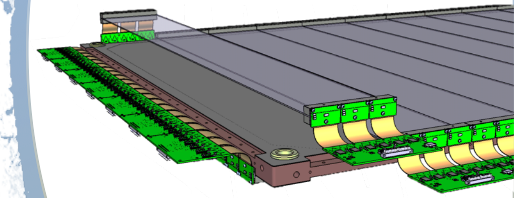
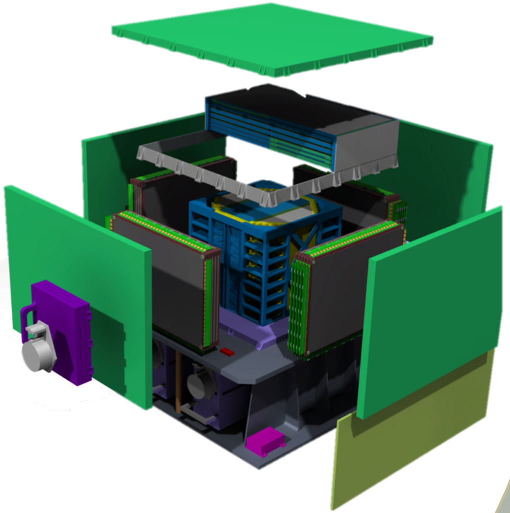


UNIVERSITÉ
DE GENÈVE
FACULTÉ DES SCIENCES
Section de physique



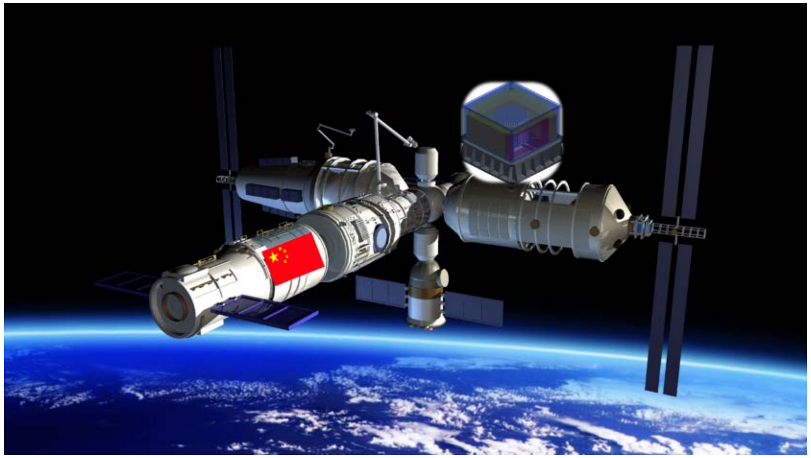
FIT: The Fiber Tracker for the HERD Facility



P. Azzarello, F. Cadoux, D. La Marra, C. Perrina, J. Wang, X. Wu
✉ chiara.perrina@unige.ch

The High Energy cosmic-Radiation Detection (HERD) Facility

- Proposed as a space astronomy payload onboard the future **China's Space Station** (CSS).
- Planned to be operational **from 2025** for more than **10 years**.



International scientific collaboration:

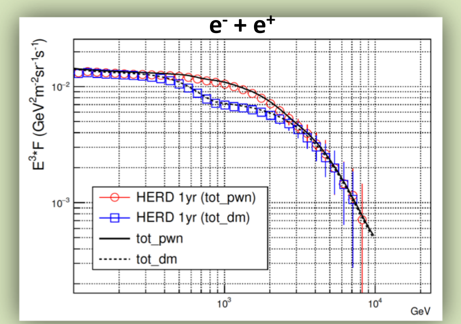
Lead by CSU and IHEP

University of Geneva

University and INFN of:
Bari, Florence, Lecce,
Pisa/Siena, Pavia, Perugia
and GSSI

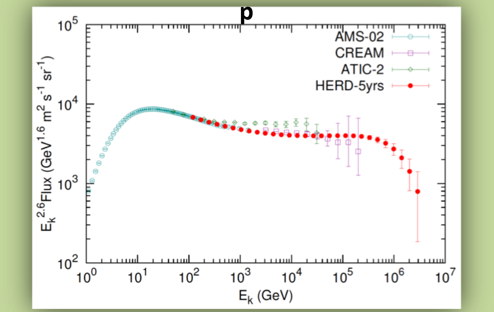
CIEMAT of Madrid

HERD: the objectives

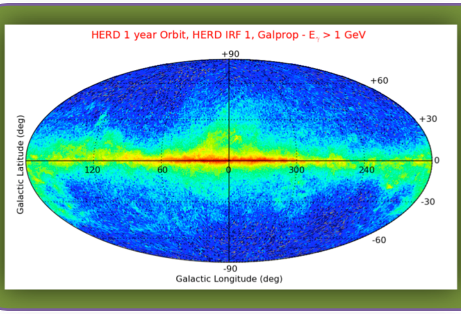


Search for signatures of annihilation/decay products of **dark matter** in

- energy spectrum and anisotropy of high energy electrons (10 GeV – 100 TeV)
- γ-rays (500 MeV – 100 TeV)



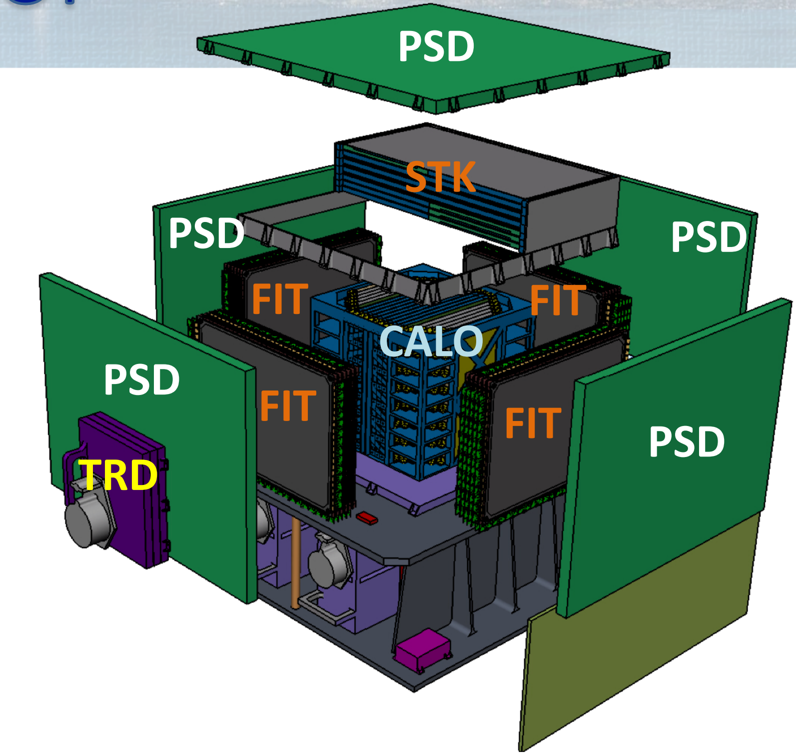
Measurements of **energy spectrum and composition** of primary cosmic rays from 30 GeV to PeV.



Wide FOV monitoring of gamma-rays from 500 MeV to study gamma-ray bursts, active galactic nuclei and galactic microquasars.

Energy range (e/γ)	10 GeV – 100 TeV
γ low energy range	500 MeV – 30 GeV
Energy range (nuclei)	30 GeV – 3 PeV
Angular resolution (e/γ)	0.1° @10 GeV
Charge resolution (nuclei)	10% – 15% for Z = 1 – 26
Energy resolution (e/γ)	< 1% @200 GeV
Energy resolution (p)	20% @100 GeV - PeV
e/p separation power	$>10^{-6}$
Geometric factor (e)	>3 m²sr @200 GeV
Geometric factor (p)	>2 m²sr @100 GeV

HERD: the detector



Calorimeter (CALO): 3D, e/γ/CR energy, e/p discrimitation

FIT «fiber tracker» (4 sides) + STK «silicon tracker» (1 side): particle trajectory, charge identification

PSD «plastic scintillator detector»: 6 sides, low energy γ, charge identification

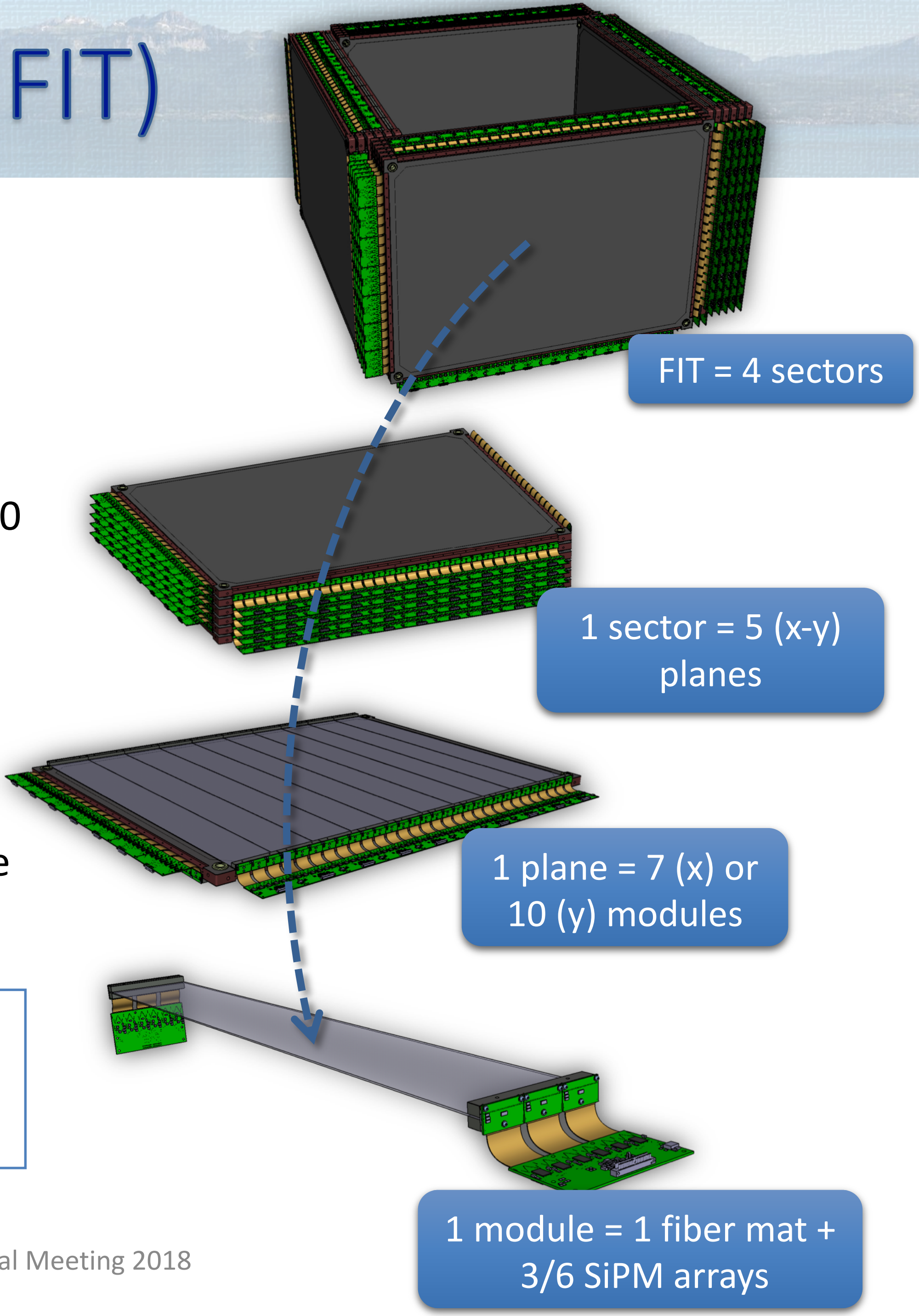
TRD «transition radiation detector»: energy calibration

Mass	< 4 t
Envelope dimensions	~ 2.3 x 2.3 x 2.6 m^3
Field of View	± 70°
Power consumption	~ 1200 W
Lifetime	> 10 years (with in-orbit replacements)

The Fiber Tracker (FIT)

- 4 identical **sectors**
- 5 (x-y) **planes** in each sector
  - 4 (x-y) with single readout to measure particles with Z = 1
  - 1 (x-y) with double readout to measure also nuclei with 1 < Z ≤ 20
- 7 **modules** (~ 1 m fiber length) in each x plane
- 10 **modules** (~ 70 cm fiber length) in each y plane
- 1 **fiber mat** + **3 (6) SiPM arrays** for single (double) readout in each module

Overall mass: ~ 250 kg;
Overall dimensions: ~ 1.4 x 1.4 x 0.9 m^3;
Overall consuption: ~ 180 W.



FIT = 4 sectors

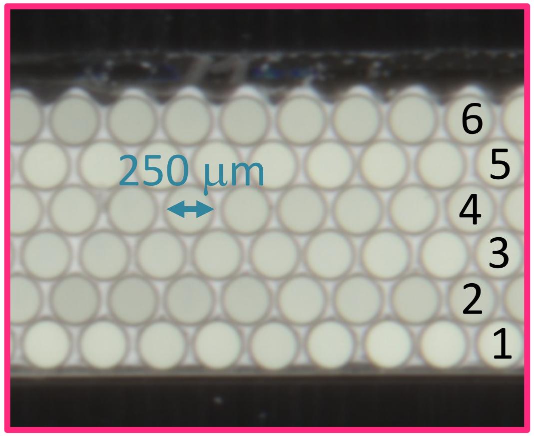
1 sector = 5 (x-y) planes

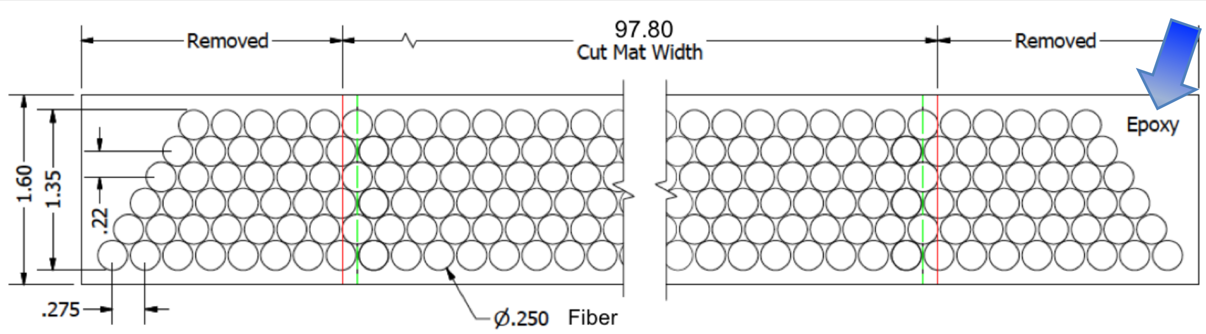
1 plane = 7 (x) or 10 (y) modules

1 module = 1 fiber mat + 3/6 SiPM arrays

FIT module: the fiber mat

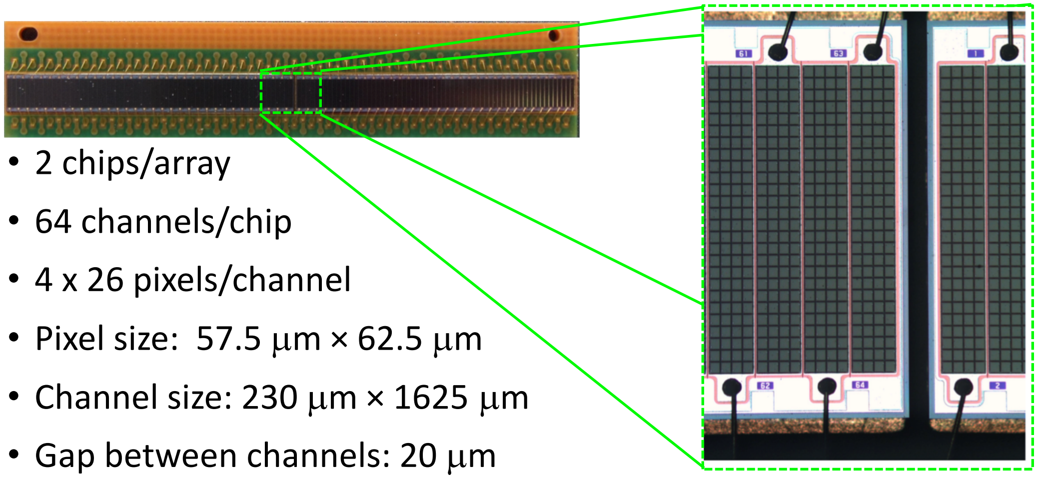
- Two possible lengths: 1.06 m and 77 cm
- **LHCb fiber tracker upgrade**
- Titanium dioxide coating (white paint) to avoid cross-talk between fibers
- 6 layers of fibers in each mat
- Fibers **KURARAY SCSF-78MJ**
  - round section
  - diameter 250 μm
  - Peak emission wavelength: 450 nm
- Mat width ≅ 97.80 mm to match 3 SiPM arrays → a layer contains ~ 350 fibers





FIT module: the Silicon Photomultiplier (SiPM) Array

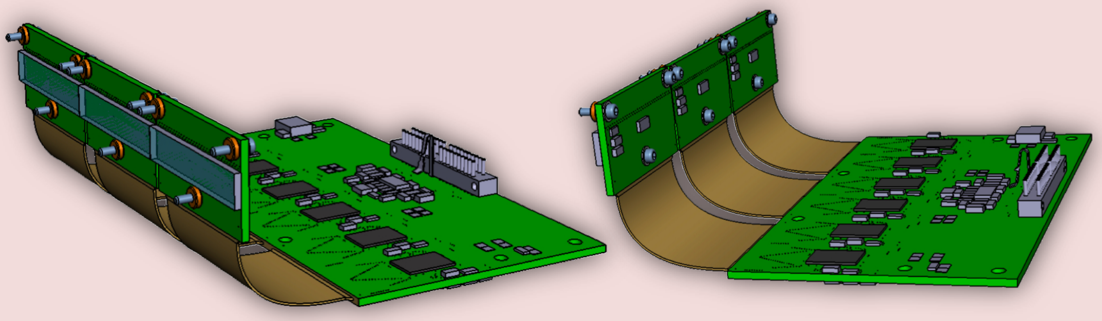
SiPM arrays from Hamamatsu (type S133552-HRQ)
(LHCb fiber tracker upgrade)



- 2 chips/array
- 64 channels/chip
- 4 x 26 pixels/channel
- Pixel size: 57.5 μm × 62.5 μm
- Channel size: 230 μm × 1625 μm
- Gap between channels: 20 μm
- Gap between chips: (220 ± 50) μm
- 105 μm epoxy resin on top

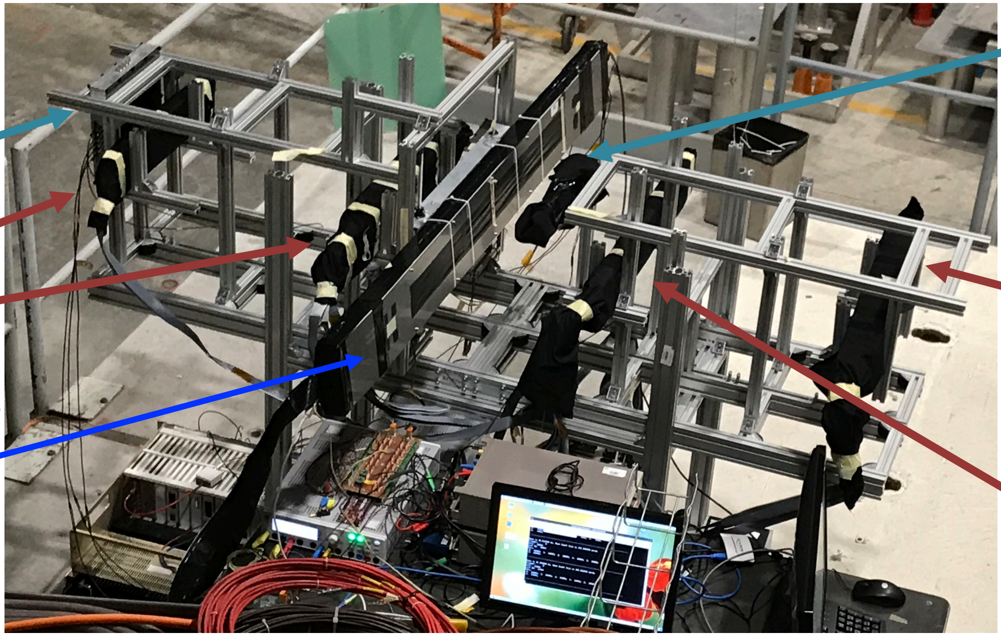
@ 25 °C:

- $V_{breakdown}$ = 48 V - 58 V
- $V_{op} = V_{breakdown}$ + 3.5 V
- Rq = 330 kΩ - 610 kΩ
- Gain @V_{op} = 3 x 10^6
- Photon detection efficiency @V_{op} = 45 %
- Sum of cross-talk + after-pulse prob. @V_{OP} = 8 %
- Temperature coefficient: $dV_{breakdown}/dT$ = 54 mV / °C



Front-end board:
6 **VATAs 64ch HDR 16**,
to readout 3 SiPM
arrays.

Beam test setup @CERN SPS North Area



Scintillators

1 AMS
Si module

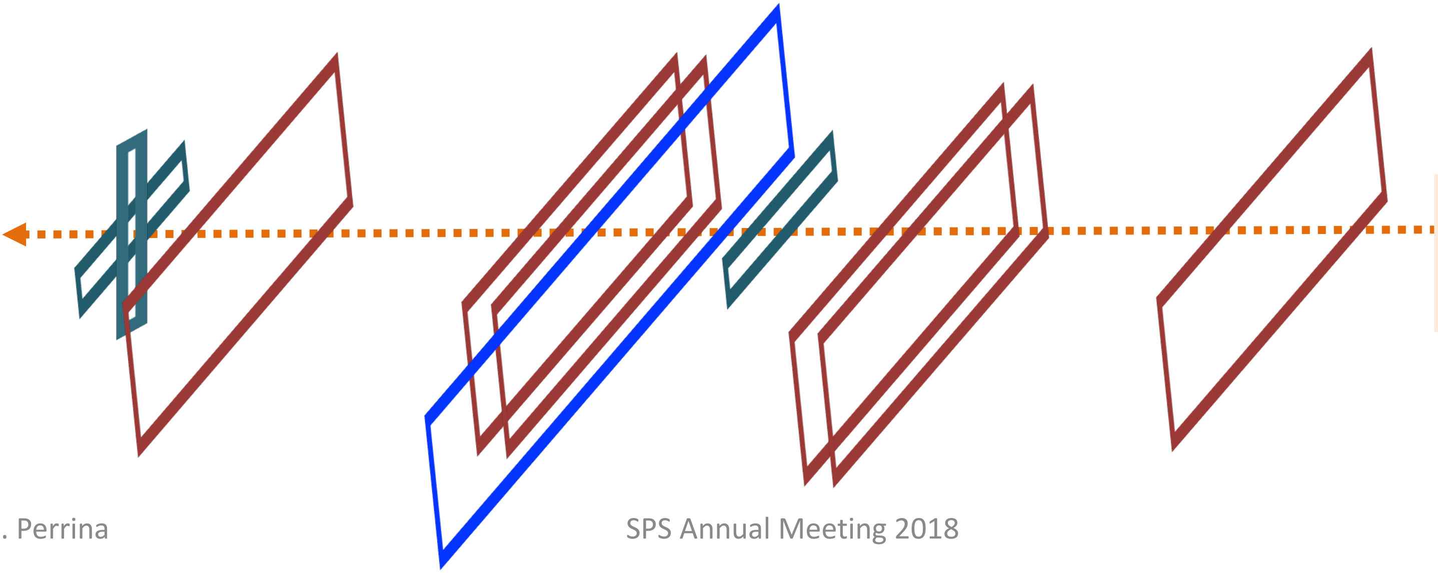
2 AMS
Si modules

Fiber
module
prototype

Scintillator

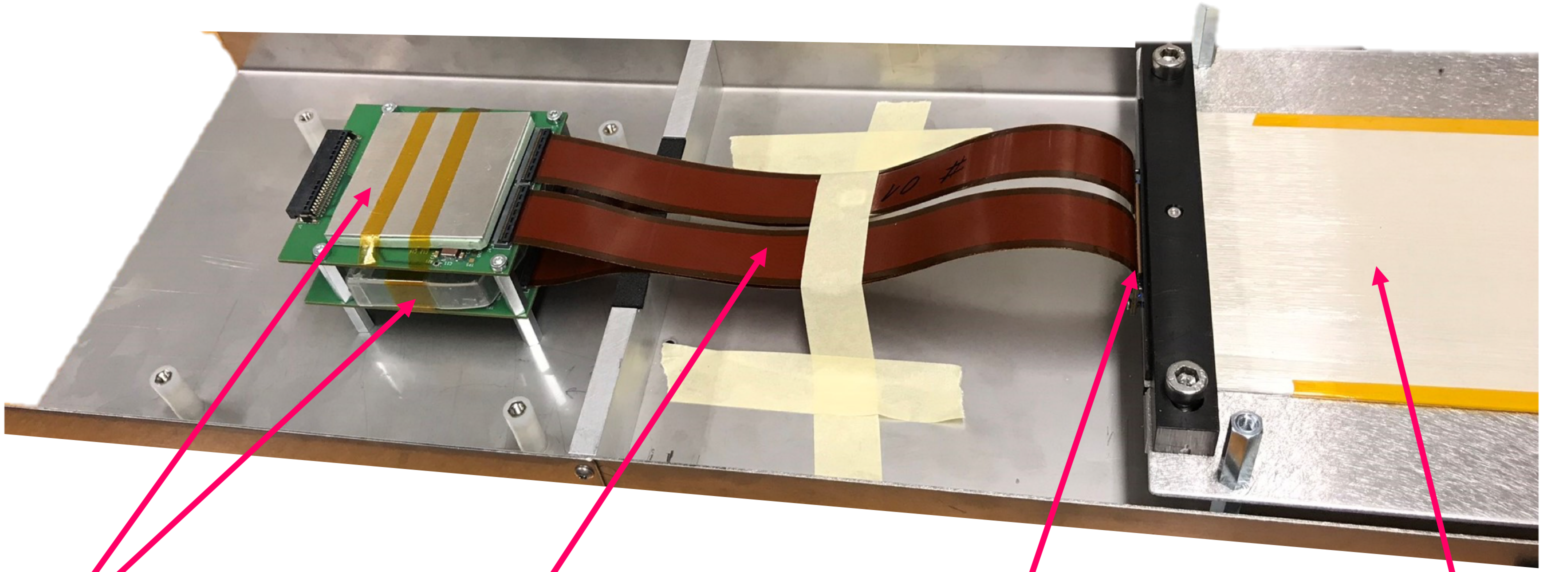
1 AMS
Si module

2 AMS
Si modules



Beam
(p, π, μ)

The Fiber Module prototype



2 VATA boards (VATA 64 HDR 16) designed by UNIGE (R&D HERD)

Rigid flex PCB (4 cables), designed by UNIGE (Mu3e)

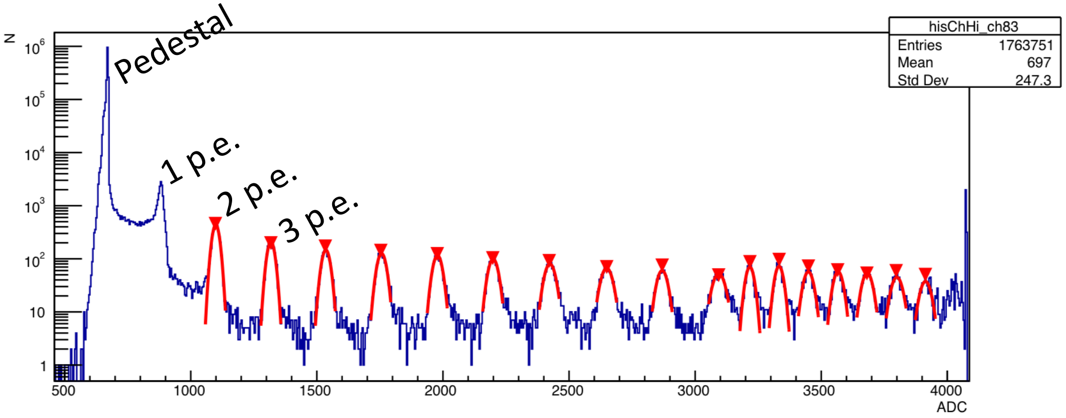
One SiPM array (2 x 64-channel chips), Hamamatsu (LHCb fiber tracker upgrade)

Fiber mat, 1 m lenght << EPFL (LHCb fiber tracker upgrade)

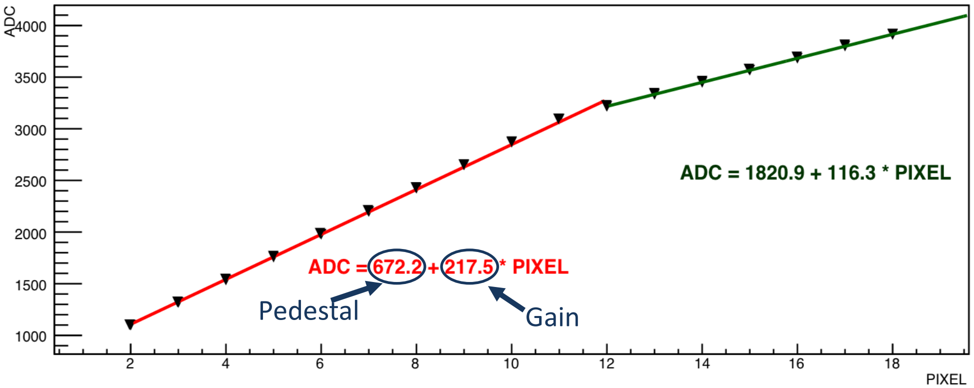
Channel charge calibration

- The ADC distribution has been analyzed to identify the position of the different photoelectron (p.e.) peaks.

(1 p.e. ≡ 1 pixel)



- The peak position has been plotted as a function of the number of photoelectrons.

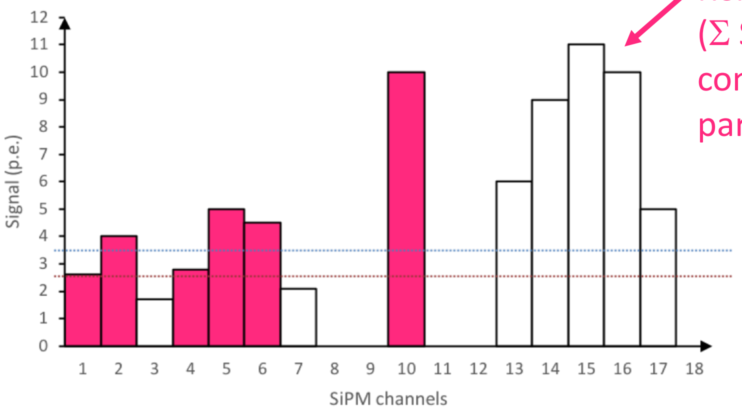


A linear fit has been performed on the two gain regions, to determine the conversion from ADC value to the corresponding number of photoelectrons.

The gain changes after 12 p.e. because of the gain saturation of the VATA chip.

Signal identification

- Once the channel calibration is done, for each event, the ADC signals have been converted in units of photoelectrons.
- A **cluster finding algorithm** has been applied, and the cluster properties - integral, center of gravity (c.o.g.), size, … - have been computed:

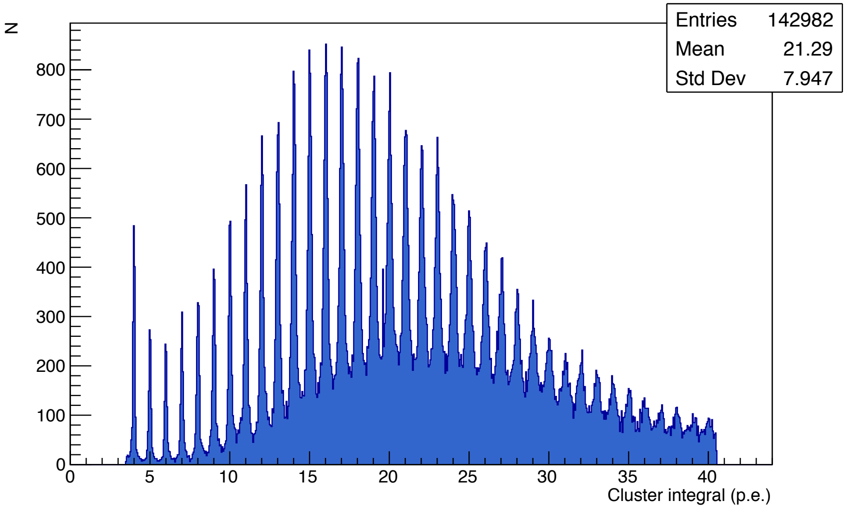


Removed by charge threshold (Σ Signal ≤ 40.5 p.e.) to avoid contributions from secondary particles

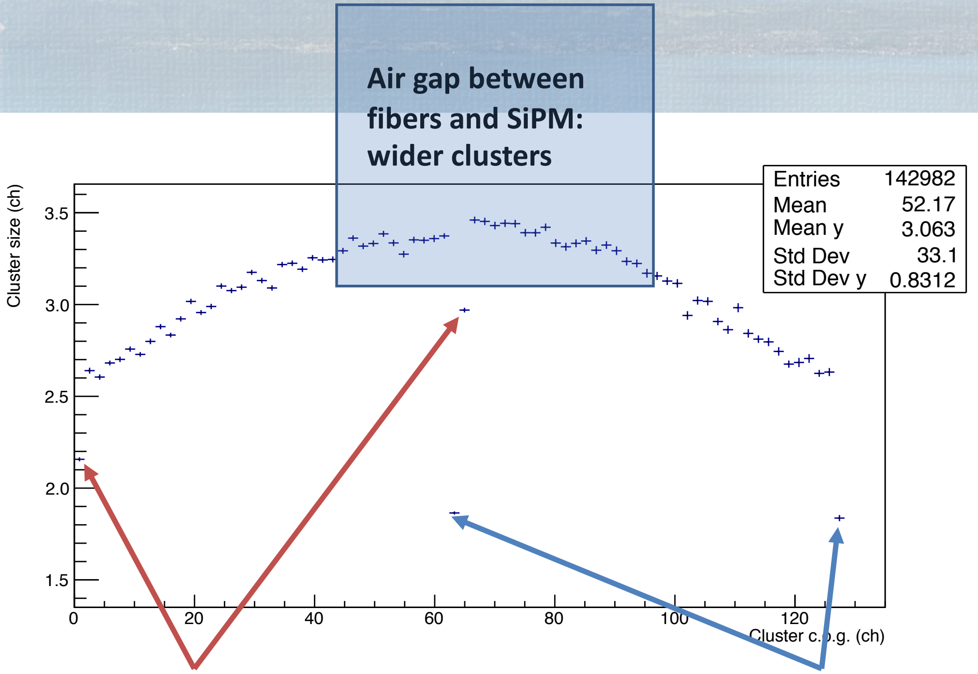
Seed threshold = 3.5 p.e.
Neighbour threshold = 2.5 p.e.

- ➢ The c.o.g. is calculated as the average of the cluster channels weighted by their signal. It is the best estimate for the crossing point of the particle.
- ➢ The cluster size is the number of channels composing the cluster.

Light yield



Signals up to 40 p.e. very well distinguishable.

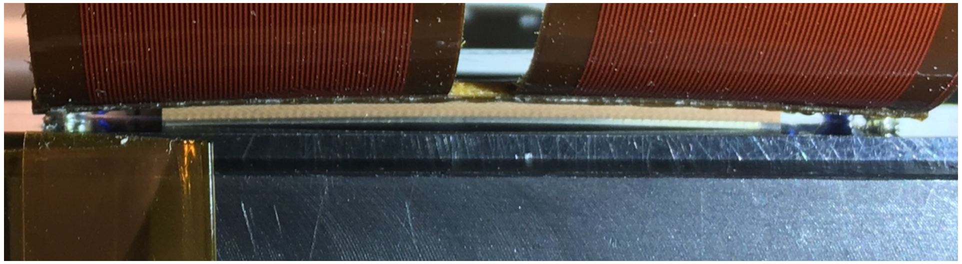


Air gap between fibers and SiPM: wider clusters

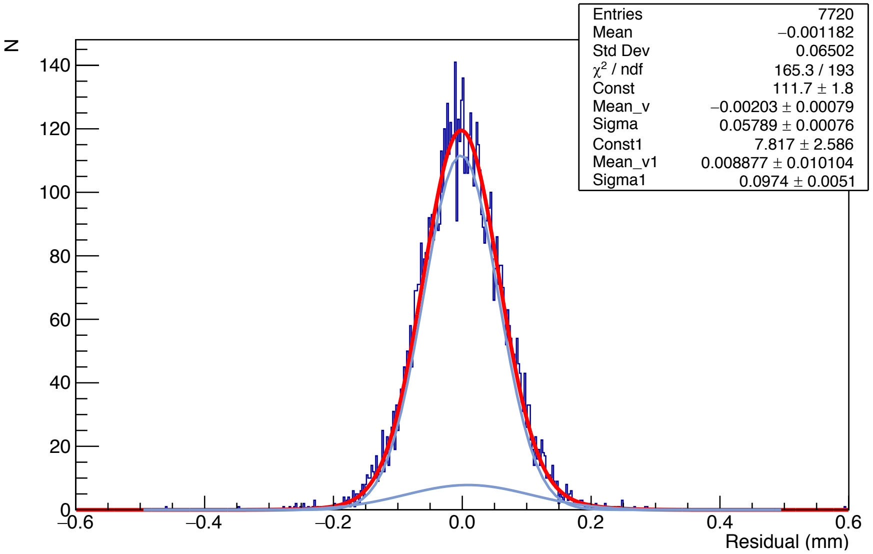
Signal cannot be shared with channels on the left

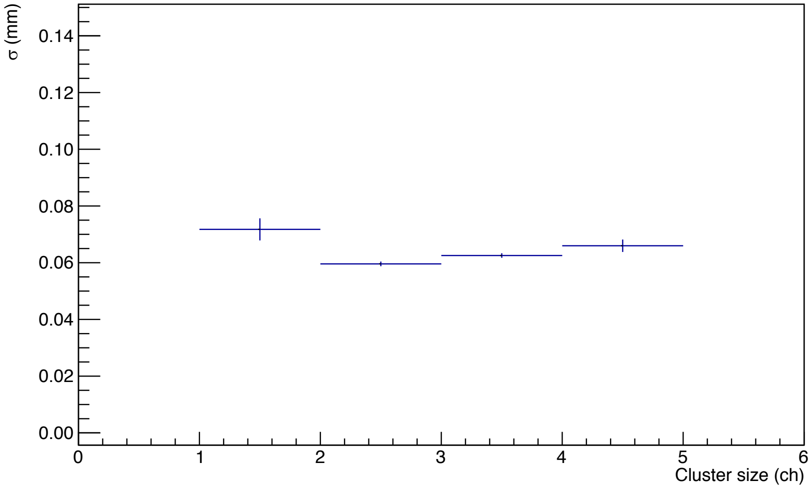
Signal cannot be shared with channels on the right

Monte Carlo comparison
→ Poster **388** presented
by **Junjing Wang**



Spatial resolution





- 100 GeV pions
- Cluster residual: 63.2 μm
- Spatial resolution: 59.6 μm (corrected for beam telescope resolution)
- Efficiency = (99.7 ± 0.2)%
- The resolution is best for a cluster width of 2 channels.

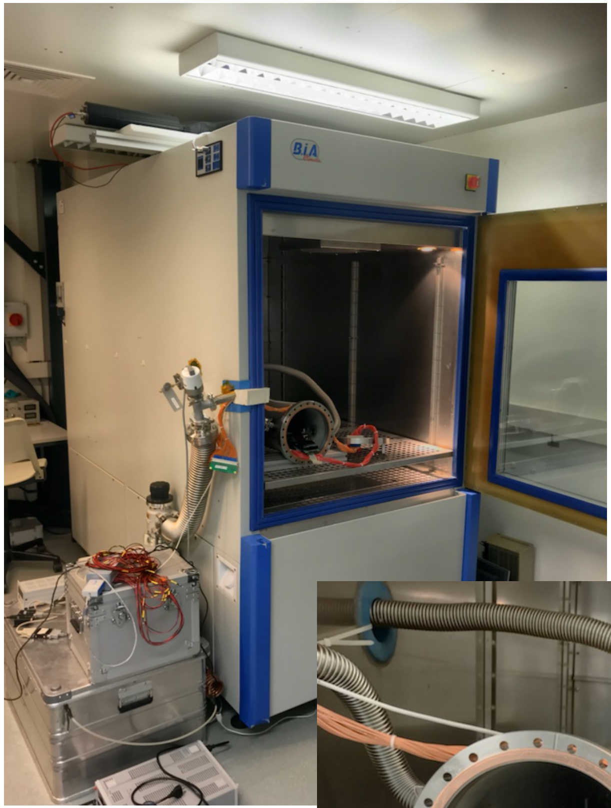
Space qualification process

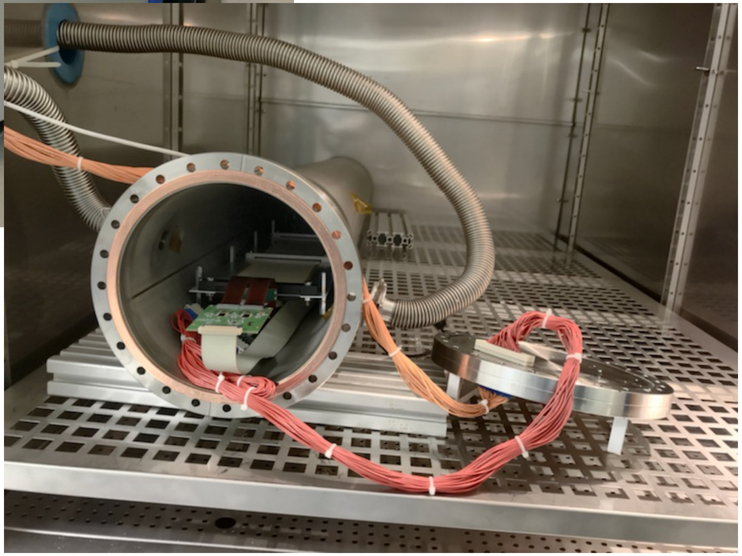
This kind of detector (**scintillating fibers + SiPMs**) **has never been used in Space.**

- Space qualification tests needed:
  - **Thermal cycling;**
  - **Thermal vacuum tests;**
  - **Vibrations and shocks.**

Purpose of **thermal cycling and thermal vacuum tests:**
demonstrate that the system is able to survive the thermal and vacuum conditions experienced in the space environment, without loss of integrity or functionality.

Purpose of **vibration tests:**
demonstrate that the primary structure and all electronic and mechanical components can withstand the vibrations and the loads experienced during launch and deployment.





Thermal vacuum test of a fiber module prototype @UNIGE clean room.

Summary and outlook

- **During the last two years, FIT has been becoming a reality.**
  - ✓ Advanced mechanichal and electronics project.
  - ✓ Two prototypes of fiber module realized and tested during 5 beam tests.

- **In May 2018 the HERD FIT Phase-B (prototype level) has been approved by the Swiss Space Office and is now funded by PRODEX.**
  - ➢ Ten more prototypes will be assembled before the end of the year.
  - ➢ A prototype front-end electronics board with three SiPM arrays is in production, and will be tested at 2 beam tests at CERN.
  - ➢ A DAQ board to readout multiple fiber modules is under design, and will be produced in 2019.
  - ➢ The first space qualification tests of the FIT module and readout electronics will start in September, and will be regularly done until the end of 2019.
  - ➢ A simulation model of the FIT is under developement, the first results of the single mat simulation are very promising (→ Poster 388 presented by Junjing Wang).

Thank you!!

A huge thanks to
the LHCb colleagues of EPFL
and
the Mu3e group of UNIGE.

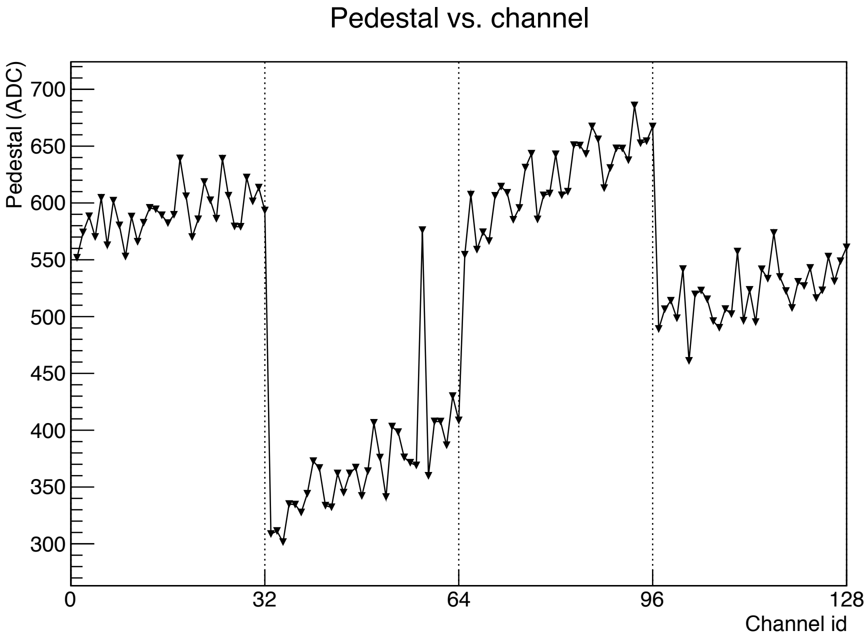
Backup

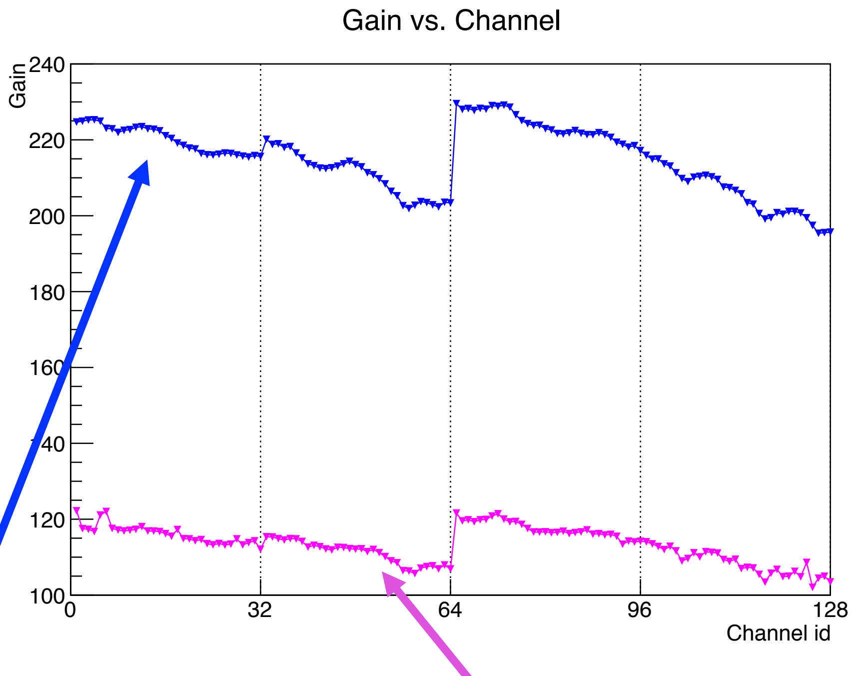
Why a fiber tracker?

- The spatial resolution is similar to the one of silicon strip detectors.
- Simpler to build long detector (of e.g. 1 m).
- Front End Electronics can be placed on one side of the detector module, even if it is long.
- Simpler to place the FEE outside of the support tray.
- Reduced dead area (no gap between sensors, no dead area on the silicon detector, FEE placed outside of support tray).
- No wire bonds on the detectors, thus the distance between support trays can be smaller than for silicon detectors.
- Lighter trays.
- Still the design needs to go through the space qualification process.

Channel pedestals and gains

The **intercept** of the fitting line from 2 to 12 photoelectrons corresponds to the channel **pedestals** and the **slope** to the channel **gains**.

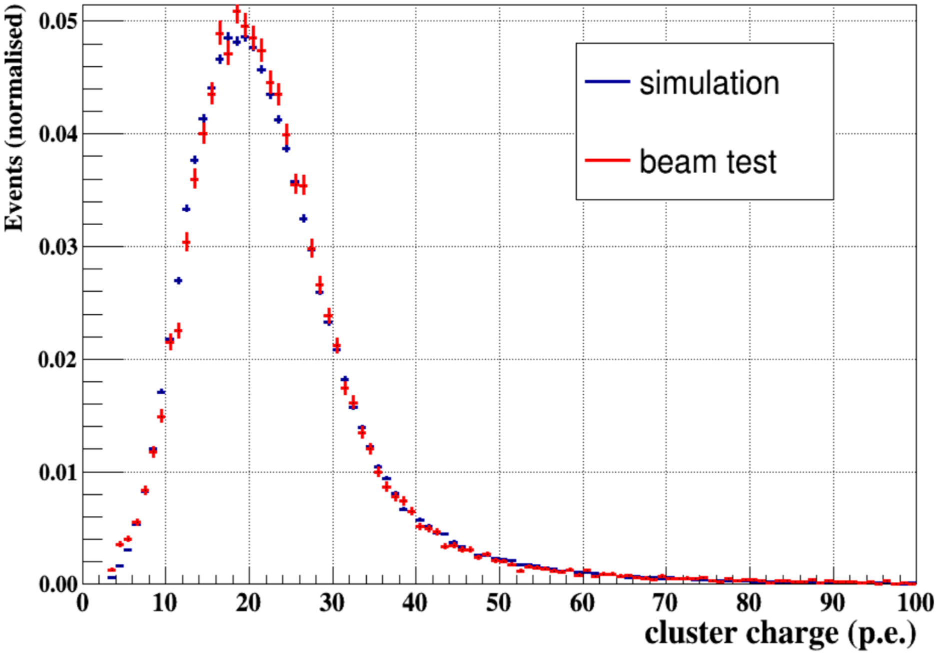

Pedestal vs. channel

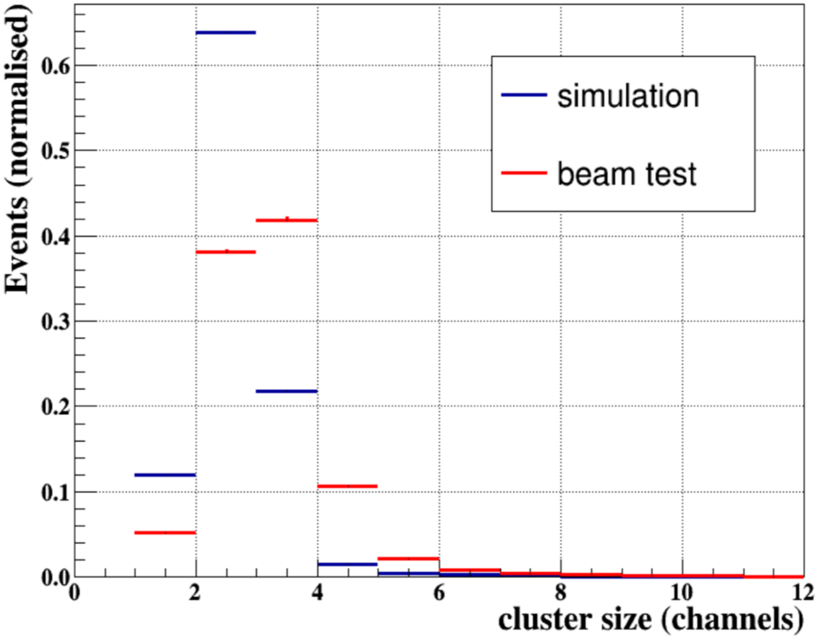

Gain vs. Channel

Normal gain (slope 1st fit) fluctuations due to non-uniformity of the breakdown voltage.

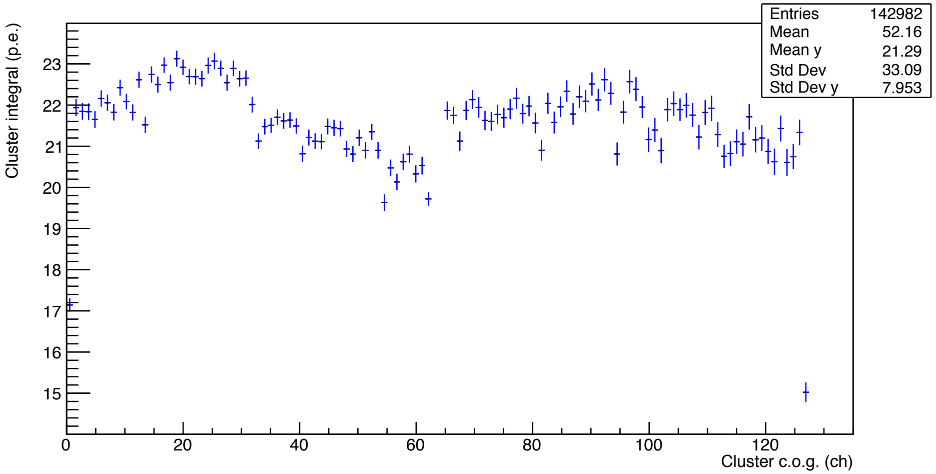
Lower gain (slope 2nd fit) due to VATA saturation.

Monte Carlo simulation data vs. test beam data



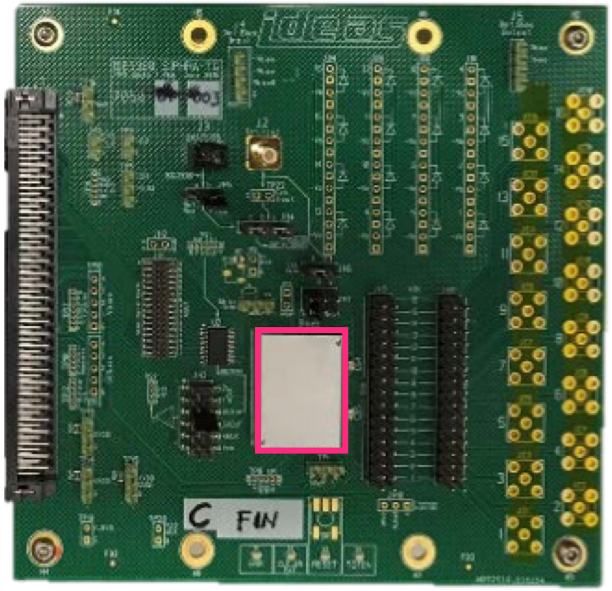


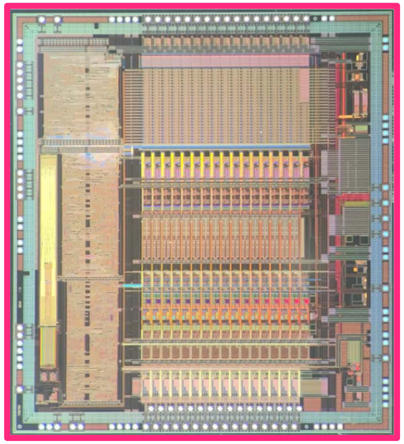
Light yield


Cluster integral (p.e.)
15
16
17
18
19
20
21
22
23
0
20
40
60
80
100
120
Cluster c.o.g. (ch)
Entries 142982
Mean 52.16
Mean y 21.29
Std Dev 33.09
Std Dev y 7.953

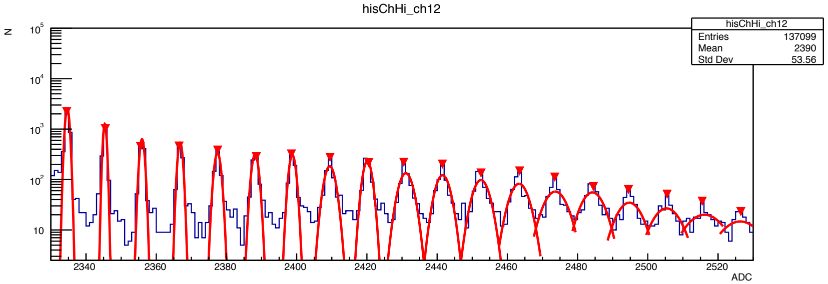
SIPHRA: Silicon Photomultiplier Readout ASIC

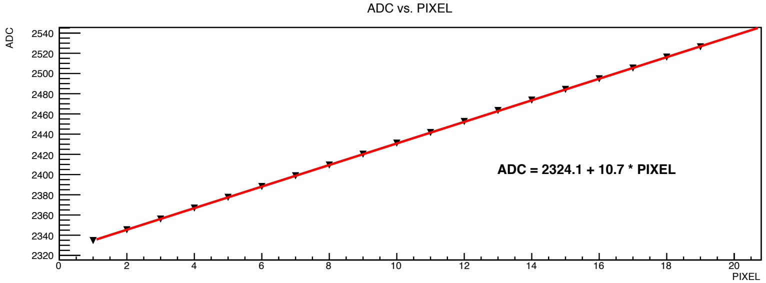
- New ASIC from IDEAS for space applications
- Prototype chip commissioned by ESA and the University of Geneva.
- 16 negative current and 16 positive current inputs
  - Negative inputs can handle large current (-16/-8/-4/-0.4 nC)
  - Positive inputs have 3 programmable individual gains (+40/+4/+0.4 pC)
- **12-bits ADC included**.
- Programmable shaping time: 200, 400, 800, 1600 ns
- Programmable hold timing: 68 ns - 4.7 µs
- One line to readout and digitize a PT100 temperature sensor.
- One single power supply voltage: **3.3 V**.
- It can provide in output only the channels with a signal higher than a programmed threshold (one for each channel) → Data reduction at ASIC level!
- 16 mW power consumption, *i.e.* 1 mW per channel.

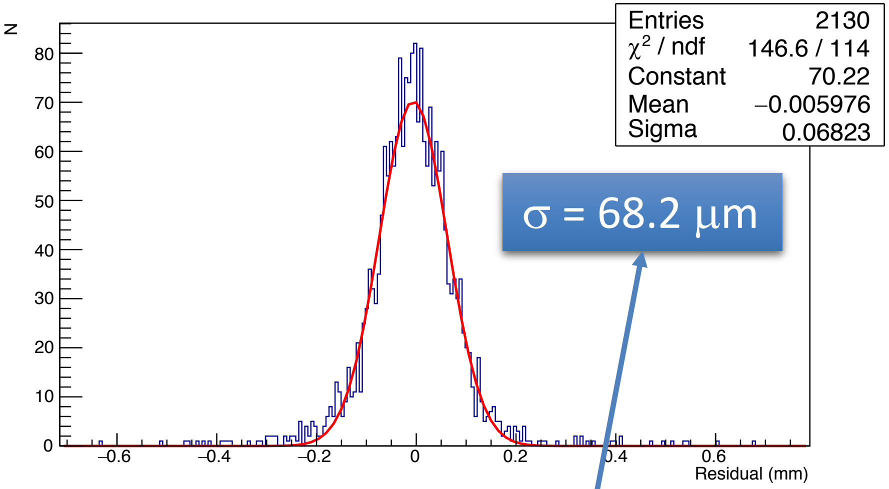




SIPHRA results







σ = 68.2 μm

Not corrected for beam telescope resolution