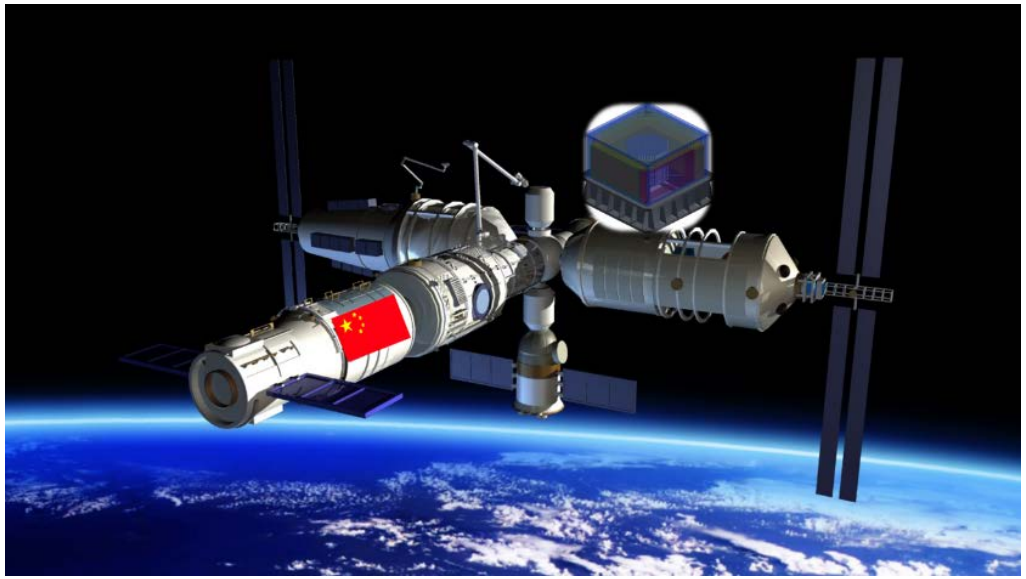
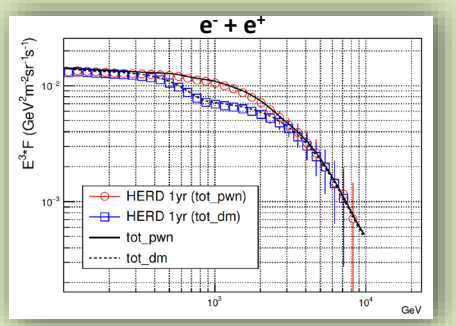
# FIT: The Fiber Tracker for the High Energy cosmic-Radiation Detection facility (HERD)

# The High Energy cosmic-Radiation Detection (HERD) Facility



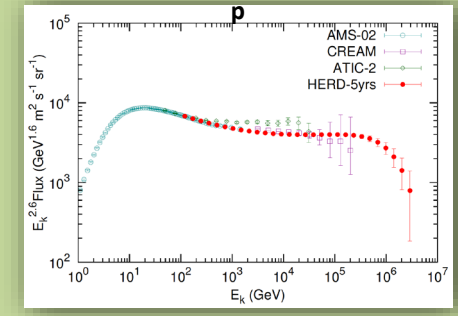
- Proposed as a space astronomy payload onboard the future **China's Space Station** (CSS).
- Launched with the China-Italy Module and installed on the module.
- Planned to be operational **from 2025** for more than **10 years**.
- Several devices are replaced or upgraded every 3-4 years.
- The HERD consortium includes 130+ scientists from China, Italy, Switzerland, Spain, Germany, Denmark, Sweden, Russia, etc.

# HERD: the objectives

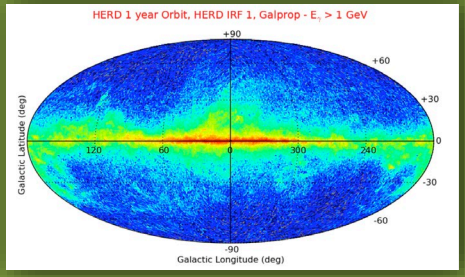



Search for signatures of annihilation/decay products of **dark matter** in

- 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 $m^2$sr @200 GeV |
| Geometric factor (p) | >2 $m^2$sr @100 GeV |

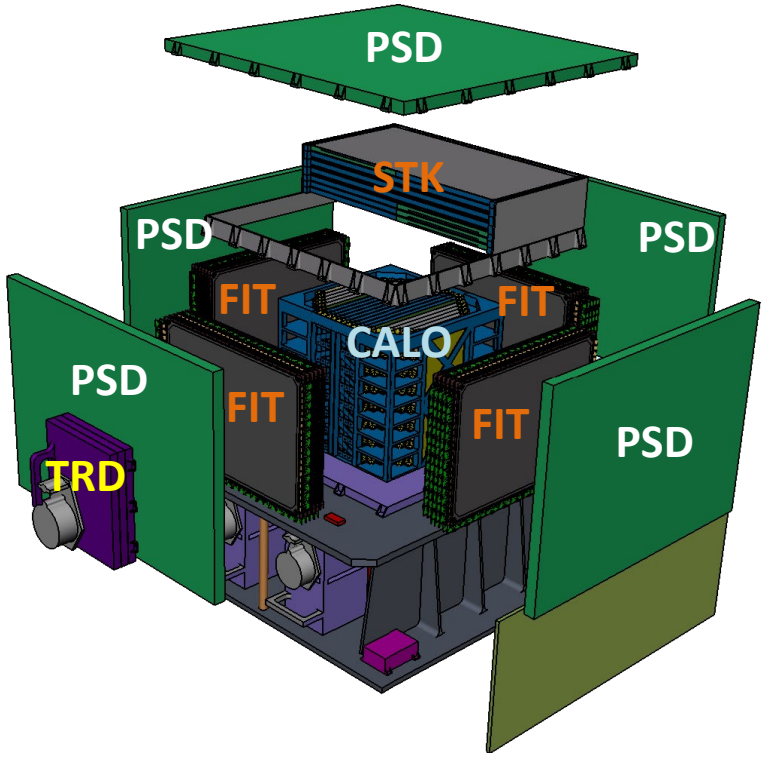
# HERD: the detector

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



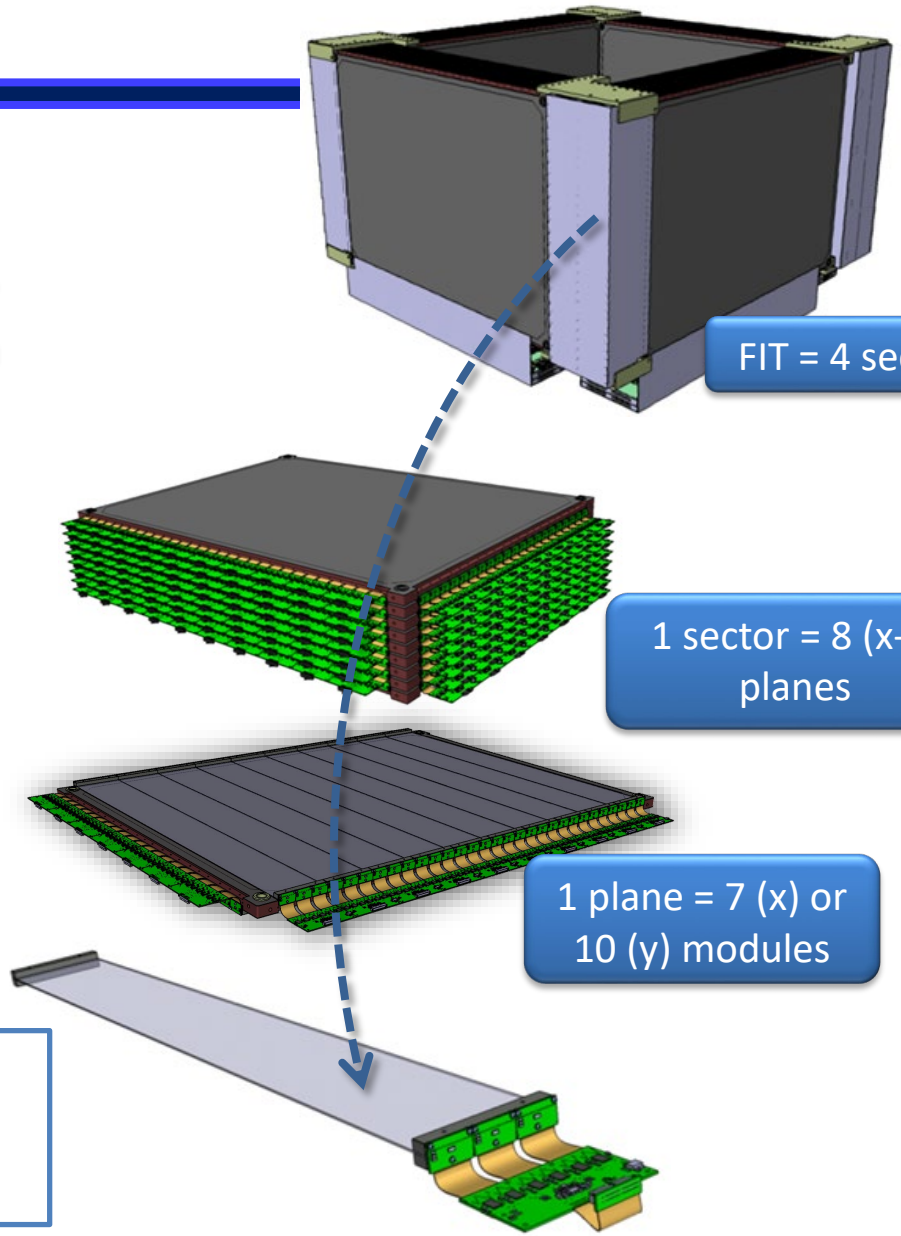

| | |
|---|---|
| Mass | < 4 t |
| Envelope dimensions | ~ 2.3 x 2.3 x 2.6 $m^3$ |
| Field of View | ± 70° |
| Power consumption | ~ 1200 W |
| Lifetime | > 10 years (with in-orbit replacements) |

# The **Fi**ber **T**racker (FIT)

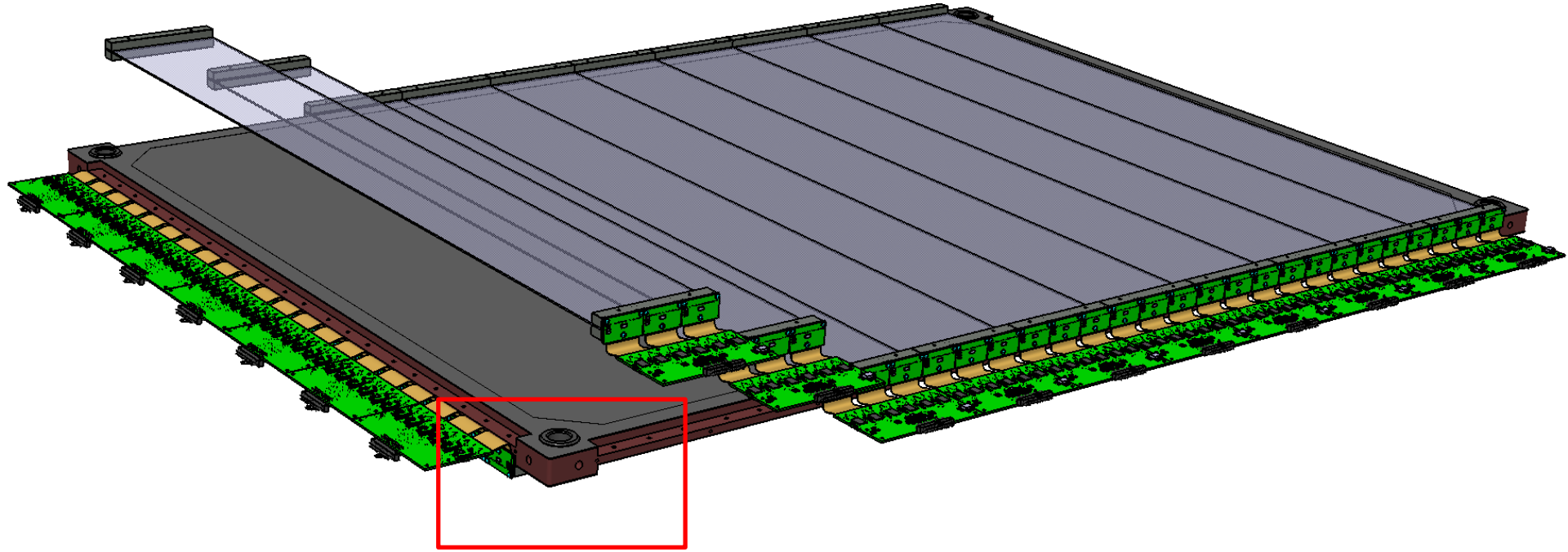
The FIT is an alternative to a tracker fully made of silicon strip detectors (based on the STK of DAMPE).

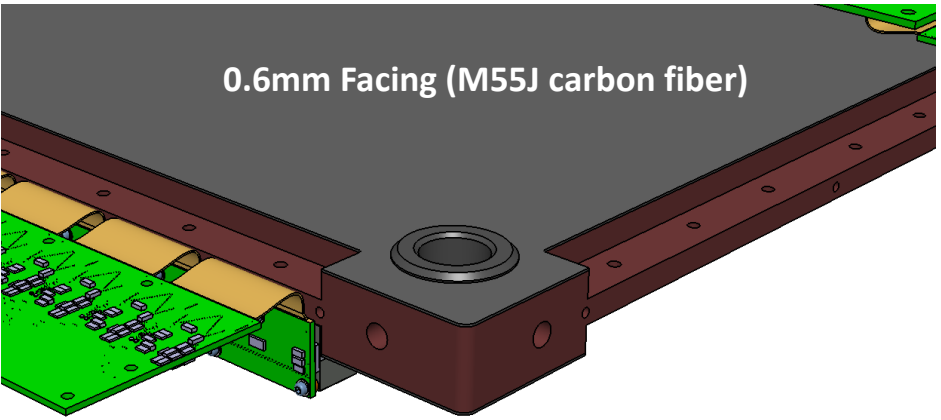
- 4 identical **sectors**
- 8 (x-y) **planes** in each sector
- 7 **modules** (~ 1 m fiber length) in each x plane
- 10 **modules** (~ 70 cm fiber length) in each y plane
- 1 **fiber mat** + **3 SiPM arrays** for single (double) readout in each module

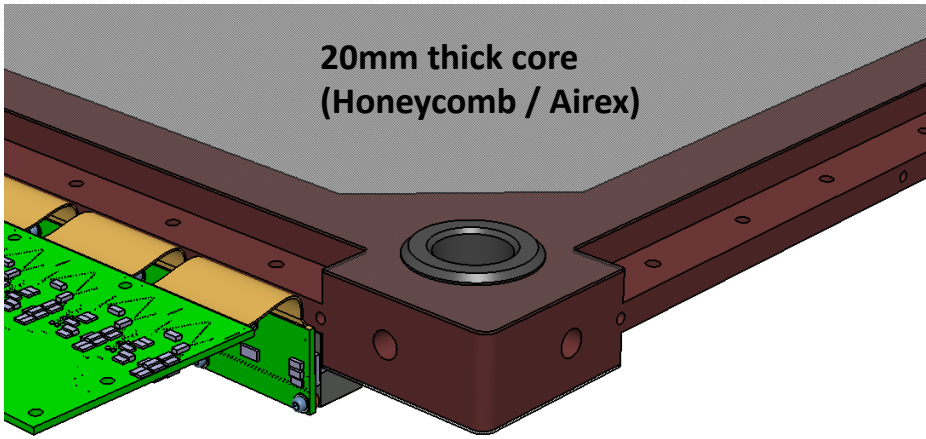
Overall mass: ~ 250 kg;
Overall dimensions: ~ 1.5 x 1.5 x 1 $m^3$;
Overall consuption: ~ 240 W.



# Support tray

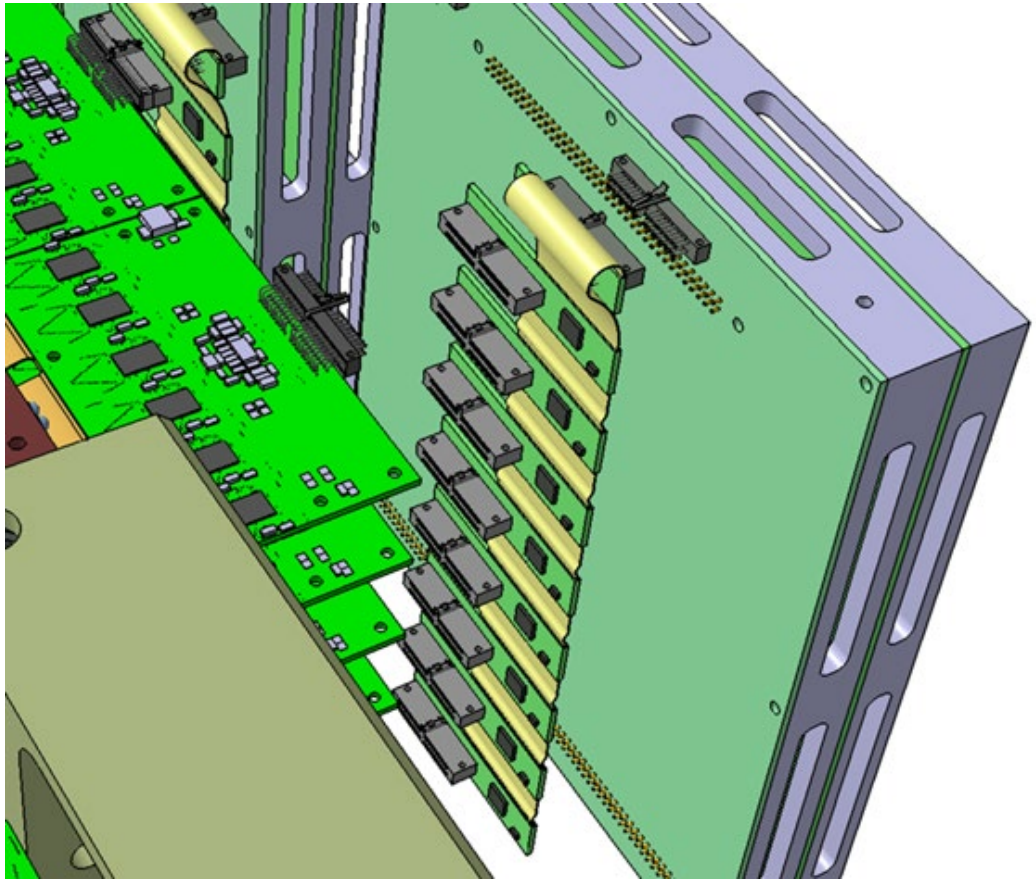




# Front-End Readout board (FRB)

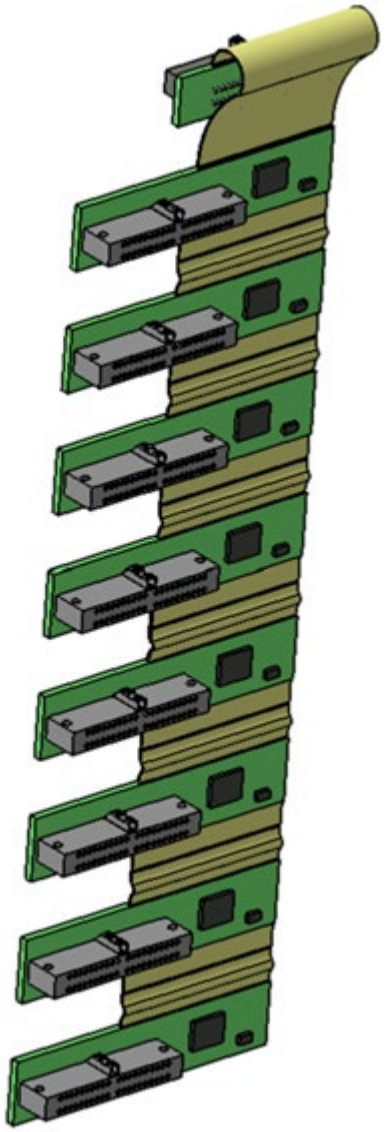
- Circuit designed to acquire up to 10 modules.
- Composed of two boards:
  - Power board, for the power supply distribution.
  - Control board, for the data acquisition and communication with higher levels of DAQ.
- In total 9 FRBs will be used for one FIT side detector.



# Interconnection between FEBs

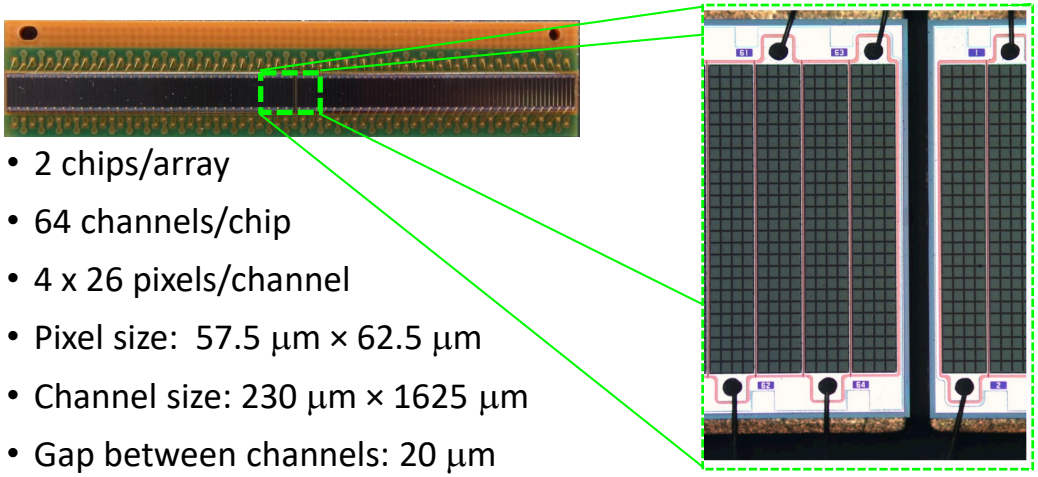
Interconnection cable:

- Connectors mounted on intermediate PCBs.
- PCBs are connected to each other with a flex cable.
- The interconnection cable is then connected to the FRB with a single connector.
- For the moment, the intermediate PCBs will also be equipped with ADCs.



# FIT module: the Silicon Photomultiplier (SiPM) Array

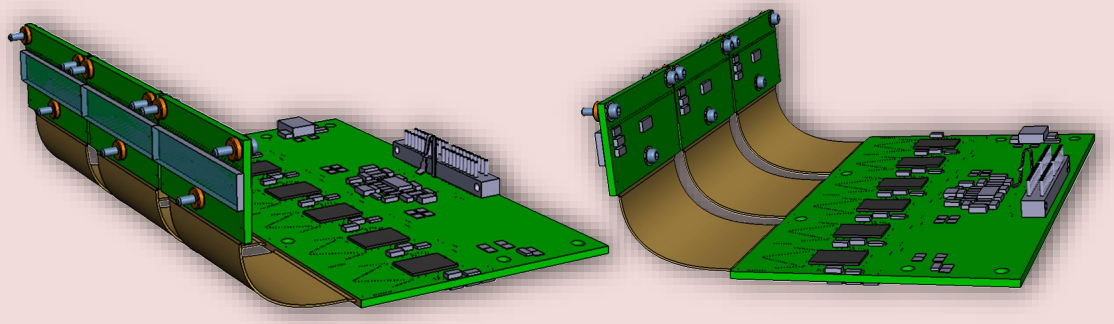
SiPM arrays from Hamamatsu (type S133552-HRQ)
**(LHCb fiber tracker upgrade)**



- 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:

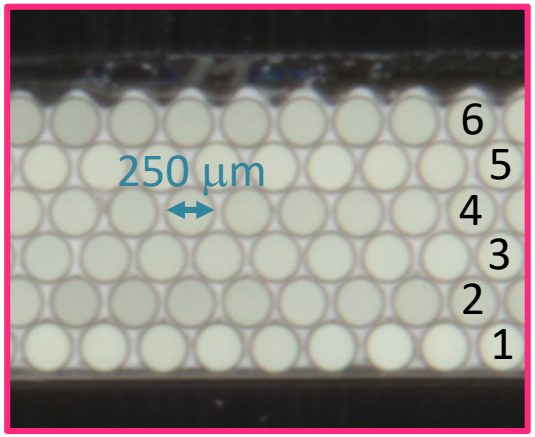
- $V_{breakdown}$ = 48 V - 58 V
- $V_{op} = V_{breakdown}$ + 3.5 V
- Rq = 330 kΩ - 610 kΩ
- Gain @$V_{op}$ = 3 x $10^6$
- Photon detection efficiency @$V_{op}$ = 45 %
- Sum of cross-talk + after-pulse prob. @$V_{OP}$ = 8 %
- Temperature coefficient: $dV_{breakdown}/dT$ = 54 mV / °C

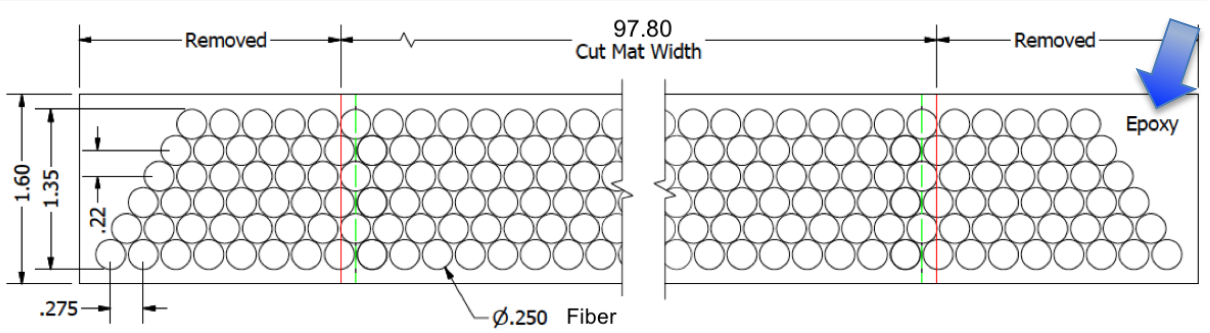


Front-end board:
6 **VATAs 64ch HDR 16**,
to readout 3 SiPM arrays.

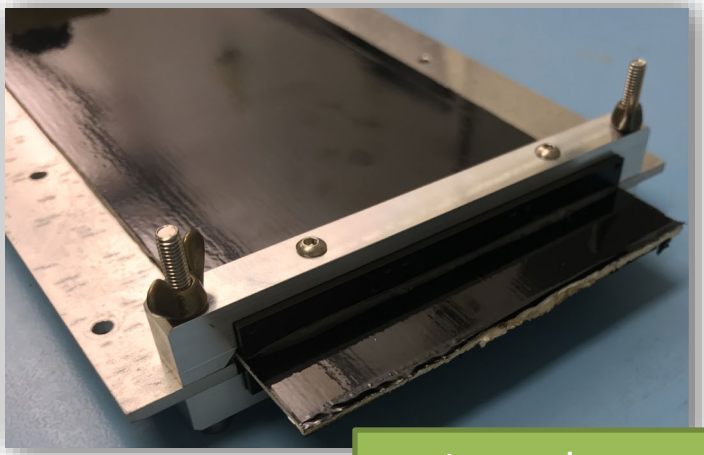
# FIT module: the fiber mat


- 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

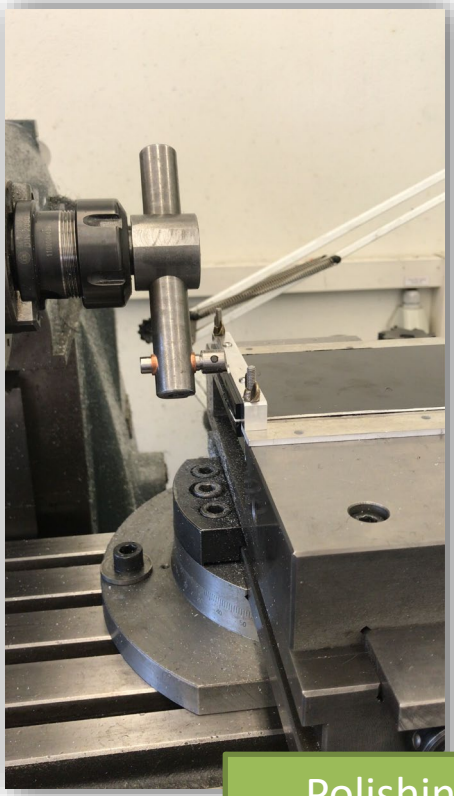


# Fiber mat preparation @Uni Geneva



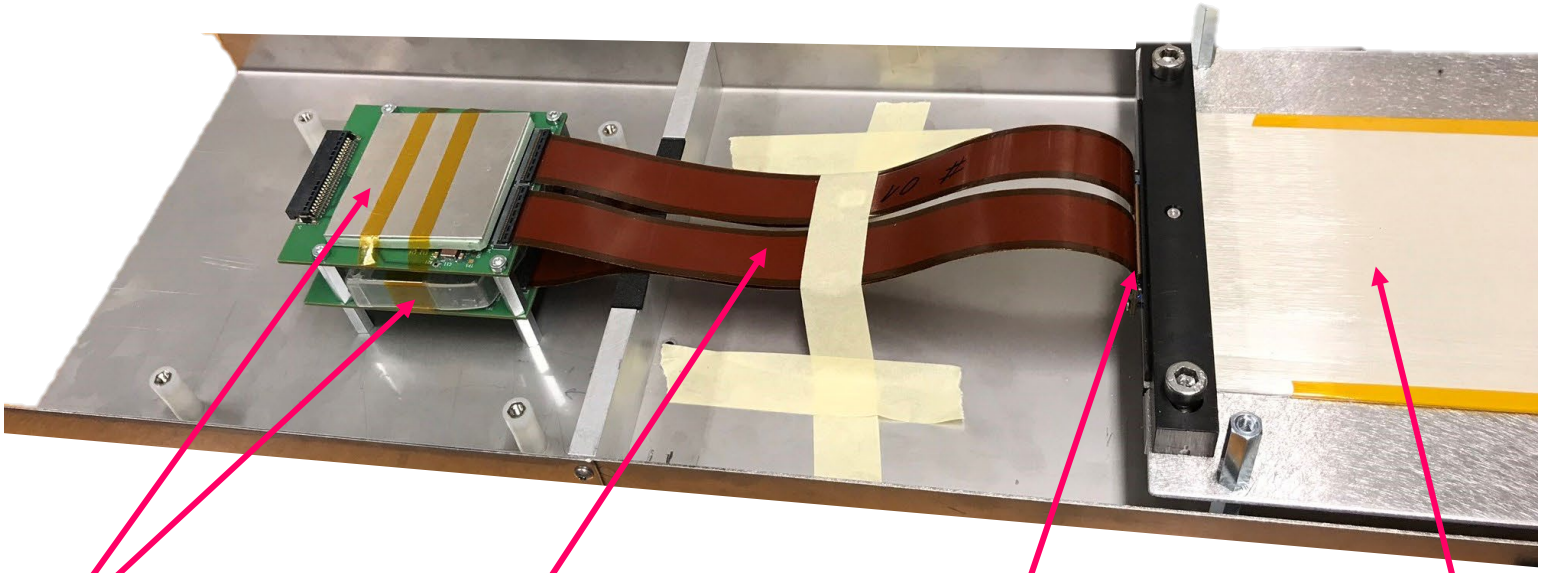
Lateral cut and end-pieces gluing



Polishing by diamond cutting tool

Ready!!

# The Fiber Module prototype



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

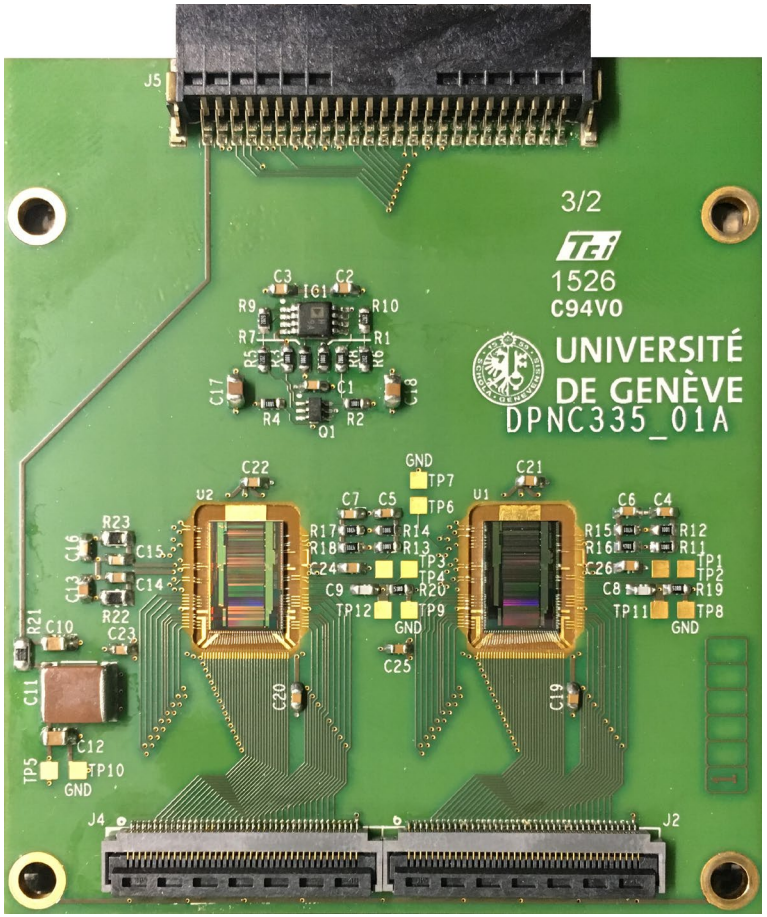
**Rigid flex PCB** (4 cables), designed by UNIGE (Mu3e)

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

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

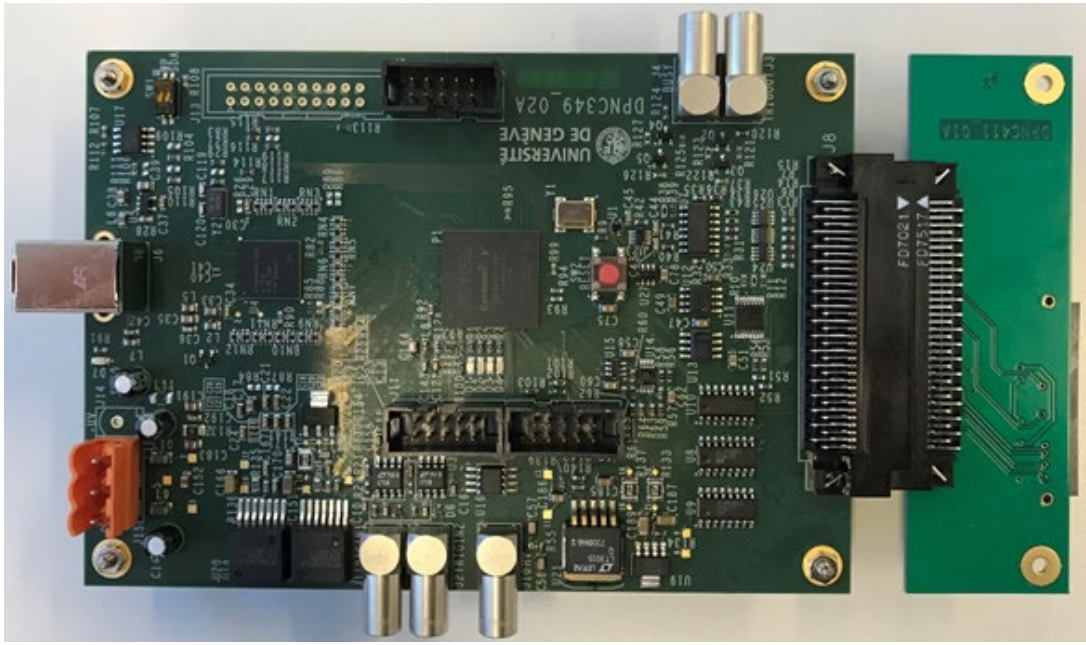
# Front-end electronics board

- 2x VATA 64 HDR 16, to readout the 128 MPPC channels.
- Analogical output is amplified with the same circuit as the DAMPE ladder FEE.
- Four zero-insertion-force (ZIF) sockets to connect the SiPM array board.

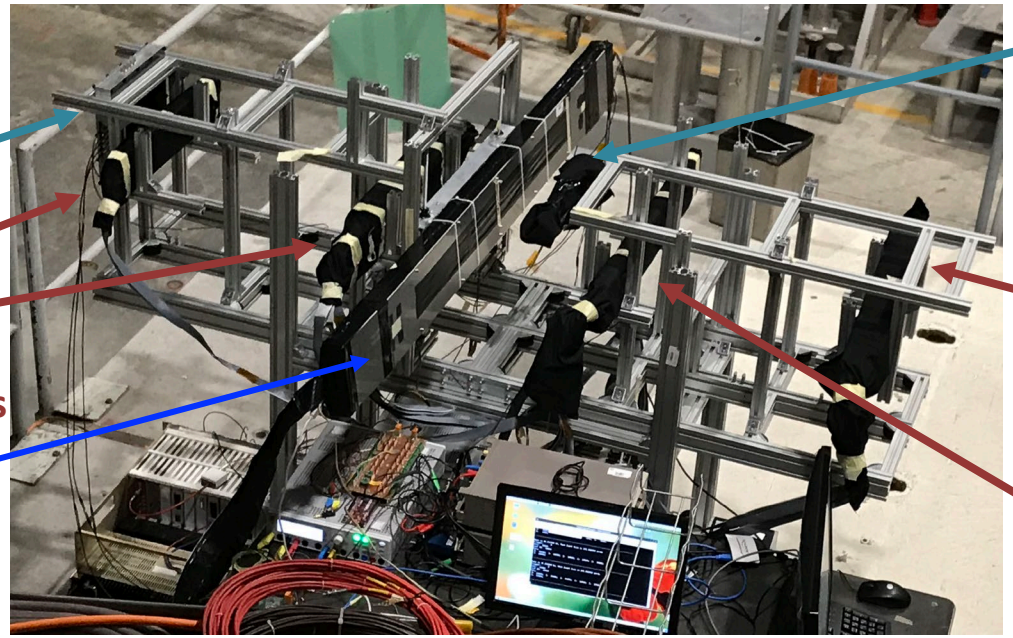


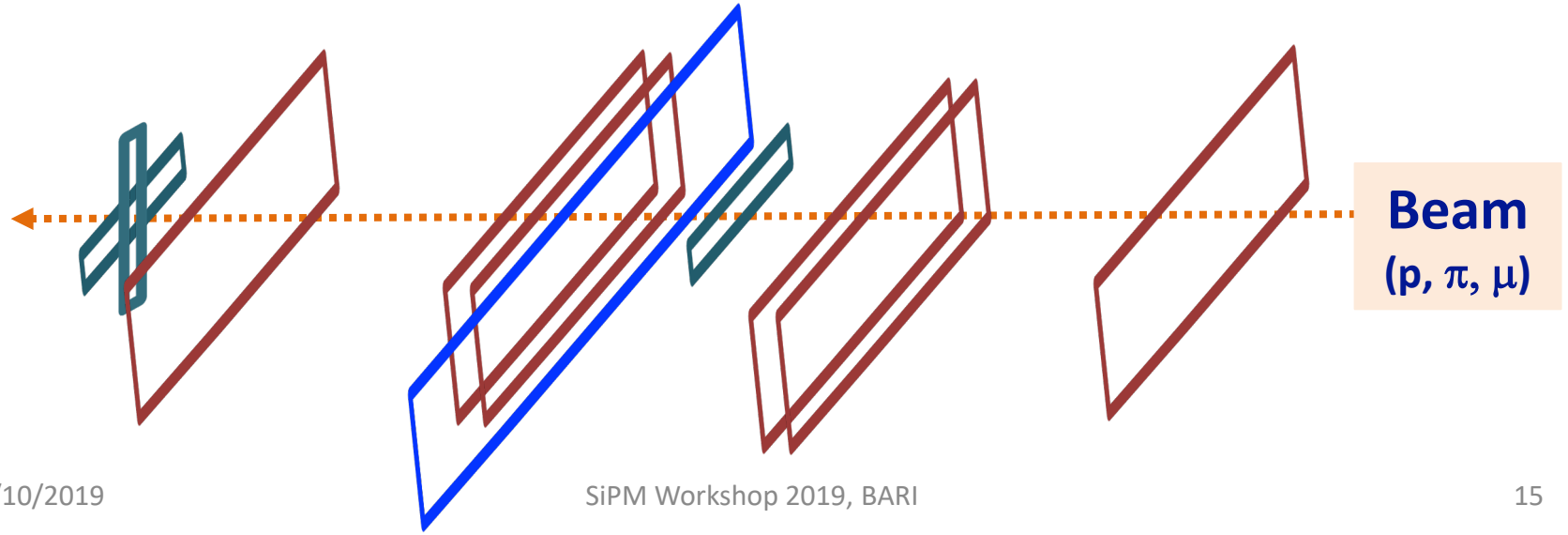
# DAQ board

- Altera Cyclone V FPGA.
- FEE board analogue signal digitization.
- Communication/data transfer via an USB3 port.
- DAQ architecture developed by the UniGE DPNC electronics group.
- Common digital interface and related control software, to be used by different experiments.



# Beam test setup @CERN SPS North Area

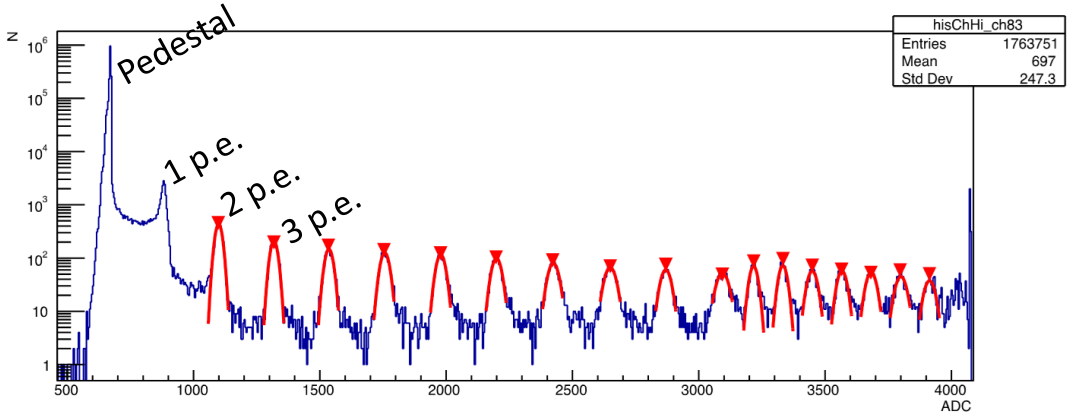


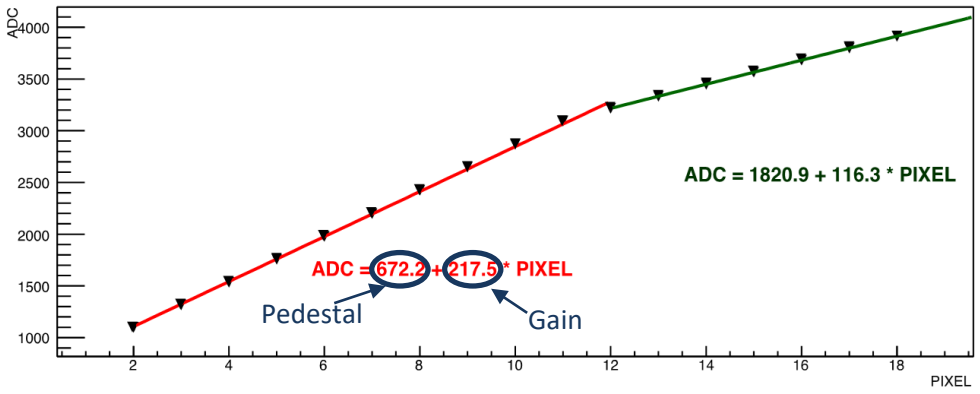
# Channel charge calibration

- 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.

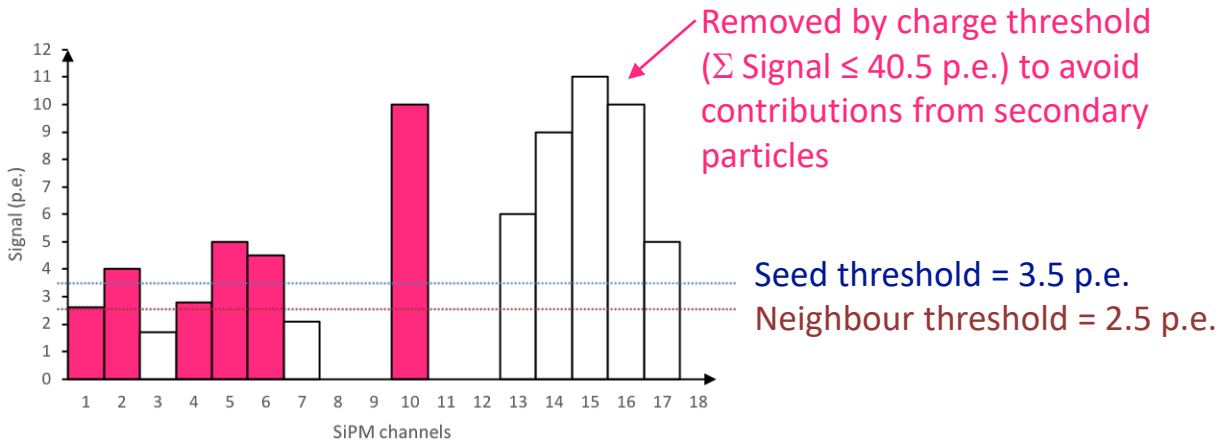



A linear fit has been performed on the two gain regions, to determine the conversion from ADC value to the corresponding number of photoelectrons.

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

# Signal identification

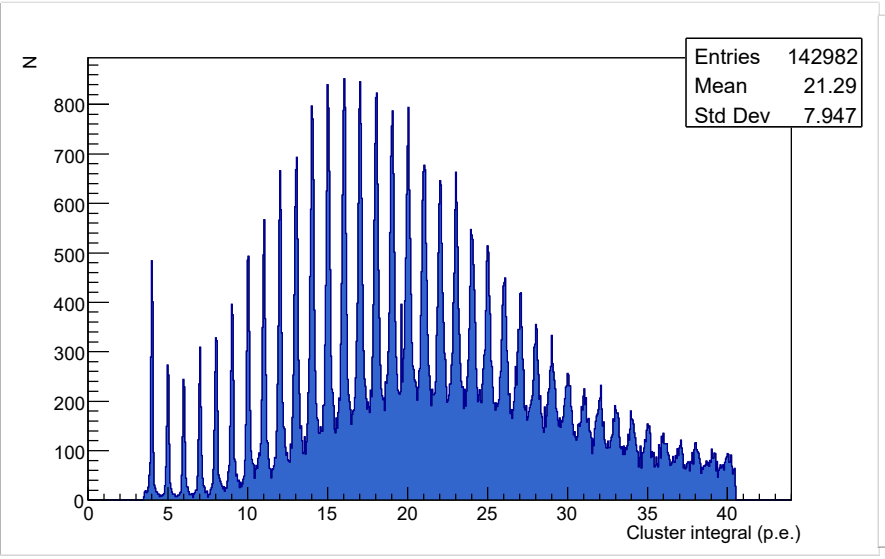
- Once the channel calibration is done, for each event, the ADC signals have been converted in units of photoelectrons.
- A **cluster finding algorithm** has been applied, and the cluster properties - integral, center of gravity (c.o.g.), size, … - have been computed:




- 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.

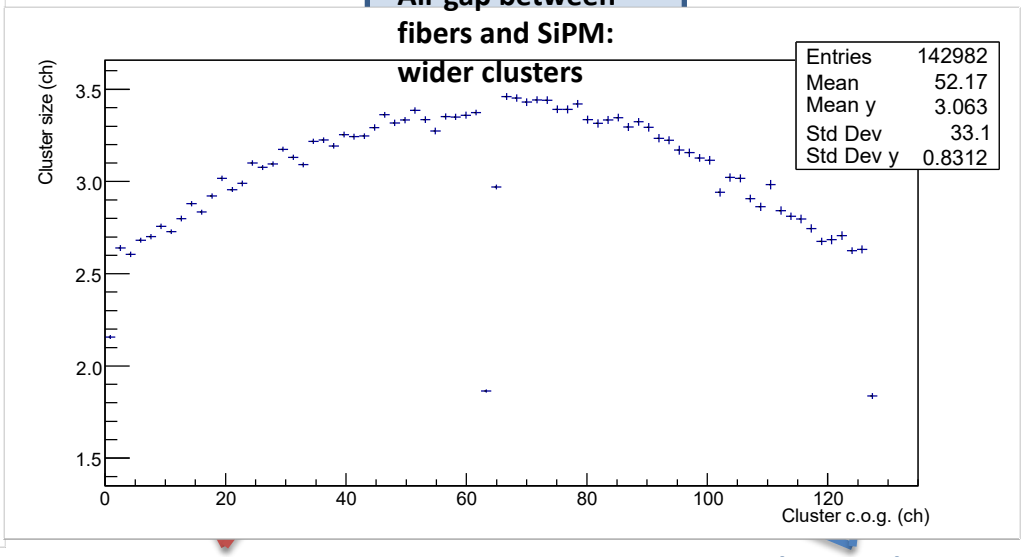
- The cluster size is the number of channels composing the cluster.

# Light yield



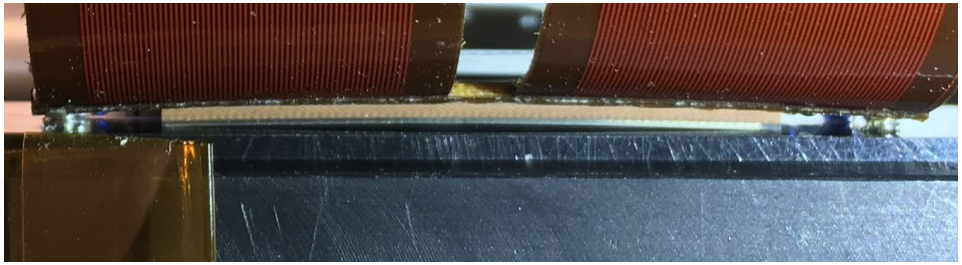

**Signals up to 40 p.e. well distinguishable.**

**Air gap between fibers and SiPM: wider clusters**

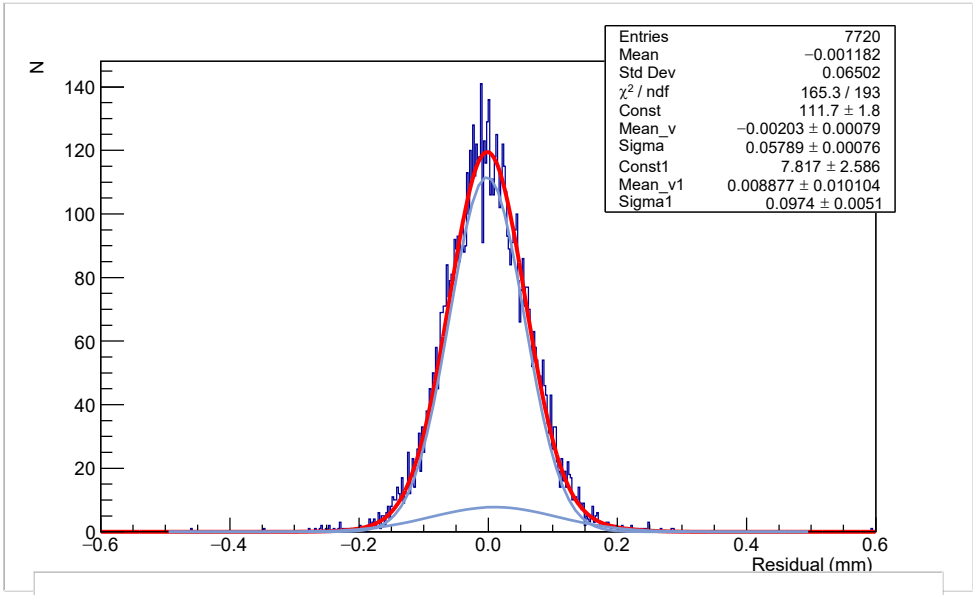


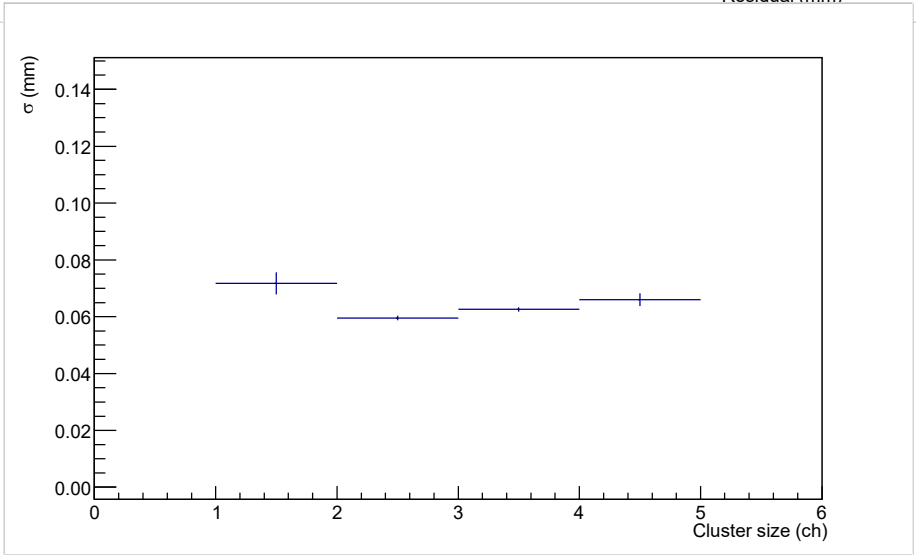

**Signal cannot be shared with channels on the left**

**Signal cannot be shared with channels on the right**



# Spatial resolution

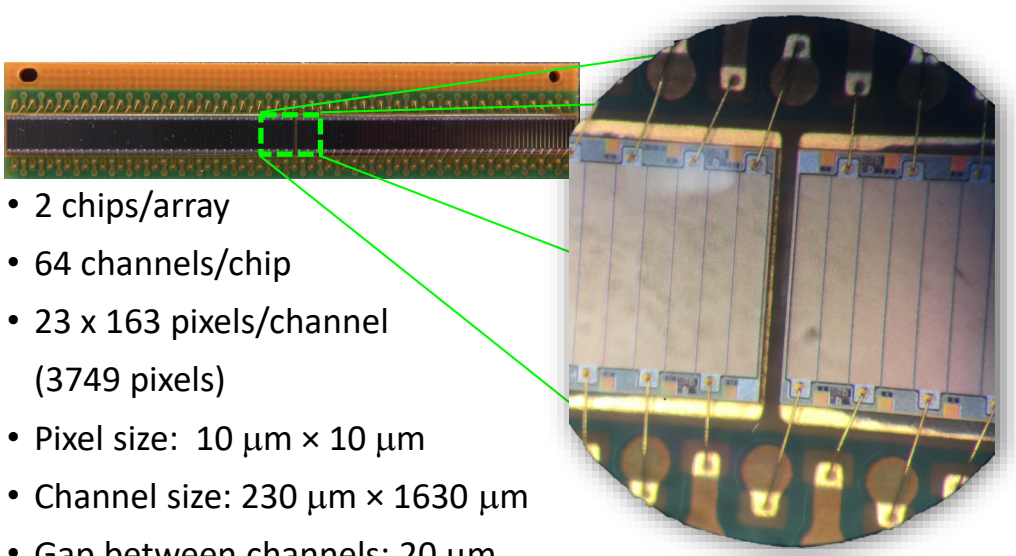



- 100 GeV pions
- Cluster residual: 63.2 µm
- Spatial resolution: 59.6 µm (corrected for beam telescope resolution)
- Efficiency = (99.7 ± 0.2)%
- The resolution is best for a cluster width of 2 channels.

# FIT module: the «10 μm» SiPM Array

SiPM arrays from Hamamatsu «10 μm» type (**S13552-10**)



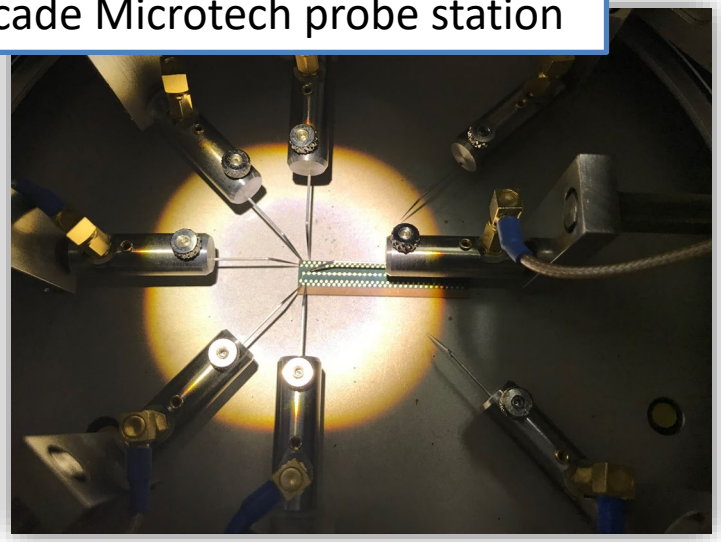
- 2 chips/array
- 64 channels/chip
- 23 x 163 pixels/channel (3749 pixels)
- Pixel size: 10 μm × 10 μm
- Channel size: 230 μm × 1630 μm
- Gap between channels: 20 μm
- Gap between chips: (220 ± 50) μm
- 105 μm epoxy resin on top

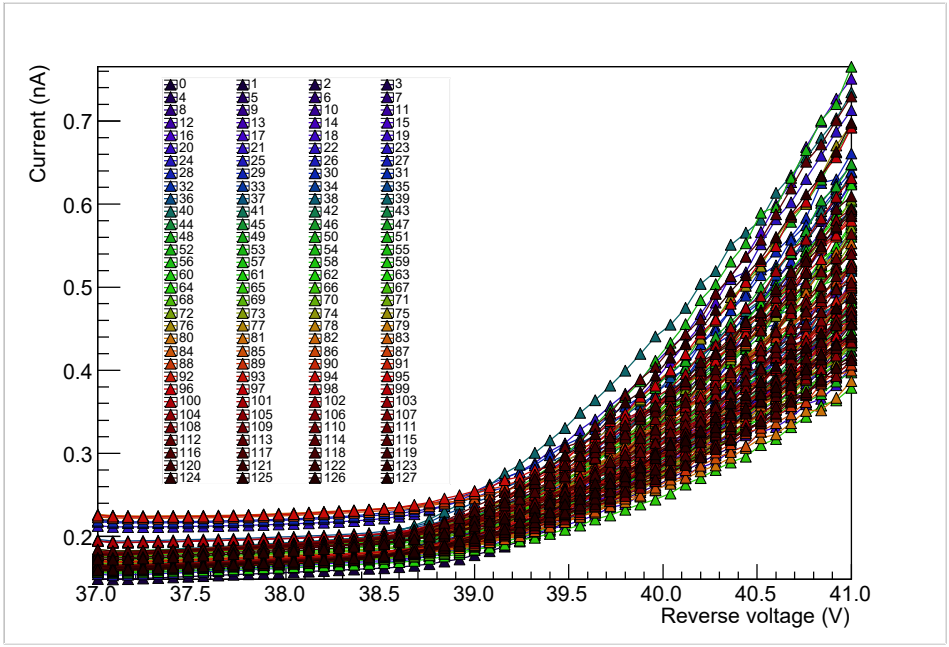
@ 25 °C:

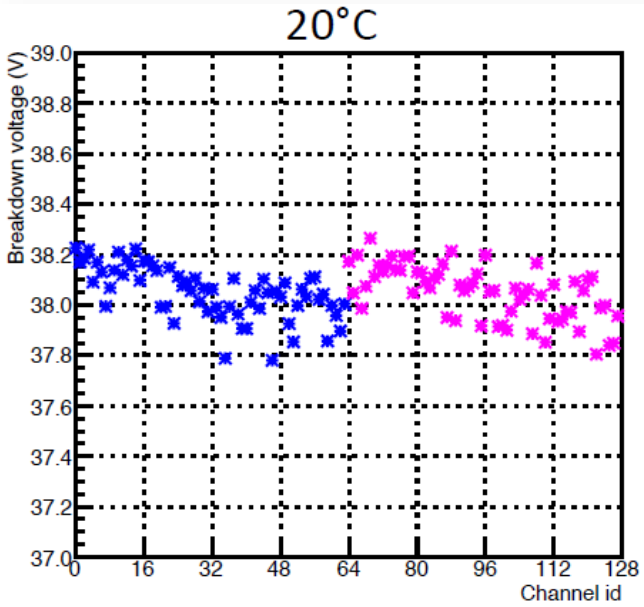
- $V_{breakdown}$ = 33 V - 43 V
  - (LHCb: 48 V - 58 V)
- $V_{op} = V_{breakdown}$ + 6.5 V
  - (LHCb: $V_{breakdown}$ + 3.5 V )
- Gain @$V_{op}$ = 2.3 x $10^5$
  - (LHCb: 3 x $10^6$)
- Photon detection efficiency @$V_{op}$ = 15%
  - (LHCb: 45%)
- Temperature coefficient:
  $dV_{breakdown}/dT$ = 34 mV/°C
  - (LHCb: 54 mV/°C)

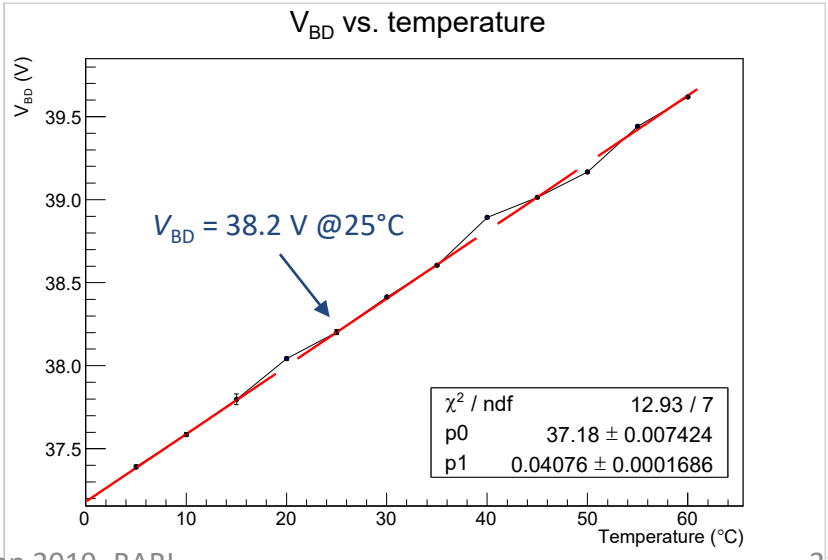
# 10 μm SiPM array: breakdown voltage measurement

Cascade Microtech probe station

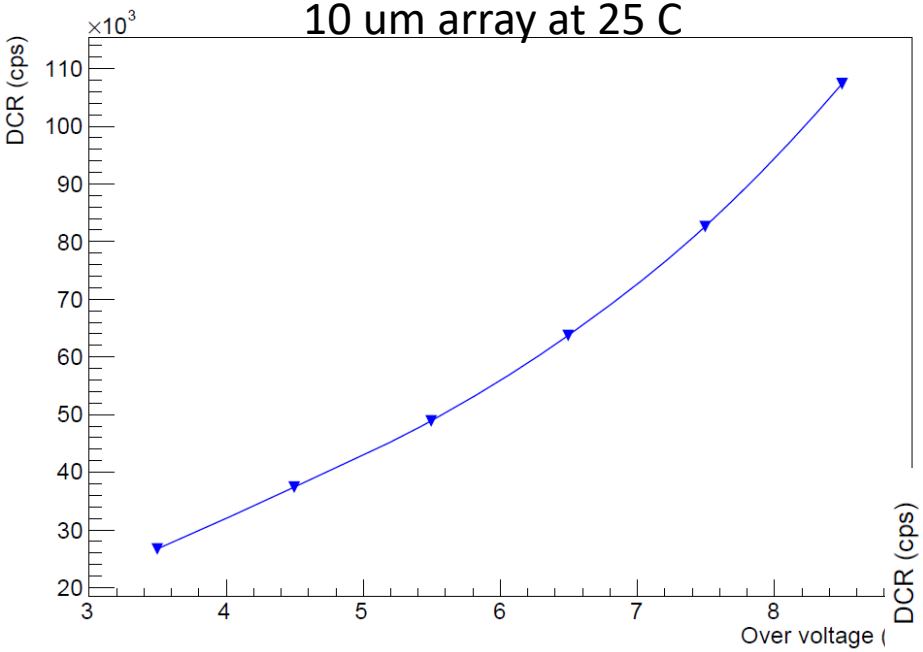


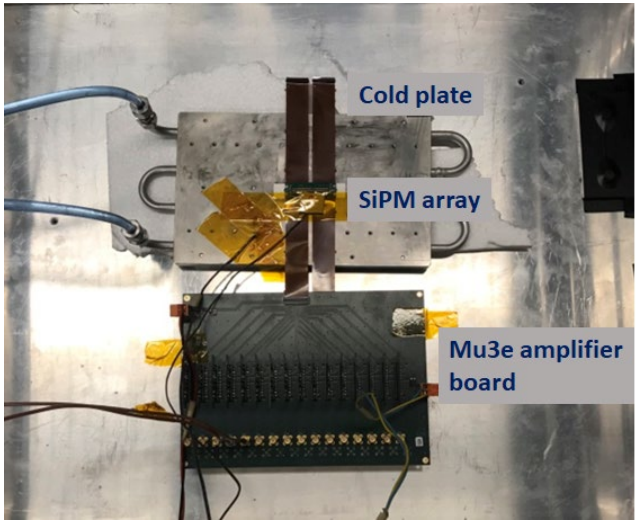


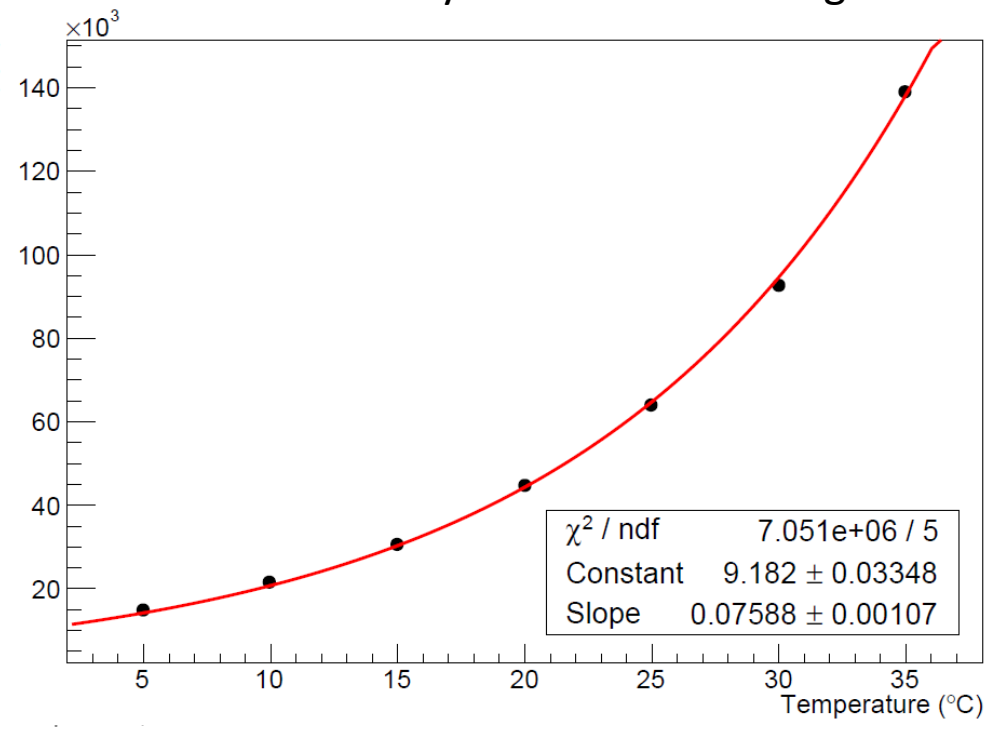



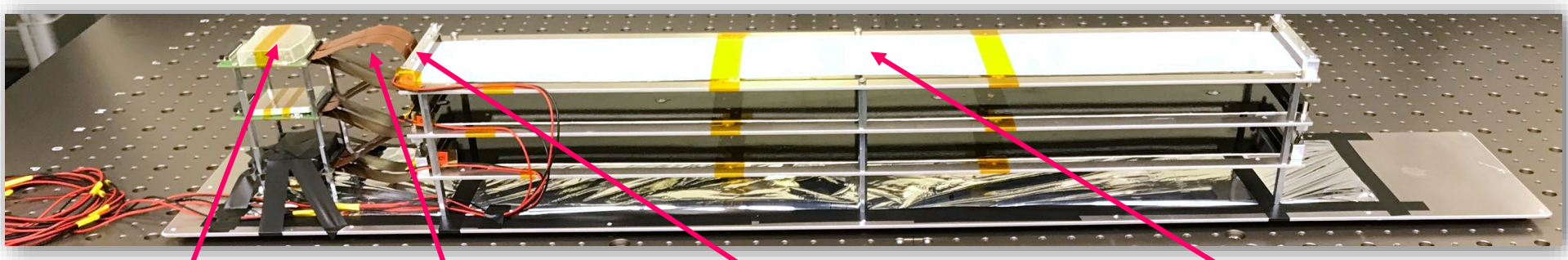
# DCR measurements on the «10 μm» arrays



# Three FIT prototype modules

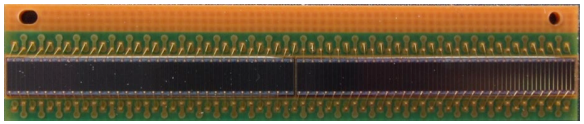


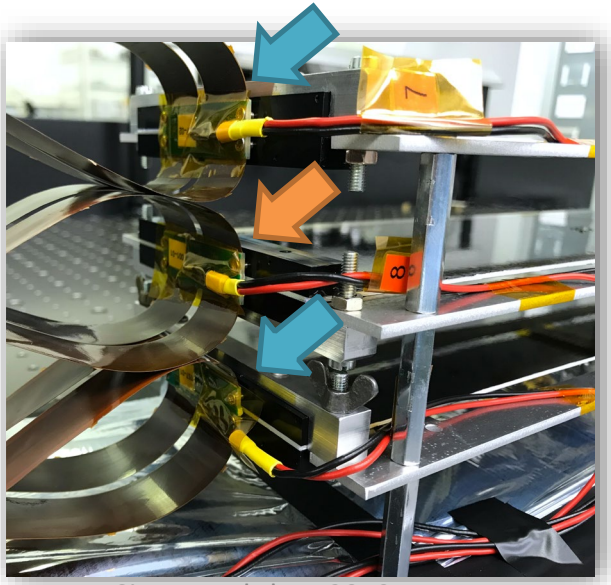
**Front-end VATA board** (2 x VATA 64 HDR 16) designed by UNIGE (R&D HERD)

**Flex PCB** (4 cables), designed by UNIGE (Mu3e & HERD)

**SiPM array**

**Fiber mat**





**@ top & @ bottom:**

**Hamamatsu «LHCb» SiPM array**

- 128 channels
- Channel size: 230 μm × 1625 μm
- Pixel size: 57.5 μm × 62.5 μm
- 104 pixels/channel
- 1 MIP = 20 p.e. (→ Z = 2)

**@center:**

**Hamamatsu «10 μm» SiPM array**

- 128 channels
- Channel size: 230 μm × 1630 μm
- Pixel size: 10 μm × 10 μm
- 3749 pixels/channel
- 1 MIP = 10 p.e. (→ Z = 19)

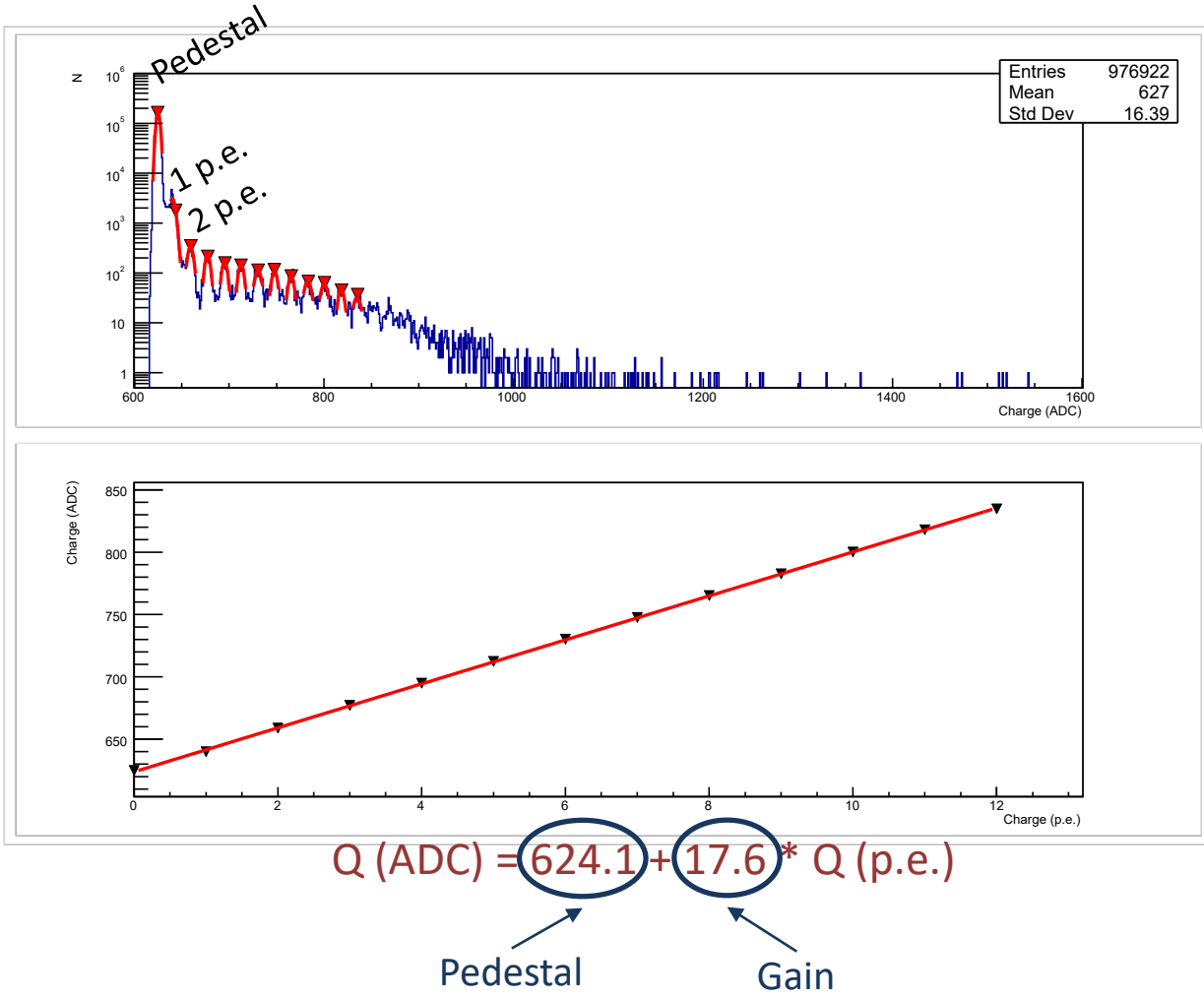
# Channel charge calibration («10 μm» SiPM arrays)

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

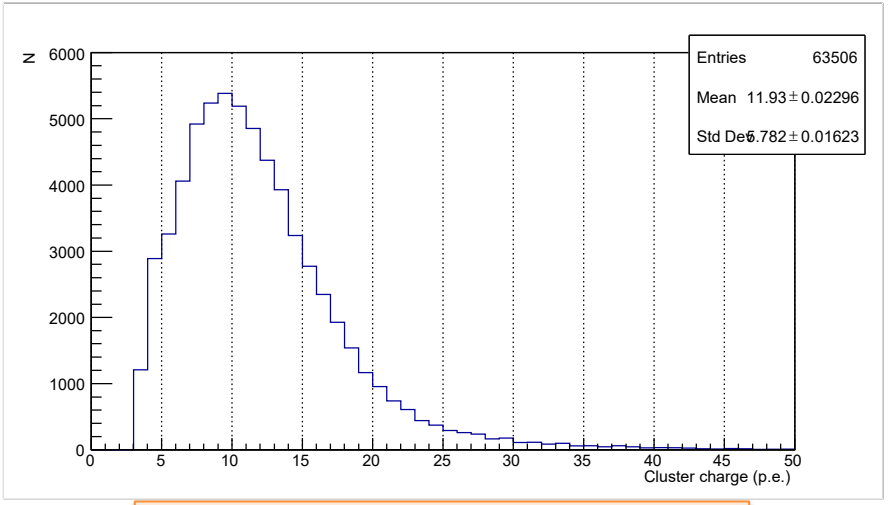
  (1 p.e. ≡ 1 pixel)

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

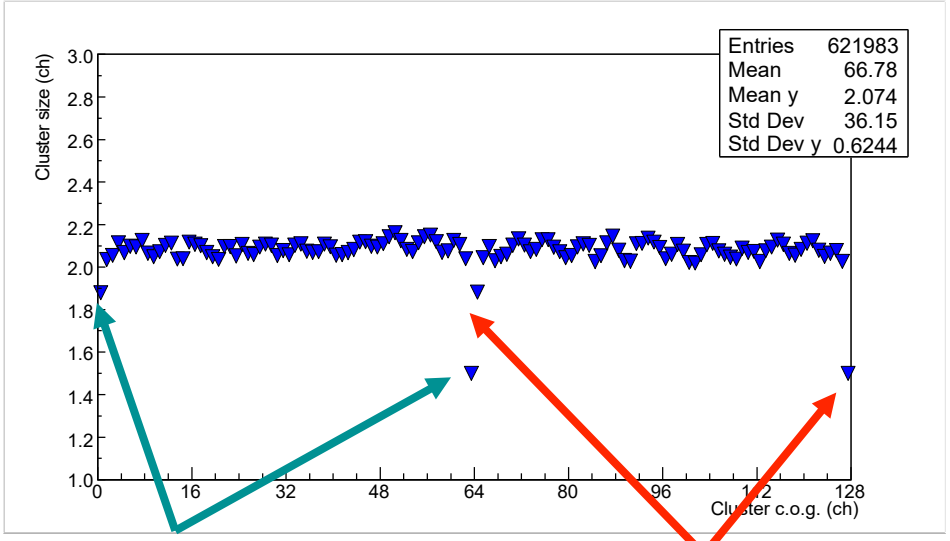
A linear fit has been performed to determine the conversion formula from ADC value to the corresponding number of photoelectrons.



# Light yield (Primary protons with p = 400 GeV/c)



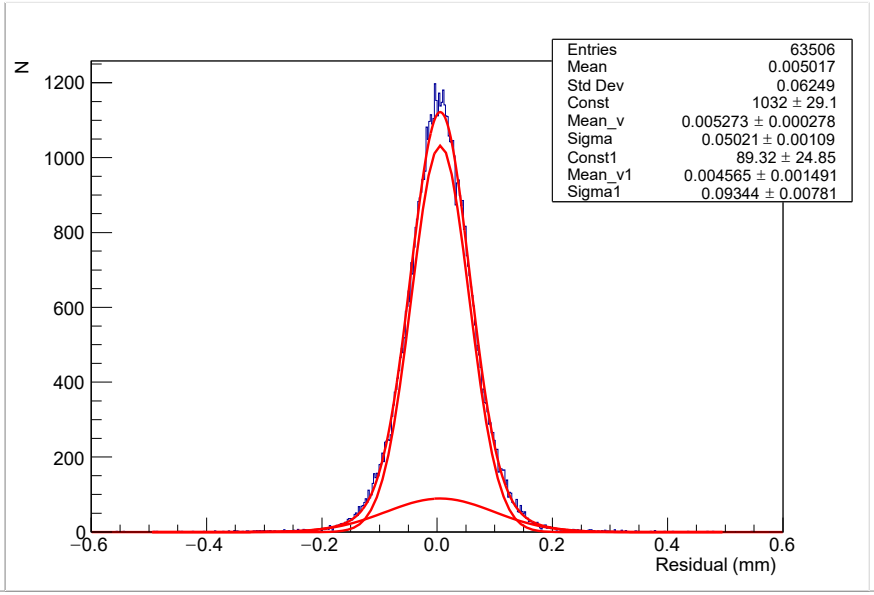

Most probable value = 10 p.e.

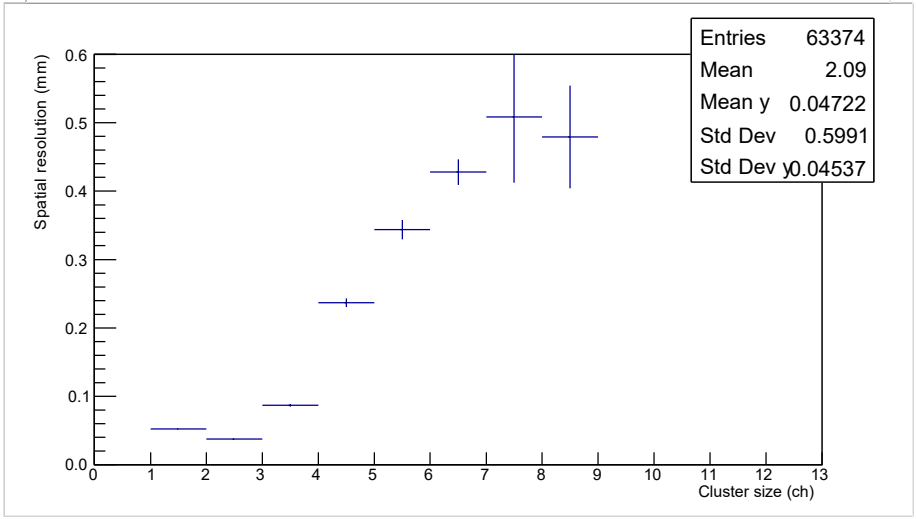



**Signal cannot be shared with channels on the left**

**Signal cannot be shared with channels on the right**

# Spatial resolution




- 400 GeV/c primary protons
- Cluster residual: 58.2 µm
- Spatial resolution: 56.4 µm (corrected for beam telescope resolution)
- 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.

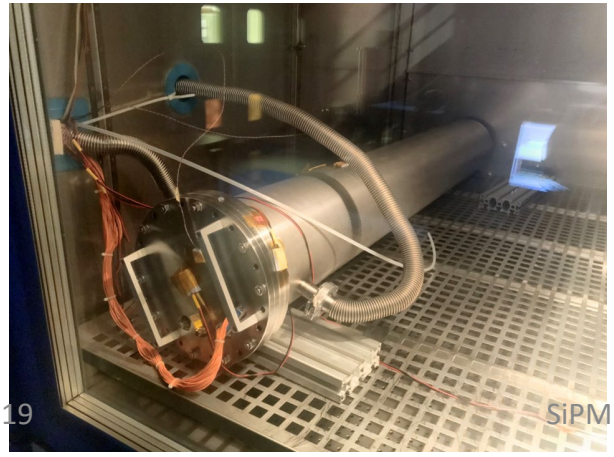
Purpose of **vibration tests:**

- 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 tests

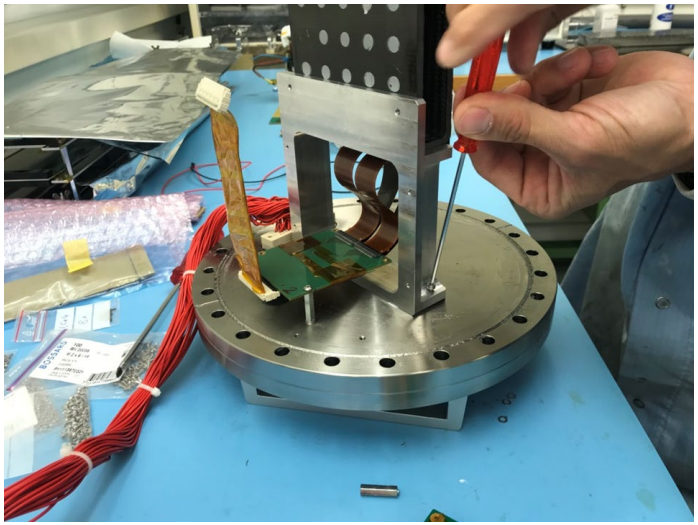
Setup at the University of Geneva:

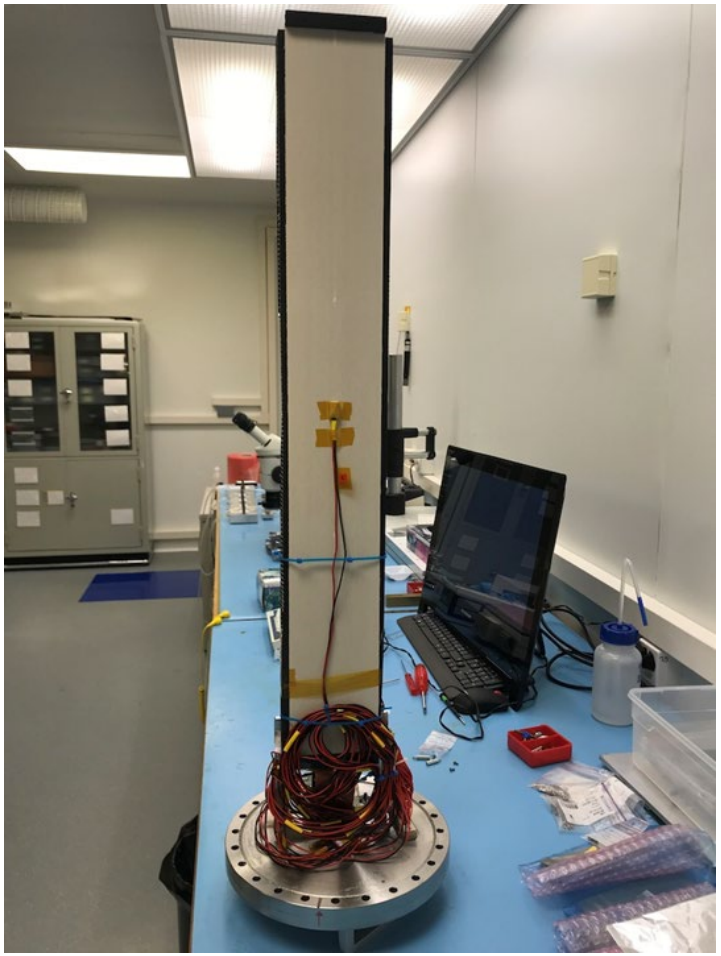
- Vacuum cylinder and pump (vacuum can go down to ca. 5e-6 mbar)
- The cylinder is placed inside a thermal chamber.
- Scintillators are placed on top and bottom of the chamber, to have cosmics triggers.



# TVT of a proto module

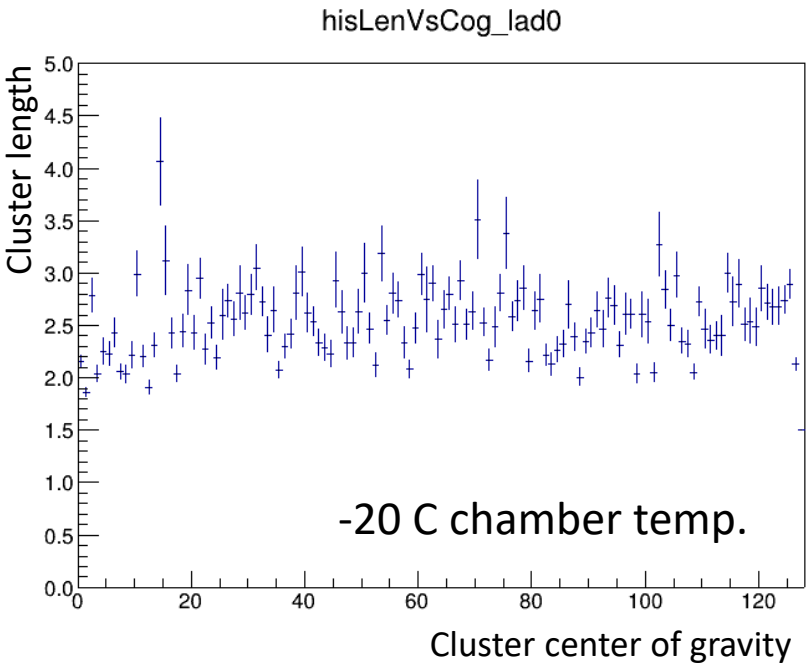
- Fiber mat mounted with one LHCb array and front-end with 2 VATAs.
- Chamber temperature set to -20 C, 0 C, 20 C.
- Cosmics DAQ.
- Data taken at -20 C, right now ongoing at 0C. We will then switch to 20 C.

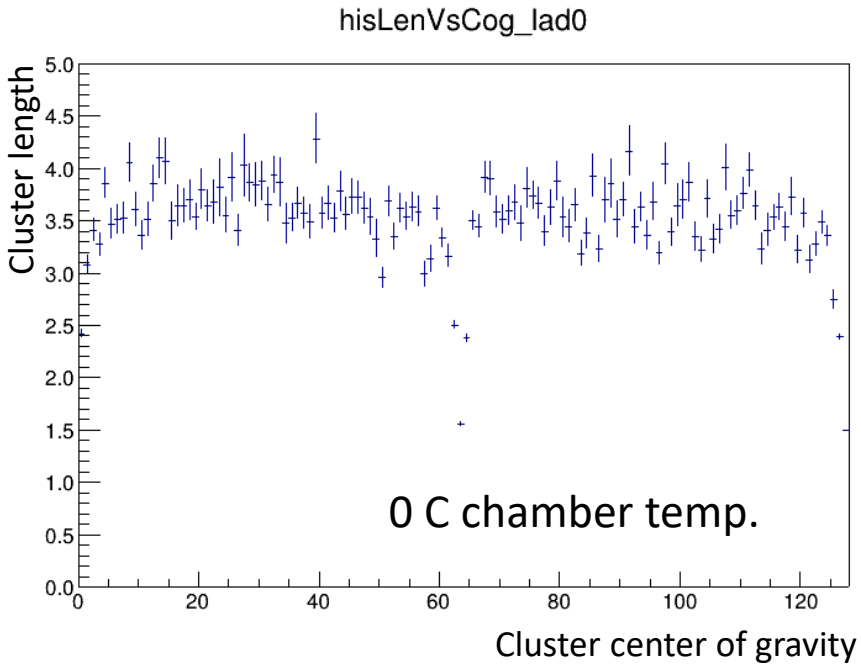




# TV of a proto module

(very) preliminary result:



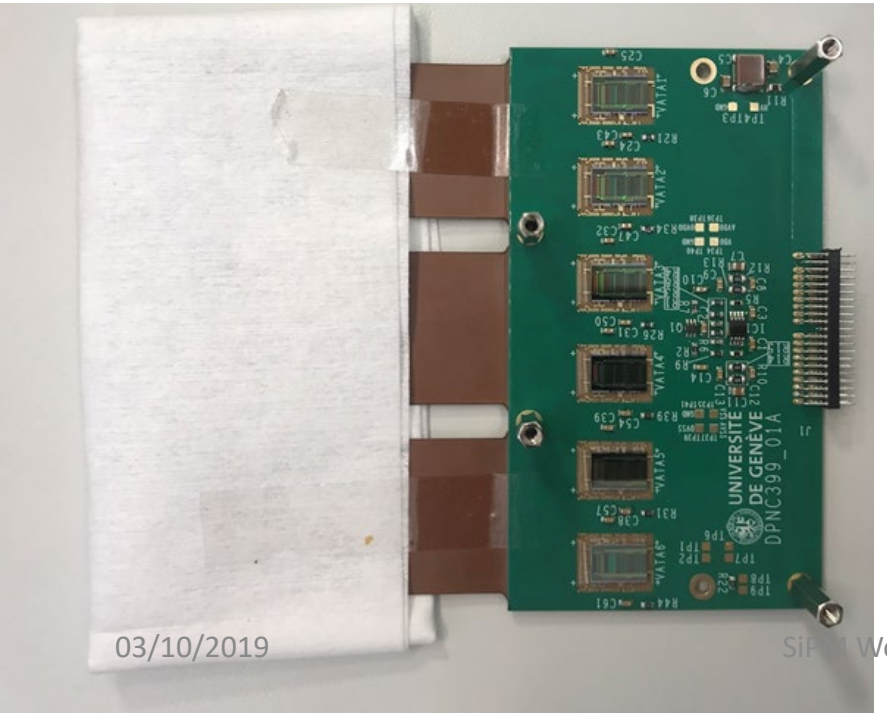

This seems to indicate some mechanical changes at the interface between SiPM and fiber but first we need to check:

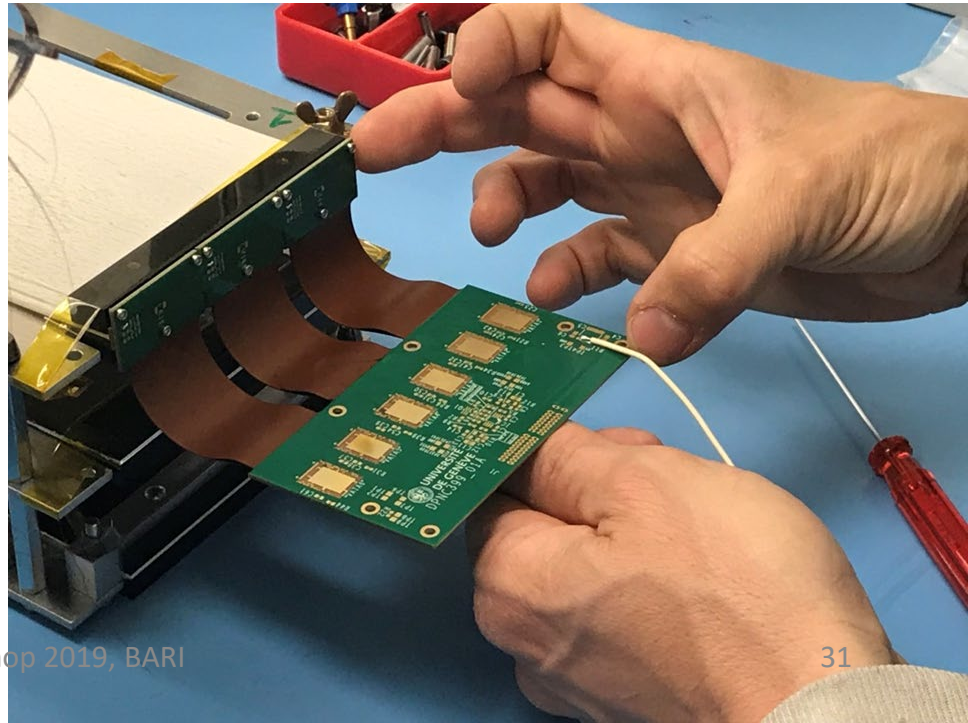
- Front-end performance
- Clustering algorithm
- Overvoltage stability
- ...

# Front-end Electronics board

The next version of the front-end board is being produced.

- Designed to read out three SiPM arrays.
- The present design uses six VATA ASICS.
- Another ASIC will be chosen for the flight.
- A preliminary study has been done to check the alignment precision and the soldering quality.
- First data with 6 VATAs taken last Monday…



# Summary

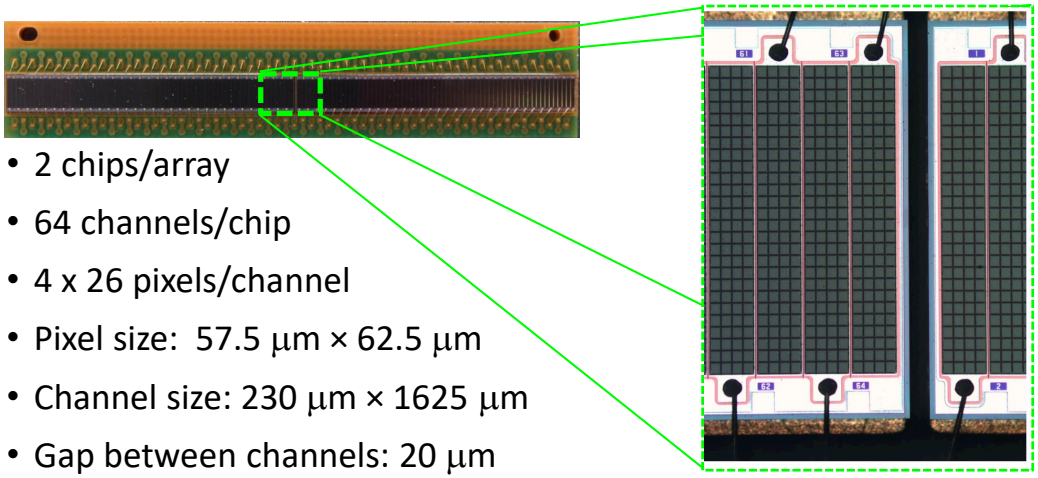
- First module prototypes have been successfully tested in various beam tests at CERN.
- Two models of SiPM arrays are examined.
- A prototype front-end electronics board with three SiPM arrays has been produced, tests have begun this week.
- Test tray design is finalized, first tray expected for mid-November.
- Vibration tests will start by the end of the year.
- The first prototype of FRB will be assembled by the end of October.

# Thank you!!

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

# FIT module: the «LHCb» SiPM Array

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



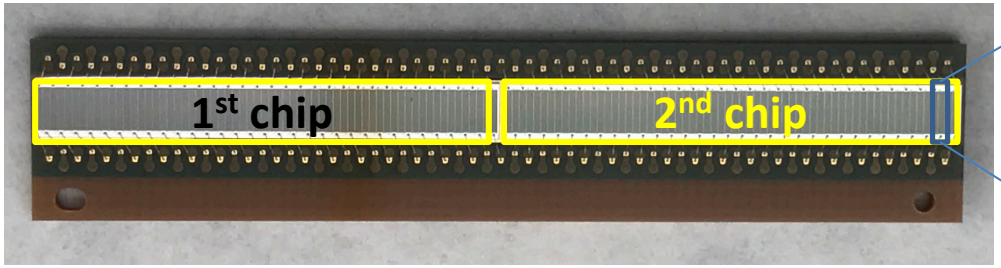
- 2 chips/array
- 64 channels/chip
- 4 x 26 pixels/channel
- Pixel size: 57.5 μm × 62.5 μm
- Channel size: 230 μm × 1625 μm
- Gap between channels: 20 μm
- Gap between chips: (220 ± 50) μm
- 105 μm epoxy resin on top

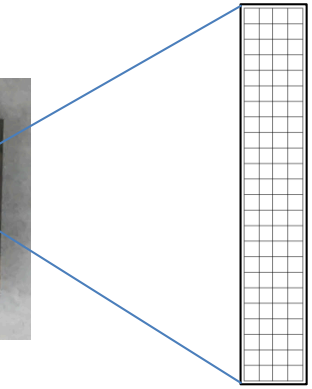
@ 25 °C:

- $V_{breakdown}$ = 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

# «LHCb» MPPC array characteristics

Product outline
- MPPC
- Effective photosensitive area 0.23×1.5mm, 128ch.Array ( 64ch/chip × 2chip )
- Surface mounted package with 2 holes



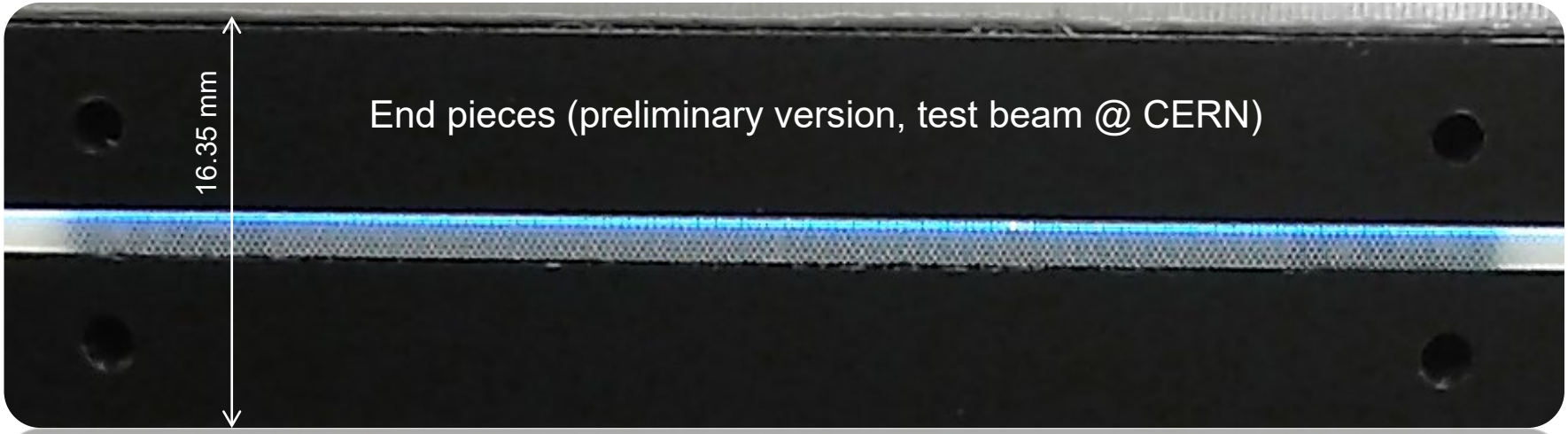



1 channel =
96 pixels =
4 x 24 pixels

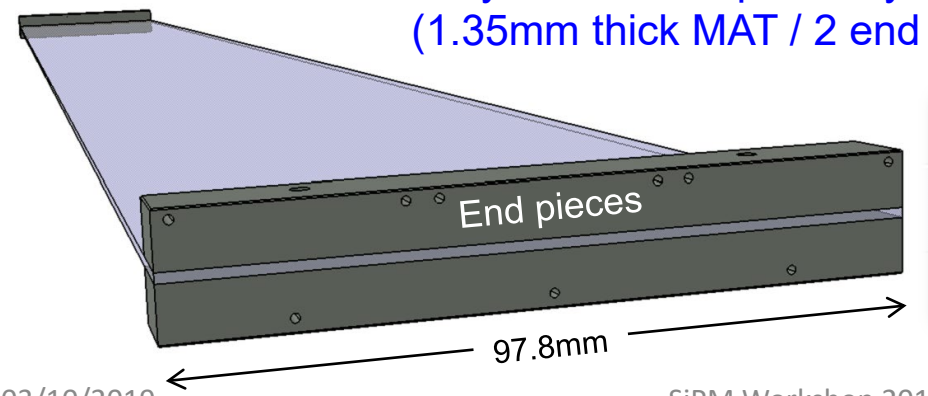
| Parameter | Symble | Rating | Unit |
|---|---|---|---|
| Effective active area / channel | -- | 230(X) × 1500(Y) | μm |
| GAP between channels (on chip) | -- | 20 | μm |
| GAP between channels (between chip) | -- | 250 ± 50 | μm |
| Number of channels | -- | 128 ( 64 × 2chip ) | ch |
| Number of pixels / channel | -- | 4(X) × 24(Y) | -- |
| Pixel size | -- | 57.5(X) × 62.5(Y) | μm |

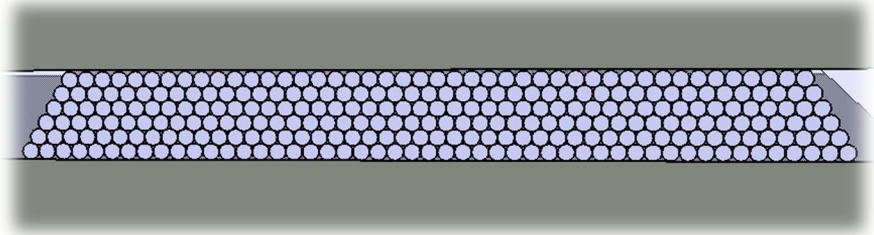
# Mat design overview

**The Fiber MAT** (stacking of 6 layers of 0.25mm diameter fibers)

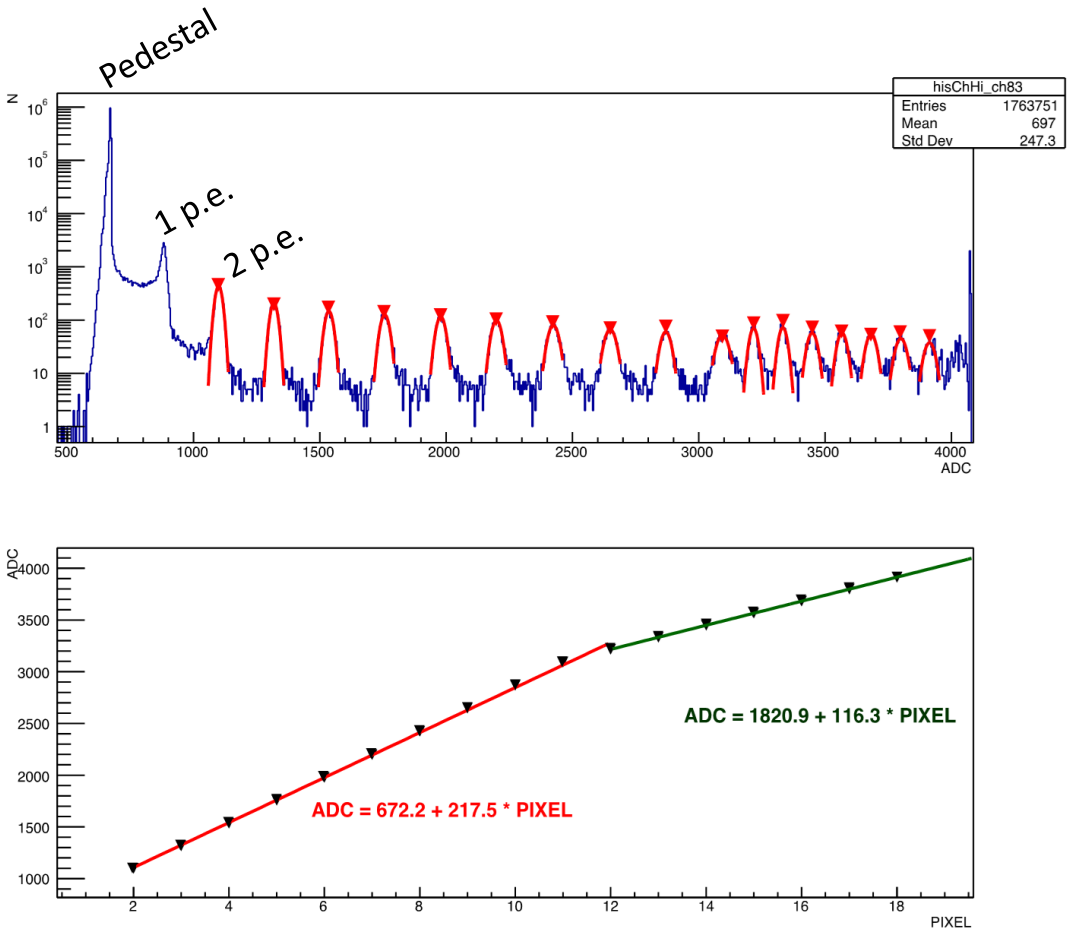



6 layers of fibers precisely lined up & glued via a tooling at EPFL
(1.35mm thick MAT / 2 end pieces for SiPM read out)



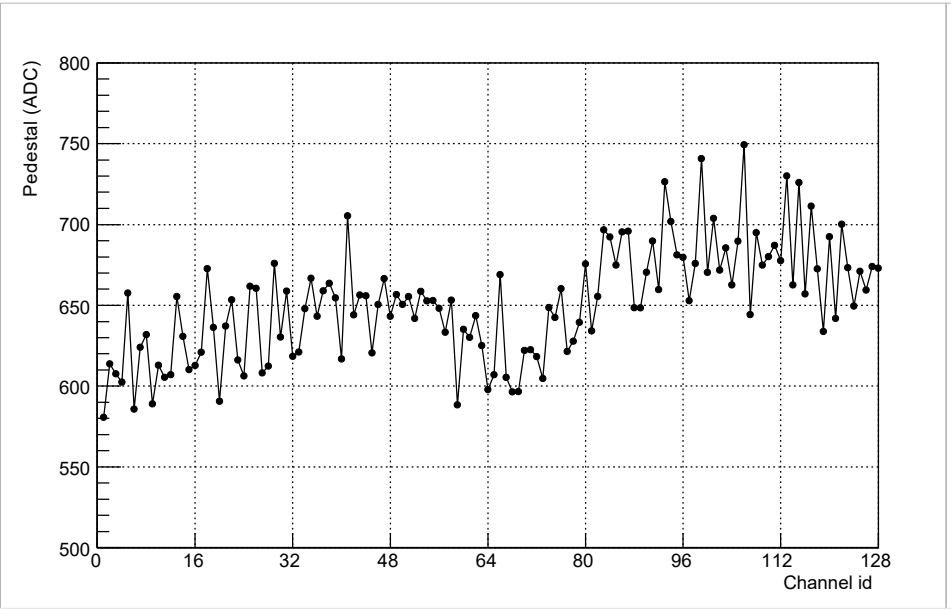



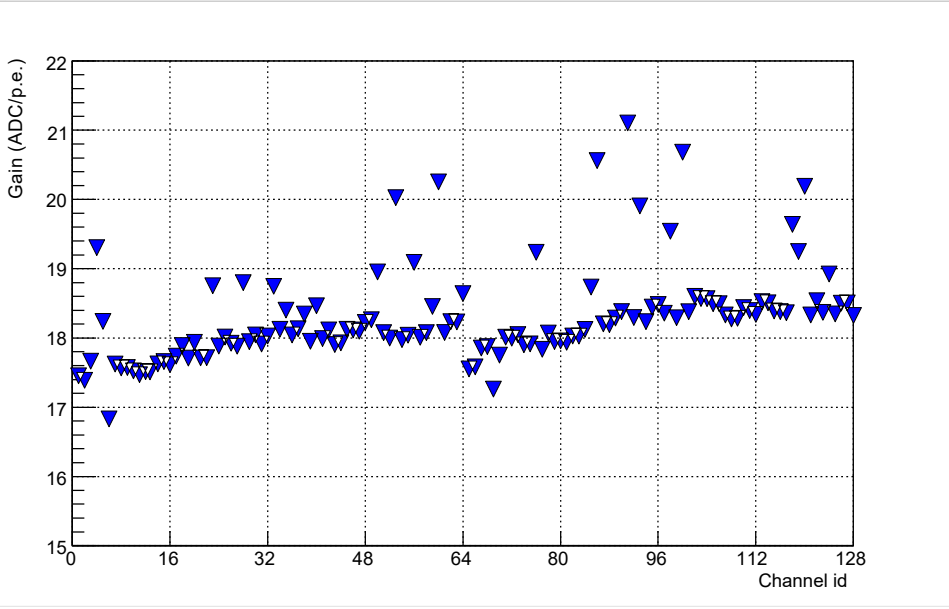
# Channel charge calibration («LCHb» SiPM arrays)



# Pedestal and gain

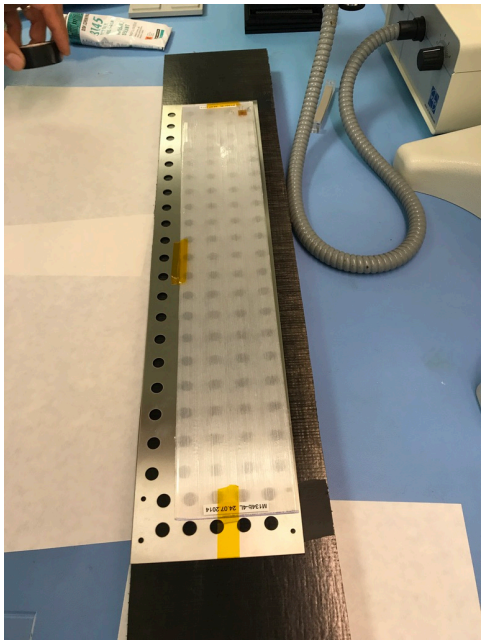
The **intercept** of the fitting line from 0 to 12 photoelectrons corresponds to the channel **pedestal** and the **slope** to the channel **gain**.

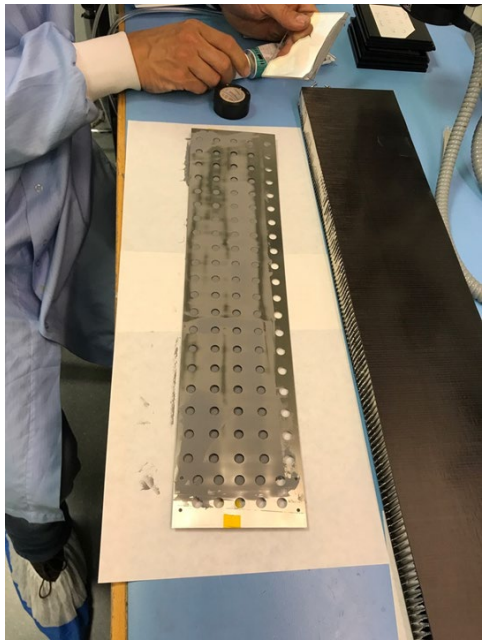


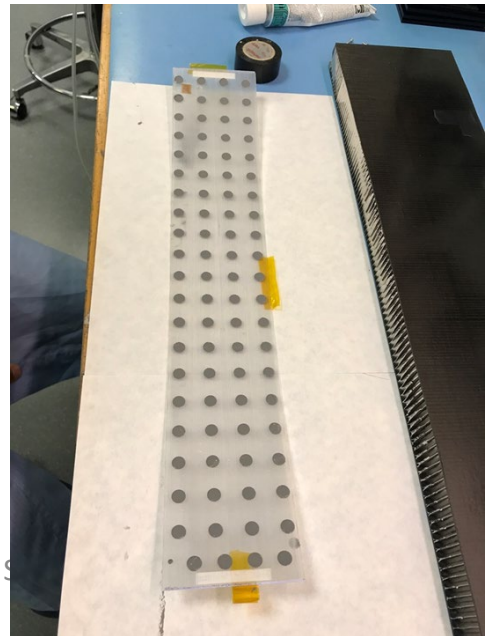



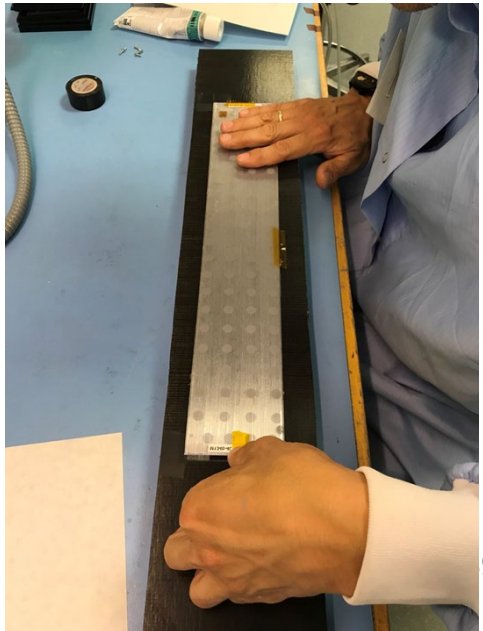
# Mat gluing

- Glue is deposited on the fiber mat through a mask, to ensure a uniform glue thickness.
- The mat is then transferred to the support structure.
- Similar approach as the one used to glue silicon modules of the DAMPE tracker.





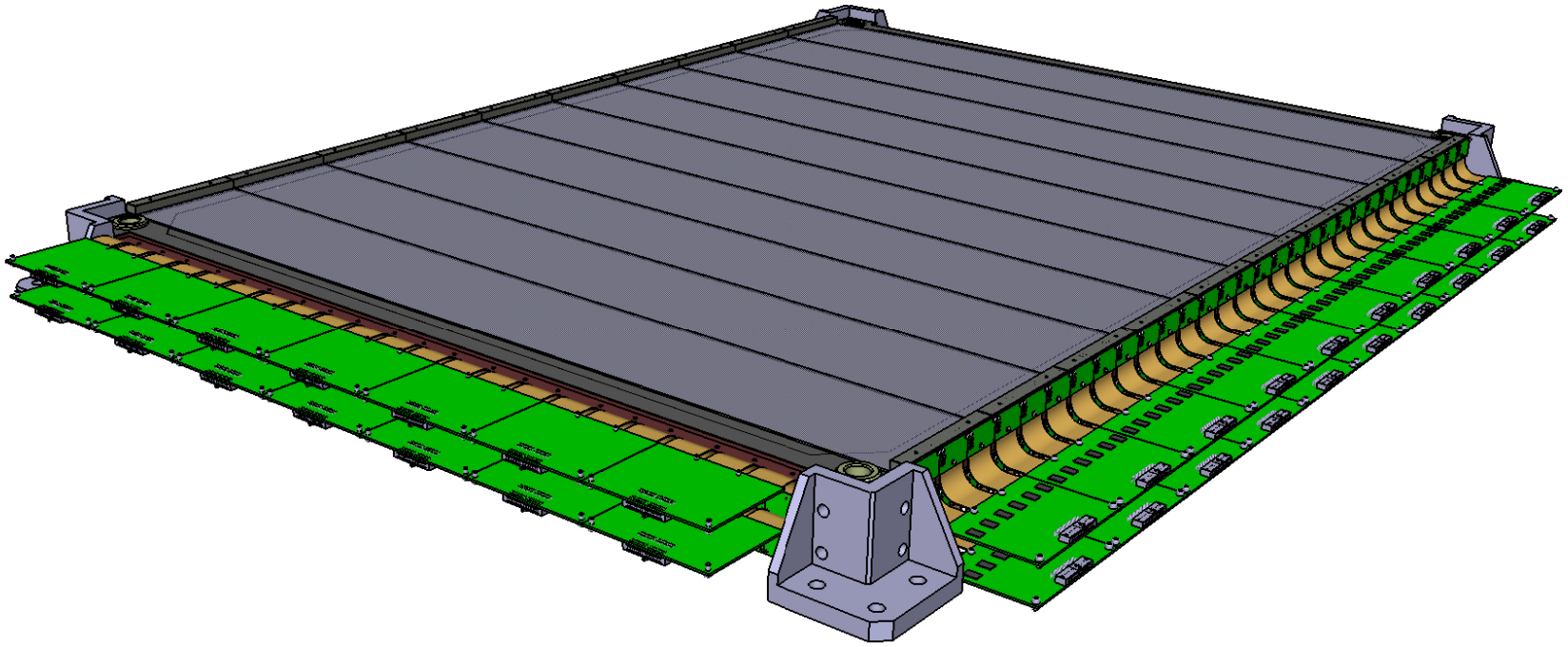


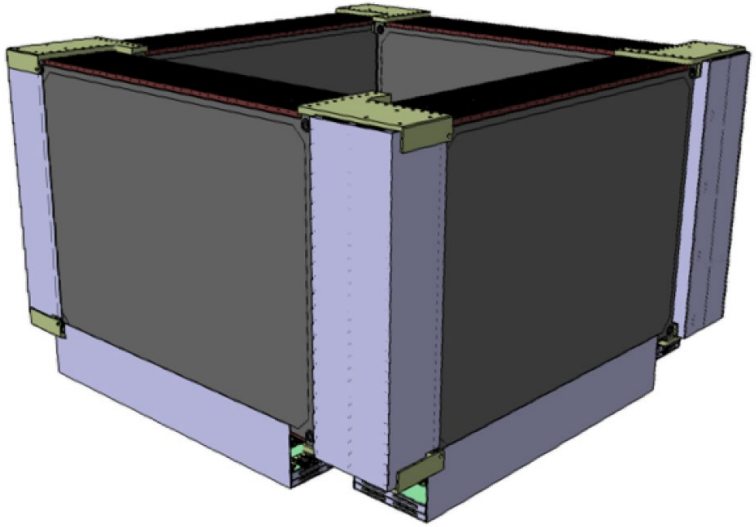


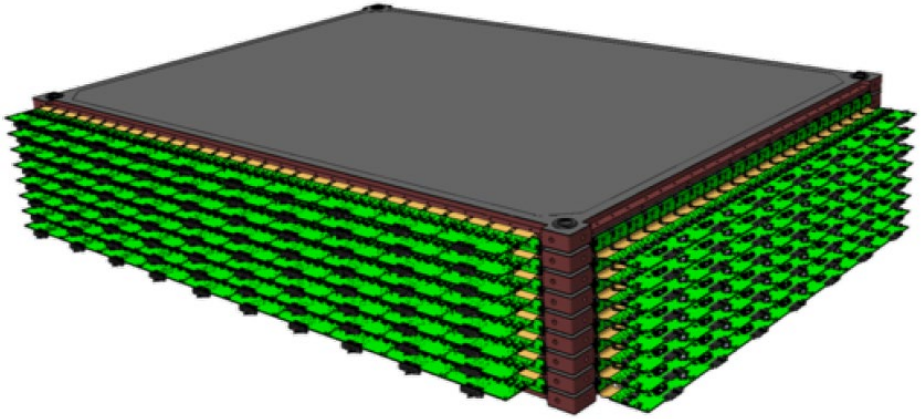
# Vibration tests

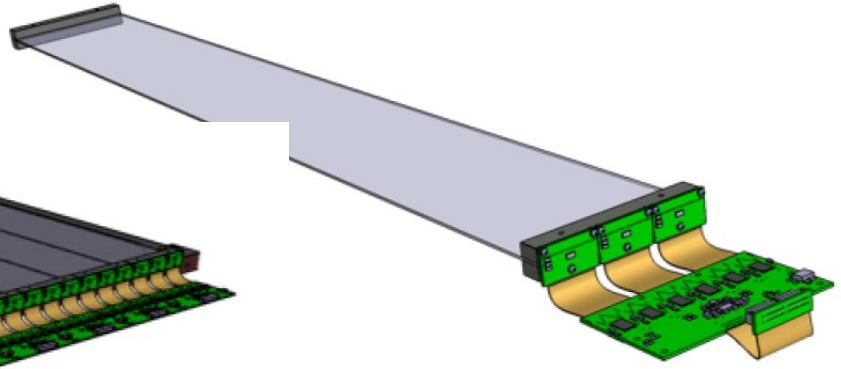
Vibration tests will be done on two trays assembled together equipped with modules (8 good ones, the rest will be made of mats with fishing line).

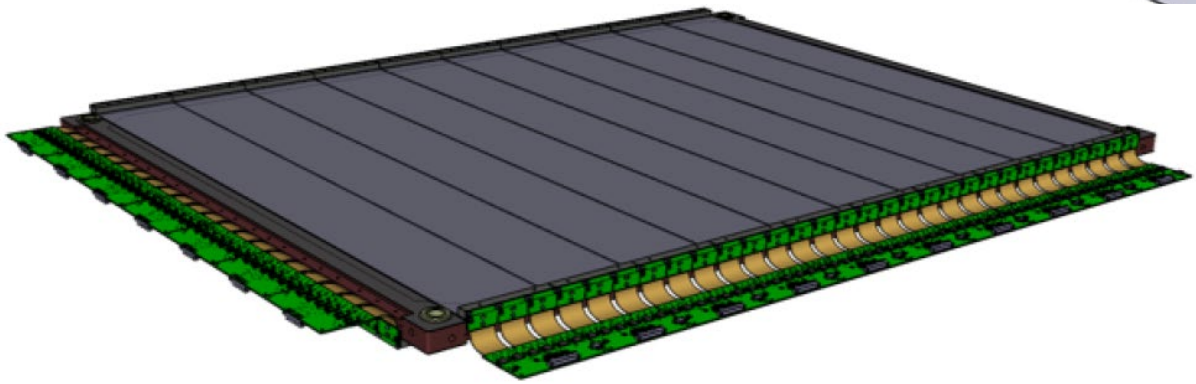
- Measuring eigenfrequencies:
  - on empty tray.
  - On equipped trays, with and without SiPMs + FE electronics.











# Support tray