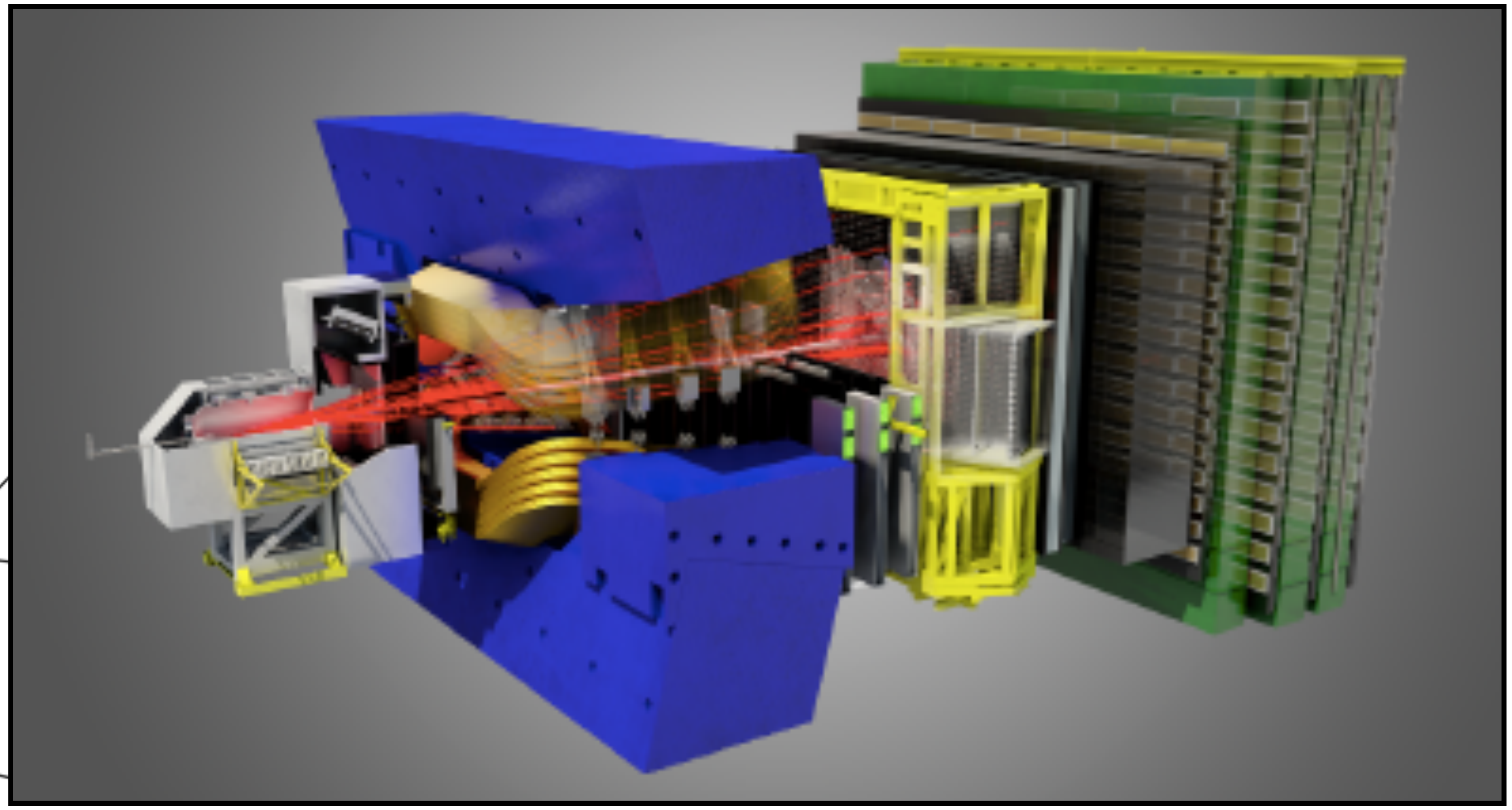
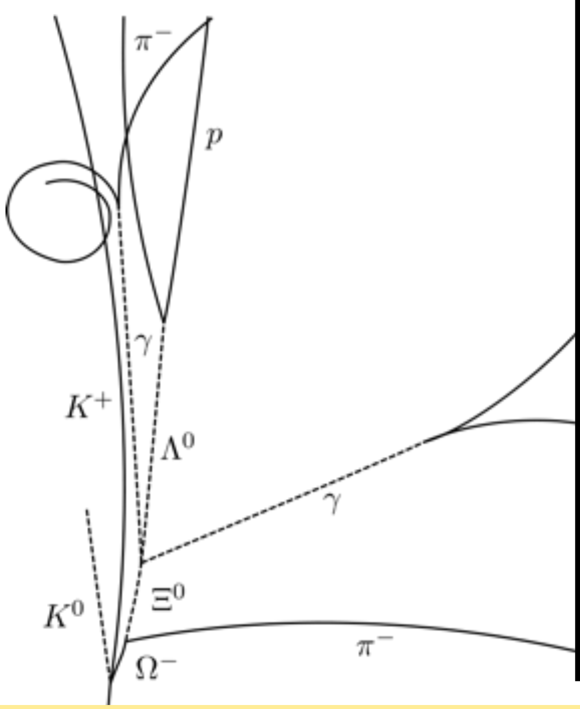
SciFi

the new tracker of the LHCb experiment





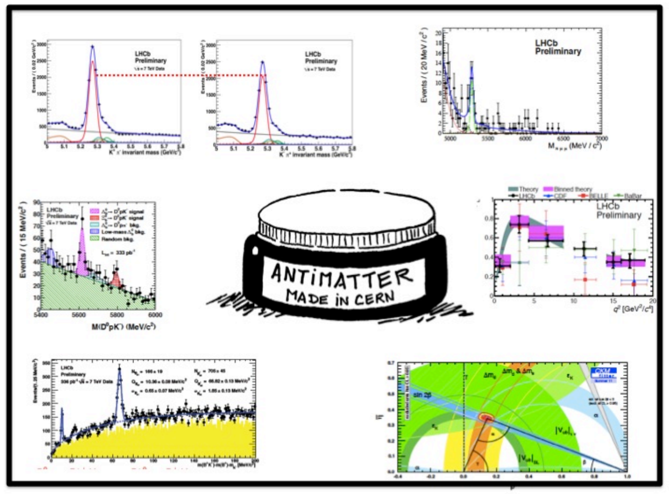
André Massafferri Rodrigues

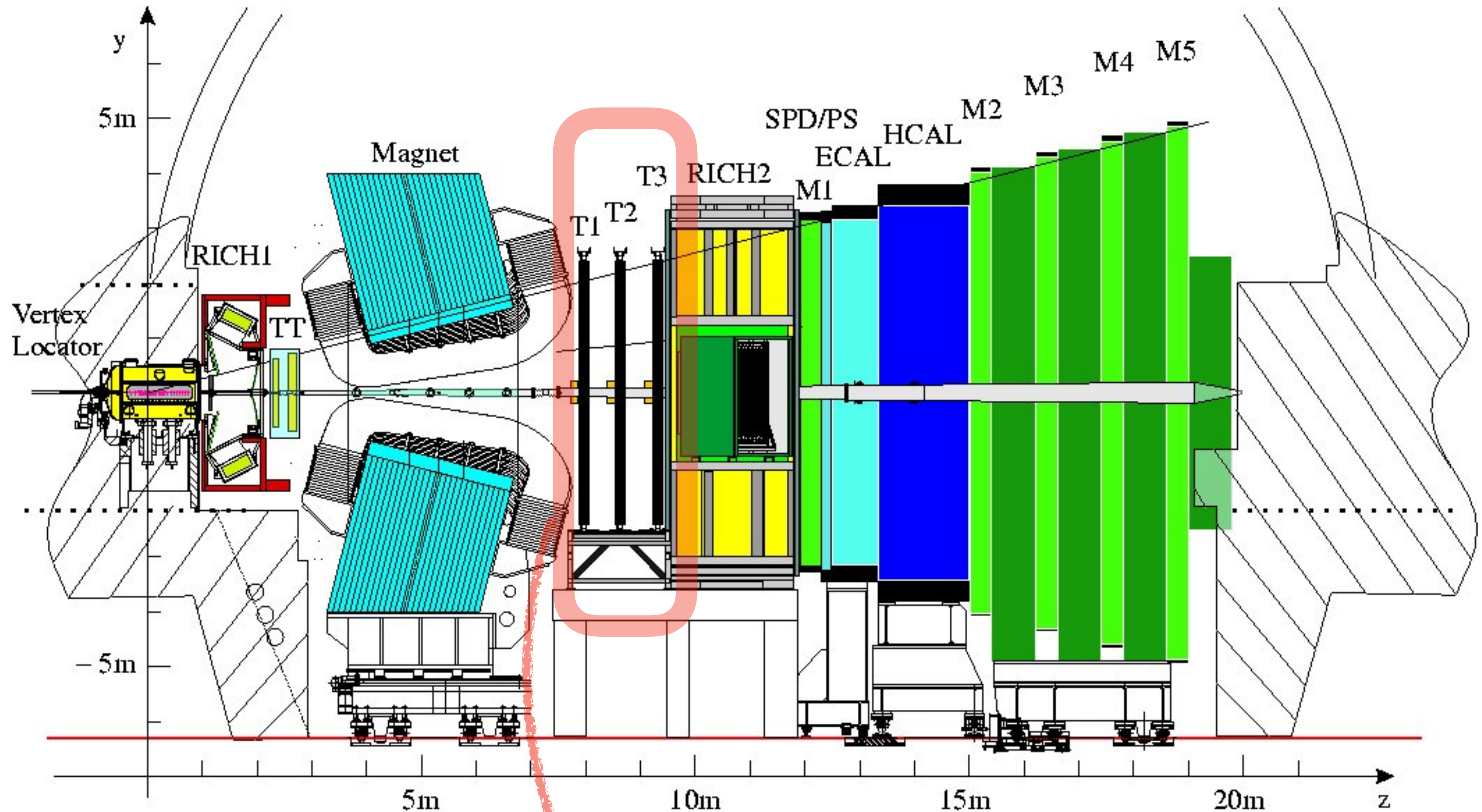
on behalf of the LHCb SciFi Tracker Collaboration

INSTR20 Conference Novosibirsky 24-28 Feb 2020

LHCb experiment

* Forward experiment dedicated to CP violation and rare decays studies: Large heavy flavour sample requiring excellent vertexing and tracking capabilities





LHCb: previous design

Main Tracker: Si-strip in inner region and straw-tube in outer region

LHCb Upgrade

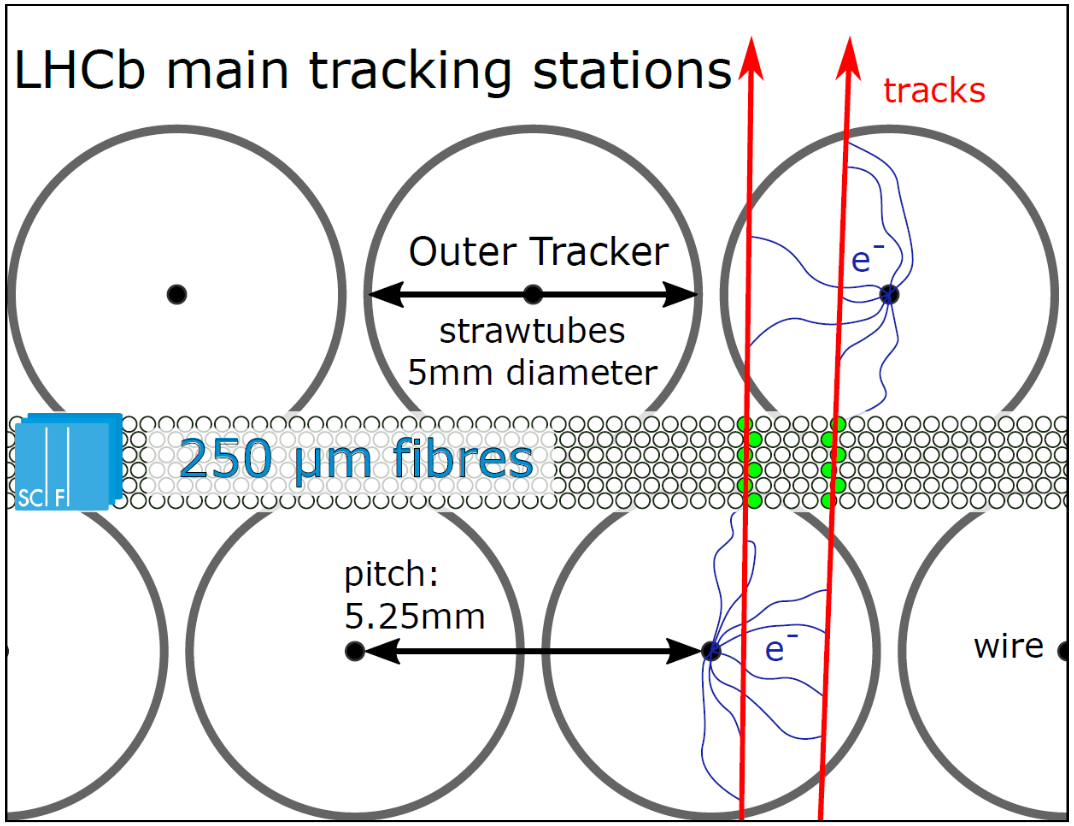
LS2 LHCb: $\mathcal{L} = 2\text{x}10^{33}$ cm^{-2} s^{-1} **5x** the current, 50 fb^{-1}@10 years

Issues

- **Bandwidth:** Saturation of L0 hadron trigger @1MHz

40 MHz (25 ns spacing) trigger-less readout electronic
Full event-selection in CPU farm

- **Multiplicity:** High Occupancy (>20%) affects Pattern Recognition Algo



Unique technology: Increase segmentation in outer tracker region, preserving spatial resolution of <100 µm in inner tracker

LS2 LHCb: $\mathcal{L} = 2\text{x}10^{33}\ \text{cm}^{-2}\ \text{s}^{-1}$ **5x** the current, 50 fb^{-1}@10 years

Requirements

New Main Tracker of LHCb experiment

- Readout at 40 MHz
- Spatial resolution in bending plane <100 μm
- X/X0 <1.5% per detection layer
- Hit efficiency ~99%

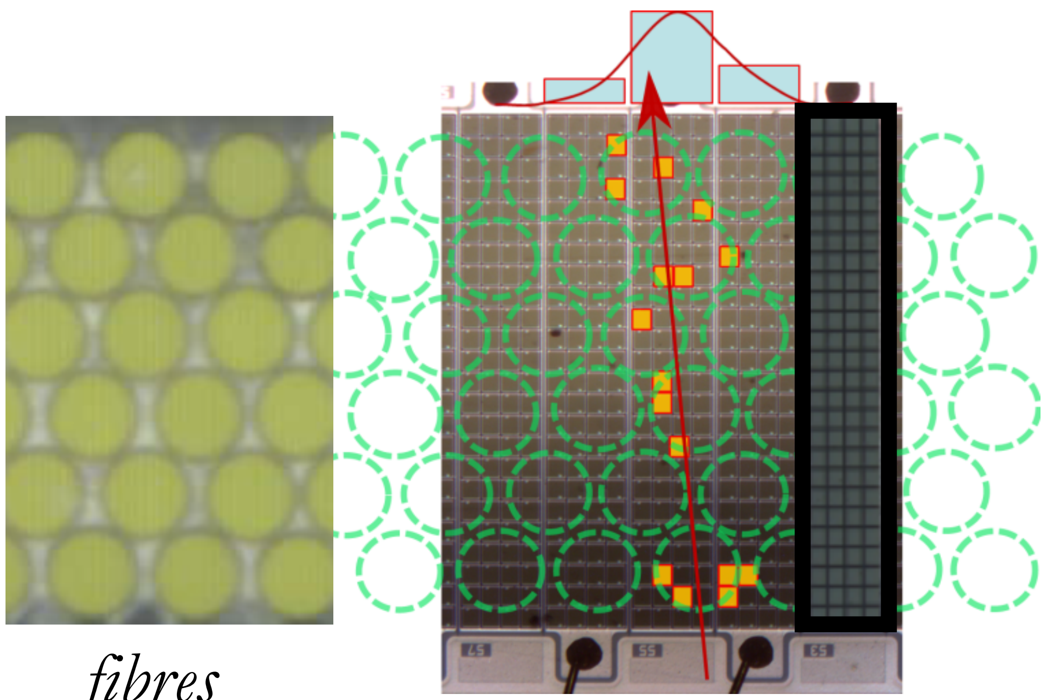
many implications

- Resist to 35 kGy dose (hottest region) and $6\text{x}10^{11}$ $^{1\ \text{MeV}}n_{\text{equivalent}}/\text{cm}^2$ (outside sensitive area)

SciFi Tracker

General Idea

* 6 layers of scintillating fibers ∅250μm readout by SiPM array



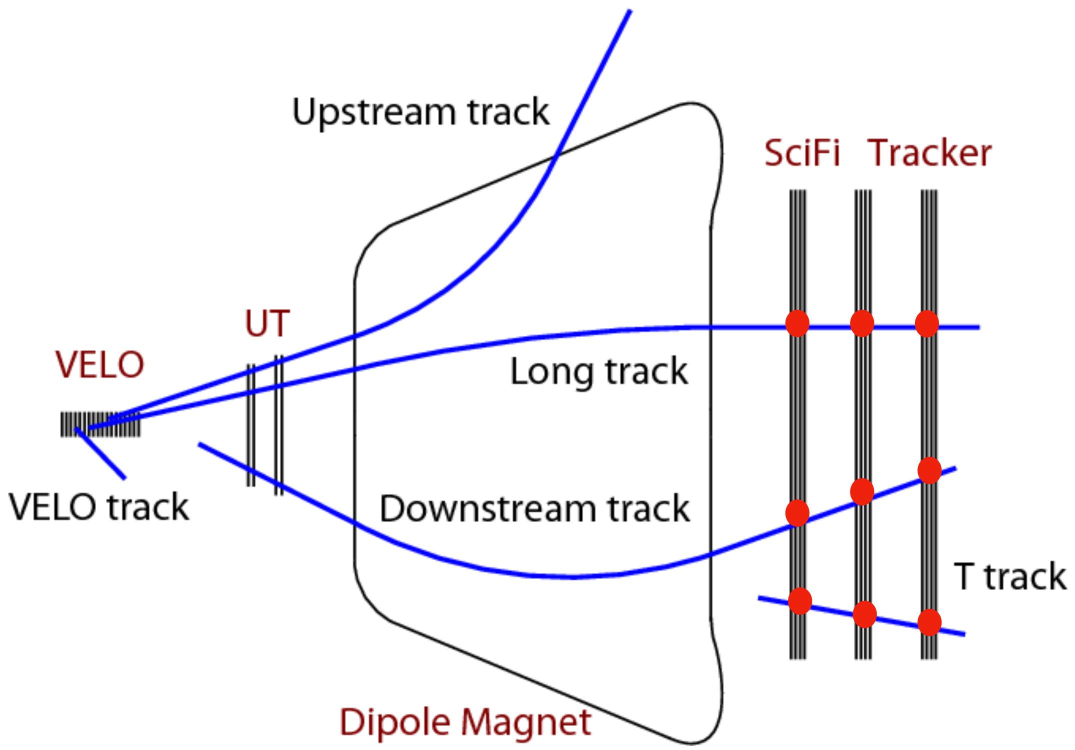
Cluster: Grouping adjacent SiPM channels to improve spatial resolution, mitigate noise and optimize data throughput

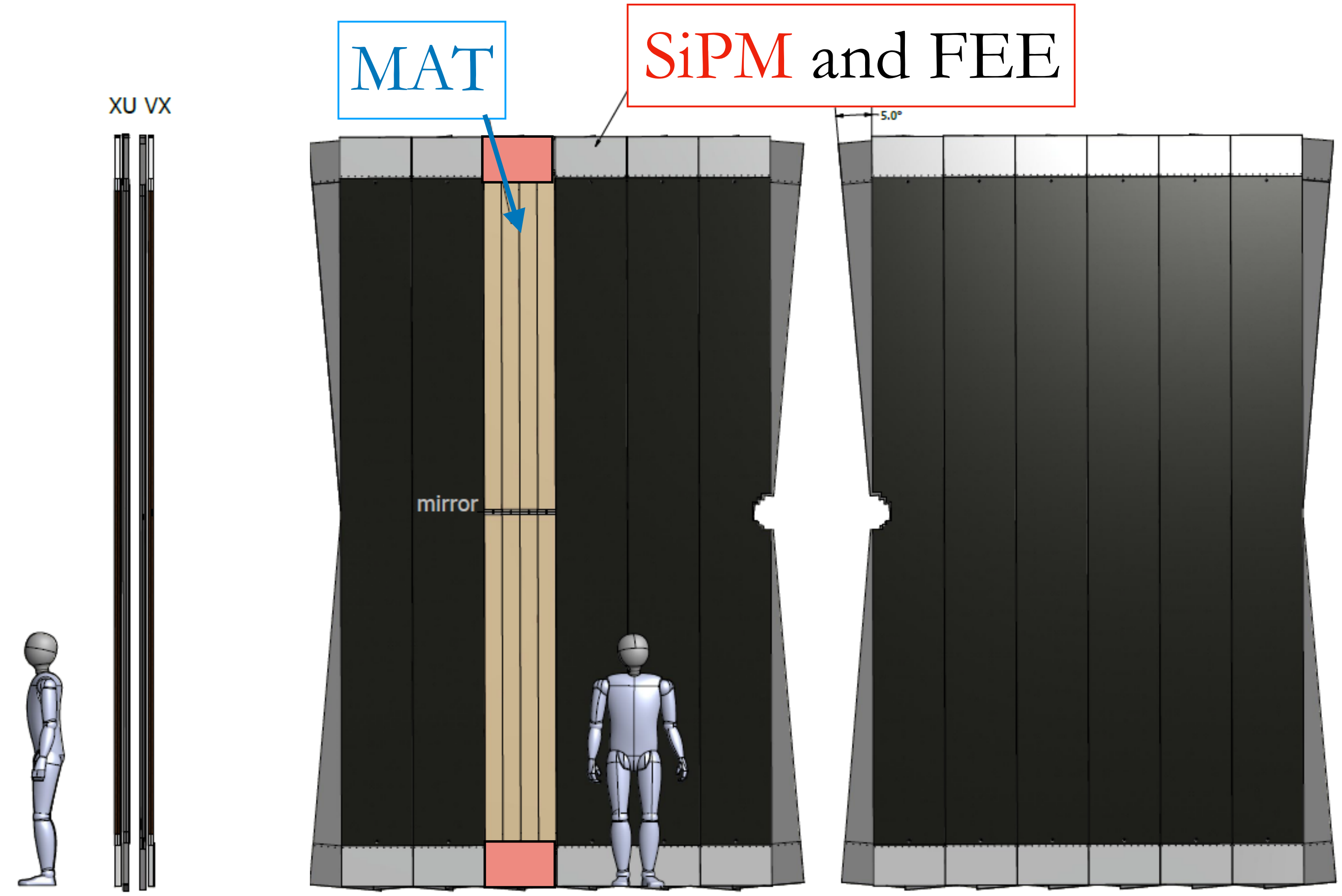
Light Detector

Photon collection outside sensitive area also improves uniformity

SciFi Tracker

- 3 tracking stations with 4 planes each ($0, +5^0, -5^0, 0$)
- **10.000 km fibers** in 128 modules
- 4096 SiPM arrays @128 channels = 524k channels





12 layers covering a sensitive area of **6 x 4.8 m^2** result to the largest high-precision scintillating fiber tracker

Fibres to Module

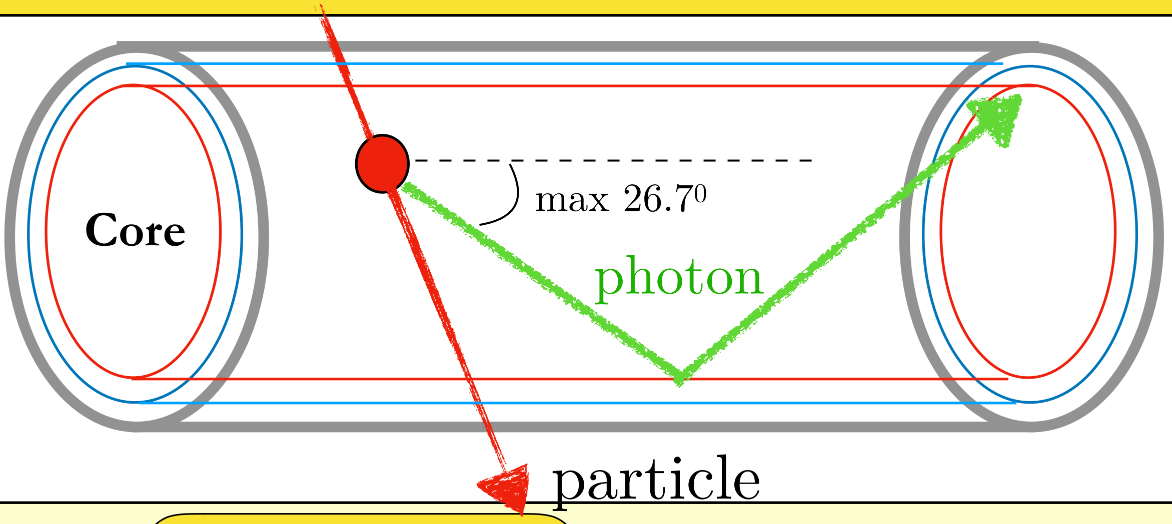
Silicon PhotoMultiplier

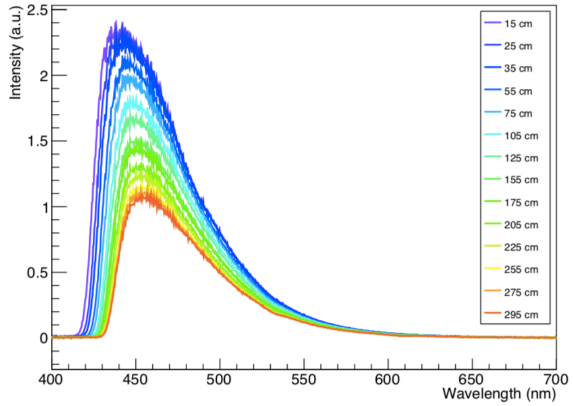
Front-End Electronics

Scintillating fibers

specs: double cladded round fibres **Kuraray SCSF-78MJ**

solvent Polystyrene, activator PTP and WLS





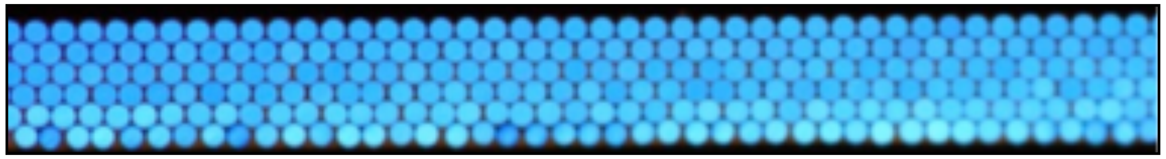
emission spectrum @ length

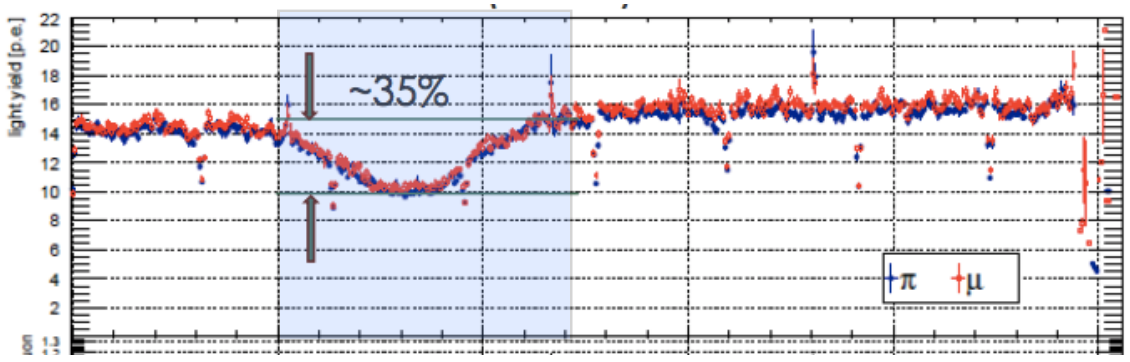
$$N_{obs} = \frac{dE}{dx}\frac{N}{dE}\Delta x \; \mathrm{Eff}_{trap} \left(e^{-\frac{l}{\Lambda}} + \eta_{mirror}\, e^{-\frac{2L-l}{\Lambda}}\right) \mathrm{PDE}_{SiPM}$$

~250 photons ~5.4% ~50% (Λ=3.5m, L=2.4m) 45%

~18 photo-electrons for 6 fibres

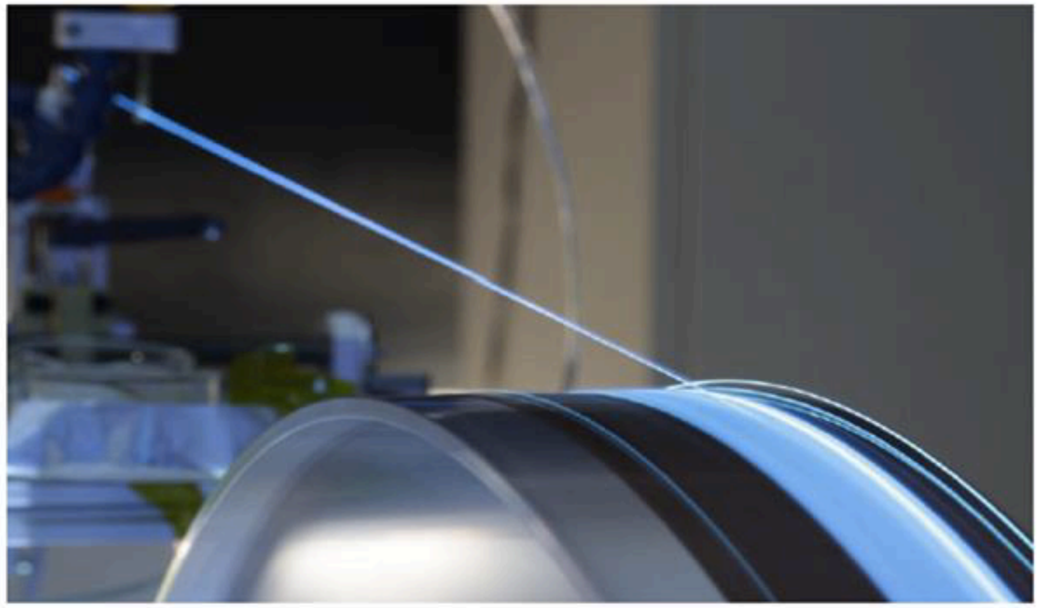
~35% drop due Radiation @10 years in beam pipe region

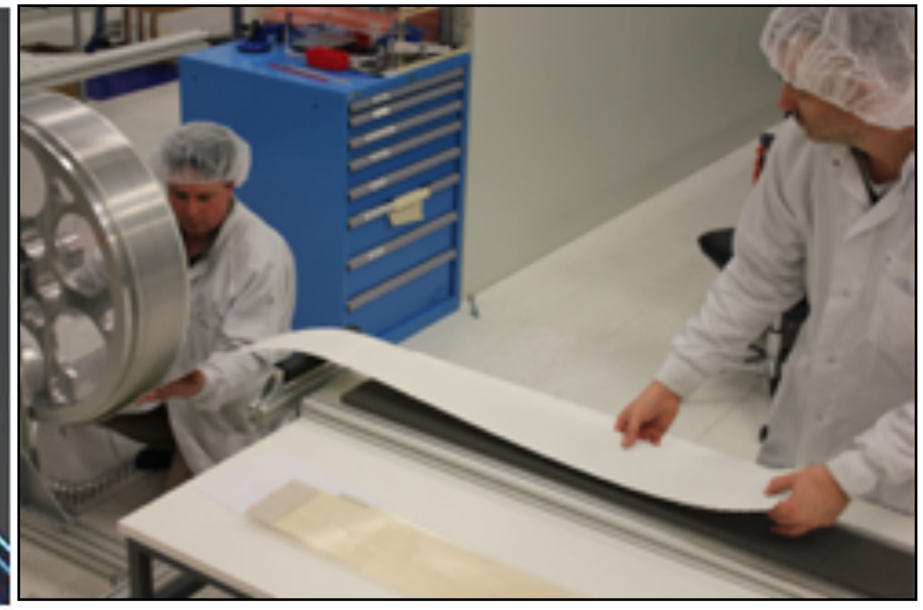


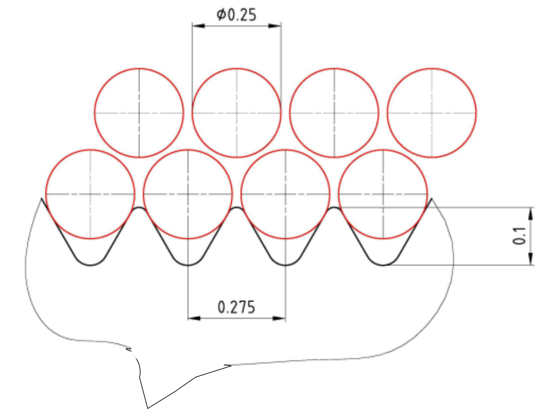


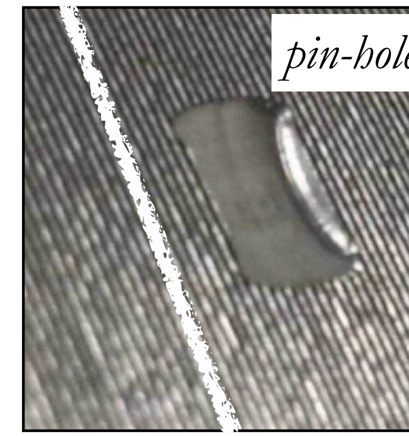
MAT Production

After a very stringent fiber quality-control ...





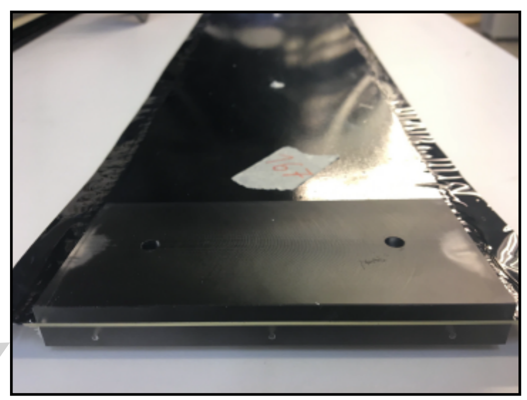




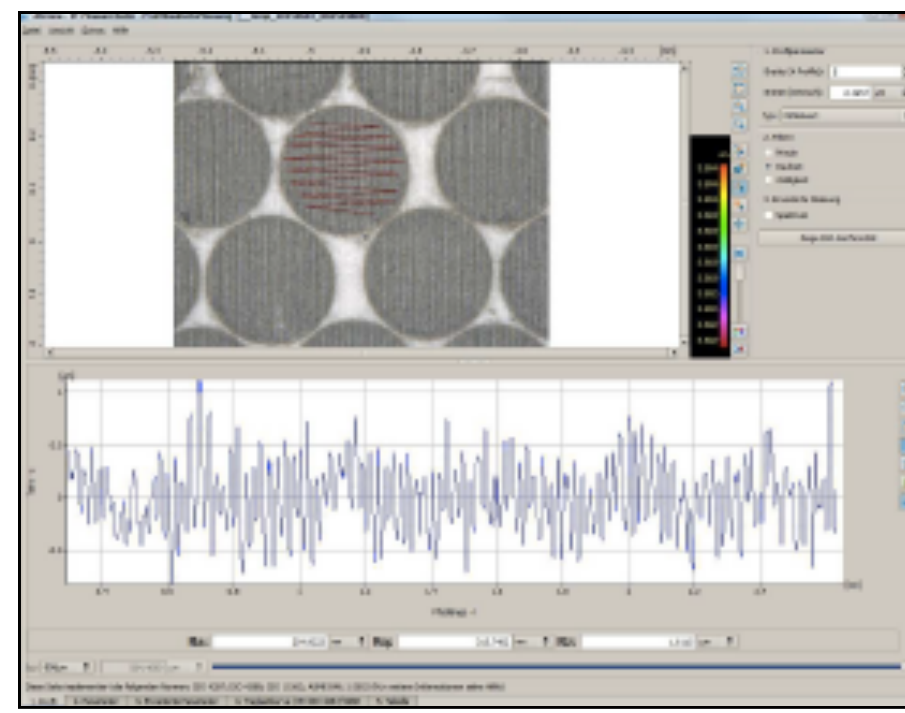
- **Winding** @80cm custom-made wheel

275 μm pitch

- 1st Lamination
- Curing
- Tempering
- 2nd Lamination
- Shrinking
- End-piece gluing
- Optical cut
- Mirror gluing

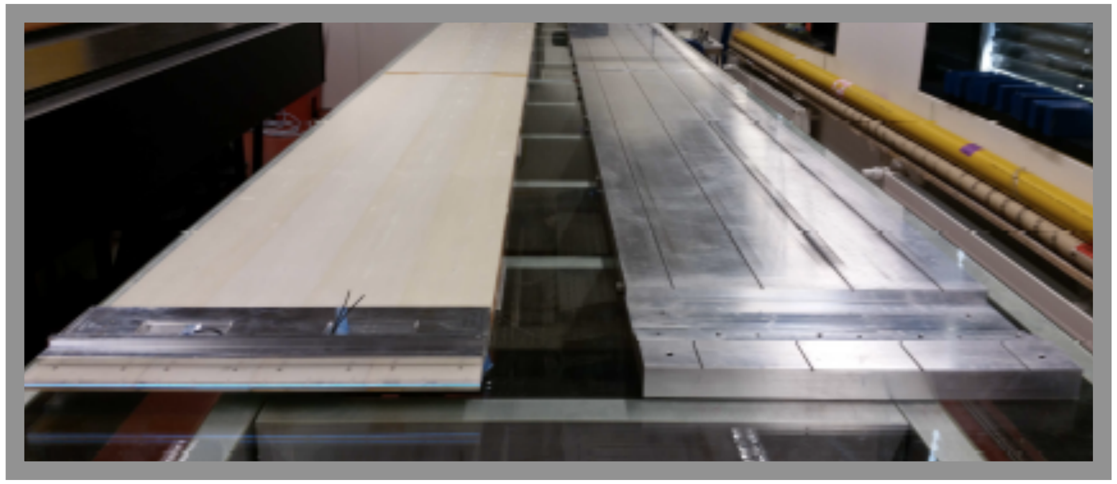


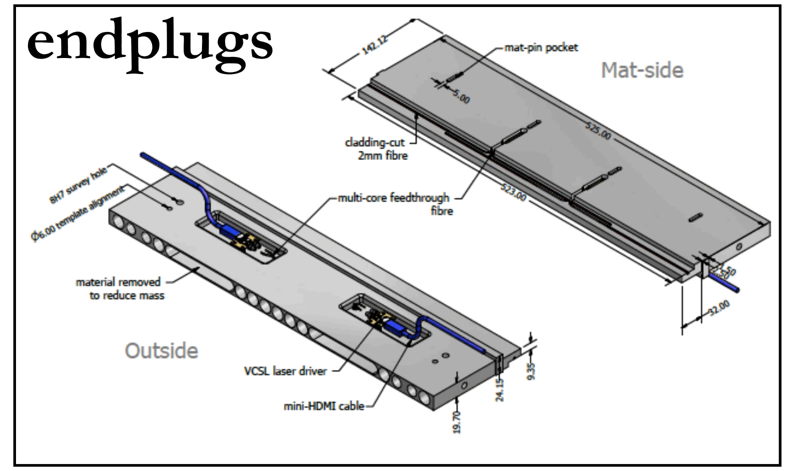
Diamond milling of optical surface



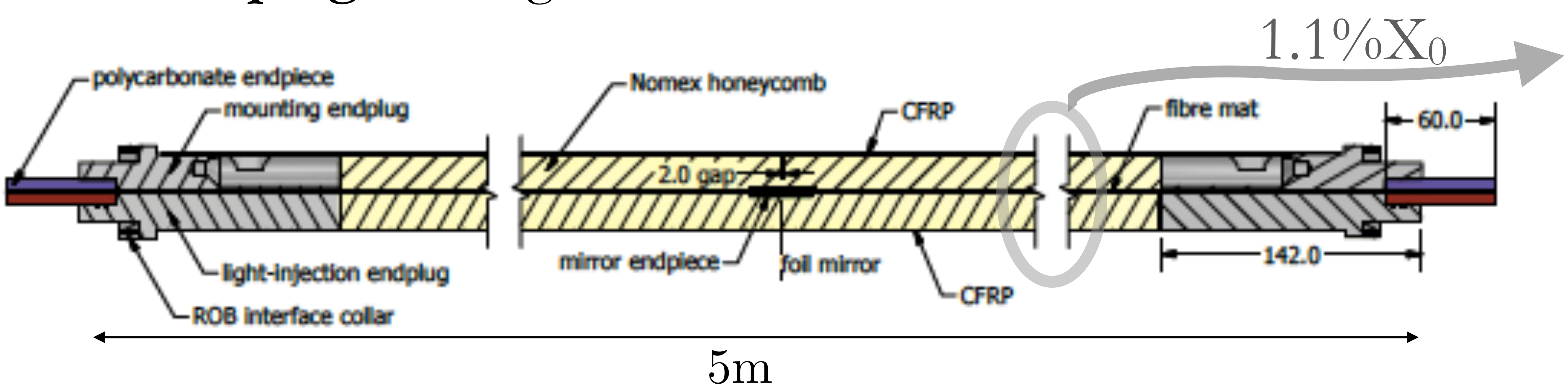
Inspection

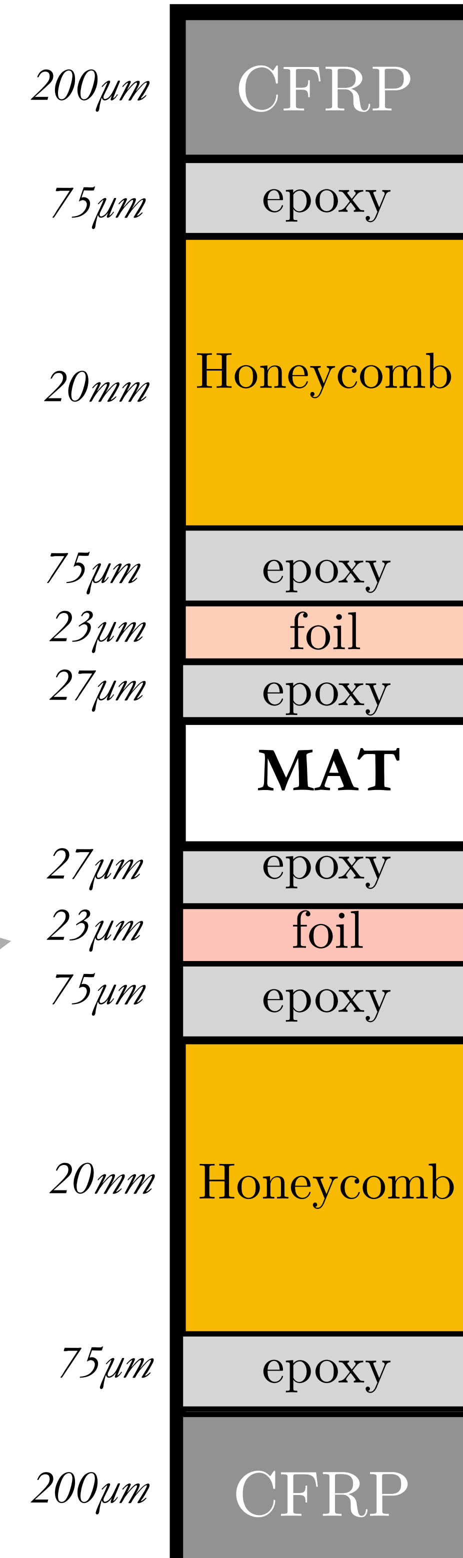
Module Production





- **2x4 MATS** aligned in precision vacuum table with grooves sandwiched by carbon fibre (rigidity) and honeycomb (planarity, lightness)
- **endplug** housing laser driver for calibration





Light and stiff detector
4M fibers aligned within 50 µm precision

Components

Fibre to Modules

Silicon Photomultiplier

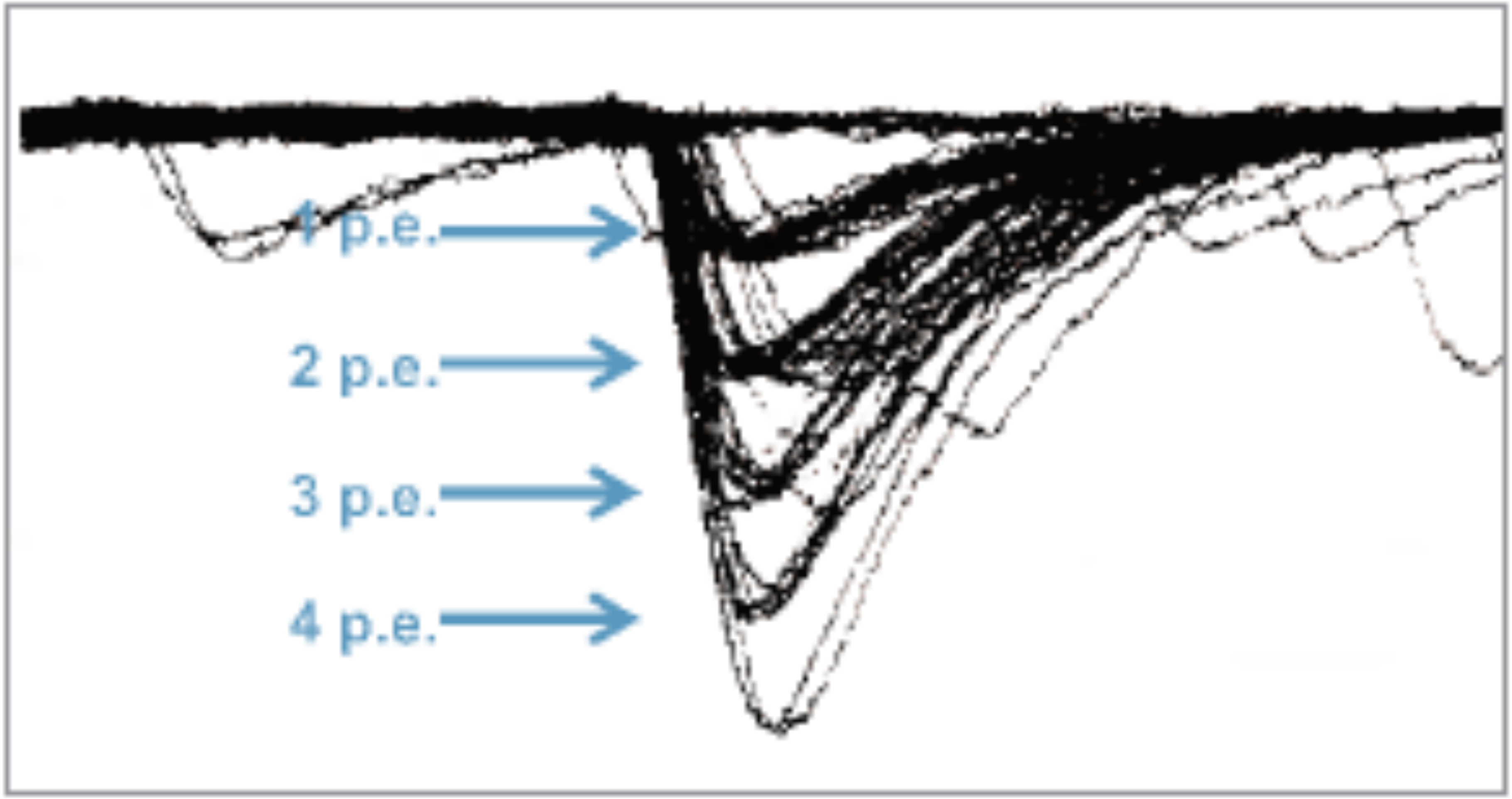
Front-End Electronics

Silicon Photo-Multiplier

Avalanche photodiode operating in geiger mode (high gain and QE)

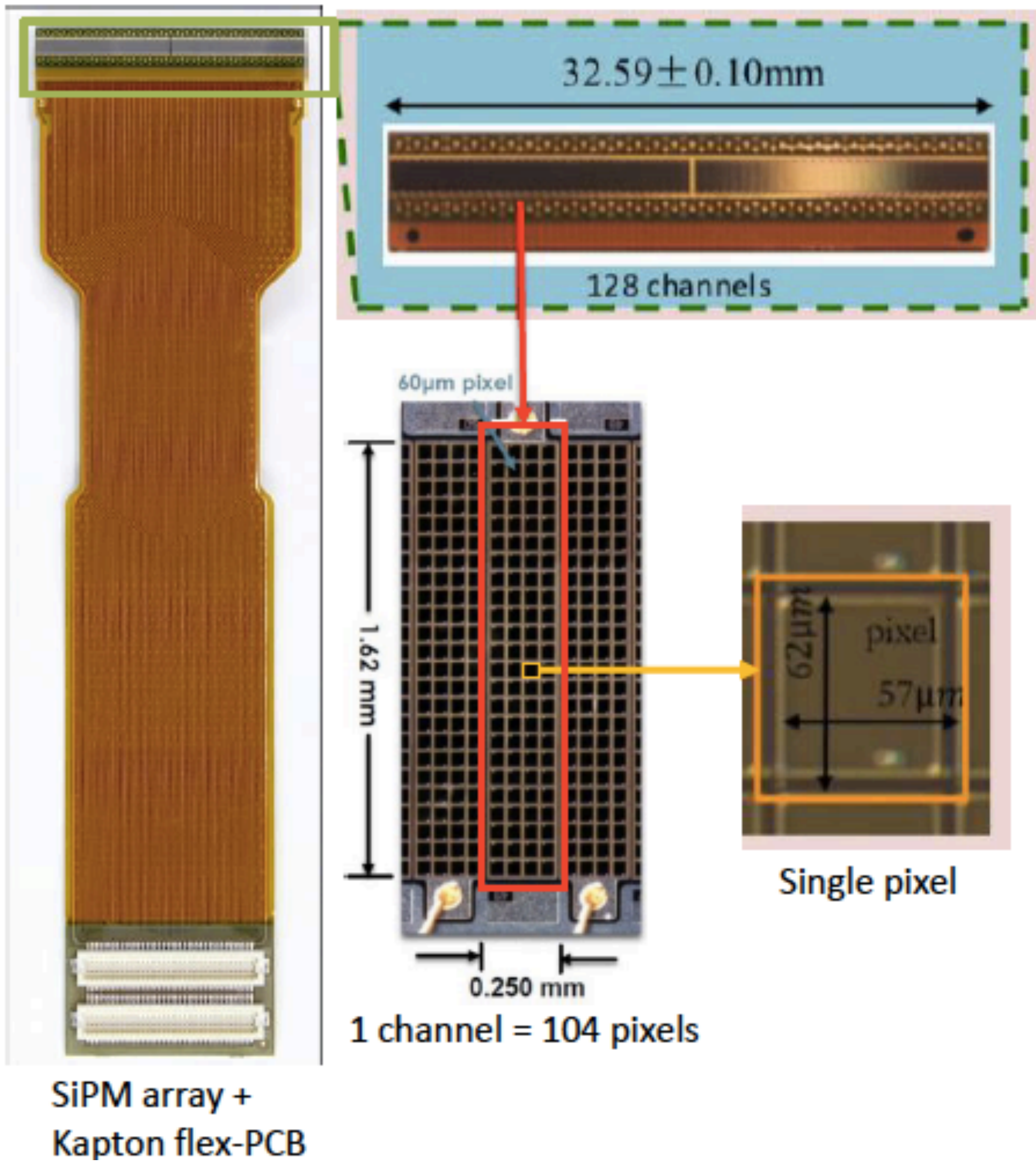
MultiPixel Photo-Counter

Charge proportional to the amount of pixels fired



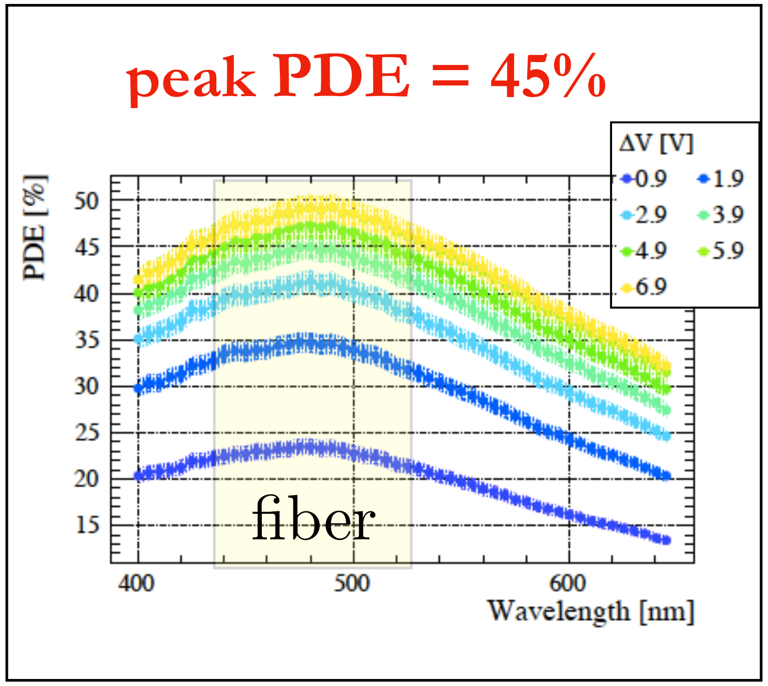
10-12 photo-electrons foreseen after many years

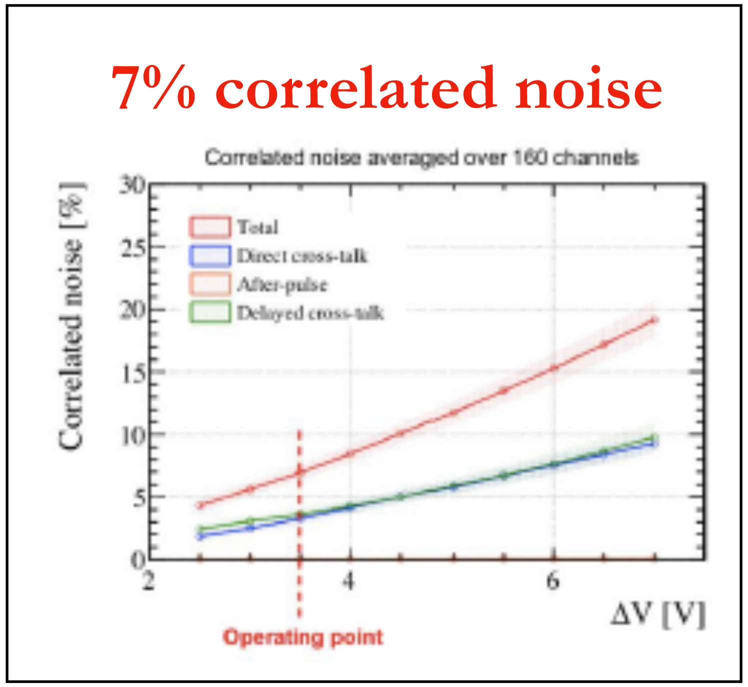
Hamamatsu MPPC S13552 - H2017



- 64x2 channels array with 250 μm pitch
- Sensors are glued in *3D* printed Ti bar
- Small distances between fibre and pixels
- After-pulse <0.1%

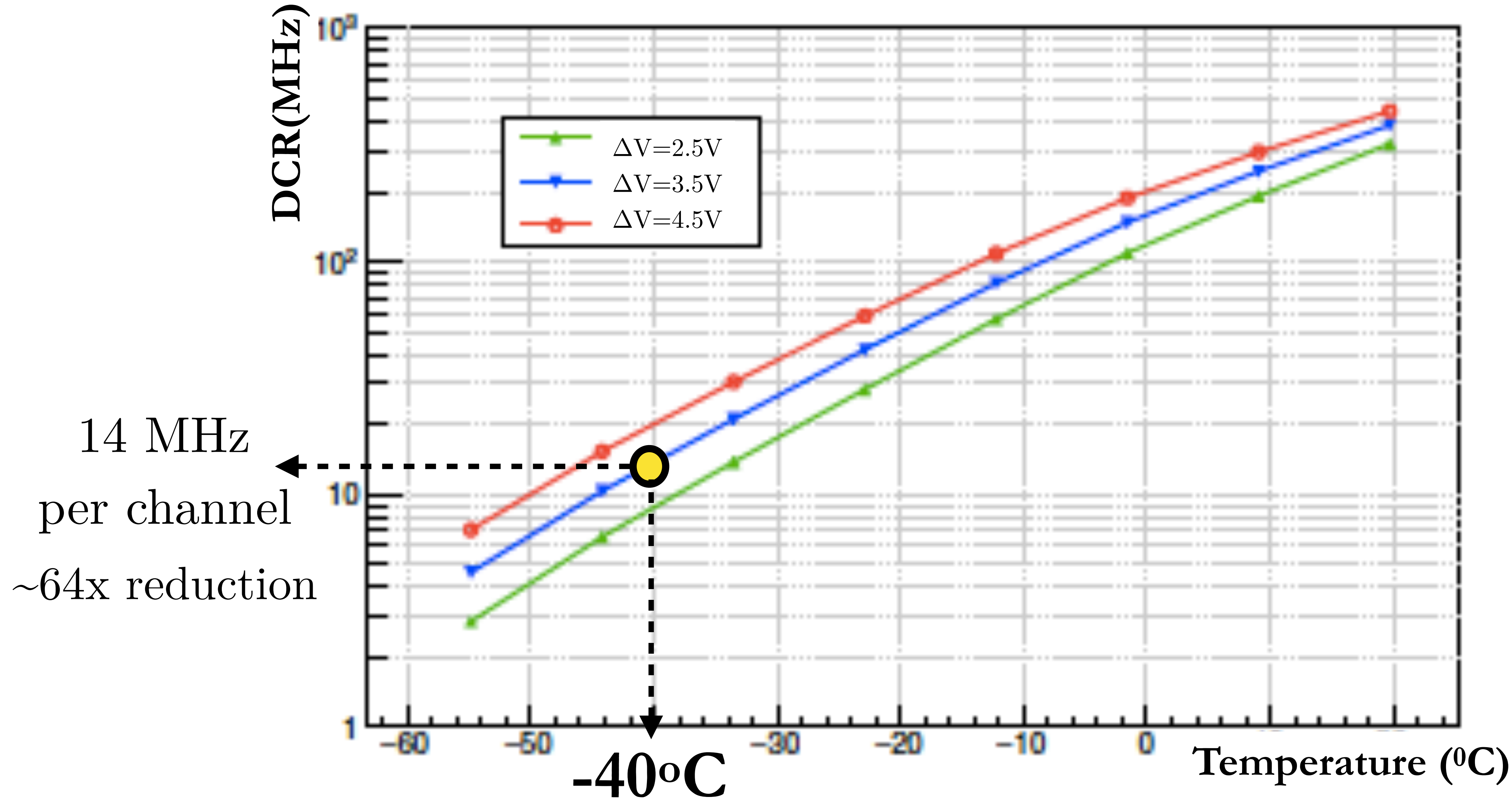
setting over-voltage of 3.5V





Silicon Photo-Multiplier

Irradiation with 6x10[11] $^{1MeV}n_{equivalent}/cm^2$



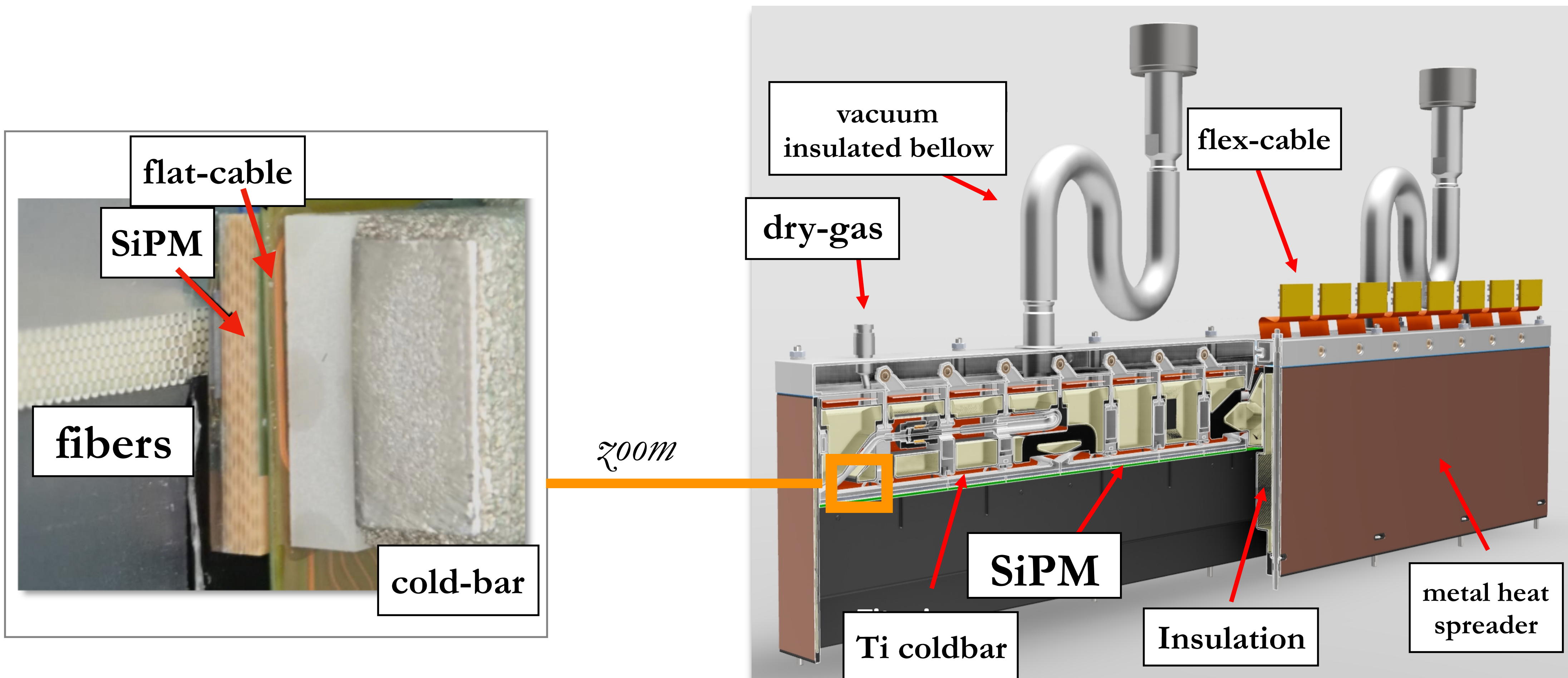
Dark Current Rate (DCR) rises exponentially due neutron radiation

Need to cool down to **-40^{0}C** → **DCR = 14 MHz per channel**

Cold-box

- Each Cold-box houses 16 SiPMs cooled at **-40⁰ C** by **Novec** 649 circulating in vacuum insulated lines
- Provides precise SiPM alignment
- Dry air flushing prevents ice formation (-70⁰ dew point)
- 3D print Ti bar design copes termal expansion

Greenhouse Warming Potential
Novec=1 & C_6F_{14}=10000

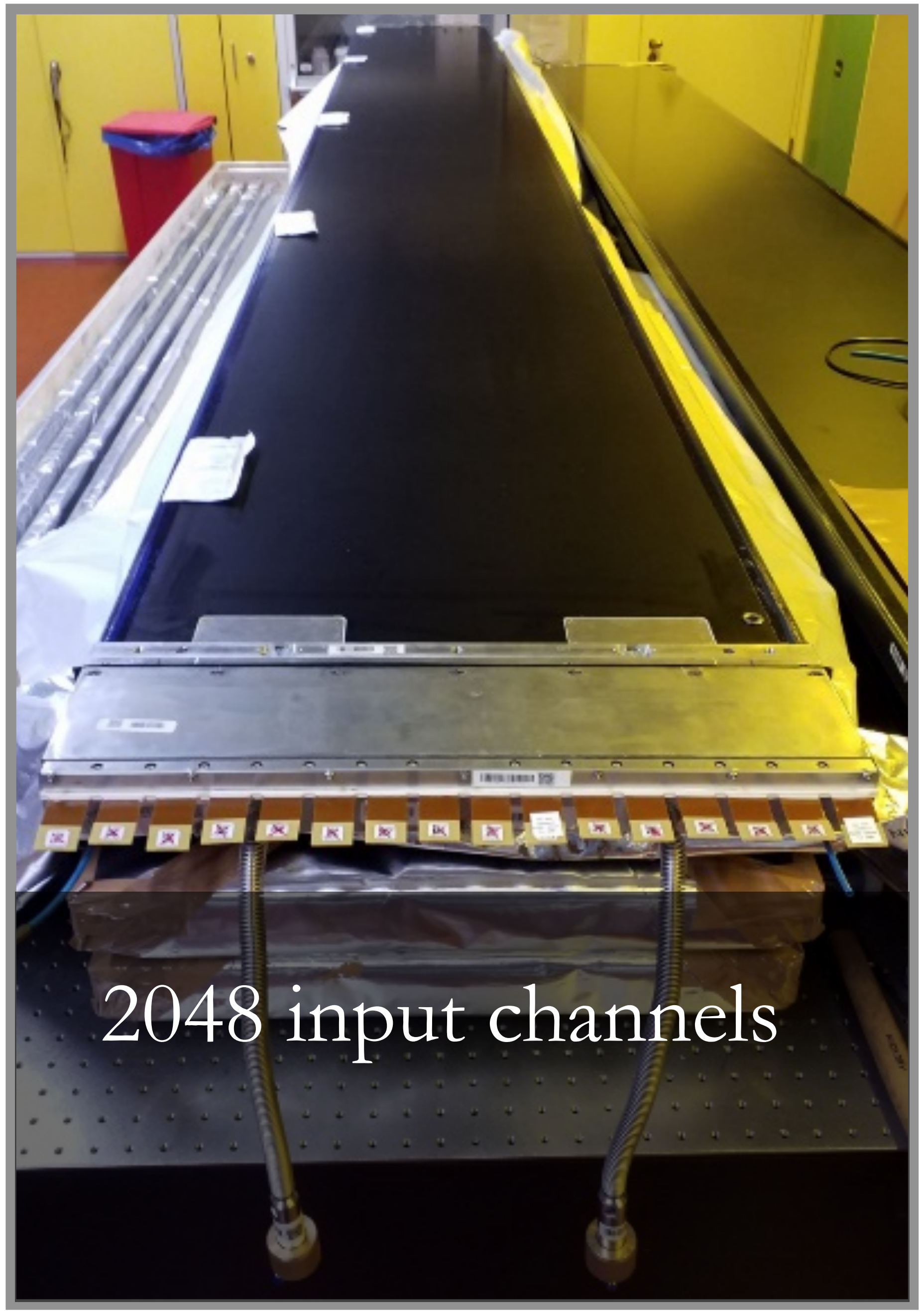


Fibre to Modules

Silicon Photomultiplier

Front-End Electronics

completed module



Challenges and Requirements

* 2048 channels @40 MHz per module

  288 units needed

  power consumption, high throughput

* large δ_{shape} SiPM signals (~18 p.e)
* signal exceeds 25 ns

  fiber length, mirror, SiPM tail

  fast shaping and integrators

* 14 MHz DCR/channel (-40^{0}C & radiation)

  efficient noise reduction

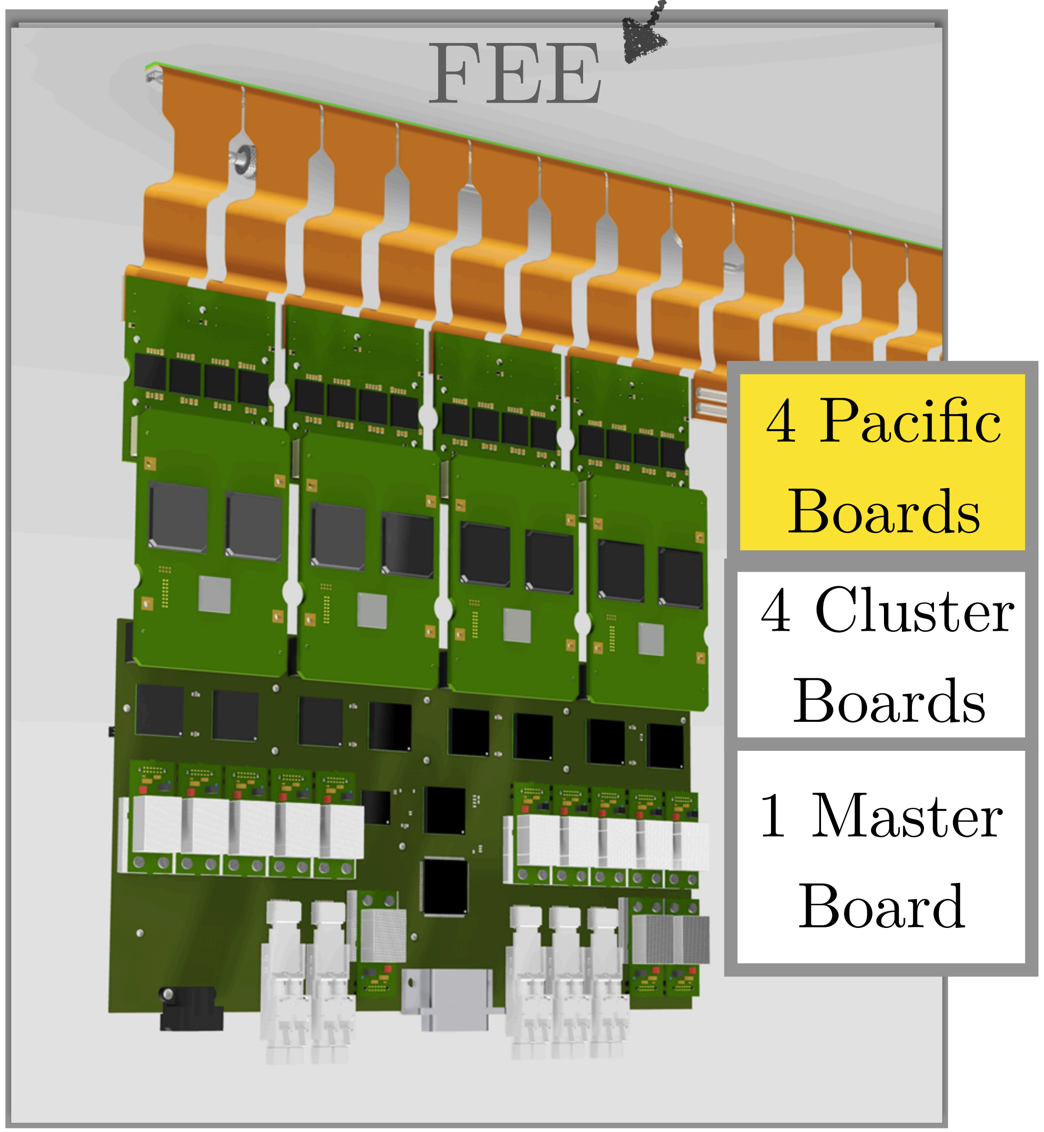
* Clusterization Algorithm

  spatial resolution, noise rejection, data compression

  "smart ADC" in digitization (optimizing bandwidth)

Front-End Electronics

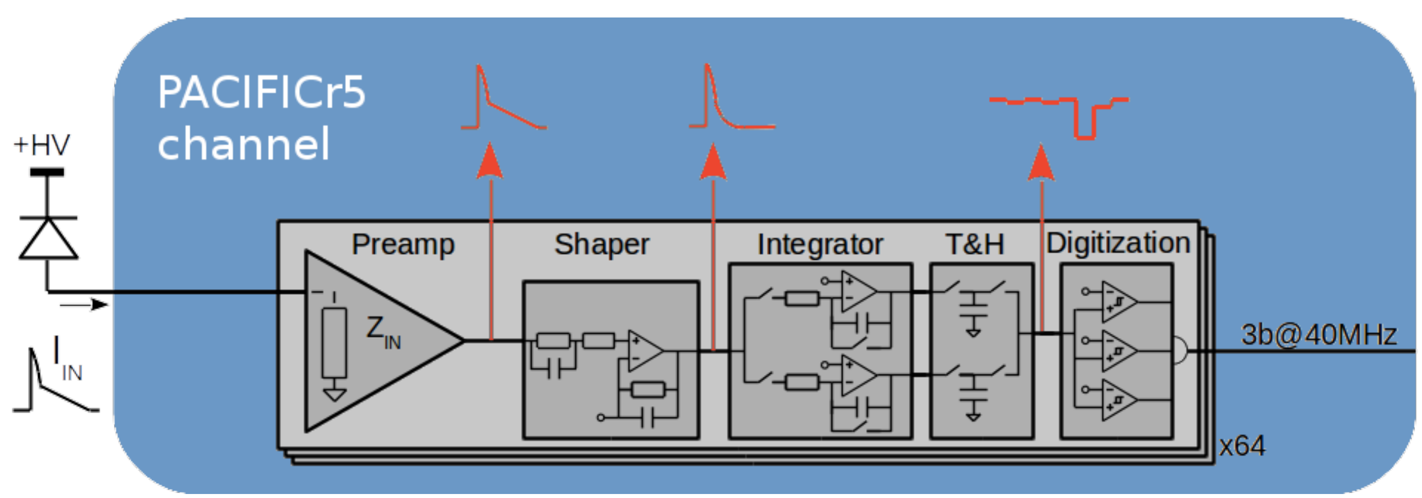
1 SciFi Module → 2 RoB → 2 FEEs

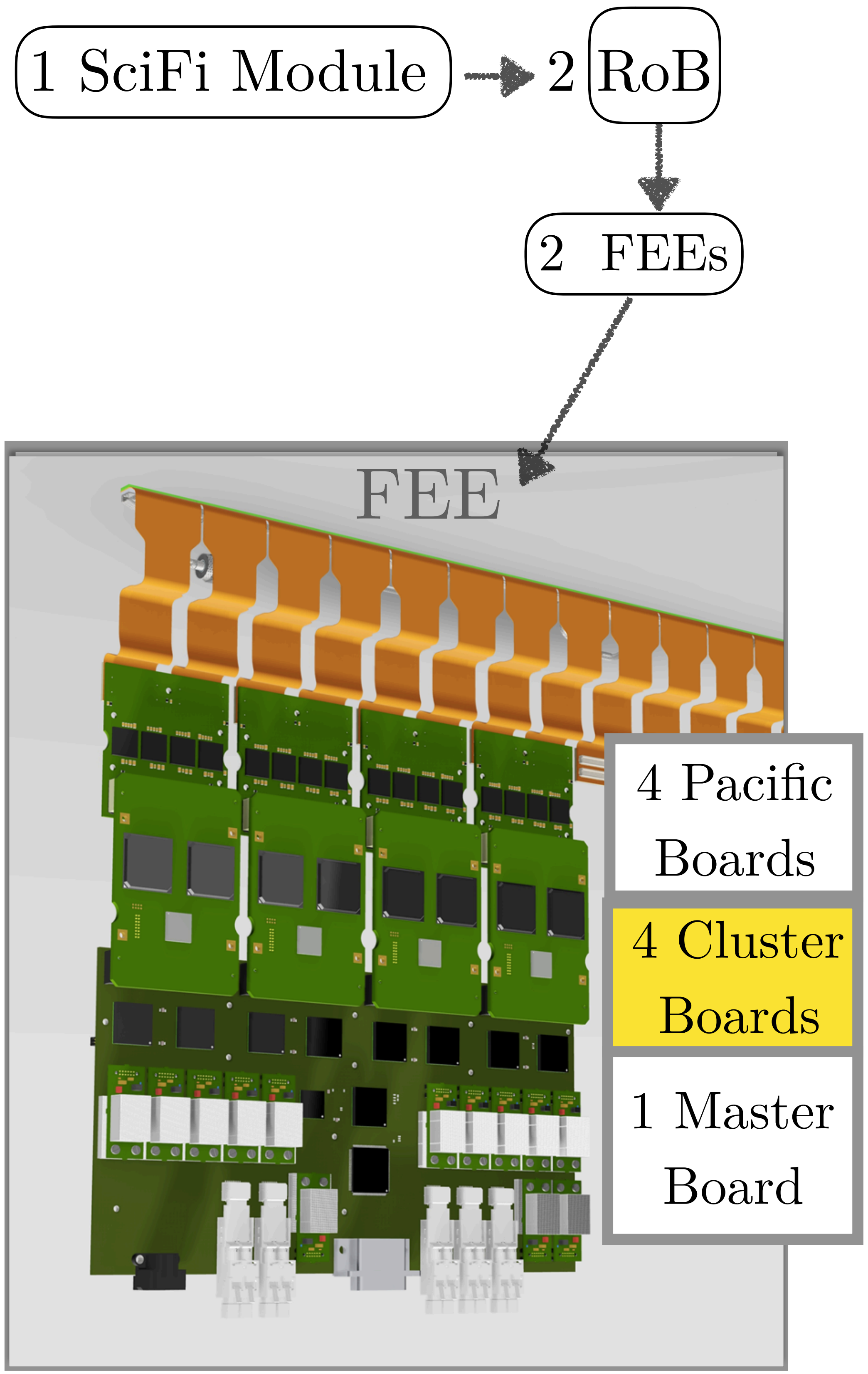


PACIFIC board

Analog and Digital

- 4 PACIFIC ASICs CMOS 130 nm technology
- 64 channel current mode input (10 mW/channel)
- Fast shaping to reduce spill over
- Double gated integrators to avoid dead time
- 2-bit/channel from 3 hysteresis comparators





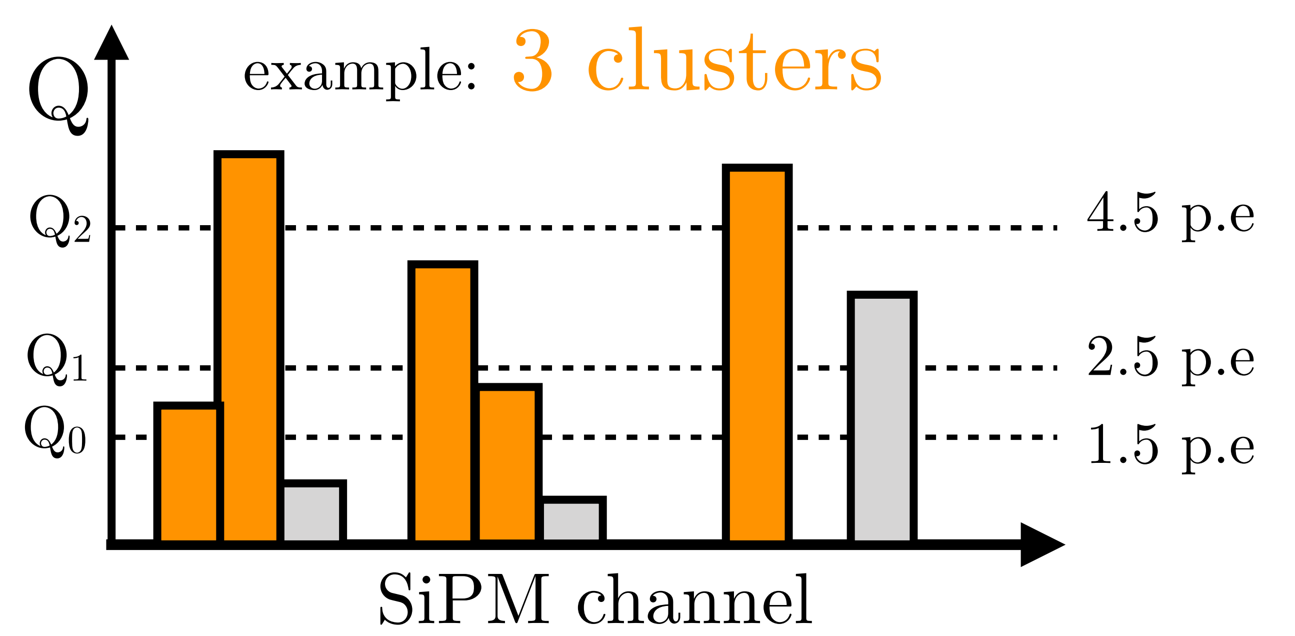
Cluster board

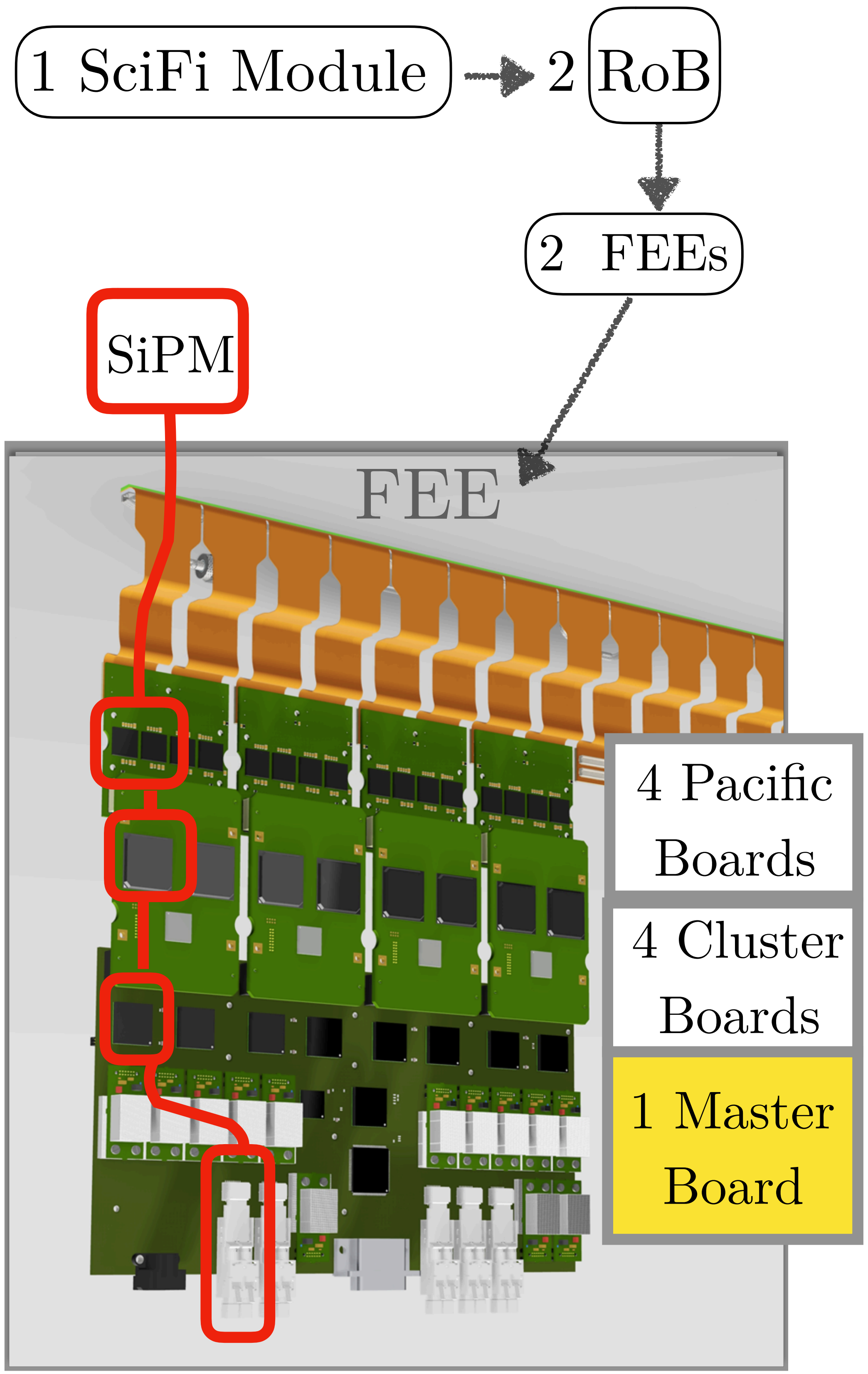
Clusterization Algorithm & Zero-Suppression

- 2 FPGAs Microsemi Igloo 64x
- Algorithm:

  Cluster criteria: $Q_{seed} > Q_1$ & $Q_{neig} > Q_0$ or $Q > Q_2$

  Position from cluster baricenter

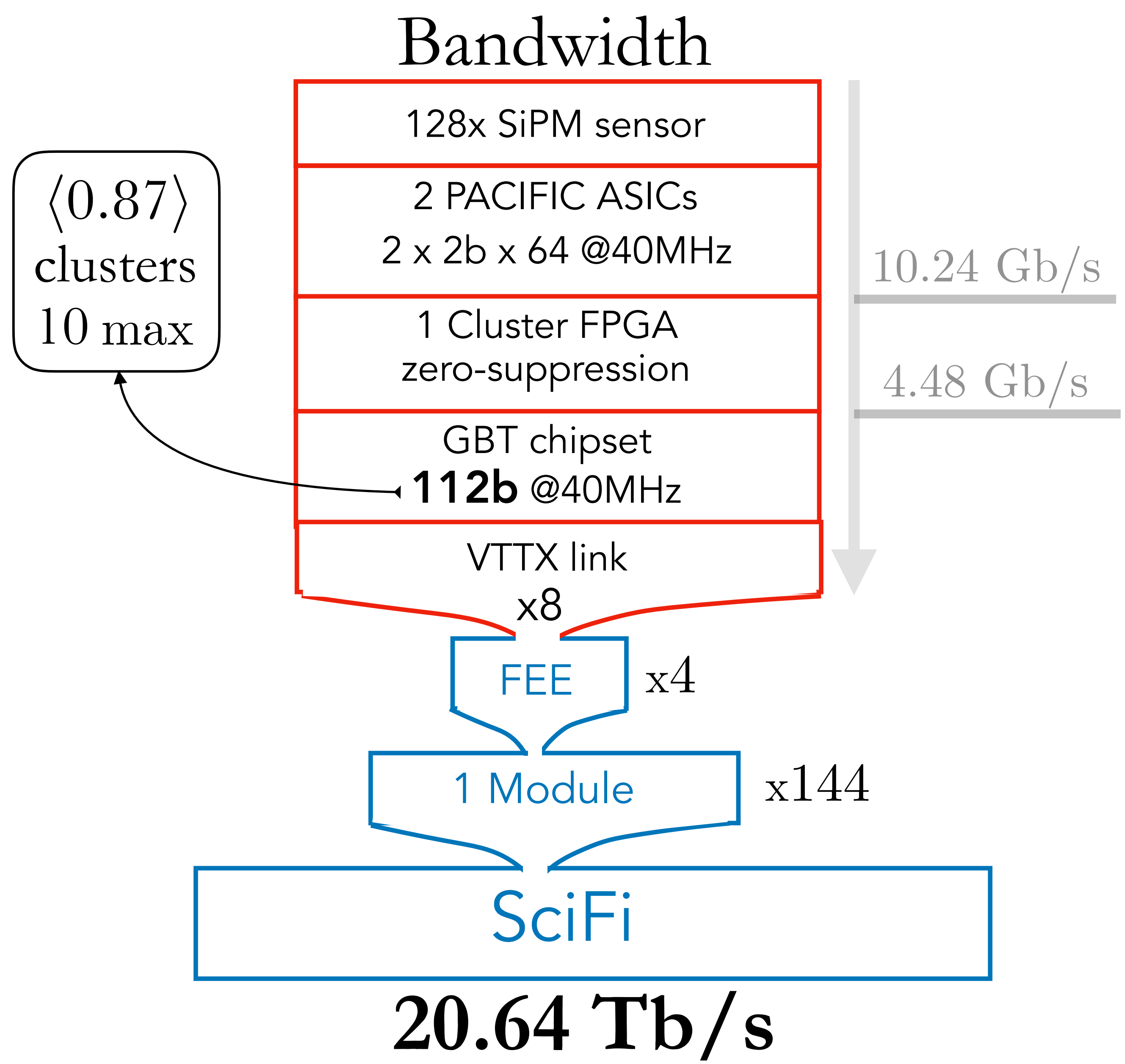




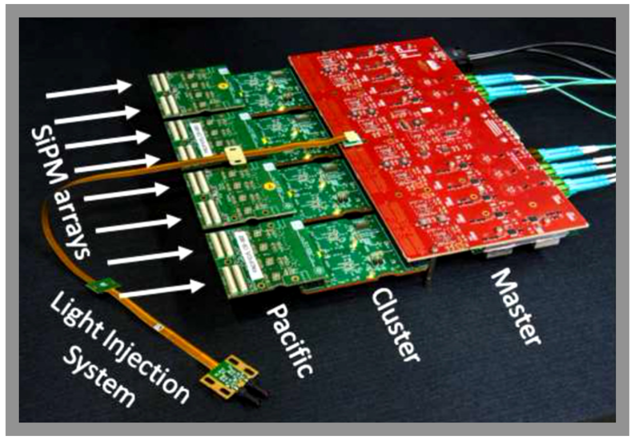
Master board

Data transmission & Slow/Fast control

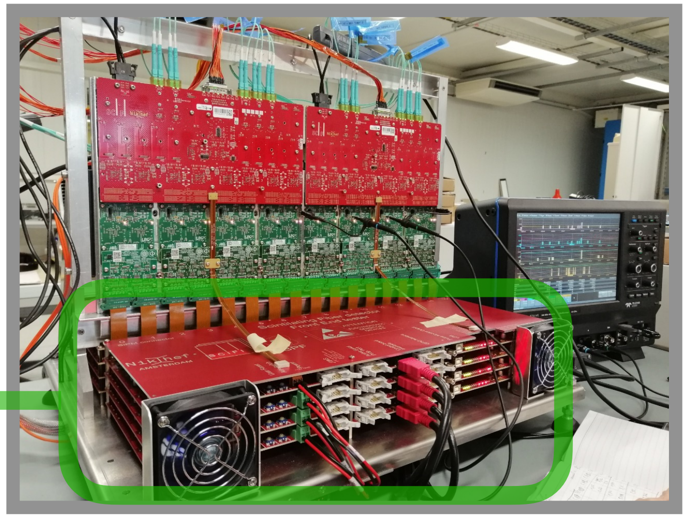
- 8+1 GBT chipset (data+control)



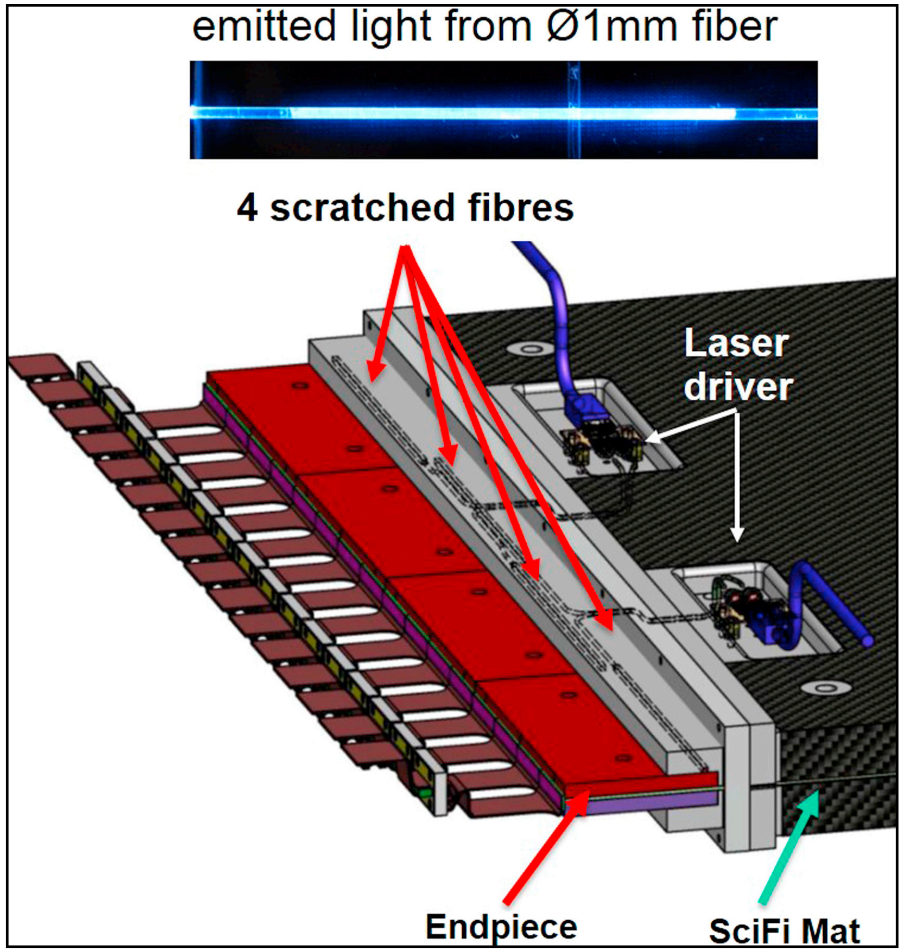
- **Front-End Electronics:**

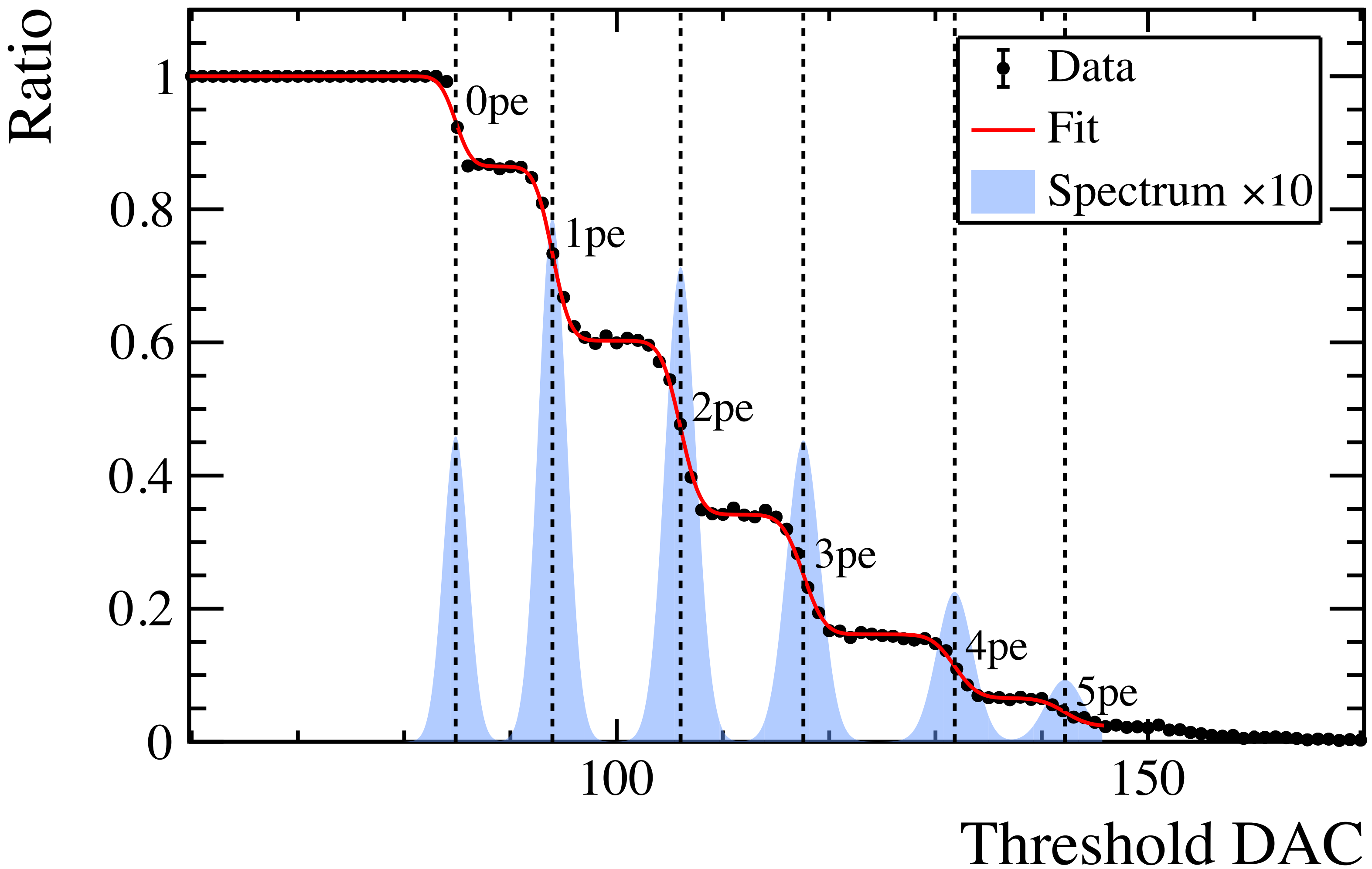


Test-system: 2048 independent pulse-injector channels to fully characterizes the RoB prior to the installation

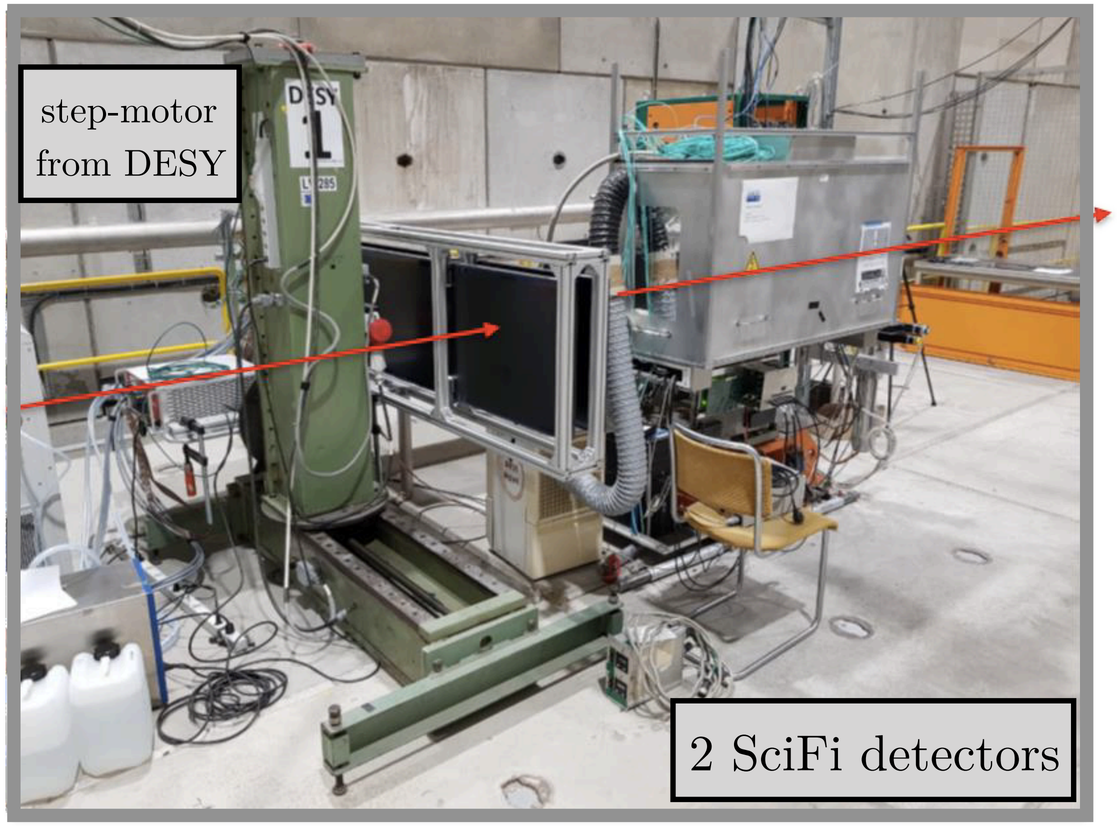


- **Full Module**: light pulse injection by laser driver triggered from FEE

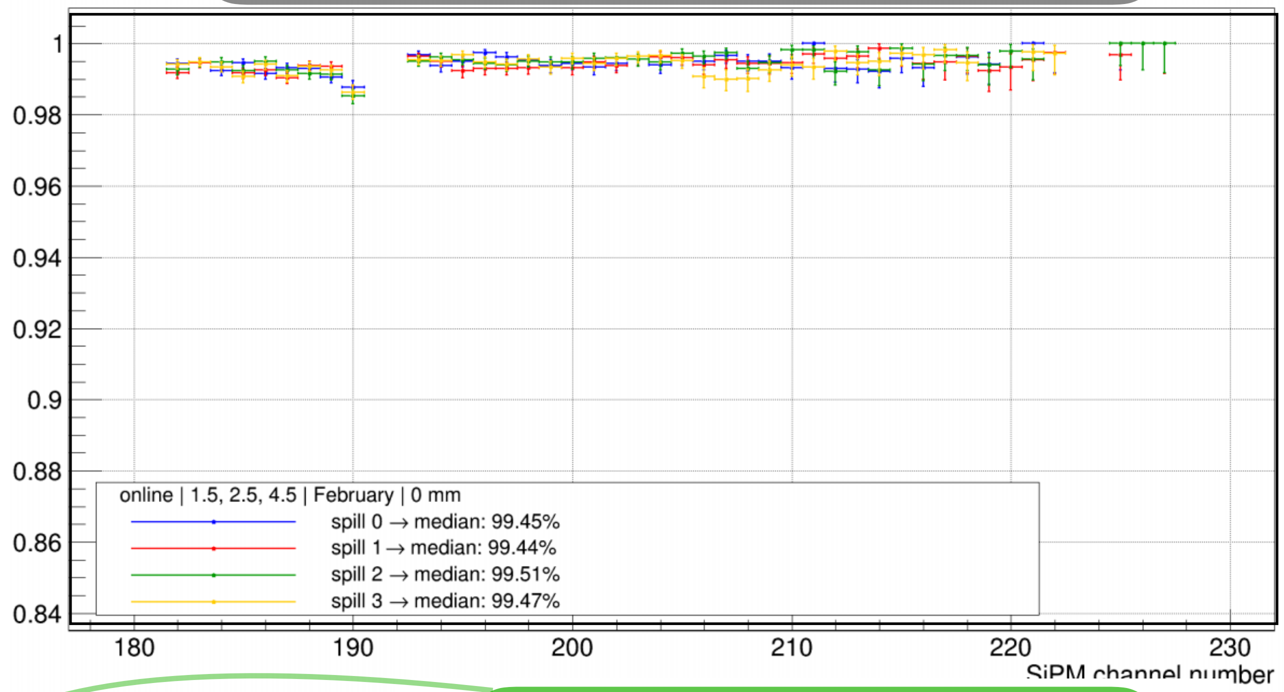


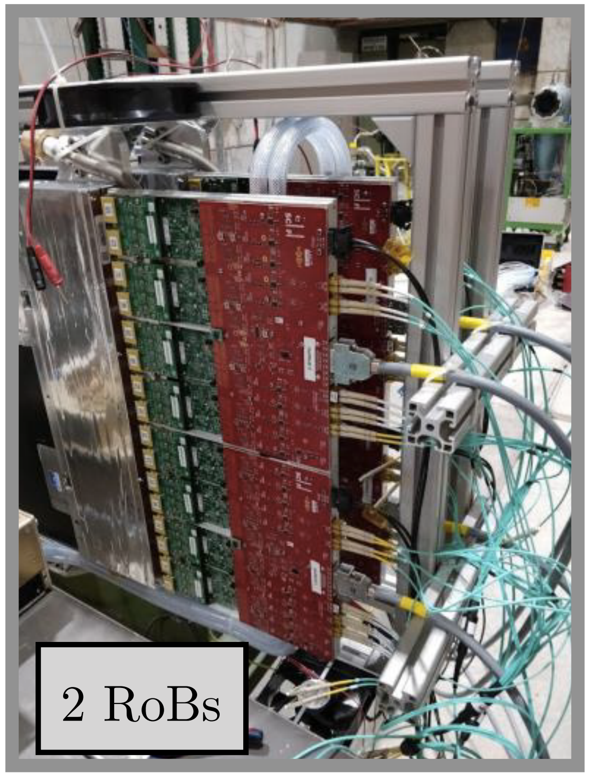


Performance



Cluster efficiency = **99.47%**

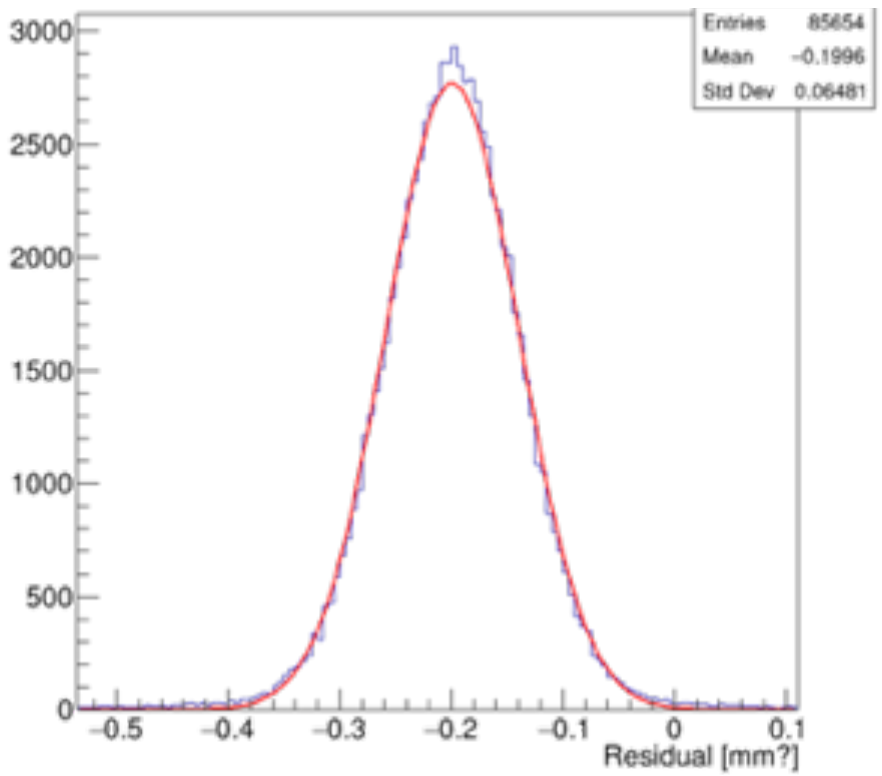




resolution without clusterization: $\frac{250\mu m}{\sqrt{12}}$ + manufacturing tolerances

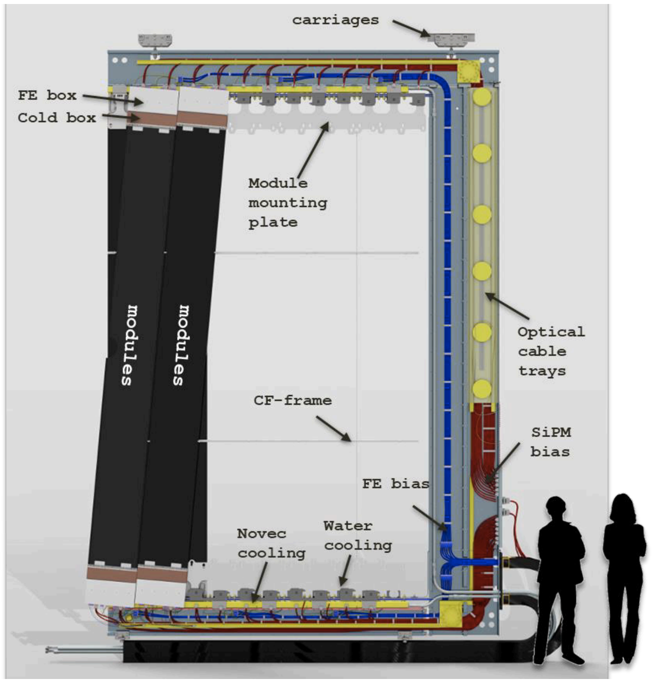
2 final Modules+FEE tested successfully with 450 GeV protons at SPS CERN in july 2018

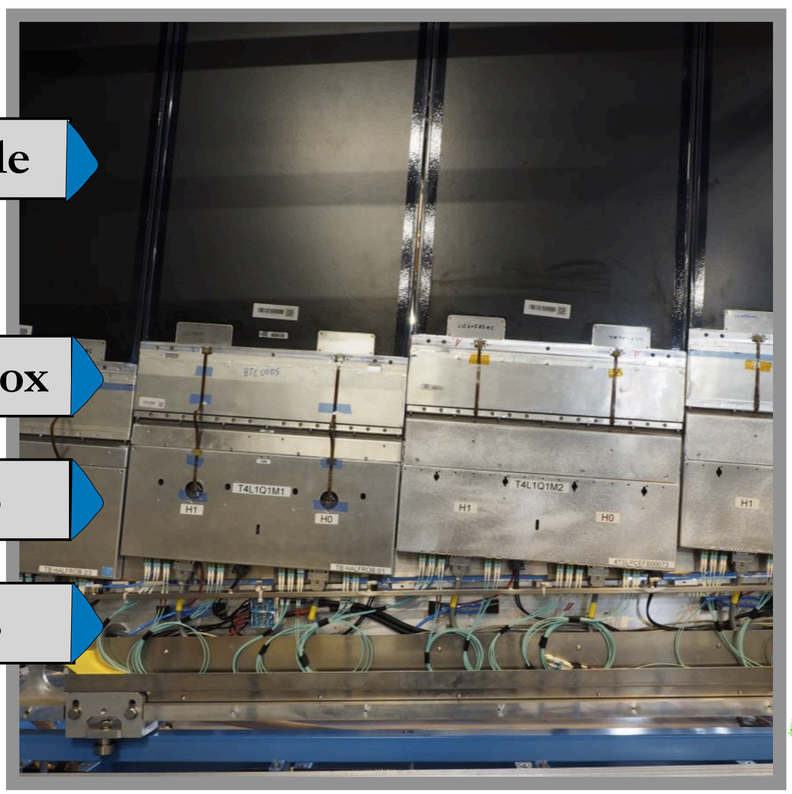
Resolution ~ **65 μm**

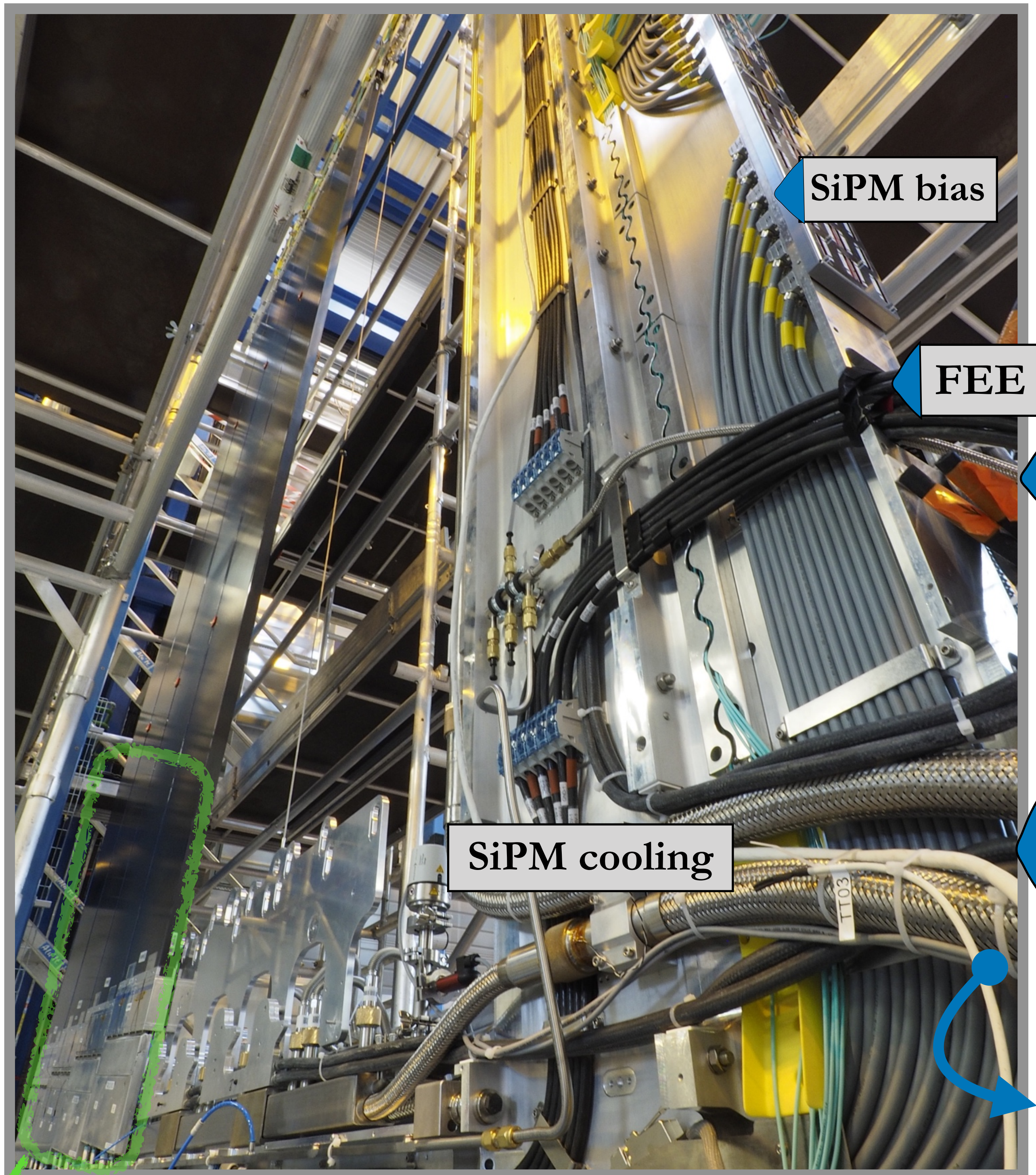


CFrames & Services

12 CFrames in total







Prototype in Spring 2019

Status & Challenges

Installation is ongoing well, to be completed in 2020

... half of CFrames before beam-pipe installation

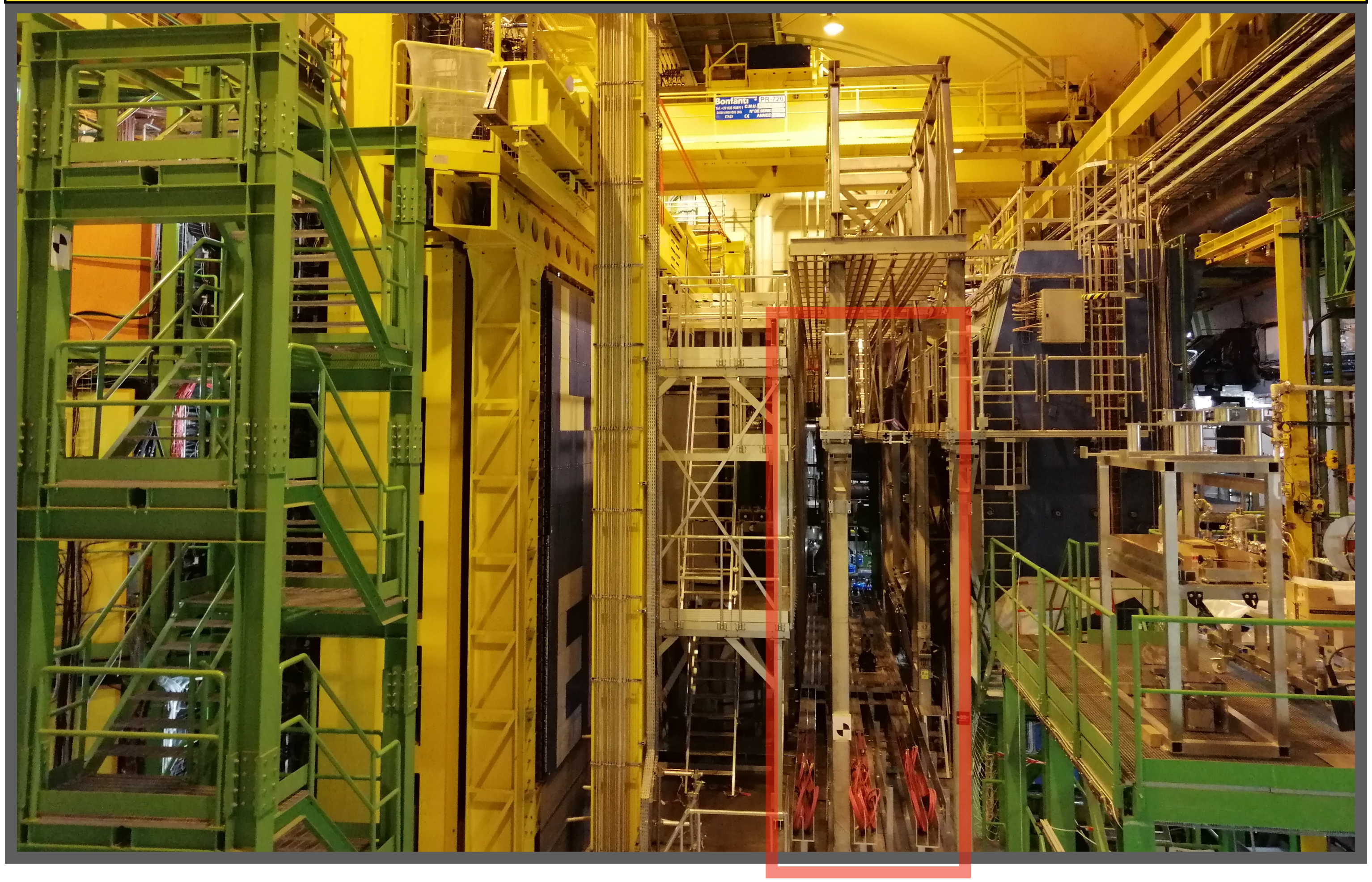
2 ready to go
2 almost there
2 just starting

@13 feb 2020

Assembly Hall

serial production of CFrames

LHCb Experimental Area



SciFi

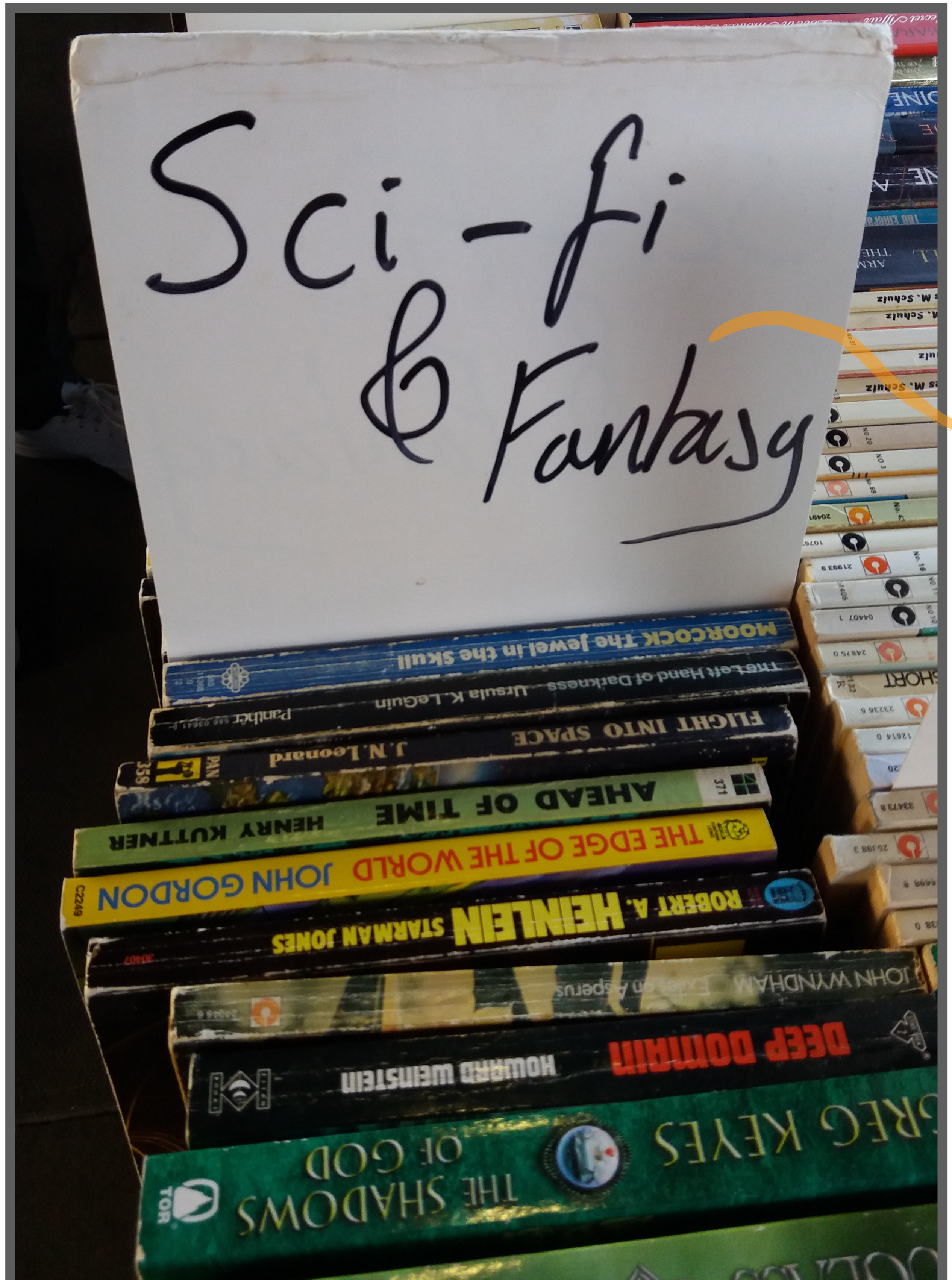
Summary

* The LHCb SciFi team is finalizing the construction of the largest Scintillating Fiber tracker ever build, able to run at 40 MHz.

* Detector installation scheduled for this summer and start of data-taking for next year.

* Collaboration composed by many people from 17 institutions.

* We have satisfied all Tracker requirements, as cluster efficiency and spatial resolutions, and overcome many challenges, mostly related to radiation environment we will face.

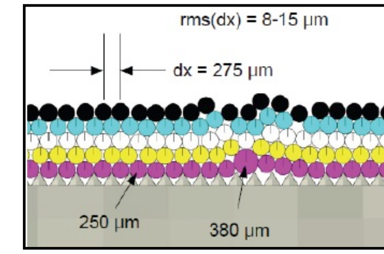

Sci-fi & Fantasy
MOORCOCK The Jewel in the Skull
The Left Hand of Darkness Ursula K. LeGuin
FLIGHT INTO SPACE
J.N. Leonard
AHEAD OF TIME
HENRY KUTTNER
THE EDGE OF THE WORLD
JOHN GORDON
ROBERT A. HEINLEIN
STARMAN JONES
JOHN WYNDHAM
DEEP DOMAIN
HOWARD WEINSTEIN
THE SHADOWS OF GOD

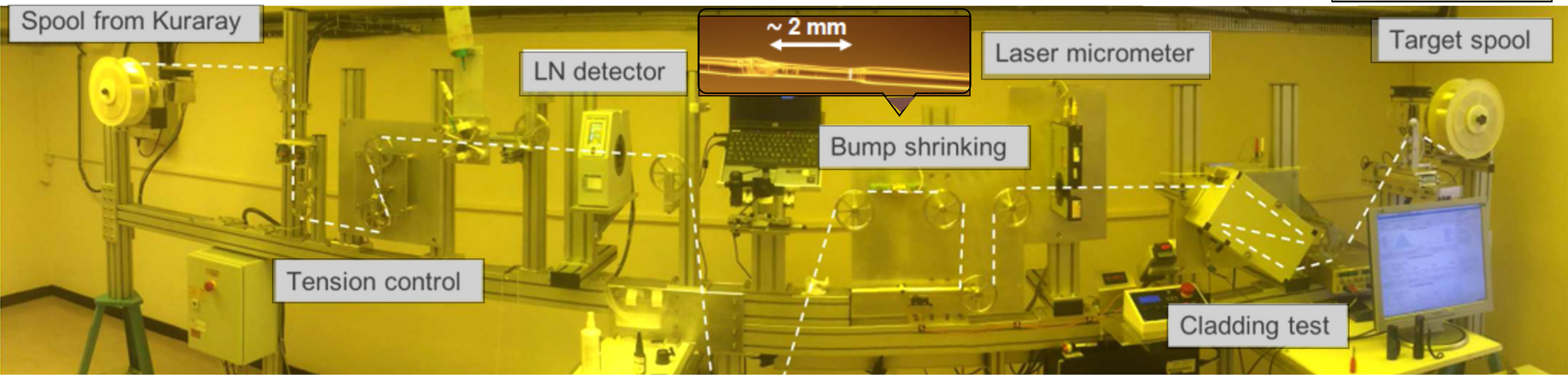
Reality

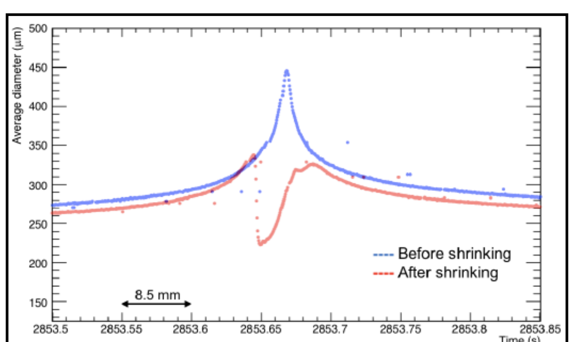
Backup slides

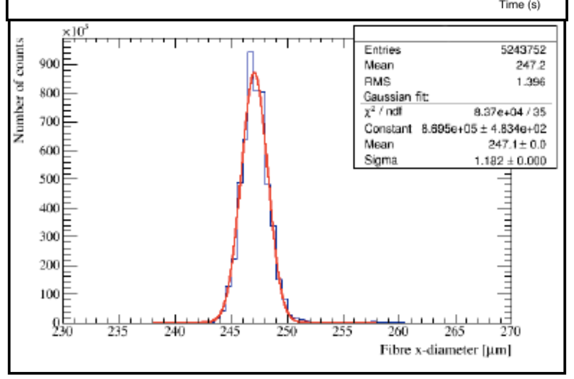
Scintillating fibers: Quality Assurance

- Diameter monitoring & cladding integrity & bump shrinking > 350 μm

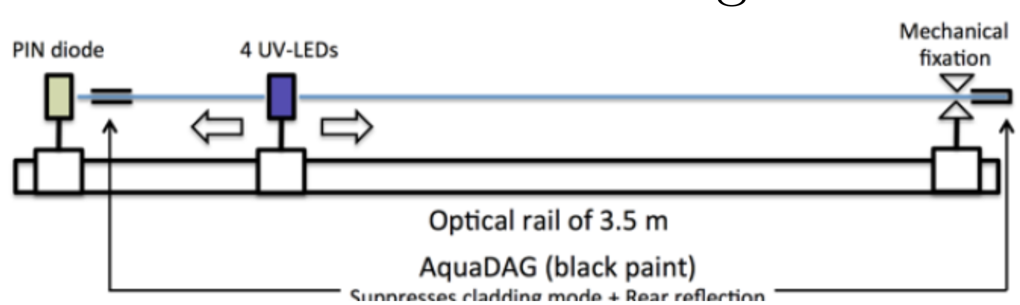






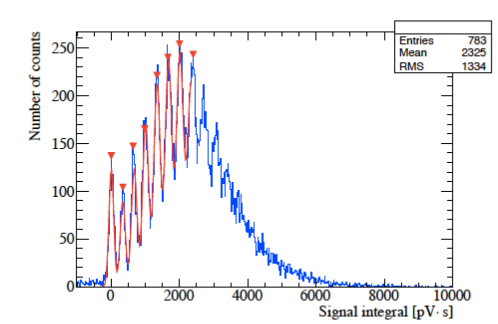


- Attenuation length



- Resistance to X-rays
- Minimum bending radius, decay time, natural aging *for a fraction of fibres*

- Ionization light-yield



10 p.e visible