SciFi

A large Scintillating Fibre Tracker for LHCb

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on behalf of the LHCb SciFi Collaboration

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The LHCb Upgrade

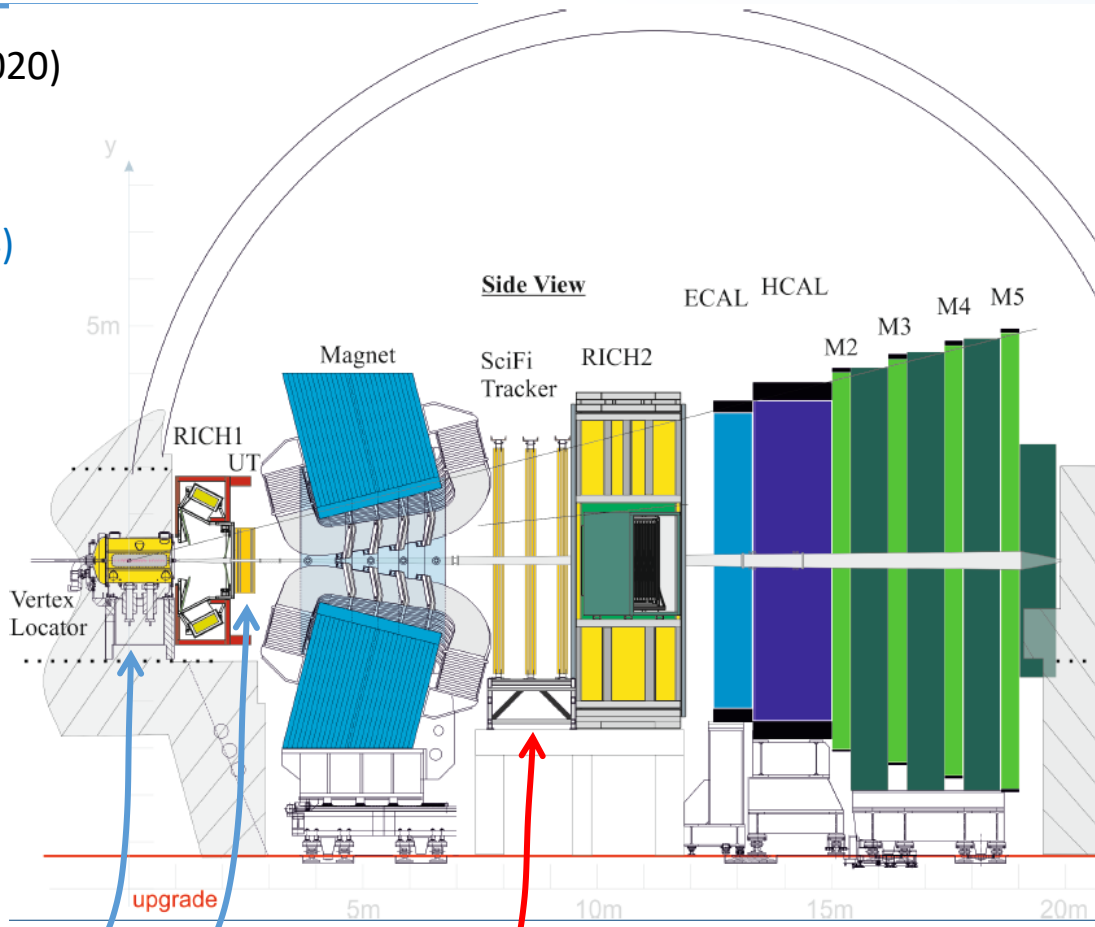
When: LHC Long Shutdown 2 (2019 – 2020)
For Runs 3 & 4 (2021 – 2029)

Why: To increase statistics
9 fb^{-1} (Runs 1-2) → 50 fb^{-1} (Runs 1-4)

How: Increasing instant. luminosity
5x higher → $L_{inst} = 2x10^{33}\ cm^{-2}s^{-1}$
Increasing readout rate
1 MHz → 40 MHz

This requires some **main changes:**

- Replace all the electronics:
  - No more hardware trigger
  - Event selection in software
- Replace the whole tracking system:
  - Vertex Locator → **Upgraded VeLo**
  - Tracker Turicensis (TT) → **UT**
  - **Outer & Inner Trackers (T1&T2&T3) → SciFi**



Outer & Inner Tracker
Upgrade
SciFi Tracker

The Tracker Occupancy Problem

Why change the tracker?

Luminosity increases

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Occupancy becomes too high

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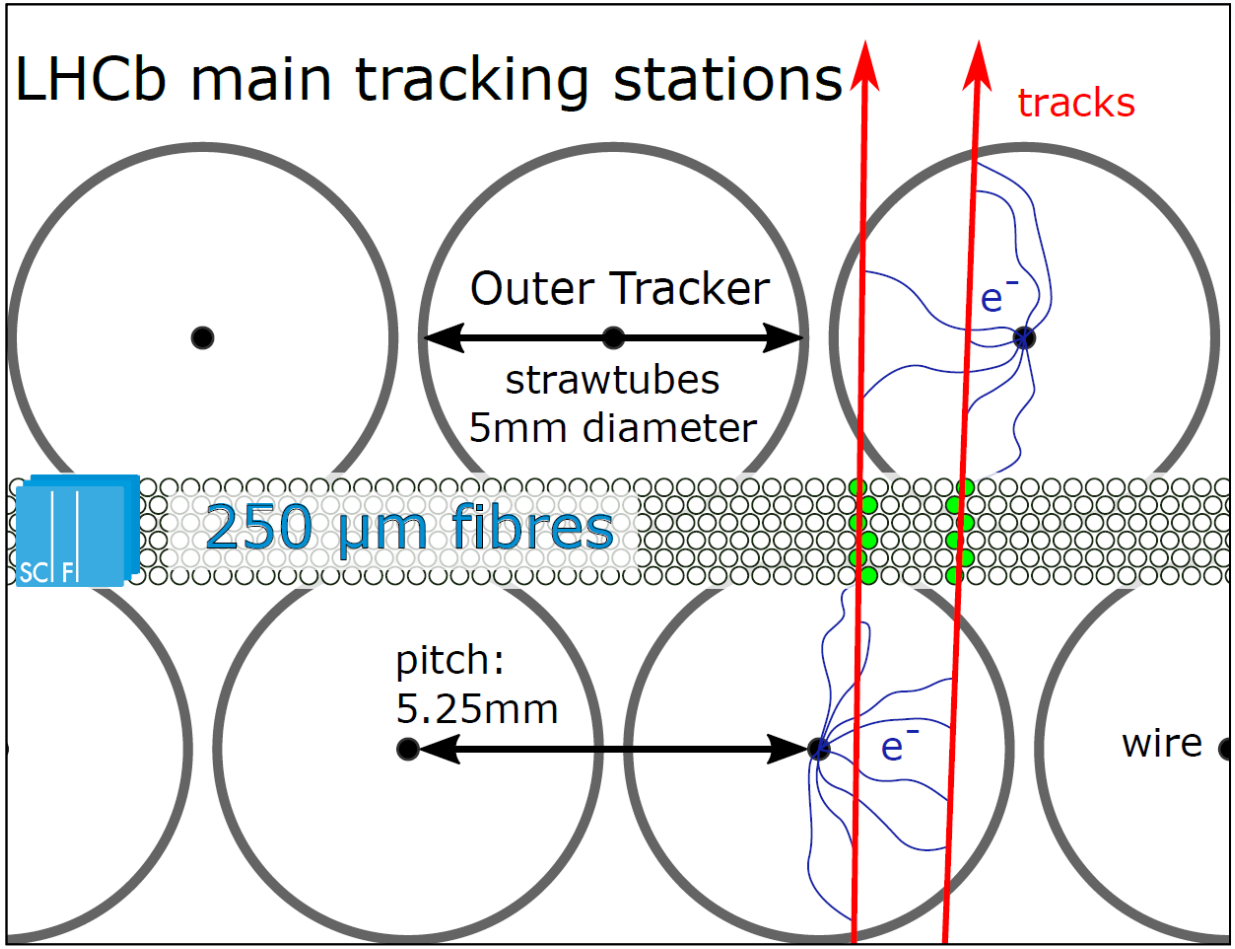
Track finding efficiency is significantly affected

SOLUTION

Build a detector with narrower channels, id. est.:

HIGHER GRANULARITY

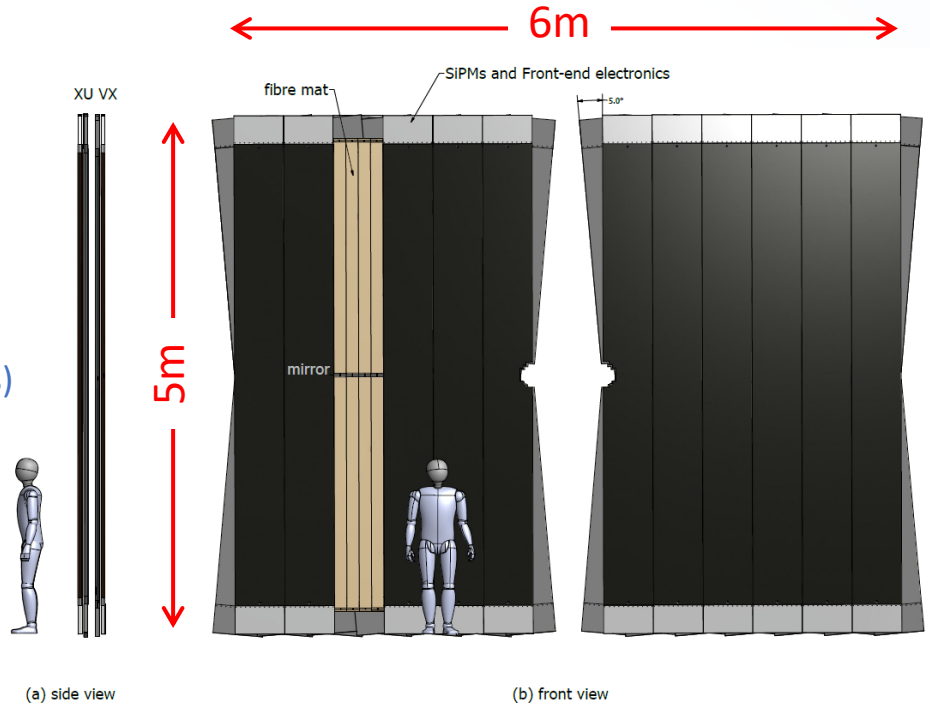


SciFi – Scintillating Fibre Tracker

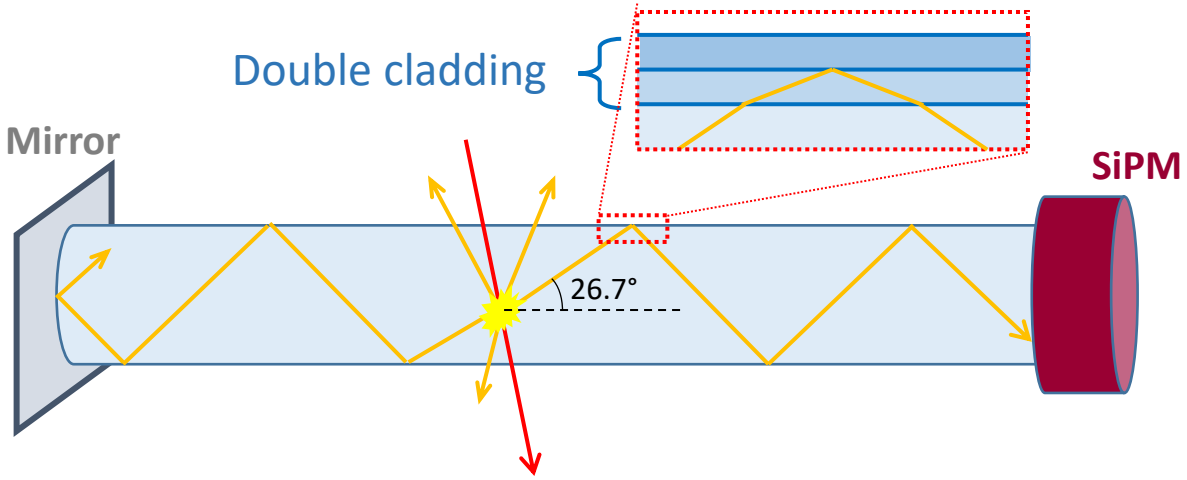
REQUIREMENTS	
Hit efficiency:	>99%
Resolution:	<100µm
Readout rate:	40MHz, no dead time
Material budget:	(X/X0) ≤ 1% per layer
Radiation:	35 kGy (fibres close to beam)
	6×10^{11} n_{eq}/cm^2 (SiPM / electronics)

CHARACTERISTICS

- 3 Tracking stations
  - 4 layers per station
    (Angled 0˚, -5˚, +5˚, 0˚)
- ~4.5 million fibres of 2.4m
- 4096 SiPM arrays
- 524 k readout channels



Scintillating Fibres



$$\varepsilon_{trap} \geq \frac{1}{4\pi}\int_0^{26.7^\circ} 2\pi \sin\theta d\theta = 5.4\%$$

Scintillation yield: dY_g/dE = 8000 ph / MeV $\rightarrow Y_g = 320$

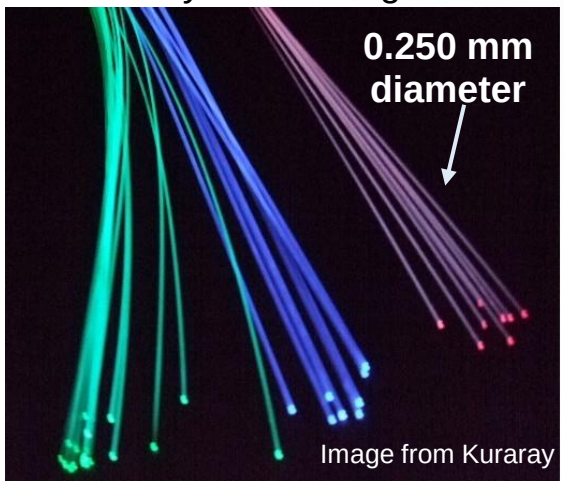
Trapping inside fibre (1 hemisphere): 5.4% $\rightarrow Y_g \sim 16$

Attenuation losses over 2 m: 50% $\rightarrow Y_g \sim 8$

Efficiency of photodetector (SiPM): 45% $\rightarrow Y_{p.e.} \sim 3$

Considering 6 layers of fibres $\rightarrow$ **$Y_{p.e.} \sim 15$**

Kuraray Scintillating fibres



TRADE-OFF

More layers of fibres

⇩

More light → **Higher efficiency**

⇩

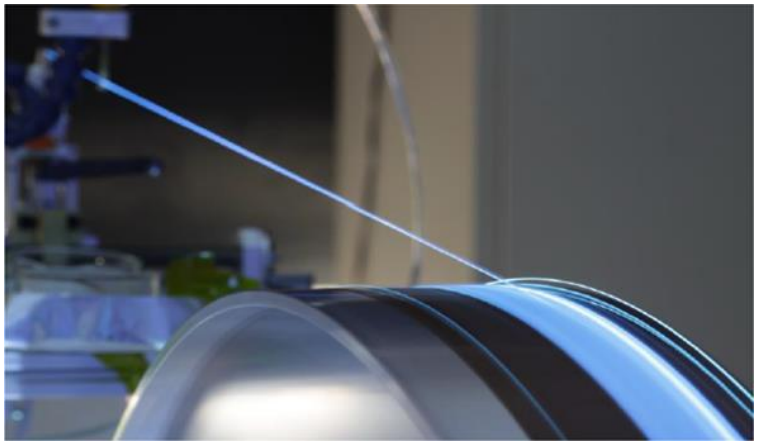
More material → **More scattering**

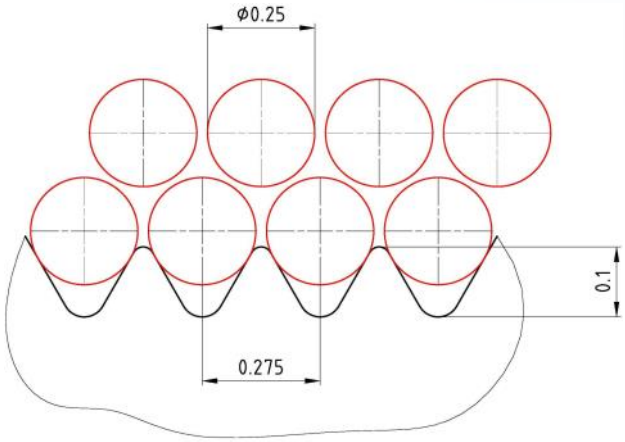
(Limited by SiPM Geometry)

6 layers proved to be optimal!

SciFi Modules

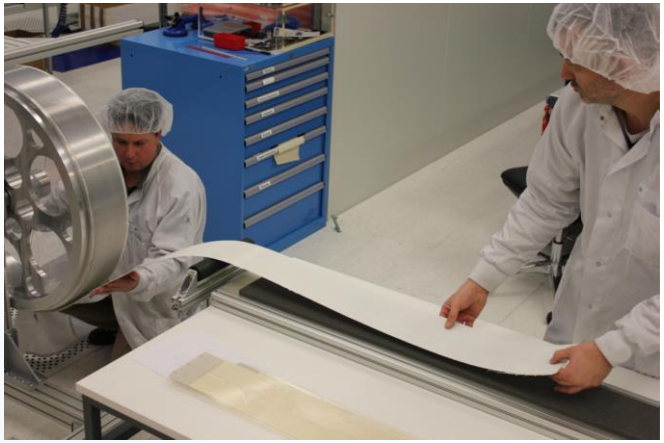
A threaded winding wheel with 275 µm pitch is used to place and glue the fibres together





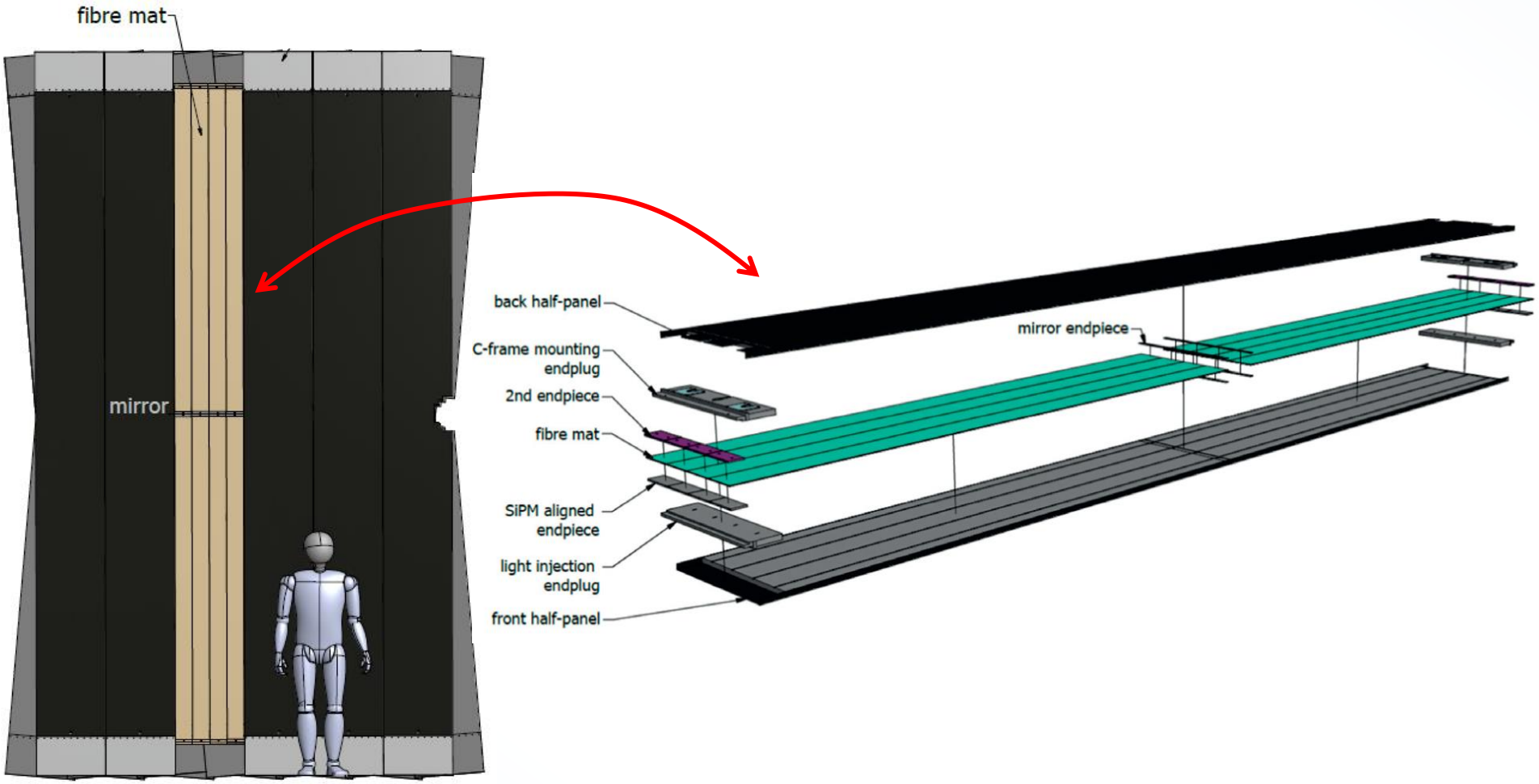
The fibre mats are cut off the wheel and glued together on the modules.

A module is 5 meters long and comprises 2 groups of 4 mats of 2.4m. Such groups are separated by a mirror in the middle of the module.



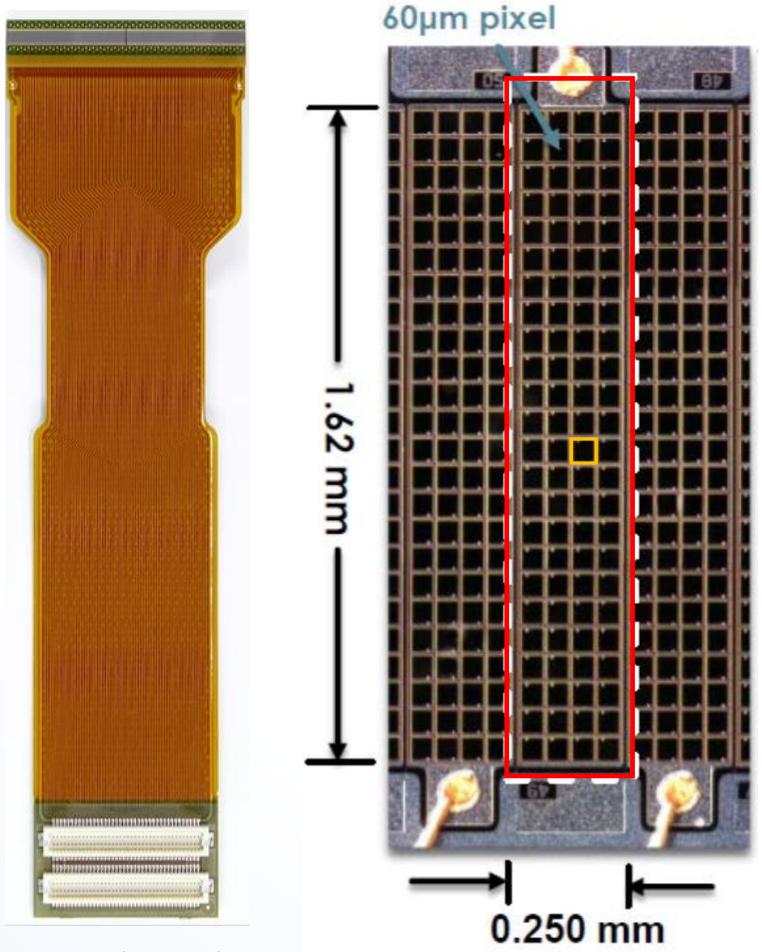
SciFi Modules

Four million fibers, of 2.4 m length, aligned in parallel within a range of 50µm.



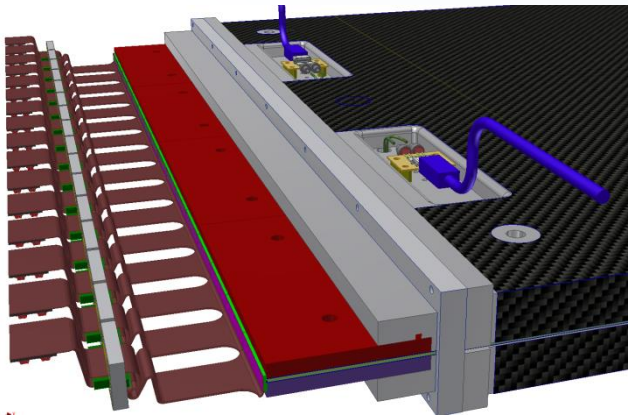
SiPMs - Silicon Photomultipliers

Light from the fibres are then detected by SiPMs placed in both sides of the modules.



1 channel = 104 pixels

16 SiPMs per module end



SiPMs optimised for:

- High PDE (large pixels)
- Low after-pulse and cross-talk
- Thin entrance window (105 µm epoxy)

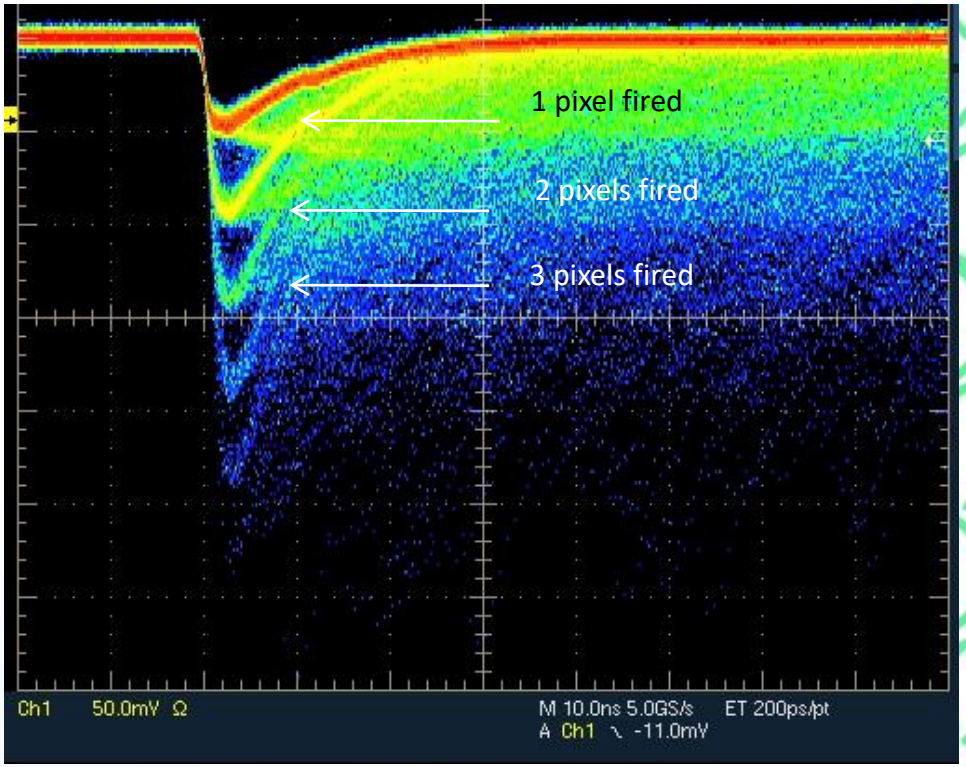
Performance:

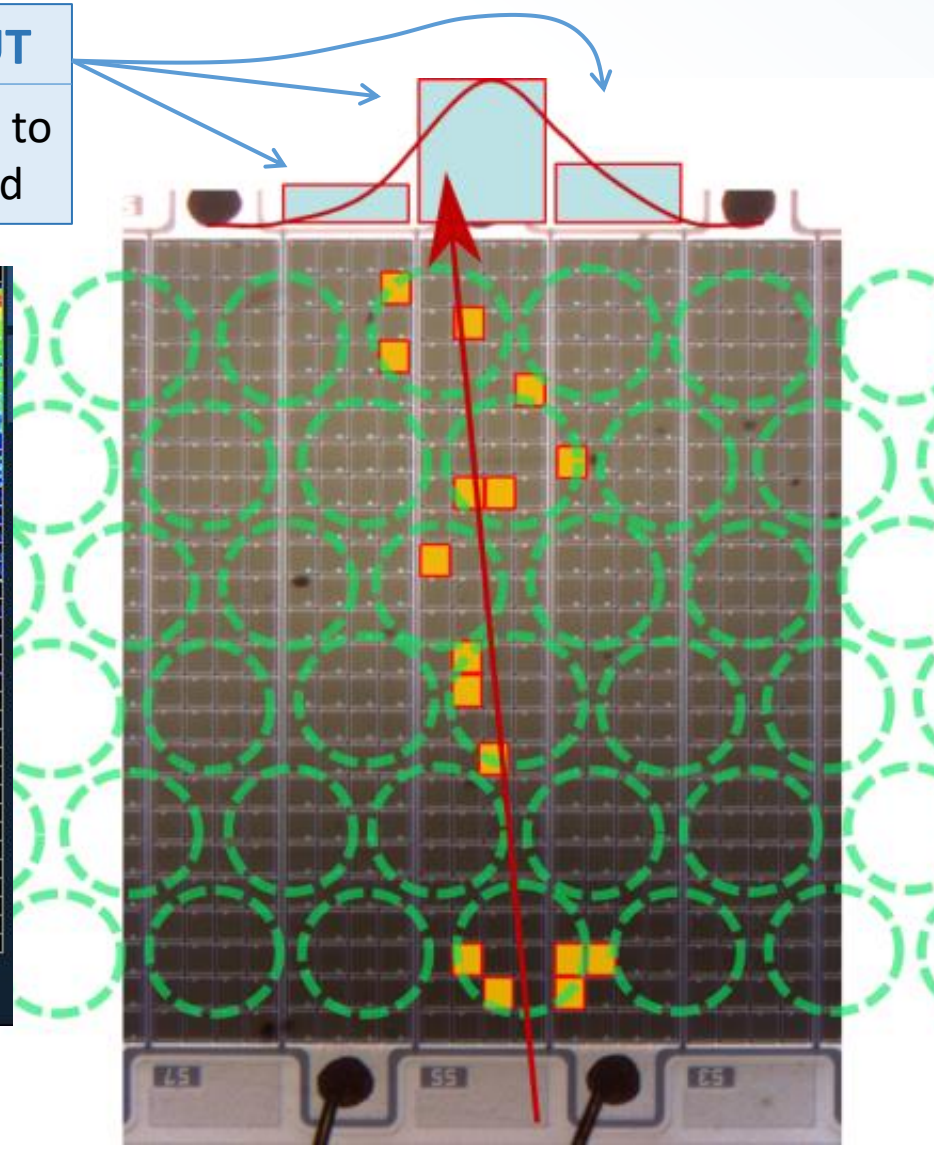
- Peak PDE = 45% (at ΔV = 3.5 V)
- After-pulse < 0.1%
- Direct cross-talk ~ 3.5%
- Delayed cross-talk ~ 3%
- Total correlated noise = 7% (at ΔV = 3.5 V)

SiPMs - Silicon Photomultipliers

CHANNEL OUTPUT

Charge proportional to amount of pixels fired





SiPMs – The Noisy Problem

PROBLEM

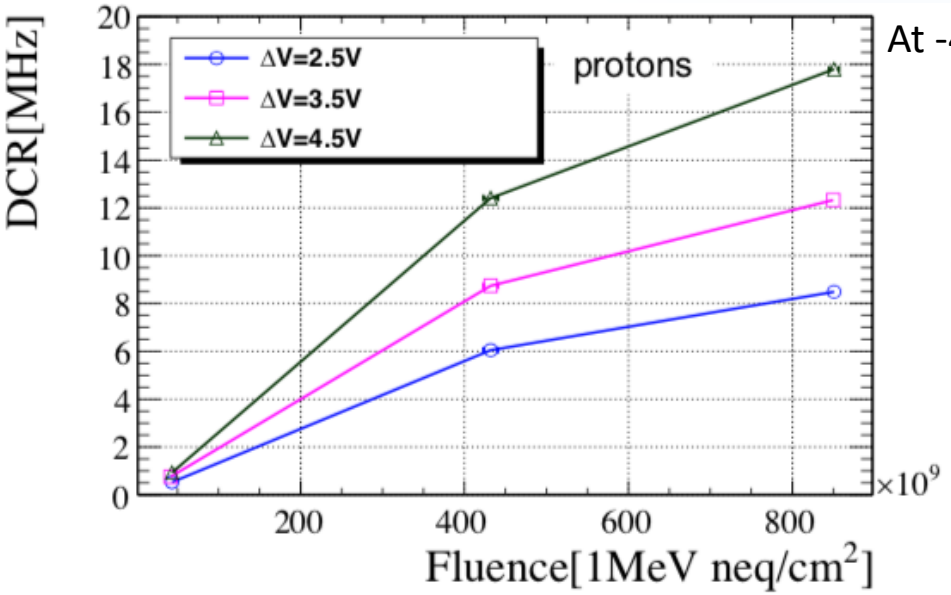
Dark Count Rate increases with radiation

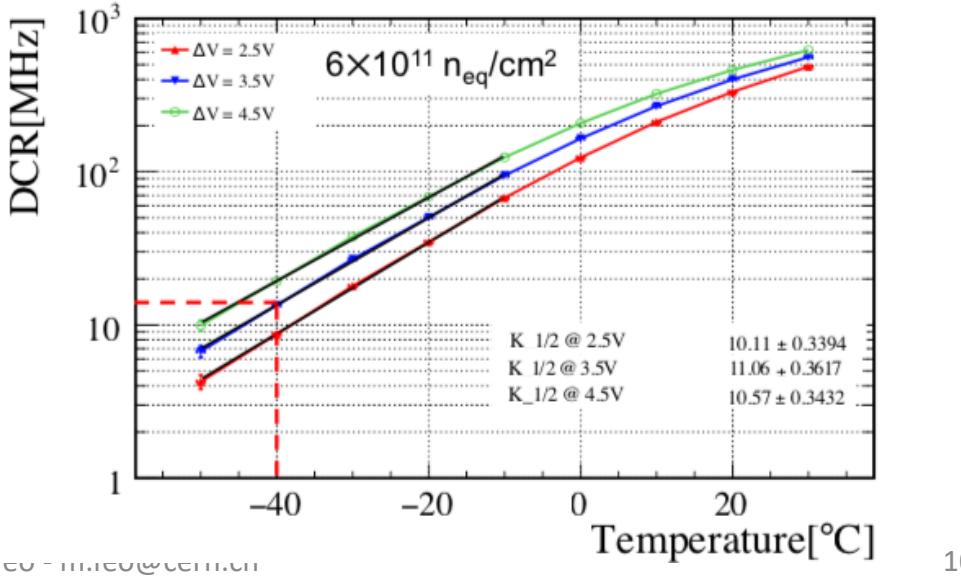
Would become unbearable with the expected dose for the SciFi (6×10^{11} n_{eq}/cm^2)

SOLUTION

COOL DOWN TO -40˚C

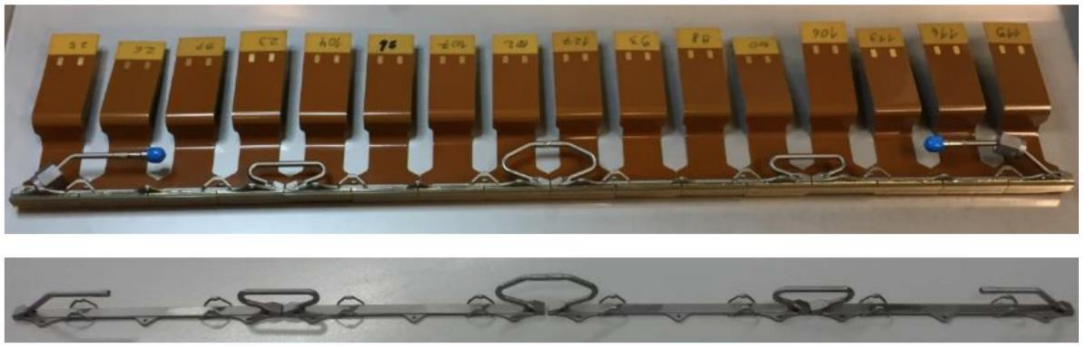
At -40˚C the DCR is low enough to not affect our tracking efficiency significantly

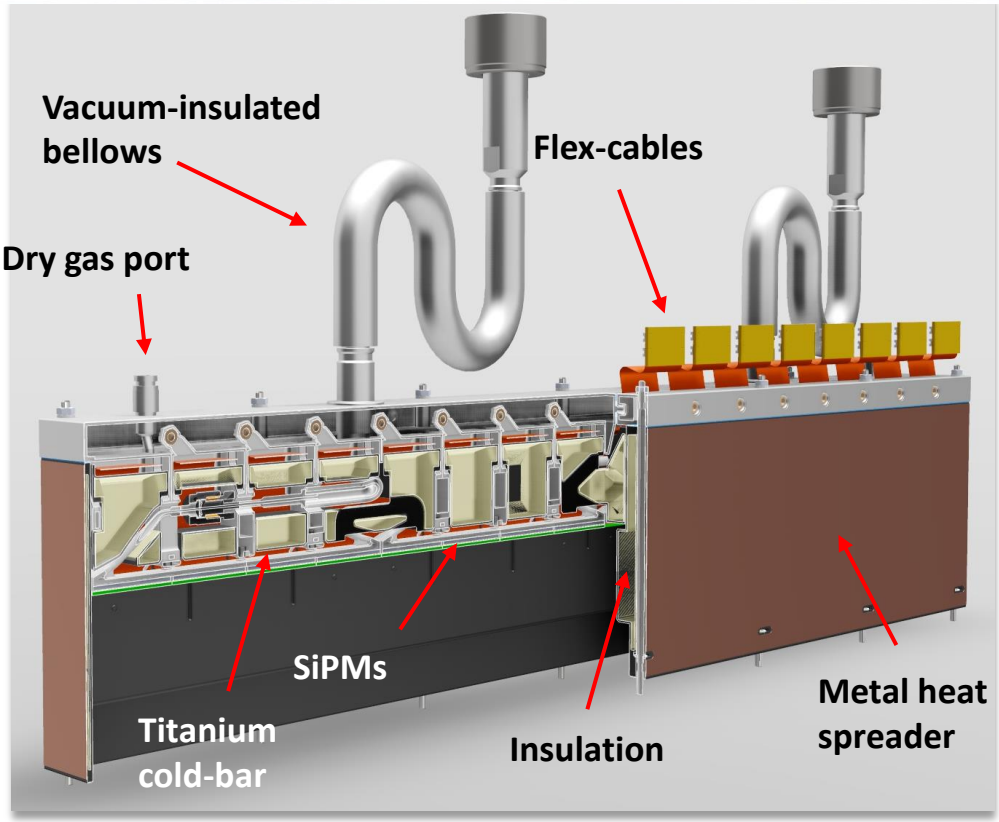




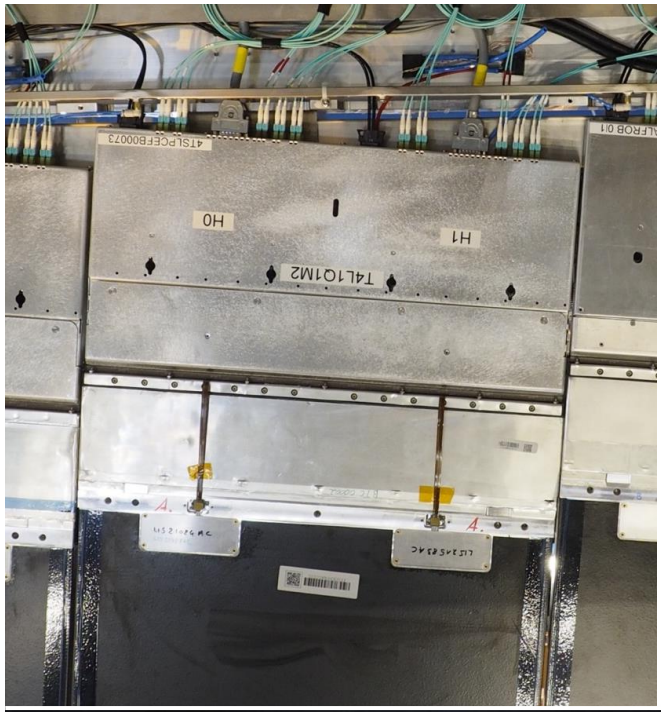
Coldbox

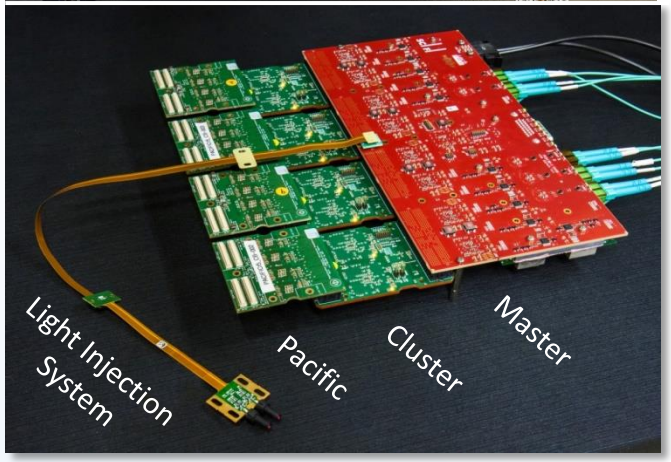
- 3D printed box
- Thermal insulation
  - Keep SiPMs at **-40˚C**
  - Prevents condensation
- SiPMs structure
  - Mechanical support
  - Alignment
- Flushed by dry gas
  - Prevents ice formation
- 3D printed titanium cooling ~~pipe~~ bar

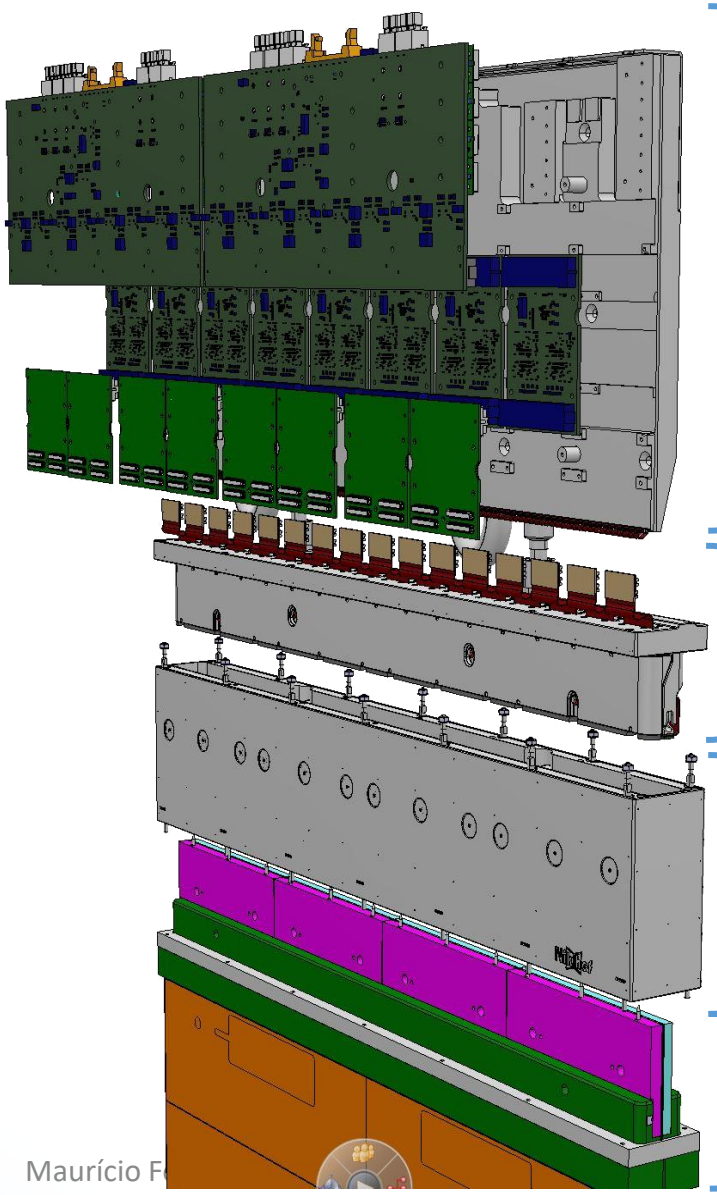




The SciFi Readout Box







Electronics

- Master Board
- Clusterization Board
- PACIFIC Board

SiPMs

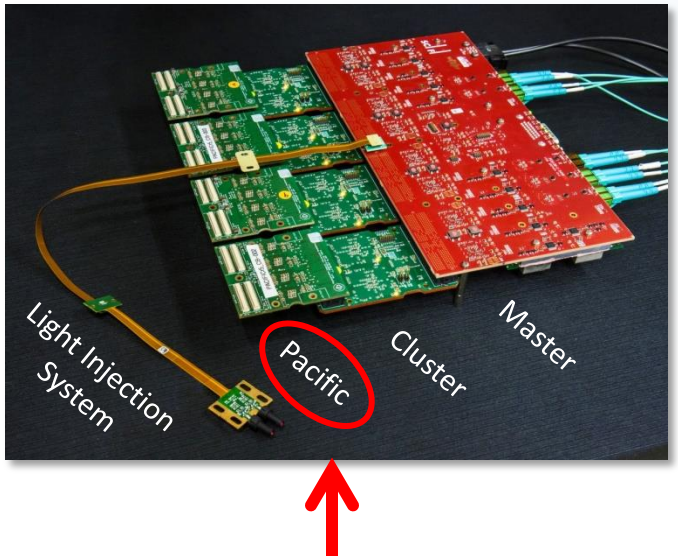
- and flex cables

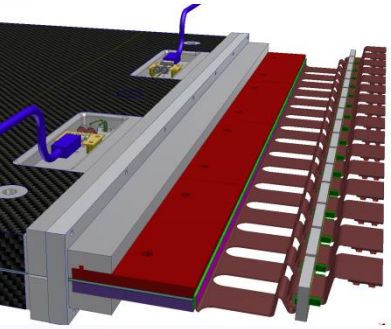
ColdBox

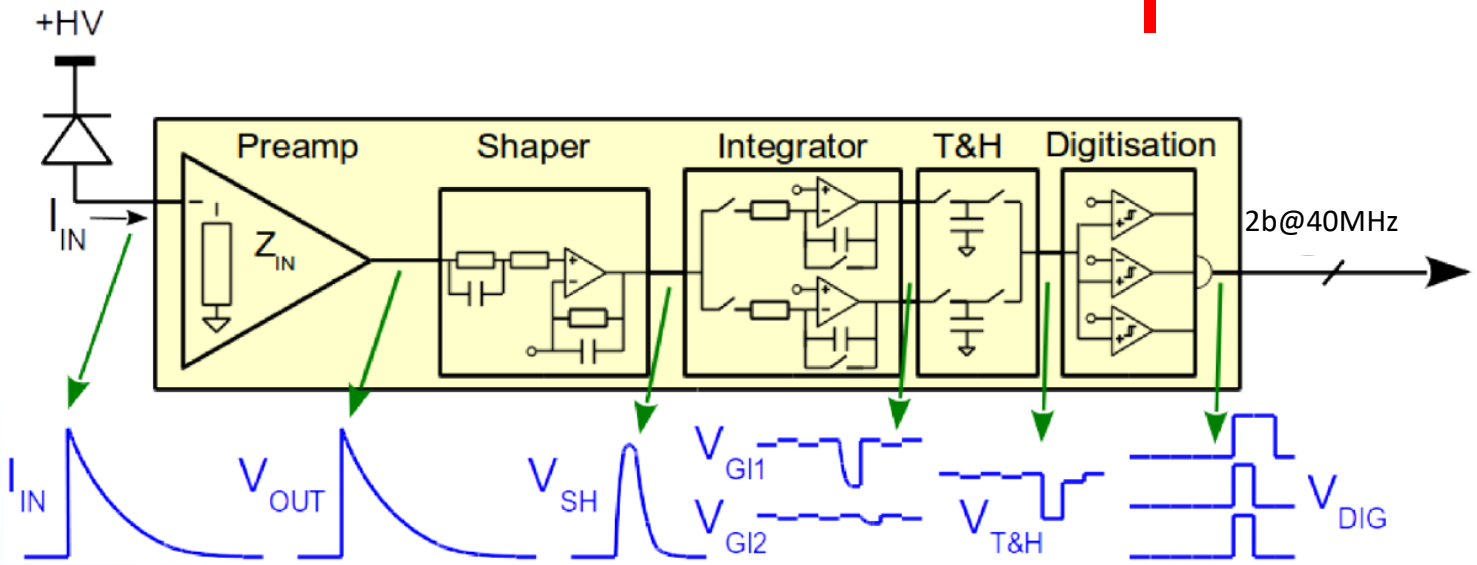
Fibre Module

The PACIFIC chip

- **P**ower **A**SIC for the s**CI**ntillating **FI**bres tra**C**ker
- ASIC responsible for the reading of the SiPMs
- Radiation tolerant
- 64 chanels @ 40MHz input
- 2 bits/chanel output
- 8mW/chanel
- I^2C control

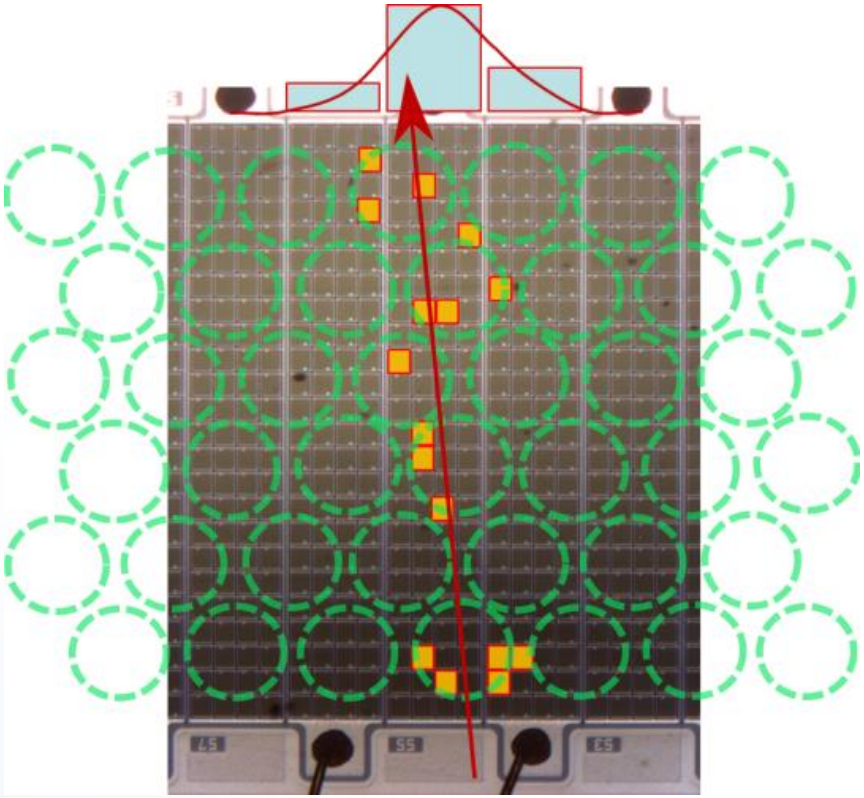


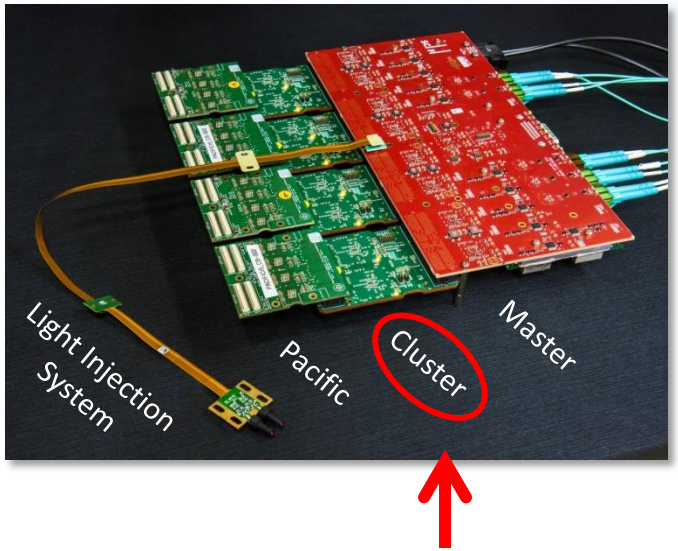


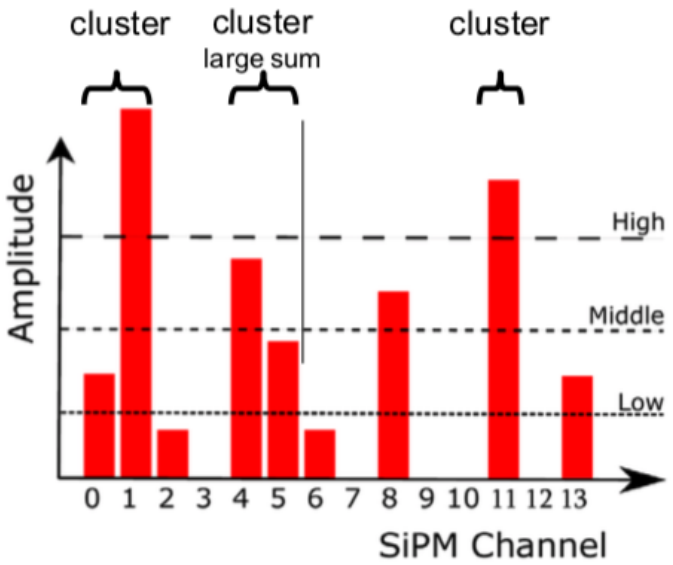


The Clusterization Board

- 2 Igloo II FPGAs processes the data from the PACIFIC
- Creates clusters out of the data
- Supresses zeros (only clusters mean pos. are sent)

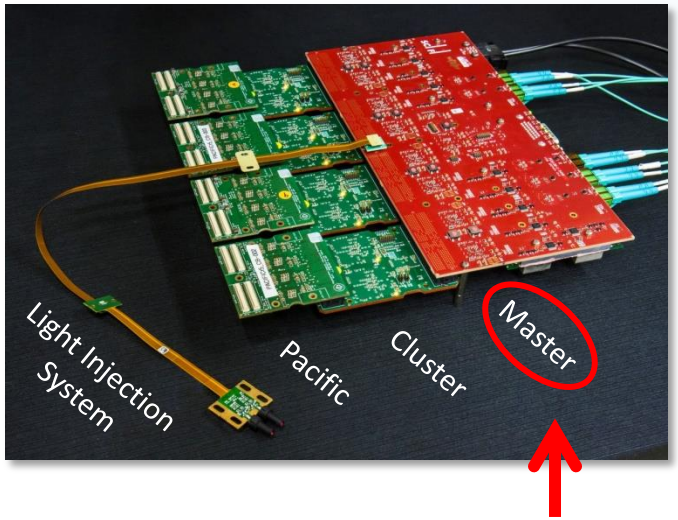


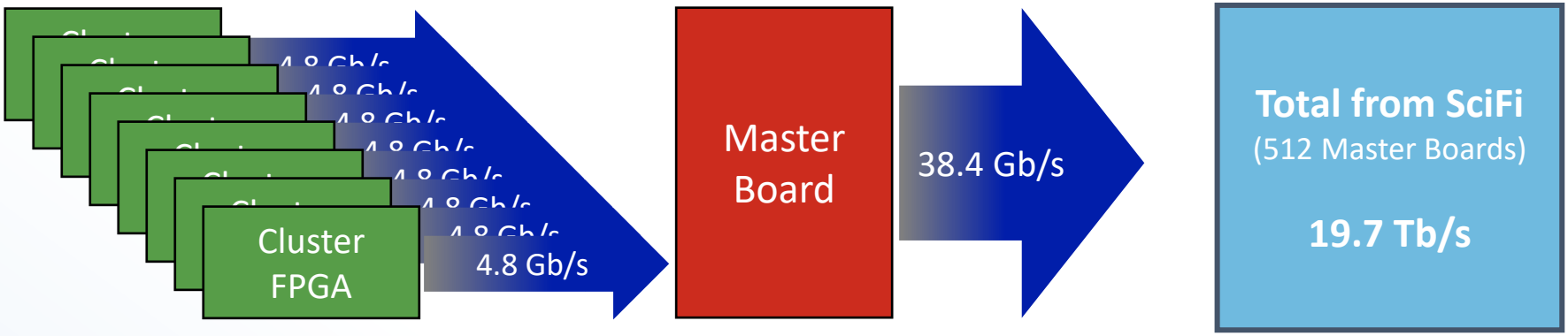




The Master Board

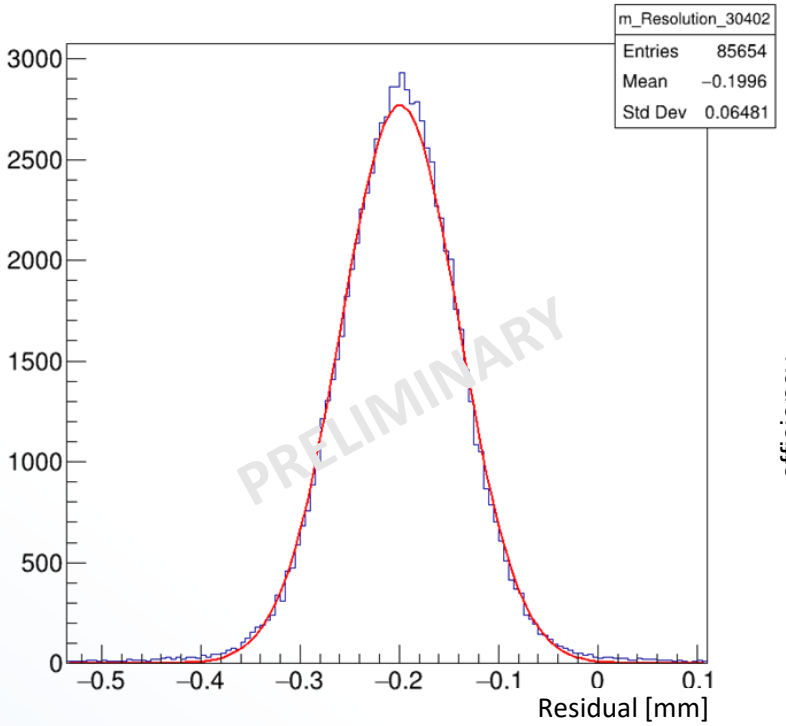
- Serialization and transmition of data
- Power distribution
- Clock distribution
- Slow and Fast Control
- 9 GBT chips (8 for data, 1 for control)





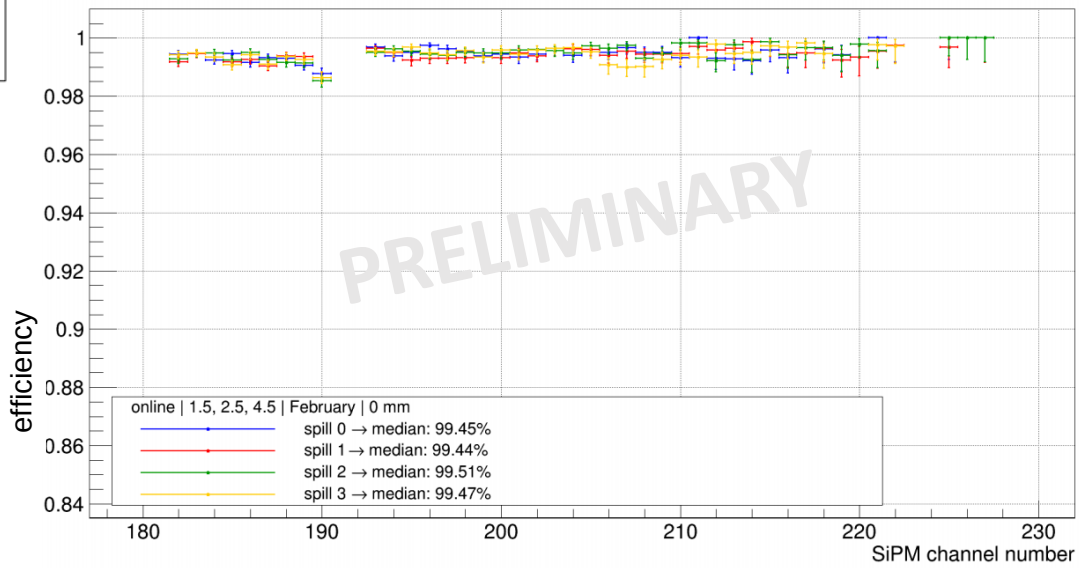
SciFi – Test Beam Results

Resolution



Resolution ~65 µm

Cluster Efficiency



* Plot by Simon Nieswand

Efficiency ~99.47%

SciFi – C-Frame & Services

C-Frame

SiPM bias

Frontend bias

Dry gas

Water cooling (for FE)

Novec cooling (for SiPM)

Vacuum insulation (for Novec)

SciFi Project Status

Right now

1st C-Frame being commissioned

By July/2020

Installation at LHCb cavern is done

March/2021

SciFi sees it's first light

Summary

- The SciFi tracker is a crucial piece of the LHCb Upgrade
- Test beam results have shown that the detector meets the upgrade's requirements
  - Resolution ~ 65 µm
  - Efficiency ~ 99.45 %
- Production and QA of most components are finished
- C-Frames being assembled and comissioned
- First light expected to be seen by March 2021