A large Scintillating Fibre Tracker for LHCb

TIPP 2017, Beijing, May 2017

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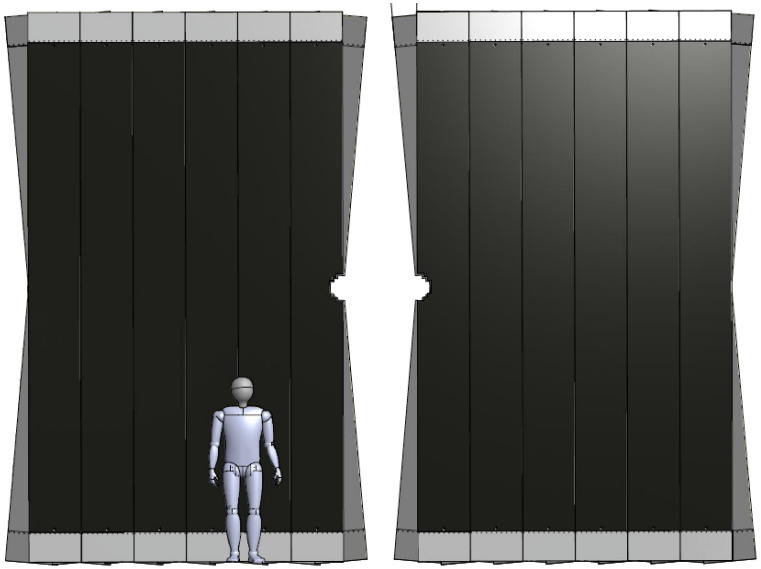
Germany



on behalf of the LHC SciFi Collaboration:

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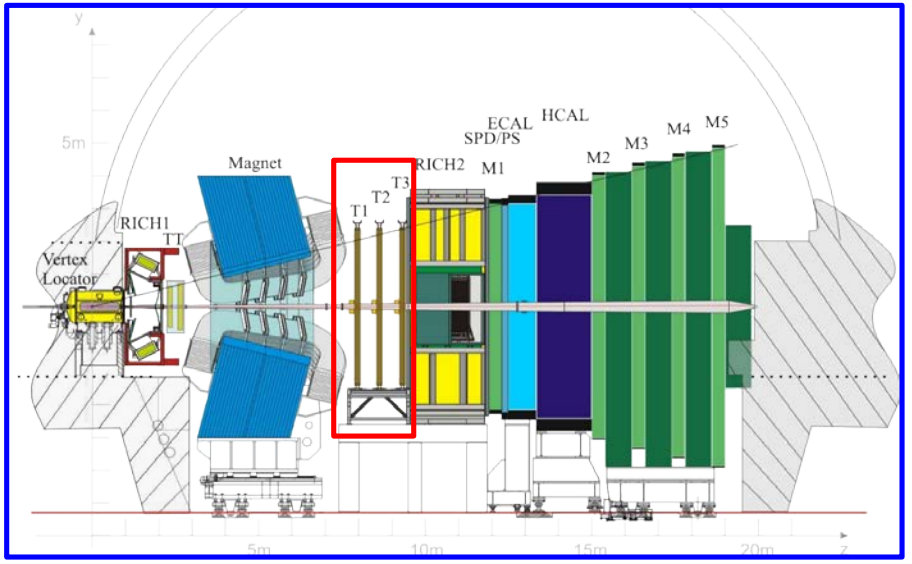
LHCb Detector Upgrade

LHCb detector upgrade during LHC LS2 (2019-2020)

Goal: increase statistics by more than ×10

- Operate at $2\times10^{33}\,cm^{-2}\,s^{-1} \rightarrow 50\ fb^{-1}$
- triggerless 40 MHz readout

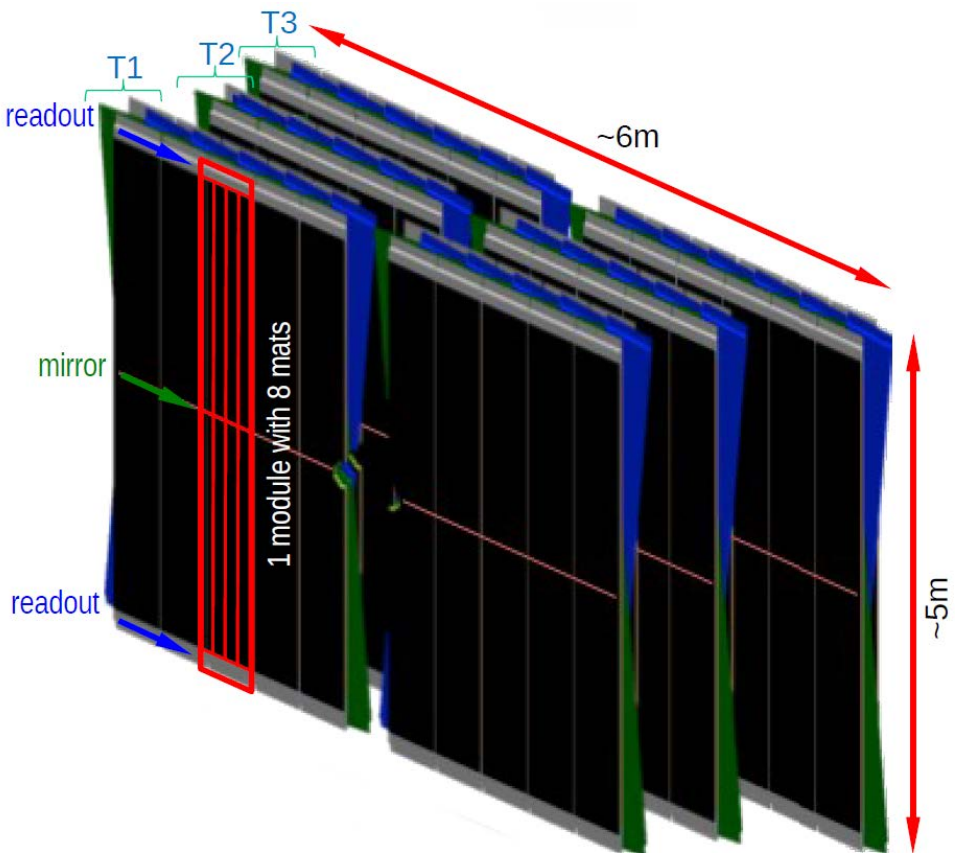


- full software trigger
- 40 MHz readout electronics: replacement of **RICH photo detectors**
- New tracking system:
  - **Vertex det**ector Si strips → pixels
  - TT Si strips → new **Si strip detector**
  - Inner (Si) and Outer (straws) Tracker → Novel **Scintillating Fibre Tracker**

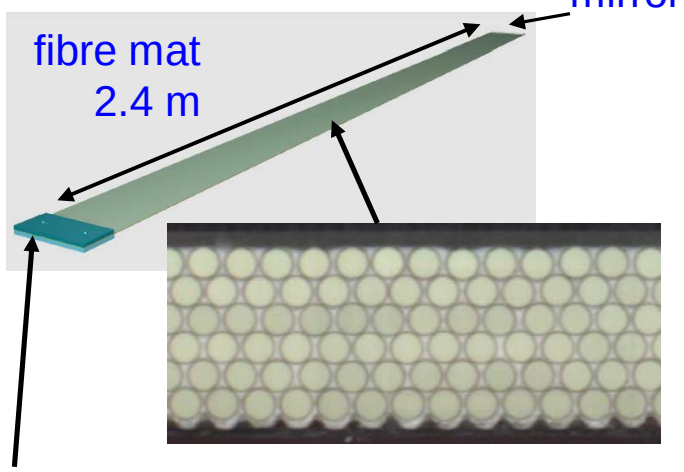
fast, high efficiency (~99%)
high granularity (250μm),
high spatial resolution (<100μm),
light (<1% X_0 /layer), up to 35 kGy

SciFi – Overview

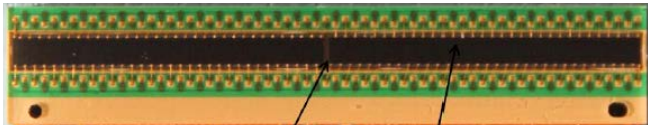
128 modules (0.5 x 5 m^2)
arranged in 3 stations × 4 layers
(XUVX)



1 module = 8 **fibre mats**



4 silicon photomultipliers (SiPM)



11,000 km of fibres, 524k channels

Goal: <100 μm resolution over a total active surface of ~ 340 m^2

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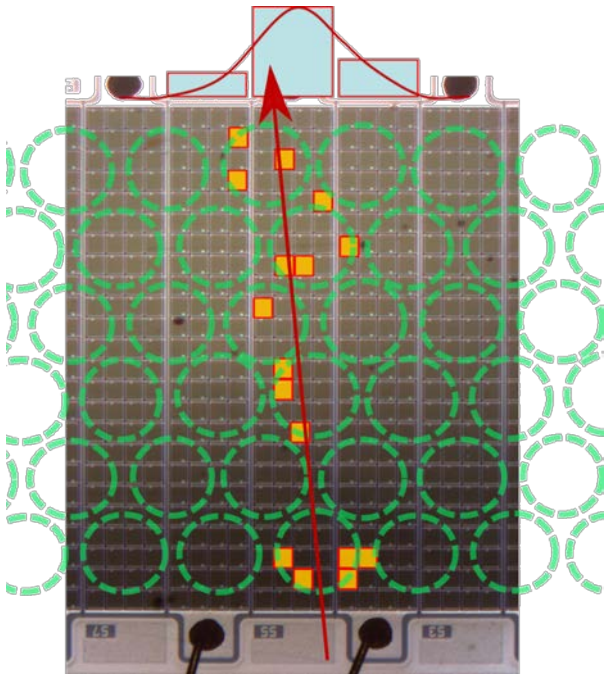
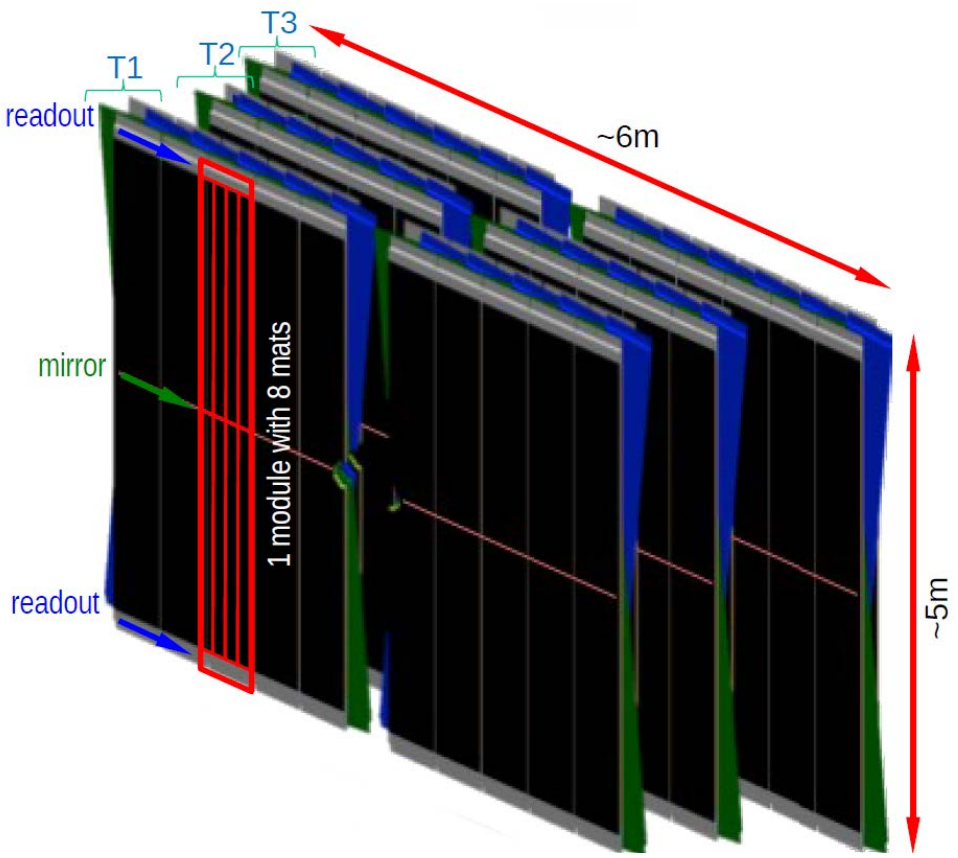


Light yield for 6-layer mat:
16–20 photo-electrons
(for particles near mat mirror)



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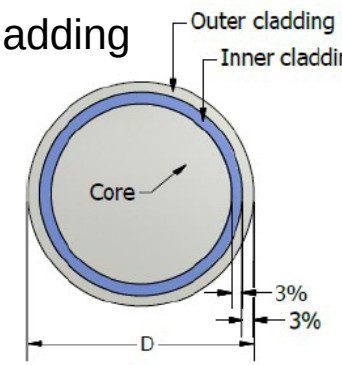
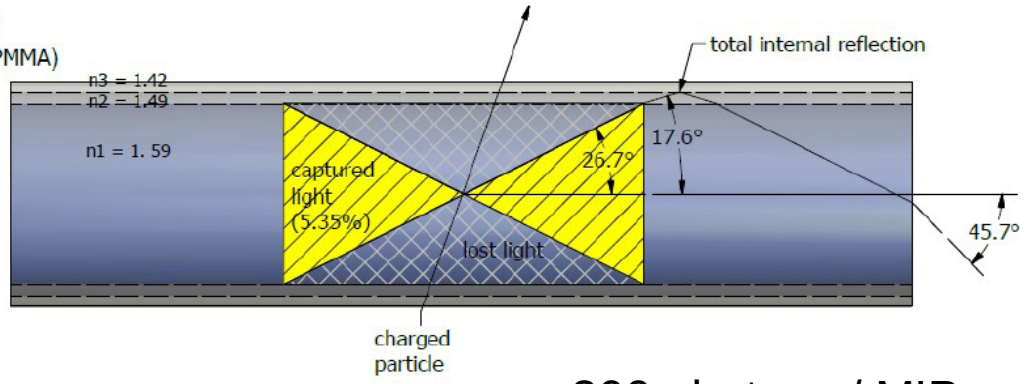
Scintillating Fibre

Kuraray SCSF-78

Double cladding

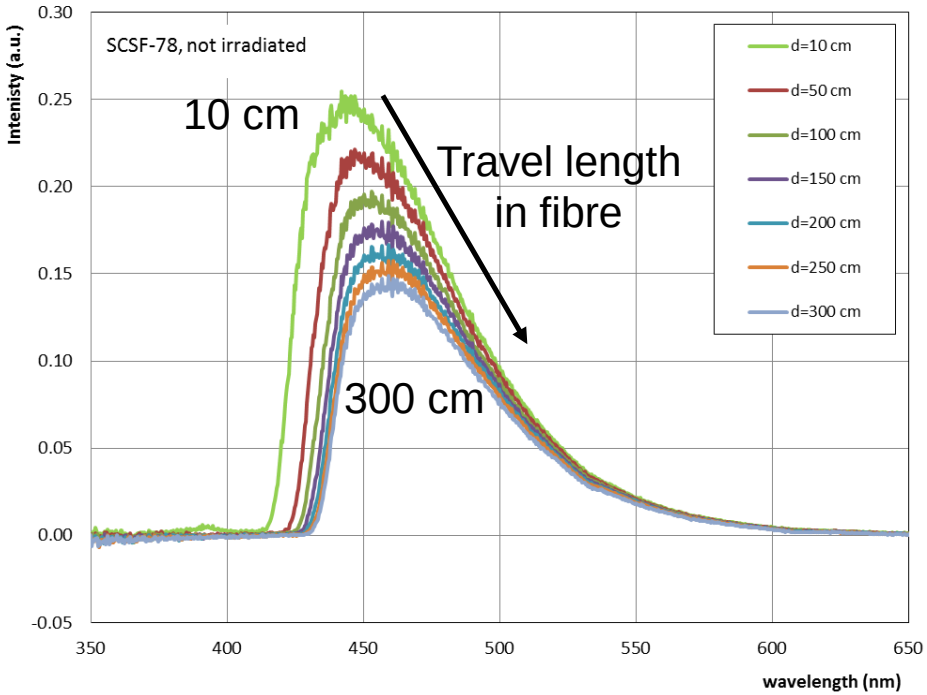
Core:
Polystyrene
+ 2 dyes





~300 photons / MIP
(only 2×5% are captured)

CERN-LHCb-PUB-2015-011



Light emission peak 460 nm
Attenuation length ~3.5 m

Ionizing radiation degrades light transmission property:
50 fb^{-1} (35 kGy) → 40 % reduction for particles near the beam-pipe

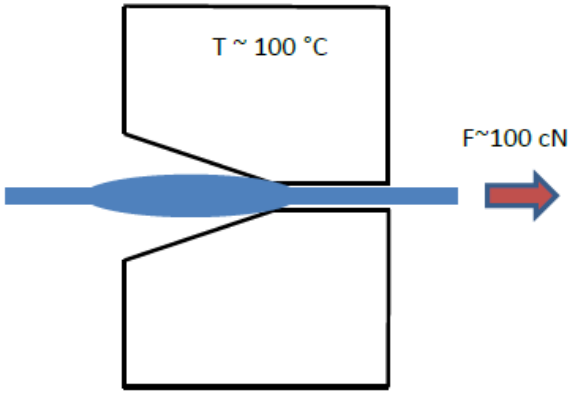
Fibre Quality Assurance

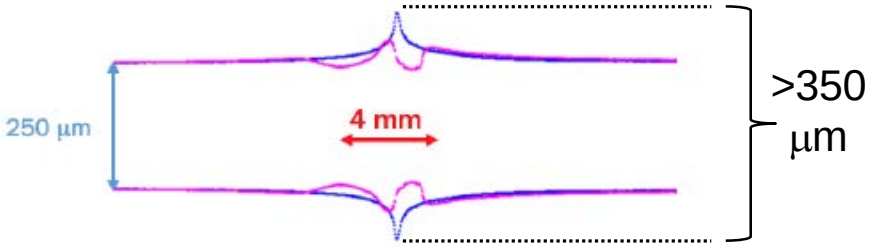
Kuraray SCSF-78

Fibre scanner, LHCb-PUB-2015-009

- All fibre spools scanned for mechanical defects and irregularities (so far ~6000 km scanned).
- We observe “bumps” = local increase of diameter.
- Bumps >350 μm (typ. ~8 per 12500 m) produce irregularities in winding pattern and must be removed.
- Automatic bump shrinkage using a “hot drawing” tool. Applied routinely.

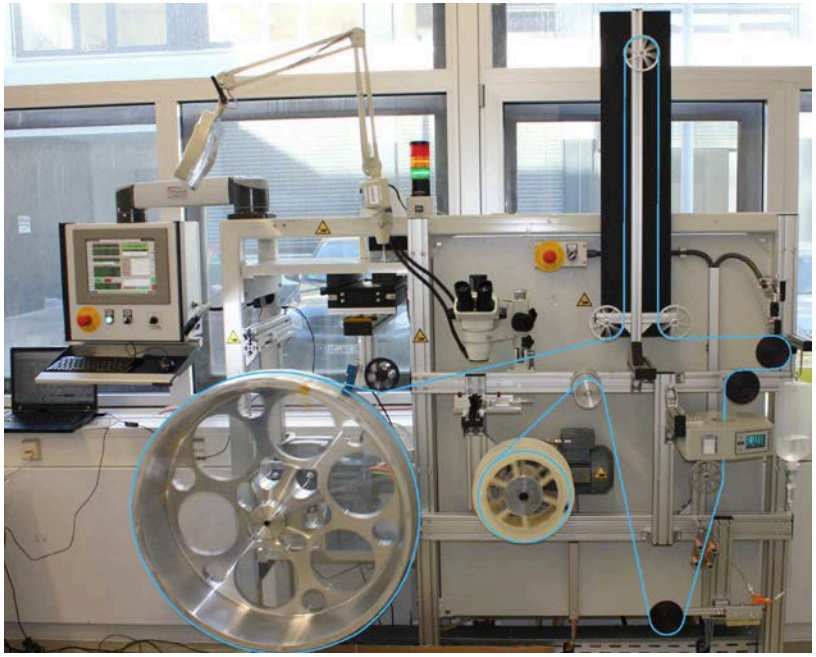
LHCb-PUB-2016-010





Fibre Mat Production

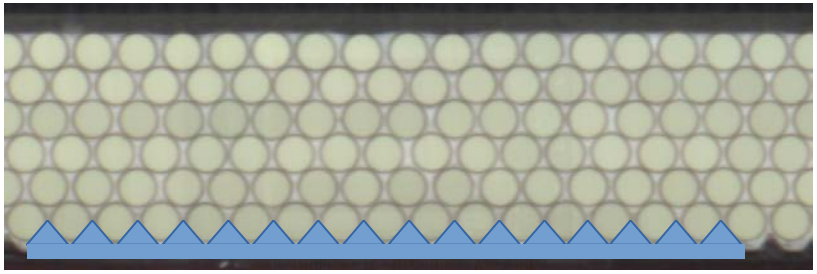
Custom winding machine using a threaded wheel



Glue filled holes on wheel used to create alignment pins

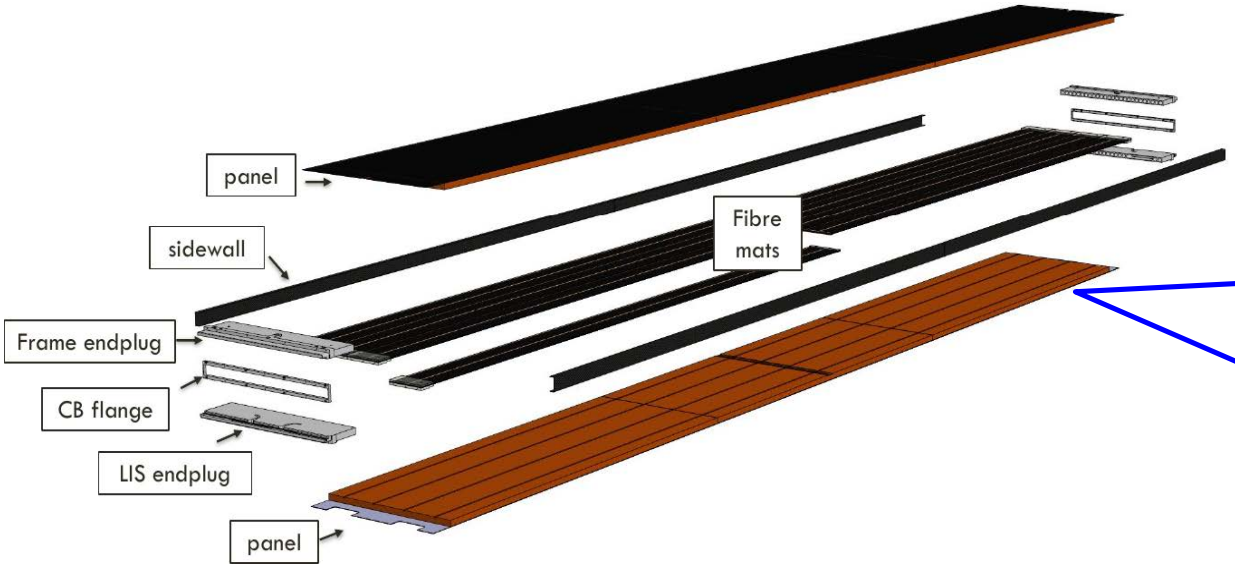
Mat dimension:
L x W x H =
2424.0 x 130.6 x 1.4 mm

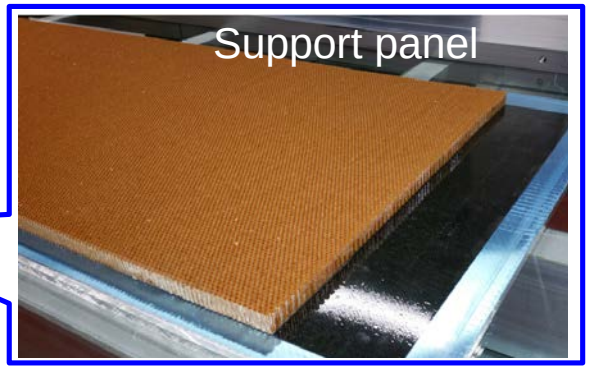
Kapton lamination for mechanical stability



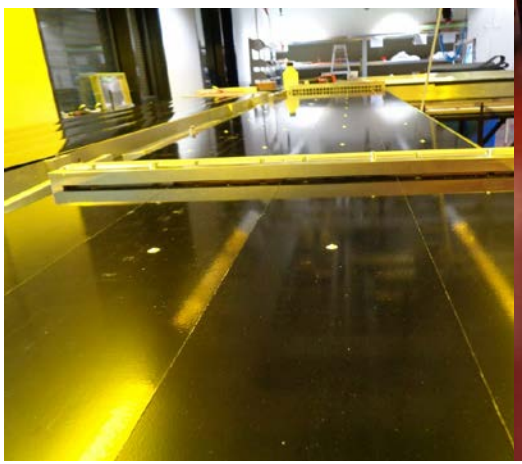
Mat production at 4 sites (1 mat/6 hours)
>25% of mats already produced

Module production



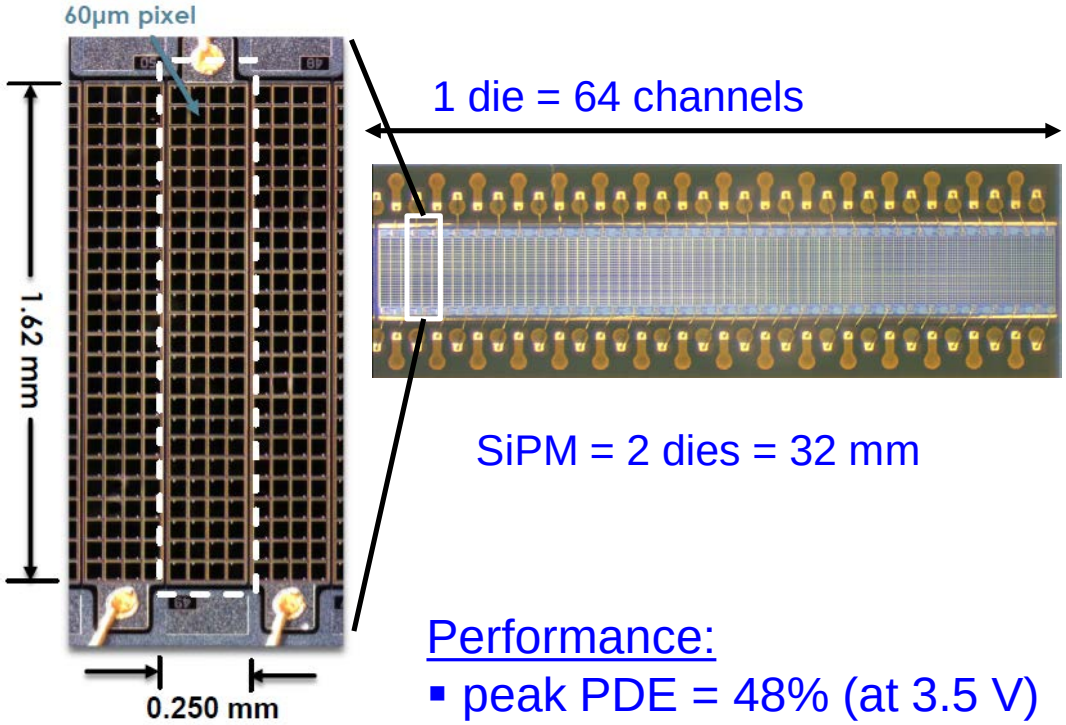


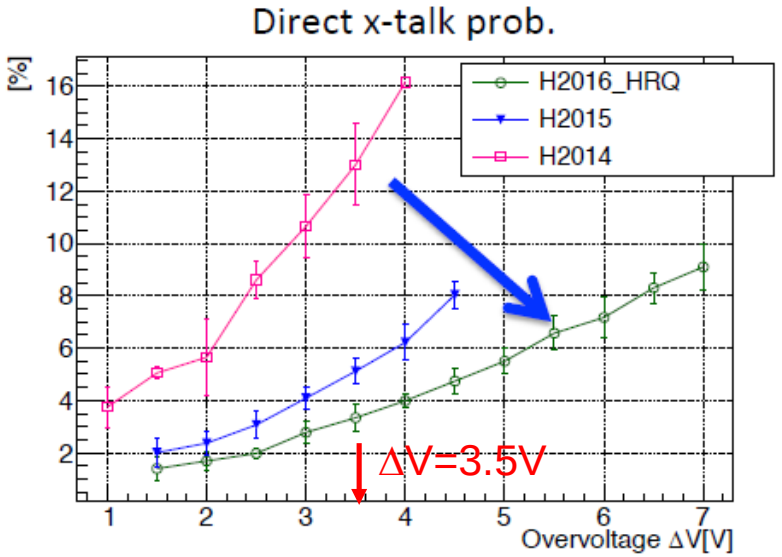
- 8 fibre mats assembled into a module
- Support panels (200g / m^2 carbon fibre tissue + 20 mm Nomex core).
- material budget: 1.1 % X_0 / module
- Alignment of mats w/r to straight line better than 50 μm over length of 5 m
  - **alignment pins** in precision template



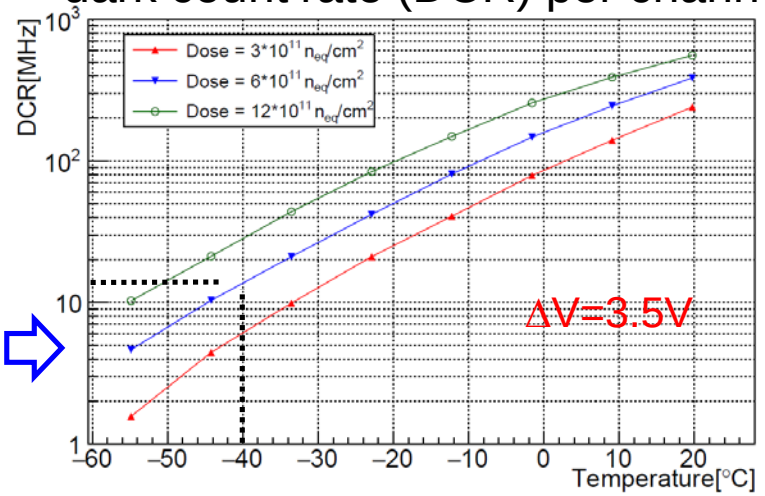
Silicon Photomultiplier

Hamamatsu, H2016-HRQ





dark count rate (DCR) per channel



Performance:

- peak PDE = 48% (at 3.5 V)
- direct cross-talk = 3 %,
- delayed cross-talk = 2.5%
- afterpulses < 0.1%.

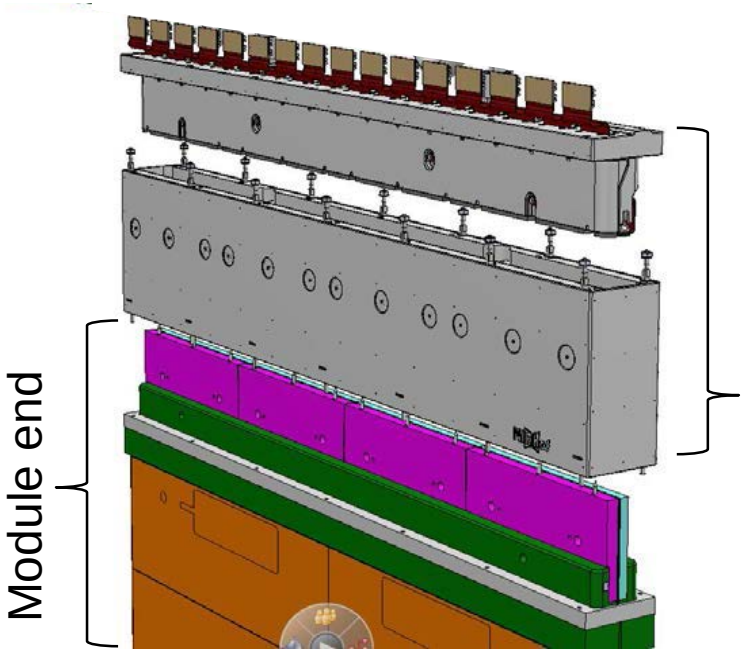
Dark count rate per channel after neutron irradiation:

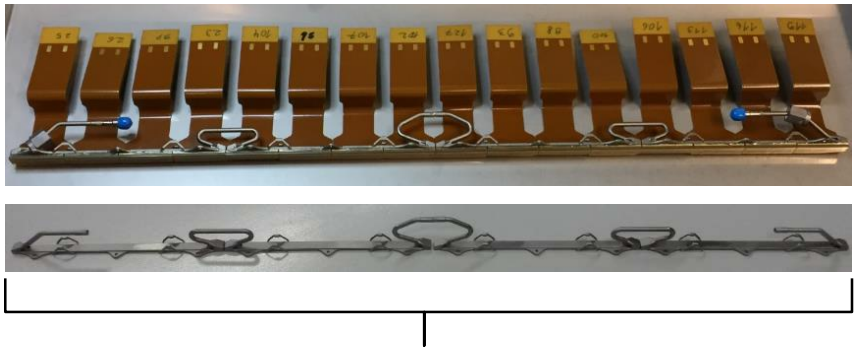
DCR halved every -10 K:

$\Phi = 6 \cdot 10^{11}$ $n_{eq}/cm^2 \rightarrow$ 14 MHz at -40C

Characterisation of the Hamamatsu silicon photomultiplier arrays for the LHCb Scintillating Fibre Tracker Upgrade, **Axel KUONEN, TIPP 2017**

SiPM Cooling and Alignment - Coldbox

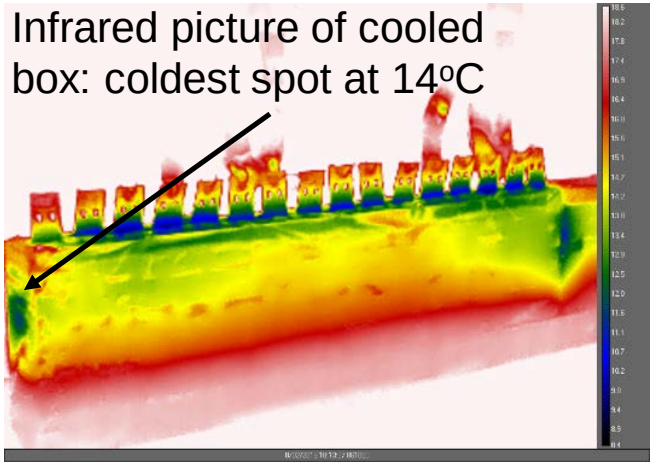




Coldbox

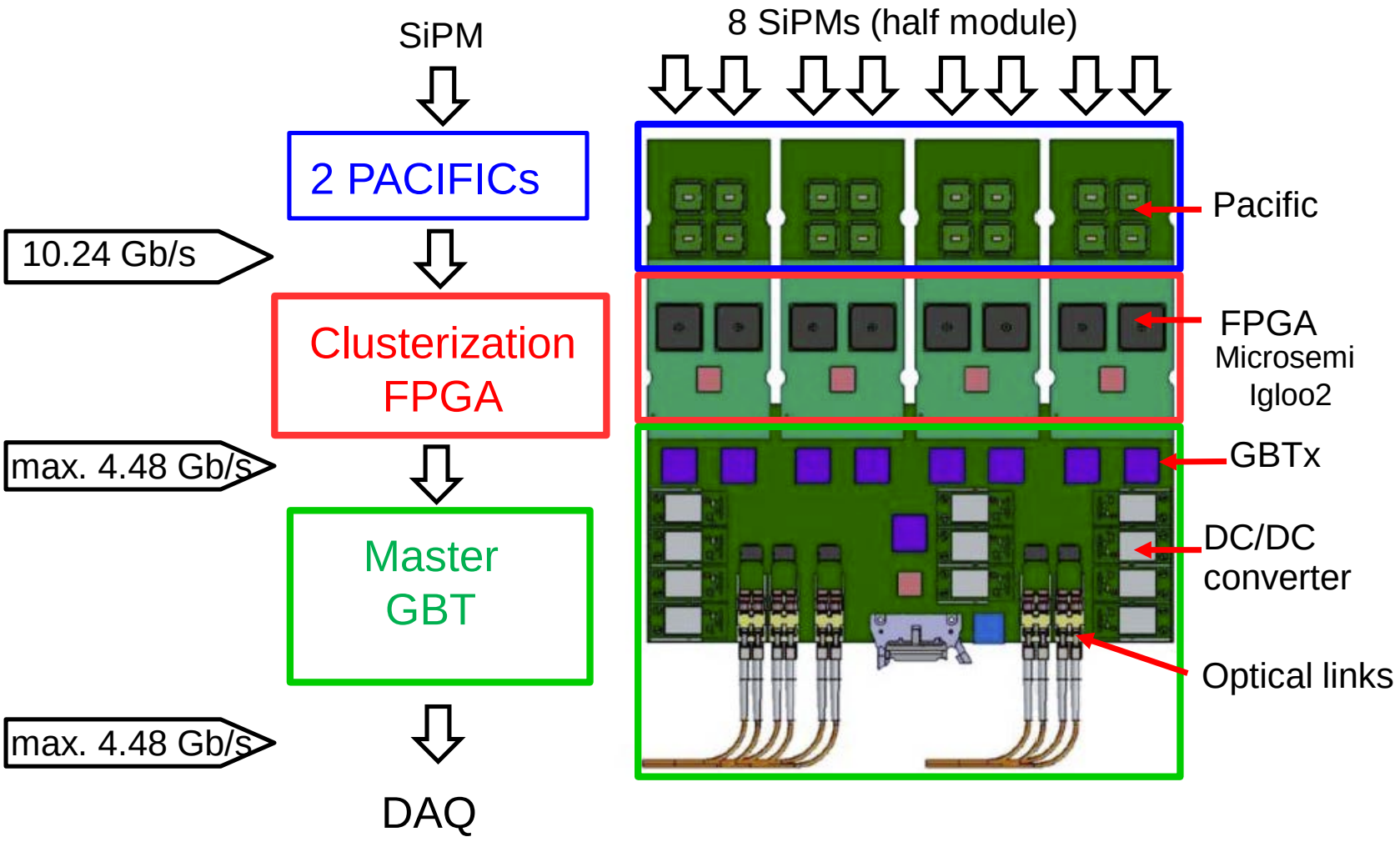
3D printed Ti cooling bar, carry/align 16 SiPMs

SiPM on flex print



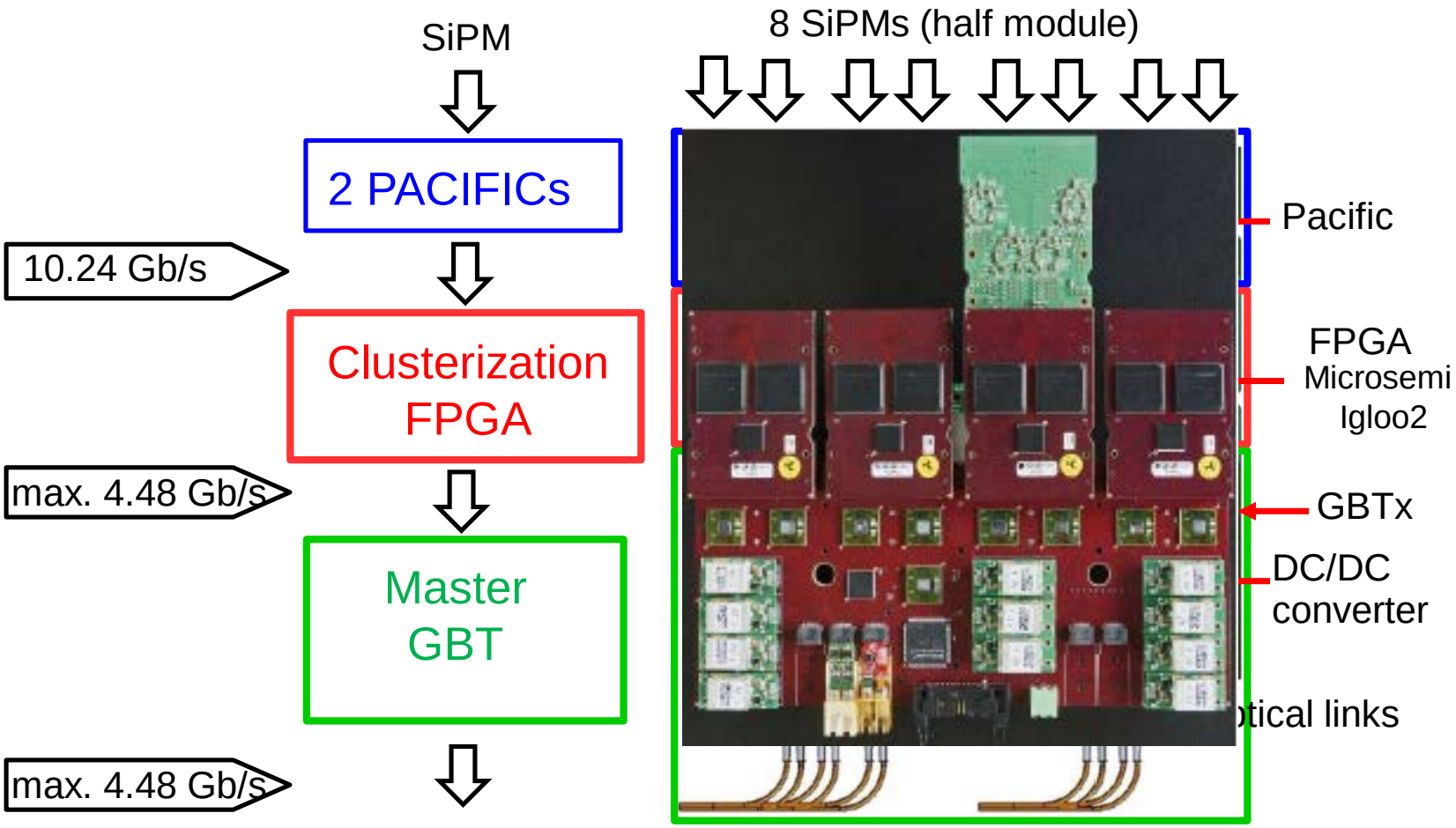
- Cold box (3D printed nylon) at each end of fibre module; houses 16 SiPMs at -40°C, aligned and in optical contact to fibre ends.
- **Challenges:** thermal insulation, humidity management inside box (total length 130m)
- Pre-series under production.

Electronics Readout



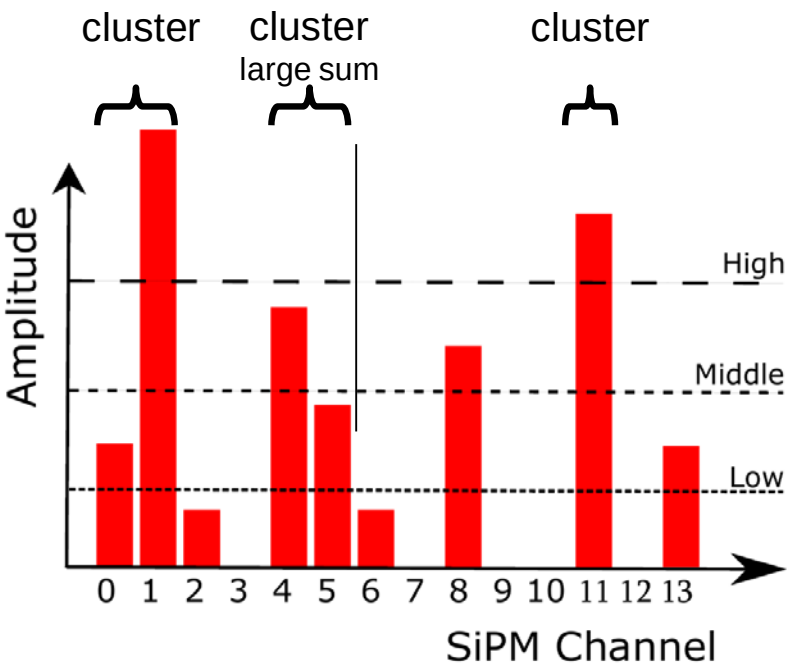
SciFi (528k channels) – 4096 GBT links (max. 2.3 TB/s)

Electronics Readout



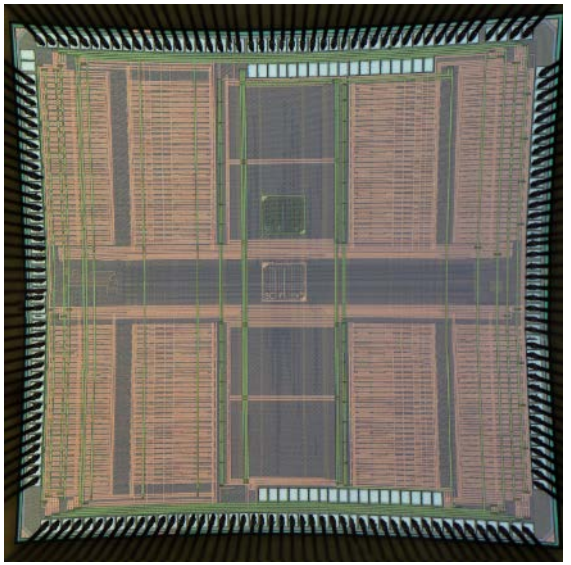
SciFi (528k channels) – 4096 GBT links (max. 2.3 TB/s)

Clusterization



2 bit/channel
low, middle,
high threshold
passed

PACIFICr4 ASIC



A readout ASIC for the LHCb Scintillating Fibre (SciFi) tracker, **X. HAN at TIPP 2017**

Clustering = key to noise / data reduction:

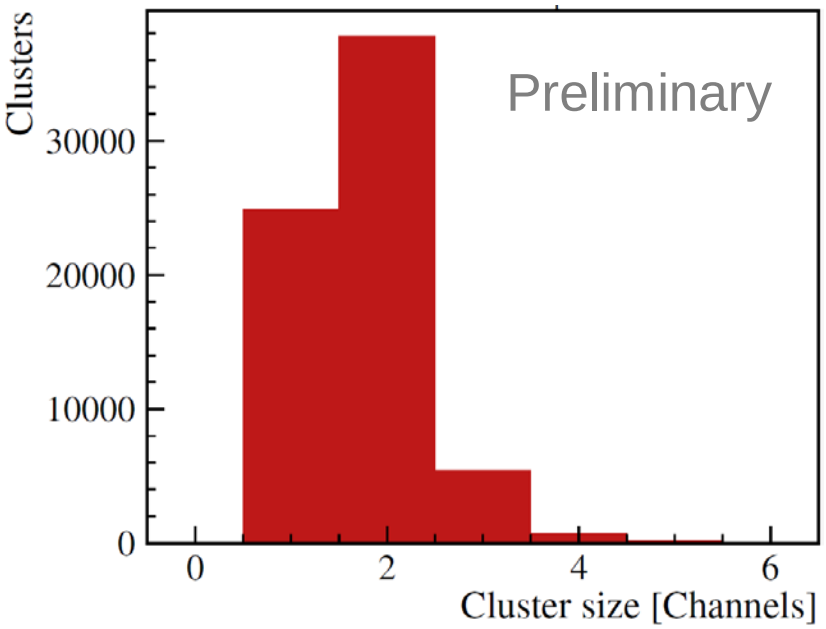
Dark count rate w/ 6×10^{11} n_{eq} / cm^2
~14 MHz / channel

cluster rate 0.8 MHz / 128 channels
calculate x-position of clusters

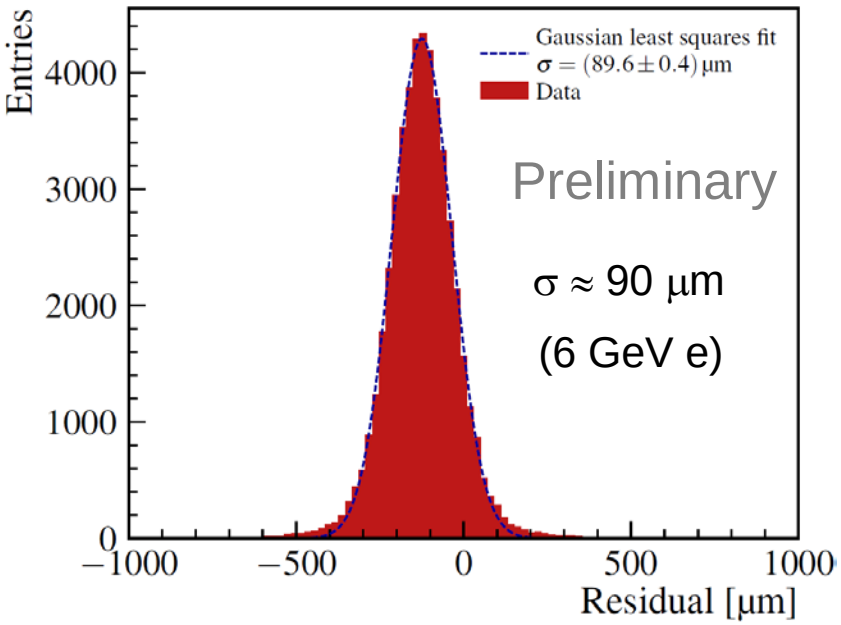
Test beam results using PACIFICr4

Measurements at DESY beamline T22 (Feb 2017)
1…6 GeV electrons (max. beam intensity @ 2 GeV)

Cluster size



Spatial resolution

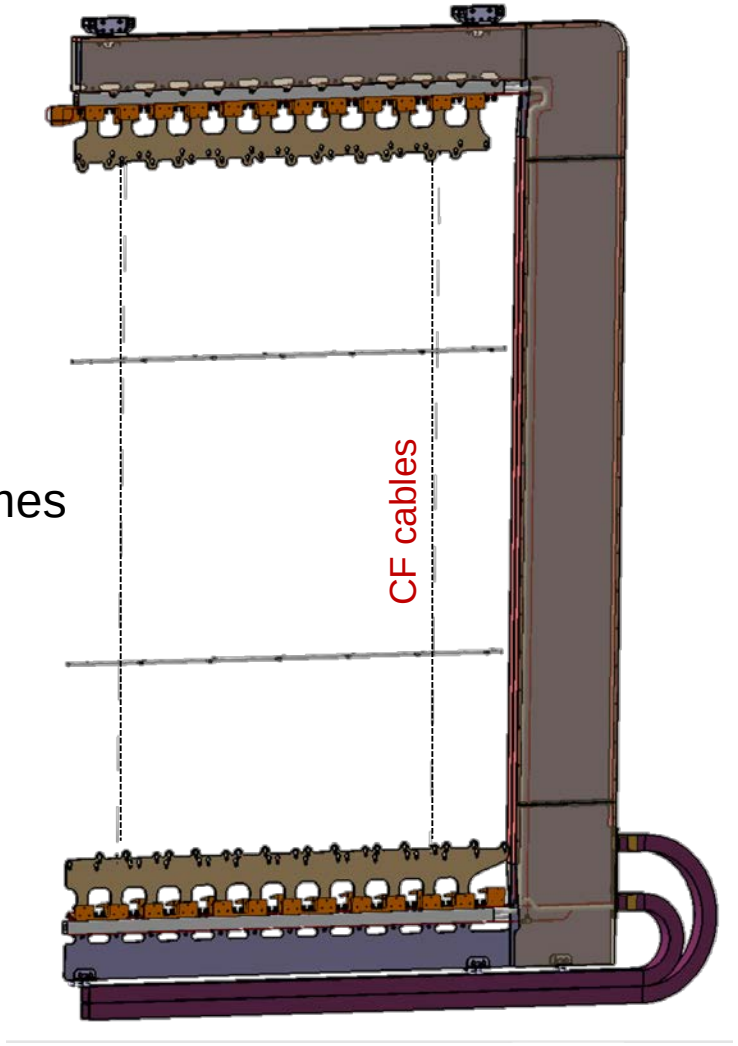


Efficiency: - analysis of recent test beam data on-going
- from earlier test beam campaigns (w/ SPIROC readout): we expect 99% hit efficiency at reference thresholds

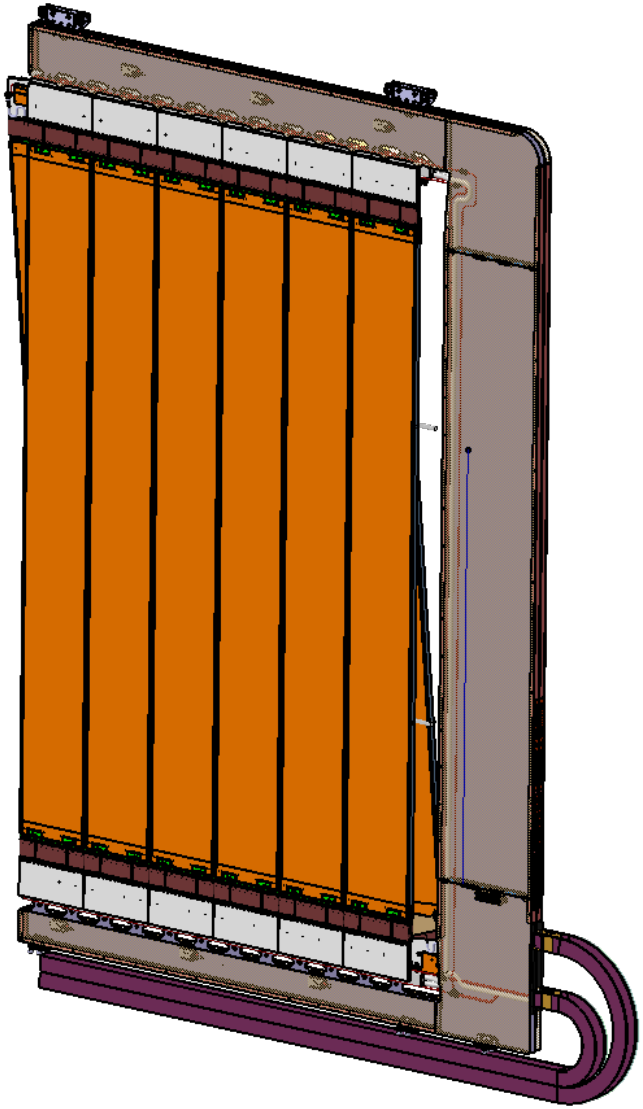
LHCb-PUB-2015-025

Mechanics and Services

2 x 6 C-frames



~ 7 m



Services: Novec (649) cooling (SiPMs), water-cooling, LV/HV, opti. fibres

Summary

- The LHCb Scintillating Fibre Tracker is a high-resolution detector covering an area of 340 m^2.
- It is based on ∅ 250 μm scintillating fibres, read-out with SiPMs
- Nominal performance parameters have been achieved in test beam measurements: <100μm resolution, 99% hit efficiency.
- The detector construction is well advanced (>25% of fiber mats, ~15% of modules already produced)
- Installation of the detector foreseen for 2019 – 2020 (LS2)

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