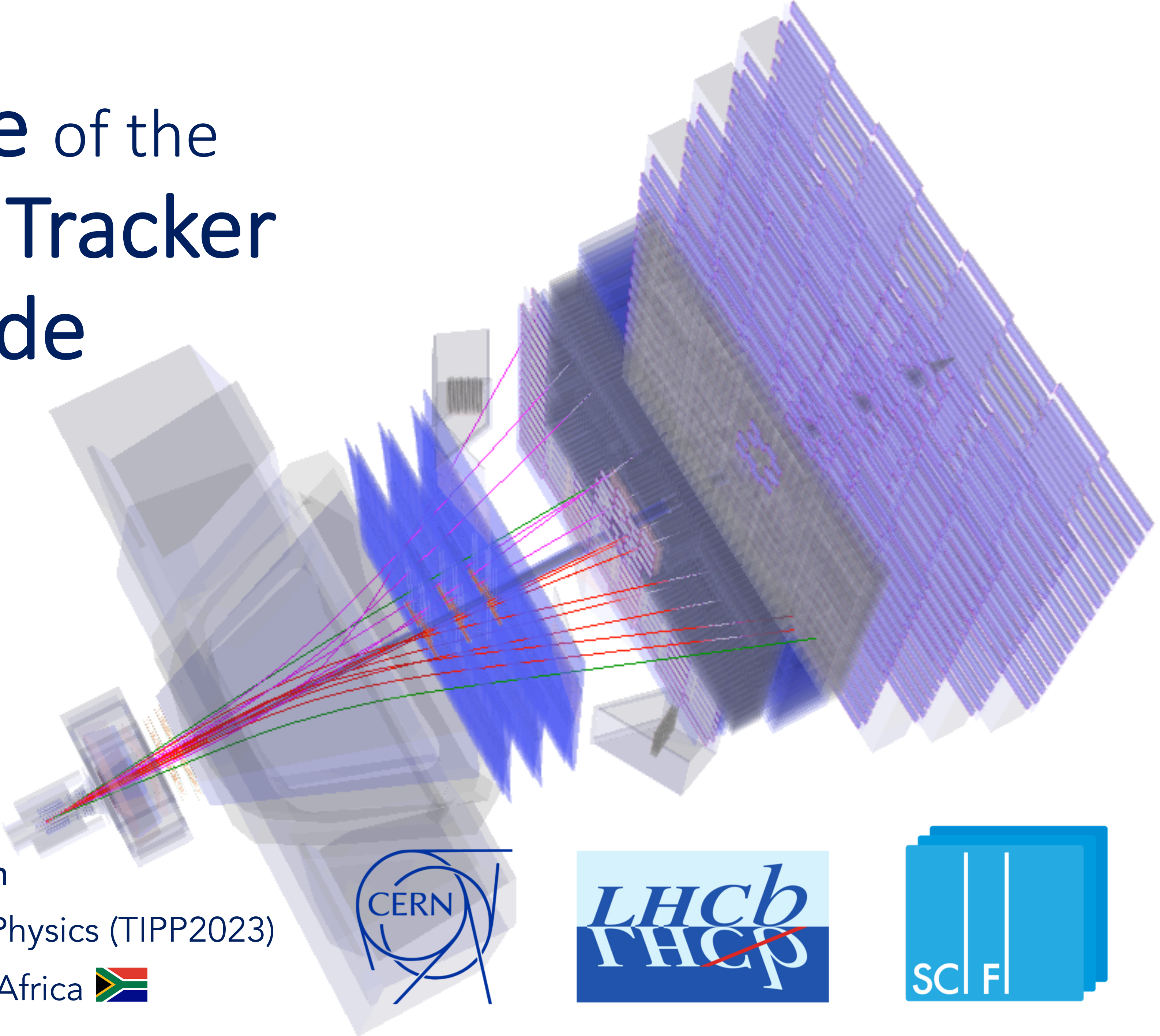
Early Performance of the Scintillating Fibre Tracker for the LHCb Upgrade



Jan de Boer

Nikhef, Amsterdam – The Netherlands

On behalf of the LHCb SciFi Collaboration

Technology & Instrumentation in Particle Physics (TIPP2023)

4-8 September 2023, Cape Town - South Africa

Outline

- LHCb Detector Upgrade
- Scintillating Fibre tracker (SciFi)
- Commissioning
- Early Performance

LHCb experiment

LHCb detector

Single-arm forward spectrometer designed to study b- and c-hadrons

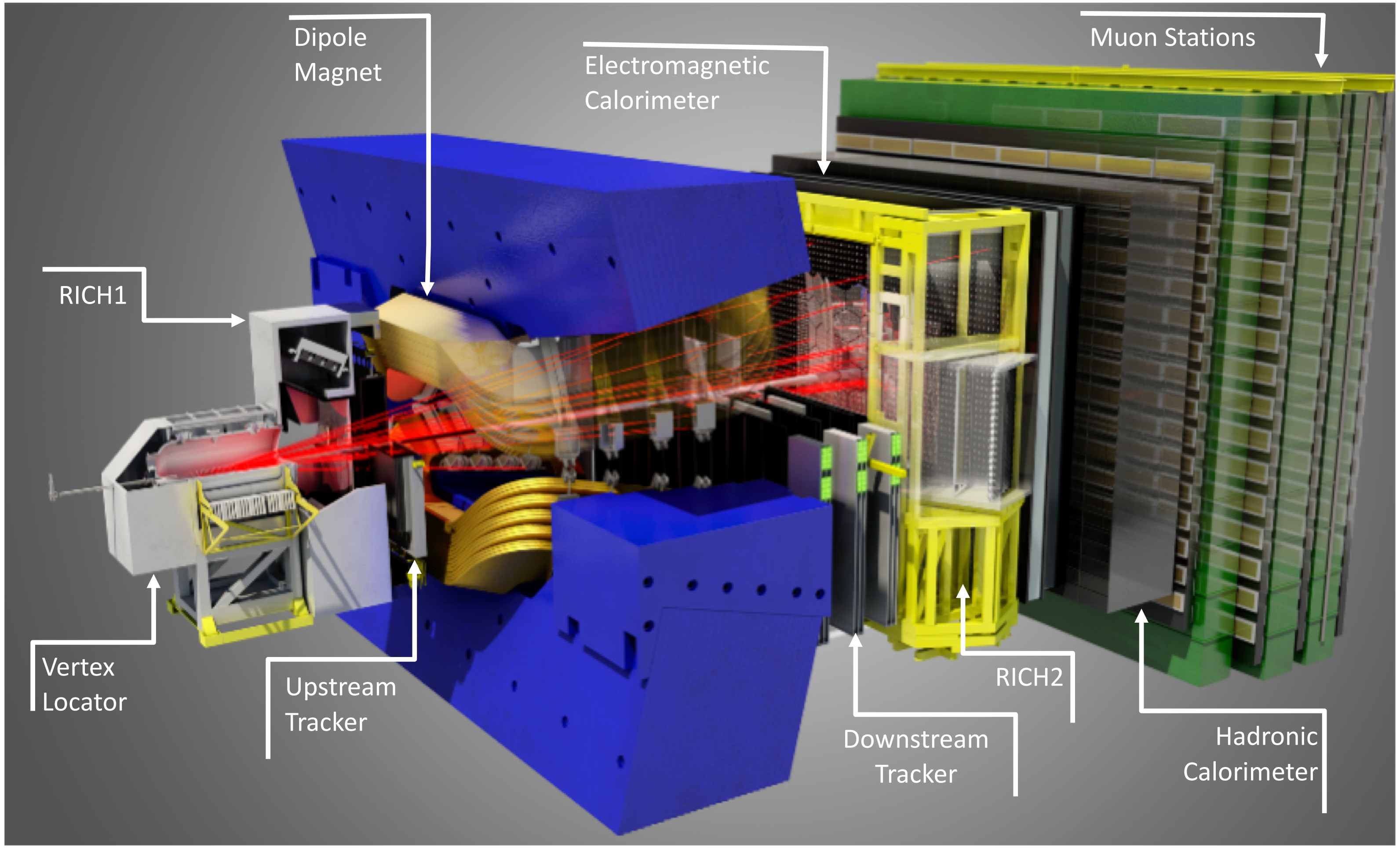
($2 < \eta < 5$)

LHC Run 1 + 2 (2011-2018)

Collected > 9 fb^{-1}

Excellent performance and extended physics program to QCD, EW, direct searches, heavy ions, …

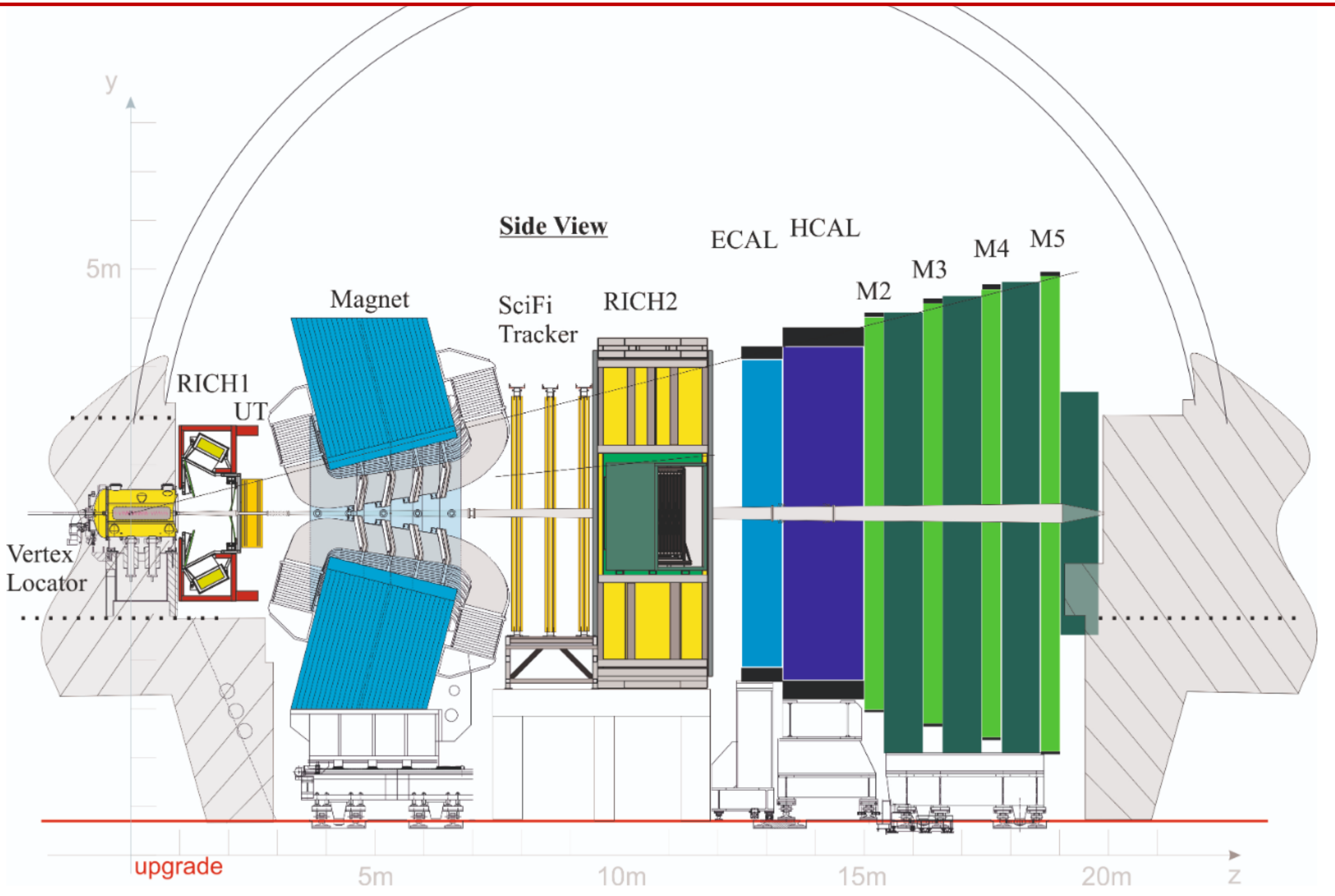
→ Forward general-purpose detector



LHCb Upgrade I (2019-2022)

LHC Run 3 + 4 (2022-2032)

- Instantaneous limunosity 5 x higher: $\mathcal{L} \rightarrow 2 \times 10^{33}\ sec^{-1}\ cm^{-2}$
- New detector readout and full software trigger at 40 MHz
- Collect 50 fb^{-1}



LHCb Upgrade I (2019-2022)

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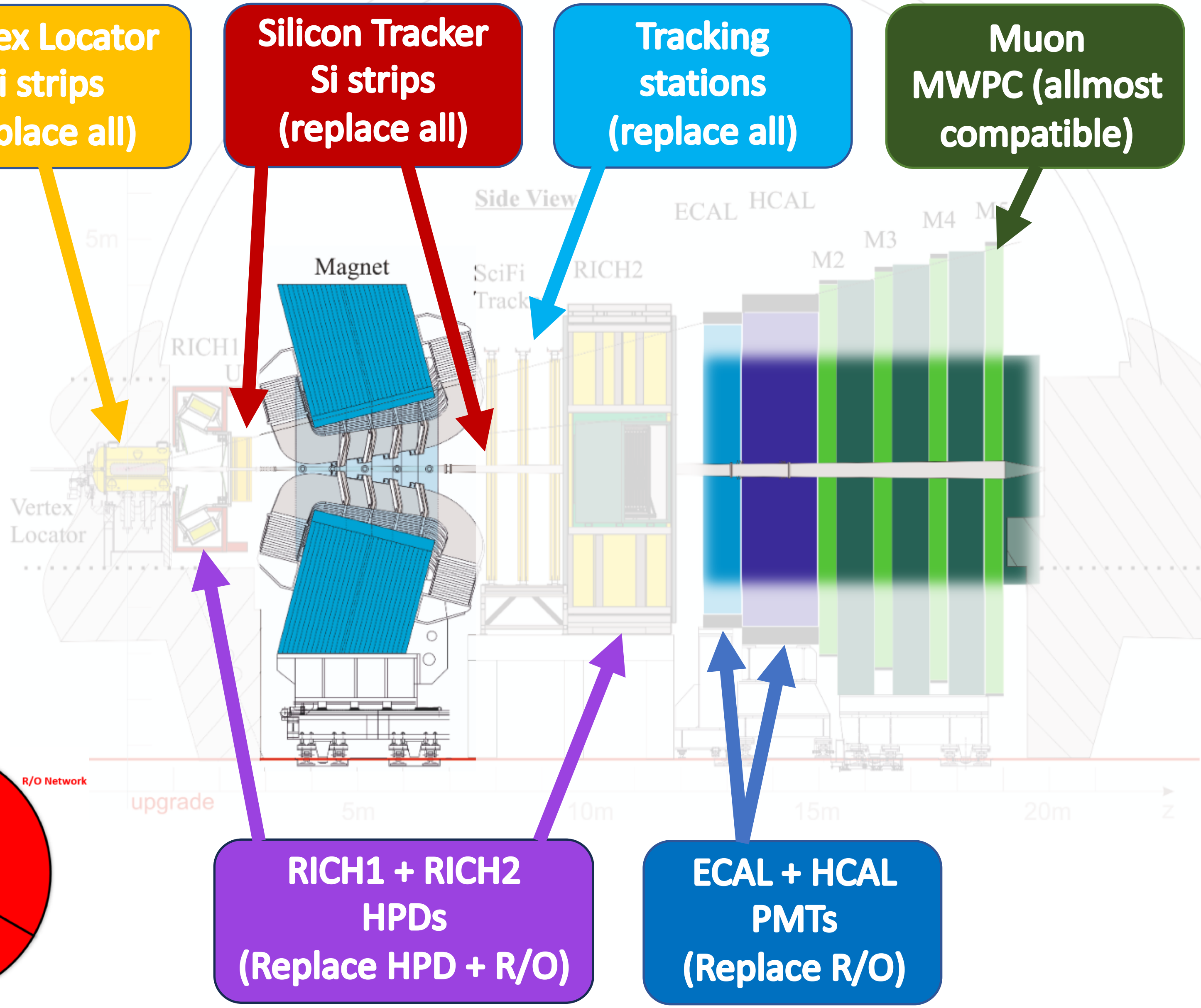
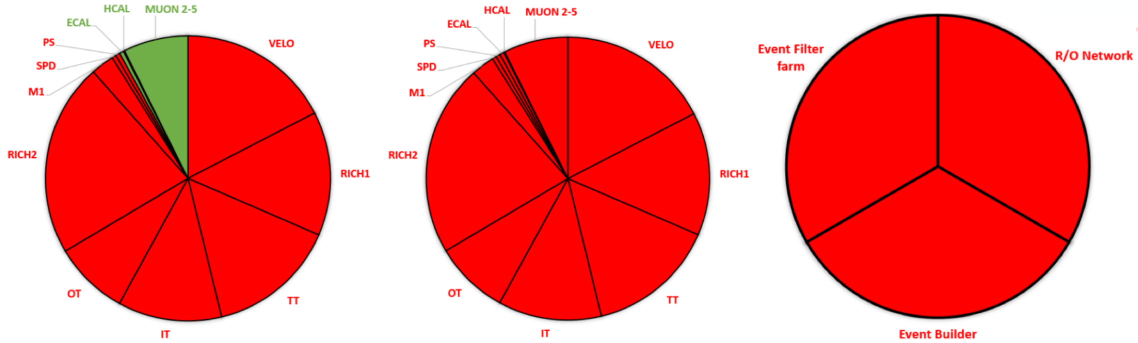
- Instantaneous limunosity 5 x higher: $\mathcal{L} \rightarrow 2 \times 10^{33}\ \text{sec}^{-1}\ \text{cm}^{-2}$
- New detector readout and full software trigger at 40 MHz
- Collect 50 fb^{-1}

→ New detector!



to be upgraded
to be kept

Detector | R/O Electronics | DAQ



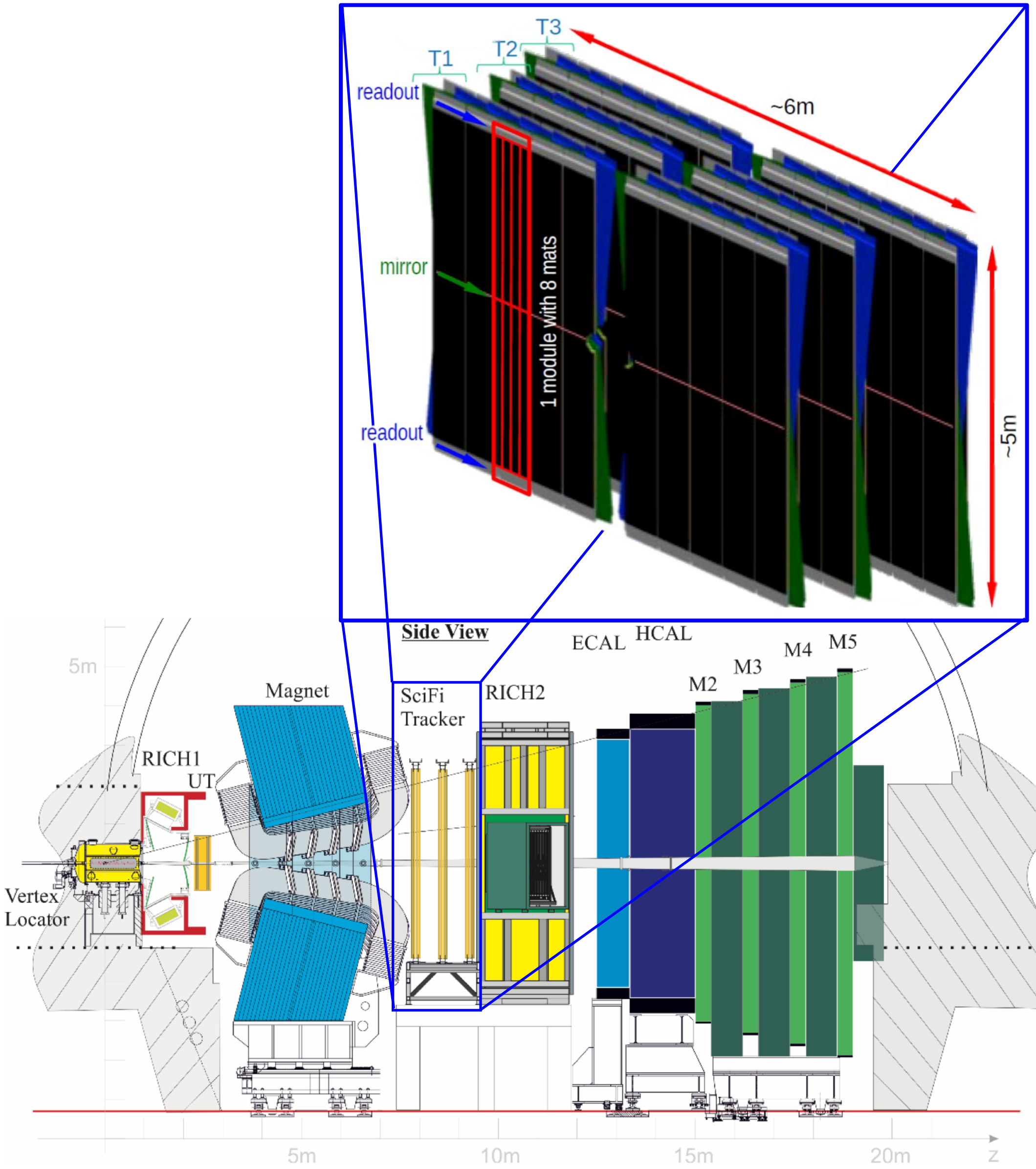
The SciFi tracker – unique in its kind

Characteristics:

- Total of 12 layers, divided over 3 stations
  - 4 stereo layers per station (0°,+5°,-5°,0°)
- Covering a total area of **340 m²**
- **> 10.000 km** of scintillating fibre
- Total of **524k** readout channels

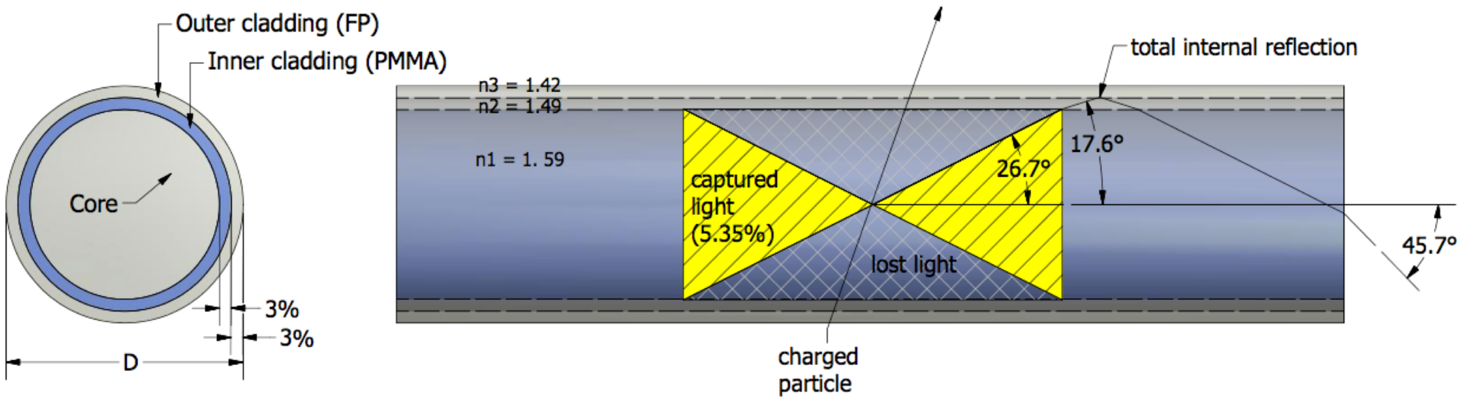
Requirements:

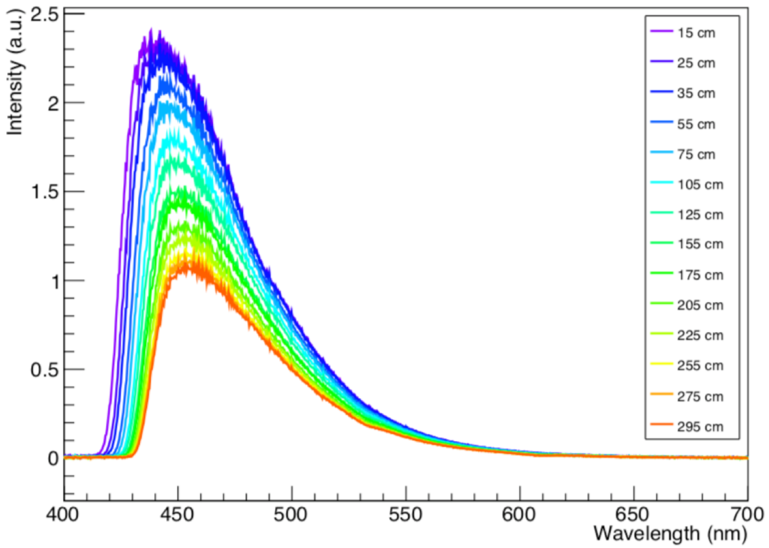
- Hit efficiency ≈ 99%
- Hit resolution < 100 μm
- Low material budget $X/X_0 \sim 1\%$ per layer
- Radiation tolerant:
  - 35 kGy near the beam pipe
  - Electronics: $6\mathrm{x}10^{11}\ n_{eq}/cm^2$ + 100 Gy



Scintillating Fibres

Double-cladded round fibres Ø 250 μm (Kuraray SCSF-78MJ) used:





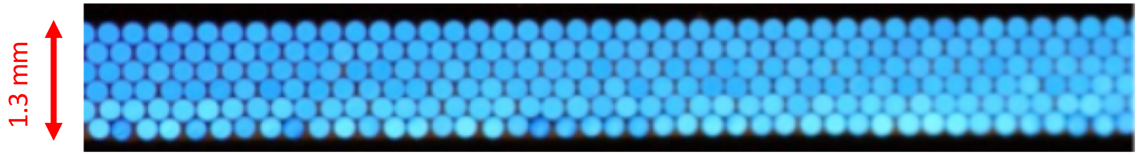
Light emission peak at ~450 nm

Attenuation Length of ~3.5 m

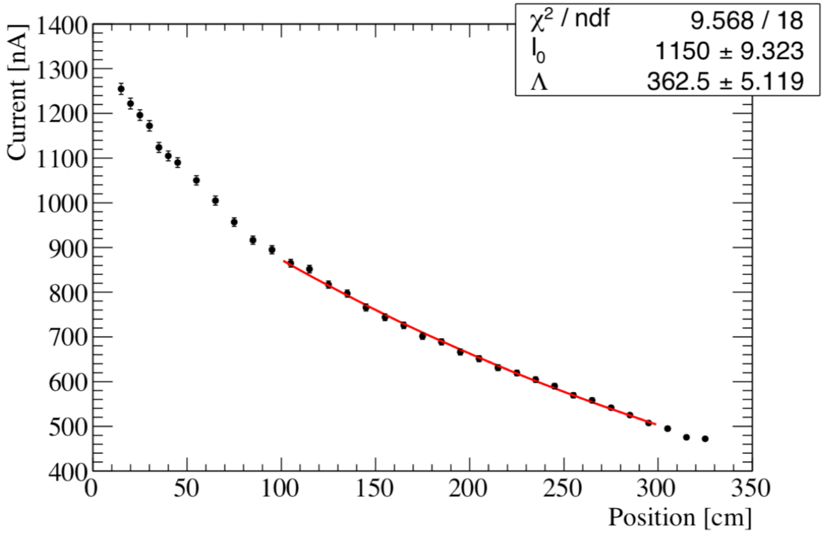
~300 photons/MIP

Trapping fraction of 5.3%, attenuation, and photon detection efficiency of SiPM:

→ *only* **3-4 photo electrons** detected @ 240 cm for a single fibre

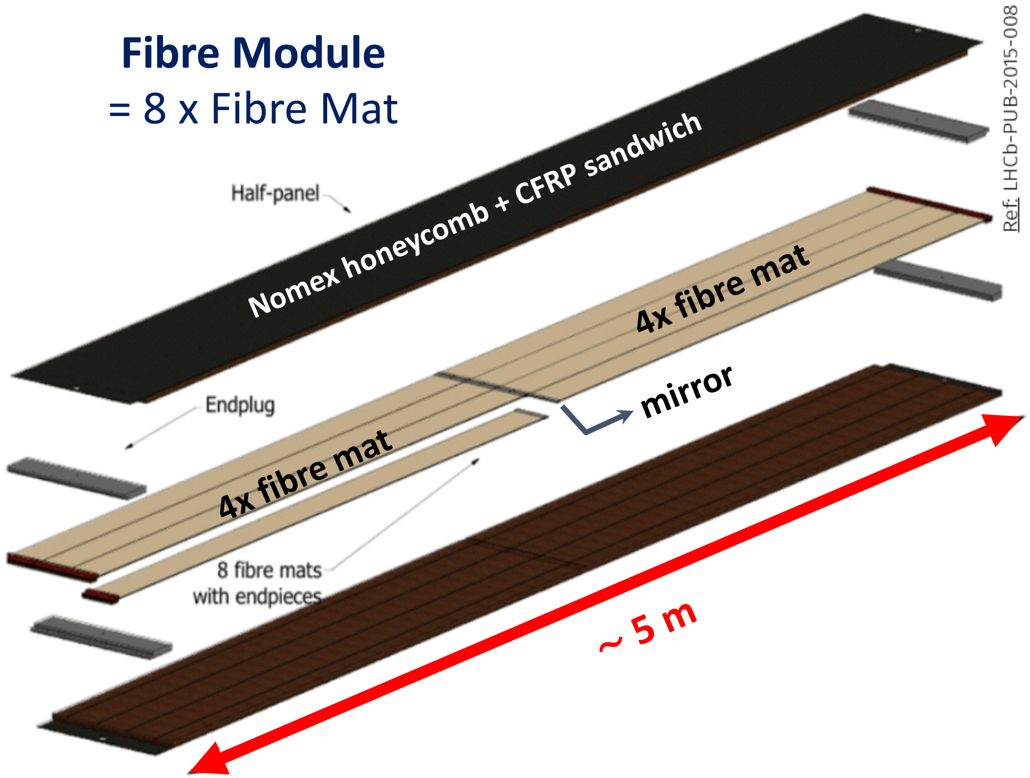


Cross-section of a single detection layer (fibre mat) in SciFi

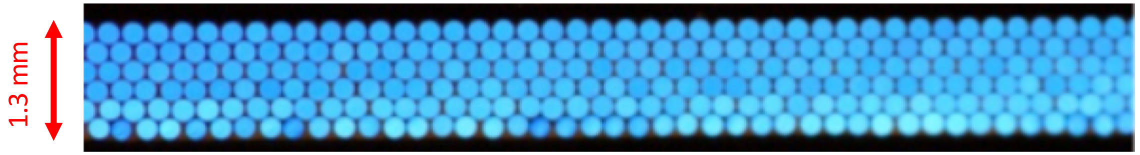


Tiny fibres making a large detector

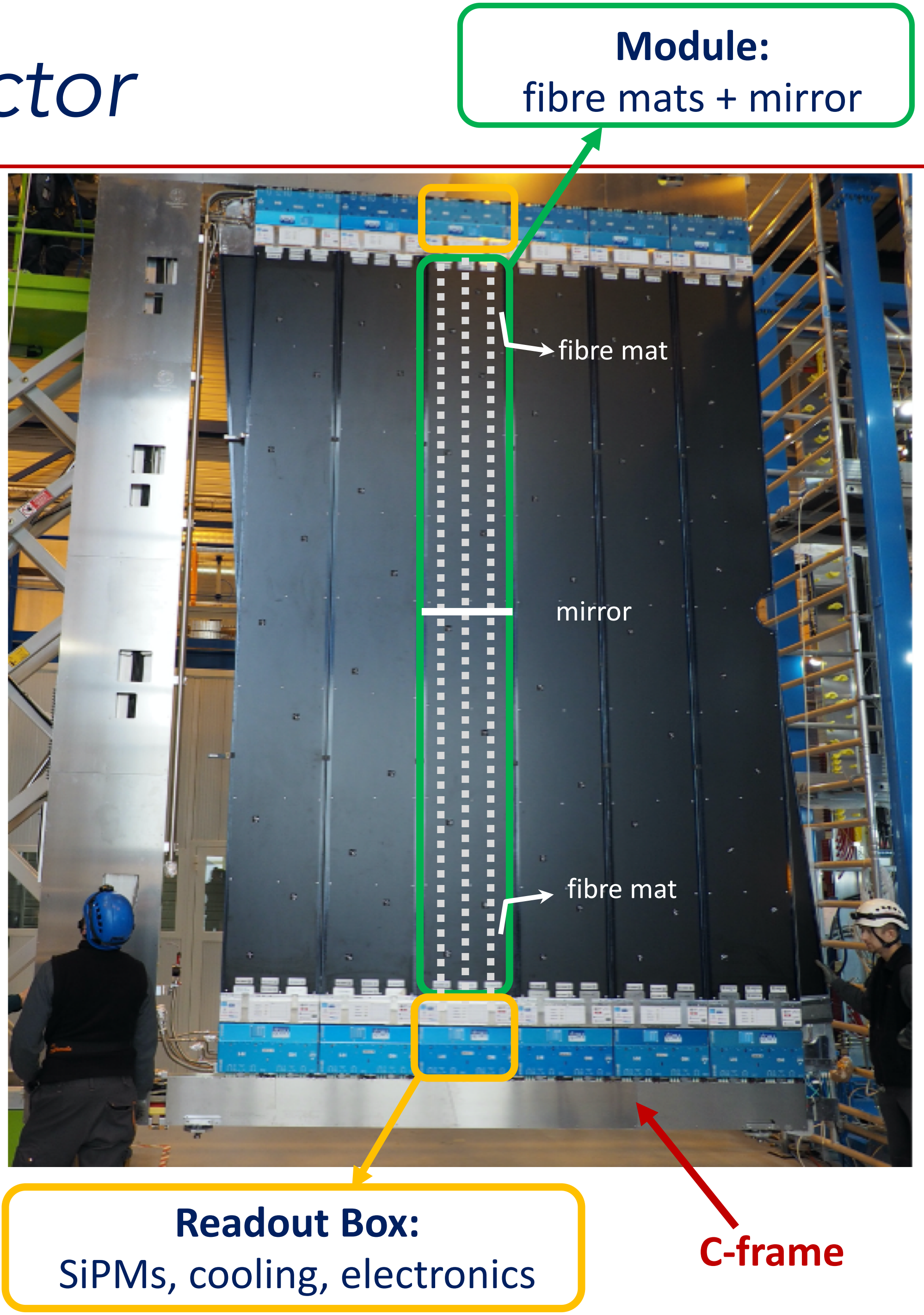
Fibre Module
= 8 x Fibre Mat



Material budget **1% X_0 per module**
Fibers aligned within **50 µm**



Cross-section of a single detection layer (fibre mat) in SciFi



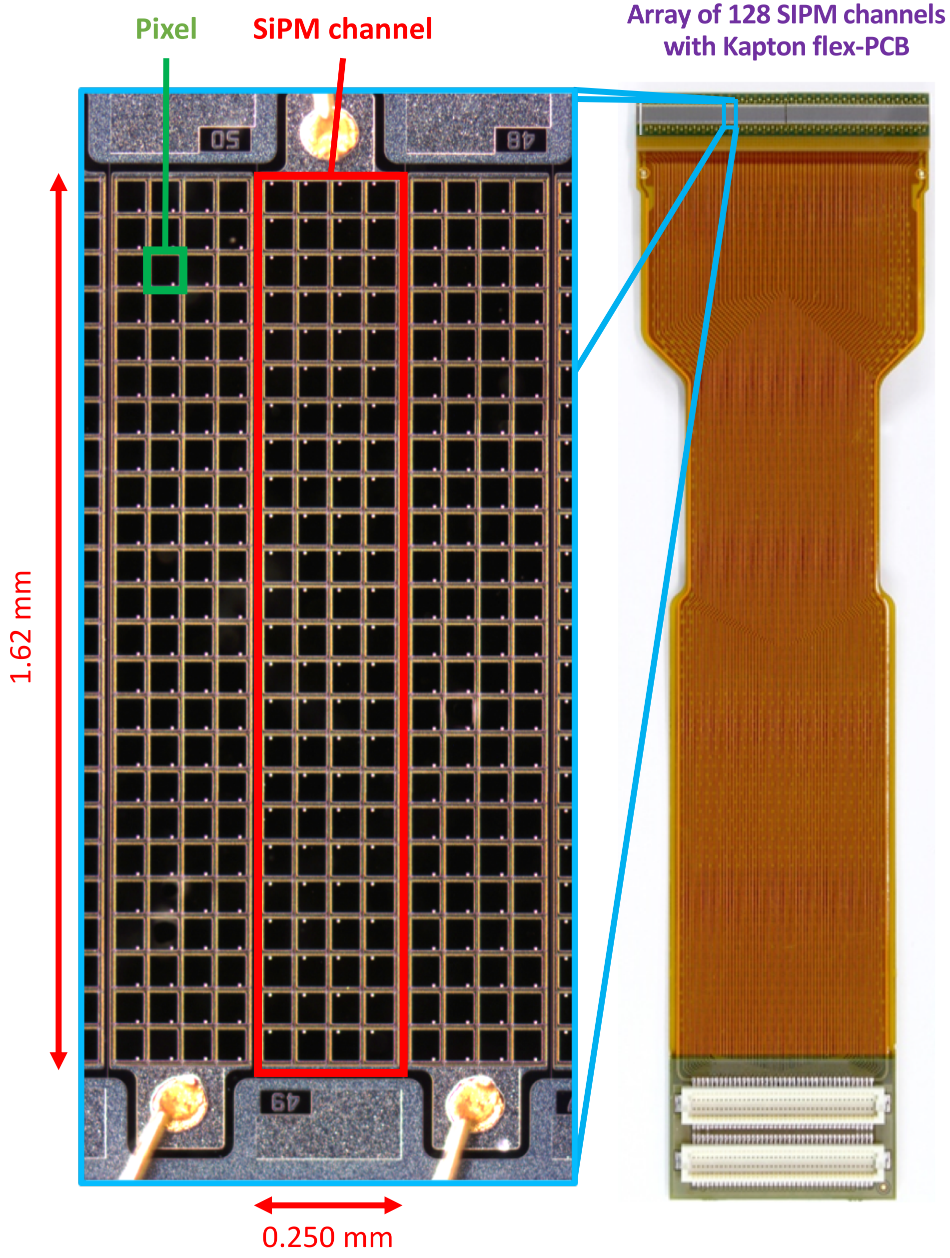
Silicon Photomultipliers (SiPMs)

128 channel SiPM array [*Hamamatsu MPPC S13552 – H2017*] used:

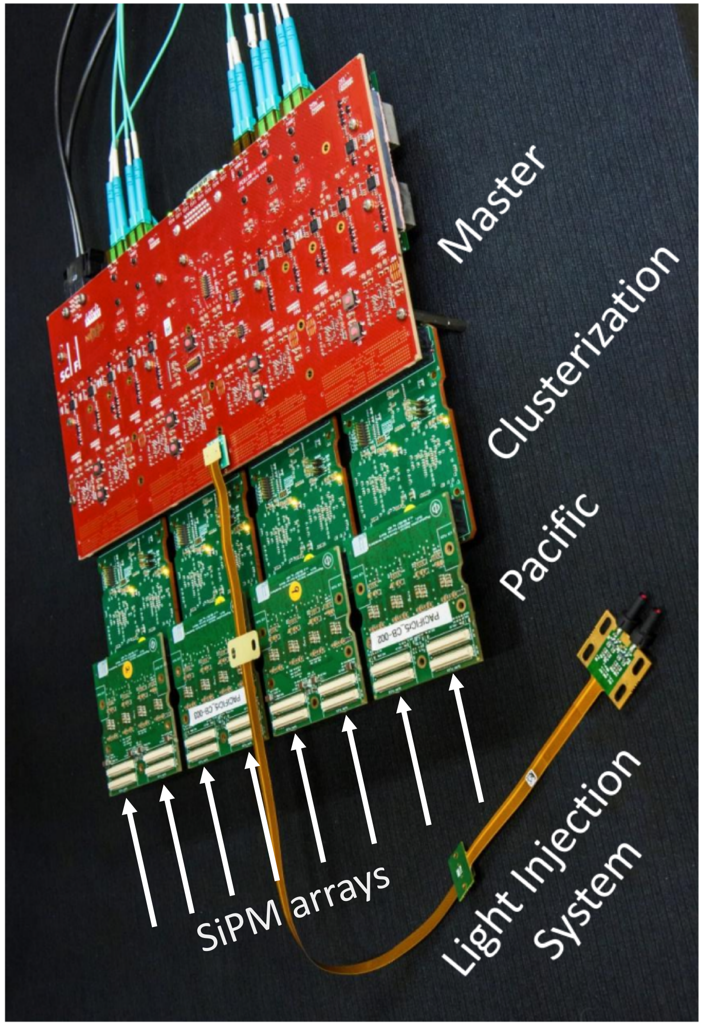
- 128 channel array consist of 2 chips of 64 SiPMs.
- Each SiPM is composed out of 104 parallel Avalanche Photodiodes in Geiger-Mode (pixels)
- Pixel pitch size of 62 x 57 µm, p.d.e. of ~45%
- The 128 channel array is mounted onto a Kapton flex-PCb

The **SciFi Tracker** uses **4096** arrays → **524.000** SiPM channels

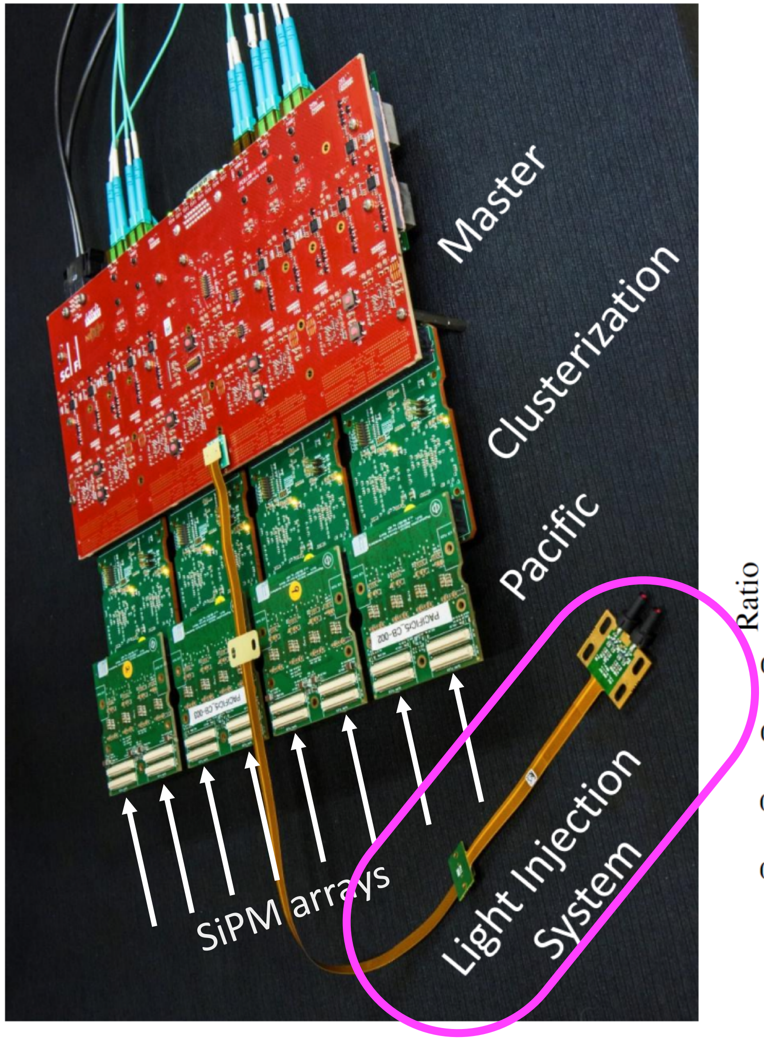
Cross-section of a single detection layer (fibre mat) in SciFi **SiPM channel**

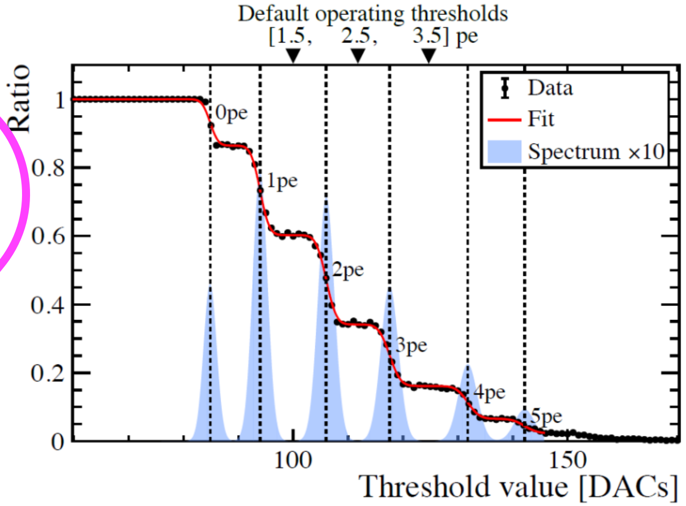


Front-end Electronics

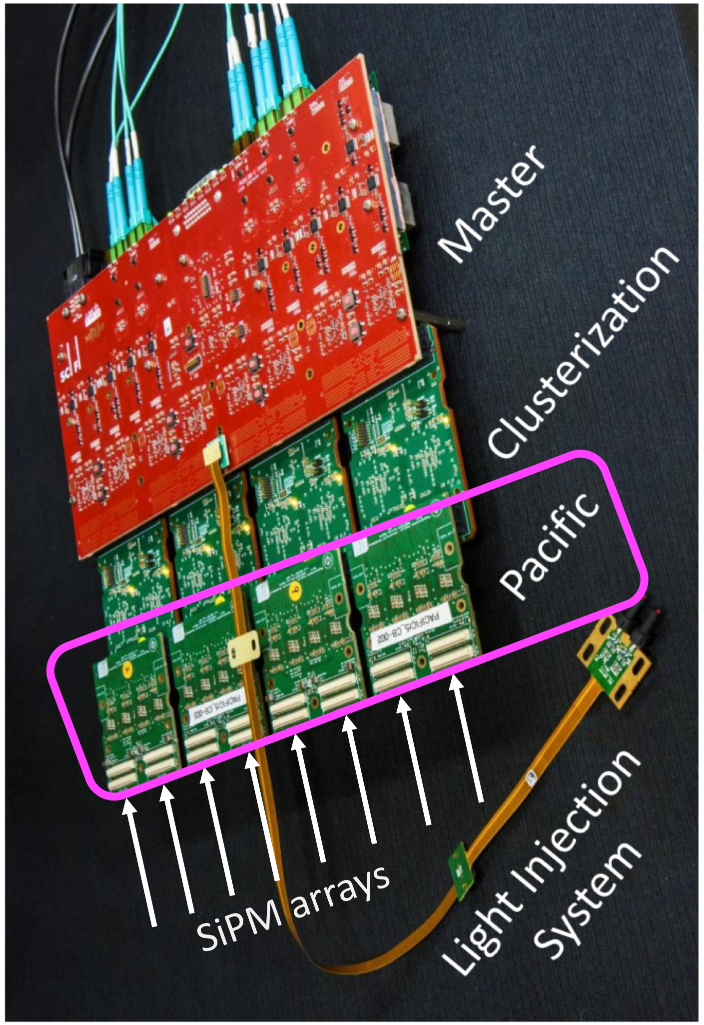


Front-end Electronics



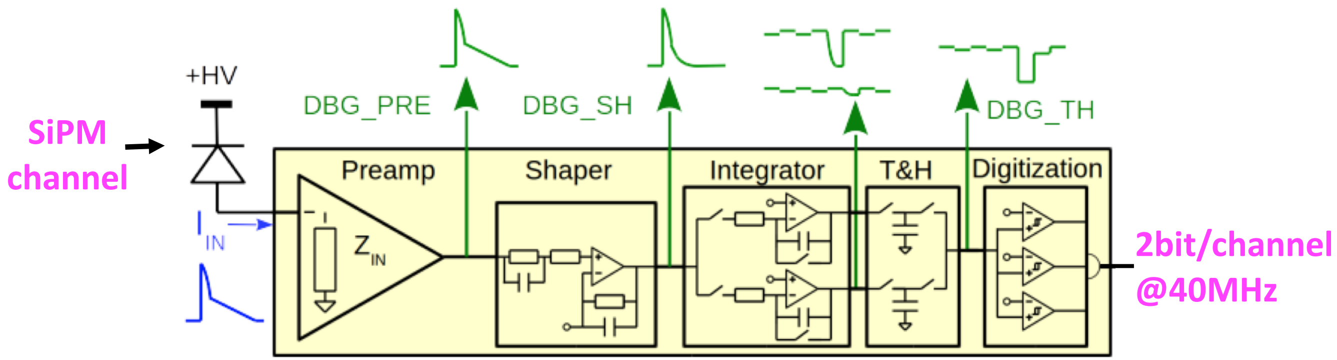


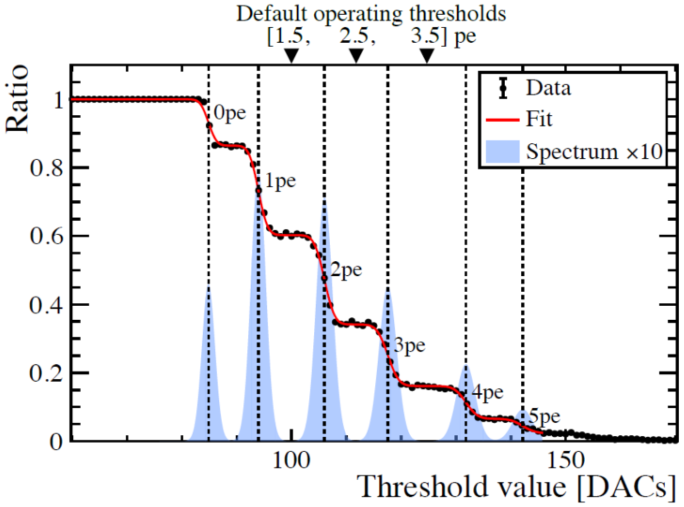
Front-end Electronics



PACIFIC Board

Reads, amplifies and digitizes the data from the SiPMs

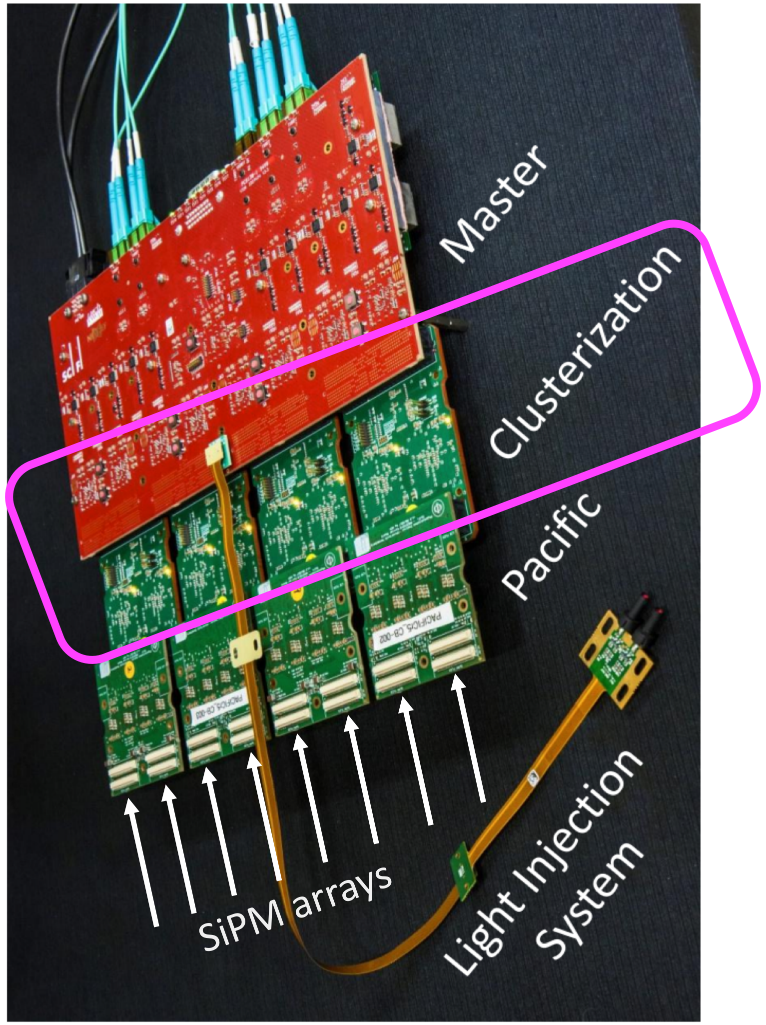




PACIFIC ASIC

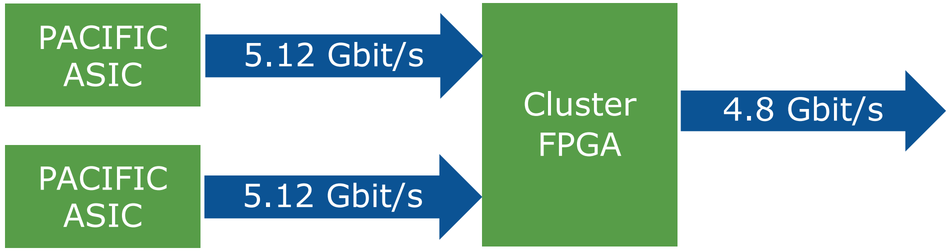
- 64-channels readout (2 per SiPM array)
- Dual 25ns integrators
- 10ns shaping
- **3 configurable comparators** per channel (noise suppression**)**

Front-end Electronics



Cluster Board

Clusterization Algorithm & Zero-Suppression



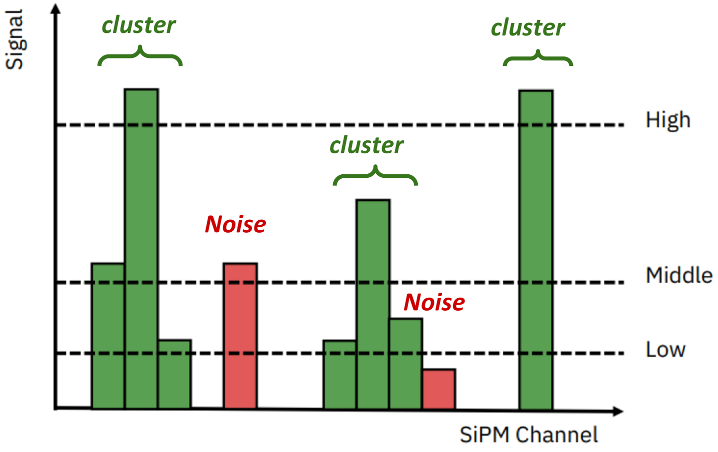
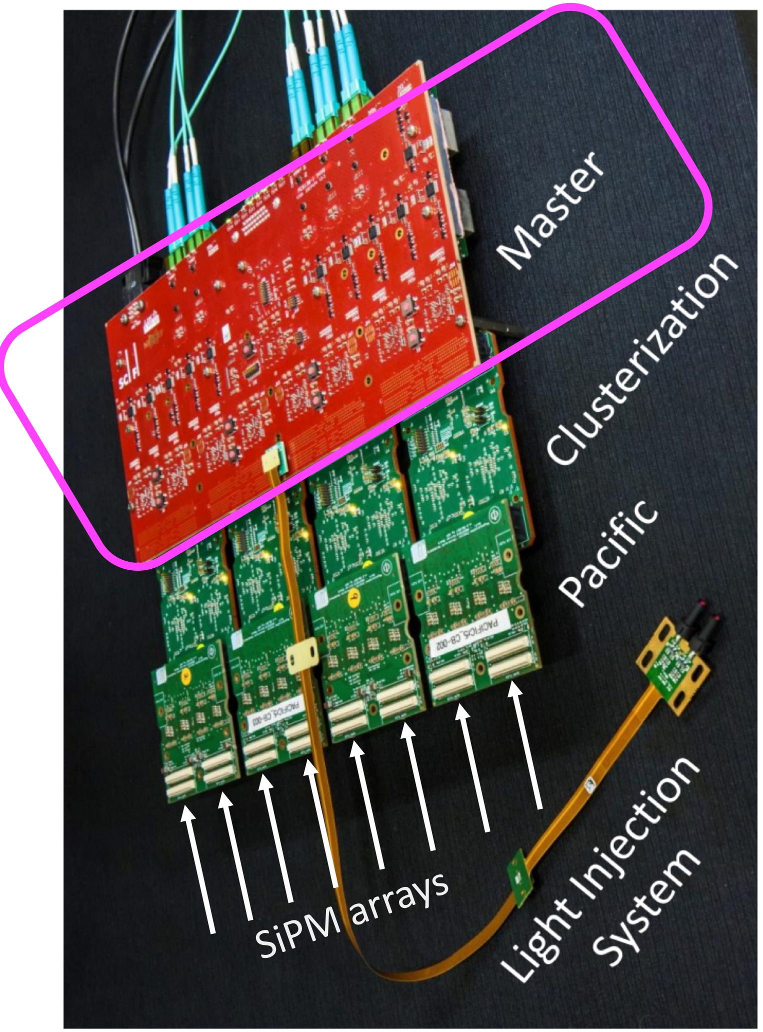


Illustration of the cluster algorithm

3 thresholds from PACIFIC:

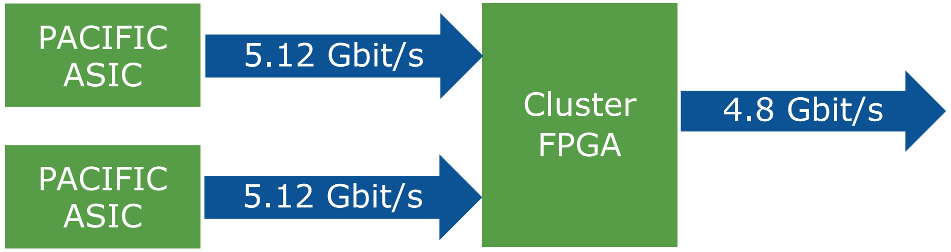
- **High threshold**
  High single channel signals
- **Middle threshold (seed)**
  Cluster candidate
- **Low threshold**
  Noise suppression

Front-end Electronics



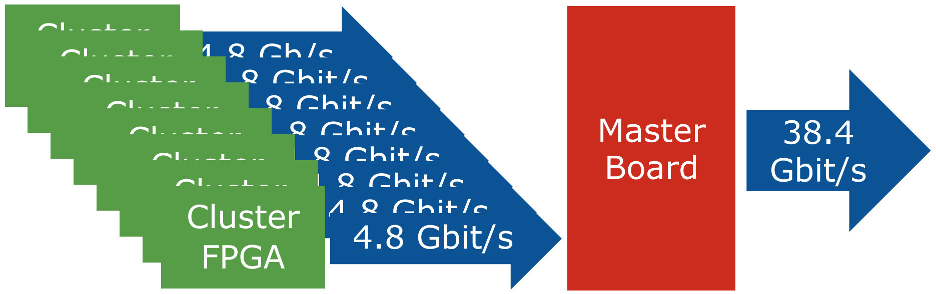
Cluster Board

Clusterization Algorithm & Zero-Suppression



Master Board

Data transmission & Slow/Fast control



Total from SciFi

512 Master Boards

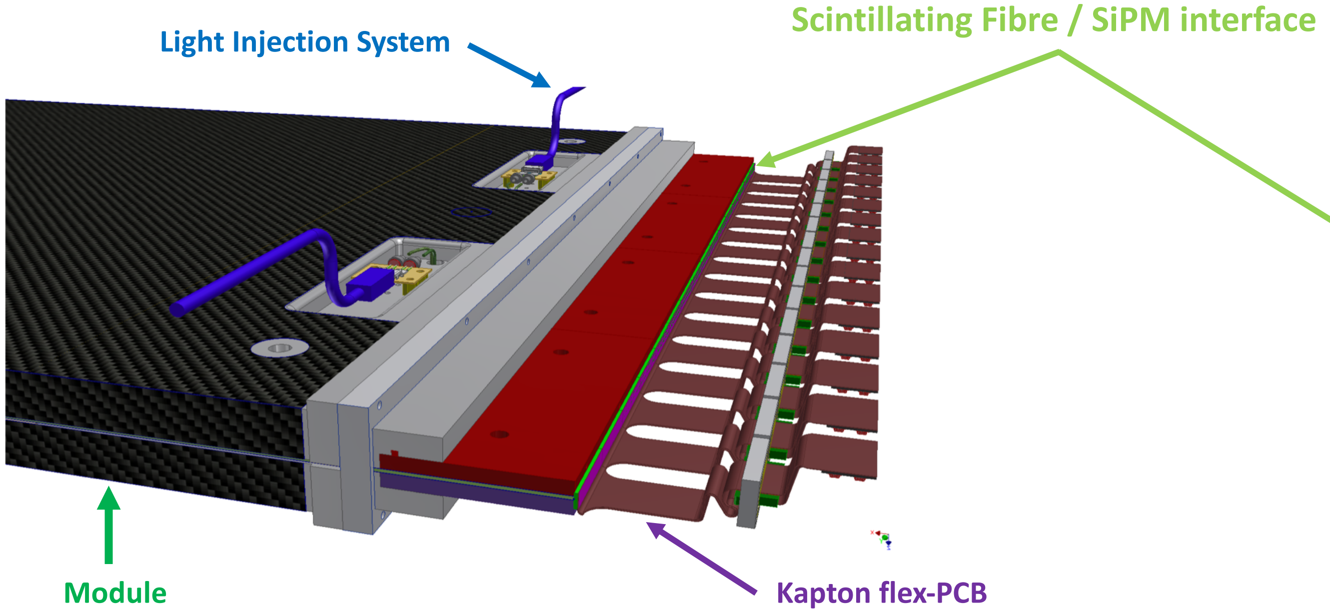
4096 data links

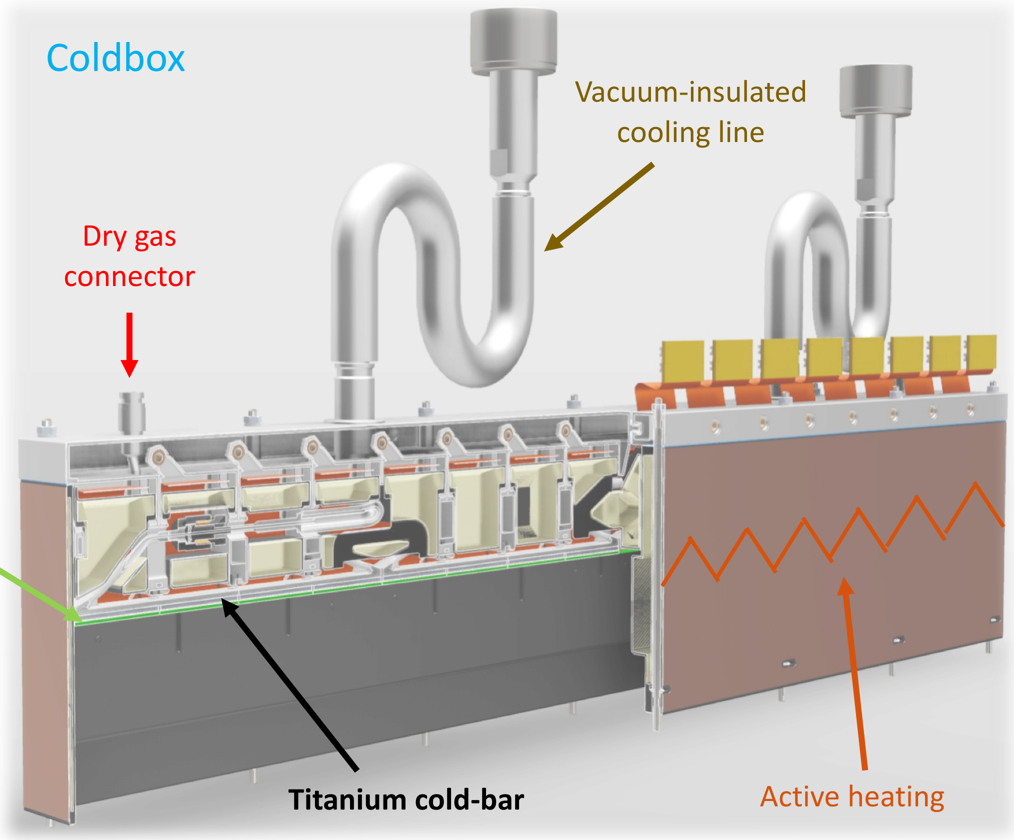
~20 Tbit/s

SiPM cooling introduces complex services

Cooling of SiPM is required maintain single photon detection capability over the detectors lifetime
Due to radiation damage, the dark noise levels would to high after only ~5% of foreseen luminosity

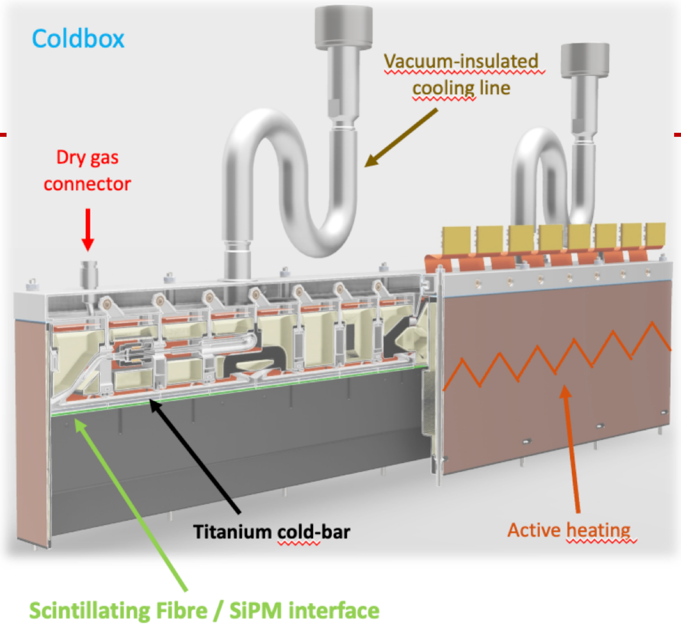
- Monophase cooling liquid (C_6F_{14}) used at the moment
- Vacuum-insulated cooling lines
- 3D printed titanium hollow cold-bar for circulating the fluid to cool the SiPM arrays
- A dry gas is continuously flushed to minimize the humidity inside the coldbox
- Limited space for thermal insulation of coldbox, active heating used on outside



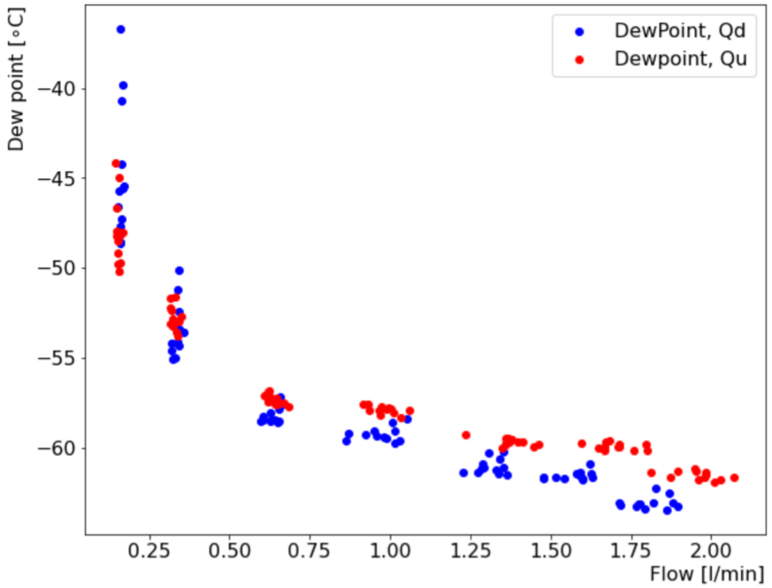


Services performance

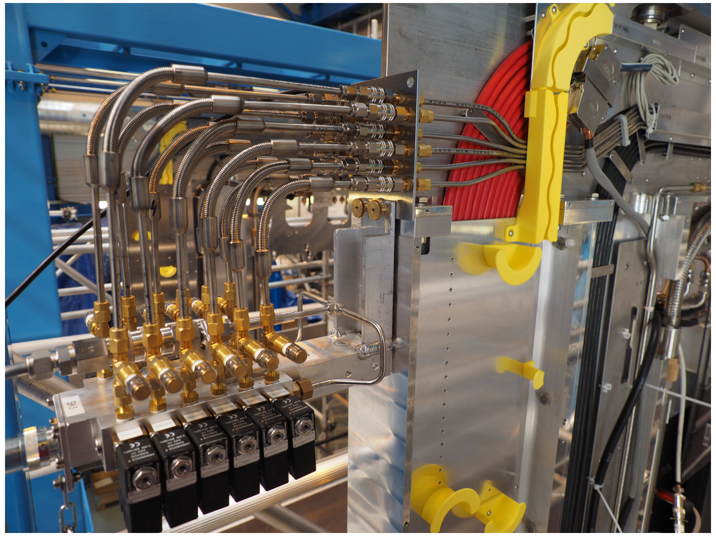
- Systematic study carried out to map out correlations of the c-frame services
  → Results used to determine operational parameters



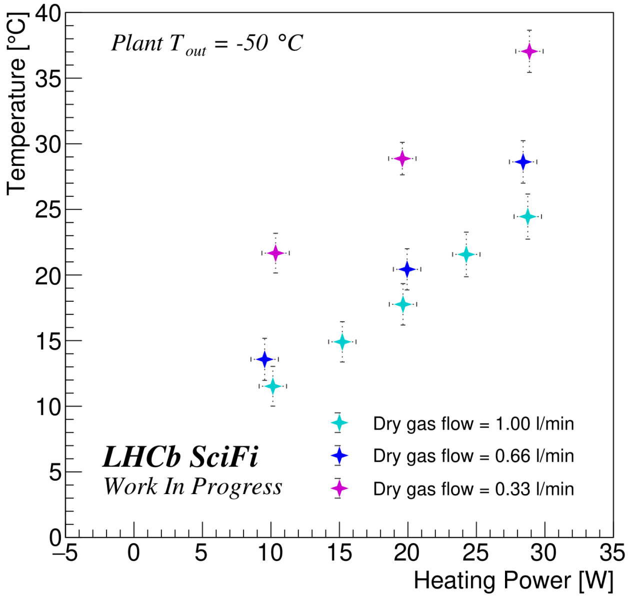
Measurements to determine the dewpoint inside the cold box as a function of the dry gas flow rate



Gas multiplexer for dew point measurements of the exhaust from the coldboxes

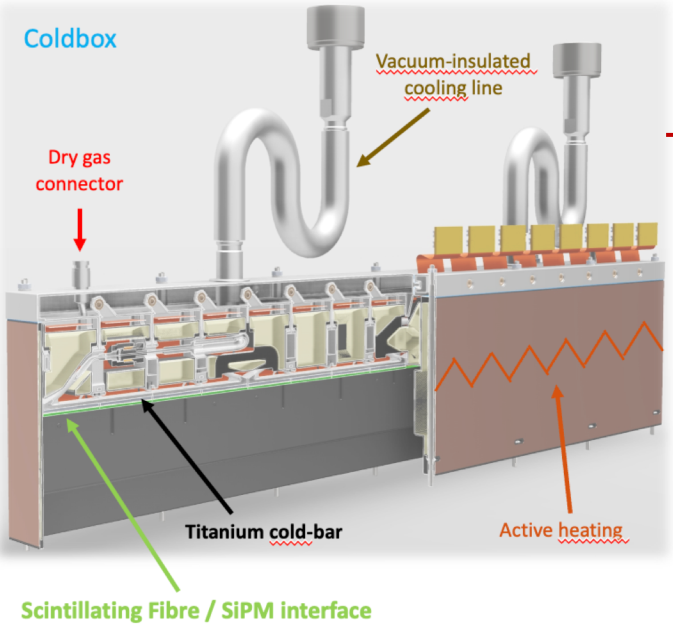


Dry gas outlet temperature vs heating power

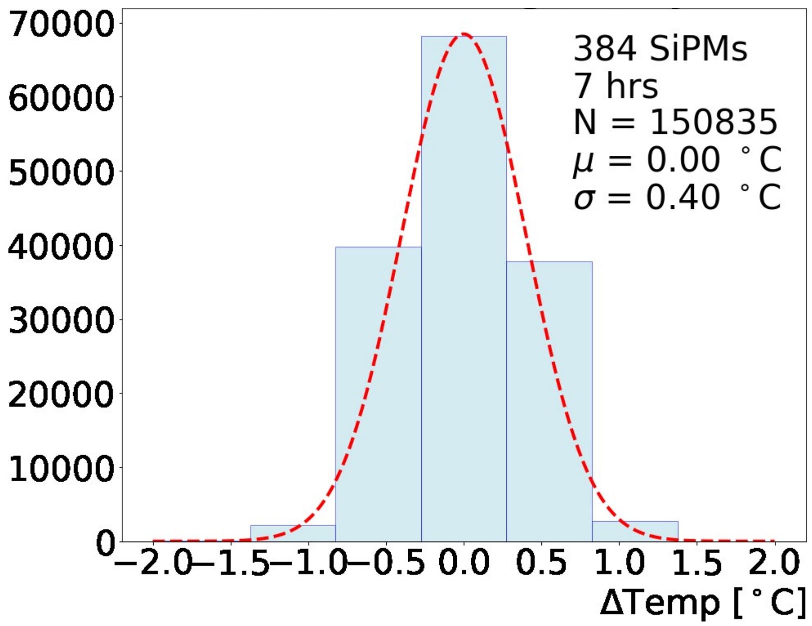


Services performance

- Systematic study carried out to map out correlations on c-frame services
  → Results used to determine operational parameters
- Cooling plant proven to be very stable at a setpoint of -40 °C
  → Upgrade ongoing to improve long term stability at a setpoint of -50 °C



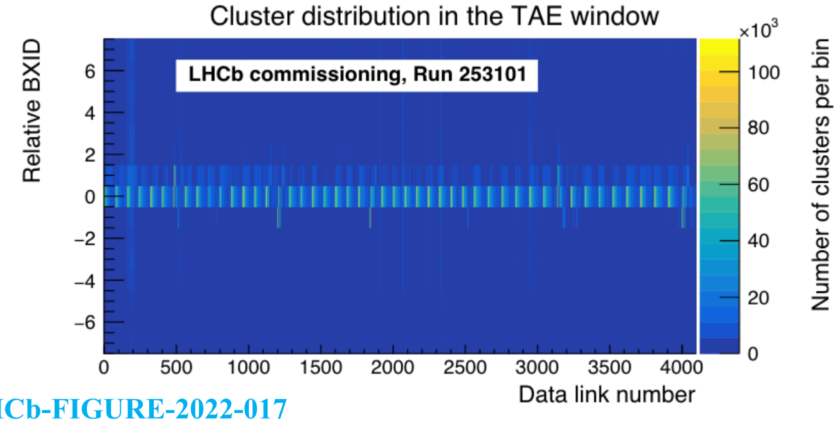
Temperature stability of all SiPMs on a C-frame



Connecting lines from the cooling plant to manifold

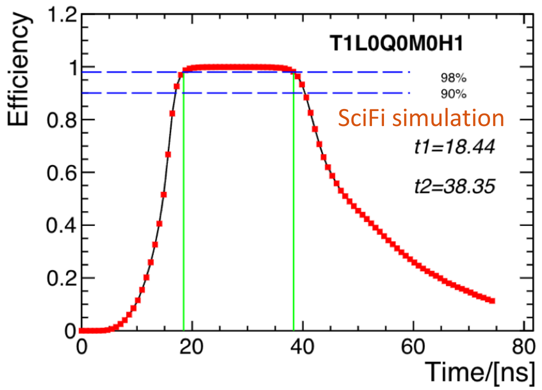
Time alignments

- Coarse BX alignment – TAE runs: wrong events if misaligned



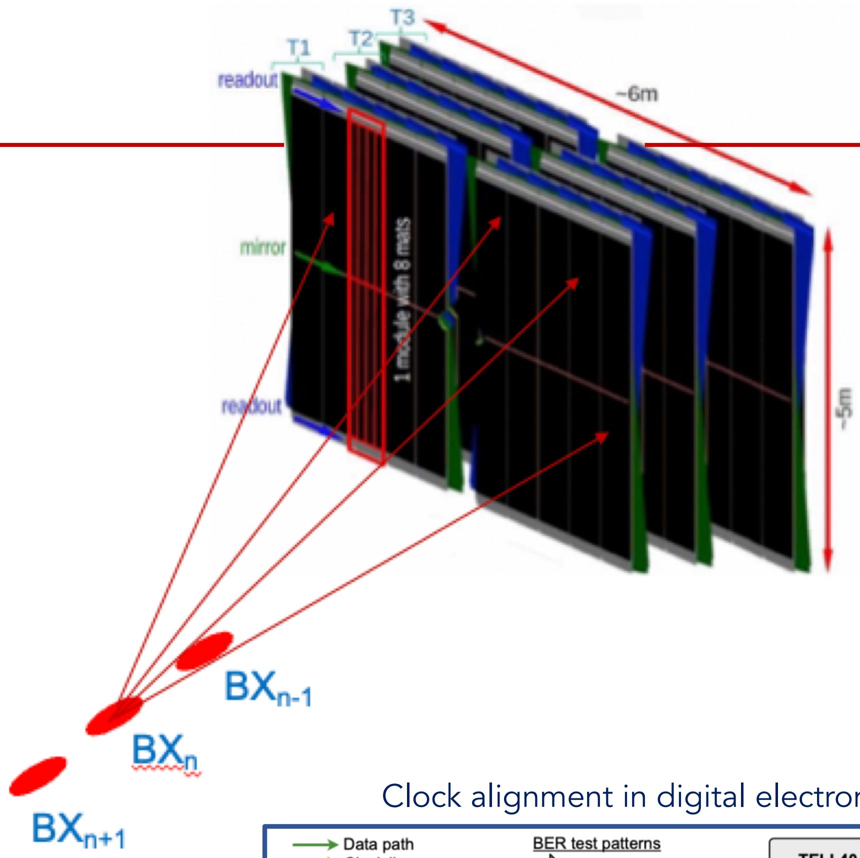
LHCb-FIGURE-2022-017

- Fine time alignment - fine time scans: efficiency drop if wrong

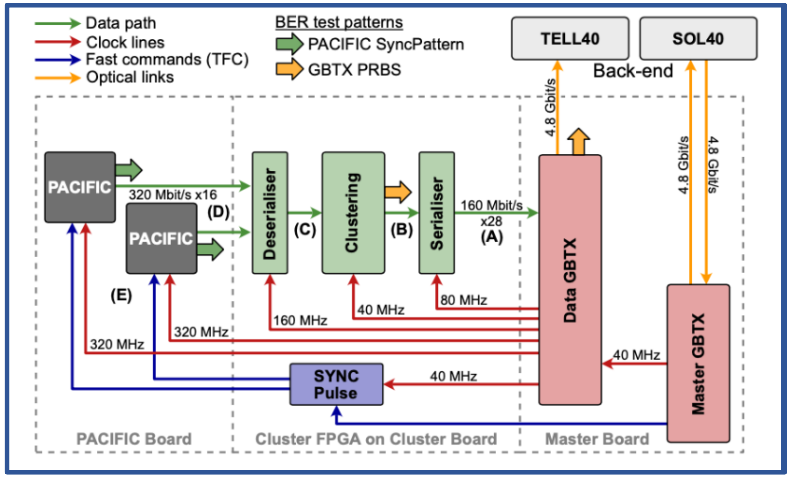


LHCb-FIGURE-2023-016

- Clock tuning in the digital readout chain: data-transmission problems if wrong



Clock alignment in digital electronics



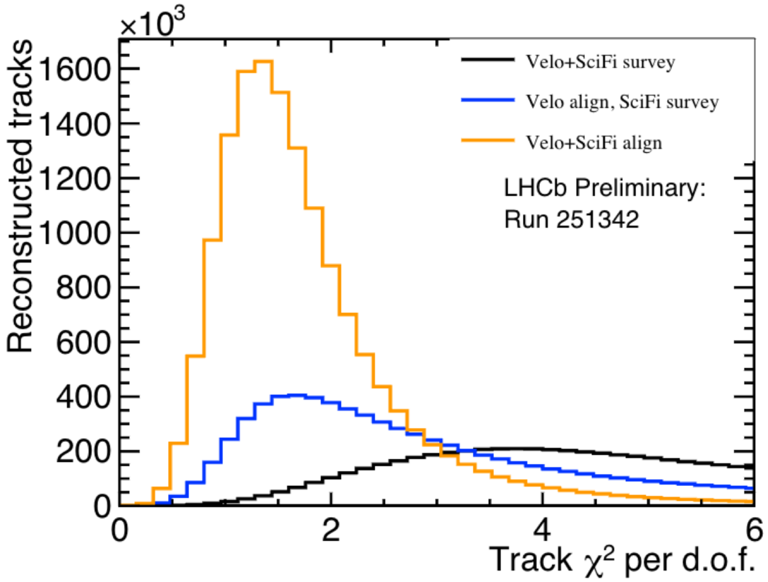
SciFi alignment per Module

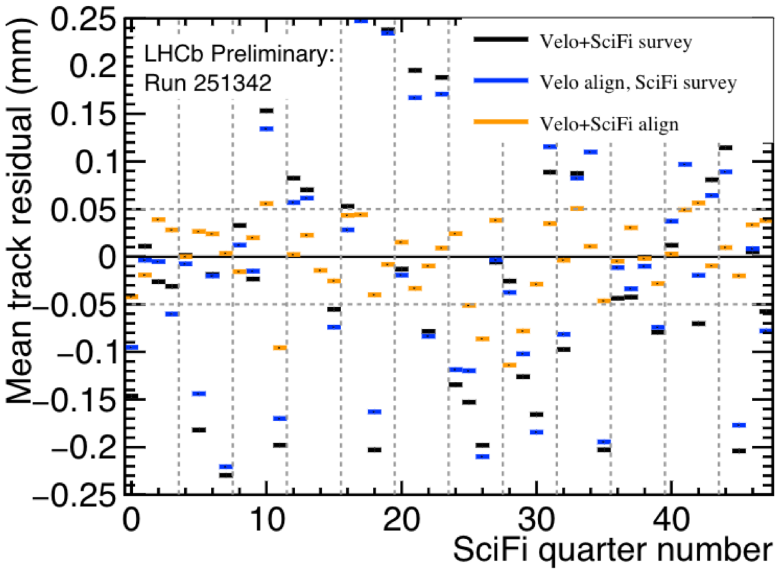
Spatial alignment of SciFi required for better track quality

Using long tracks (SciFi + Velo) by the track-based alignment* procedure to improve:

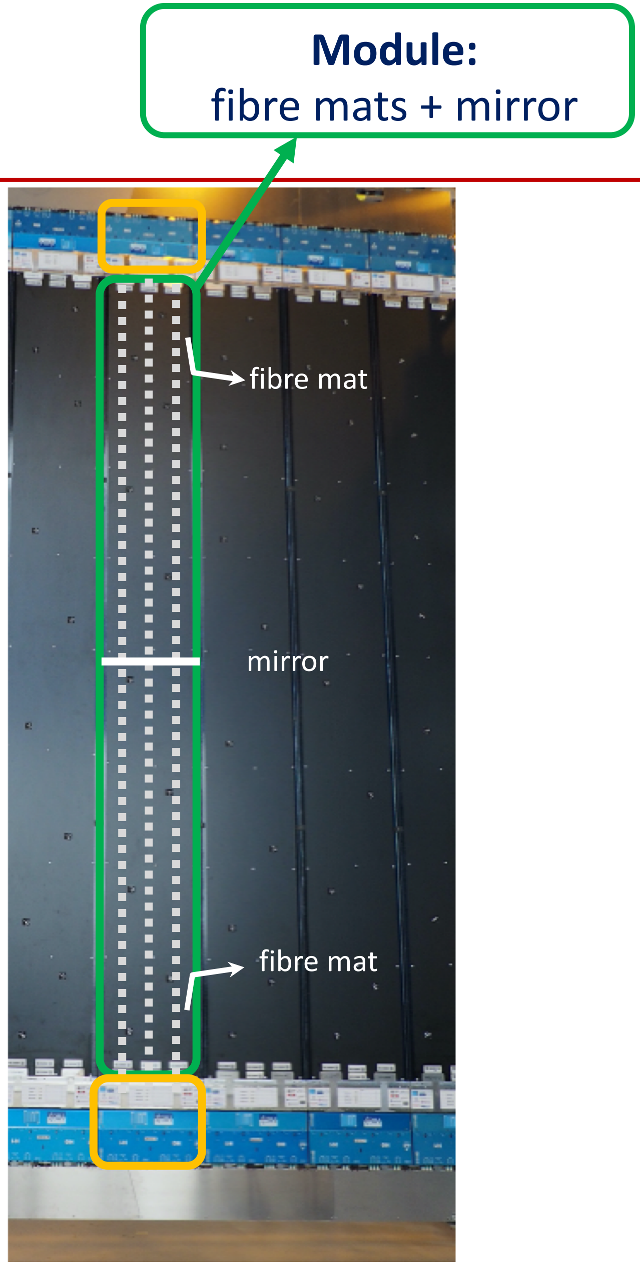
- The number of reconstructed tracks (efficiency)
- The track quality

*SciFi alignment per Module





LHCb-FIGURE-2022-018



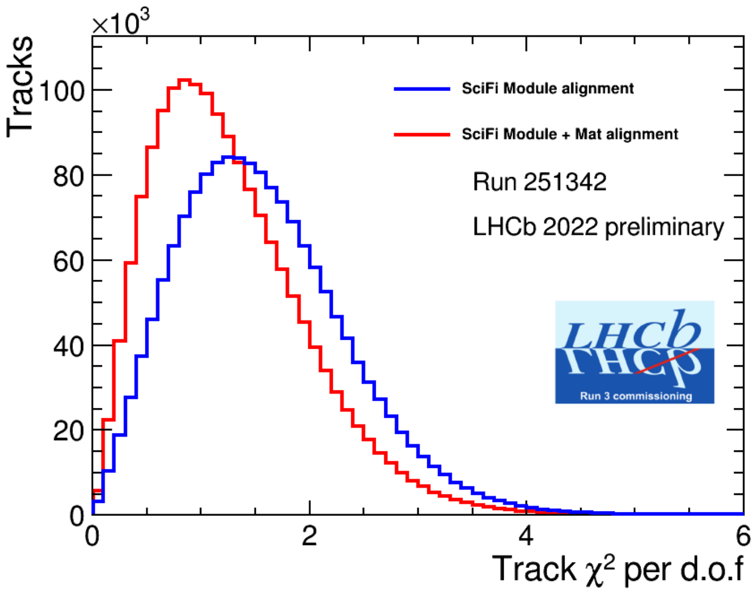
SciFi alignment per Mat

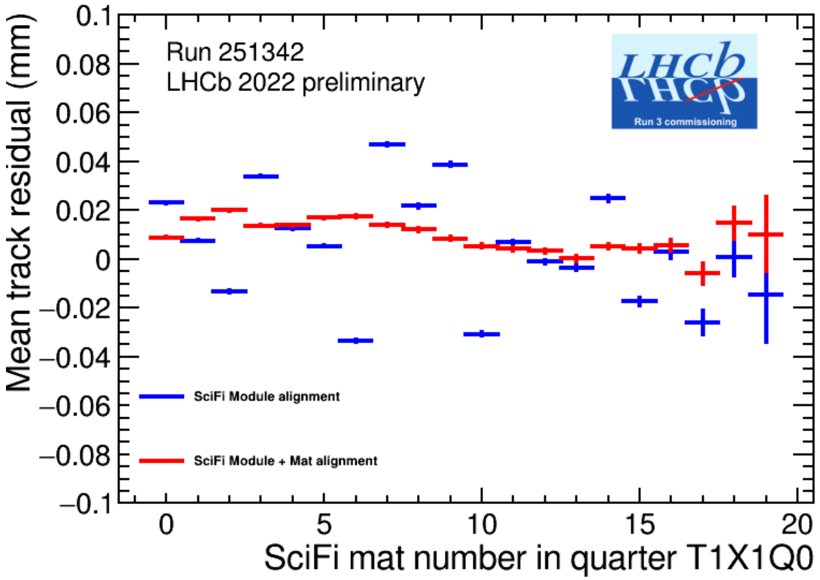
Spatial alignment of SciFi required for better track quality

Using long tracks (SciFi + Velo) by the track-based alignment** procedure to improve:

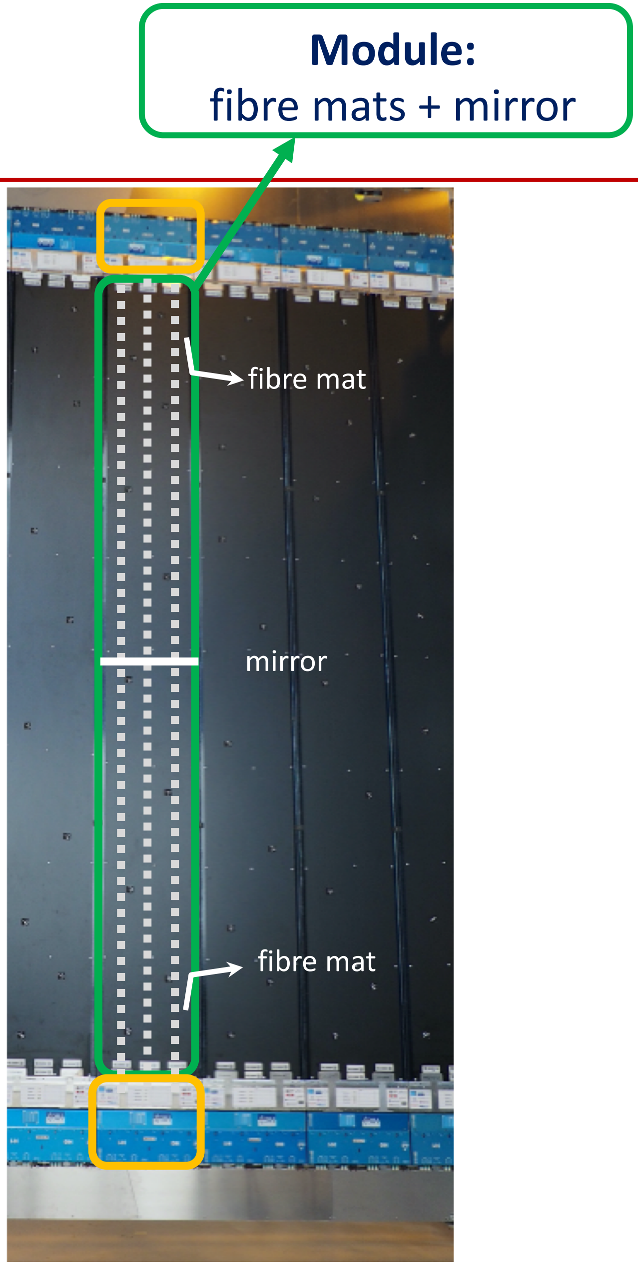
- The number of reconstructed tracks (efficiency)
- The track quality

**SciFi alignment per Mat further improves the above, residuals < 0.02 mm





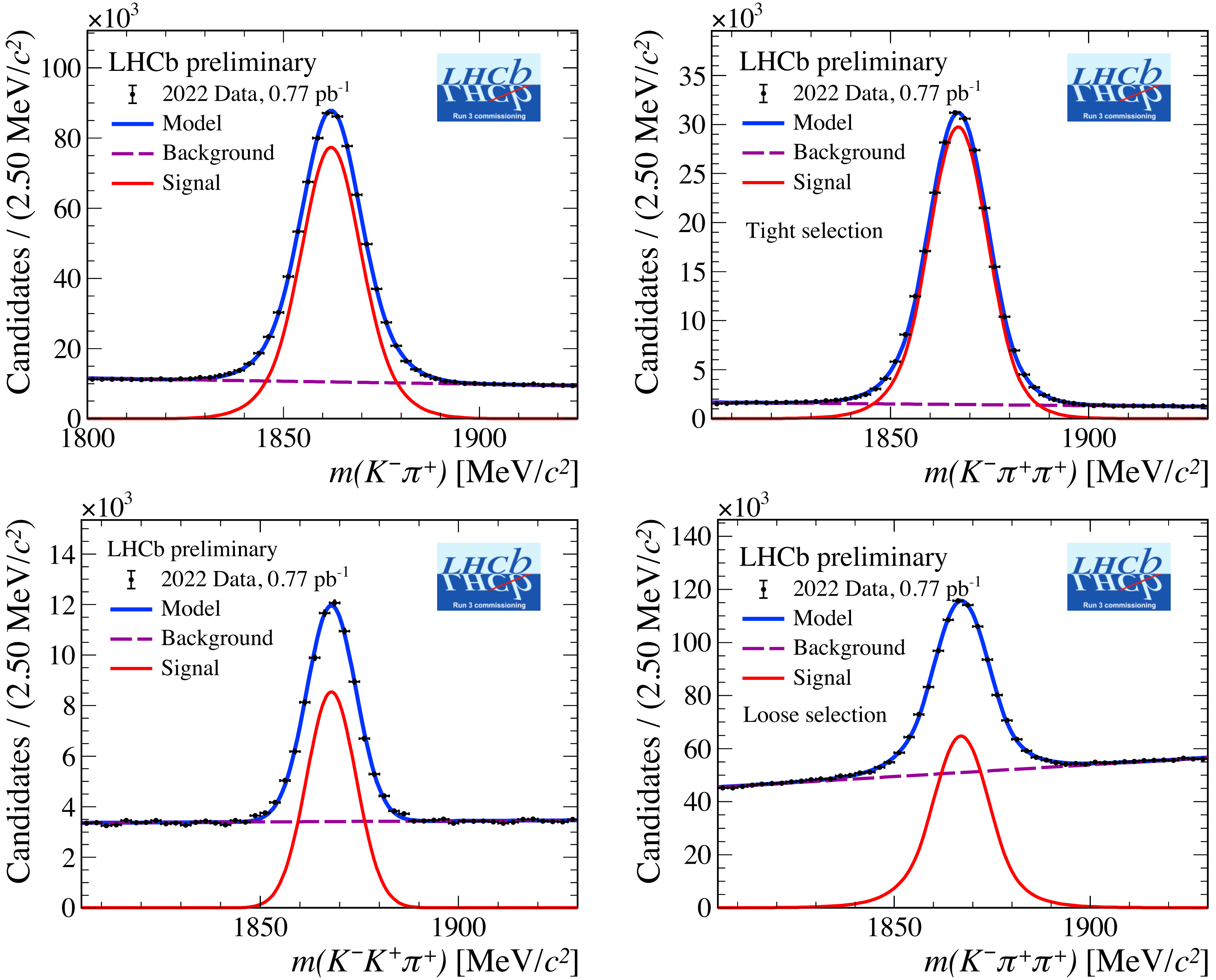
LHCb-FIGURE-2023-018



Physics performance

SciFi as a main tracker:
→ Direct impact on signal mass resolutions

Charmed mesons:

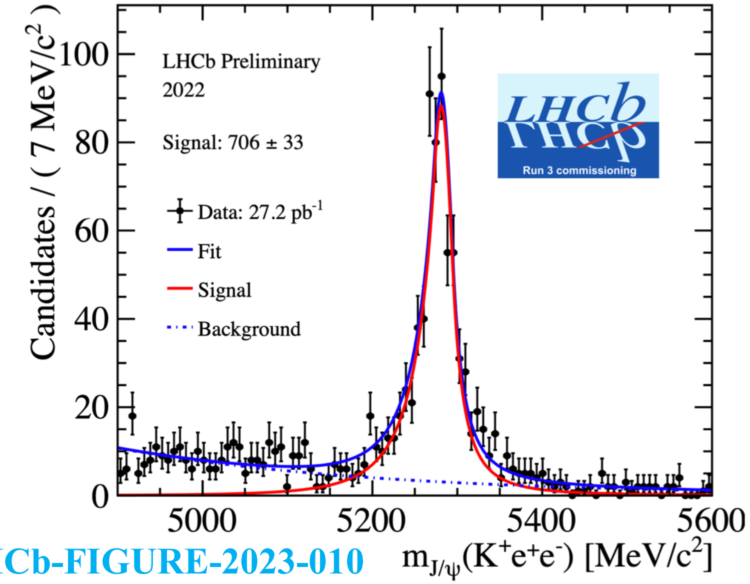


LHCb-FIGURE-2023-011

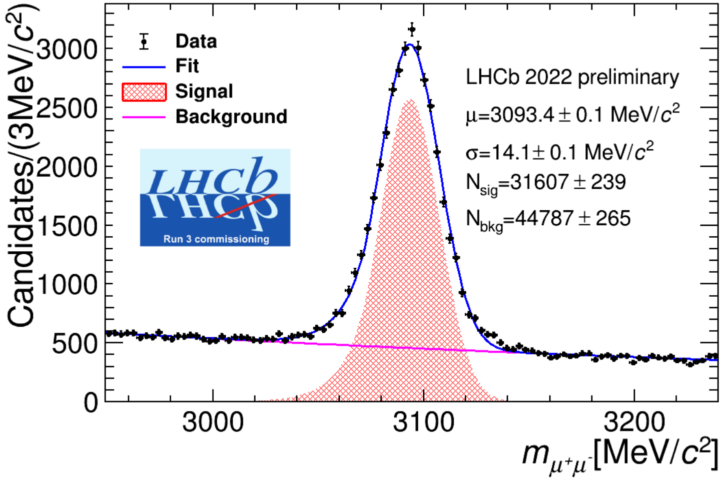
Physics performance

SciFi as a main tracker:
→ Direct impact on signal mass resolutions

From *pp* collisions :

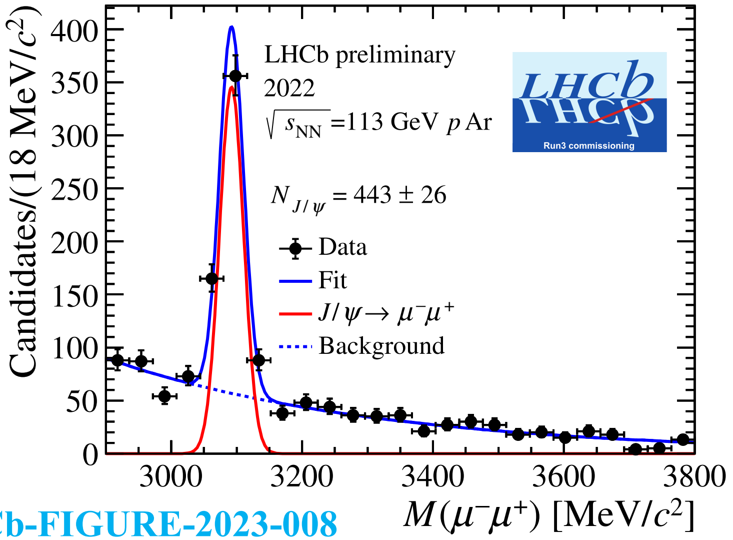


LHCb-FIGURE-2023-010



LHCb-FIGURE-2023-015

From *pAr* and *pH* collisions :

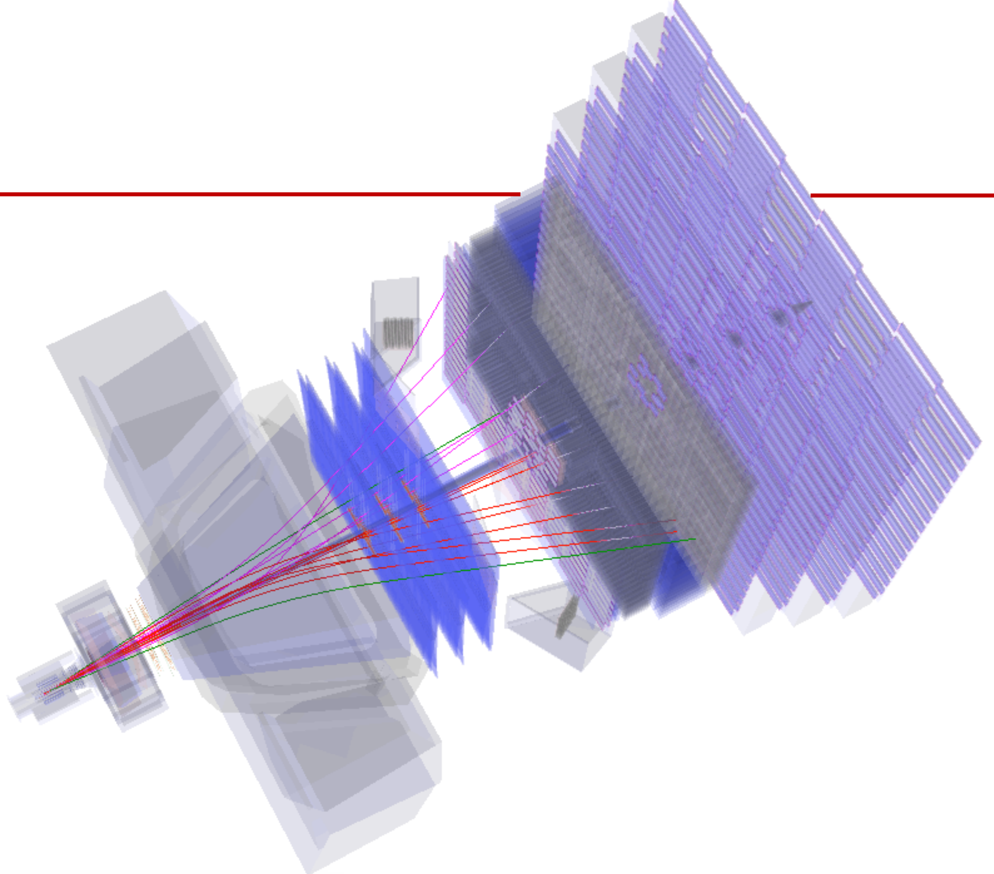


LHCb-FIGURE-2023-008

Summary & Outlook

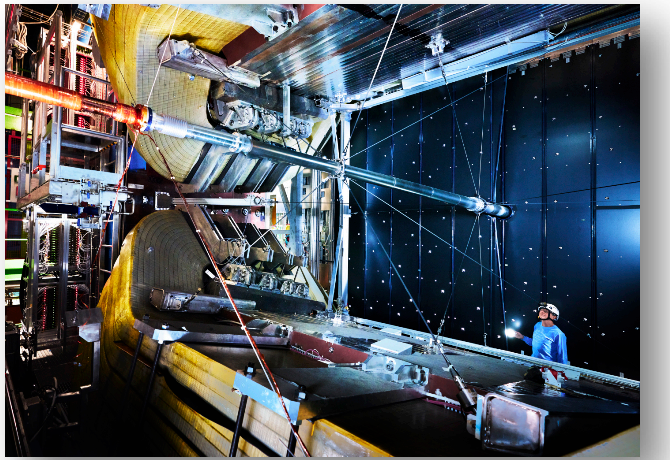
The SciFi Tracker has been under beam commissioning since April 2022:

- Functioning tracker for LHCb
- Physics signal mass resolution similar to MC expectations
- Lots of progress towards further optimizing its operation



Outlook:

- Since a couple of days, the LHC beam came back:
  → Finer optimizations on time/thresholds/position alignments
- Ready to take part in PbPb runs this fall
- LHCb detectors to run at Run 3 nominal instantaneous luminosity from next year



Backup slides

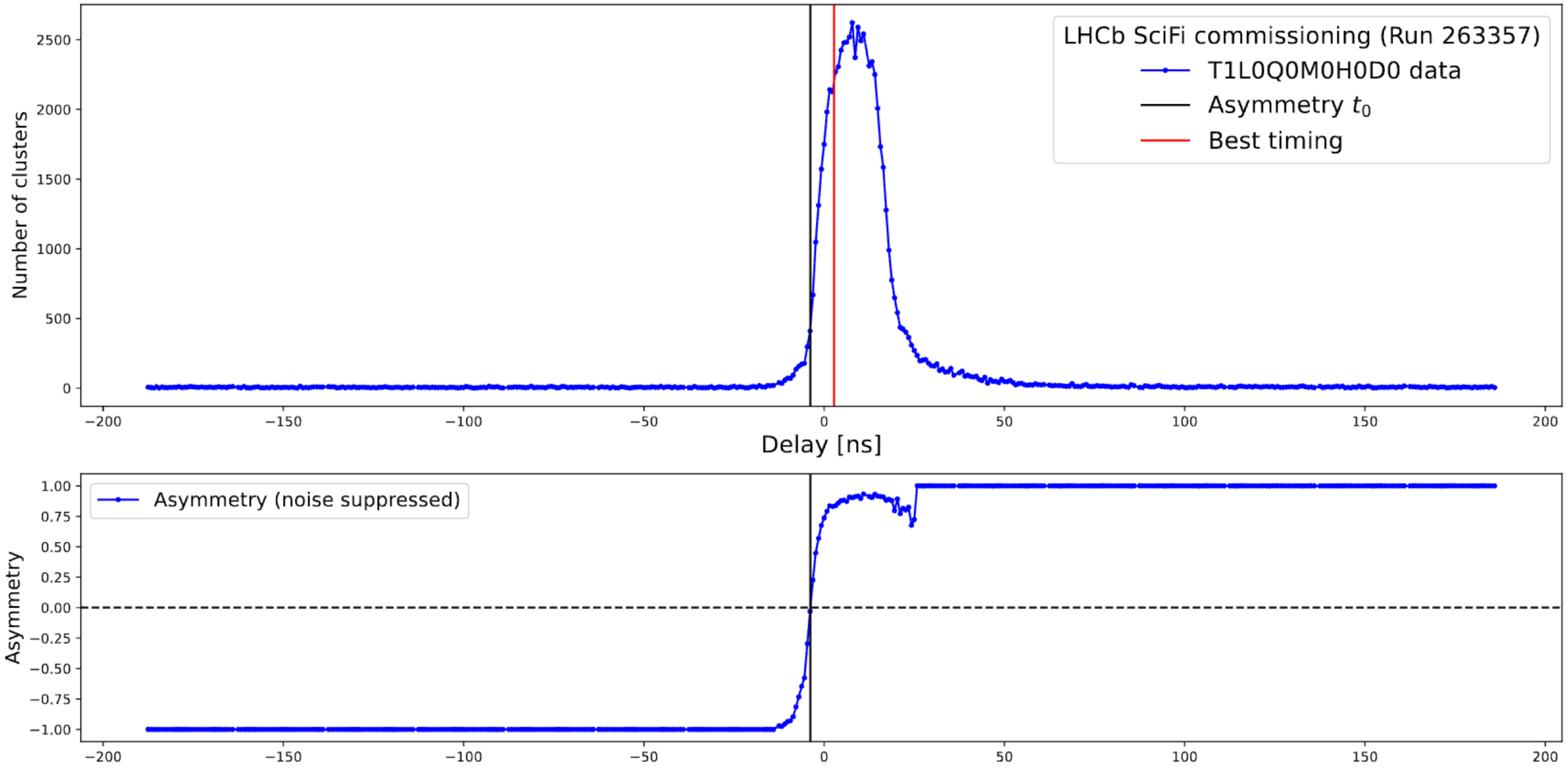
Baseline time per datalink

Beam scan data taken from isolated bunch crossings:

- TFC delayed time-step scan with 0.78 ns step size

Baseline time, t_0, define from assymetry:

- Asy = [O(i+1) – O(i)]/[O(i+1) – O(i)], t_0 defined a Asy = 0
- i present the current time window, O(i) the corresponding cluster occupancy

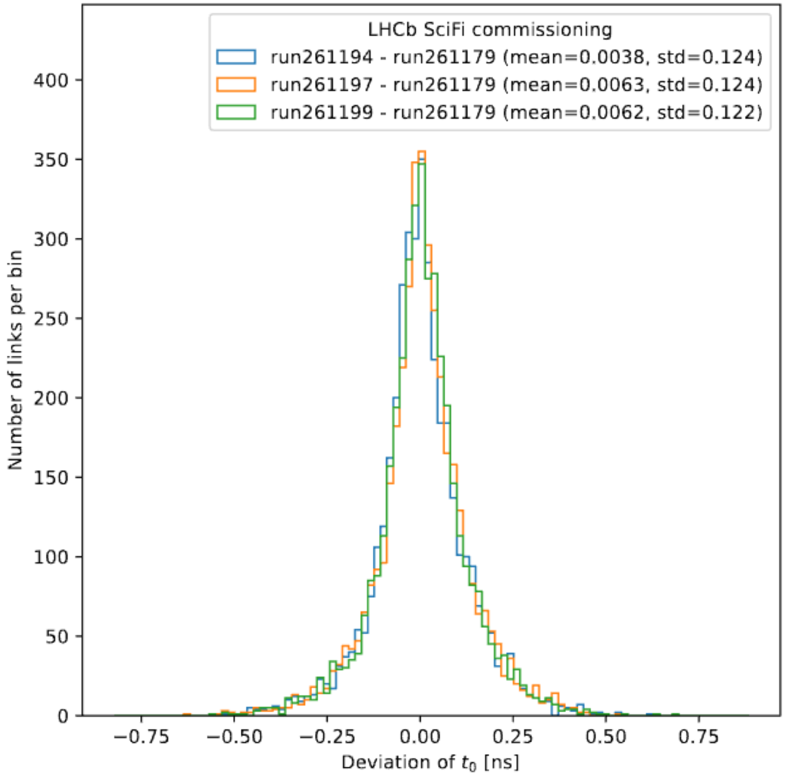


LHCb-FIGURE-2023-016

Timing stability

Deviation of t_0 (from asymmetry) among 4 runs (May 2023)

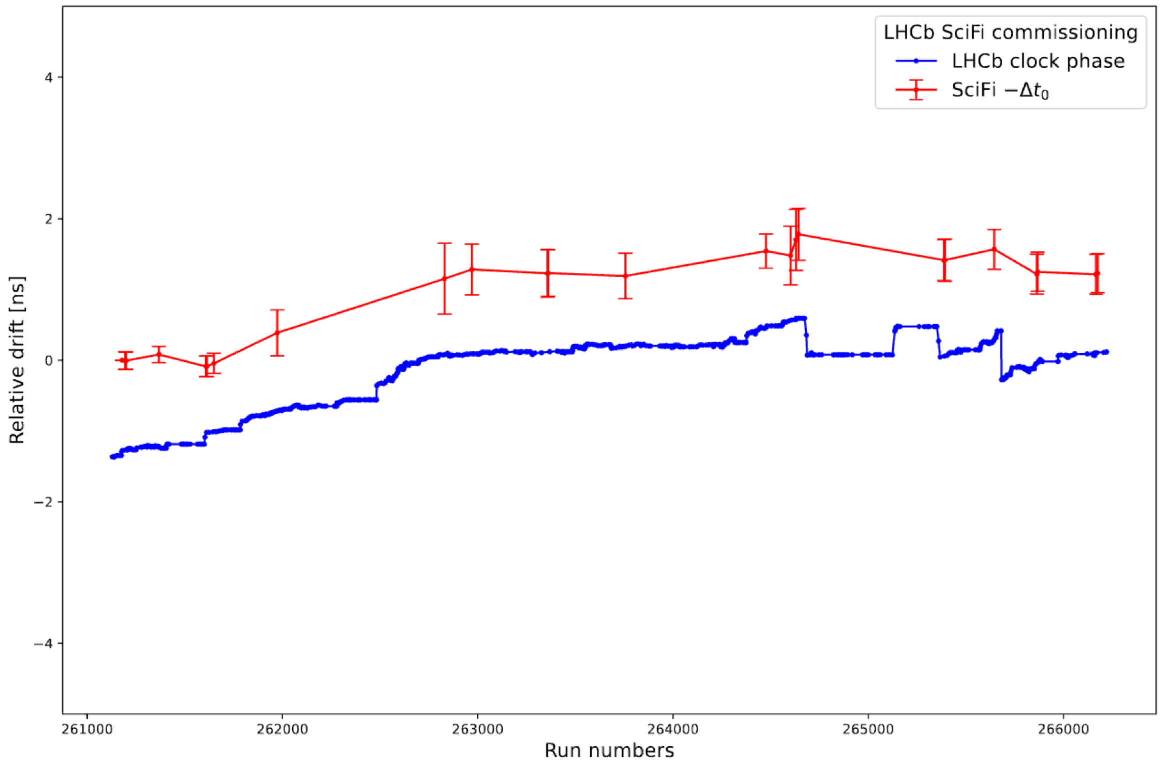
→ Small intrinsic time resolution



LHCb-FIGURE-2023-016

Variation of t_0 over ~1 month (May 2023)

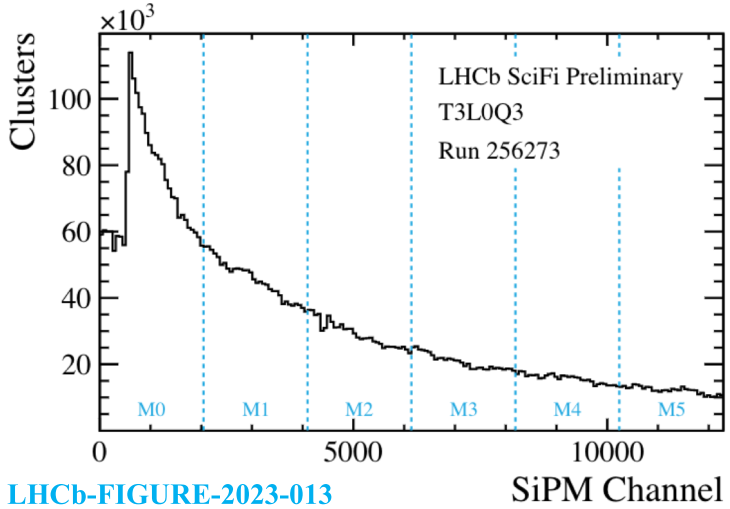
→ Variation of $t_0 < 2$ ns and following the LHCb clock phase



LHCb-FIGURE-2023-016

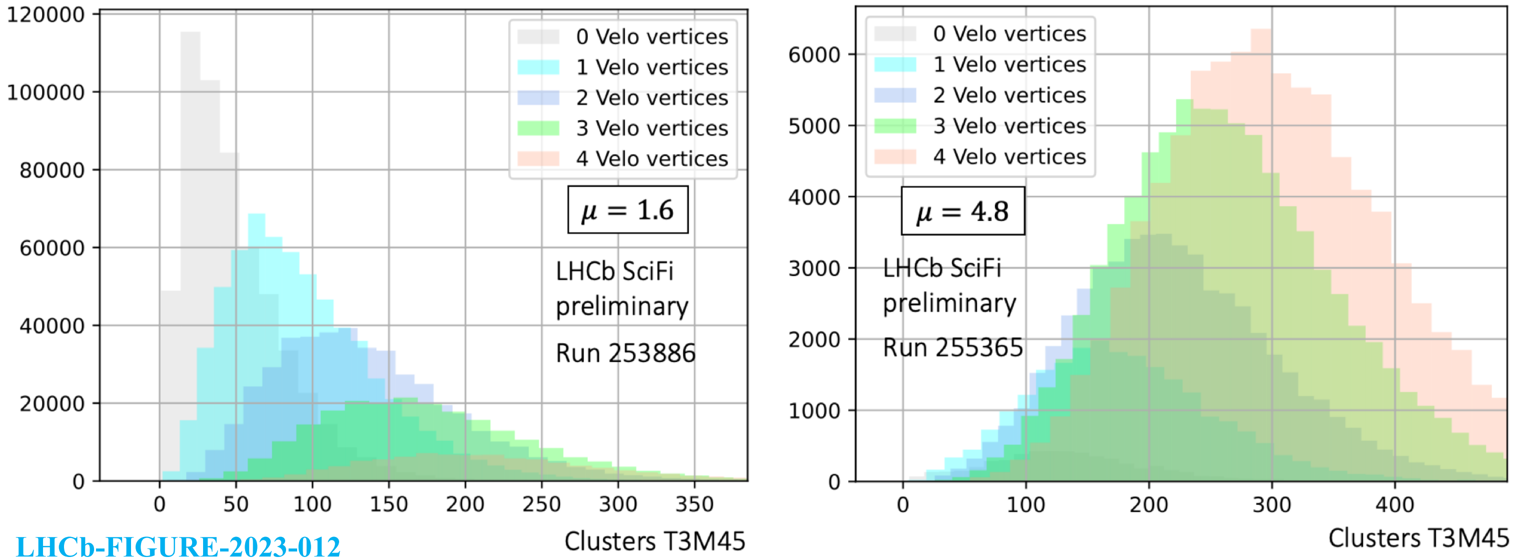
Cluster distributions after time alignment

Number of clusters as a function of SiPM channel:



LHCb-FIGURE-2023-013

Number of cluster at different pile-up:



LHCb-FIGURE-2023-012