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The LHCb SciFi Tracker

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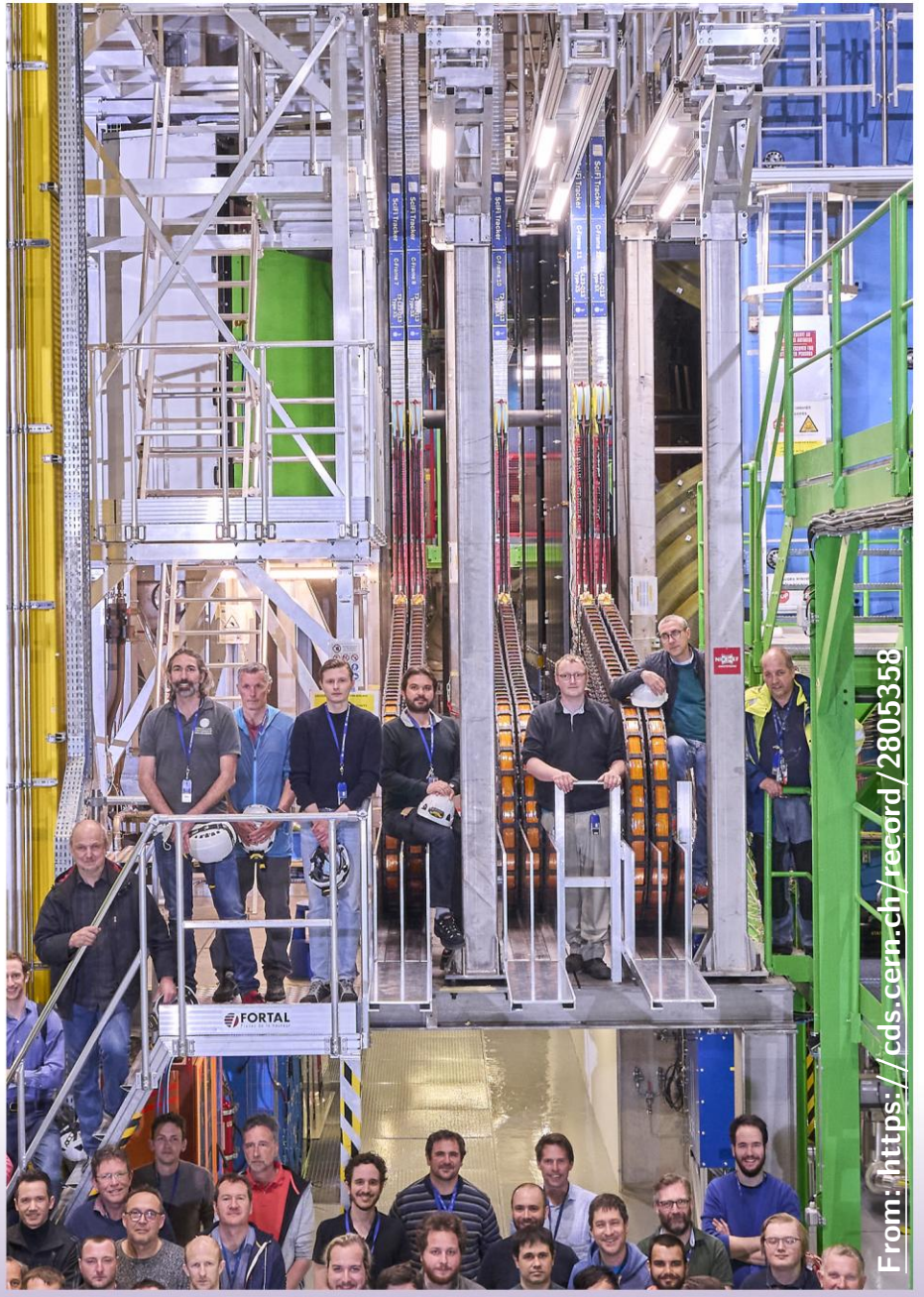
on behalf of The LHCb Experiment

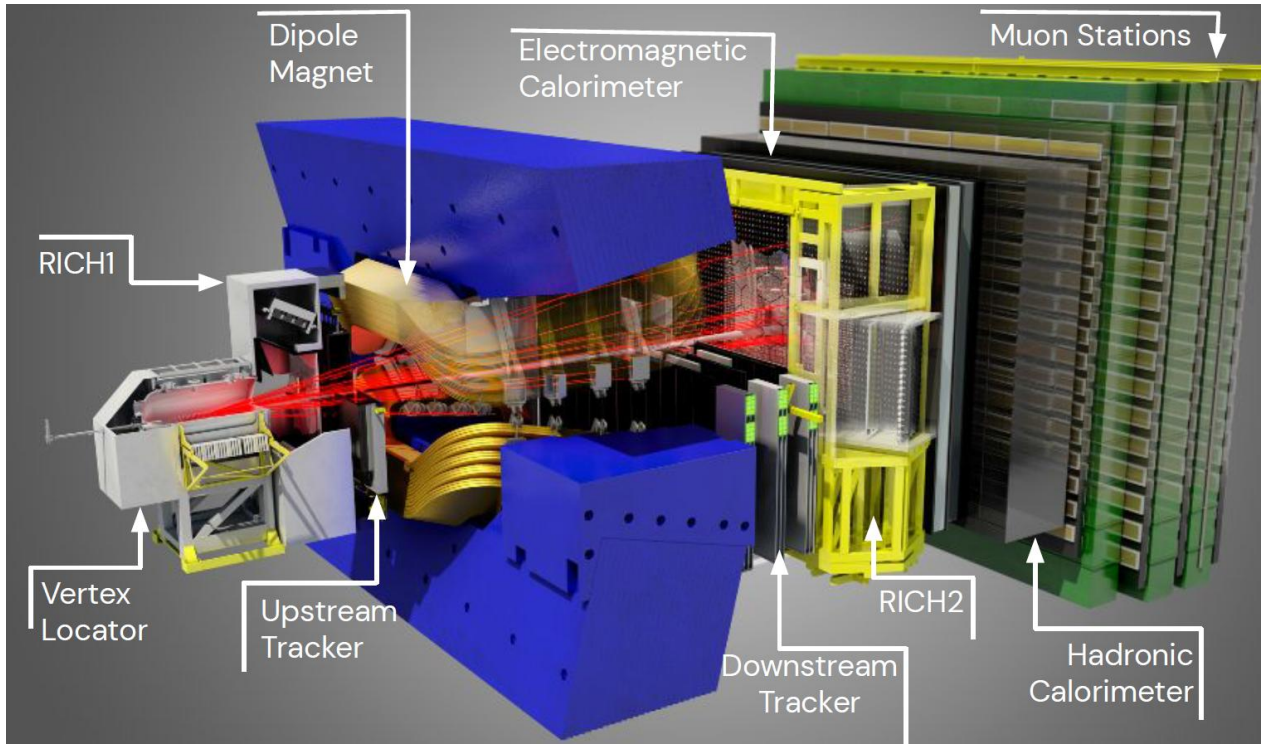
18-July-2024



Introduction: The LHCb Experiment

LONG STORY SHORT

- **The LHCb Experiment:**
  - *Designed to* ***investigate CP violation*** *and indications of* ***physics beyond SM***
  - *Focused on flavour physics and precision measurements*
  - ***Requires outstanding vertex and tracking systems***
  - *Recorded Integrated luminosity* $\approx 10\, fb^{-1}$ *in LHC Runs 1 & 2*

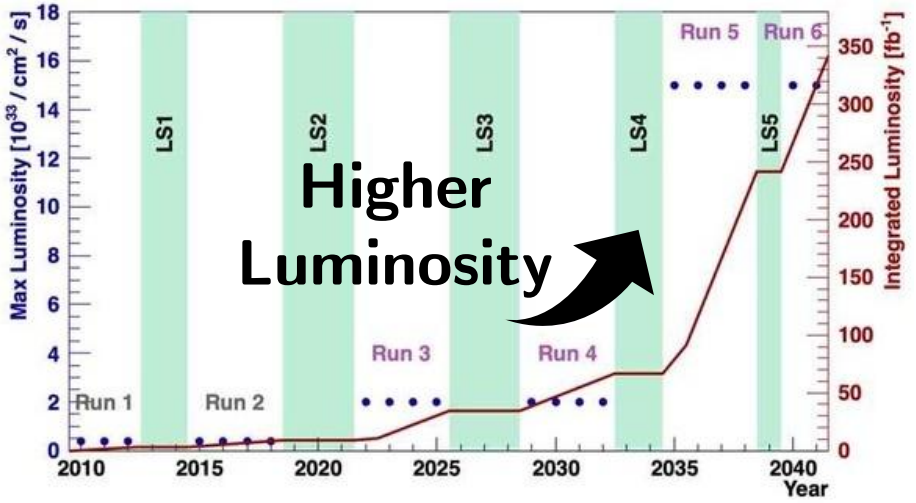


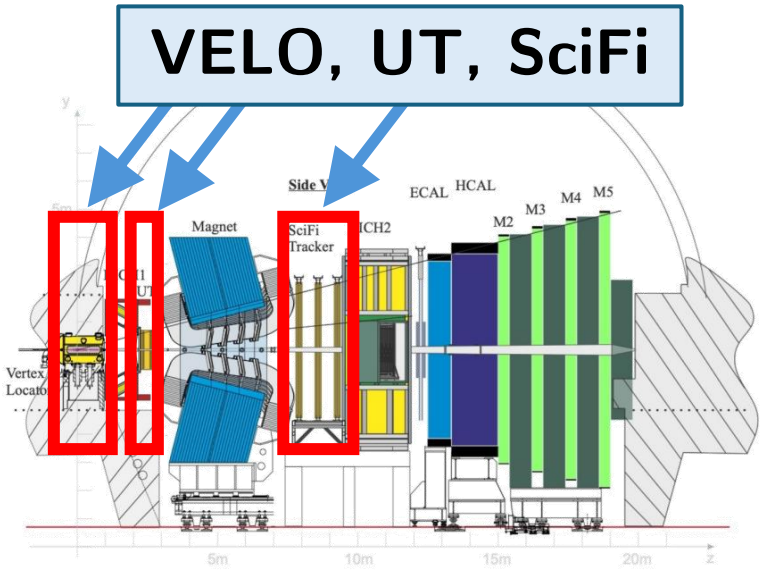
» THE LHCb EXPERIMENT

Introduction: SciFi Tracker Motivation

LHCb UPGRADE I: A NEW ERA

- **LHCb *UPGRADED* for LHC Runs 3 & 4**
  - ≈ 5*x* *Run 2 instantaneous luminosity:*
    - *Further improve Physics Research, but…*
    - *…to cope with increased luminosity…*
    - *…LHCb must deal with* ***higher occupancy***
  - *Substantial increase on readout rate:*
    - *From Hardware to Software trigger (40MHz)*

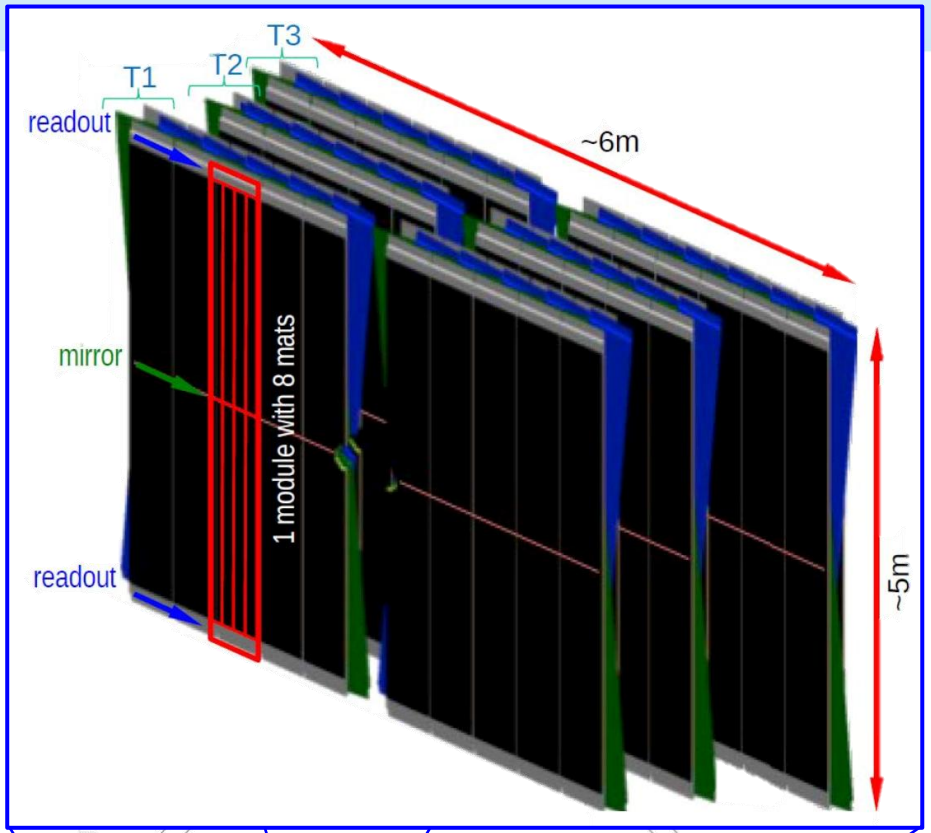


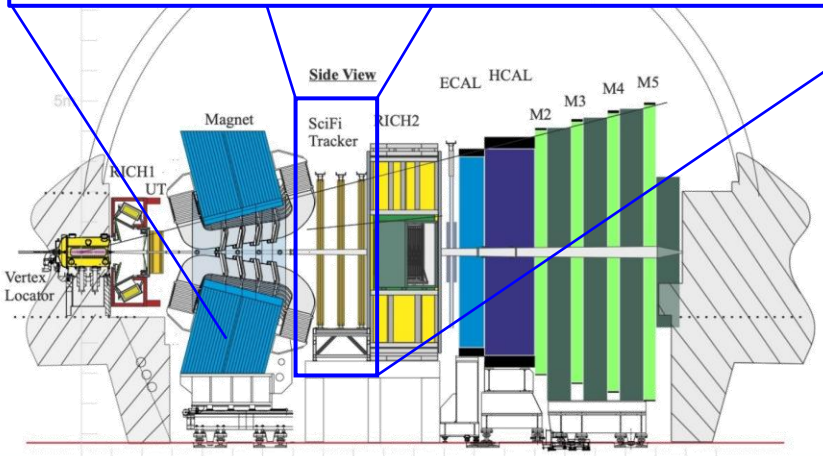


UPGRADED LHCb »»

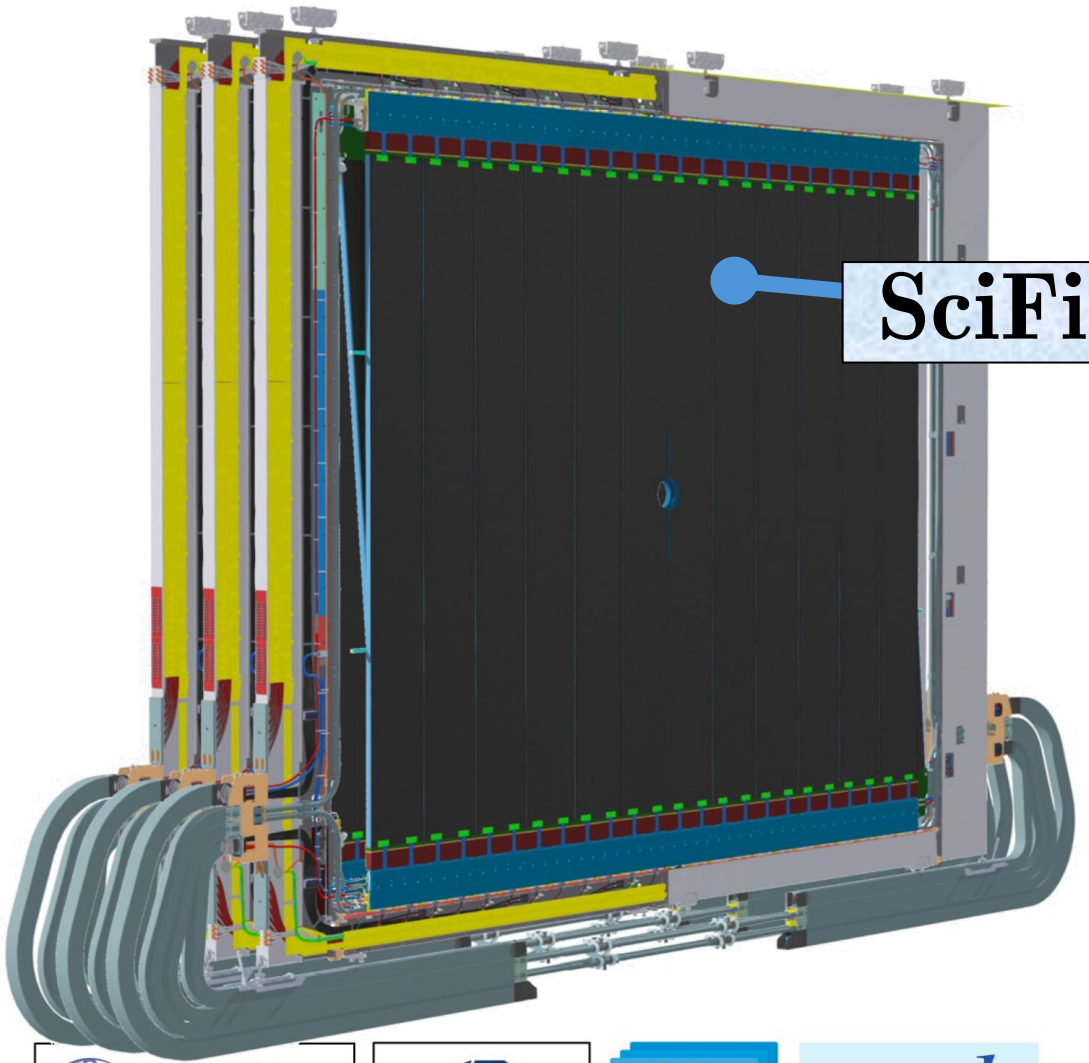
The LHCb SciFi Tracker: Design Overview

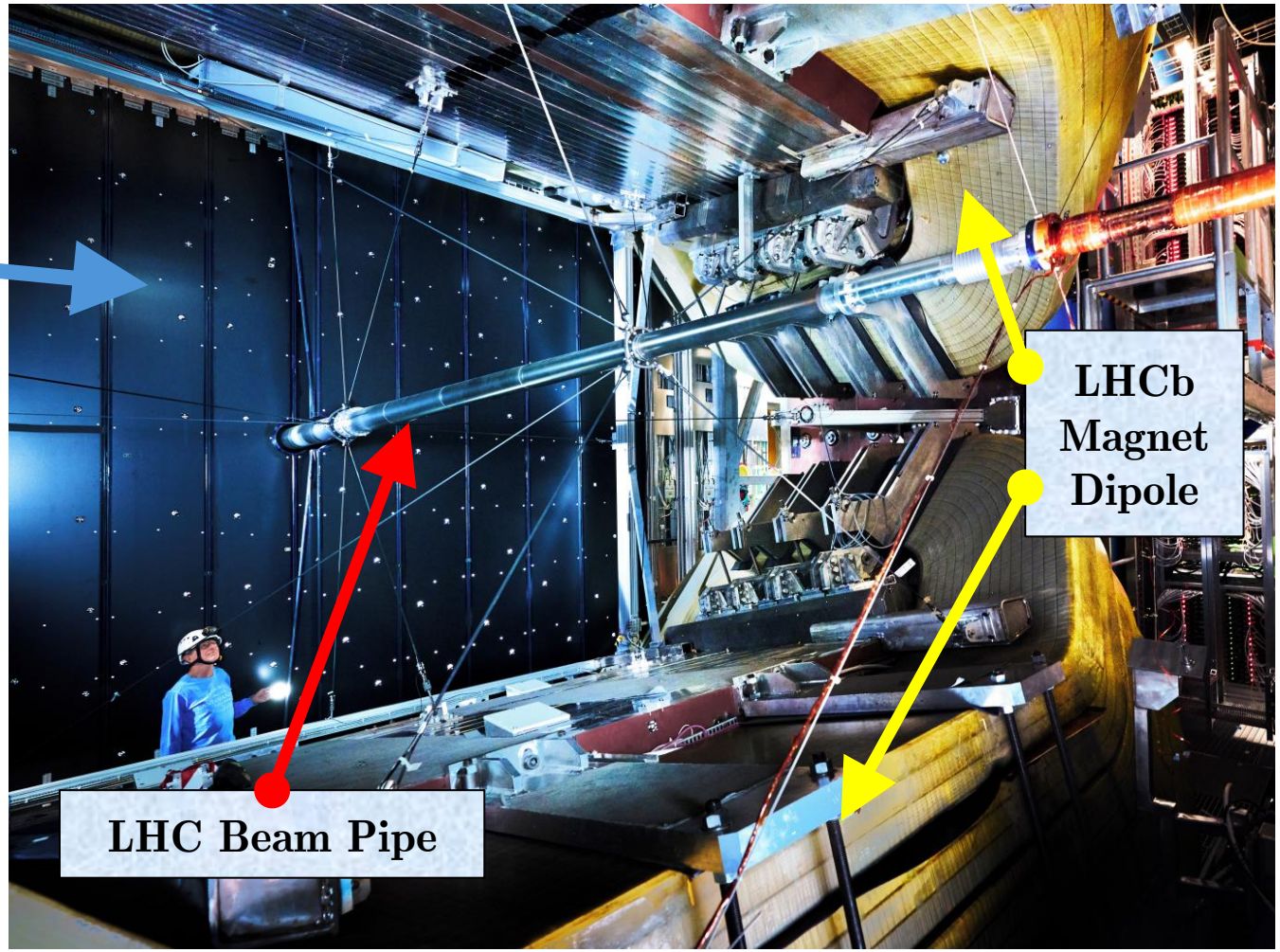
- **Large Instrumented Area:**
  - ➢ 3×4 *Layers,* $340\ m^2$ *active area*
- **Outstanding Requirements:**
  - **High Tracking Performance:**
    - ➢ *Hit detection efficiency* $> 99\ \%$;
    - ➢ *Spatial resolution* $< 100\ \mu m$
  - **Low Material Budget:**
    - ➢ $\sim 1\%\ X_0$ *per layer*
  - **Challenging readout electronics:**
    - ➢ *Very-high-density (Channel pitch* $= 250 \mu m$*)*
    - ➢ 524'288 *SiPM channels among* 256 *FE-Boxes*
    - ➢ *Zero-suppressing algorithm in FPGA*



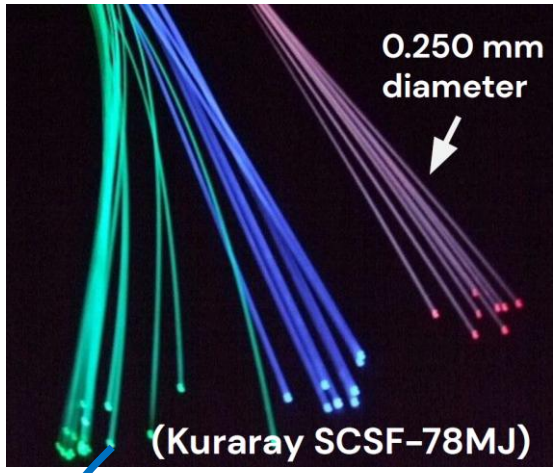


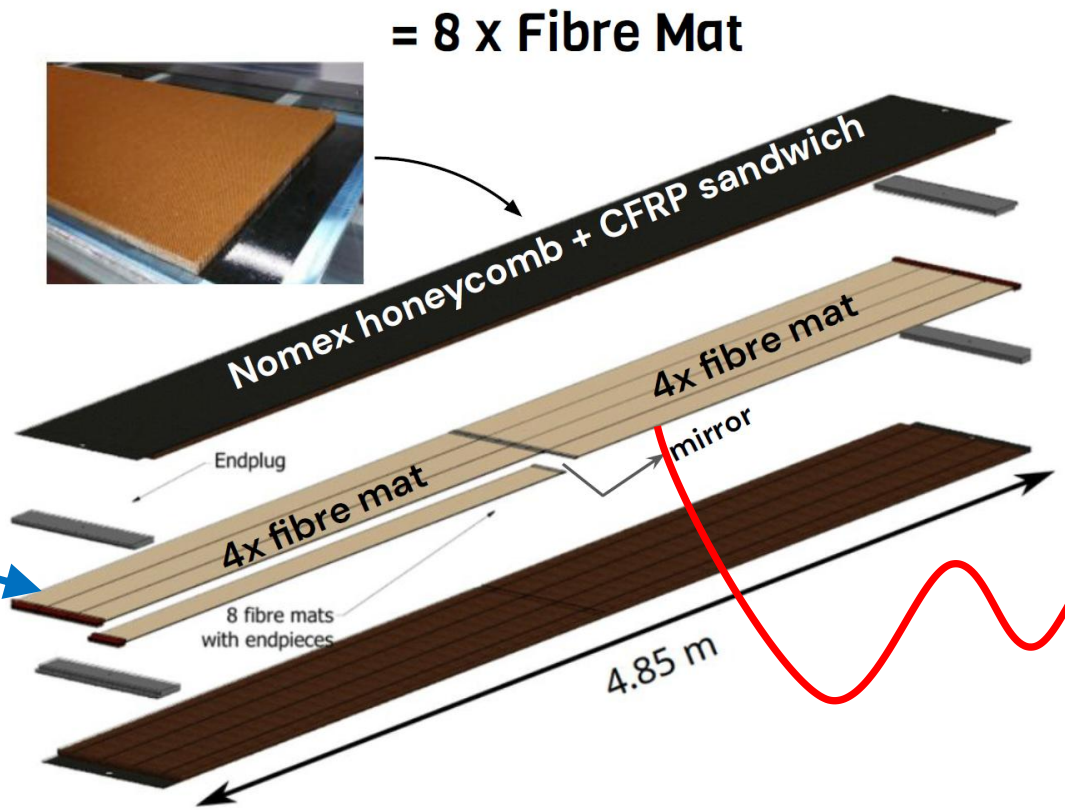
The LHCb SciFi Tracker: Installed Detector

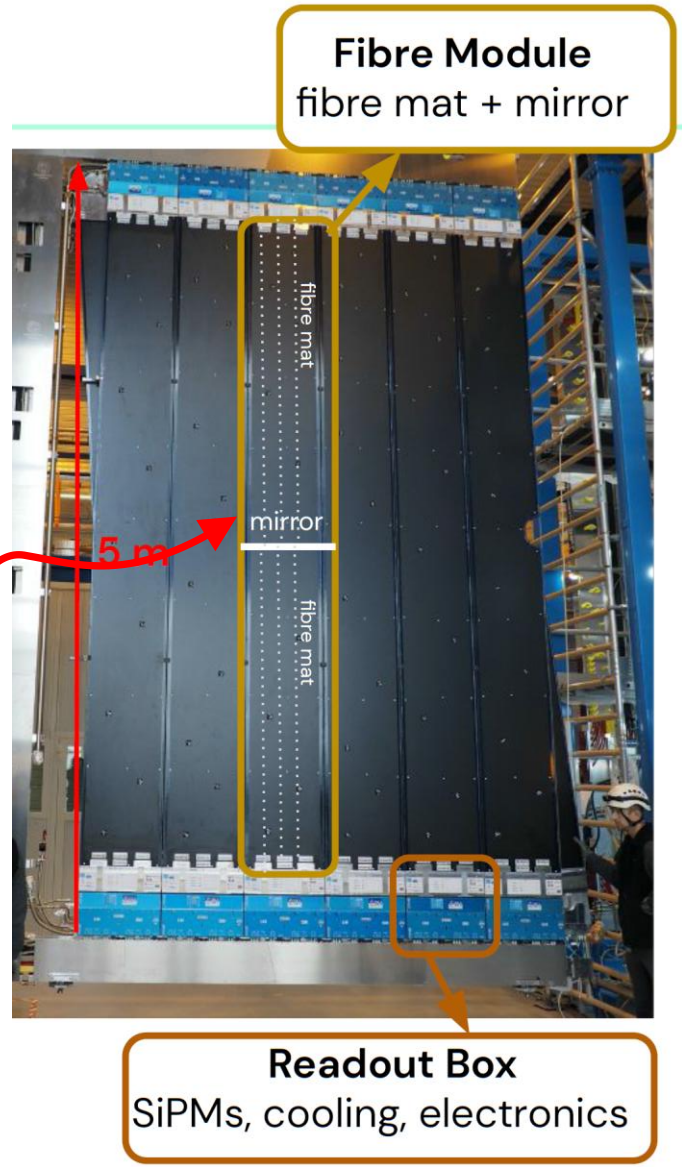




The SciFi Tracker in Details: Modules (Scintillating Fibre Mats)



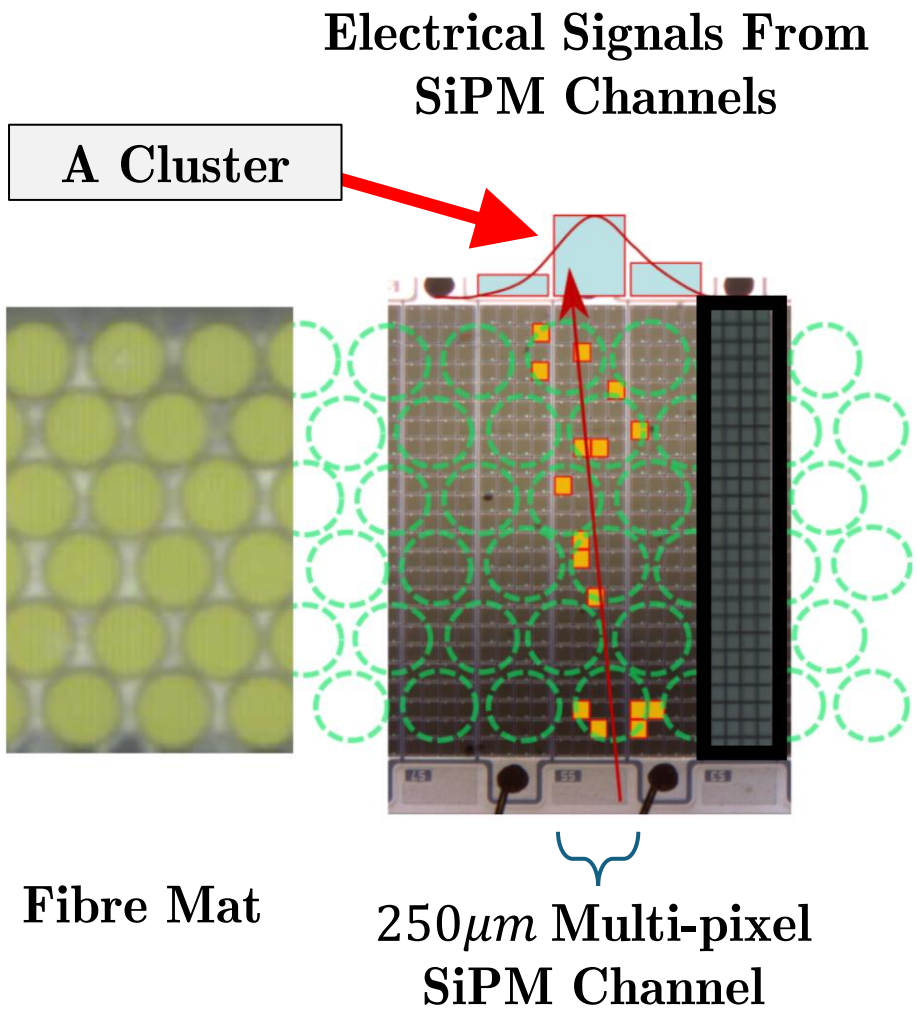


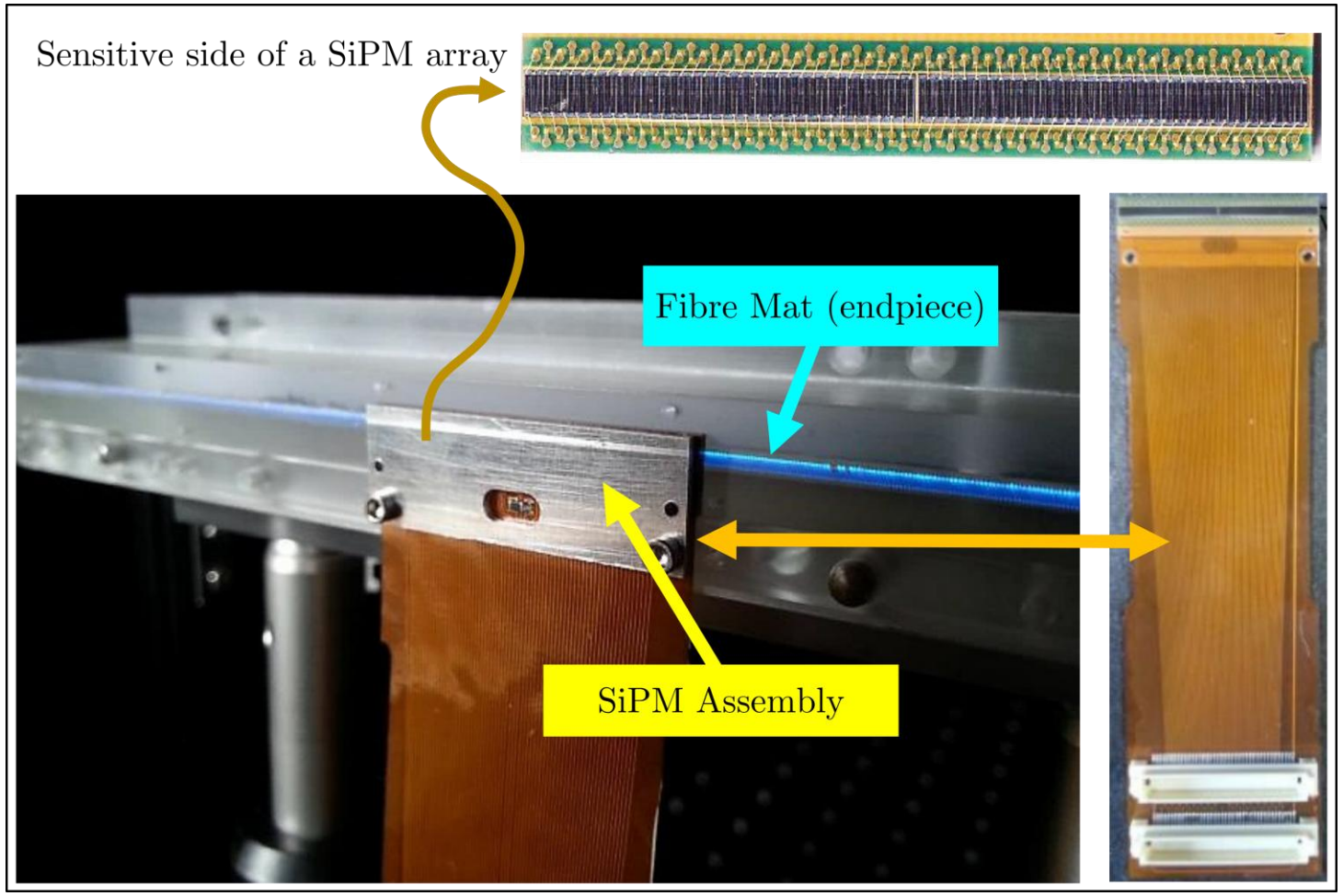


Hit

DOI: 10.1016/j.nima.2010.07.059

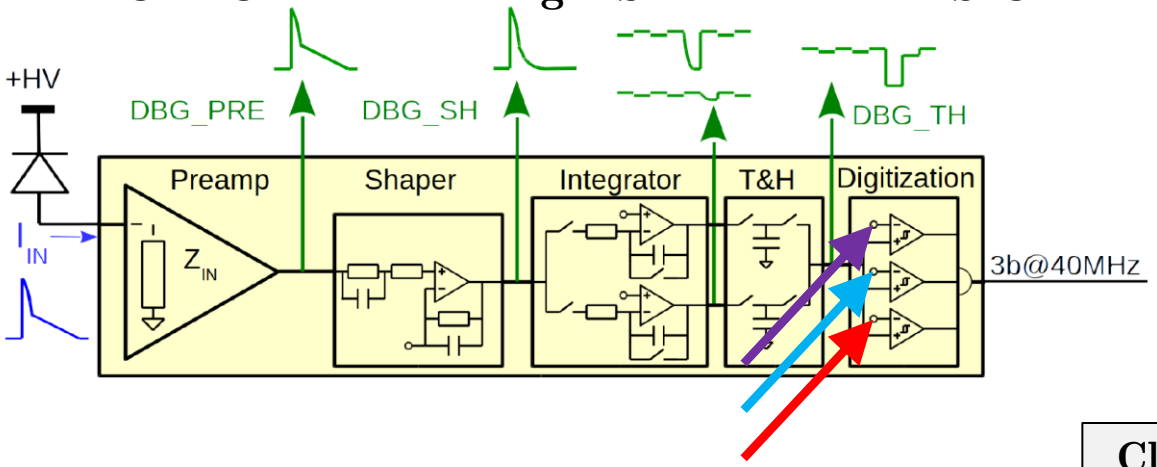
The SciFi Tracker in Details: Readout Principle



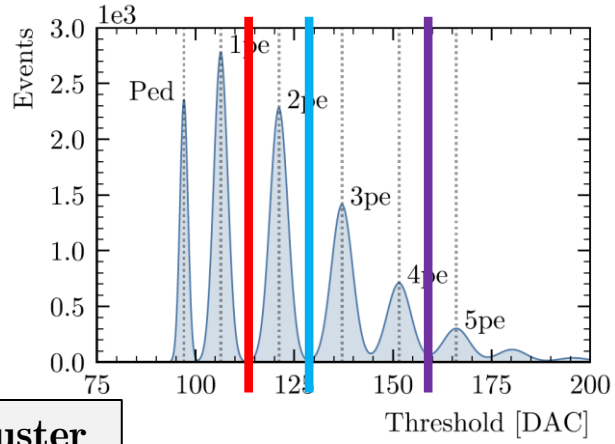


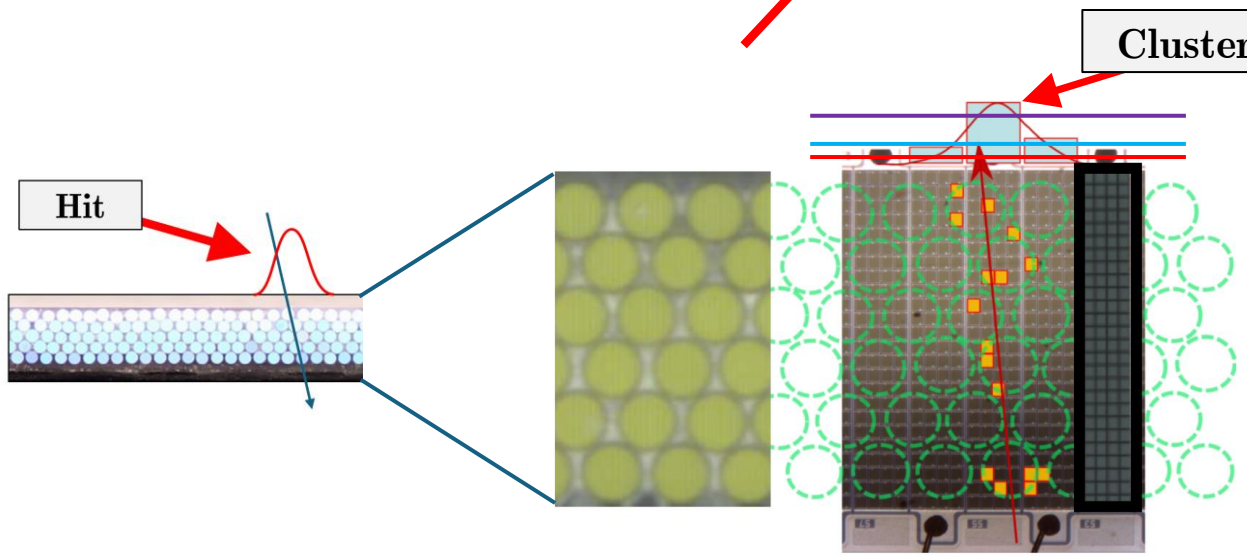
The SciFi Tracker in Details: From ionizing particles to Hits

PACIFIC - FEE 1st stage: SciFi readout ASIC



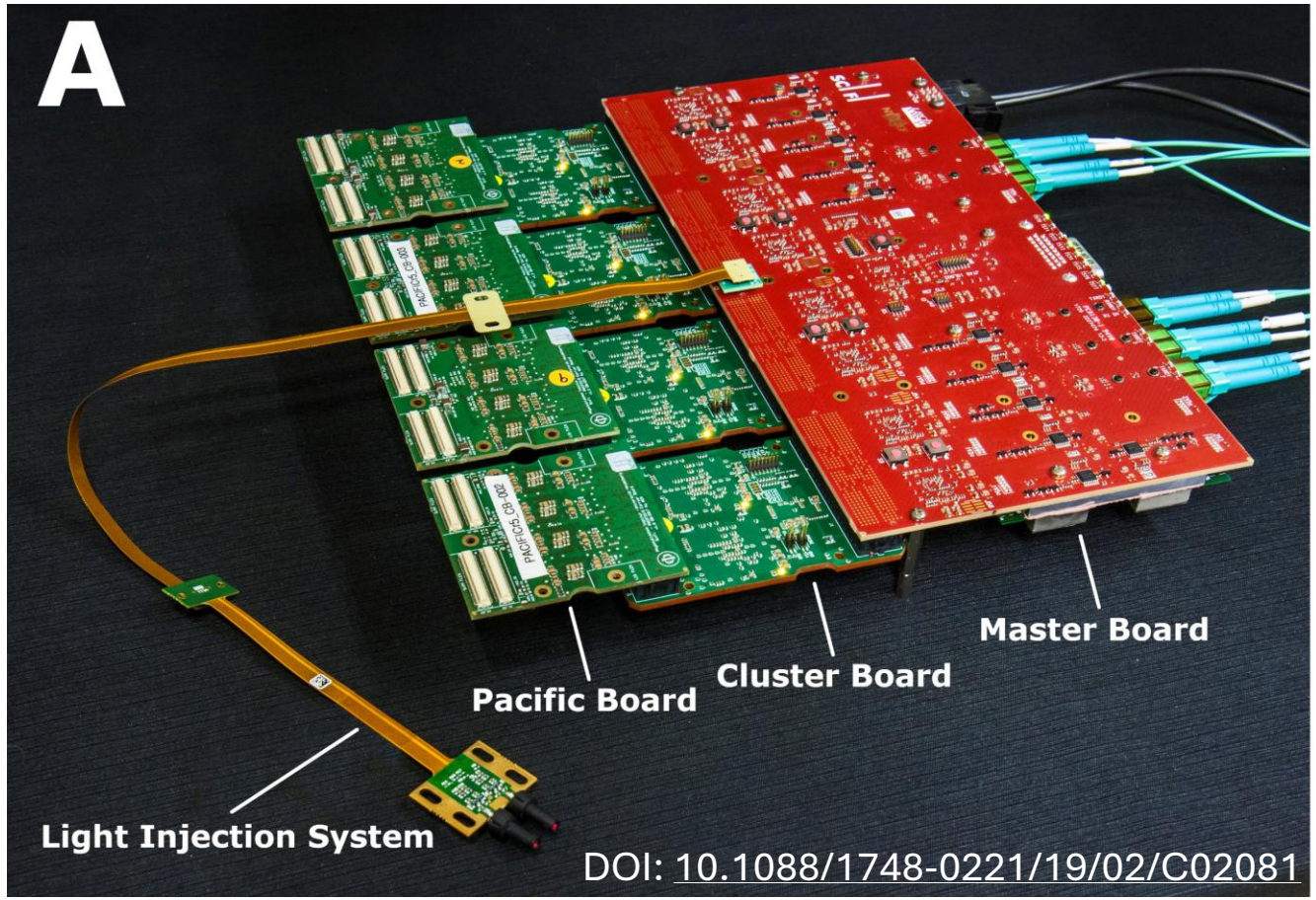
Typical SiPM response





- **Light** — A >MIP produce photons in scintillating fibers
- **Signal** — Photons arrives at SiPMs and produce signals
- **Cluster** — Signals are digitized and grouped into clusters
- **Hit** — Clusters are decoded as hits on LHCb software
- **Hit Eff.** — The ability to make the overall process happen

The SciFi Tracker in Details: Front-End (on-detector) Electronics



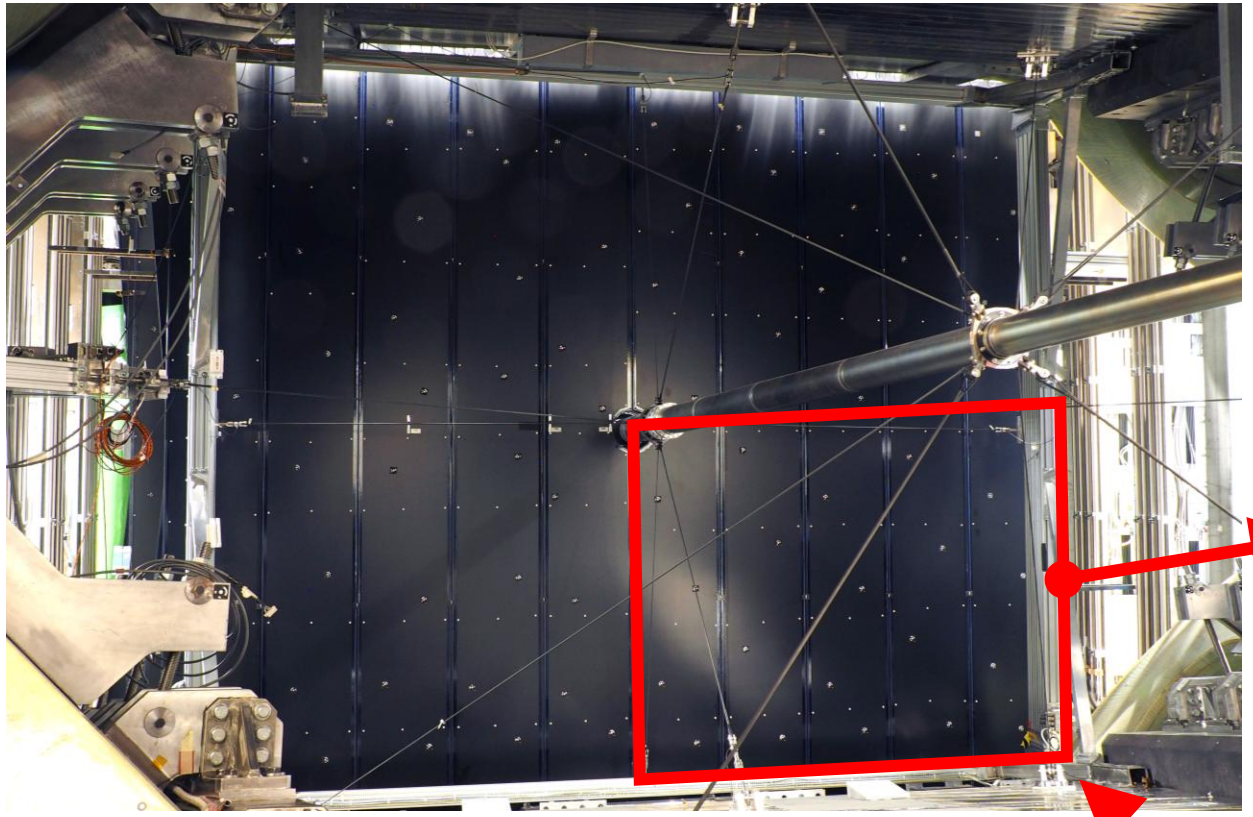
"Small" remark:

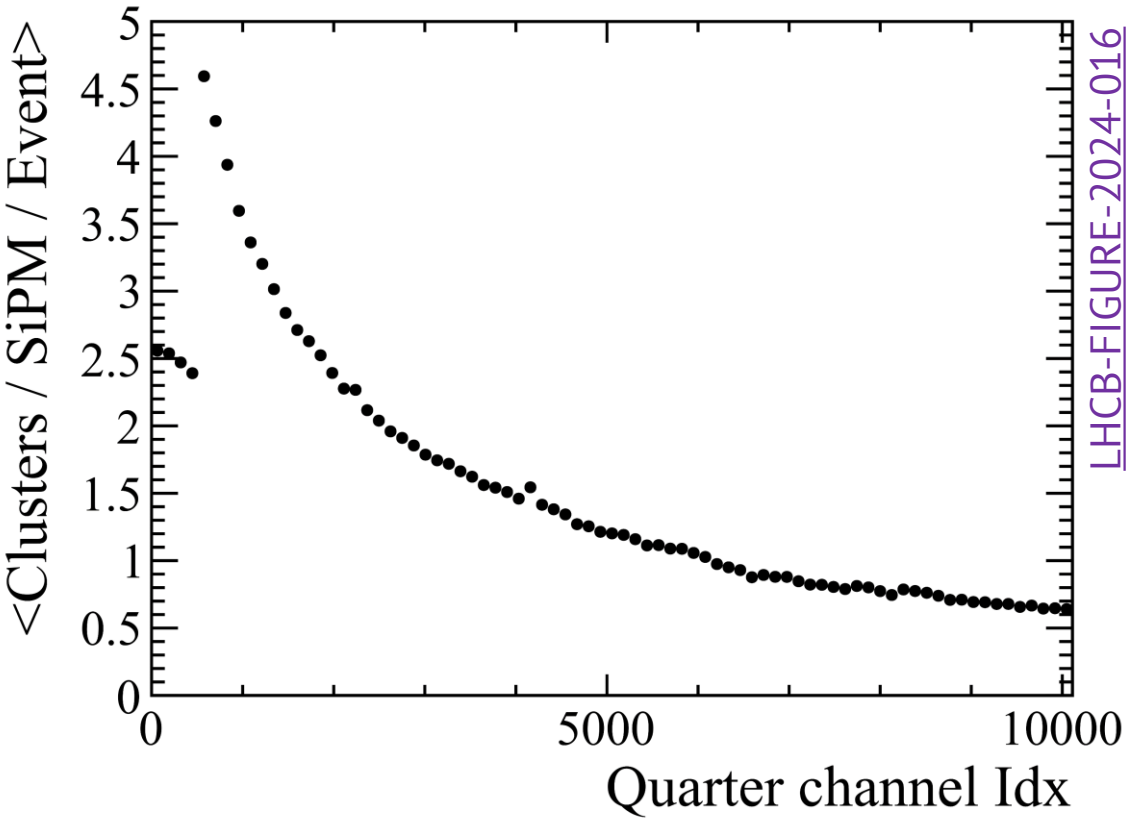
Entire SciFi has 4096 data links at 4.8 *Gbps* each: 19.7 *Tbps*
(40 MHz trigger-less readout)

A lot of data !
Even after zero-suppression

SciFi has 4096×128 *channel* SiPM Arrays

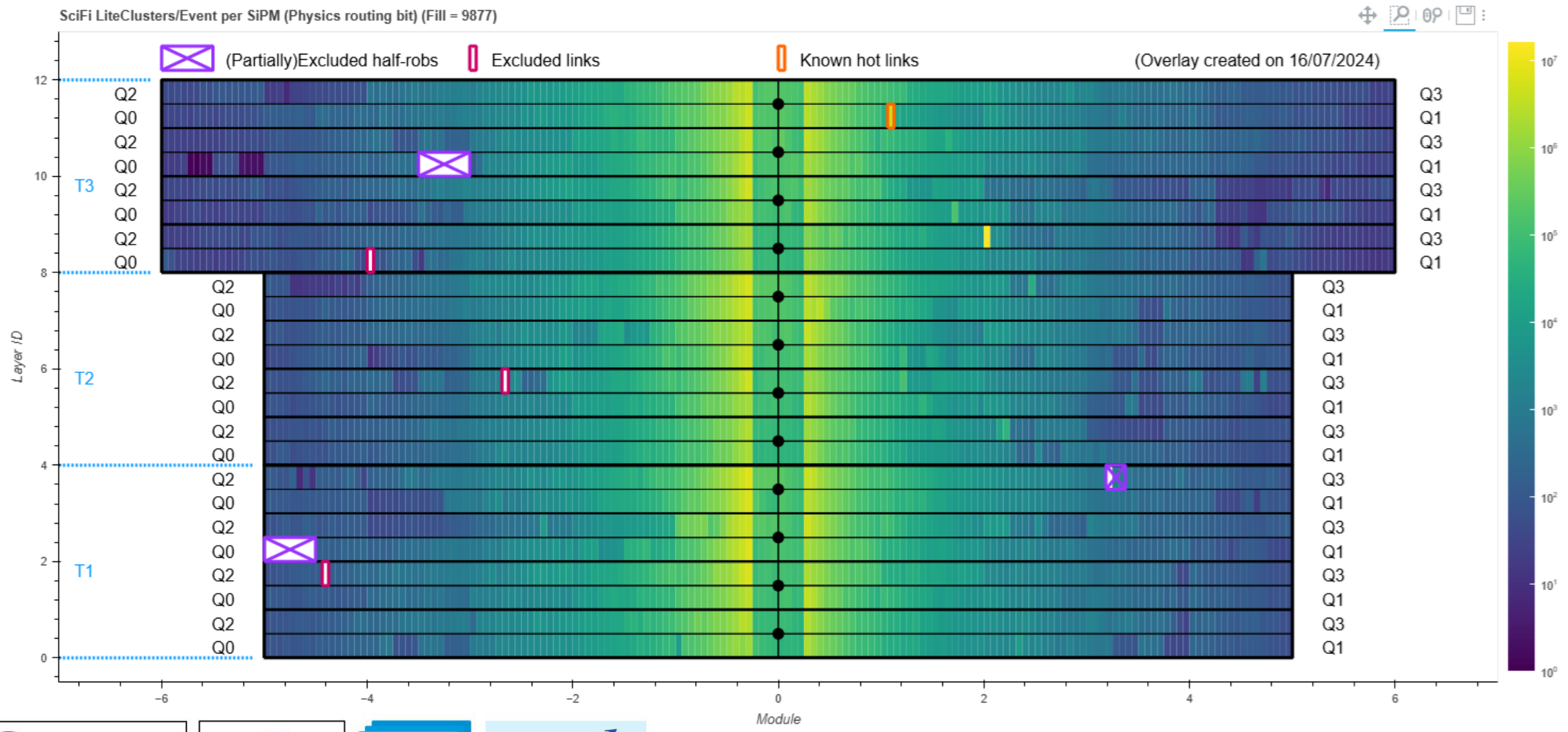
How is SciFi Tracker doing: Occupancy





SciFi Quarter

How is SciFi Tracker doing: Occupancy



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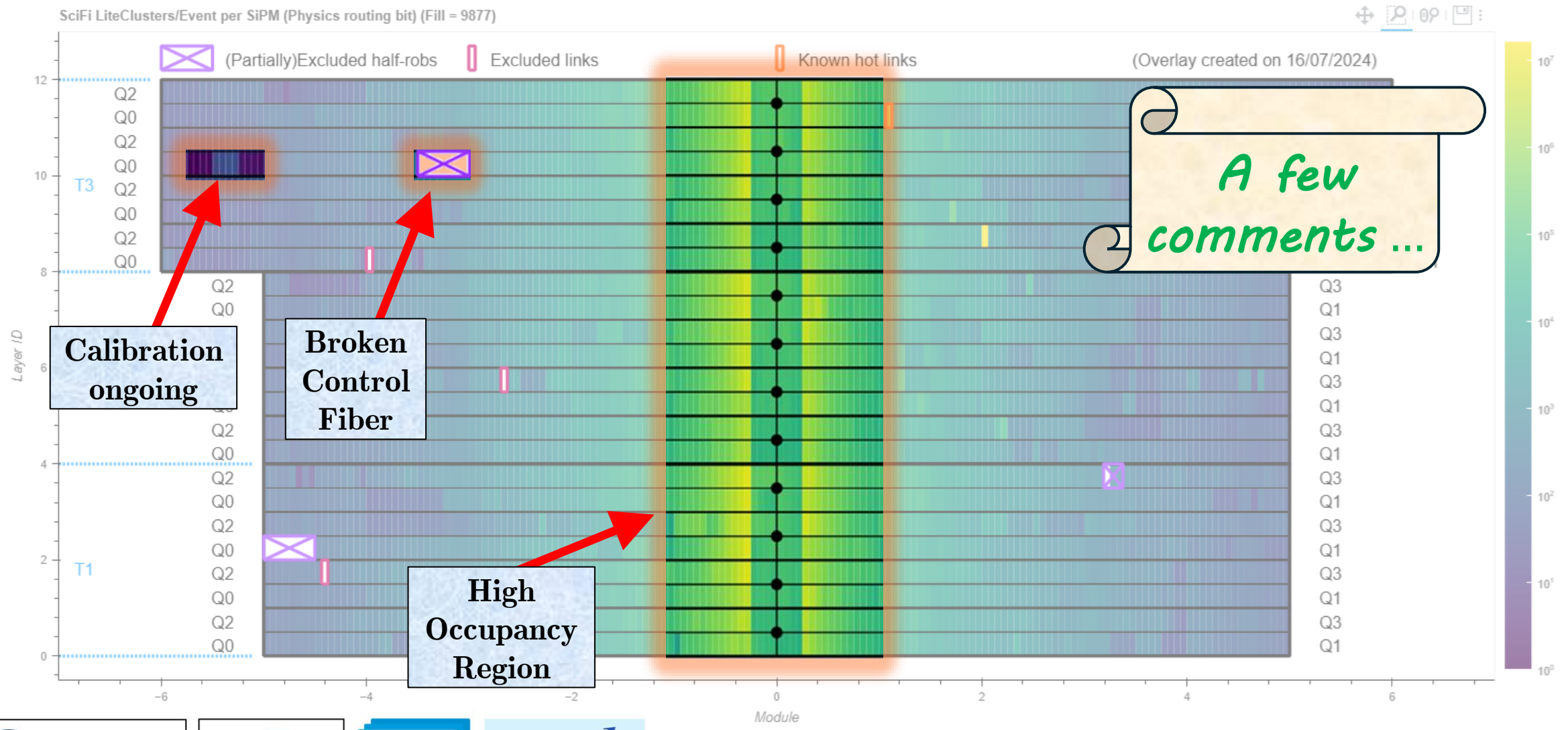

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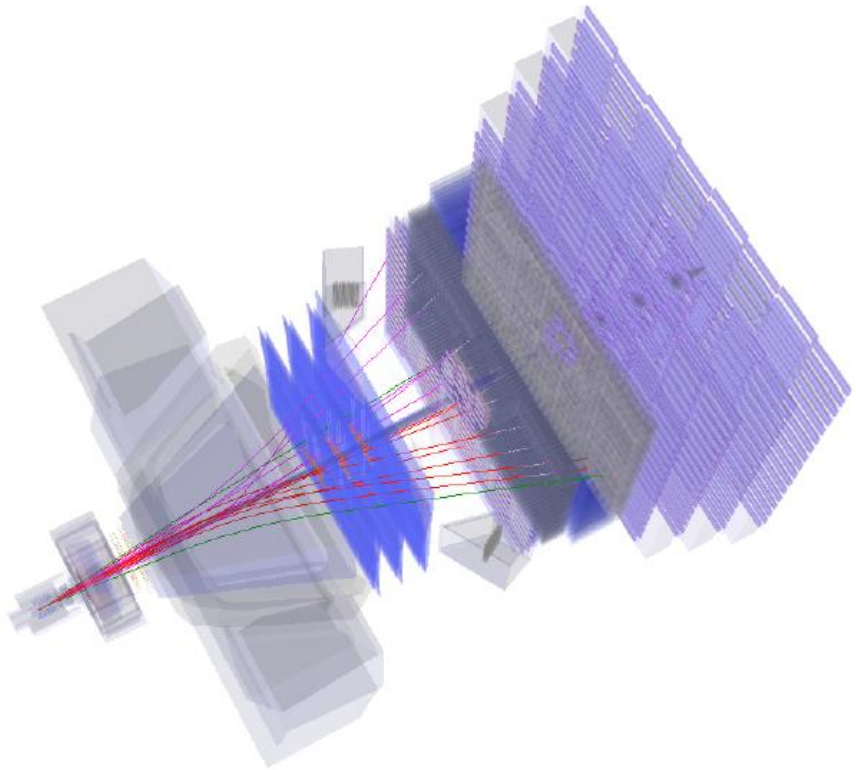
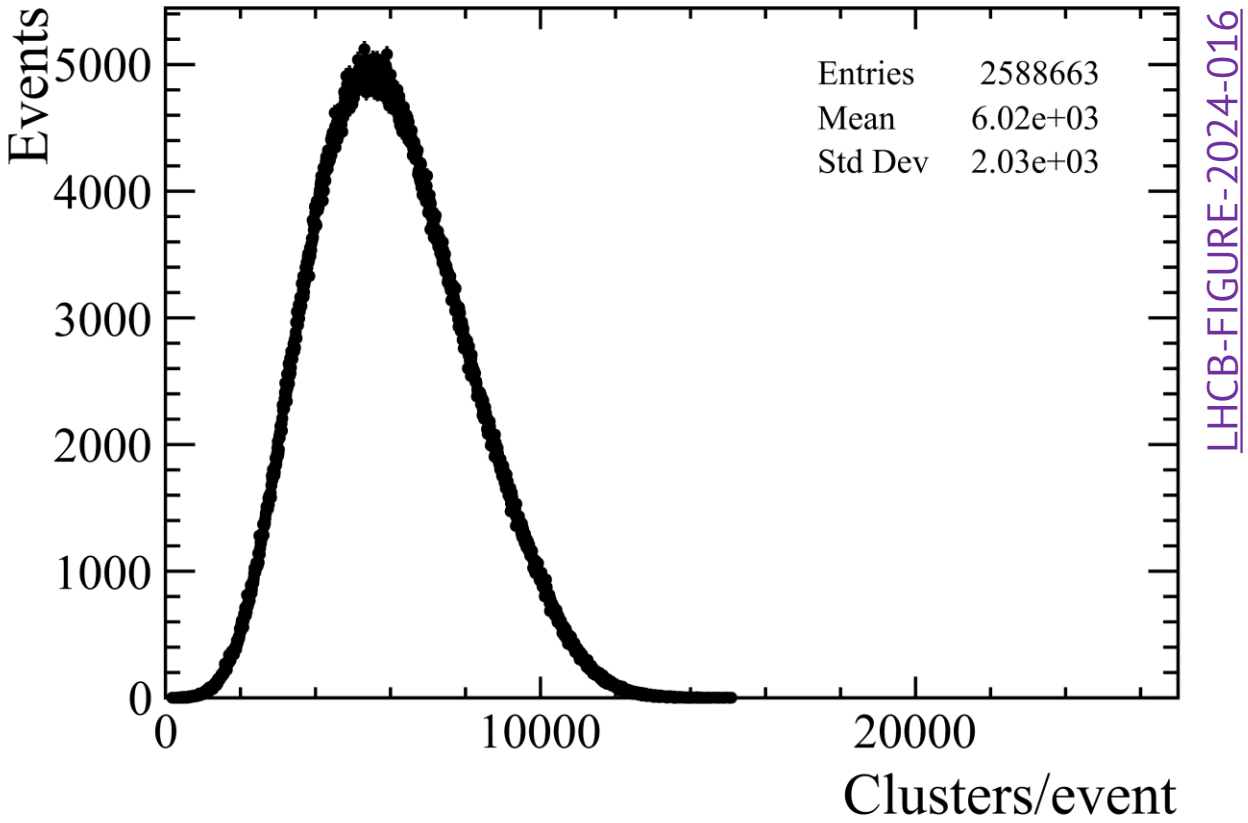
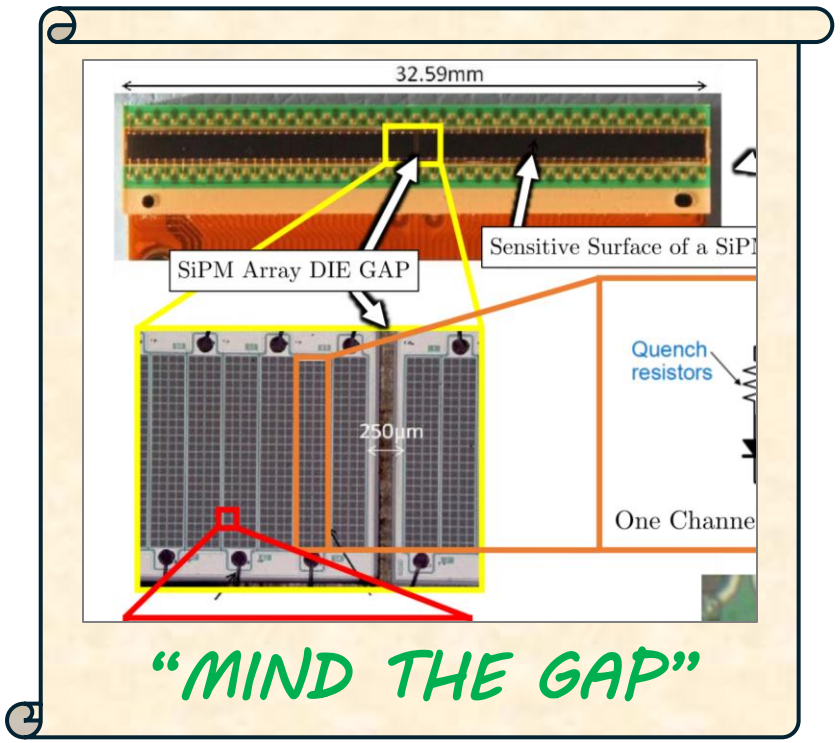
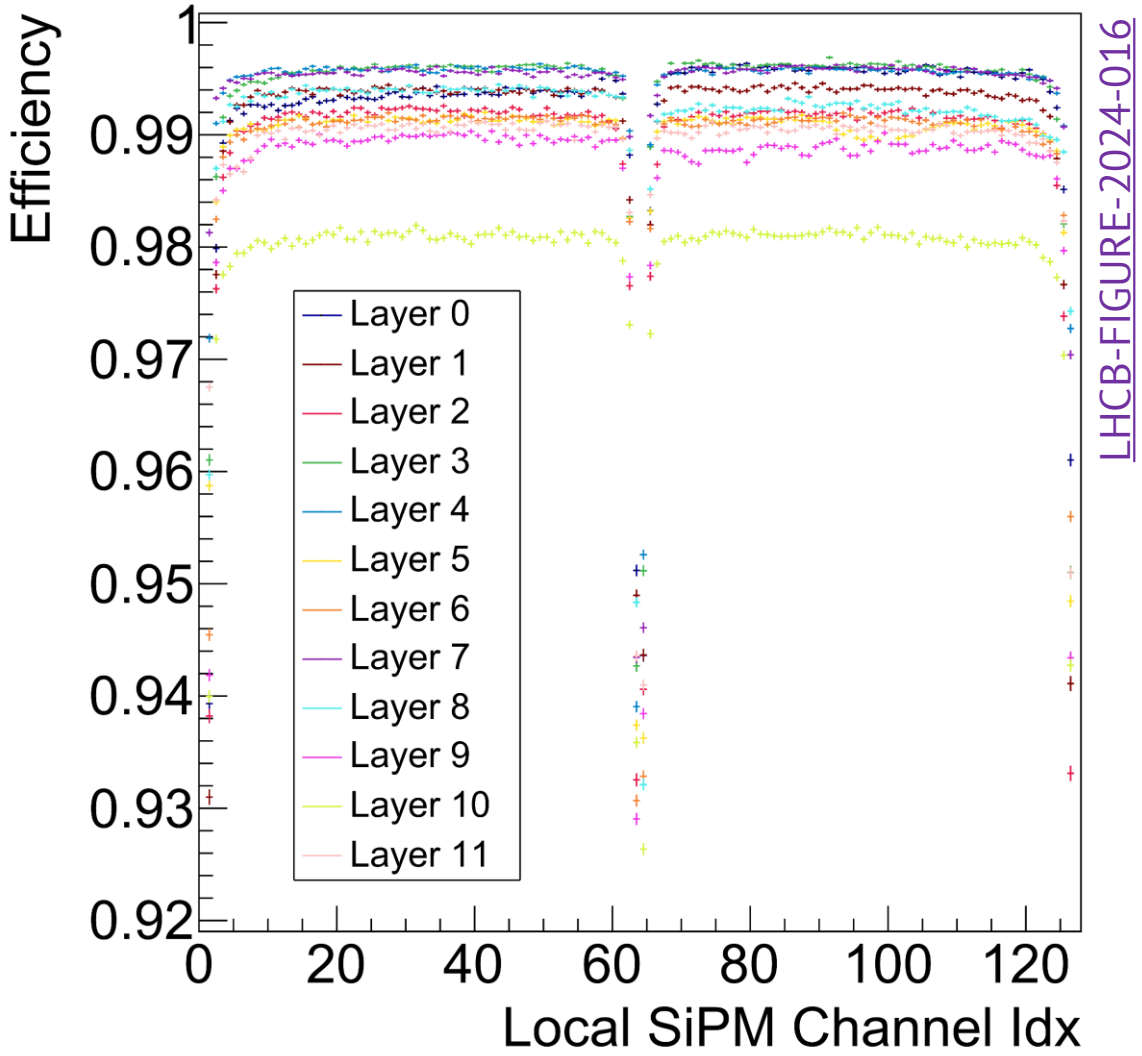




How is SciFi Tracker doing: Hit Efficiency





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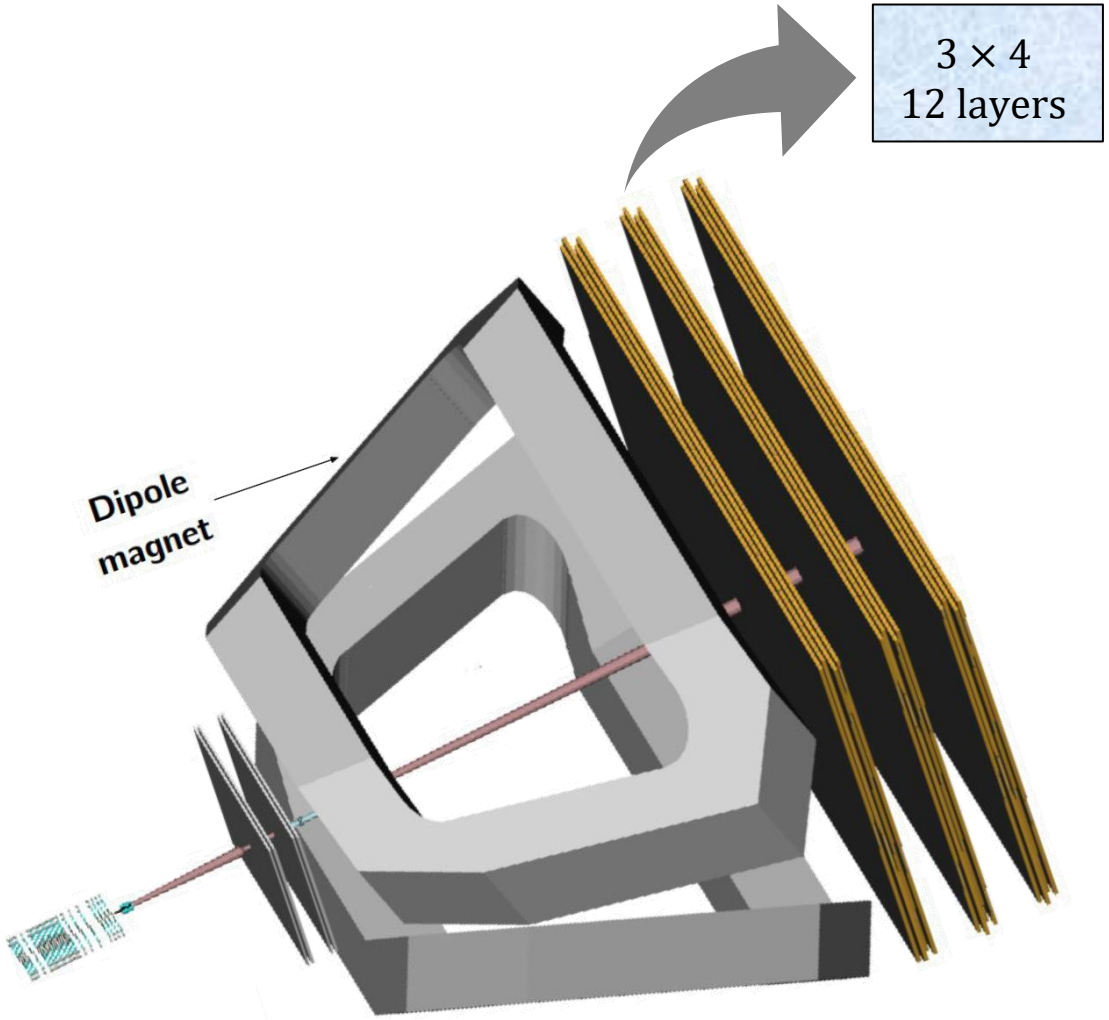
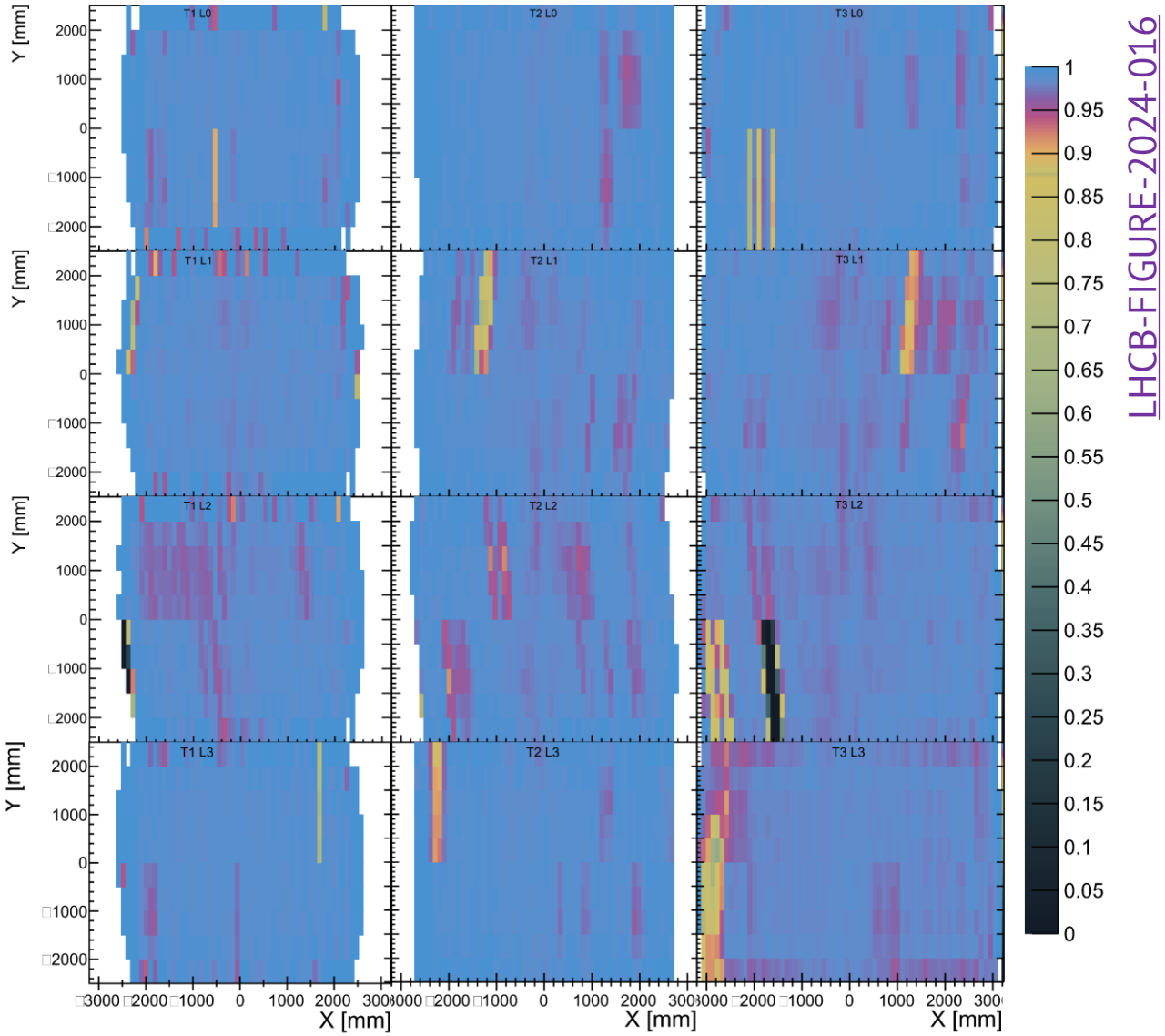




Conclusions

LHCb SciFi Tracker: The largest of its kind ever built $\Longrightarrow$ $340\,m^2$ | $> 520\,k$ channels

Successfully installed in the LHCb detector: Taking physics data since 2022

Commissioning & Calibration: A huge enterprise! Tons of software & dedicated tools

More than half million channels to calibrate (See Zehua's talk: 16h45)

29k7 sub-nanosecond clock lanes to be fine-tuned

Performing well within specifications: A few data links off (~1%) to be fixed next TS

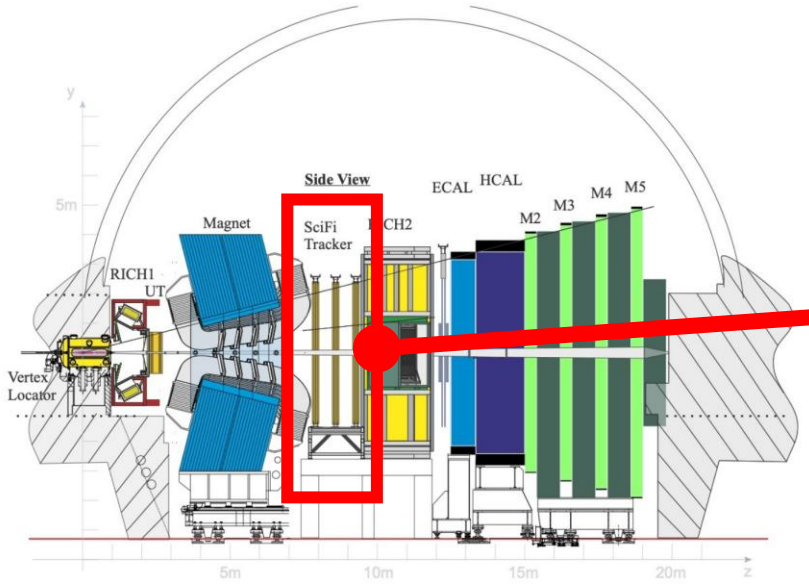
(as earlier presented by Giulia) Hit efficiency $> 99\%$ in most of the SciFi area

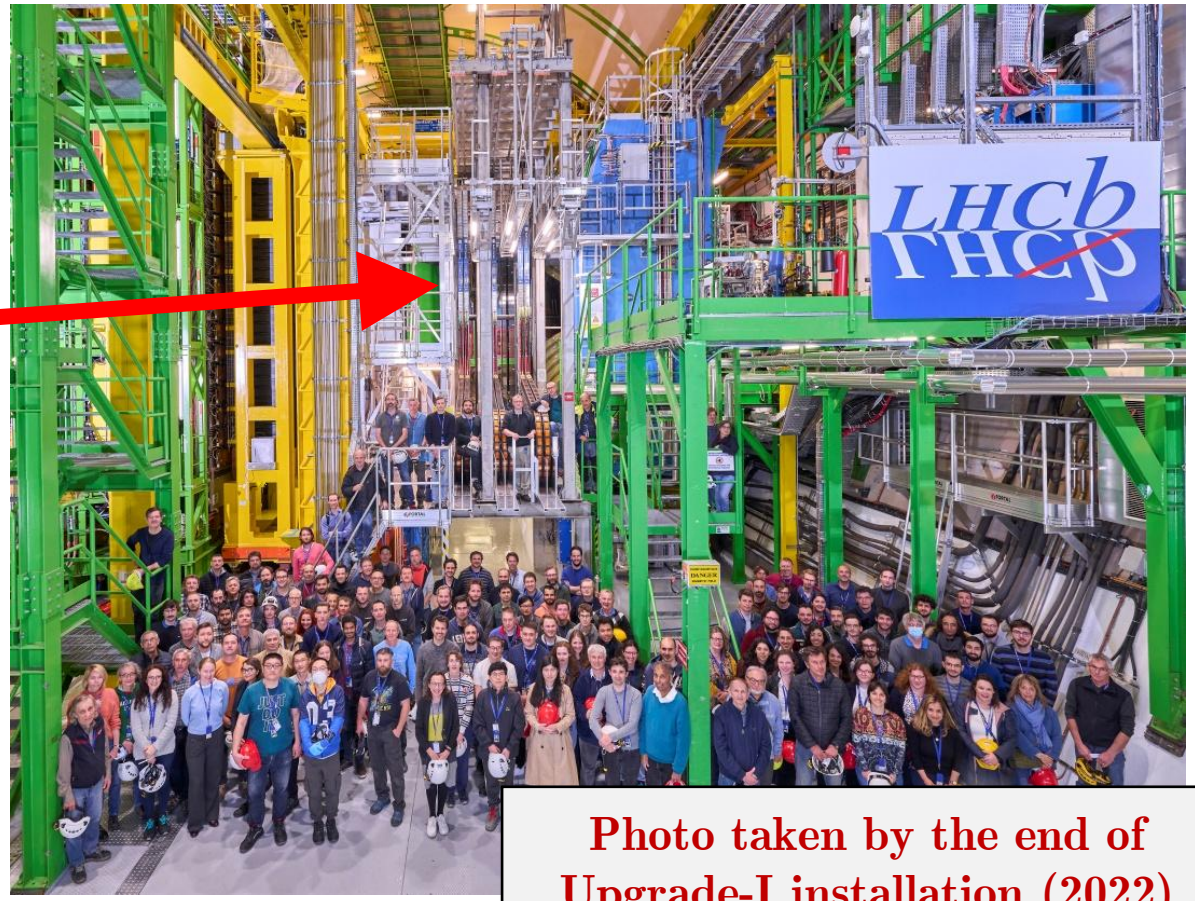
Looking forward to Upgrade-II (as presented by Renato)

➥ **Also:** Don't miss "The LHCb Mighty Tracker" Tai-Hua' poster

Thank you !

u.carneiro@cern.ch



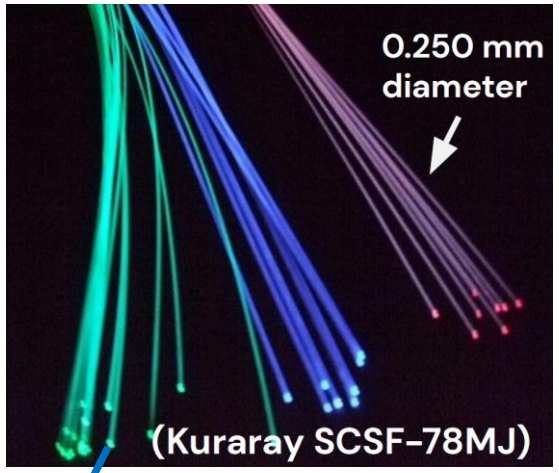


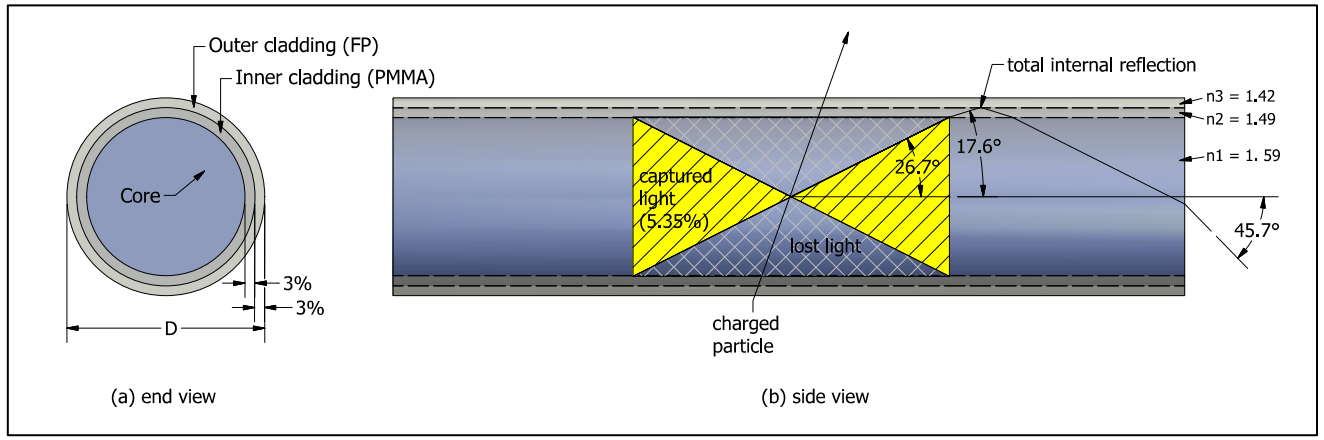
https://cds.cern.ch/record/2805358

Photo taken by the end of Upgrade-I installation (2022)

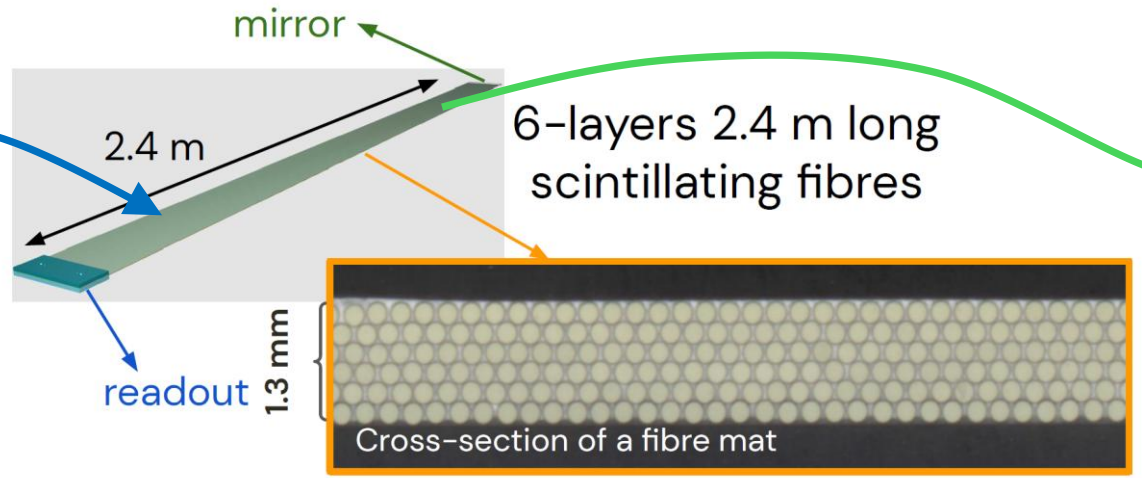
Backup Slides

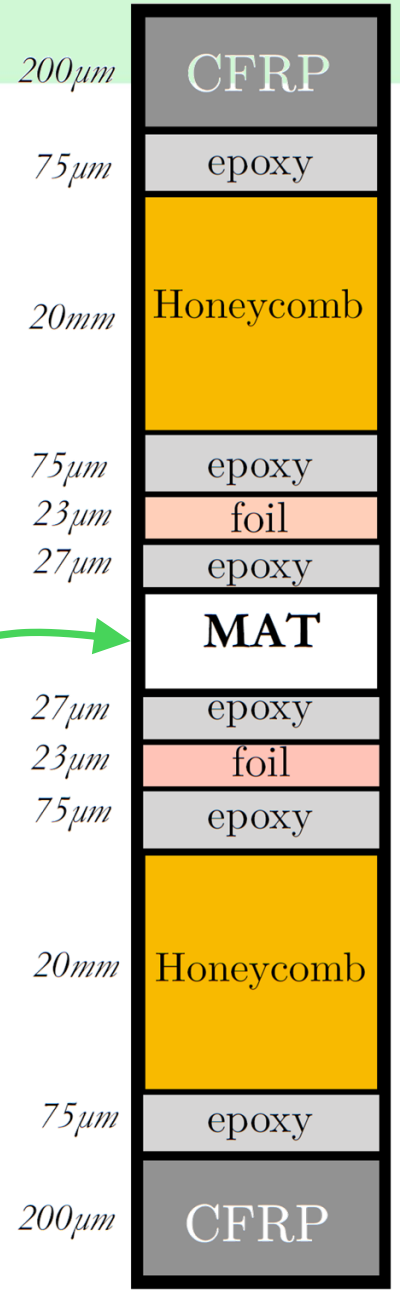
The SciFi Tracker in Details: Modules (Scintillating Fibre Mats)



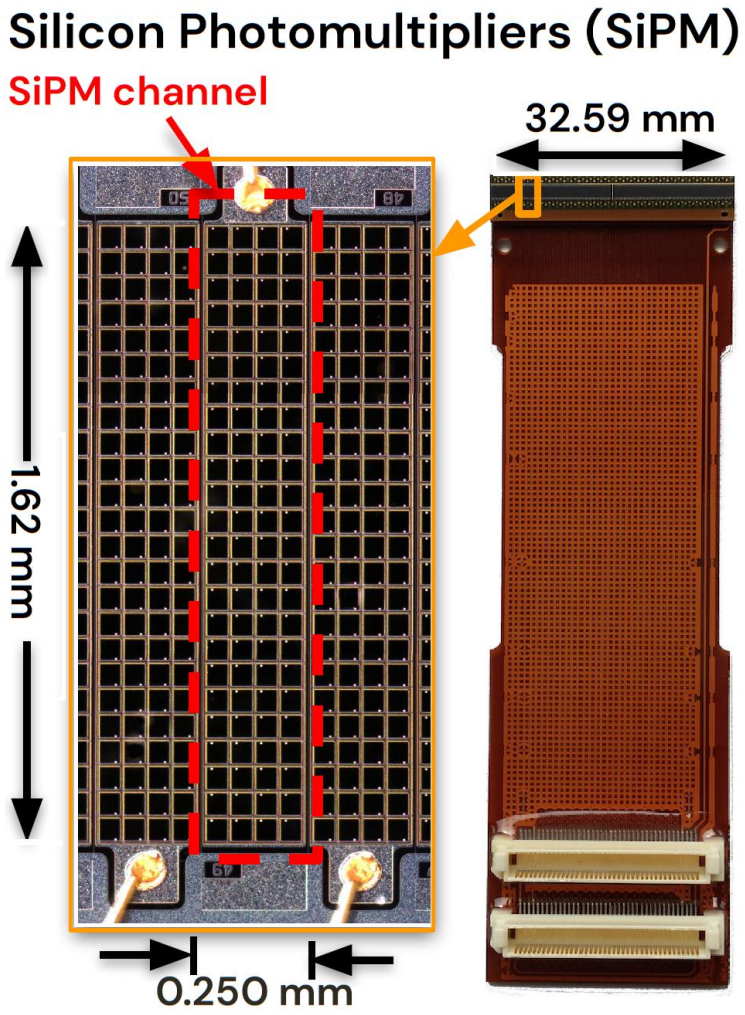


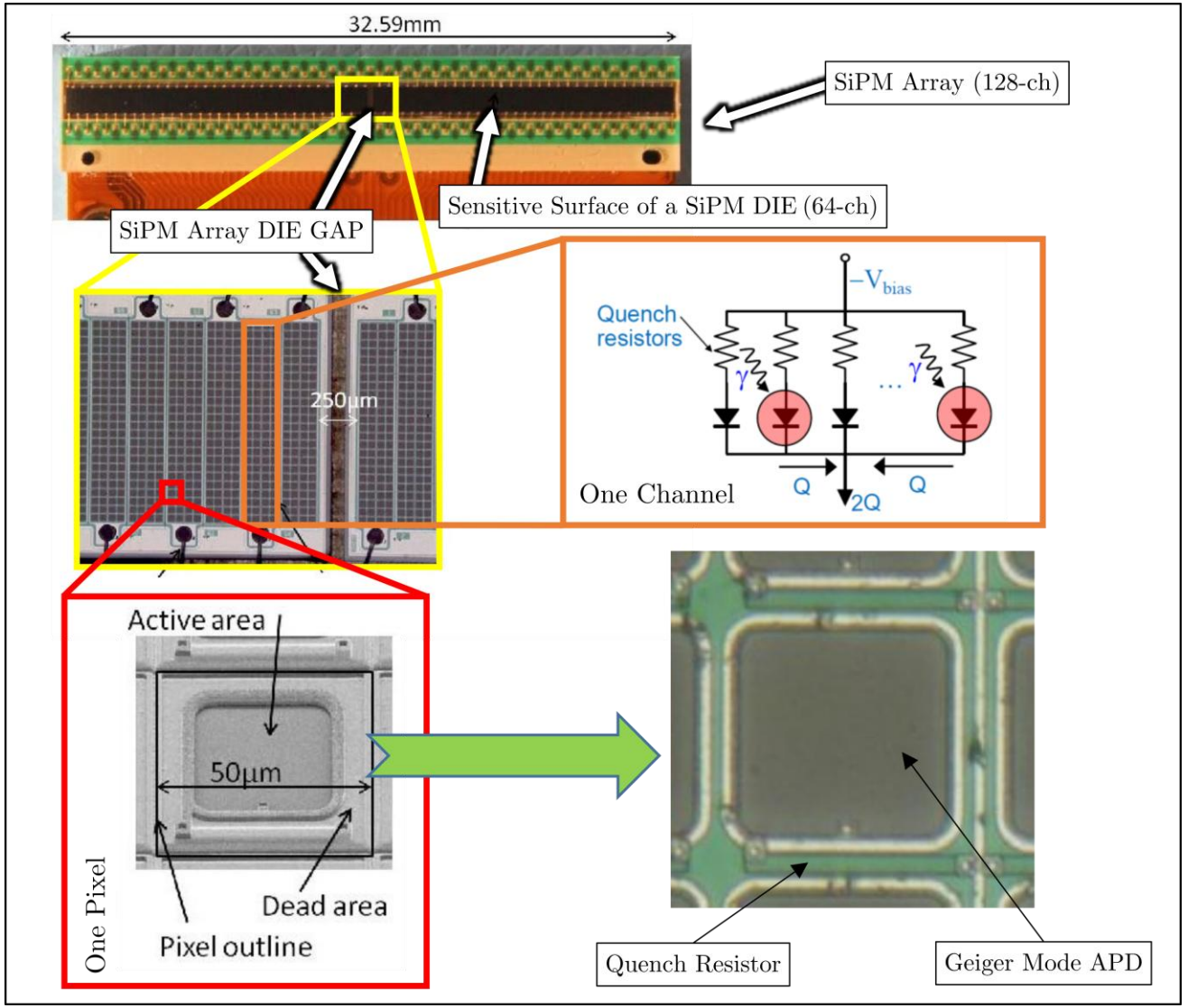
DOI: 10.1088/1748-0221/10/08/C08005



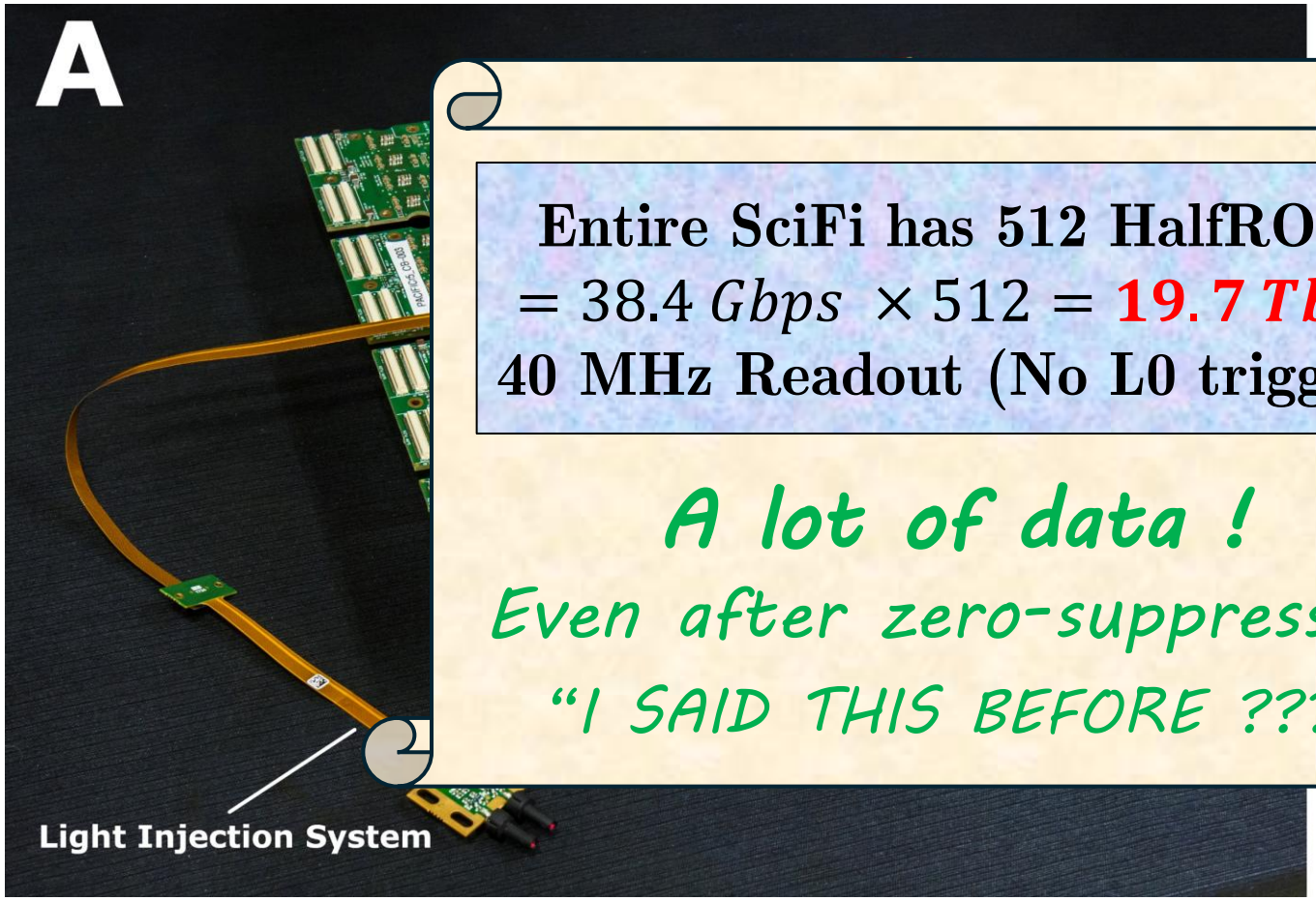


The SciFi Tracker in Details: SiPM's (Silicon Photo-Multipliers)



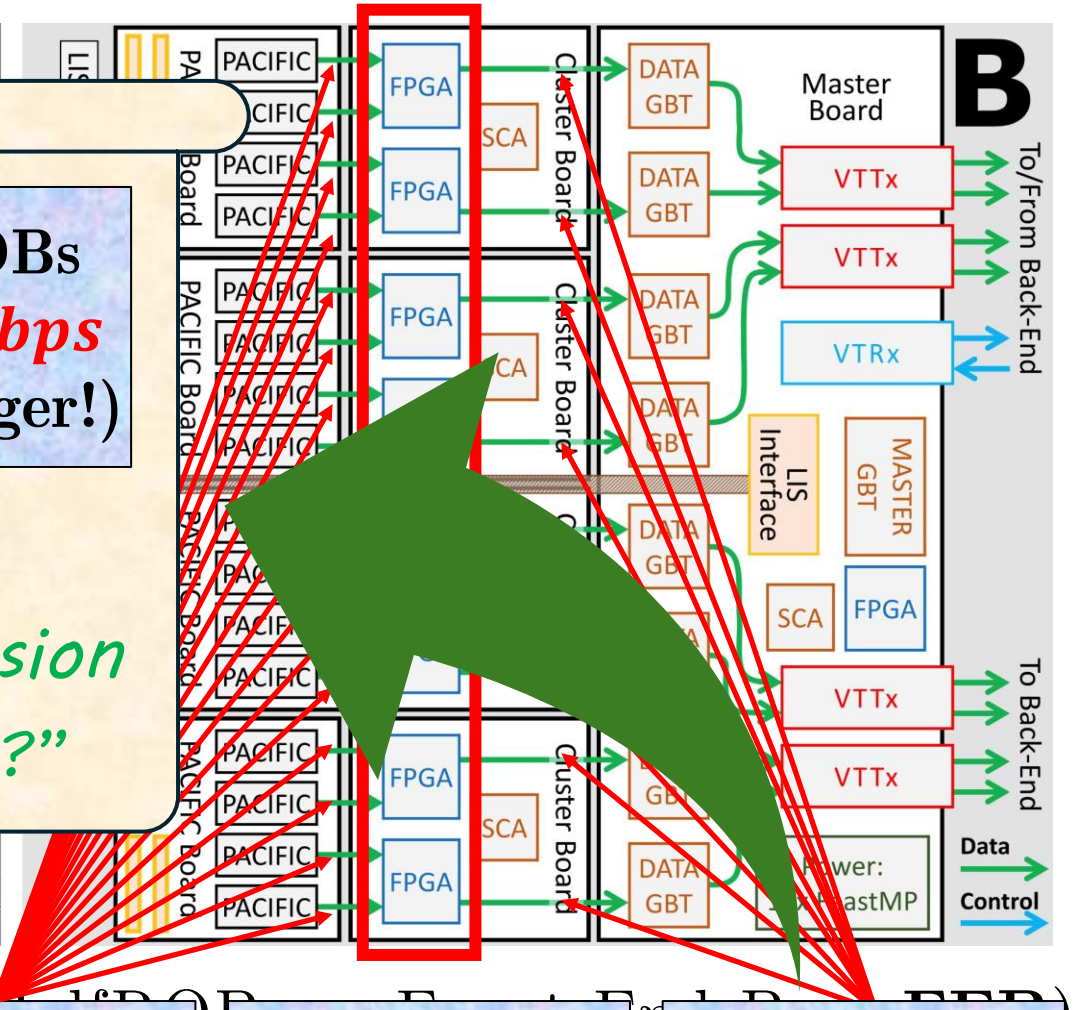


The SciFi Tracker in Details: Front-End (on-detector) Electronics



Entire SciFi has 512 HalfROBs
$= 38.4\ Gbps \times 512 = 19.7\ Tbps$
40 MHz Readout (No L0 trigger!)

A lot of data !
Even after zero-suppression
"I SAID THIS BEFORE ???"



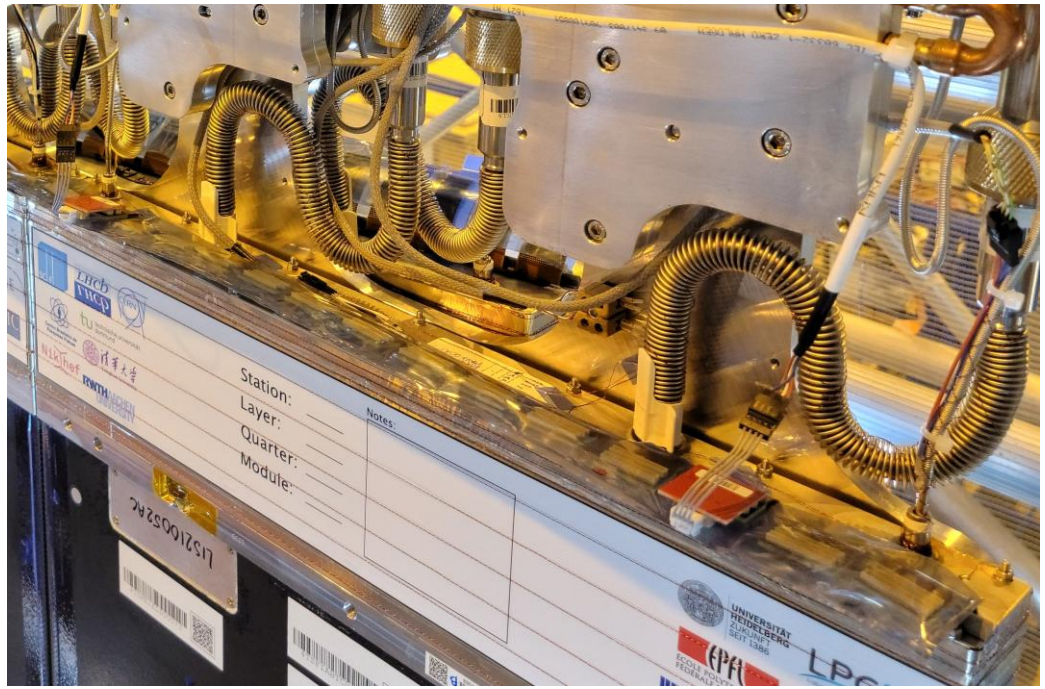
A SciFi **HALF** Readout Box: HalfRO[illegible]

$16 \times 5.12\ Gbps = 81.92\ Gbps$

Clustering (zero-suppression)

$8 \times 4.8\ Gbps = 38.4\ Gbps$

The SciFi Tracker in Details: Services

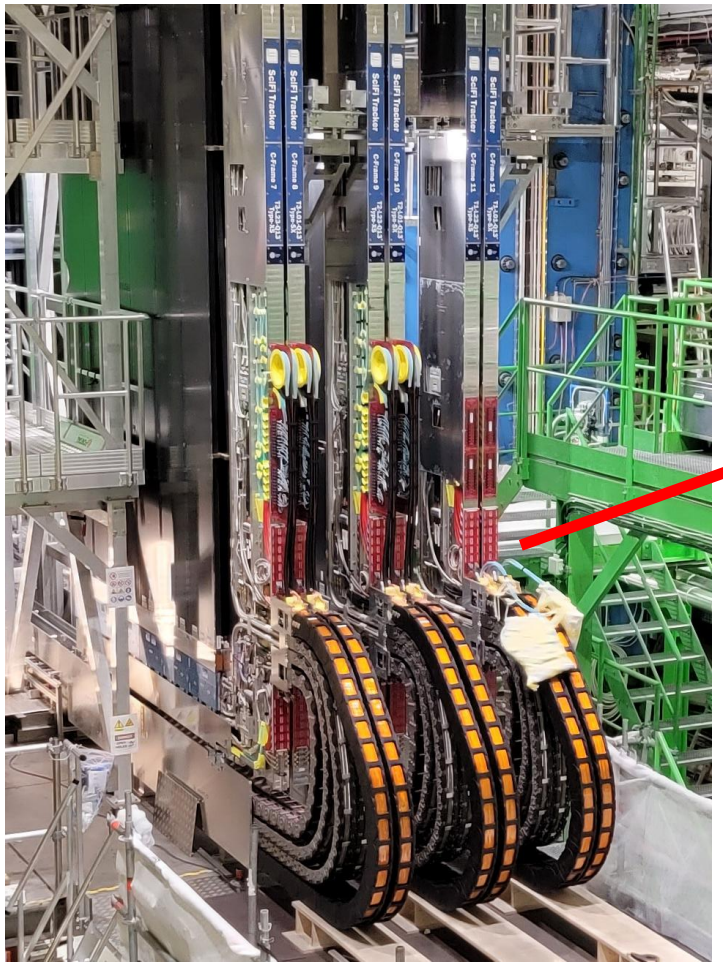


- **SiPM' cooling posed a great engineering challenge**
  - ➢ *−40°C coolant flushing through all the SiPM arrays*
  - ➢ *Avoiding condensation required vacuum, dry gas, etc…*

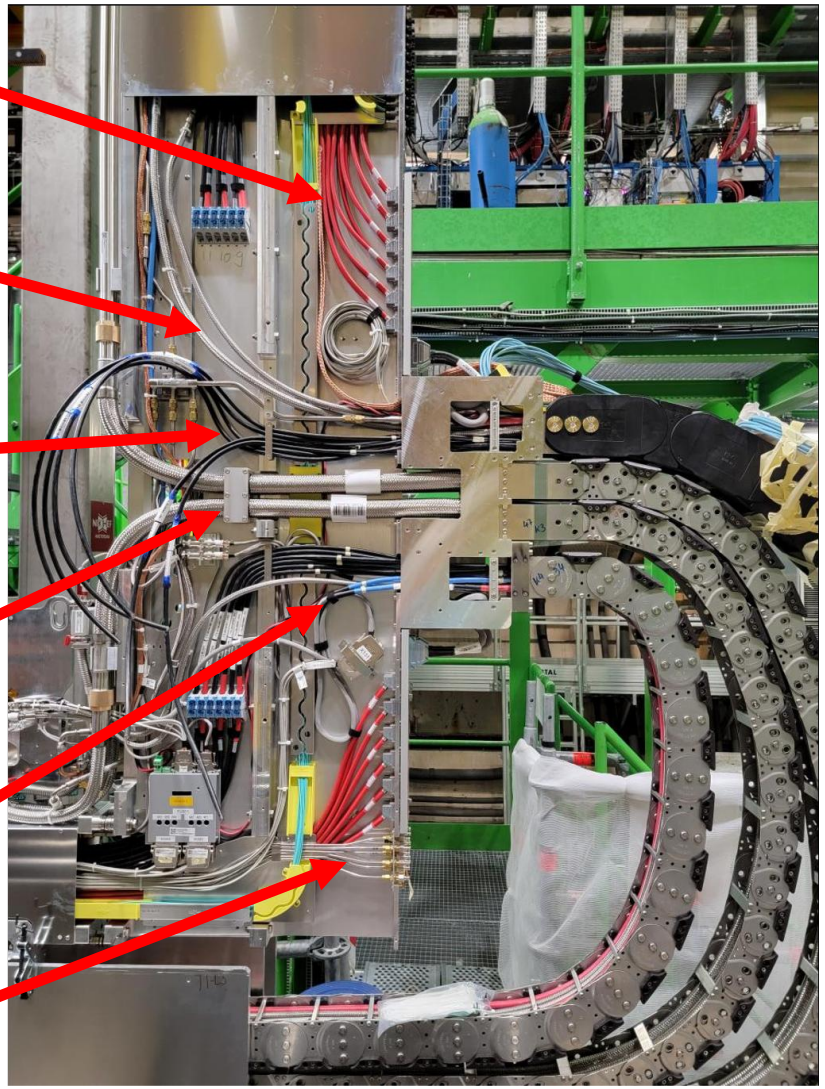
- **Of course, we also have:**
  - ➢ *Low and High Voltage PSUs*
  - ➢ *Monitoring, automation…*

See Sune' talk:
https://indico.cern.ch/event/1291157/contributions/5900405/

The SciFi Tracker in Details: Services

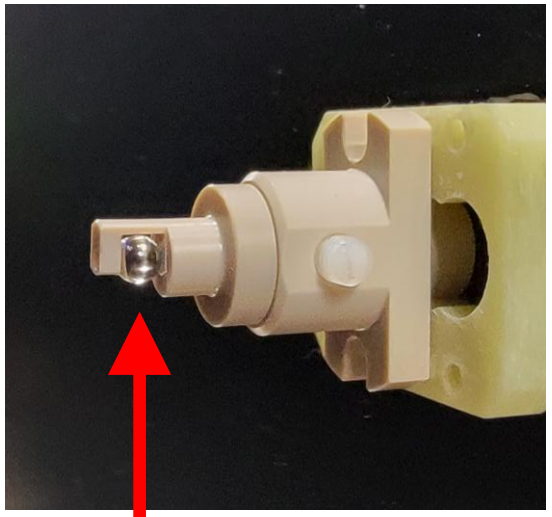


- High Voltage Cabling
- Water Cooling (for Electronics)
- Low Voltage Cabling
- Vacuum-Insulated Coolant (for SiPMs)
- Monitoring Cables (DSS)
- Dry Gas Pipes (Condensation Prev.)



The SciFi Tracker in Details: BCAM System (Real-time geometry monitoring)

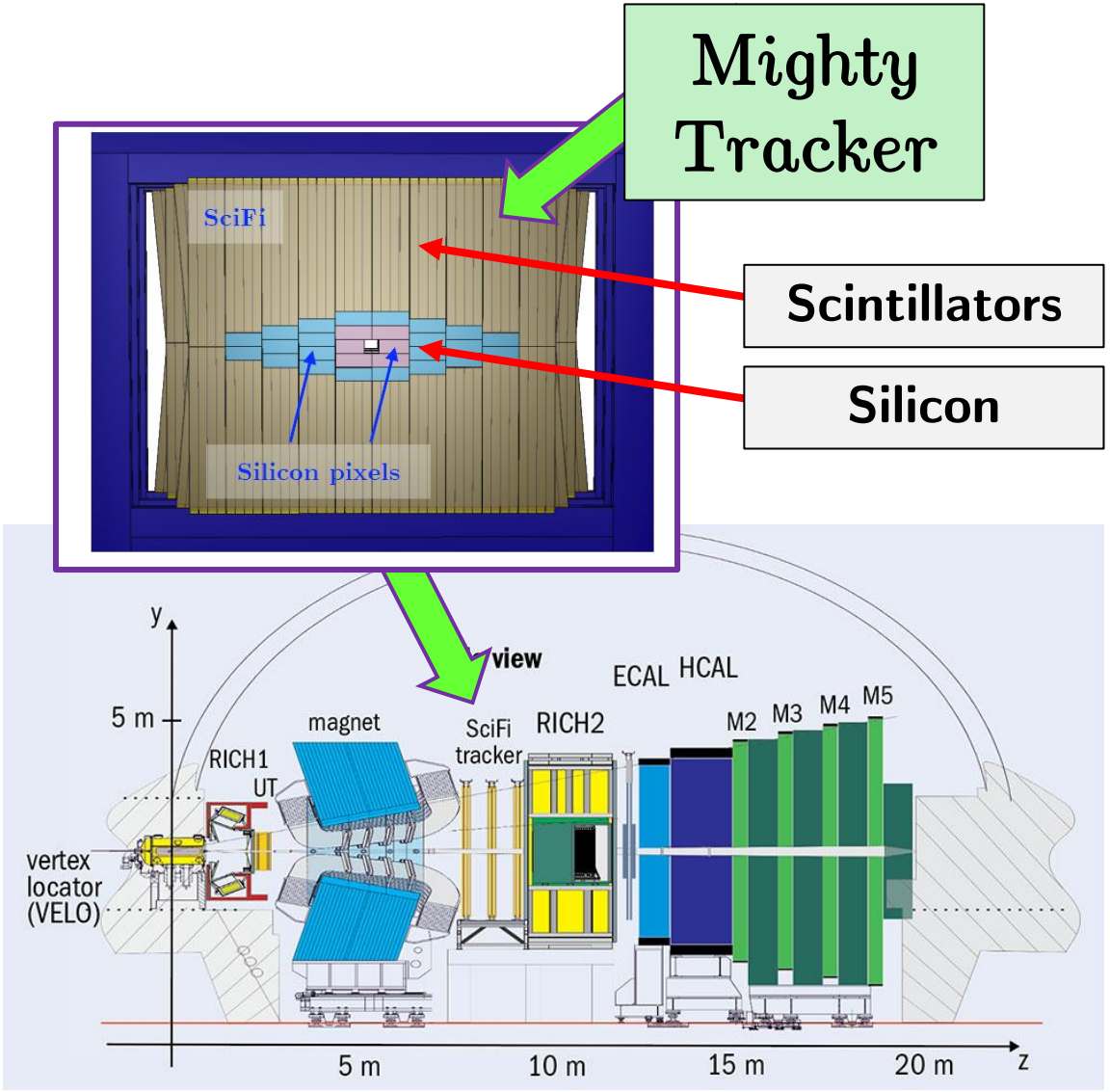
- **BCAM (Brandeis CCD Angle Monitor):**
  - *24 cameras are installed under SciFi floor;*
  - *42 targets (glass balls) installed (glued) on the C-frames, on a special holder;*
  - *Targets illuminated with 650 nm diode lasers and photographed by multiple cameras/angles;*
  - *Detector's geometry is reconstructed from the measurements of relative angles;*
  - *Tracks slightly moves due to, for example, changes on temperature and magnetic field.*



Targets

Lasers and Cameras (under the detector)

A look to the future: Post-Run 4 LHCb

FOR LHCb UPGRADE II

- **Replacement of SciFi after LHC Run 4**
  - *Radiation damages will require substantial replacement of components;*
  - *Even higher instantaneous luminosity leads to even more multiplicity, and trace density poses a challenge to stereoscopic tracking;*
  - *For the innermost area (the "hottest" one) Might Tracker will use Solid State (Silicon) pixel sensors;*