

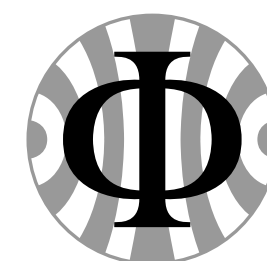
# LHCb SciFi Tracker Commissioning & First Data

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HighRR Seminar 05.10.2022

Lukas Witola

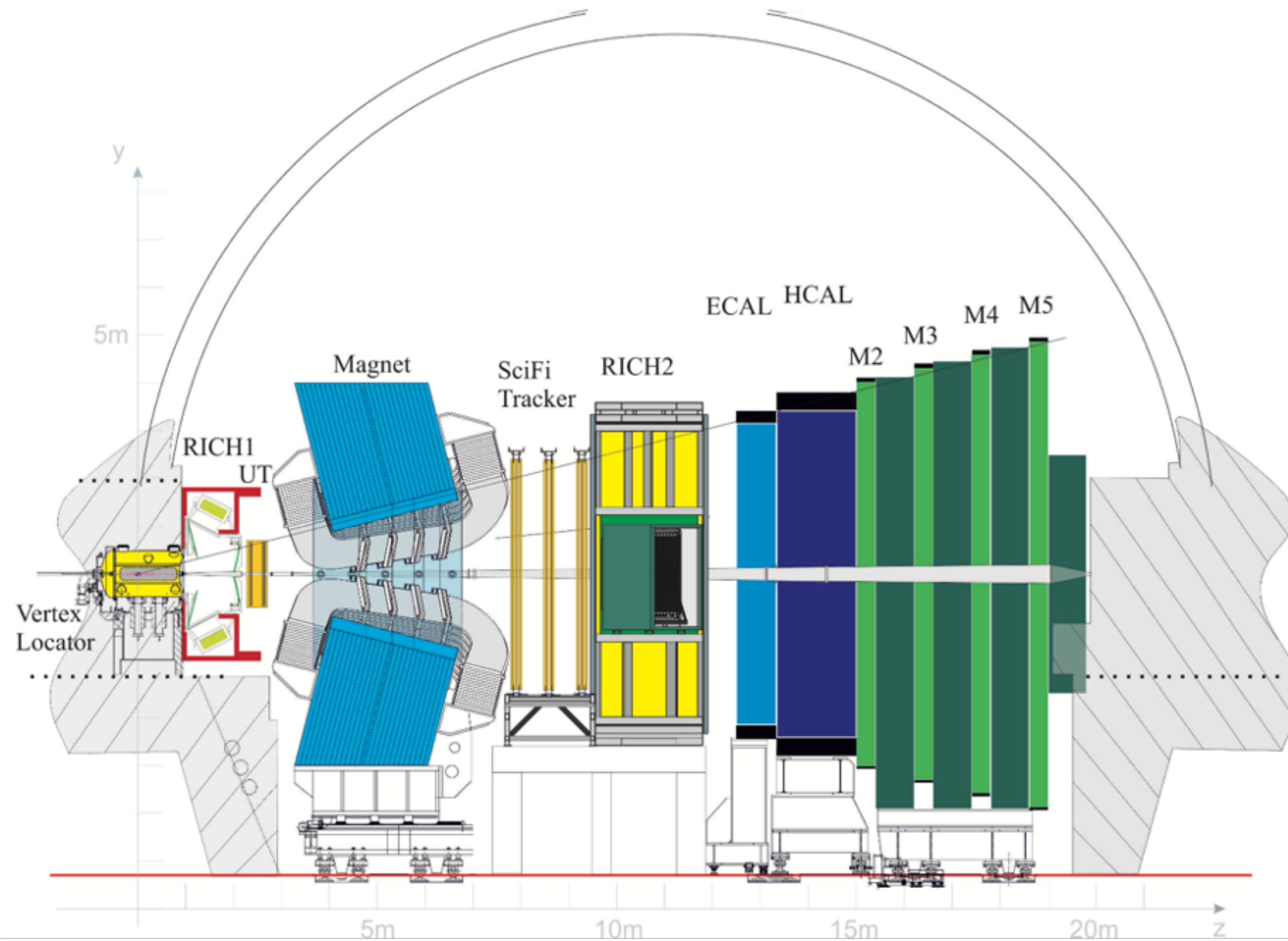
Physikalisches Institut  
Universität Heidelberg



**FSP** LHCb  
Erforschung von  
Universum und Materie

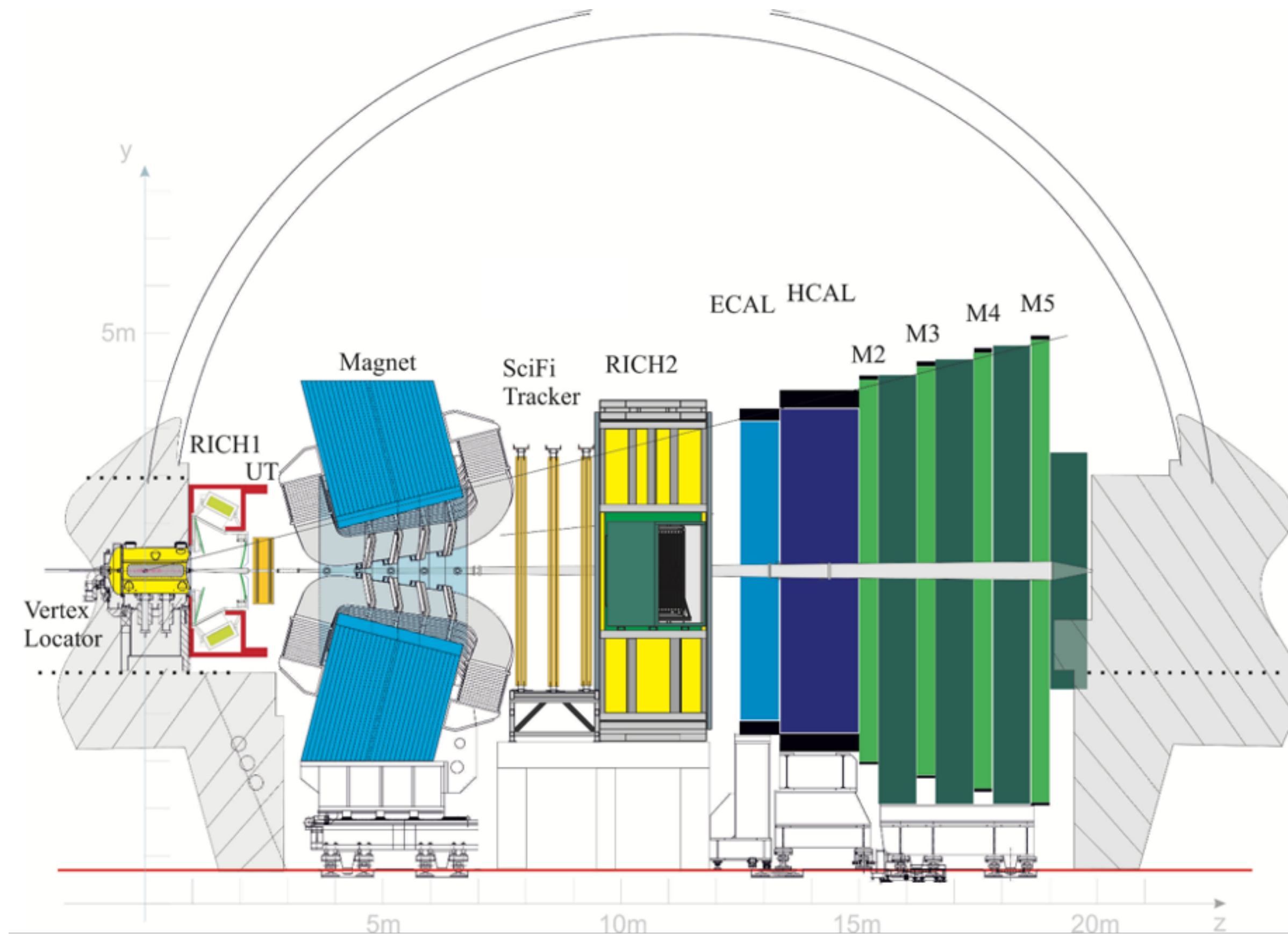


# LHCb Detector



- Single-arm forward spectrometer
- Optimised for  $b$  and  $c$  physics
  - Precise vertexing and tracking
  - Excellent particle identification
- General purpose detector
  - Electroweak physics
  - Rare decays
  - Spectroscopy
  - ...

# LHCb Detector Upgrade



- Reduce statistical uncertainties by collecting more data:  $9 \text{ fb}^{-1} \rightarrow 50 \text{ fb}^{-1}$
- **Increased instantaneous luminosity**
  - $4 \cdot 10^{32} \text{ cm}^{-2}\text{s}^{-1} \rightarrow 2 \cdot 10^{33} \text{ cm}^{-2}\text{s}^{-1}$
  - Higher occupancy requires new tracking system (VELO, UT, SciFi Tracker)
- **Full 40 MHz readout & software trigger**
  - Removal of 1 MHz hardware trigger
  - Replacement of all readout electronics and DAQ system

# LHCb SciFi Tracker

## Large instrumented area

- 3×4 layers, 340 m<sup>2</sup> active area

## High tracking performance

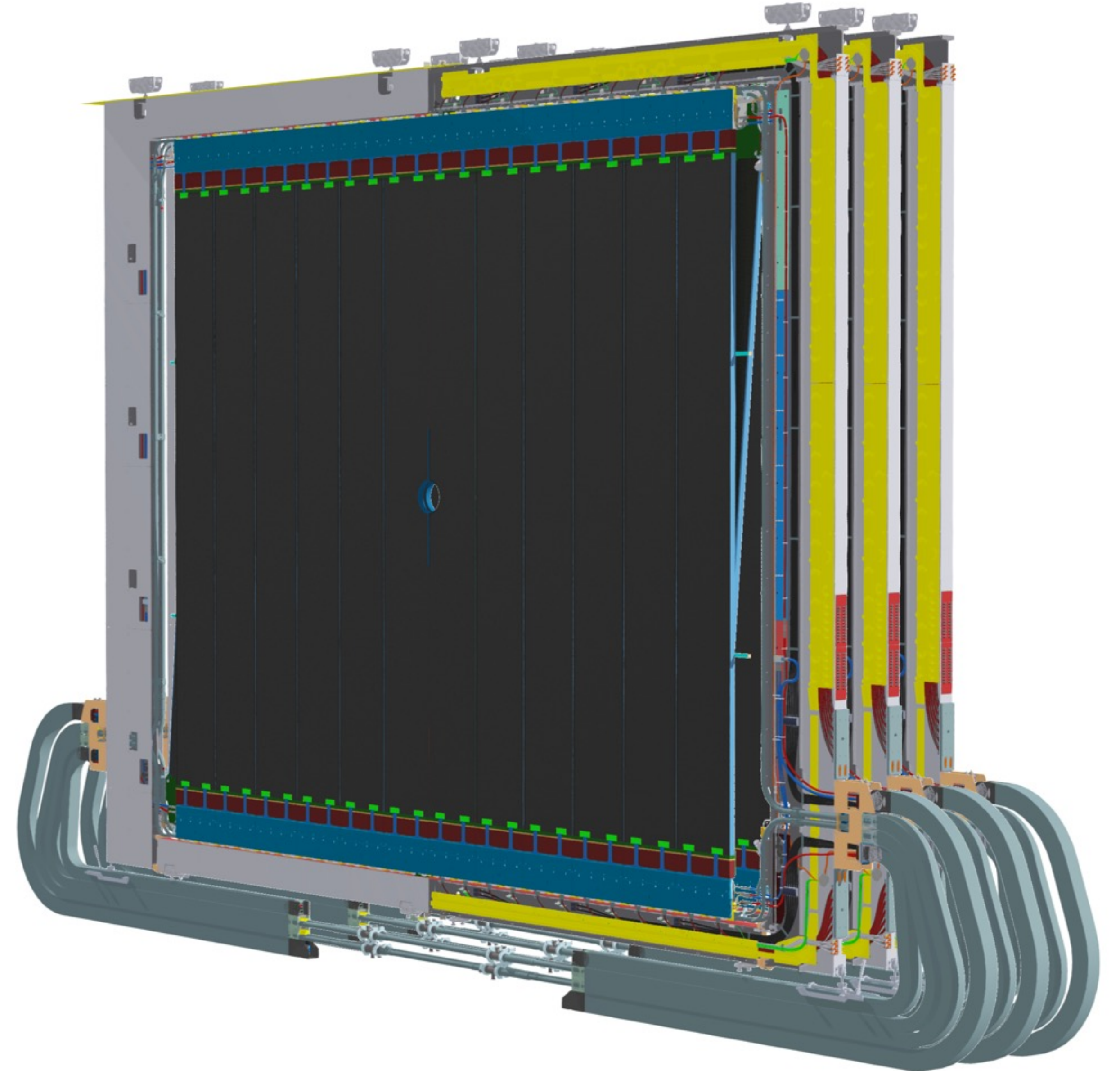
- Hit detection efficiency > 99%
- Spatial resolution < 100 μm

## Low material budget

- ~1% X<sub>0</sub> per layer

## Fast readout electronics

- 40 MHz without dead-time



# LHCb SciFi Tracker

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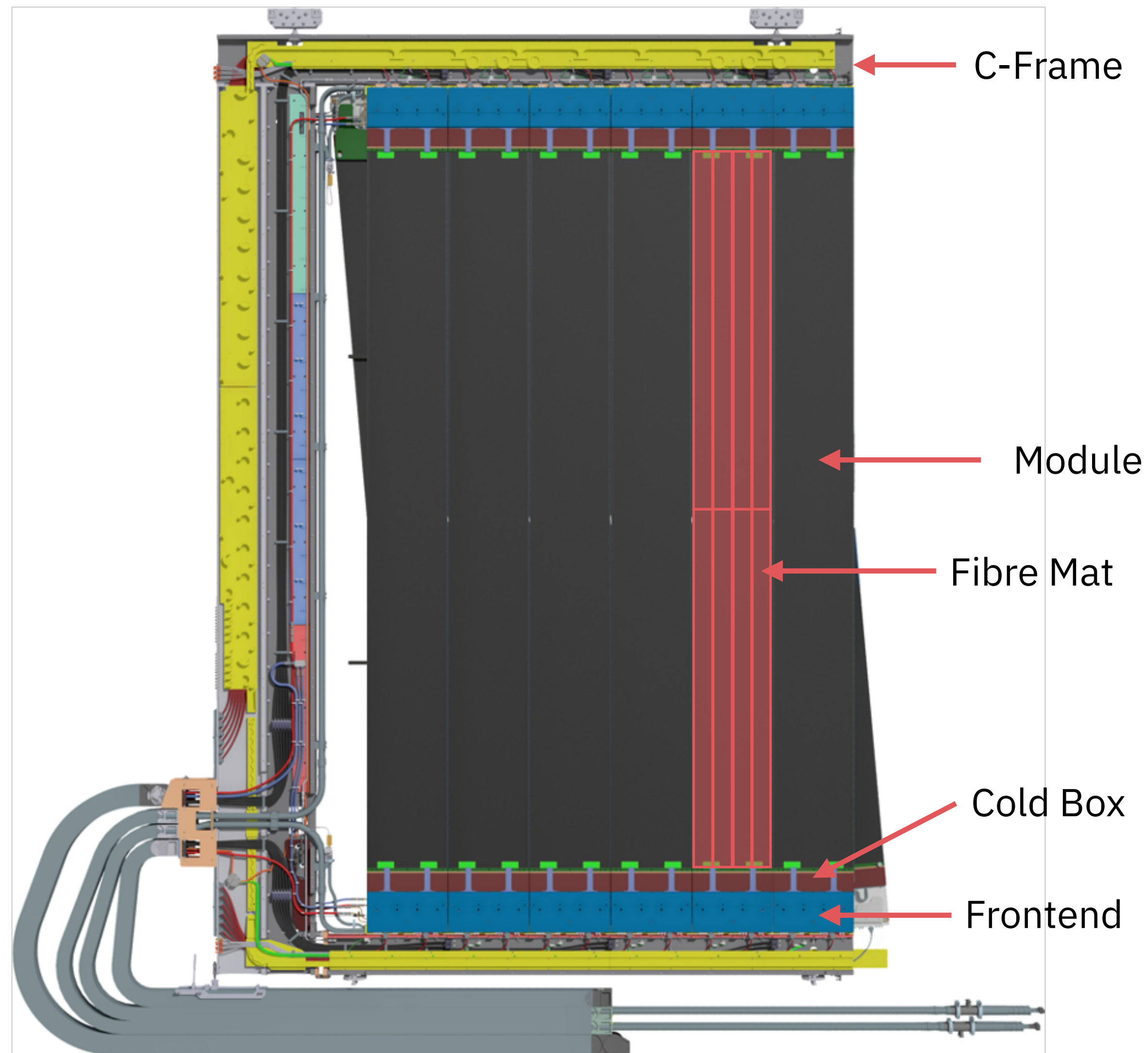
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## Fast readout electronics

- 40 MHz without dead-time

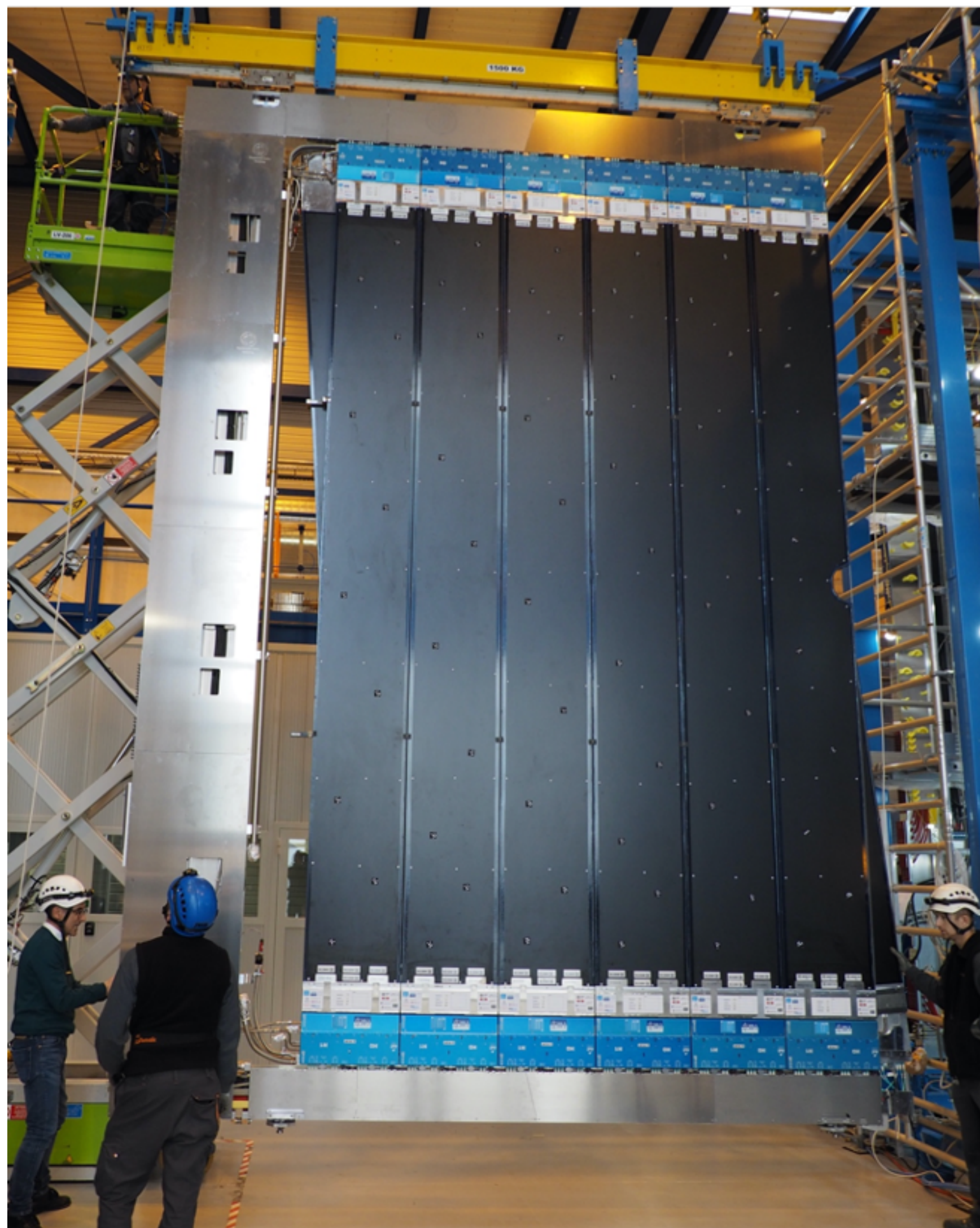


# C-Frames



- Two layers per C-Frame ( $x$  and *stereo*)
  - Up to six modules per layer
  - Eight fibre mats per module
  - Twelve C-Frames in total
- 2.5 m long, 250  $\mu\text{m}$  diameter scintillating fibres
  - ~11,000 km in total
- Silicon photomultiplier (SiPM) readout
  - 524,288 channels in total
  - Cooled to  $-40^\circ\text{C}$
- 40 MHz frontend electronics

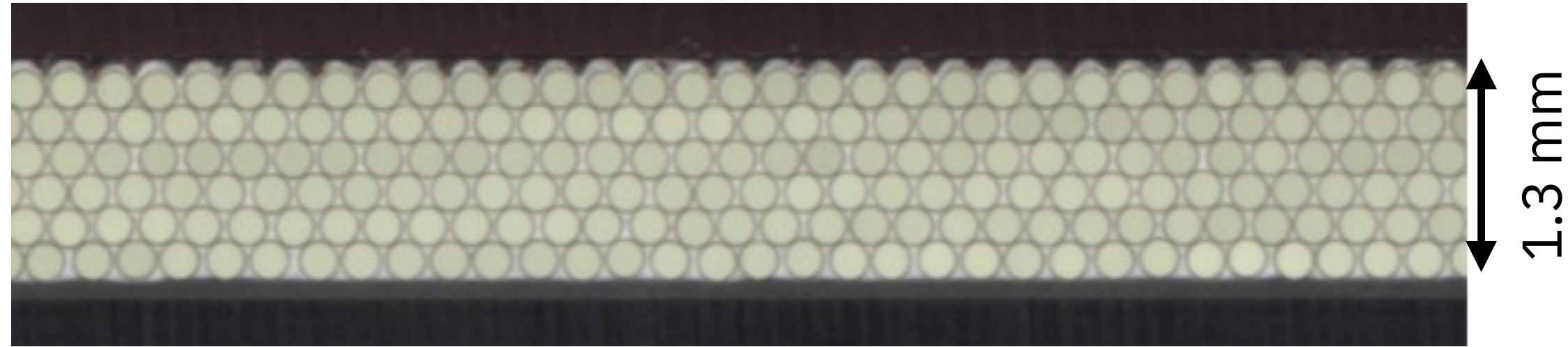
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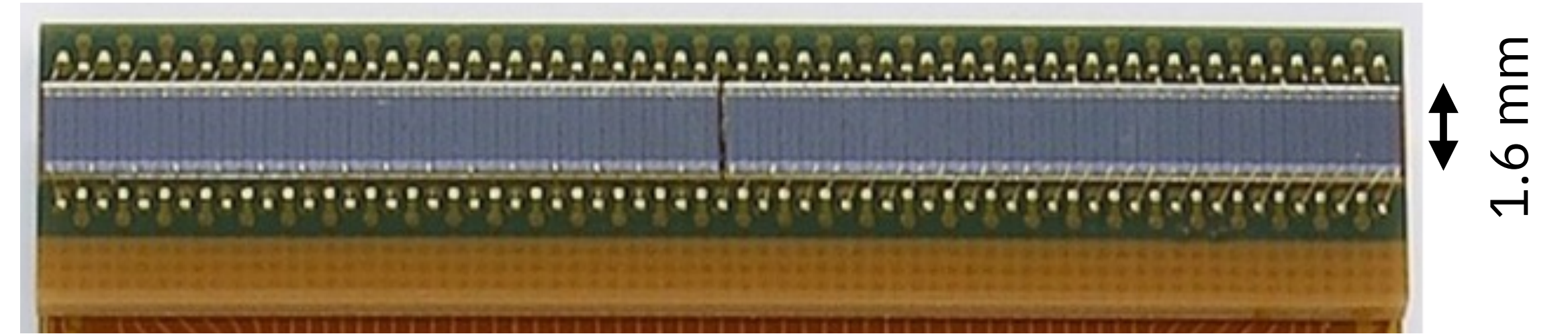
# Fibre Mats & SiPM Arrays

## Fibre Mat



- 2650 mm long, 140 mm wide
- Six layers of staggered fibres
- 1024 mats installed in total

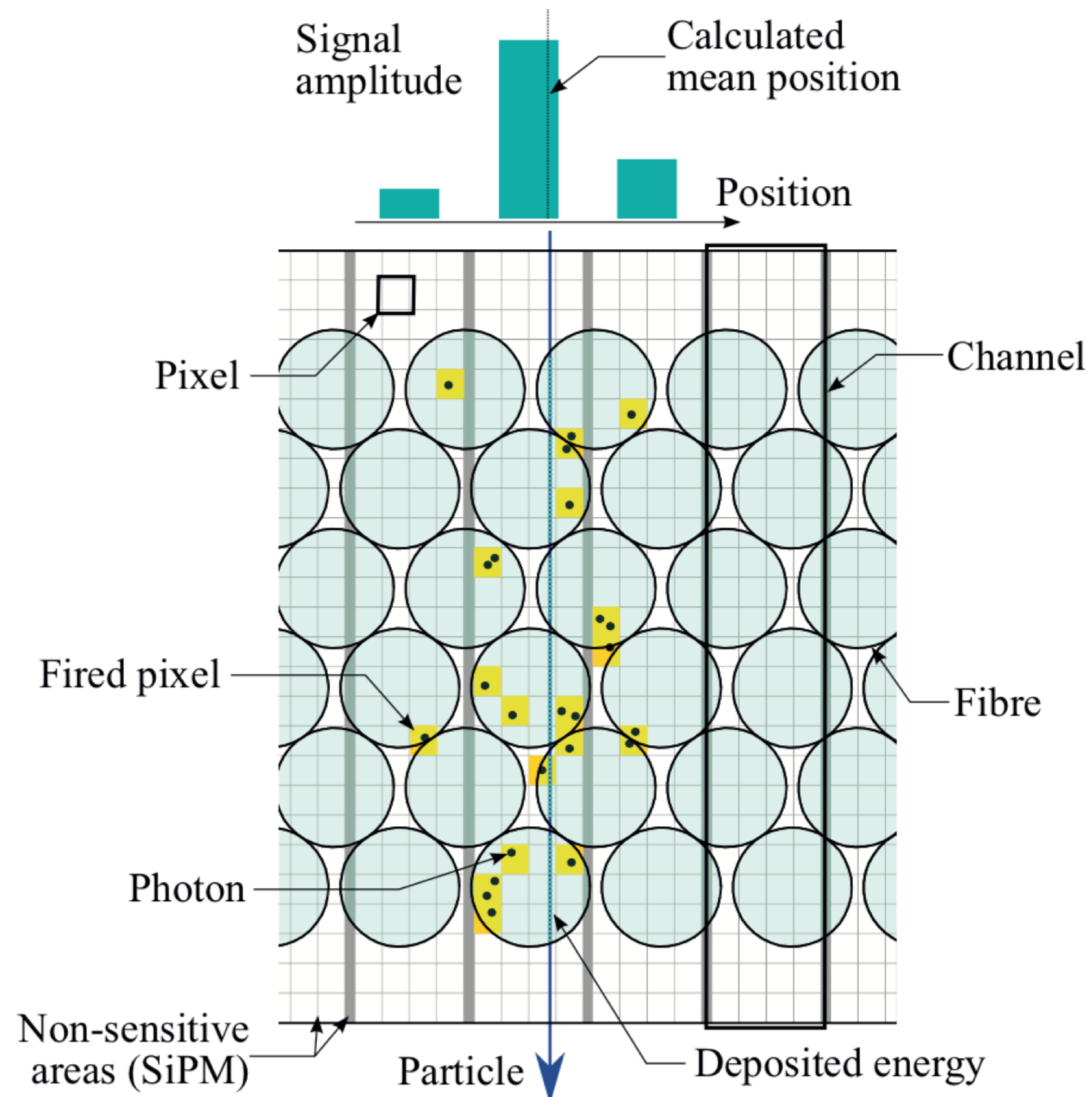
## Silicon Photomultiplier Array



- 128 channels, 250  $\mu\text{m}$  pitch
- 104 pixels per channels
- Active area slightly taller than fibre mat
- 4096 arrays installed in total



# Working Principle



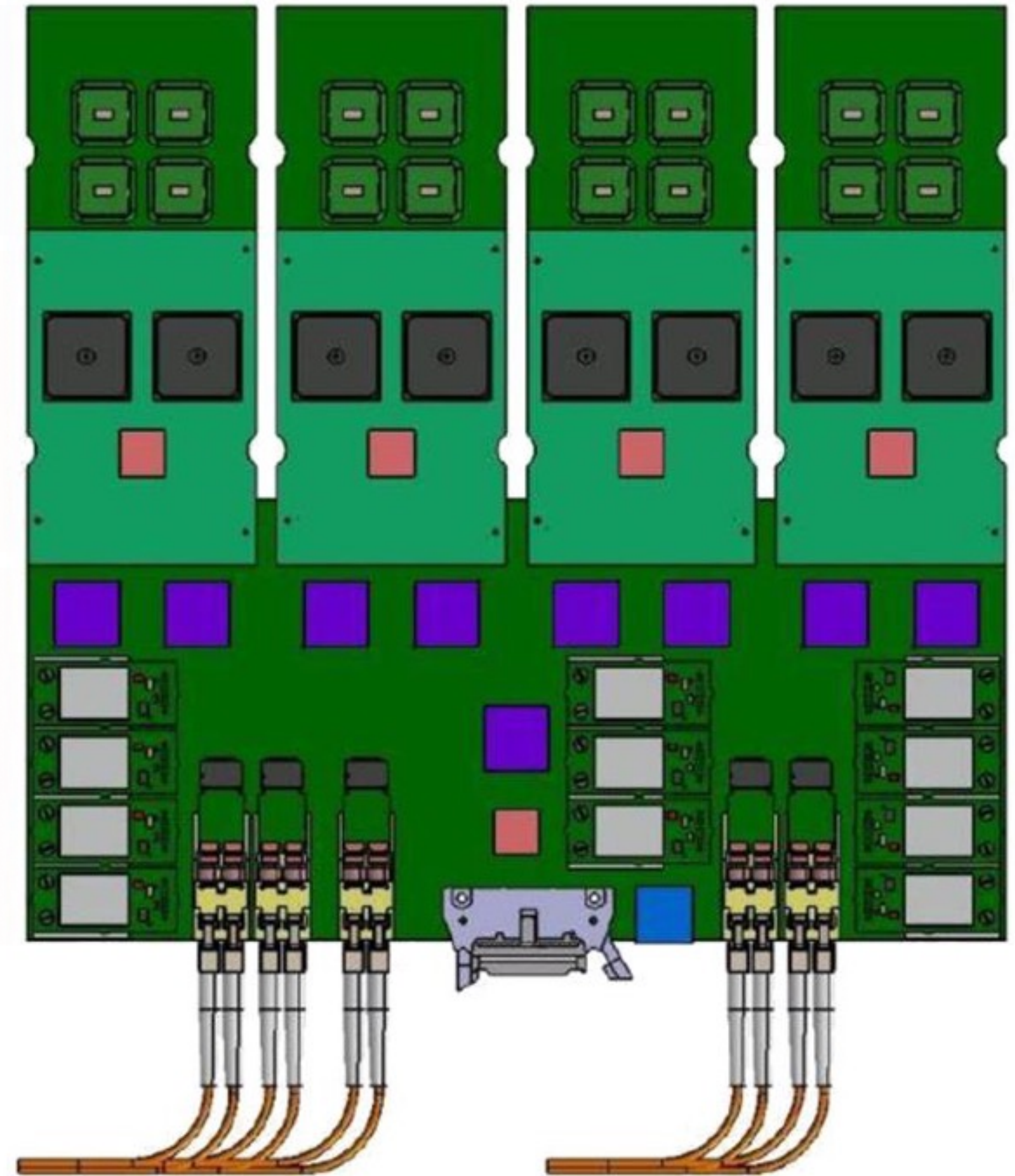
- Particle deposits energy in several fibers along its path
- Scintillation photons are transported to SiPM arrays via total reflection
- Photons are detected by SiPMs
- Amplitude in each channel  $\propto$  Number of detected photons
- Position reconstructed using weighted mean

# Frontend Electronics

PACIFIC Board

Cluster Board

Master Board

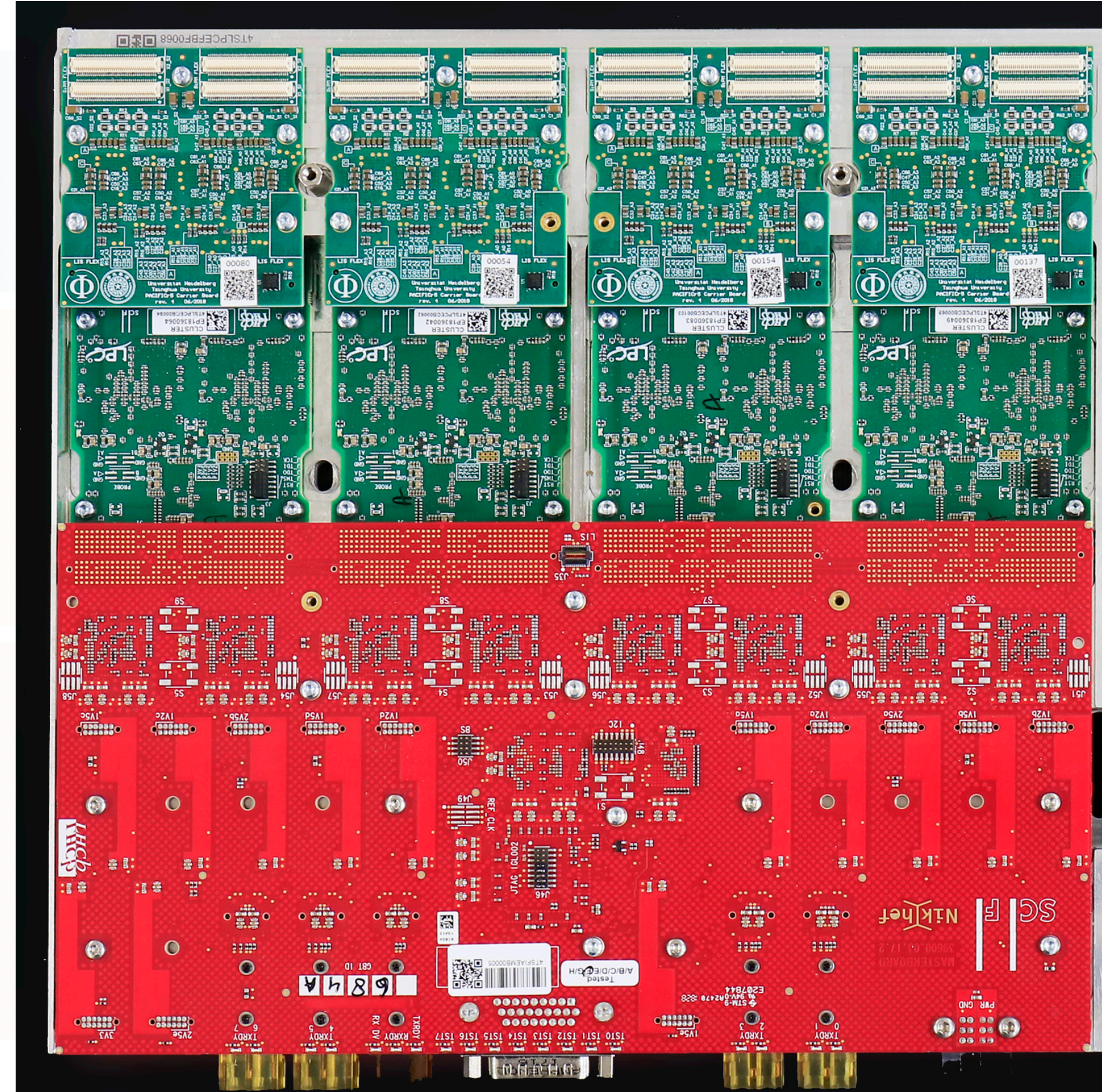


# Frontend Electronics

PACIFIC Board

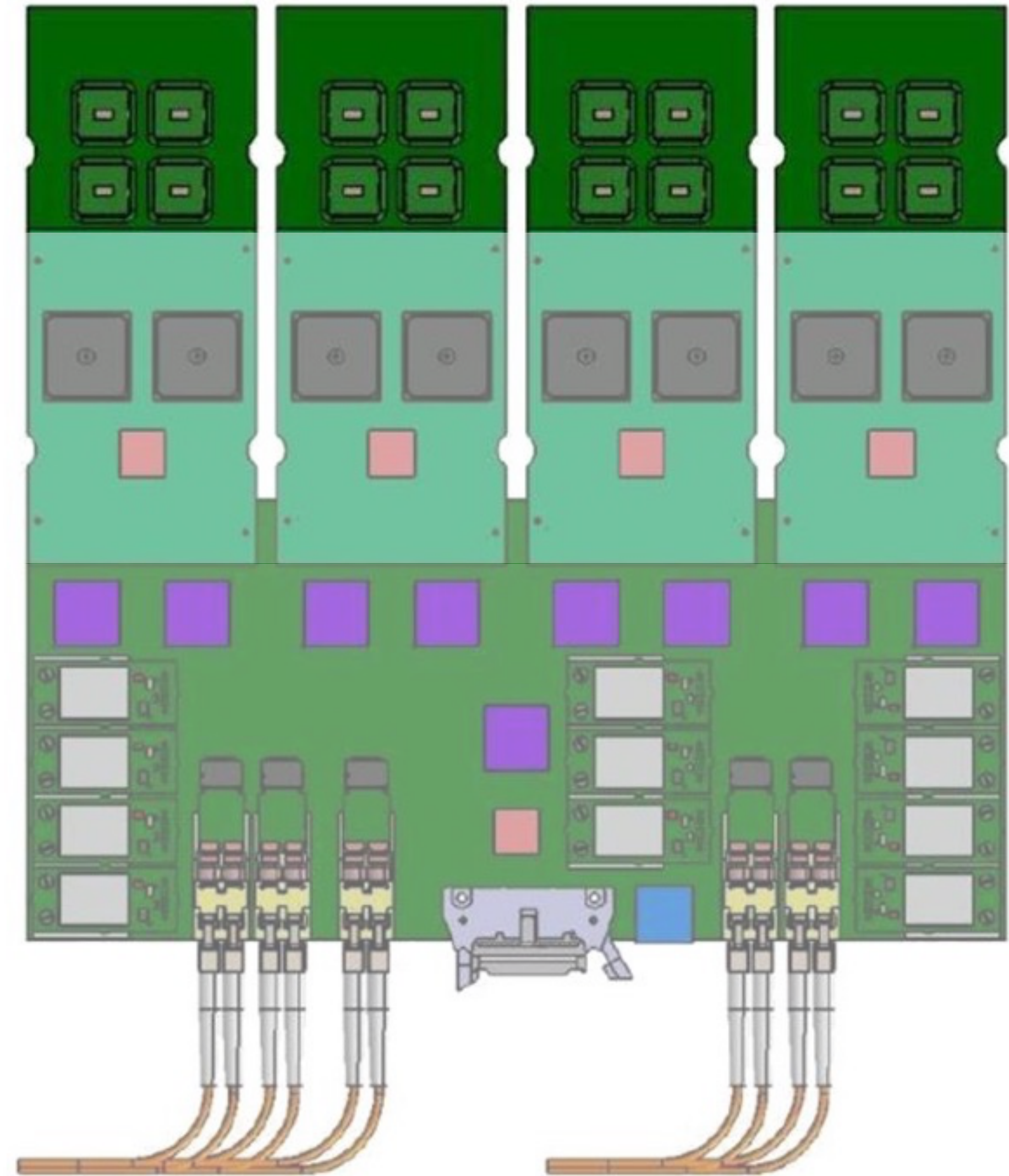
Cluster Board

Master Board



# Frontend Electronics PACIFIC Board

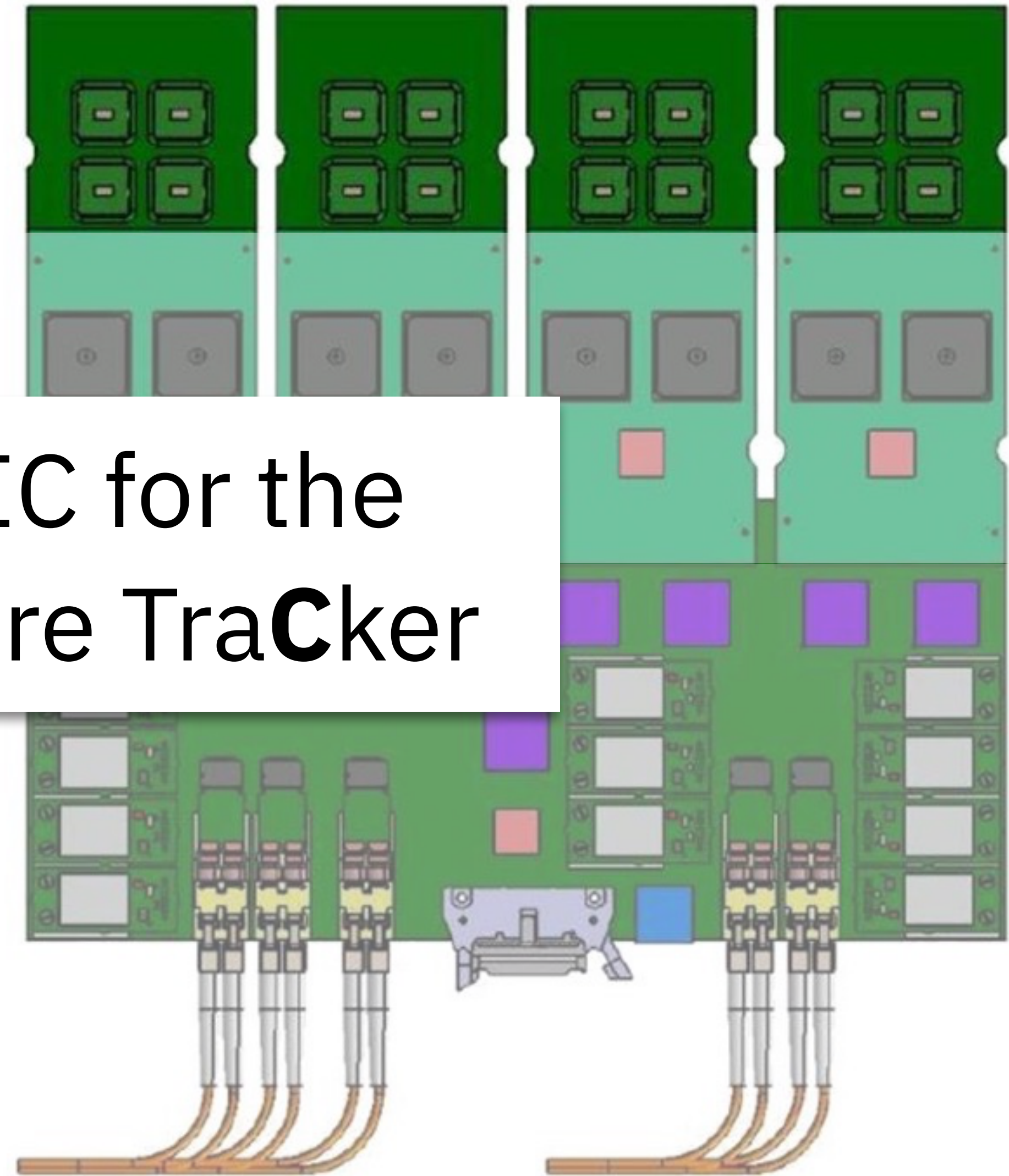
- Two PACIFIC ASICs per SiPM array
  - 64 channels per ASIC
  - Analogue processing & digitisation
- **Shaper:** Reduce long tail of SiPM signal
- **Integrator:** Two gated integrators to minimise dead-time
- **Digitisation:** Three comparators with adjustable thresholds
  - Sum of comparators  $\rightarrow$  2 bit per channel
- 10.2 Gb/s per SiPM array (SciFi 42 Tb/s)



# Frontend Electronics PACIFIC Board

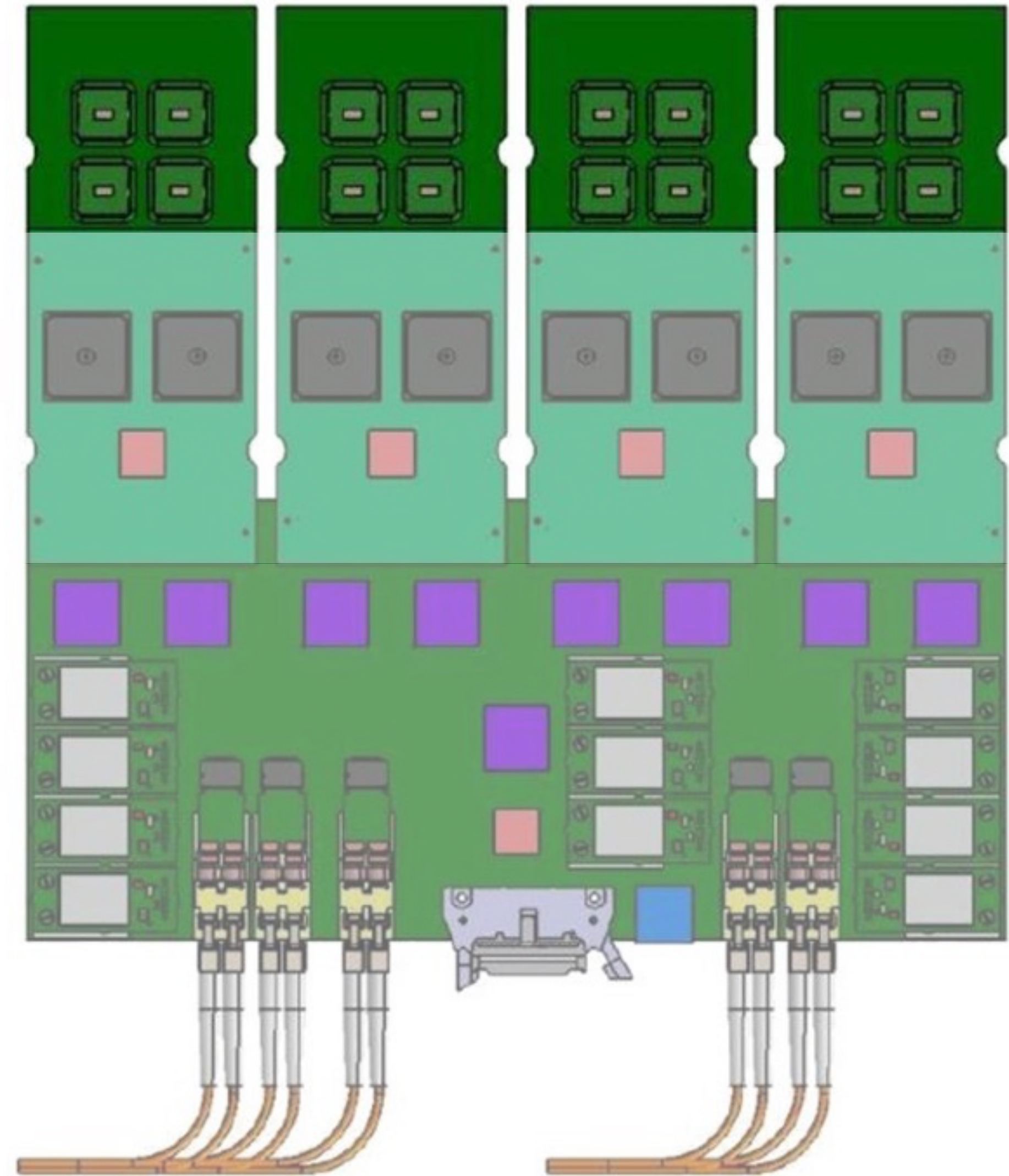
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Low **P**ower **A**SiC for the  
**SC**Intillating **F**ibre **Tra**Cker



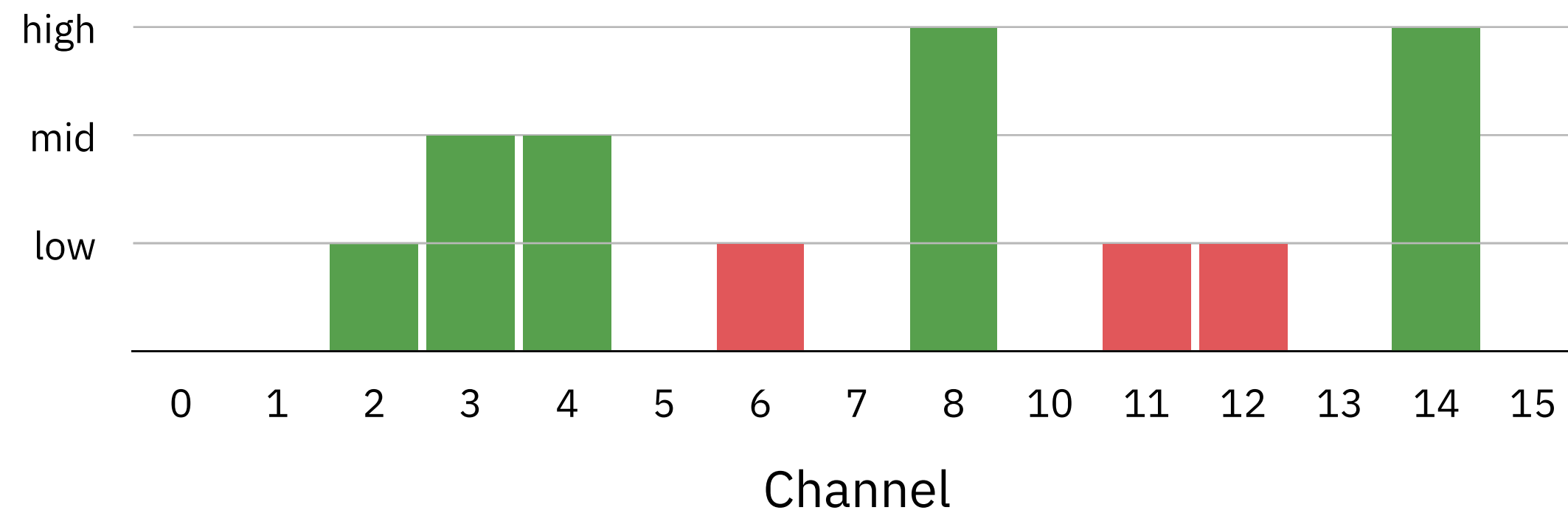
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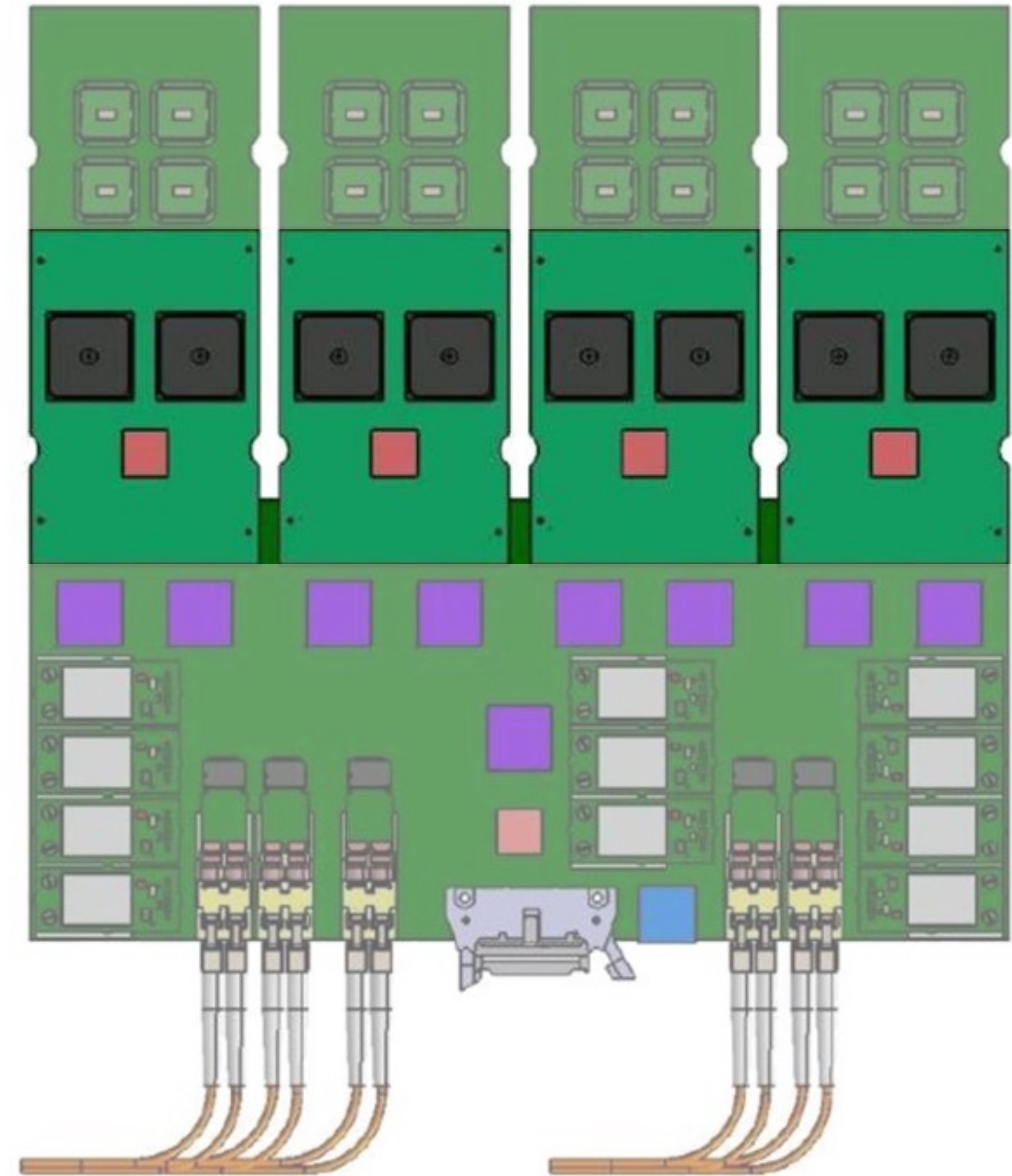


# Frontend Electronics Cluster Board

- One FPGA per SiPM array
  - Hit reconstruction & noise suppression
- **Cluster Algorithm:**
  - PACIFIC 2-bit amplitude per channel (*zero, low, mid, high*) as input

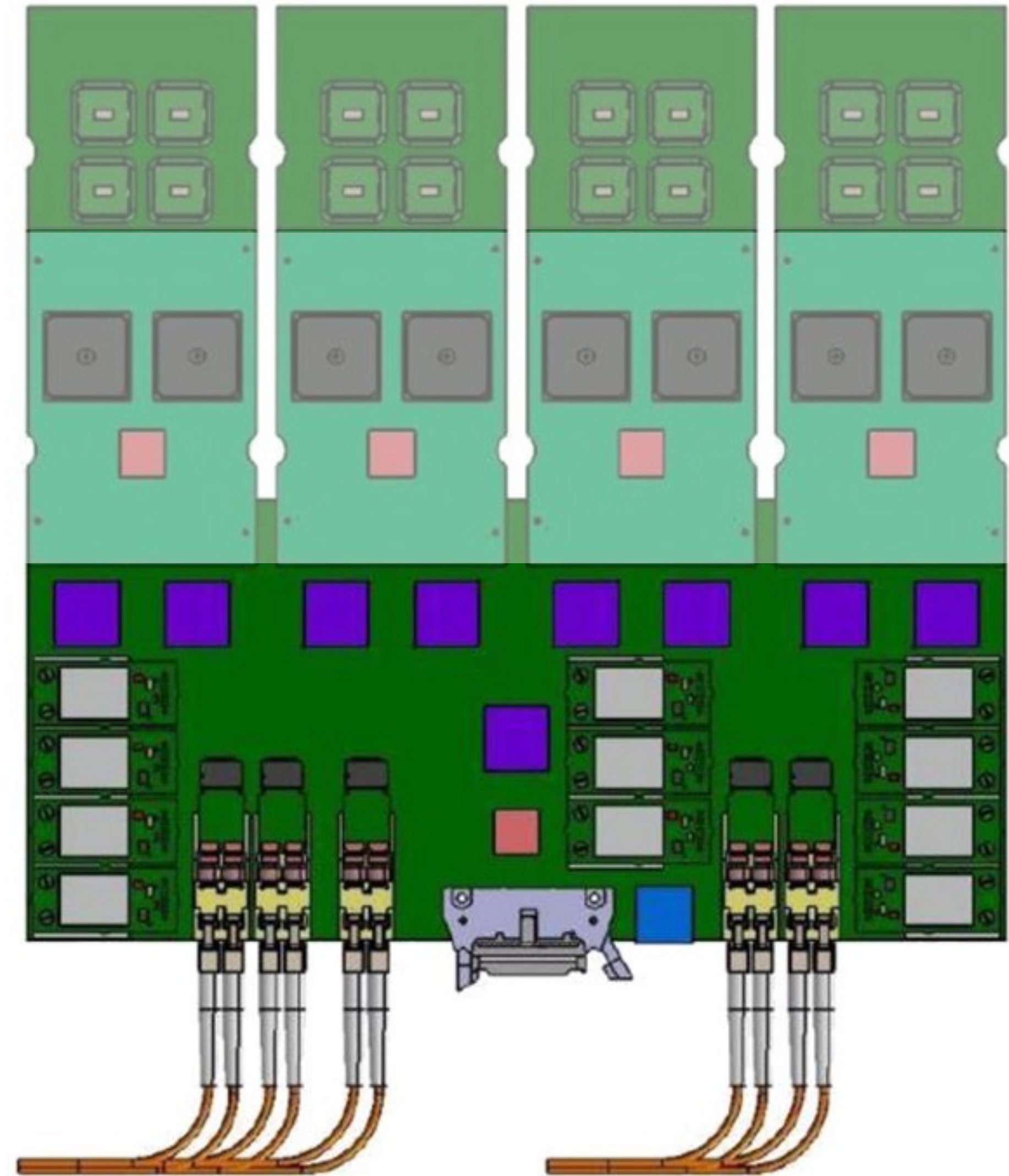


- Reduce noise 14 MHz  $\rightarrow$  2 MHz per array
- Reduce data rate 10.2 Gb/s  $\rightarrow$  4.8 Gb/s per array (SciFi 20 Tb/s)



# Frontend Electronics Master Board

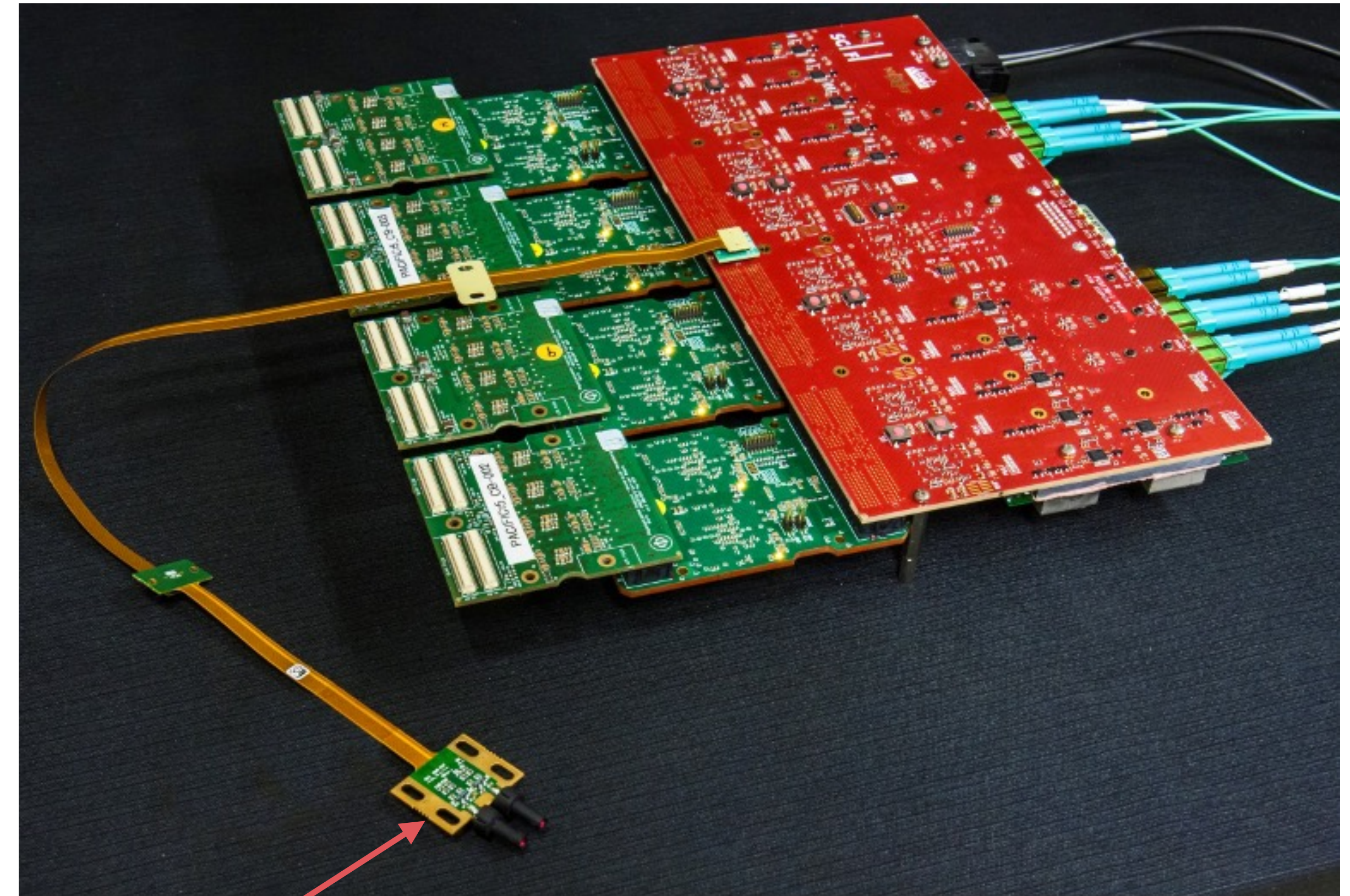
- Distribution & regulation of LV, HV
- Transmission of slow & fast control, and clock signals
  - Two optical links for control (transmitting & receiving)
- Data serialisation & transmission
  - Eight (one per SiPM array) unidirectional optical links (4.8 Gb/s)
- Control of Light Injection System





# Light Injection System

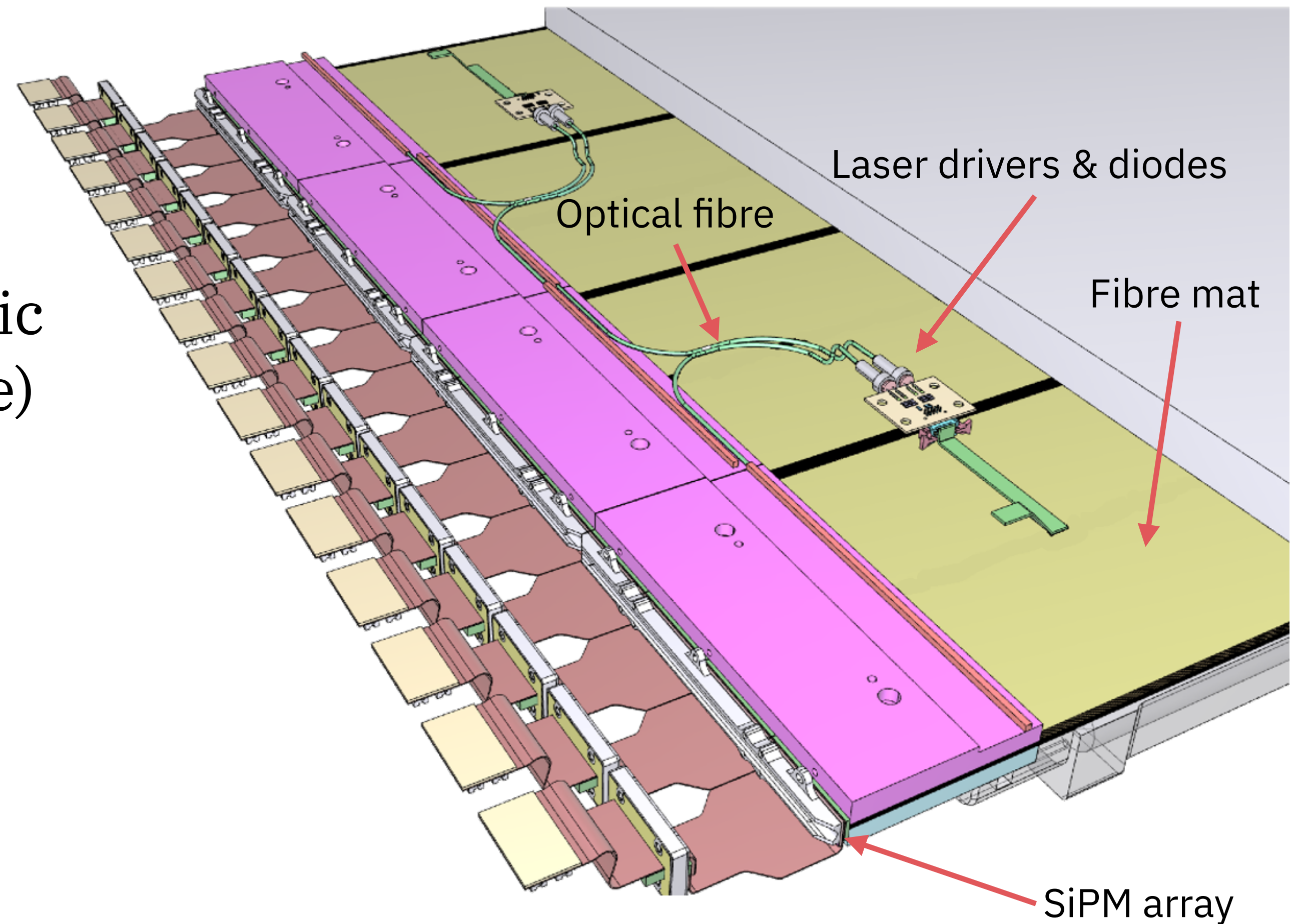
- Allows to inject light onto the SiPM arrays to calibrate the PACIFIC comparator thresholds
- Laser driver & diode connected to plastic optical fibre (embedded in fibre module)
- Optical fibre guides & distributes the light over the width of one fibre mat



Laser drivers & diodes

# Light Injection System

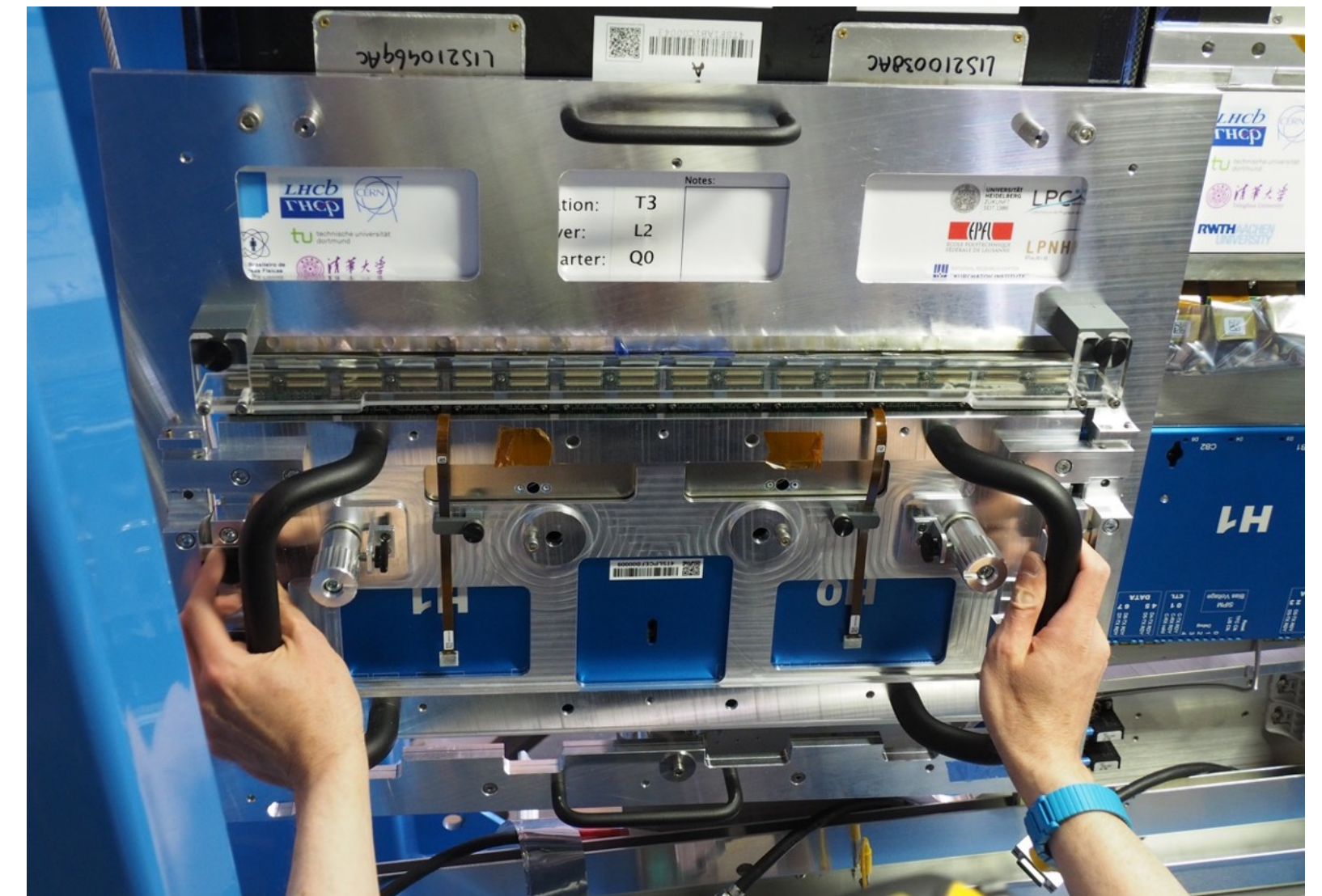
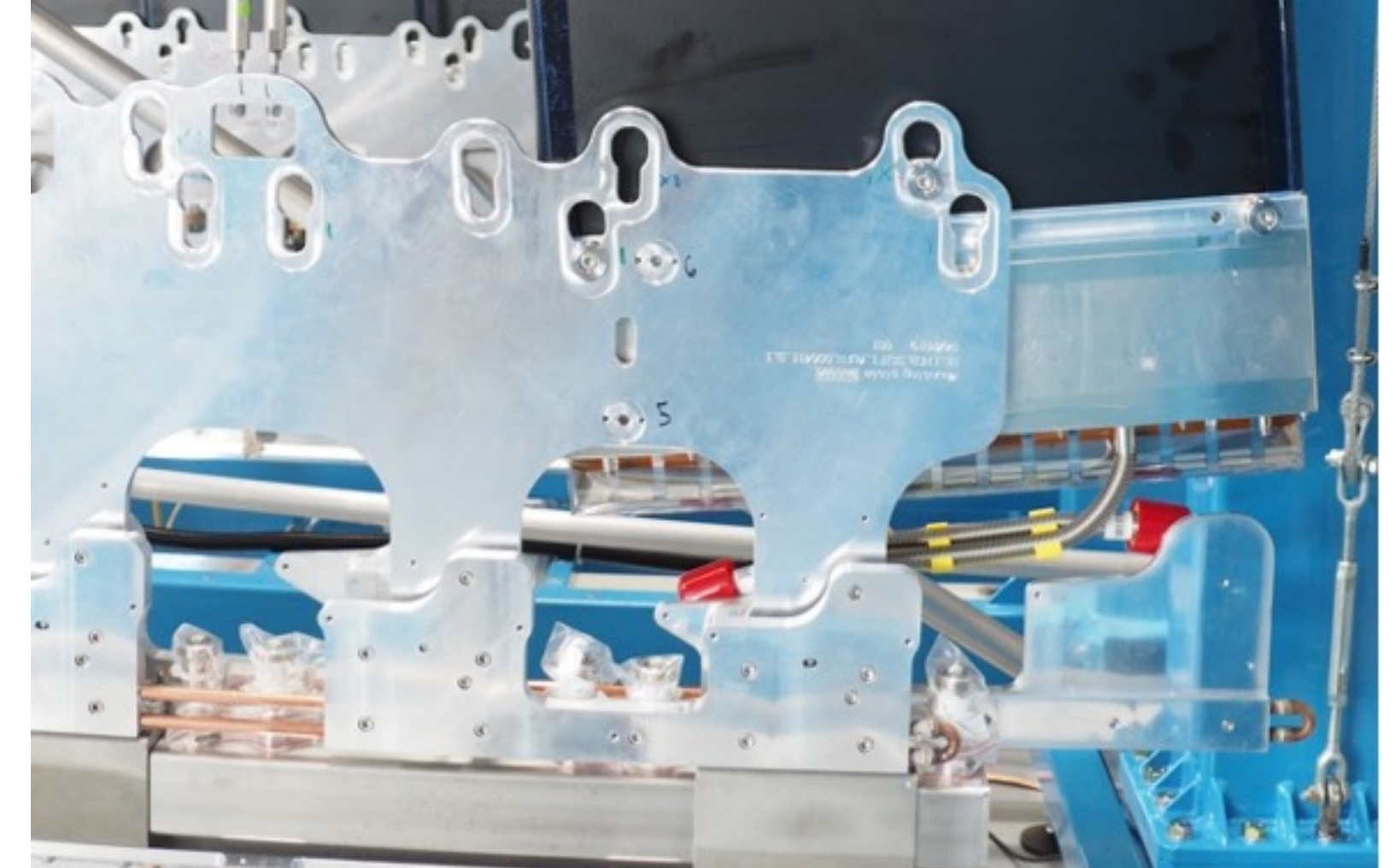
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# Assembly

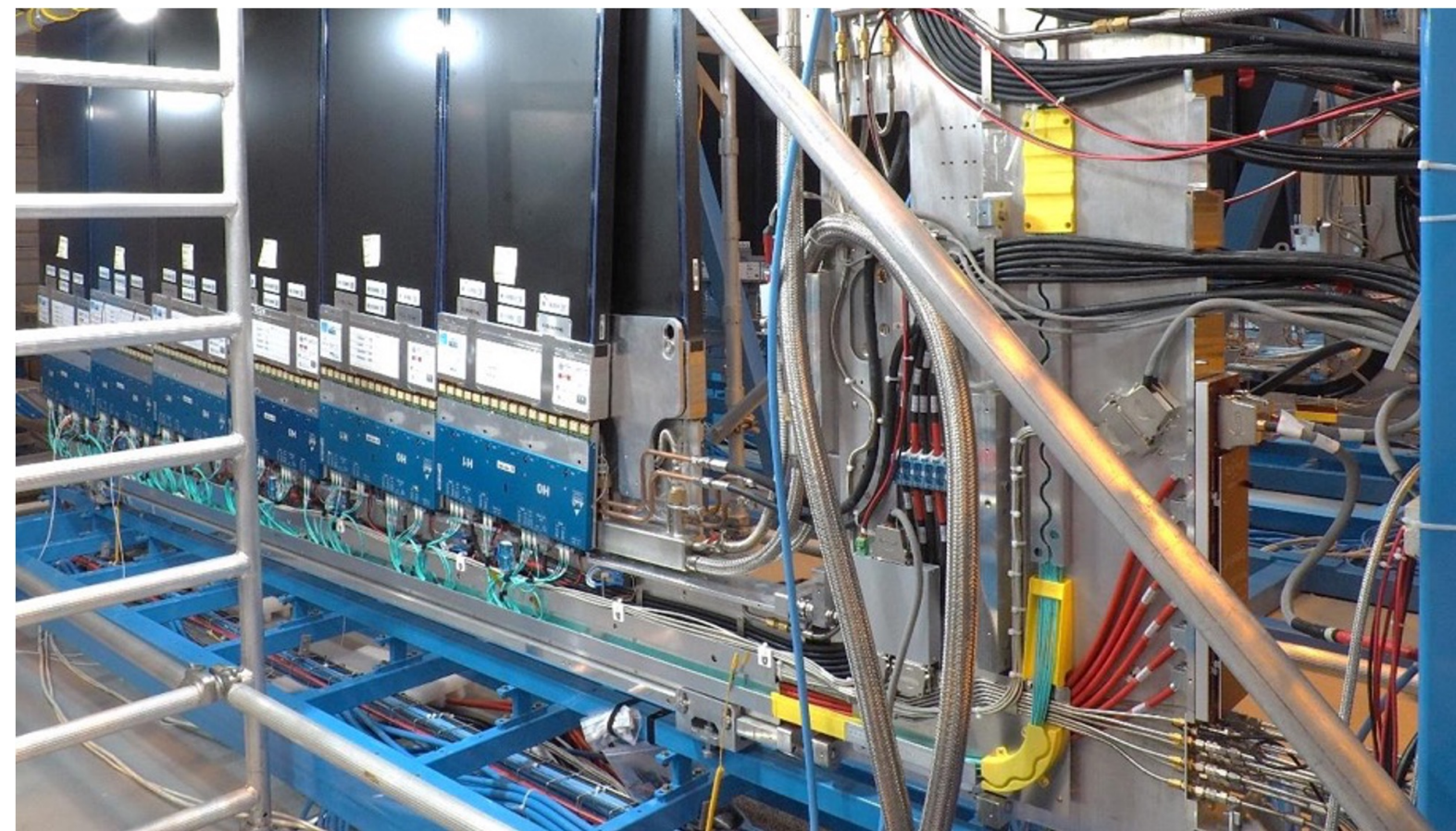
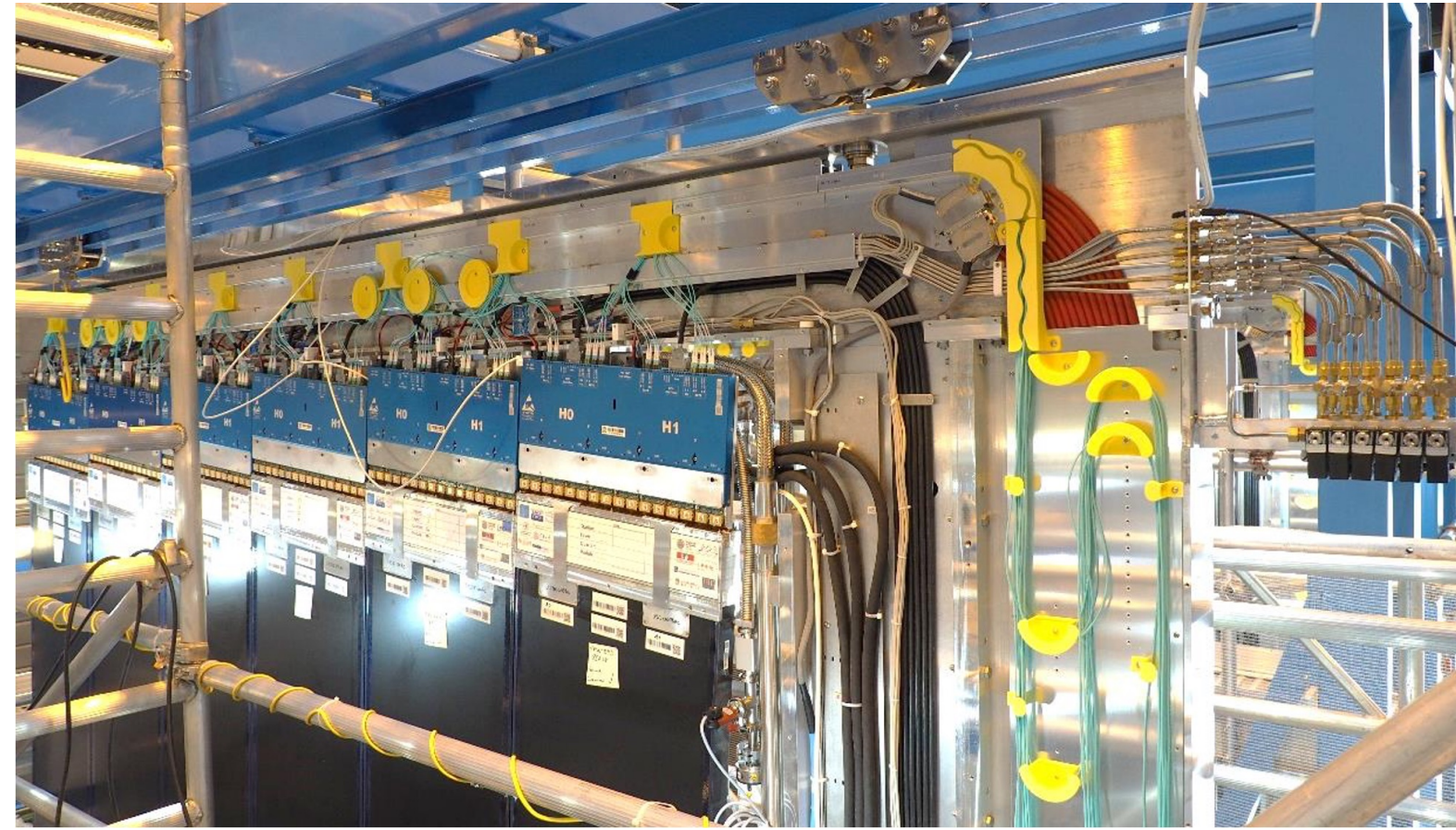
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# Mechanical Assembly

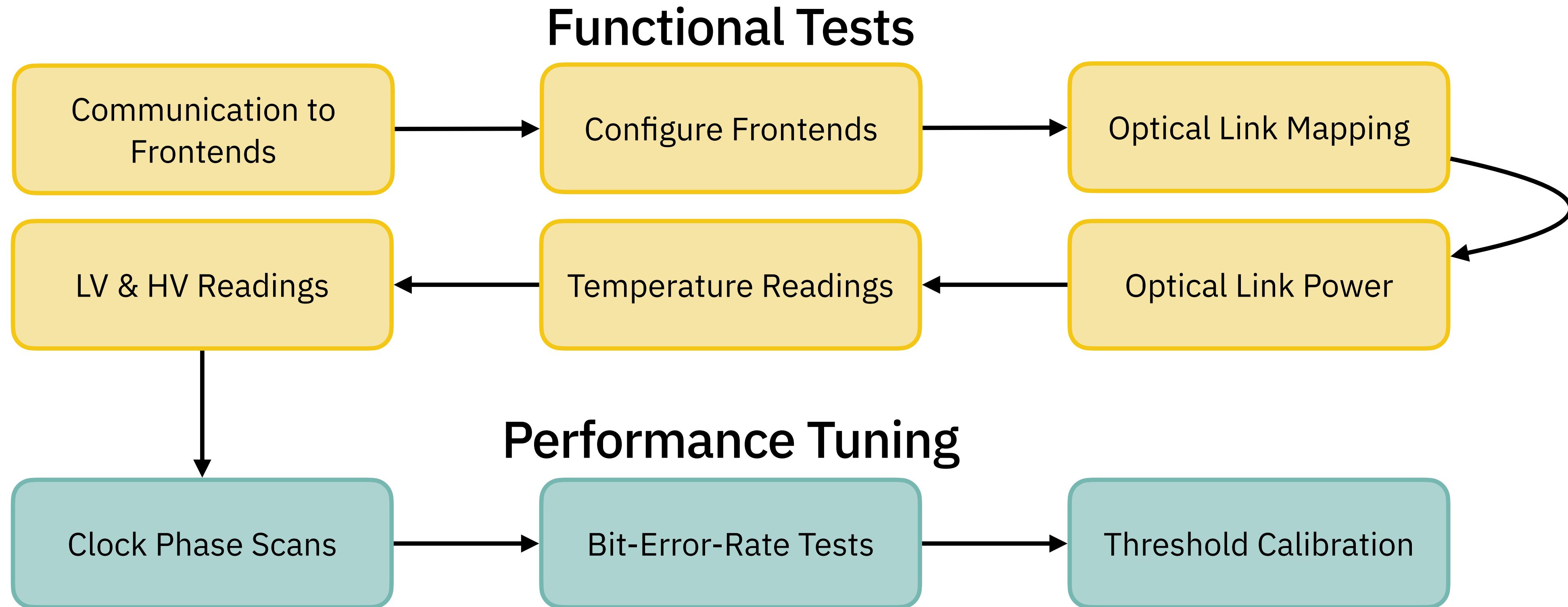


# Cabling & Optical Fibres

- Connect all cables & fibres
  - 512 LV & HV cables
  - 4096 SiPMs
  - 6144 optical fibres (4608 data, 1024 control, 384 spares)
- Test LV & HV connections
- Inspect & clean all optical fibres



# C-Frame Commissioning



- Verify that each C-Frame is operational before installation in the cavern
- From basic functional tests to complete system test

# Assembly Status

- Assembly & commissioning above ground of all twelve C-Frames is completed
- Concluded three years of assembling & commissioning C-Frames
  - C-Frame 1 (04.03.19) – C-Frame 12 (11.02.22)
- Successfully commissioned ~500k channels
  - Only found 3 broken channels



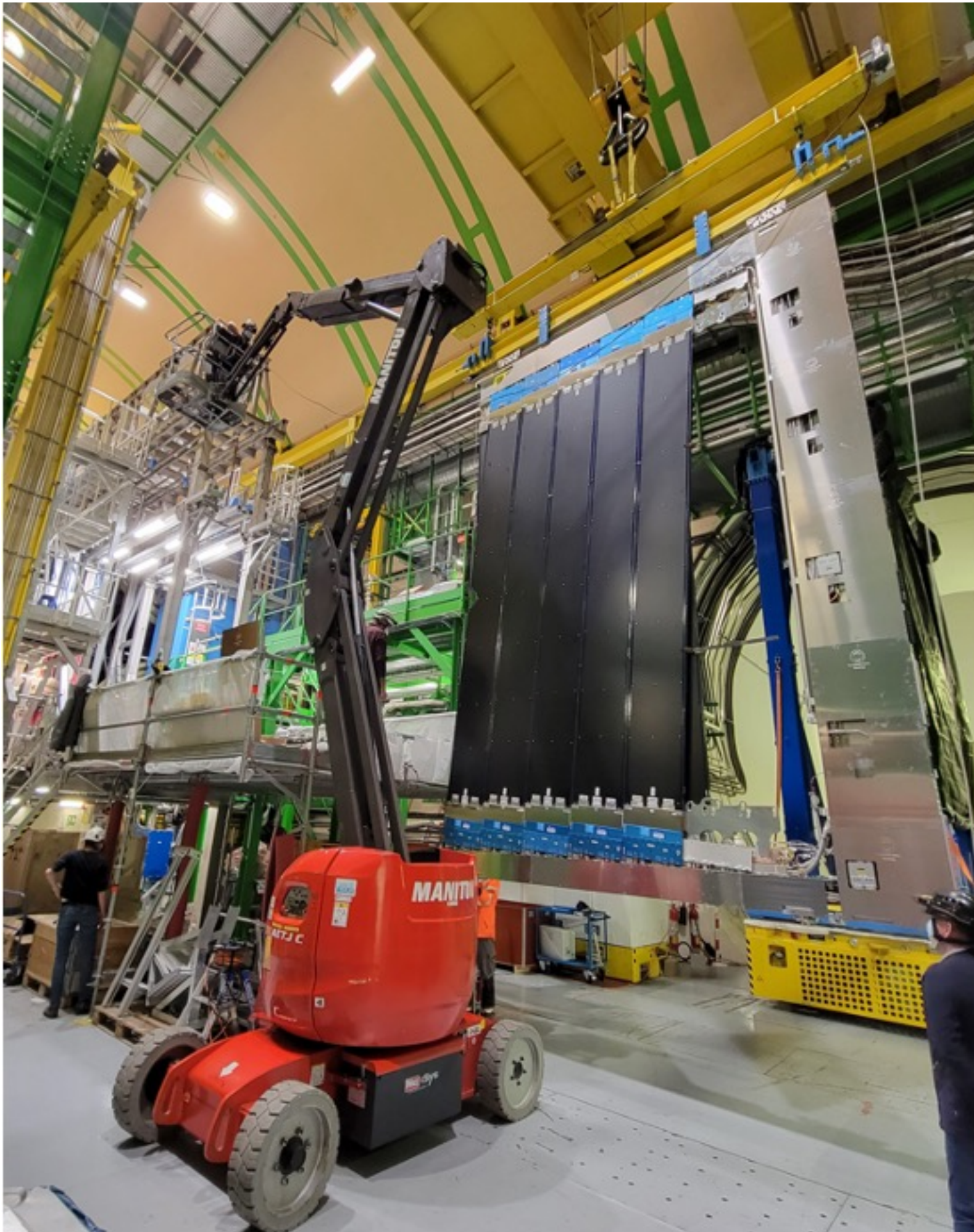
Empty SciFi assembly slots at Point 8

# Installation

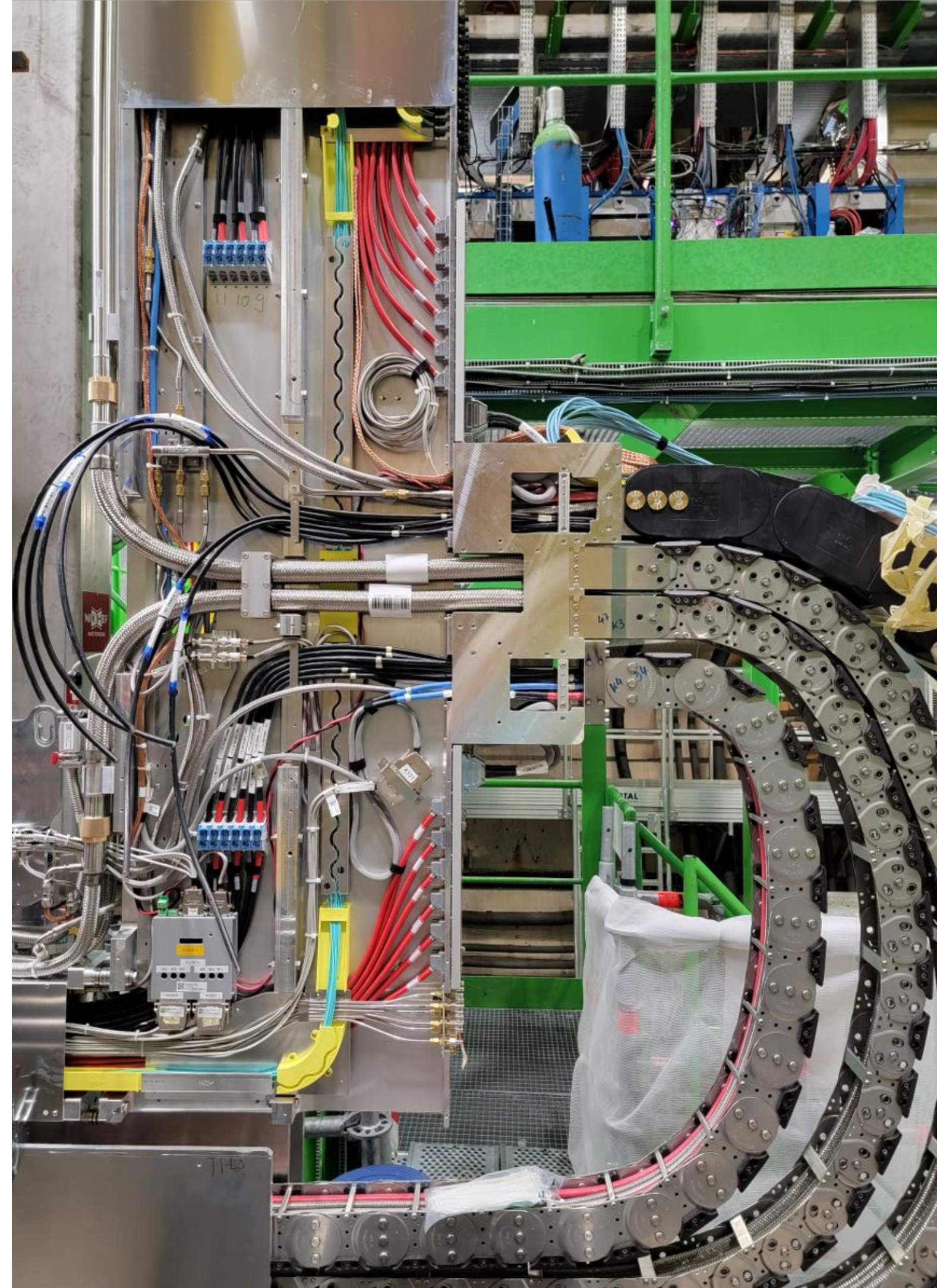
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# Transport & Installation



# Cable Chains



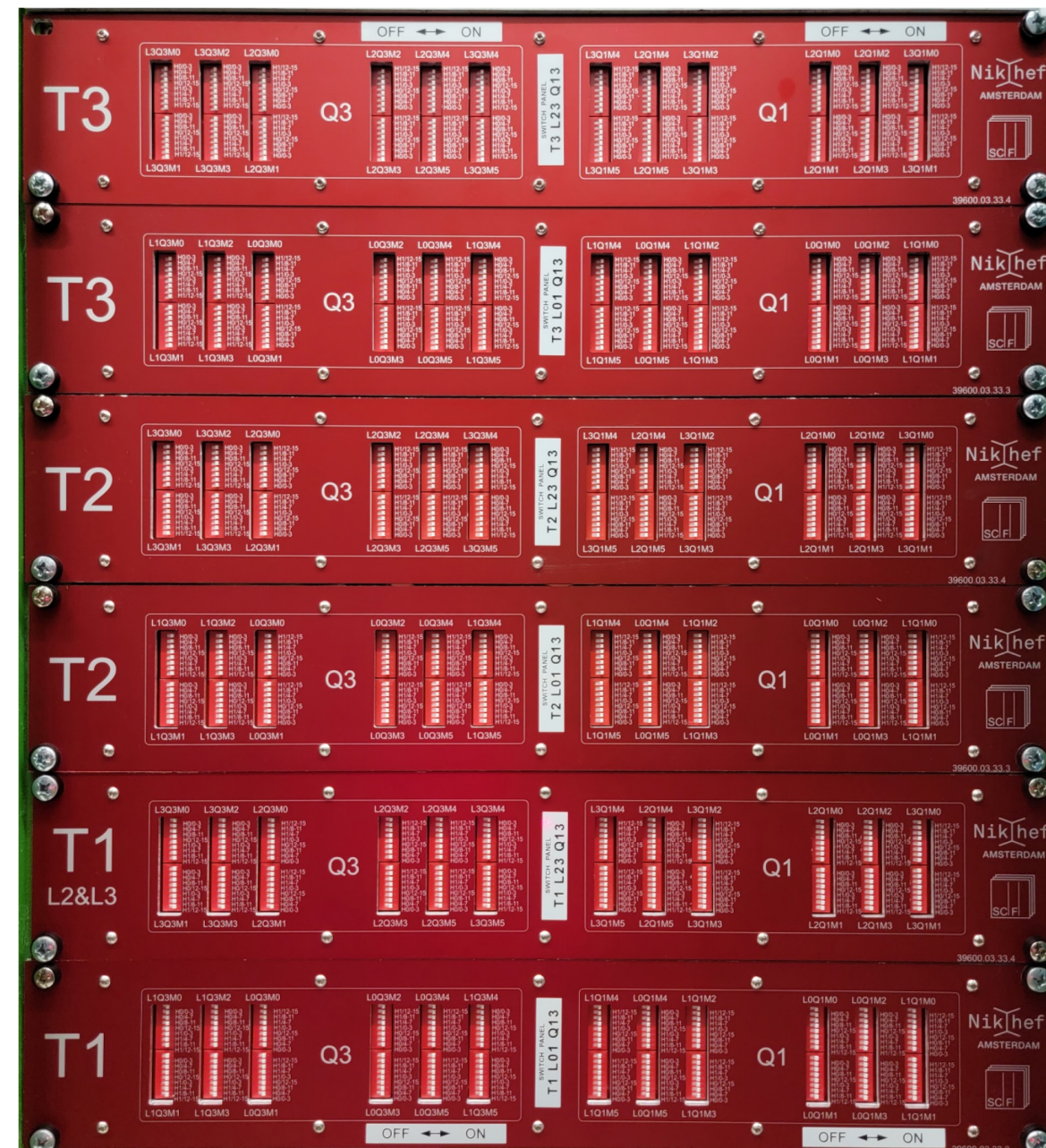
- C-Frames are moveable to allow maintenance
- Moveable cable chains to carry & protected all cables and pipes
  - HV & LV
  - Optical fibres
  - Cooling (water & cryo)
  - Dry gas
  - Grounding

# Services & Optical Fibres

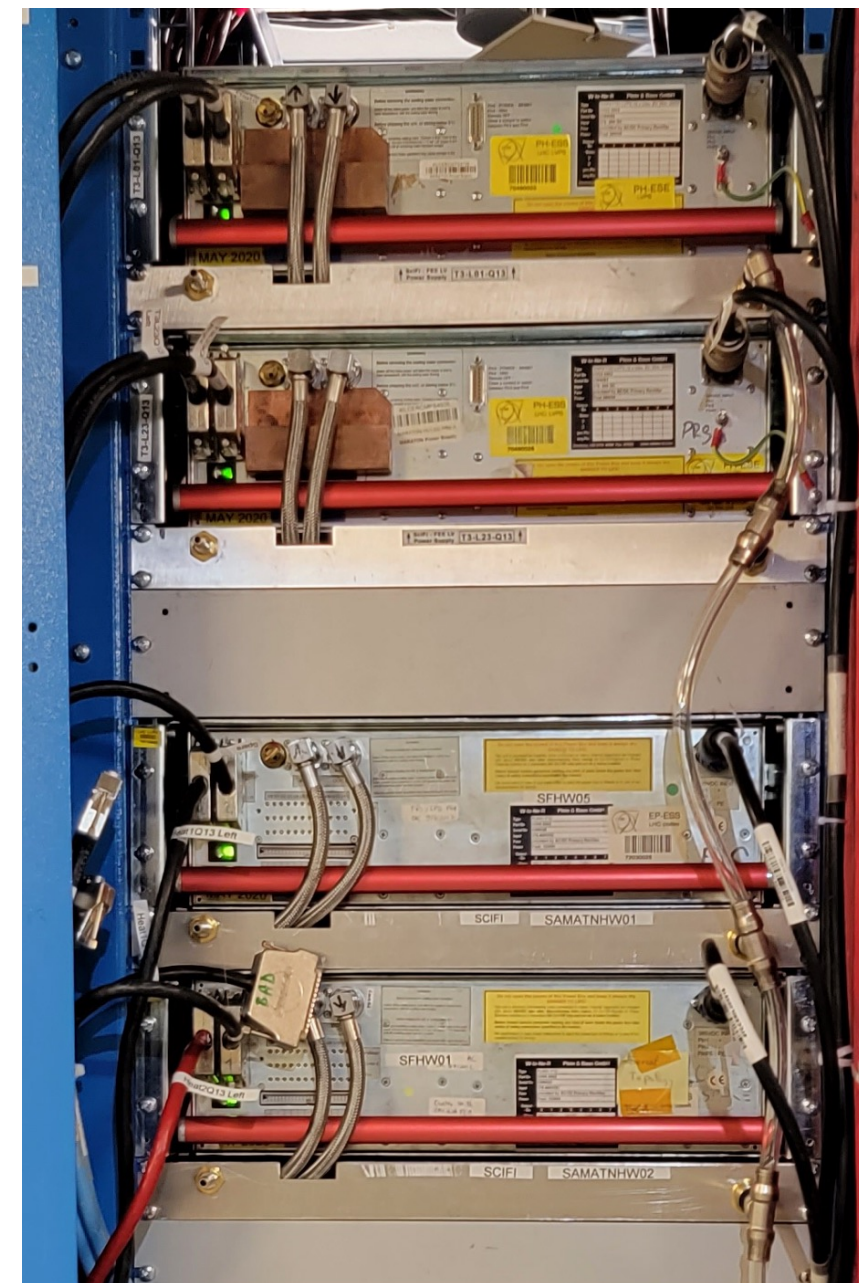
- Complex, large scale system of services & optical fibres
  - LV & HV power supplies
  - Water & cryo cooling plants
  - Condensation prevention
  - Long distance optical fibers



HV power supplies & patch panel



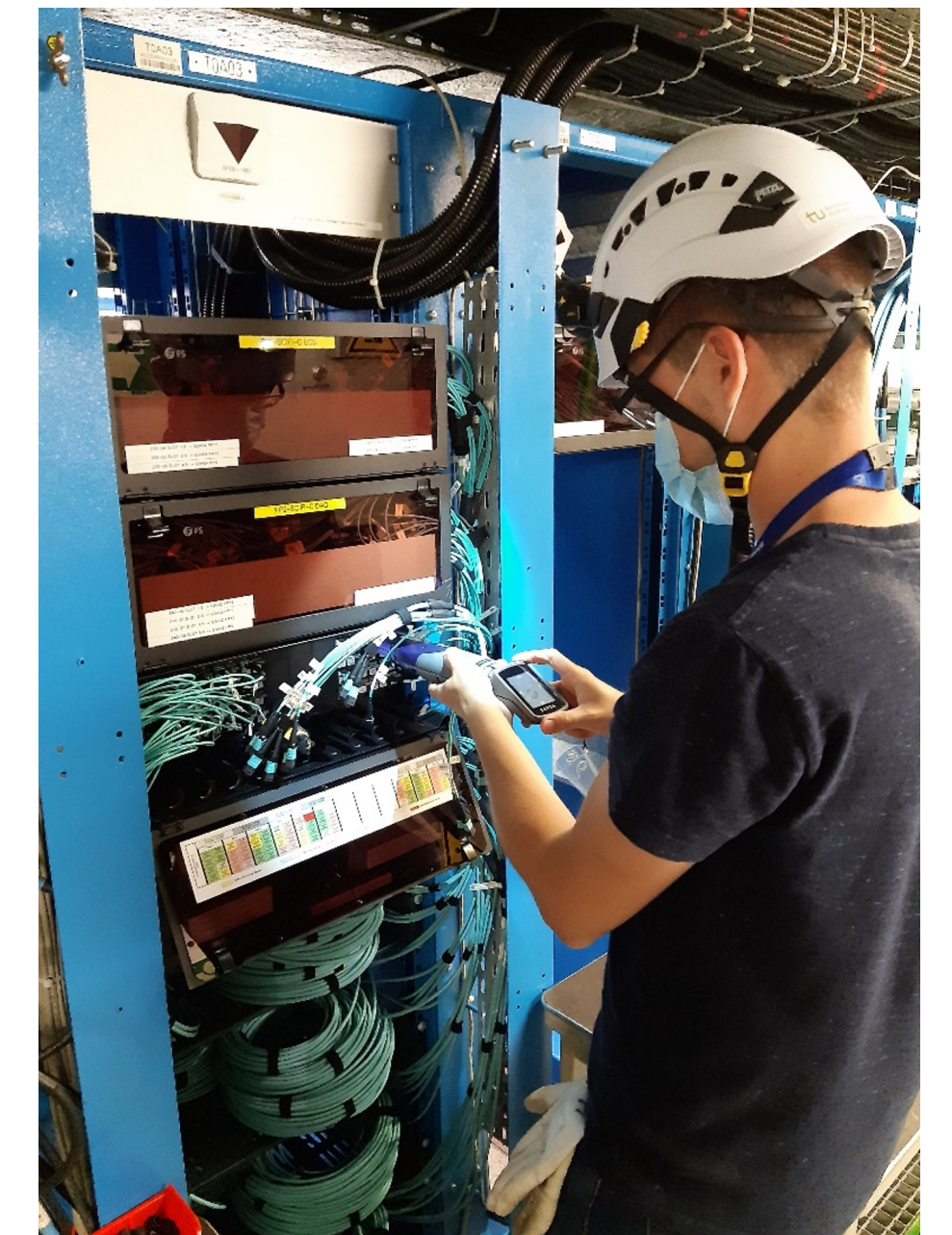
LV power supplies



Cryo manifold



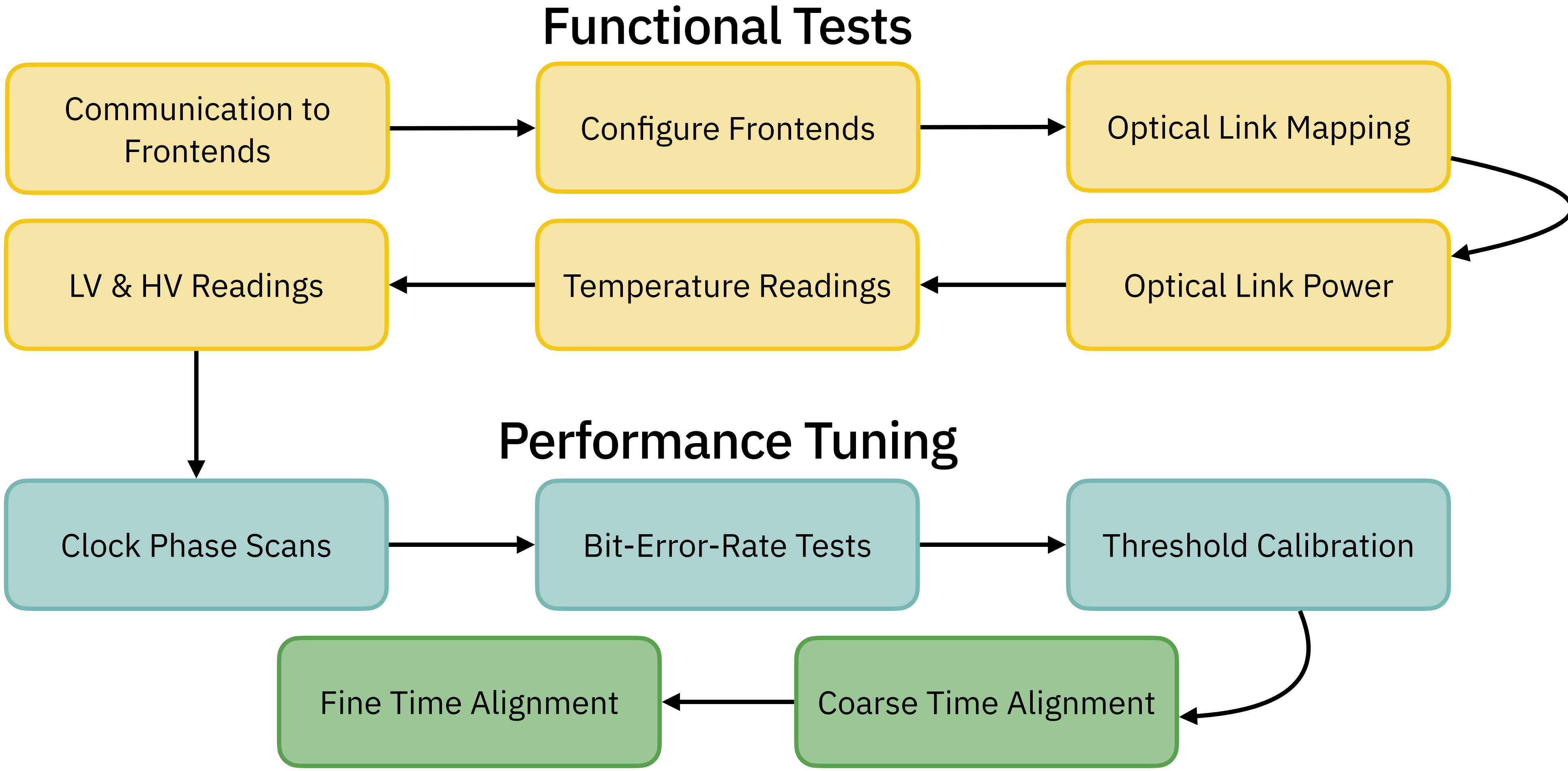
Fibre patch panel



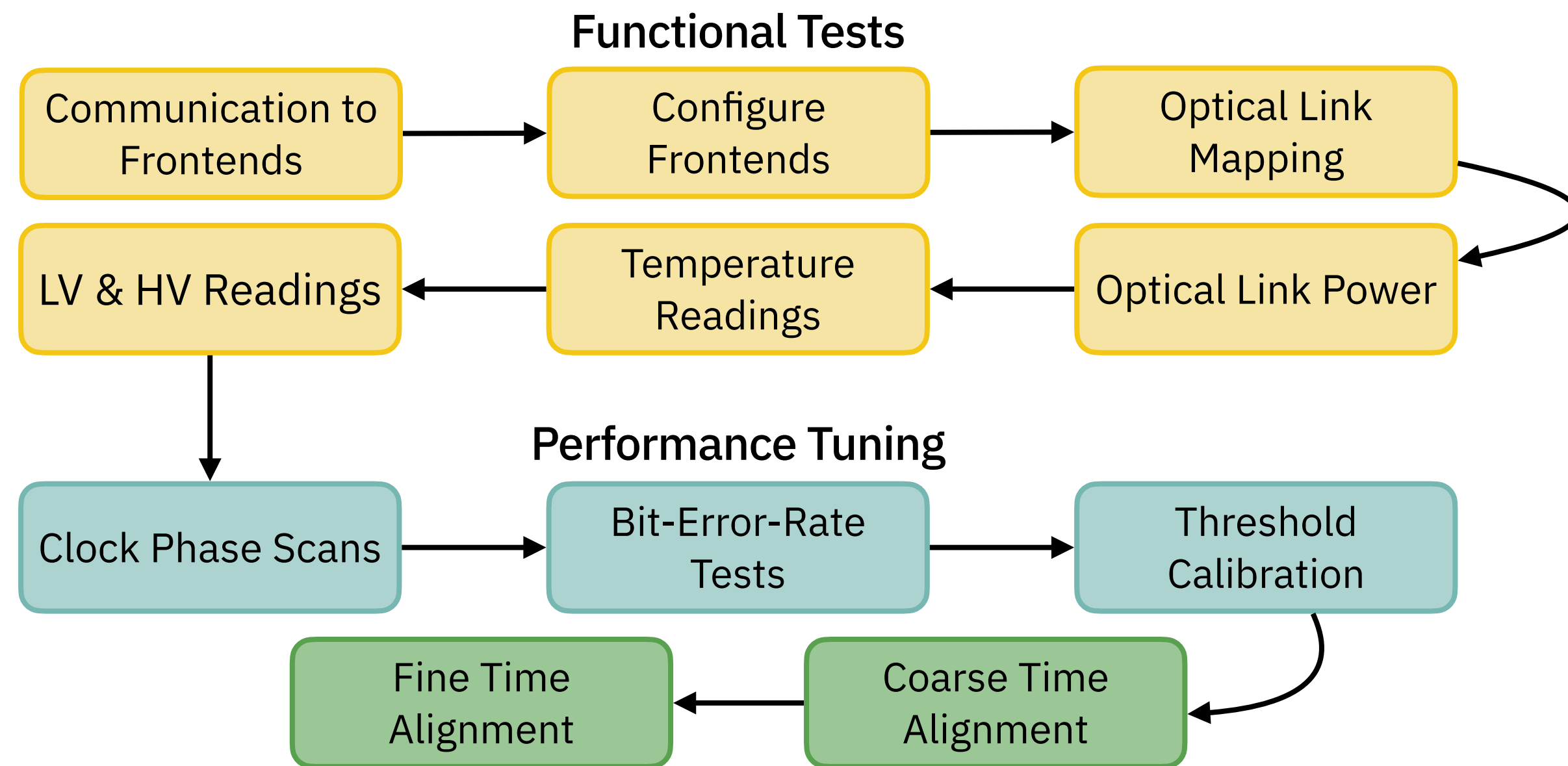
# Commissioning

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# Commissioning



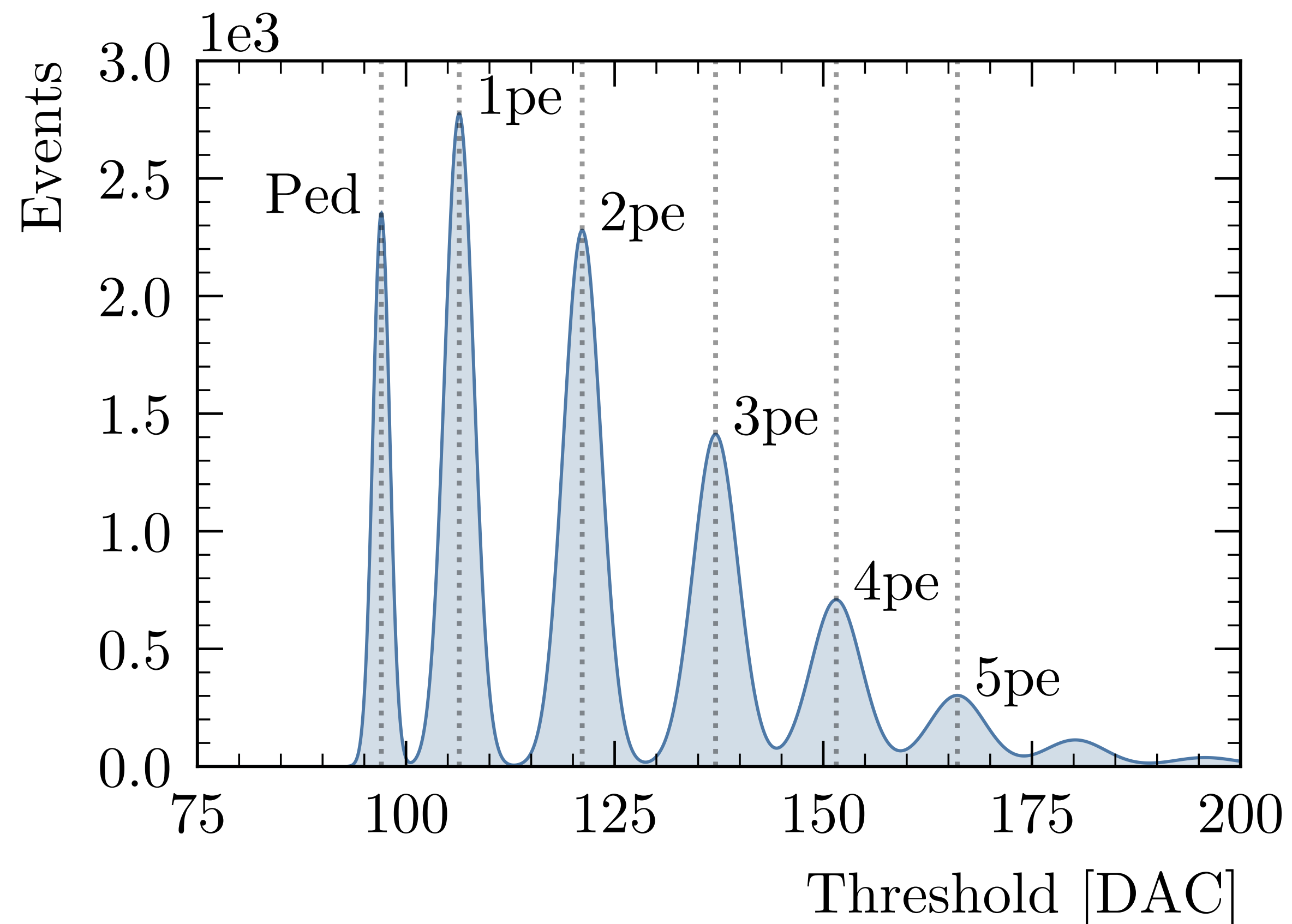
# Commissioning



- Successfully repeated all functional tests for the whole detector
- Performance tuning ongoing
- Requires all parts of the data chain to be operational (electronics, DAQ, controls, reconstruction)
- Parallel commissioning of detector hardware, DAQ system, and software

# Threshold Calibration

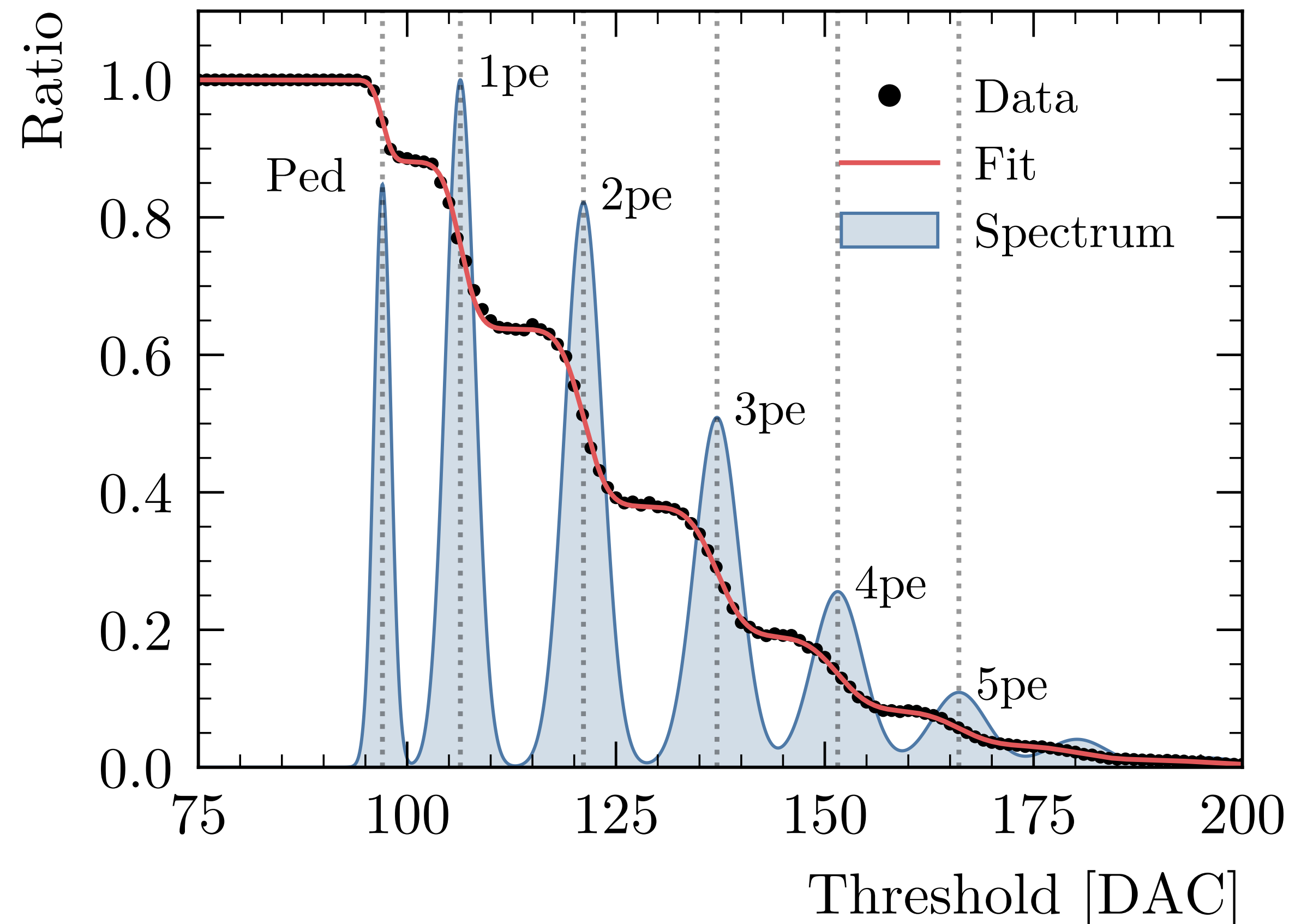
- Convert PACIFIC comparator threshold from digital values (DAC) to photoelectrons (pe)
- Measure SiPM pulse height spectrum
- Threshold Scan (S-Curve)
  - Sweep comparator threshold
  - Shine pulsed light on the SiPMs
  - Collect  $N$  events & count events over threshold



SiPM pulse height spectrum

# Threshold Calibration

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  - Sweep comparator threshold
  - Shine pulsed light on the SiPMs
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Threshold scan & SiPM pulse height spectrum. Data from C-Frame commissioning



# Threshold Scans

- Requires every part in the data chain to work together
  - Control & DAQ system
  - Frontend electronics
  - Backend electronics
  - Online data processing
  - Offline data analysis

The screenshot displays the SciFi Experiment Control System interface for the SFC (SciFi Control Framework) system. The main window title is "SFC: TOP". The system status is "READY". The interface is divided into several sections:

- System Status:** A table showing the status of various sub-systems.
- Run Info:** A section containing run parameters and configuration options.
- Input Rate, Output Rate, and Dead Time:** Three gauges showing the current rates.
- Data Destination and File:** Fields for specifying where data is stored and the file name.

Sub-System	State
SFC_HV	READY
SFC_DCS	READY
SFC_DAQ	READY
SFC_RunInfo	READY
SFC_TFC	READY
SFC_EB	READY
SFC_Monitoring	NOT_ALLOCATED

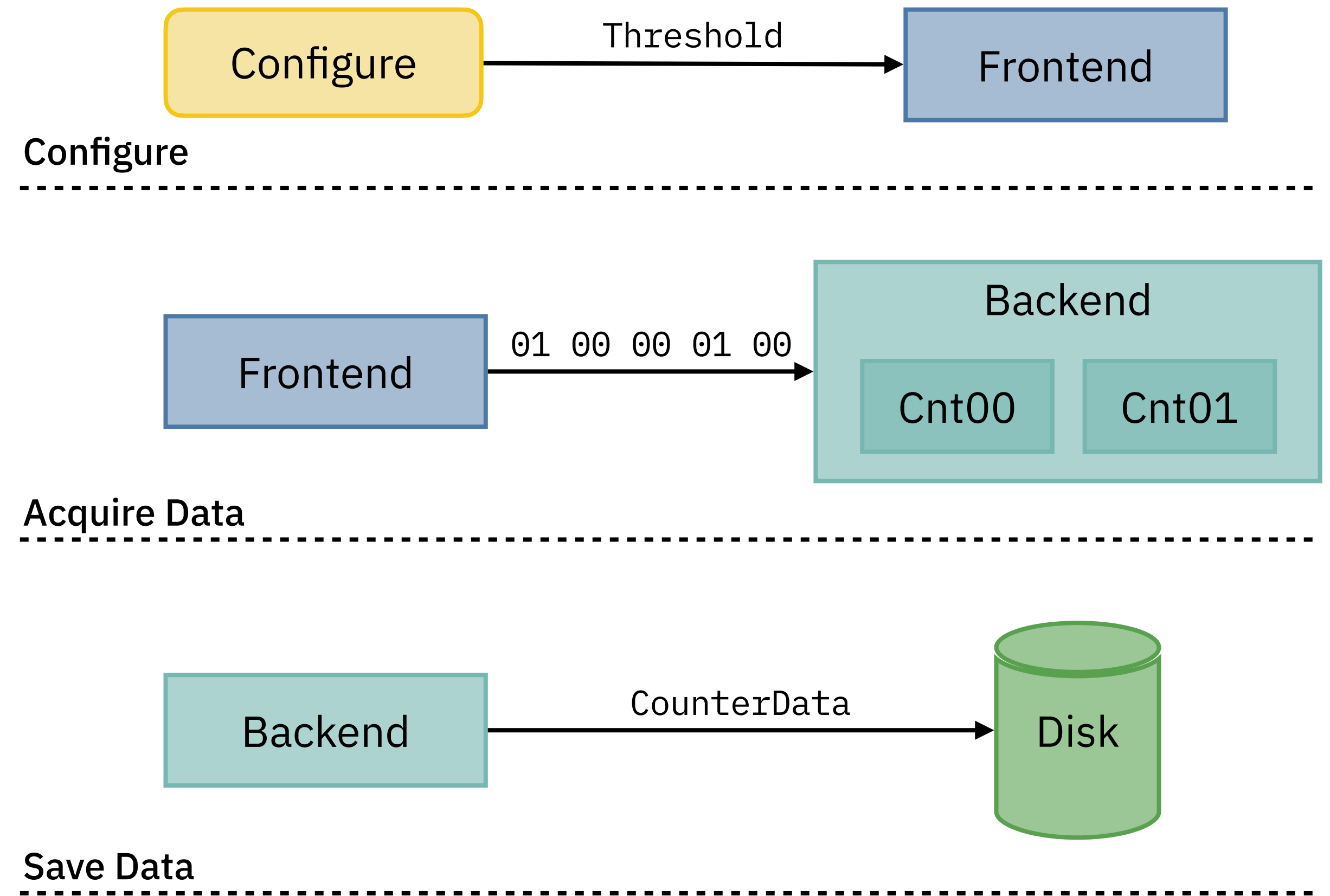
**Run Info:**

- Run Number: 242217
- Run Start Time: 10-Aug-2022 12:21:54
- Run Duration: 005:55:01
- Nr. Events: 99'970'769
- Step Nr: 769, To Go: 0
- Activity: LIS\_TH\_SCAN
- Trigger Config: PassThrough
- Time Alignment:  TAE half window 0
- Max Nr. Events:  Run limited to 130001 Events
- Automated Run with Steps:  Step Run with 768 Steps Start at 1
- Input Rate: 0.00 kHz
- Output Rate: 0.00 kHz
- Dead Time: 0.00 %
- Data Destination: Local
- Data Type: -
- File: /hit2/objects/SFC/0000242217

SciFi Experiment Control System

# Threshold Scans

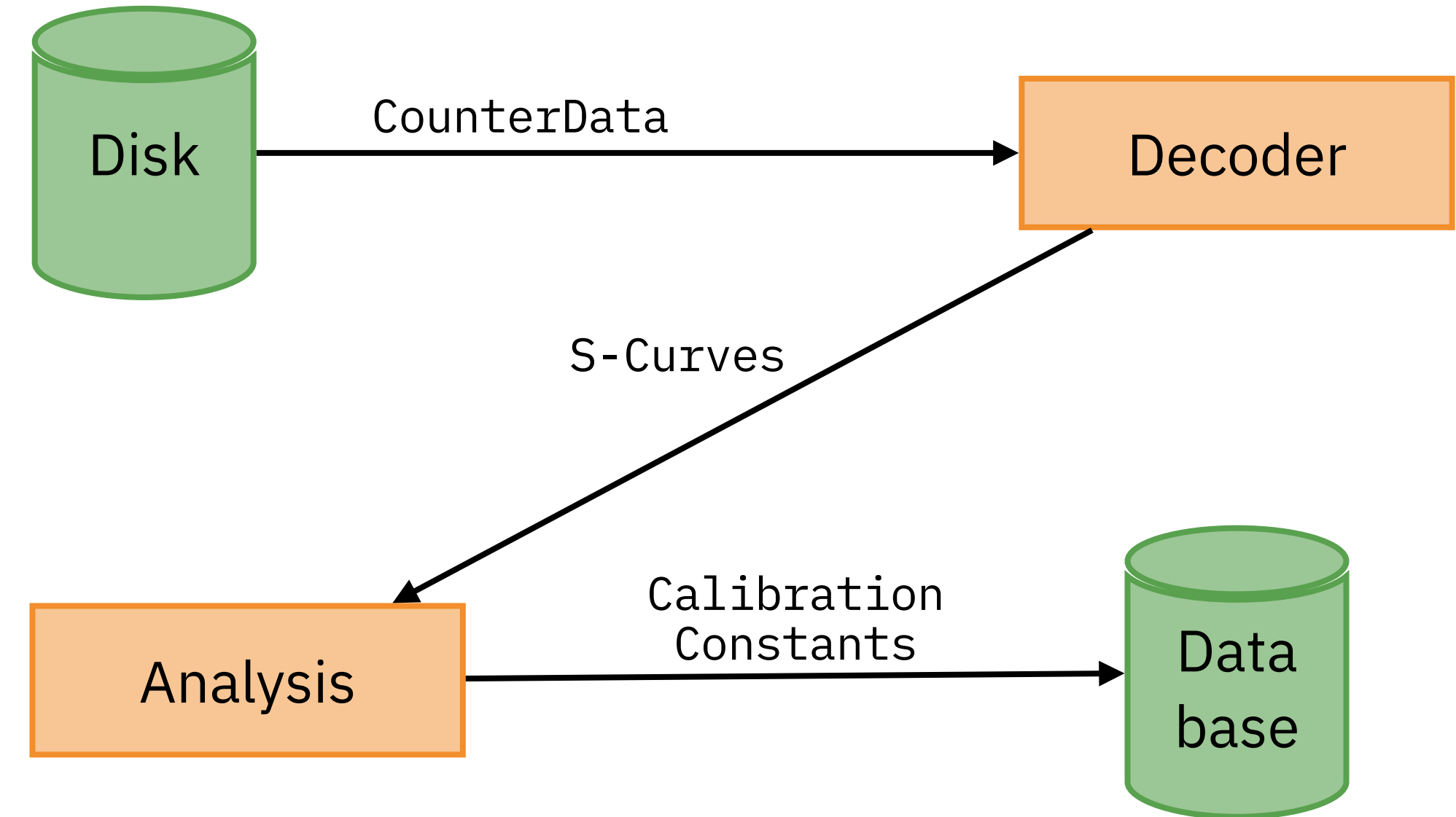
- Requires every part in the data chain to work together
  - Control & DAQ system
  - Frontend electronics
  - Backend electronics
  - Online data processing
  - Offline data analysis



Sequence of one step in the threshold scan

# Threshold Scans

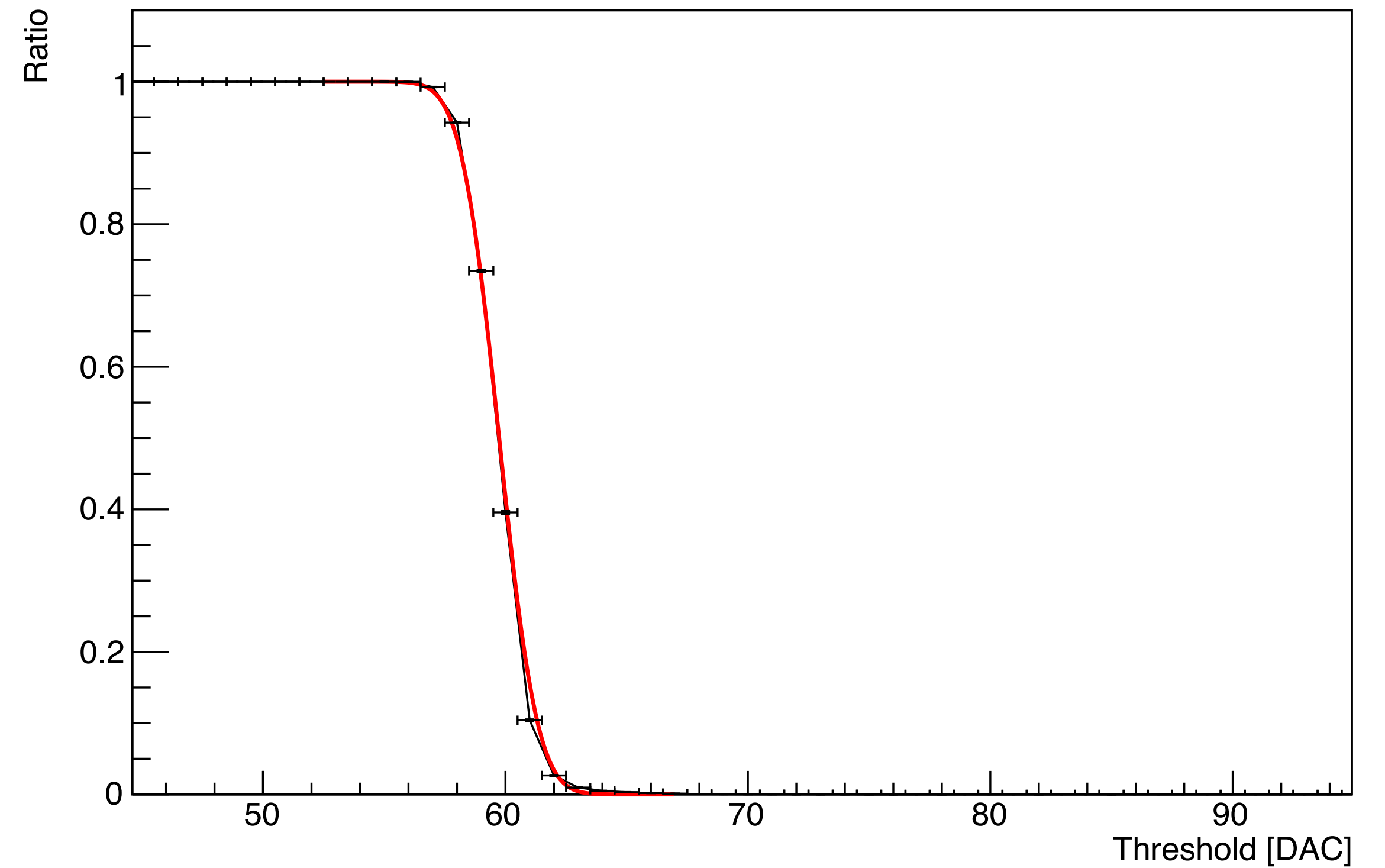
- Requires every part in the data chain to work together
  - Control & DAQ system
  - Frontend electronics
  - Backend electronics
  - Online data processing
  - Offline data analysis



Analysis of threshold scan data

# Threshold Scans

- Requires every part in the data chain to work together
  - Control & DAQ system
  - Frontend electronics
  - Backend electronics
  - Online data processing
  - Offline data analysis
- Performed first threshold scans without light injection for the whole detector
- Used the determined pedestal to update the calibration constants



Threshold scan without light injection and calibration fit

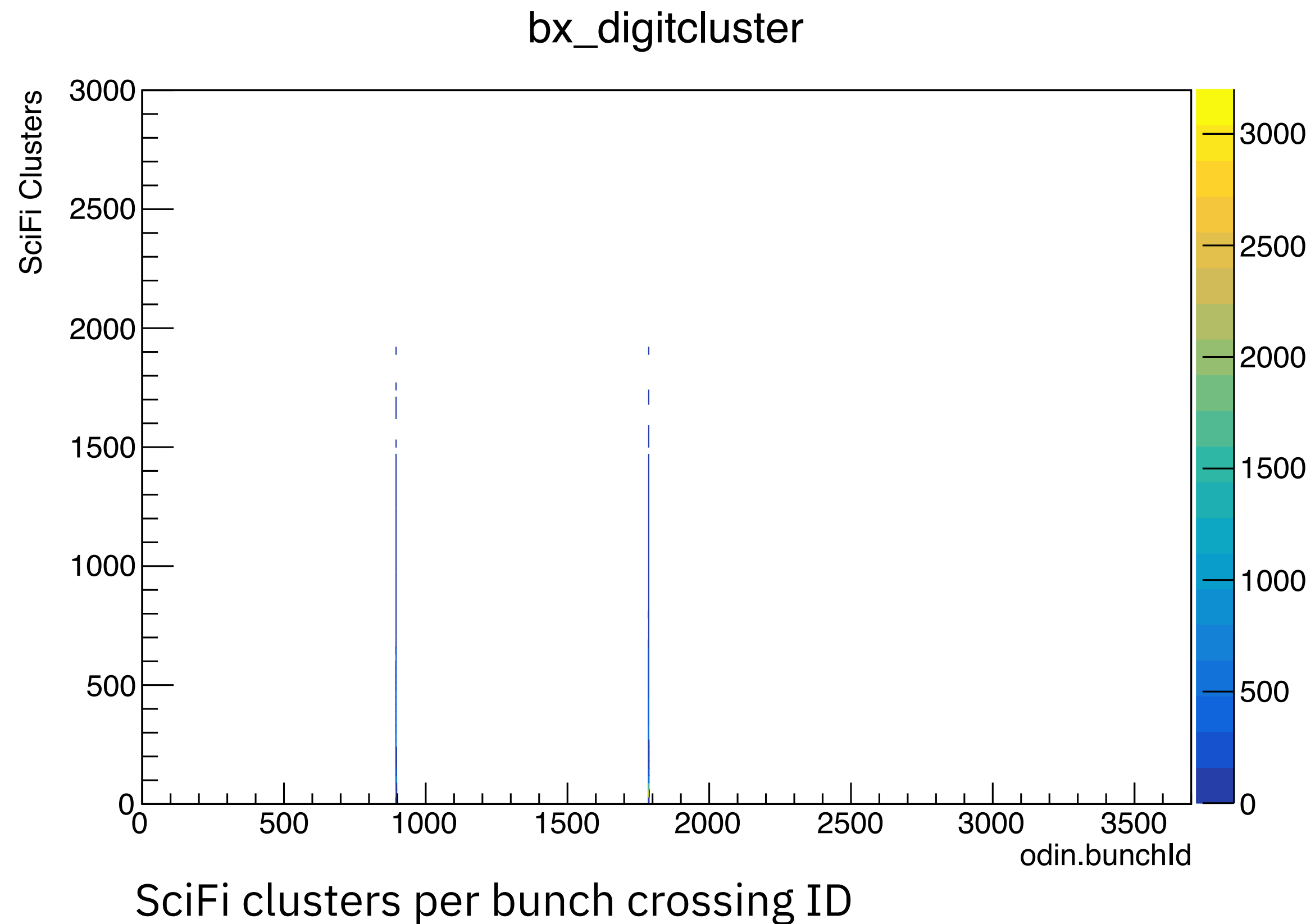
# Start of LHC Run 3



LHCb control room during the start of LHC Run 3

- Start of LHC Run 3 on 05.07.2022
  - First collisions since 3.5 years
  - Record energy of 13.6 TeV
- CERN hosted a livestream for the event
  - [Recording on YouTube](#)

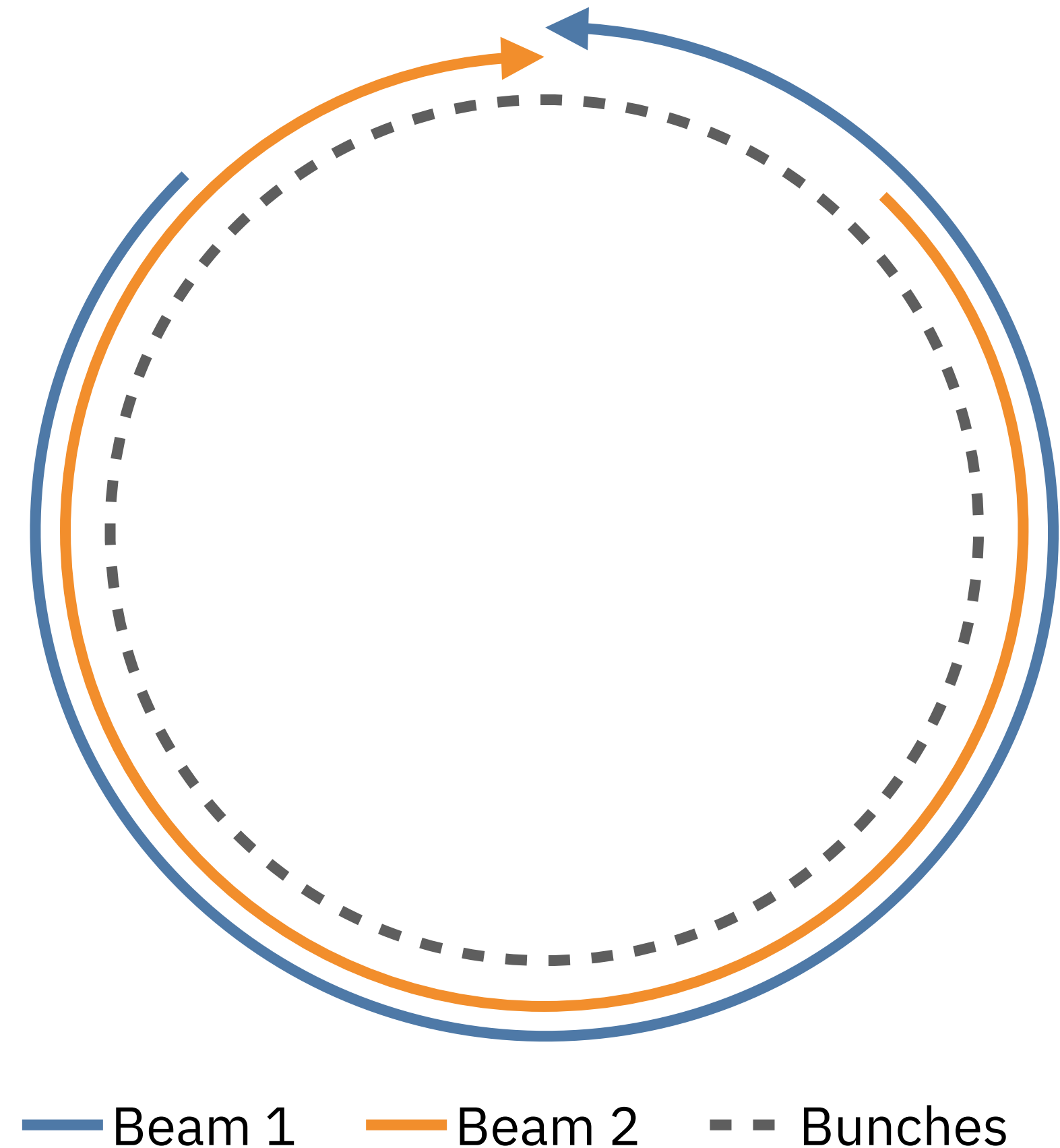
# First Collisions



- Two bunches colliding at LHCb during start of LHC Run 3
- First clusters from collisions seen by the SciFi Tracker

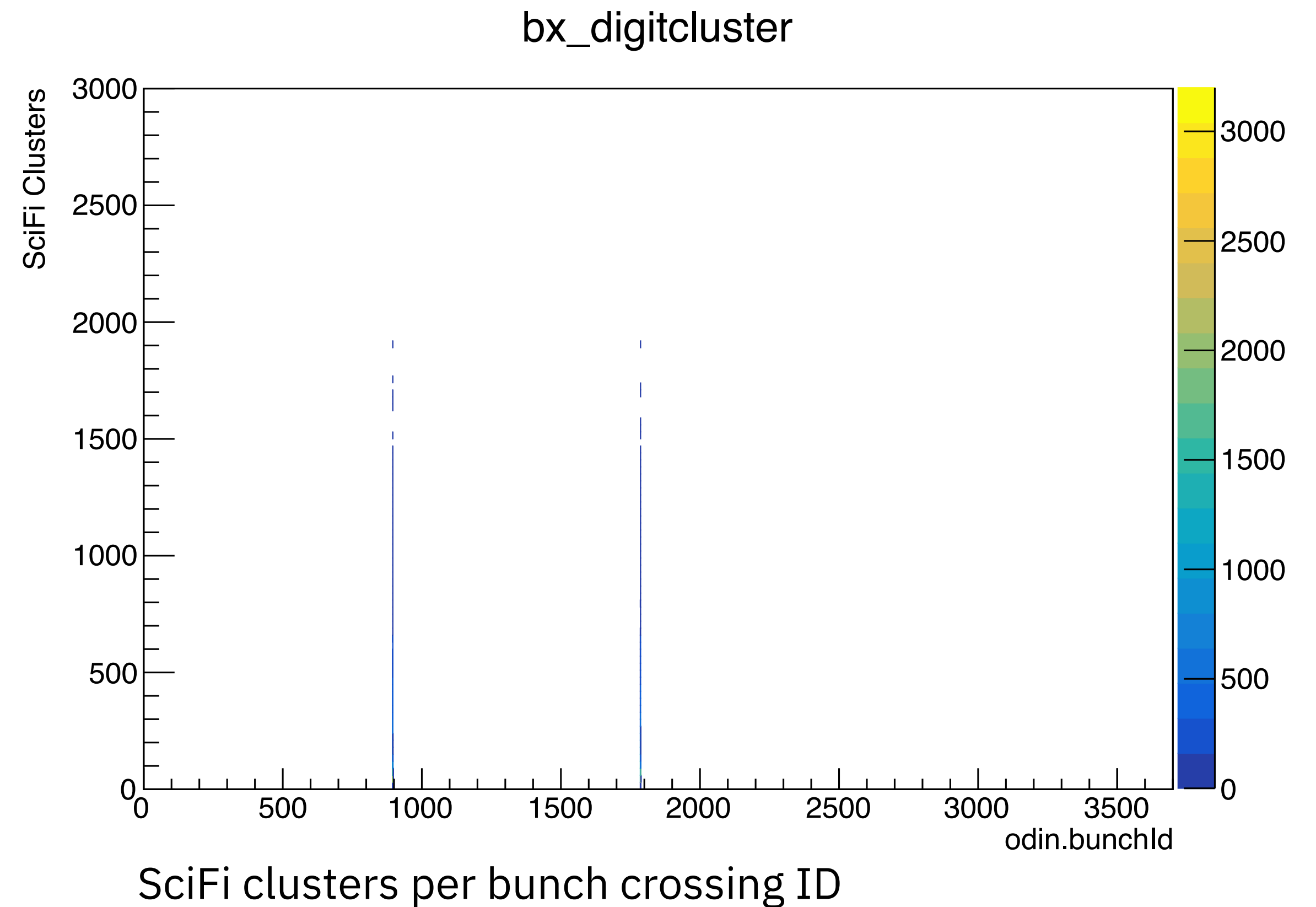
# Time Alignment

- Align the signal in the SciFi to the rest of LHCb & the LHC beam collisions
  - One LHC orbit contains 3564 25ns bunch spacings
1. **Coarse Time Alignment:** Shift in bunch crossings ( $n \times 25$  ns)
  2. **Fine Time Alignment:** Adjustments within one bunch crossing



# Coarse Time Alignment

1. Find the offset in bunch crossing ID between SciFi and the LHC
  - Record isolated collision using random triggers
  - Determine difference between SciFi & LHC bunch ID

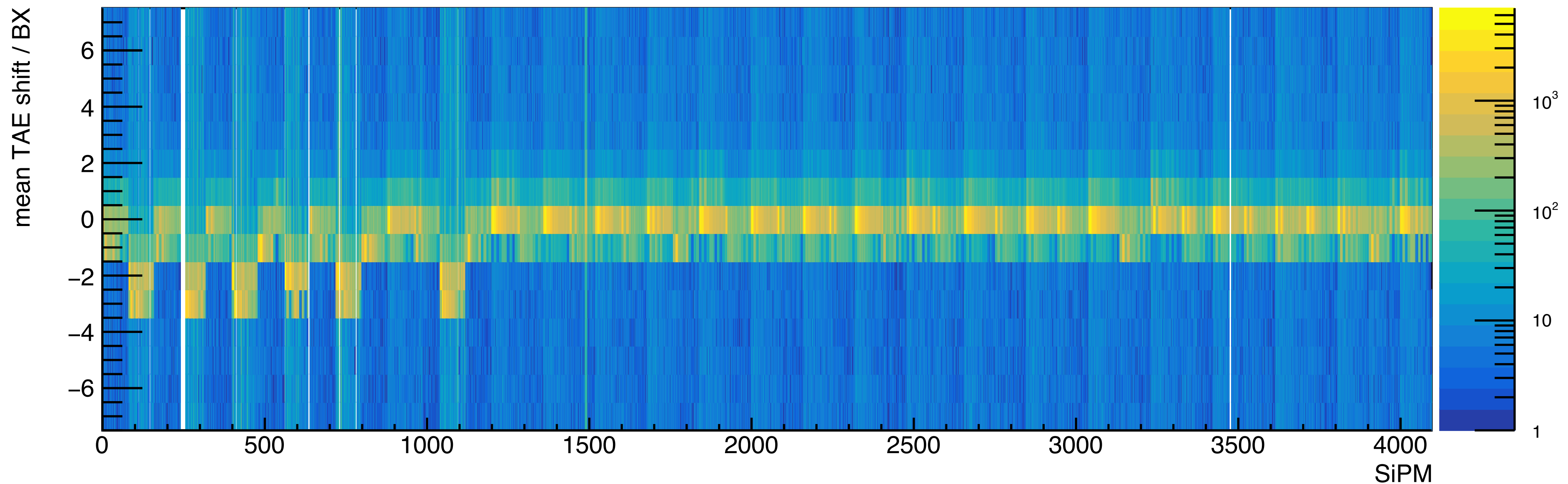




# Coarse Time Alignment

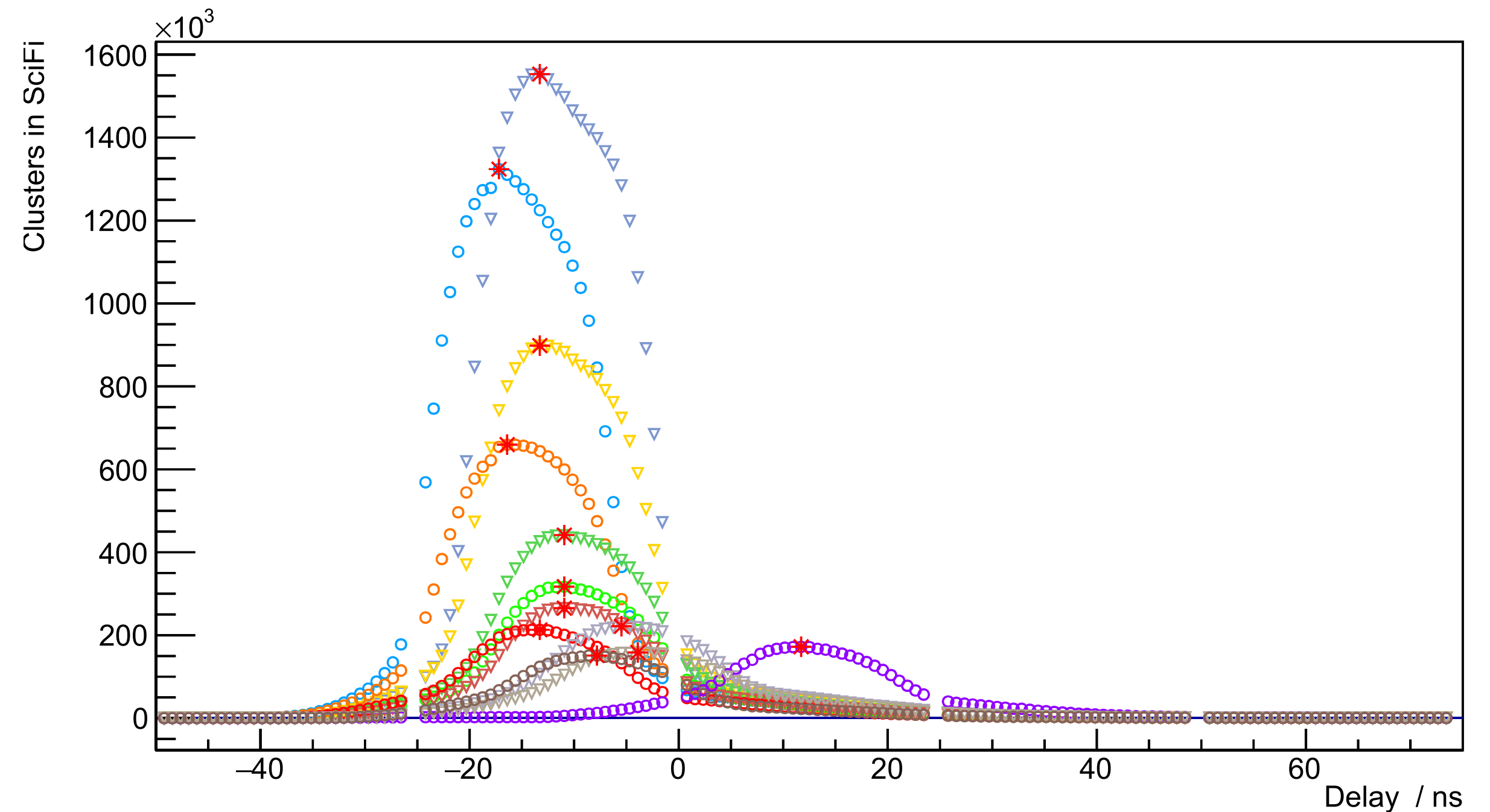
## 2. Synchronise frontend electronics to one bunch crossing

- Record data for isolated collision +/-  $N$  bunch crossings (time-aligned-events, TAE)
- Calculate mean TAE ID per data link (should be at zero)



# Fine Time Alignment

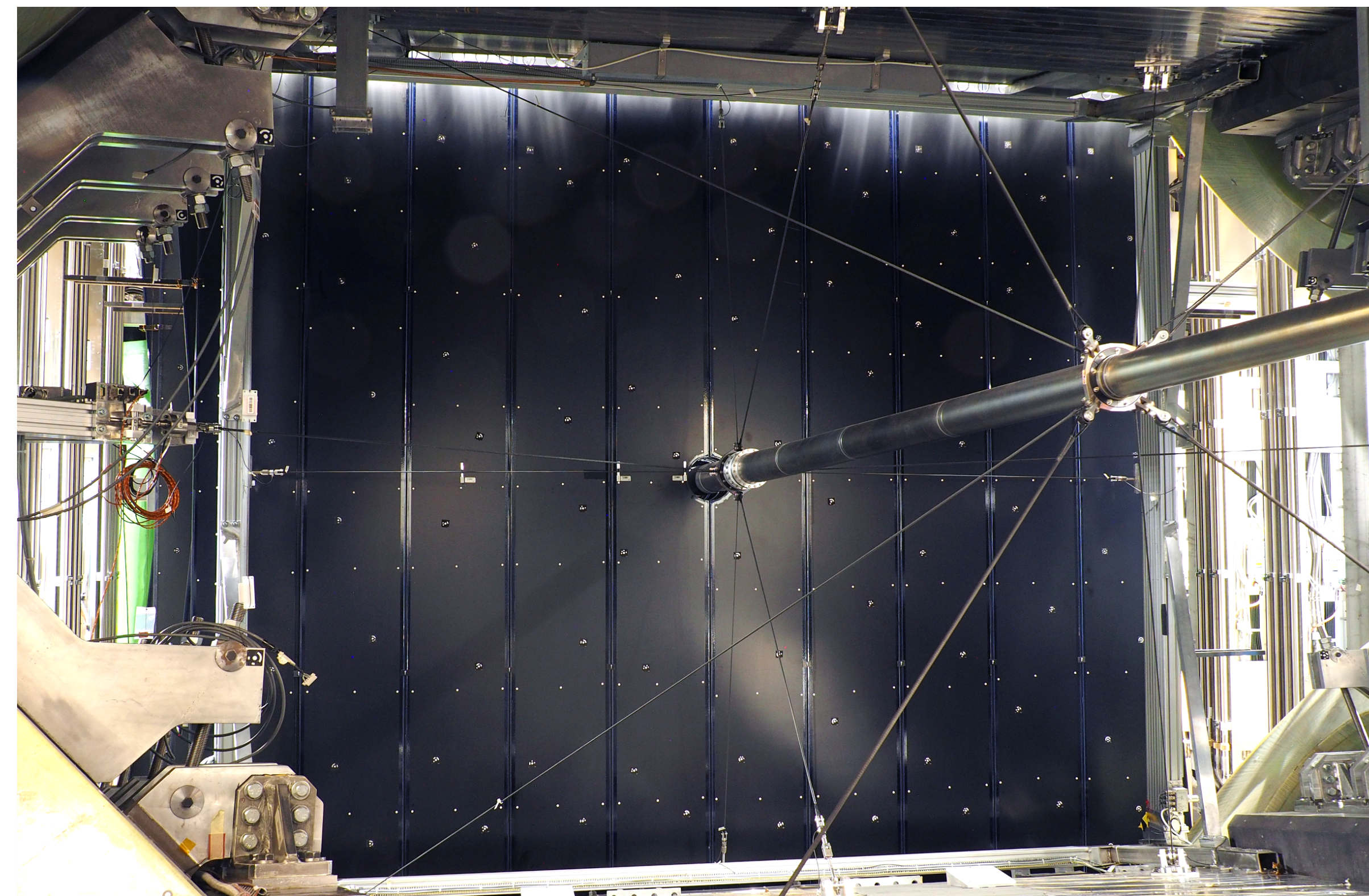
- Signal arrival time varies across the detector
  - Length of scintillating fibres
  - Time-of-flight of particles
- Need to align PACIFIC sampling with beam collisions for optimal efficiency
- Sweep the phase of the MasterGBT clock & record data



Beam timing scan for six SciFi modules

# Summary

- The LHCb SciFi Tracker is the largest scintillating fibre tracker
  - 340 m<sup>2</sup> active area & 524,288 channels
- Successfully assembled & installed all detector stations in the LHCb cavern
- Detector commissioning well advanced
  - First time alignment done
  - Updated calibration constants
  - Regularly taking data as part of LHCb
- First reconstructed tracks imminent



SciFi Tracker seen from the magnet

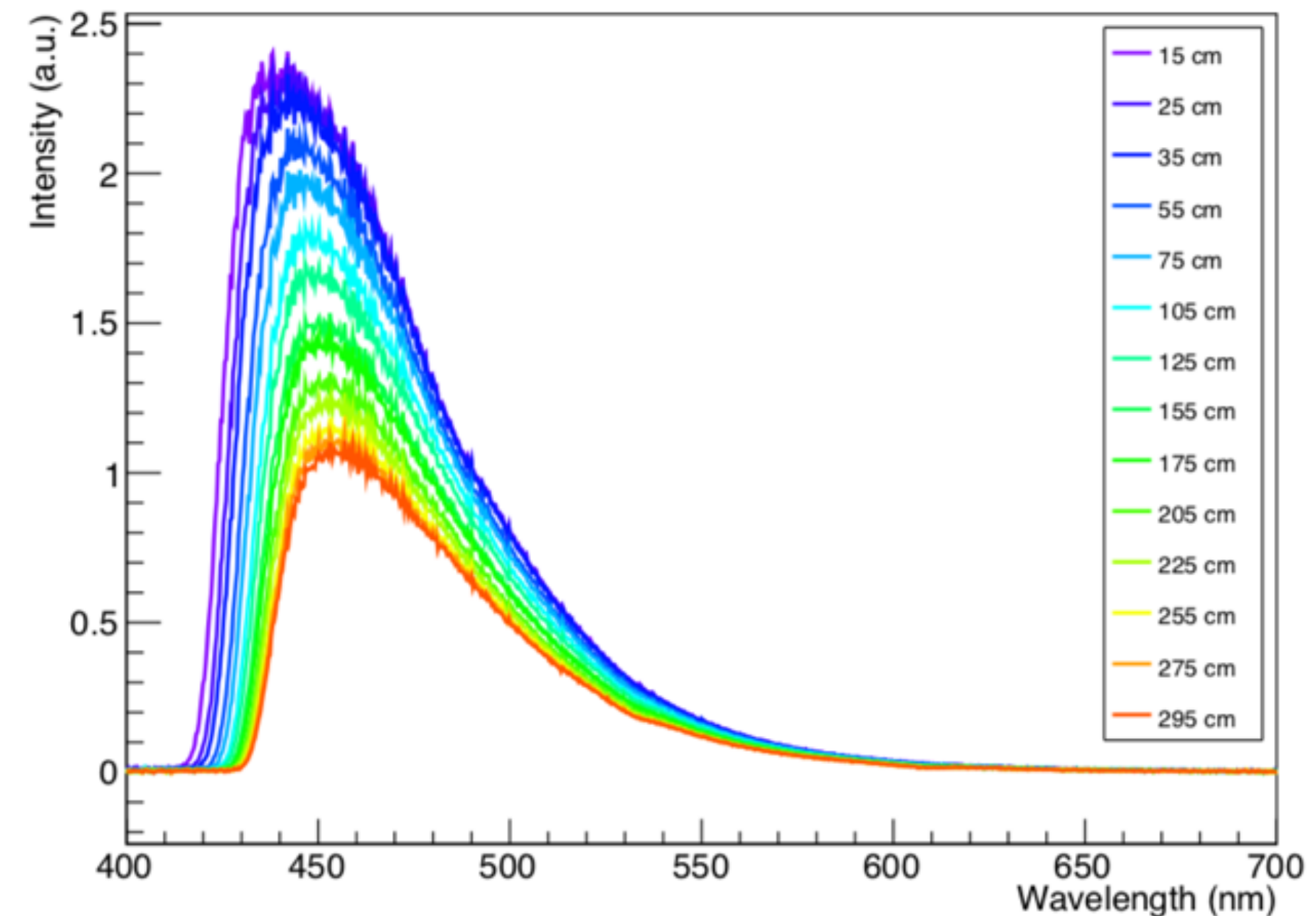
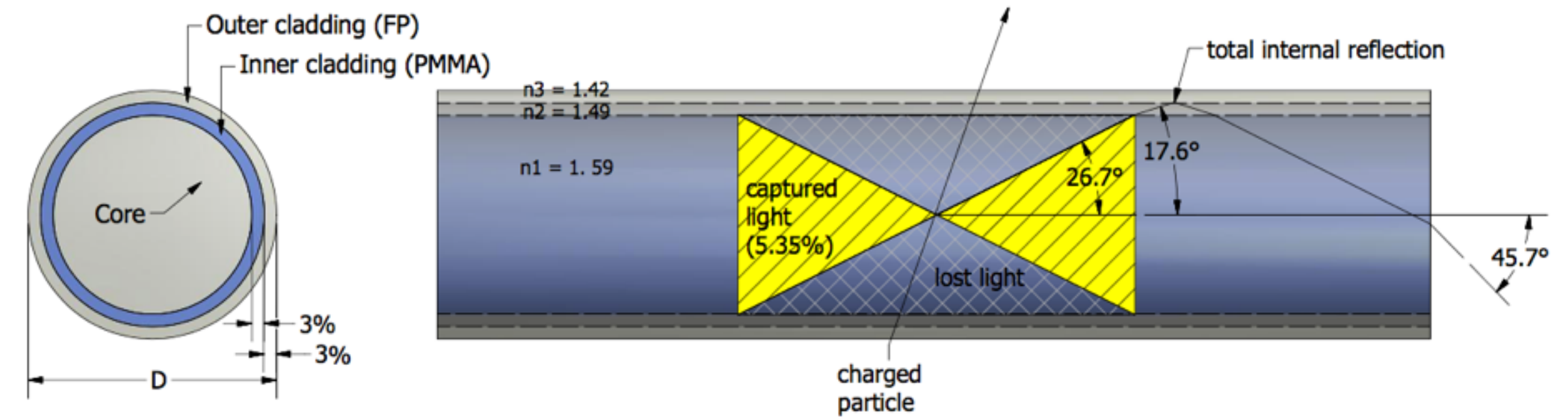


# Backup

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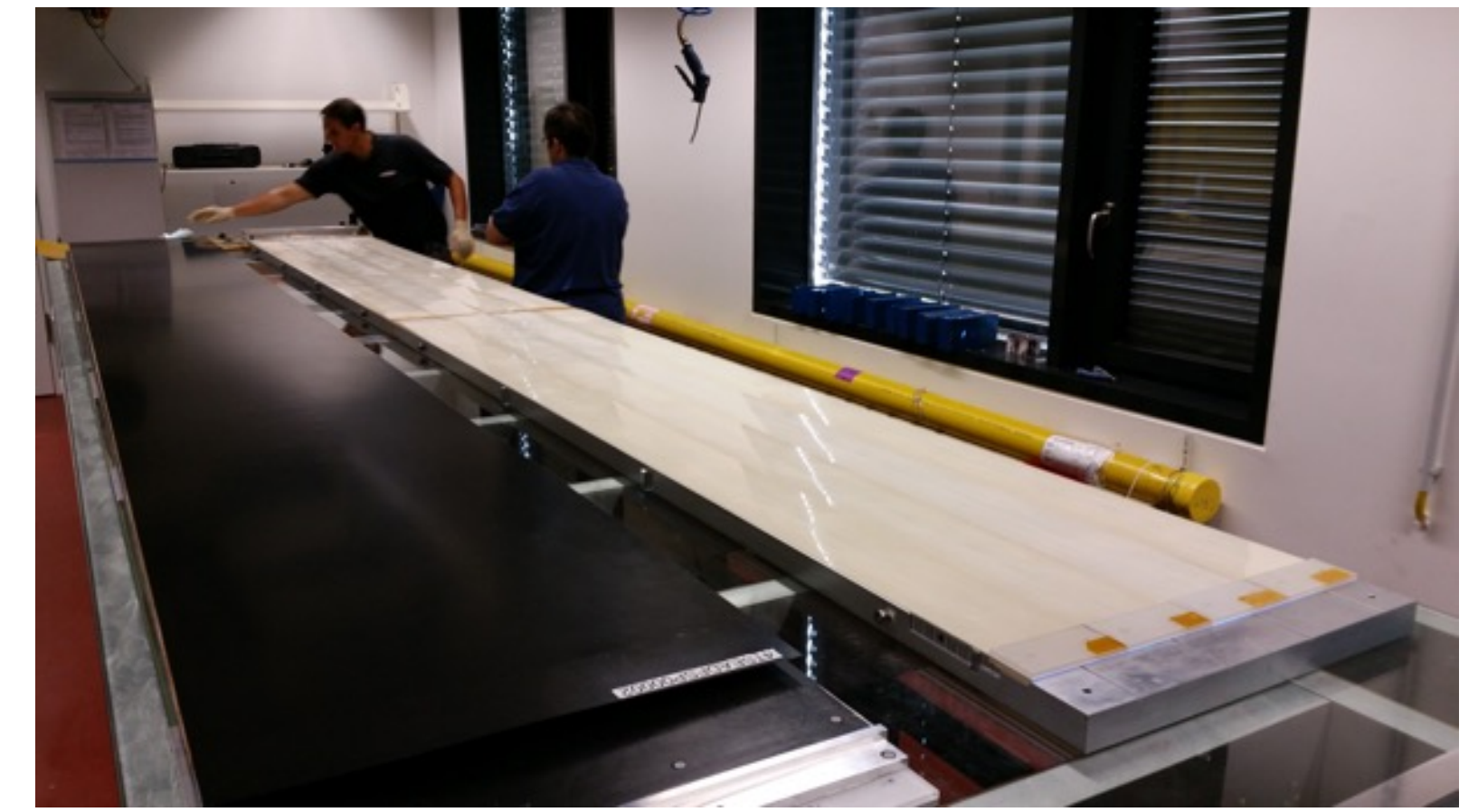
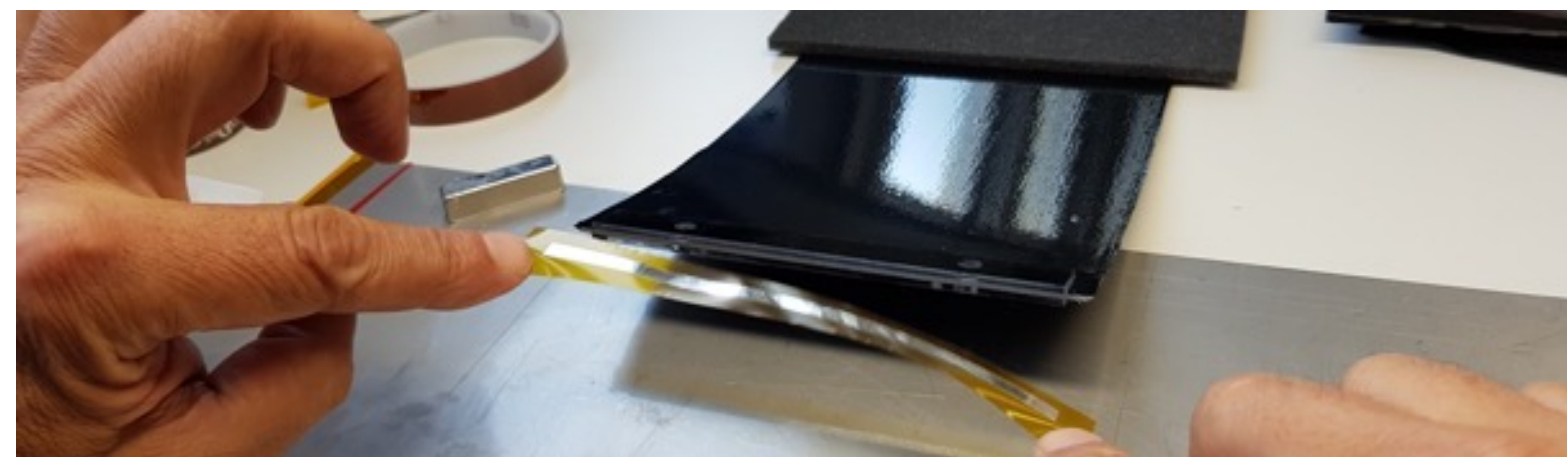
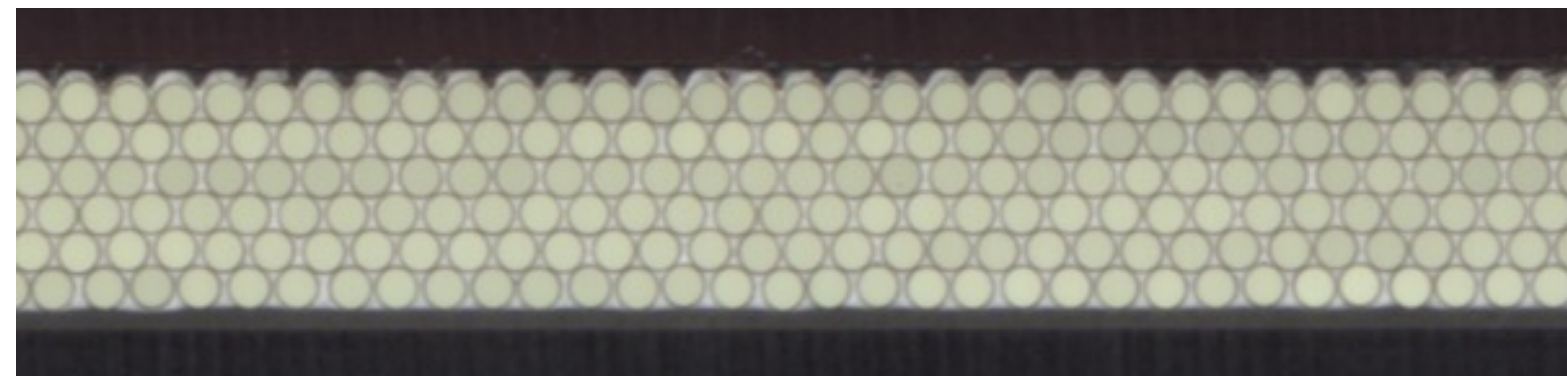
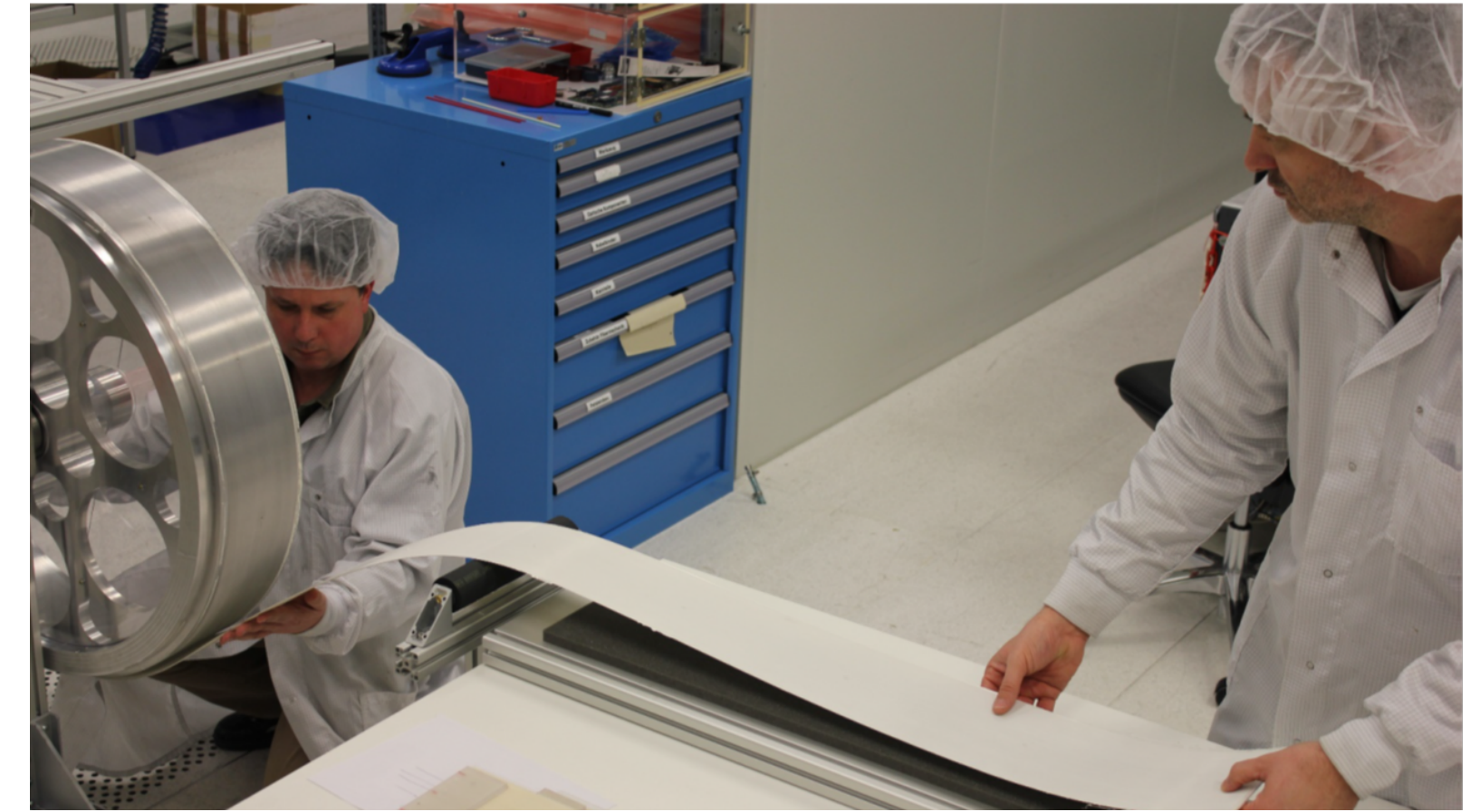
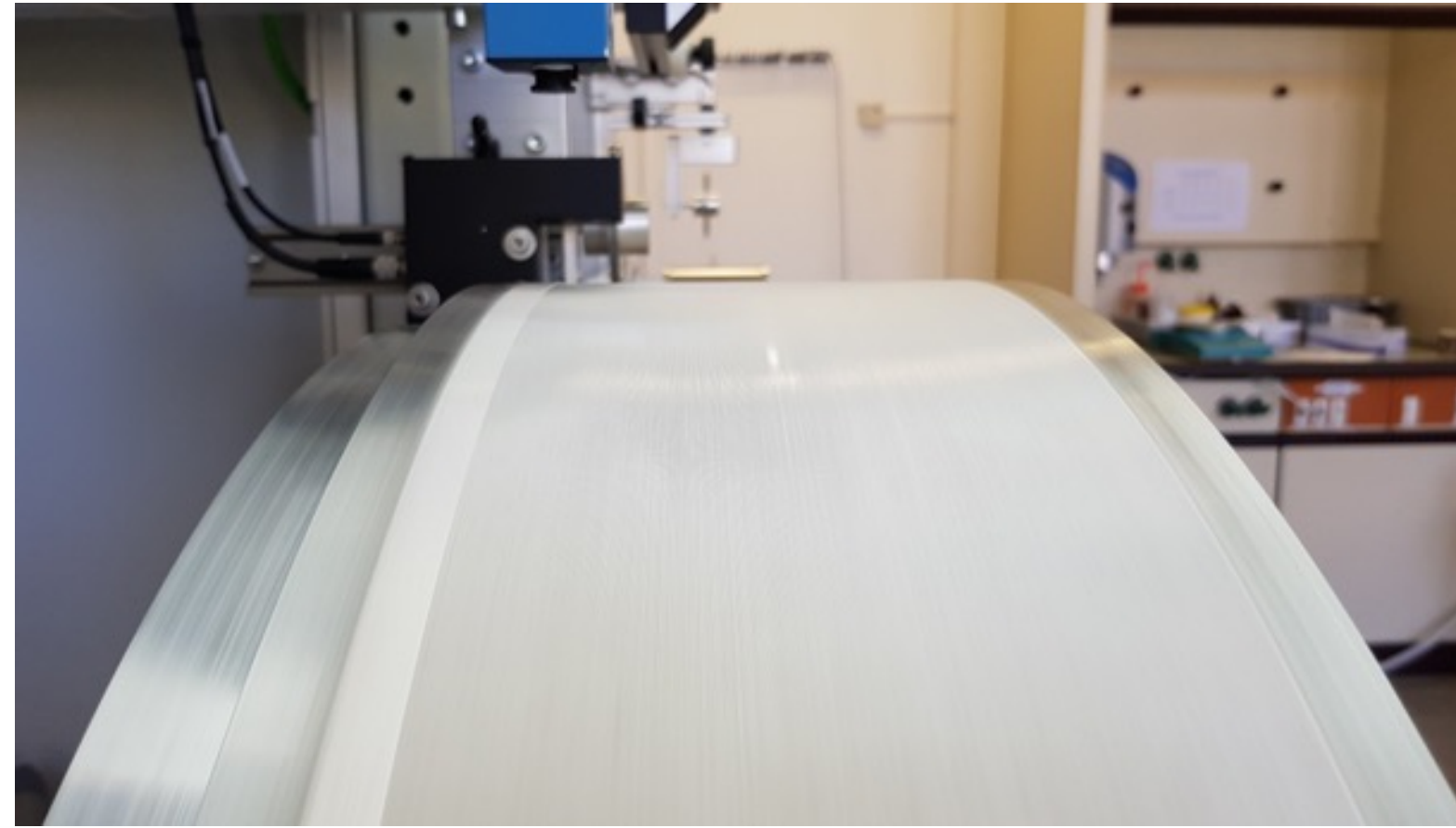
# Scintillating Fibres

- Kuraray SCSF-78MJ
  - Polystyrene Base
  - Double cladding (PMMA + FP)
  - PT primary dye
  - TPB wavelength shifter
- 250  $\mu\text{m}$  diameter
- Emission peak  $\sim 450$  nm
- Decay time  $\sim 2.8$  ns
- Attenuation length  $\sim 3.5$  m

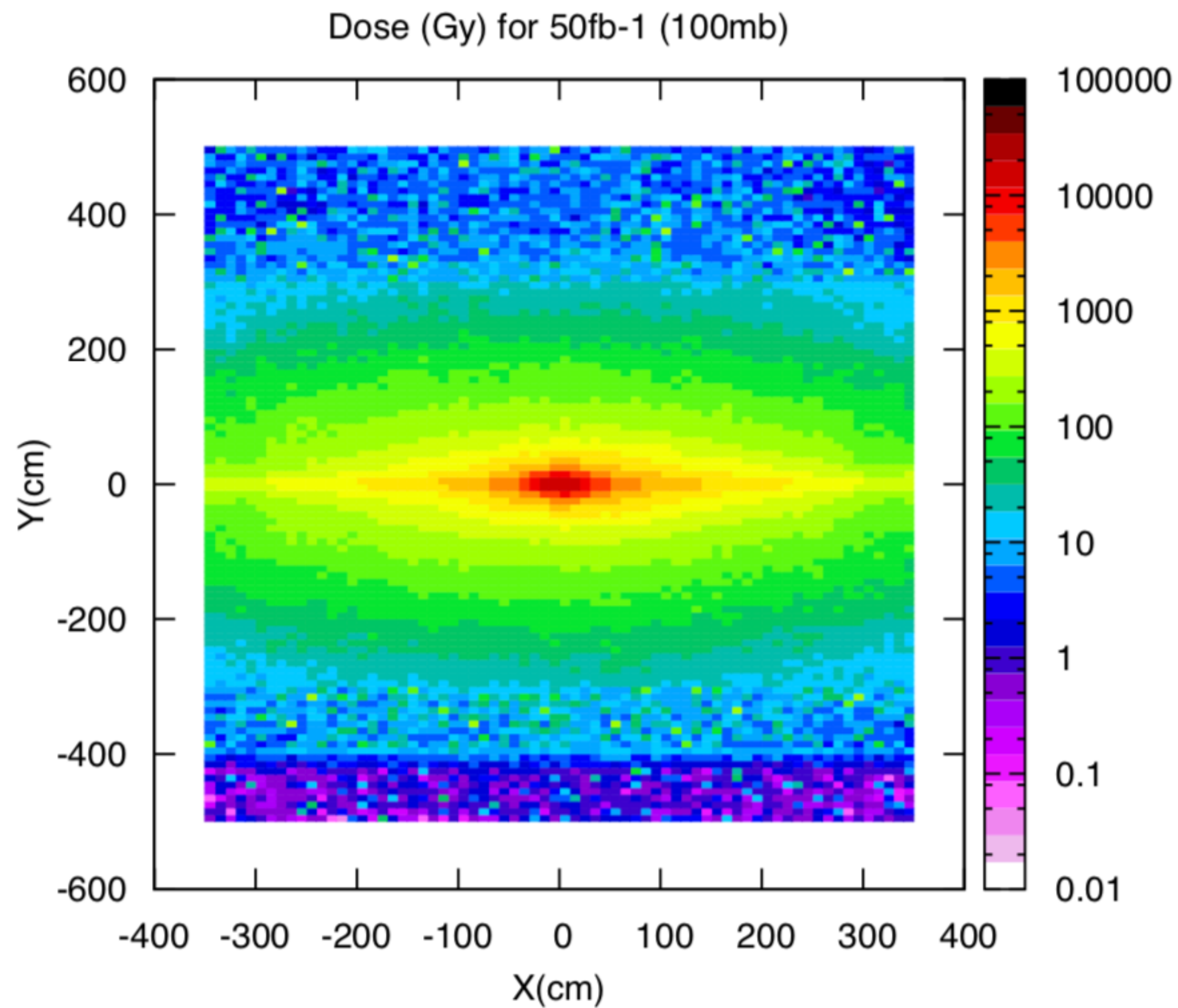


# Fibre Mats & Modules

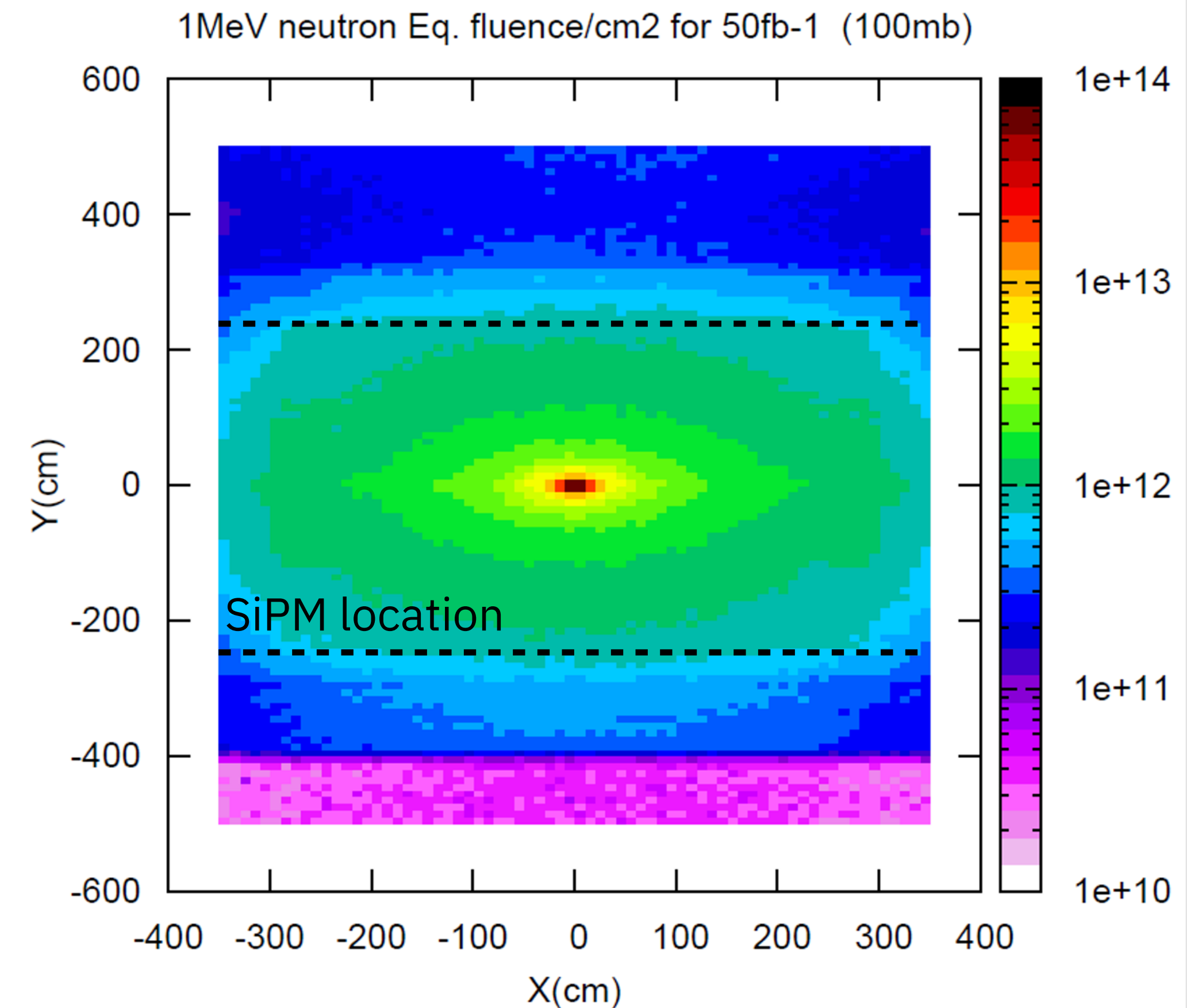
- Winding of fibers into 2.5 m long fibre mats
  - 6 staggered layer
  - Mirror on one end
- 8 fibre mats combined into one fibre module



# Radiation Environment



- 35 kGy in hottest region around the beam pipe

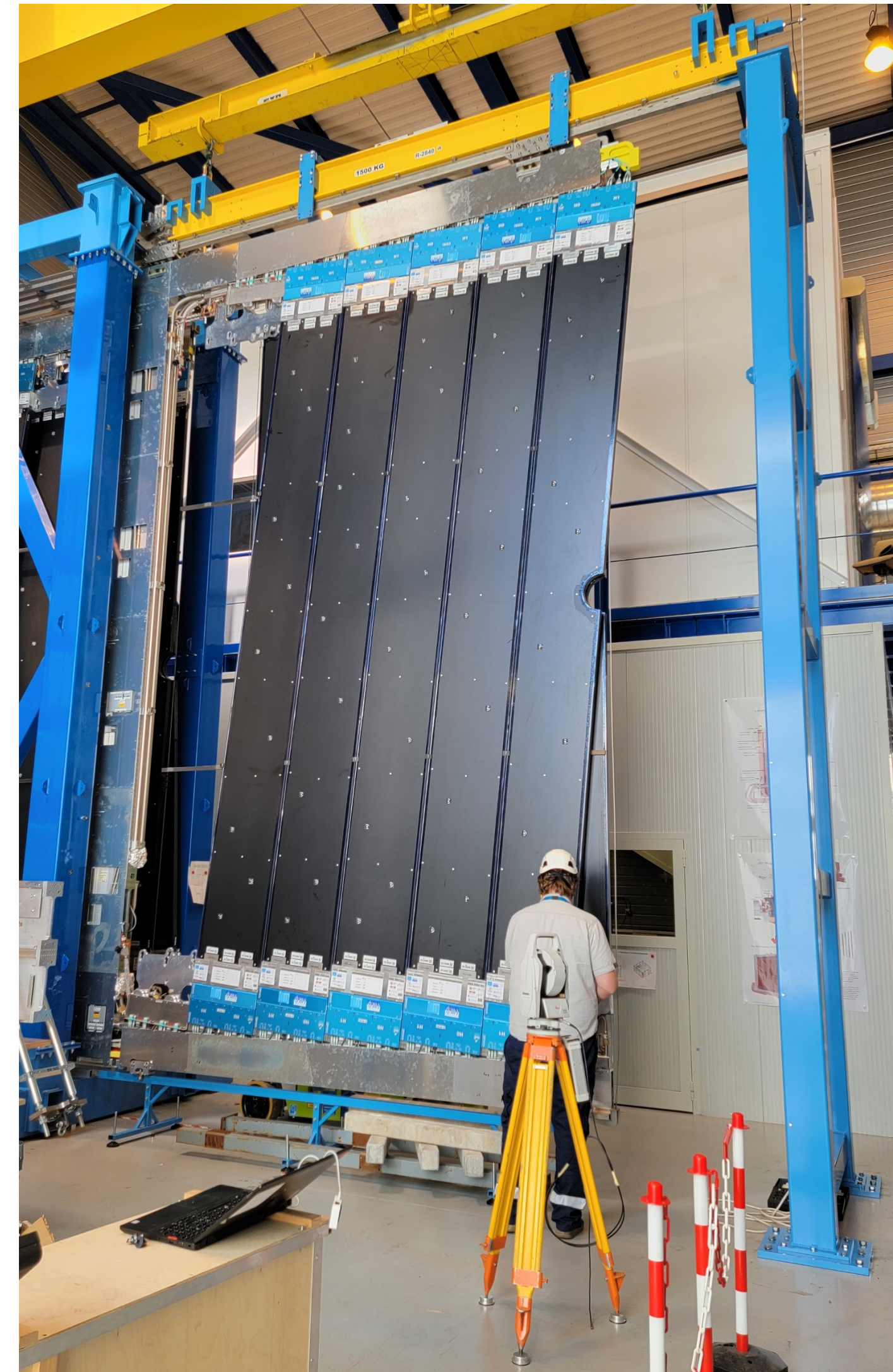
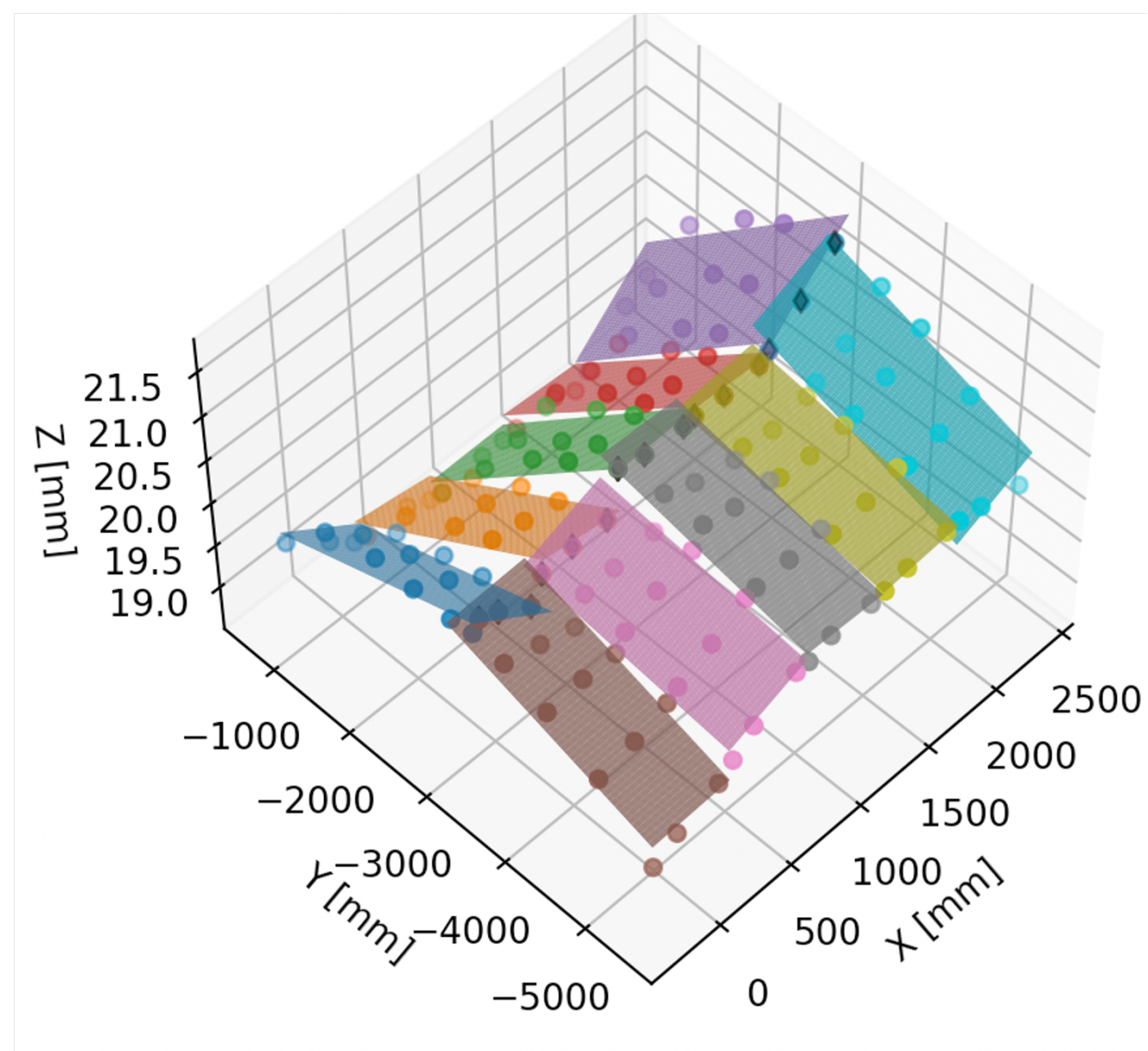


- $6 \cdot 10^{11} \text{ n}_{\text{eq}} \text{ cm}^{-2}$  at SiPM location



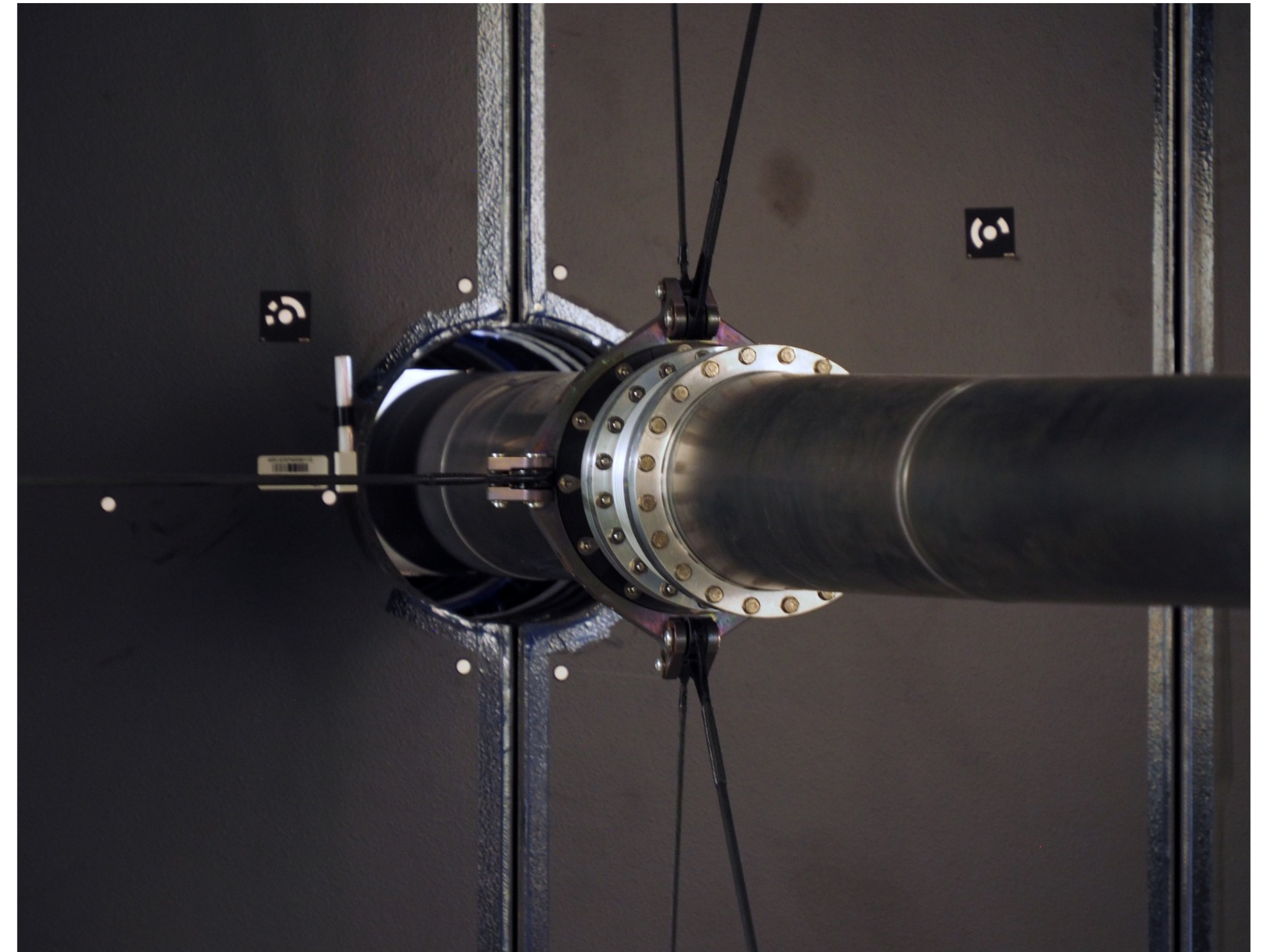
# C-Frame Survey

- Each finished C-Frame was surveyed using photogrammetry
- Additionally a few points were measured with a laser system
- A plane was fitted to each half module



# Detector Alignment

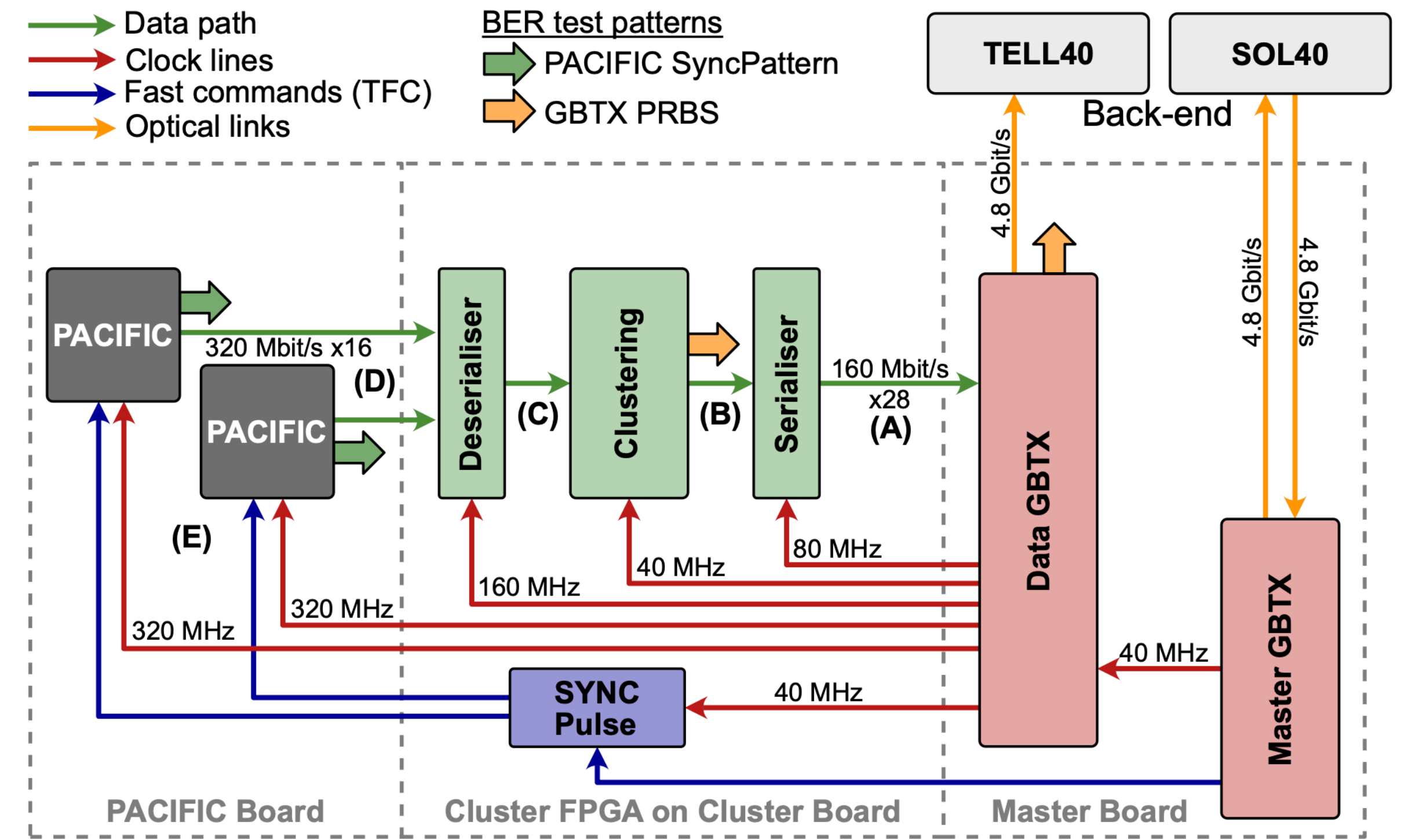
- C-Frames can be moved and adjusted on the support carriages
- Adjust such that cut-out fit around the beam pipe (minimum 20 mm)
- Both sides of the detector overlap without touching (2 mm clearance)
- Survey the detector alignment using laser system
- Provide starting point for track based alignment together with C-Frame survey



Beam pipe and cut-out in the SciFi Tracker

# Clock Phase Scans

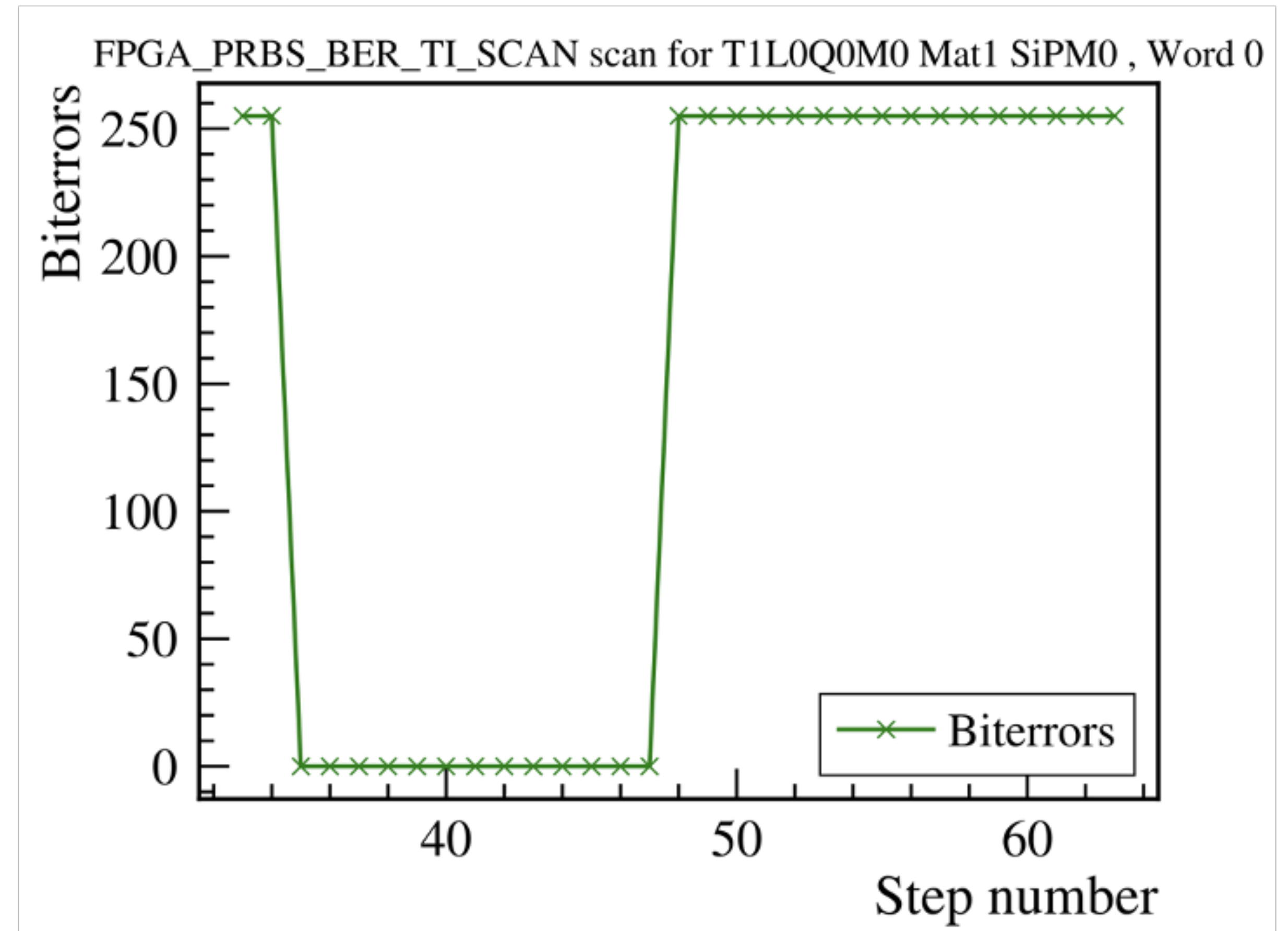
- Frontend electronics contain several interdependent clock domains (40, 80, 160, 320 MHz)
- Align clock phases to ensure error-free data transmission
  - Sweep the clock phase range
  - Send known bit sequence through electronics chain
  - Compare sequence & count errors in DAQ



Clock scheme of the SciFi frontend electronics

# Clock Phase Scans

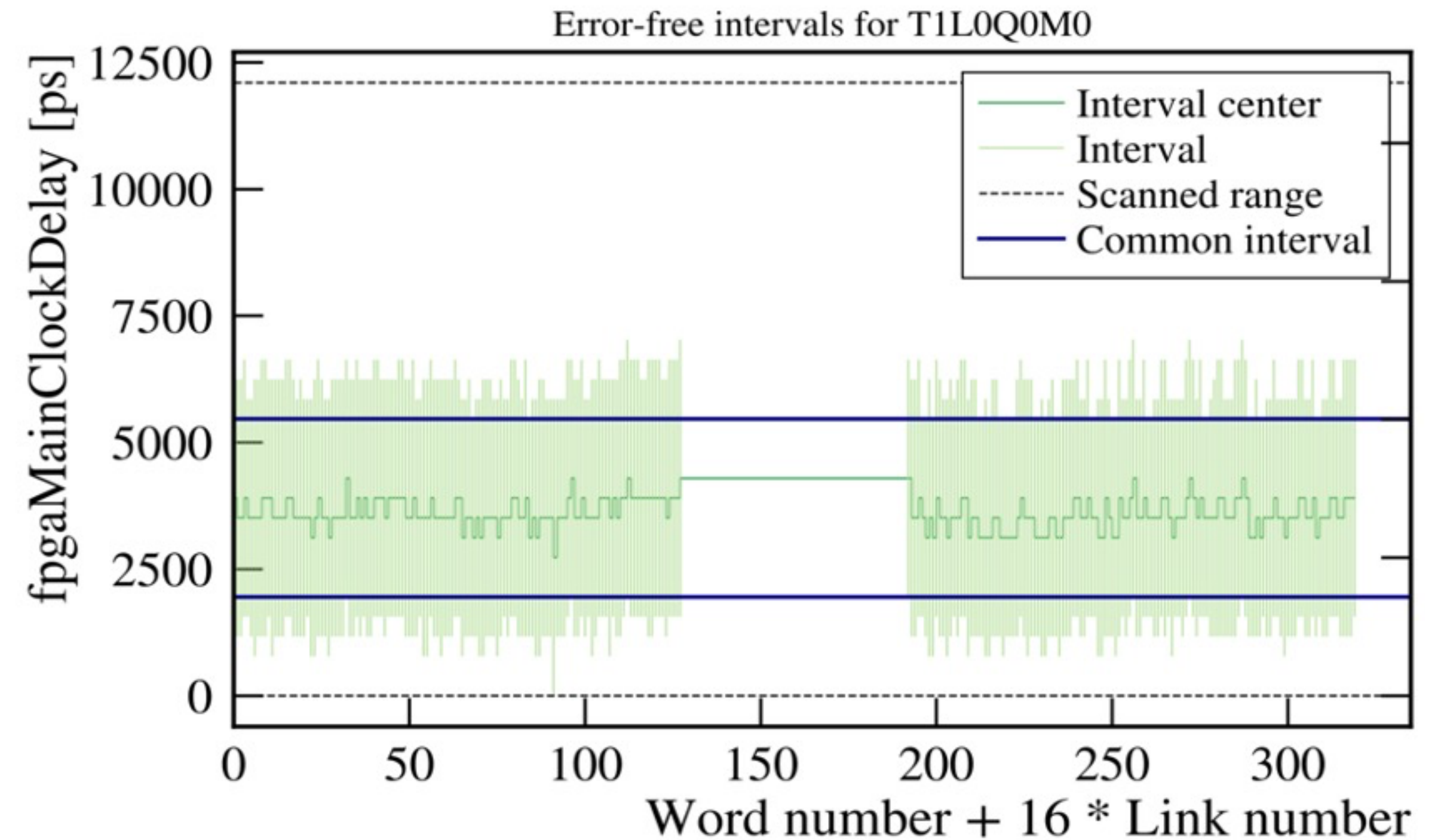
- Frontend electronics contain several interdependent clock domains (40, 80, 160, 320 MHz)
- Align clock phases to ensure error-free data transmission
  - Sweep the clock phase range
  - Send known bit sequence through electronics chain
  - Compare sequence & count errors in DAQ



Clock phase scan for the Cluster FPGA

# Clock Phase Scans

- Frontend electronics contain several interdependent clock domains (40, 80, 160, 320 MHz)
- Align clock phases to ensure error-free data transmission
  - Sweep the clock phase range
  - Send known bit sequence through electronics chain
  - Compare sequence & count errors in DAQ



Clock phase scans for the Cluster FPGAs of one SciFi module