Status of the LHCb SciFi Tracker

HighRR Seminar
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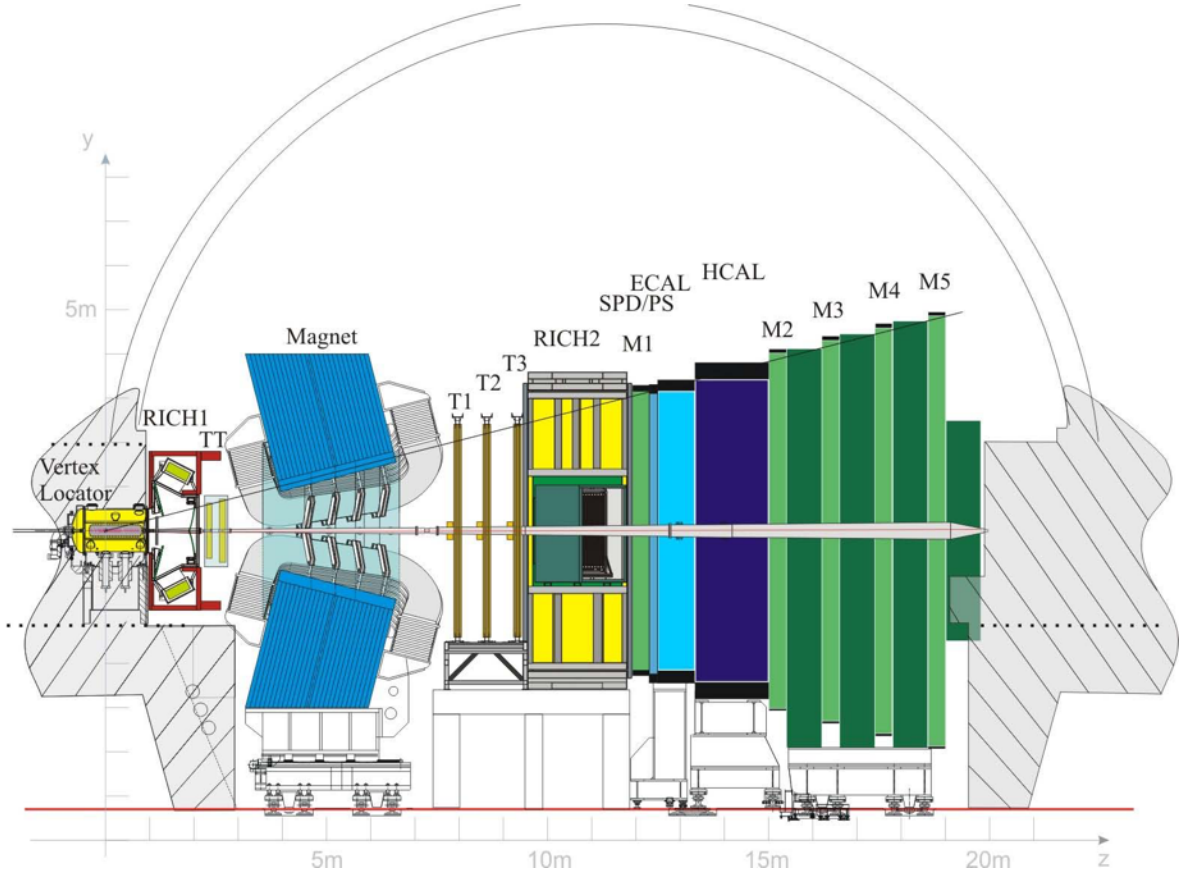
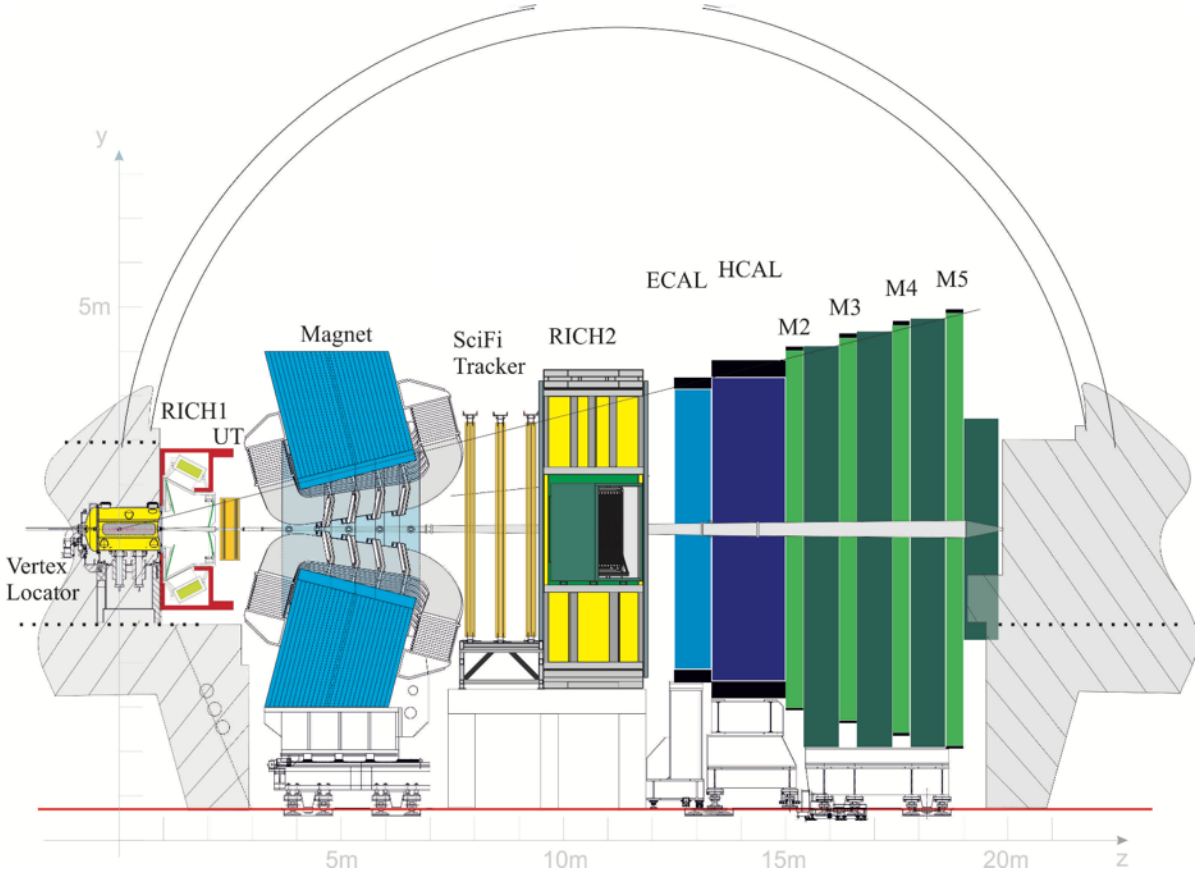
27/05/2020

The LHCb Detector



- Optimised for b and c physics
  - Forward spectrometer
  - Precise vertexing and tracking
- Broad physics programme beyond flavour developed over the years
- General purpose detector in the forward region
- Precision probe of the Standard Model
- Major upgrade for next LHC run

The Upgraded LHCb Detector



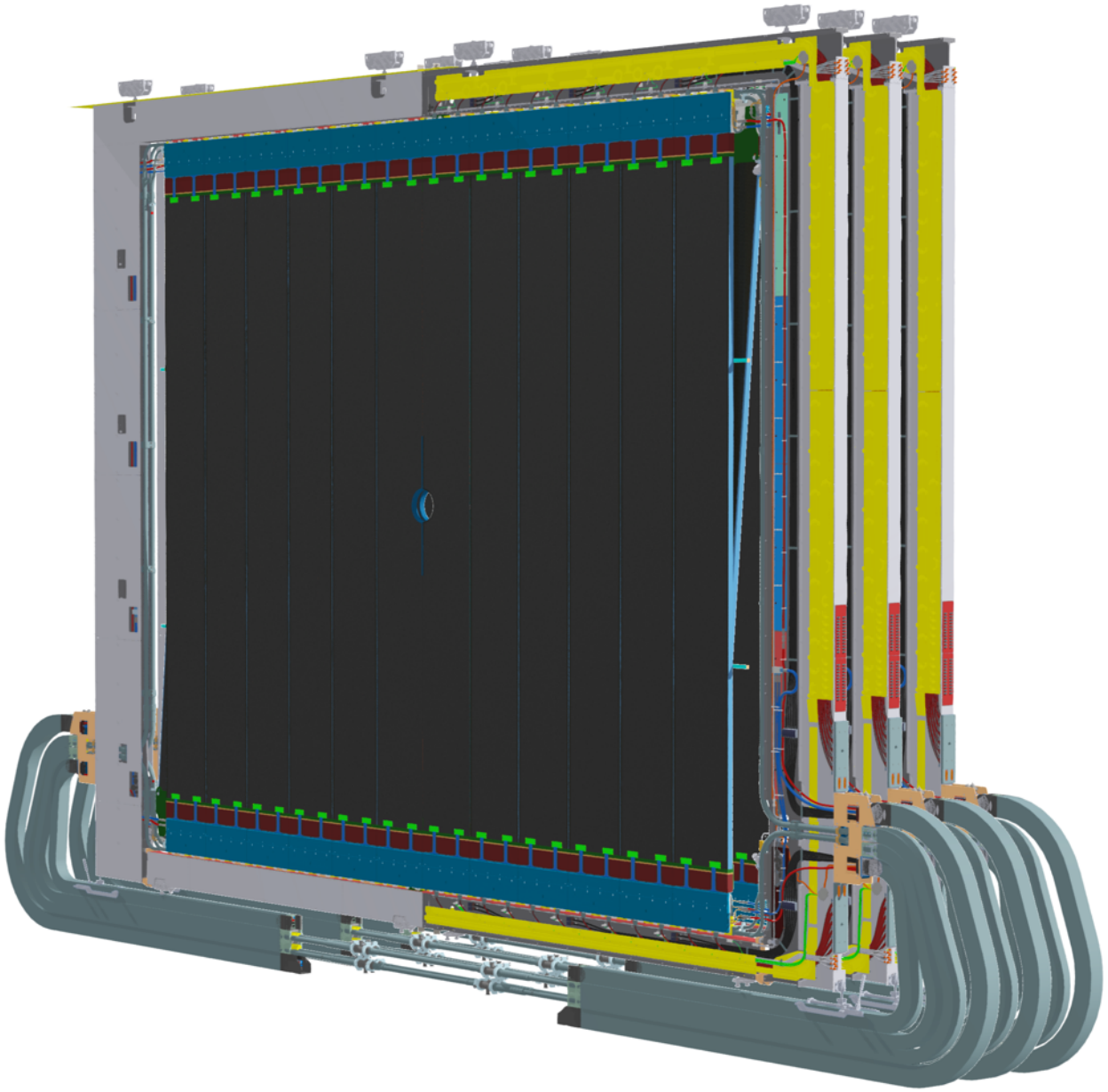
- Reduce statistical uncertainties by collecting more data: 9 fb^{-1} → 50 fb^{-1}

1. Increased instantaneous luminosity
   - $4 \cdot 10^{32}\ cm^{-2}s^{-1}$ → $2 \cdot 10^{33}\ cm^{-2}s^{-1}$
   - Requires new high granular main tracker: **Scintillating Fibre Tracker**

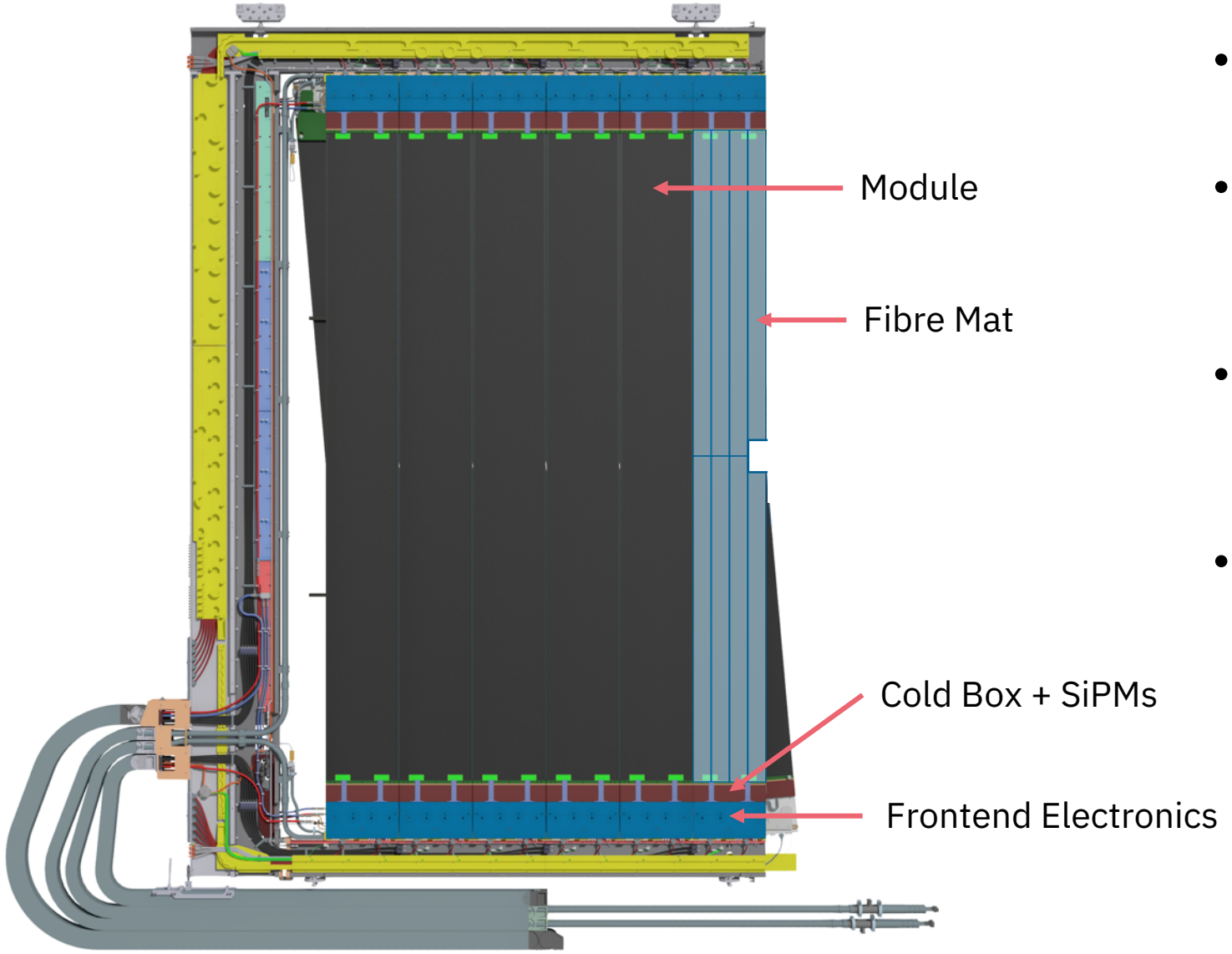
2. Full 40 MHz readout & flexible software trigger
   - Removal of 1 MHz hardware trigger
   - Replacement of all readout electronics and DAQ system

SciFi Tracker

- **Large:** 3×4 layers, 340 m^2 active area
- **Light:** ~1%X_0 per layer
- **Precise:**
  - Hit efficiency ~99%
  - Hit resolution <100 µm
- **Radiation tolerant:**
  - Fibres up to 35 kGy
  - Electronics 100 Gy, $6 \cdot 10^{11}$ $n_{eq} cm^{-2}$
- **Fast:** 40 MHz readout w/o dead-time



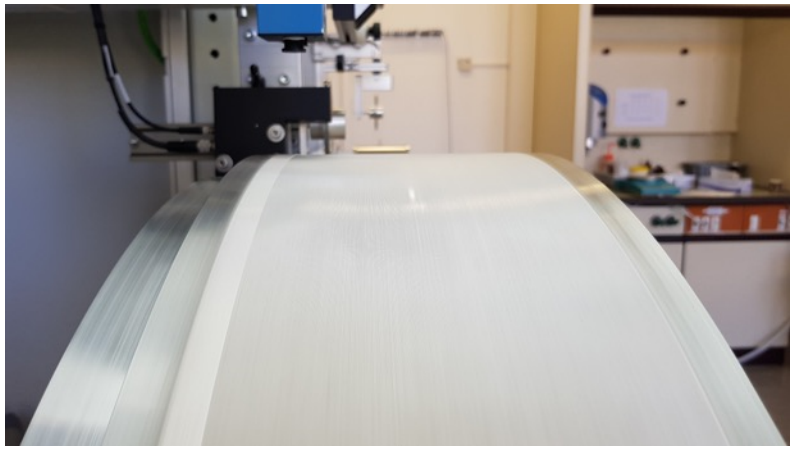
SciFi Tracker Design

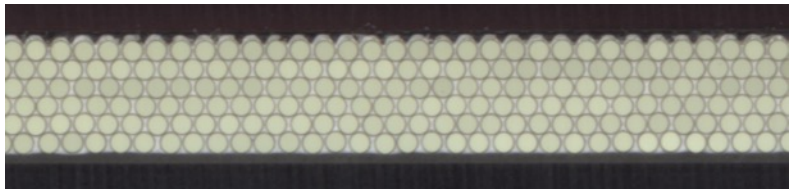


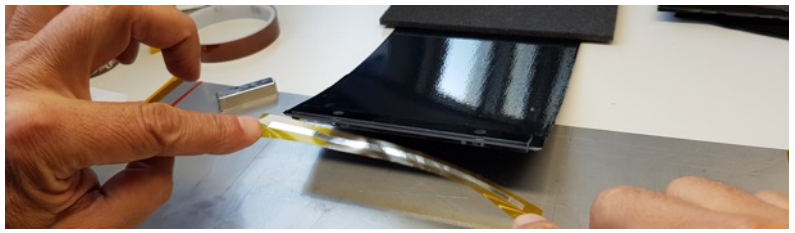
- Mechanical support & services provided by C-Frame
- 2.5 m long, 250 µm diameter scintillating fibres
  - ~11,000 km in total
- Silicon photomultiplier (SiPM) readout
  - 524,288 channels in total
- 40 MHz frontend electronics

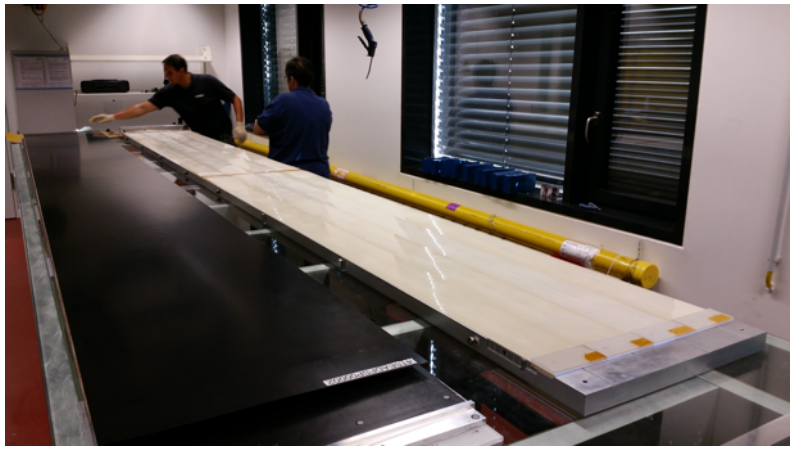
Fibre Mats & Modules

- QA of scintillating fibres
  - ~11,000 km
- Winding of fibres into 2.5m long mats
  - 6 staggered layers
  - Mirrored on one end
  - ~1500/1024 produced
- 8 mats combined into one module
  - ~140/128 produced

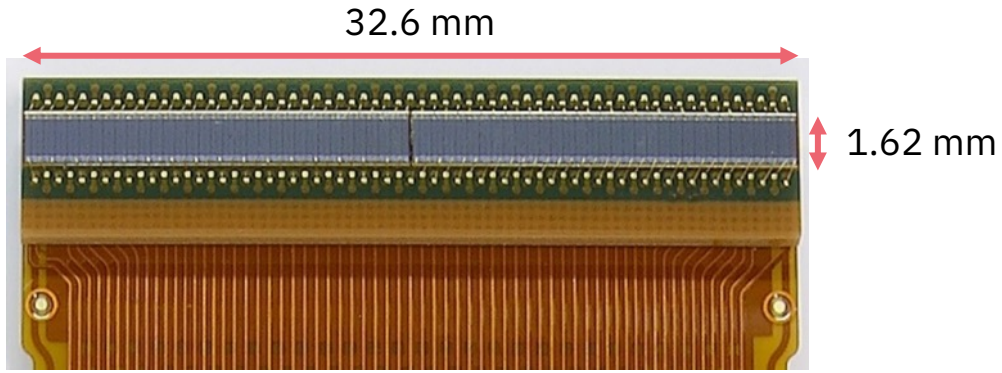




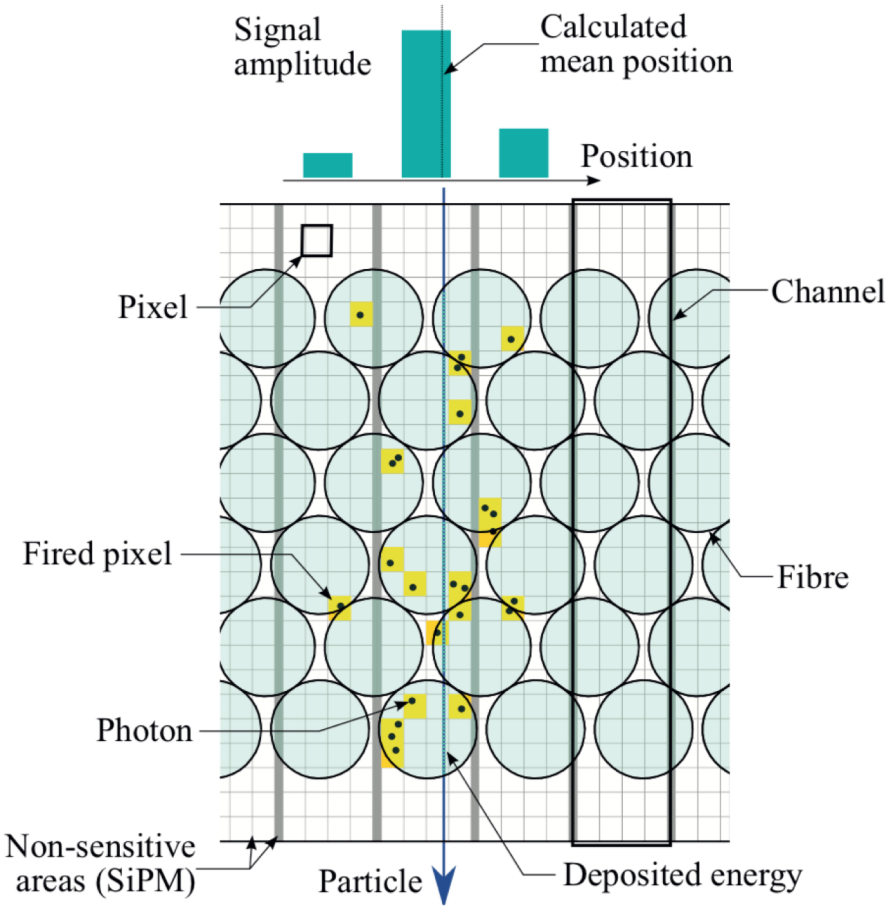




Silicon Photomultipliers

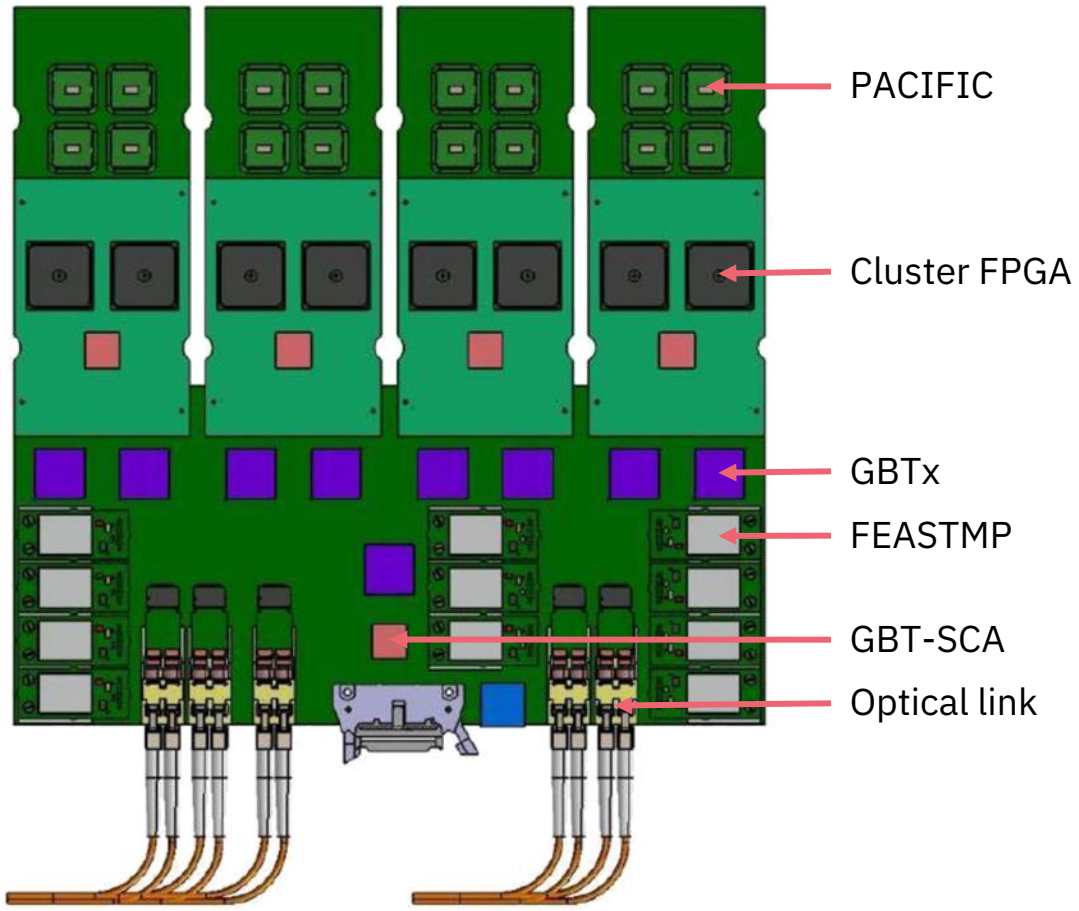


- **Hamamatsu H2017 array**
- 128 channels, 250 µm pitch
- 104 pixels per channel
- Cooled to -40 °C
- ~5500/4096 delivered & tested



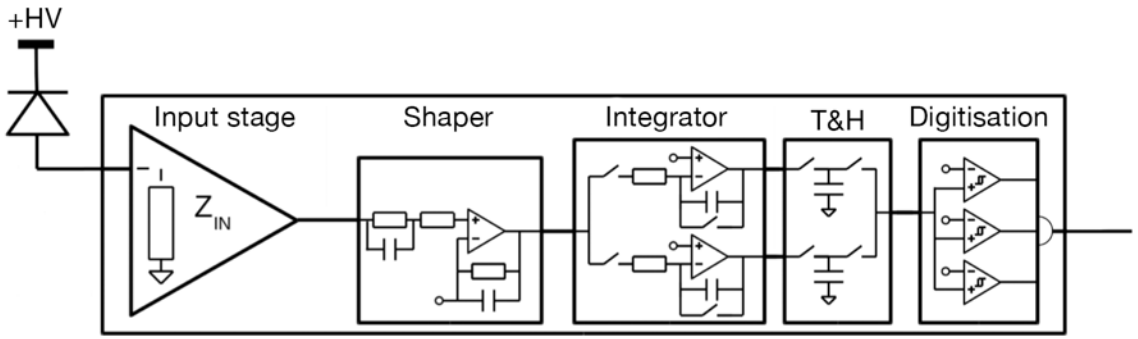
Frontend Electronics

- **PACIFIC Board:** 4 ASICS
  - 64 channels per ASIC (2 ASICs per SiPM)
  - Analogue processing & digitisation
- **Cluster Board:** 2 FPGAs
  - Hit reconstruction & noise suppression
- **Master Board:**
  - Distribution of power, slow & fast control, and clock
  - 8+1 GBTx ASICs (4.8 Gb/s transceiver)
  - 8 links for data transmission
  - 1 link for control commands



PACIFIC

- **Shaper:** Reduce long tail of SiPM signal
- **Integrator:** Two gated integrators to minimize dead-time
- **Digitisation:**
  - Three comparators with adjustable thresholds
  - $Thr_{Neighbour} < Thr_{Seed} < Thr_{High}$
  - 2 bit per channel at 40 MHz



Per SiPM

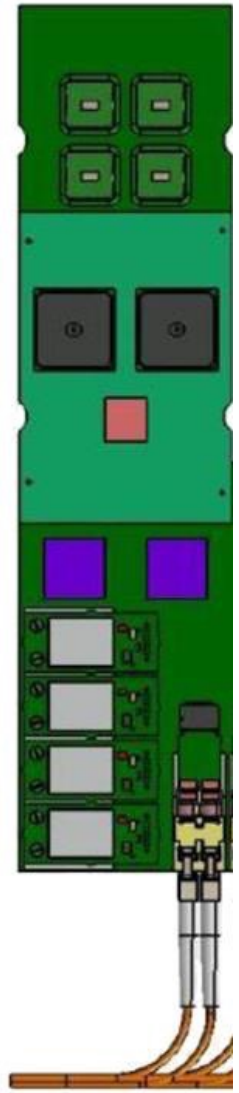
10.2 Gb/s

Full SciFi

42 Tb/s

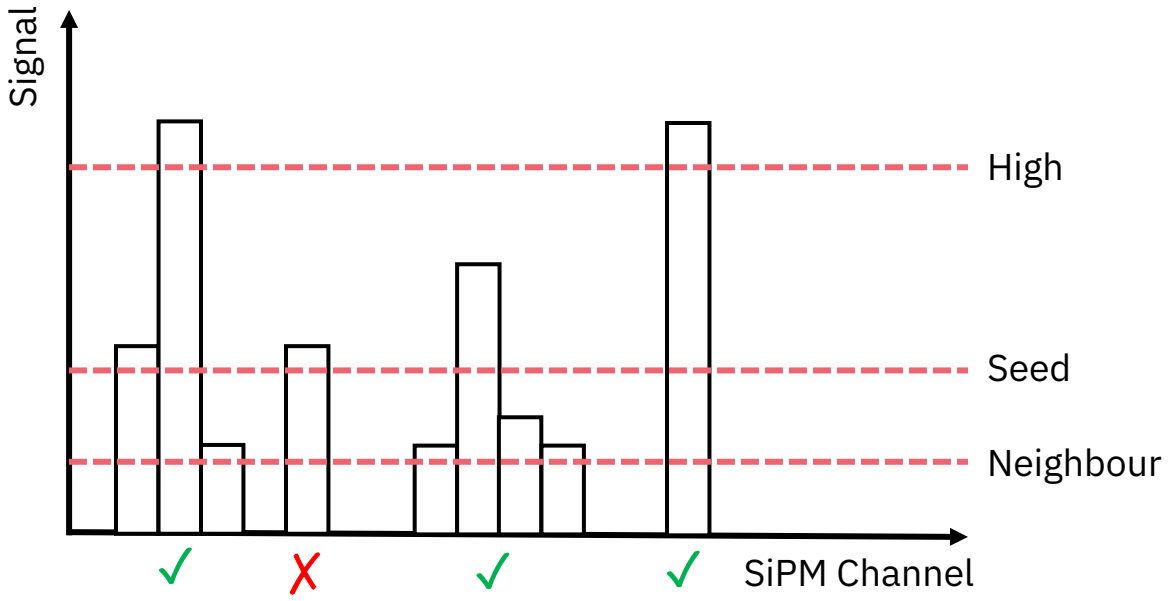
LHCb

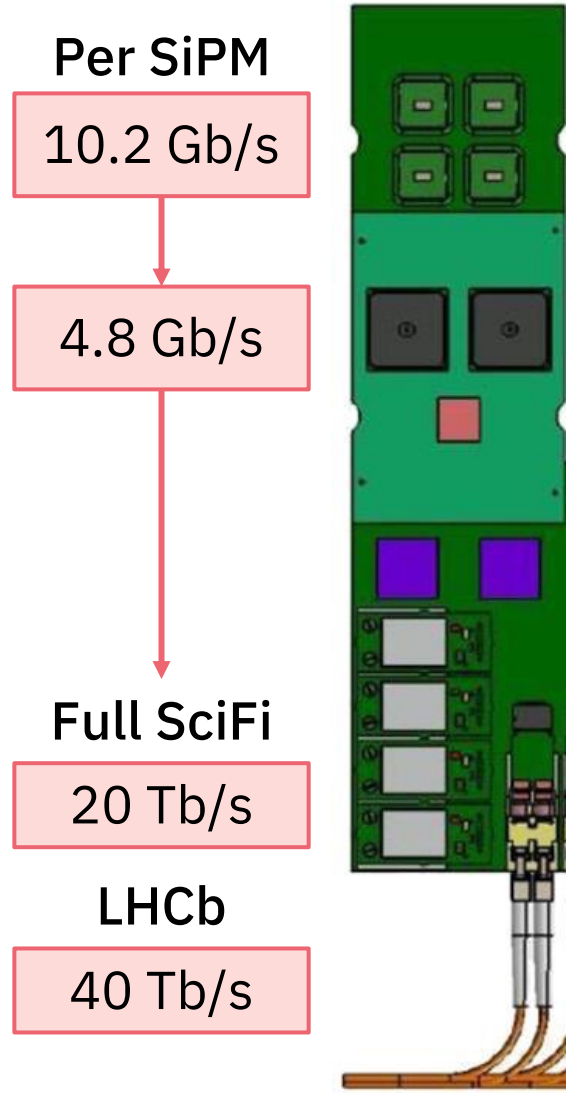
40 Tb/s



Cluster FPGA

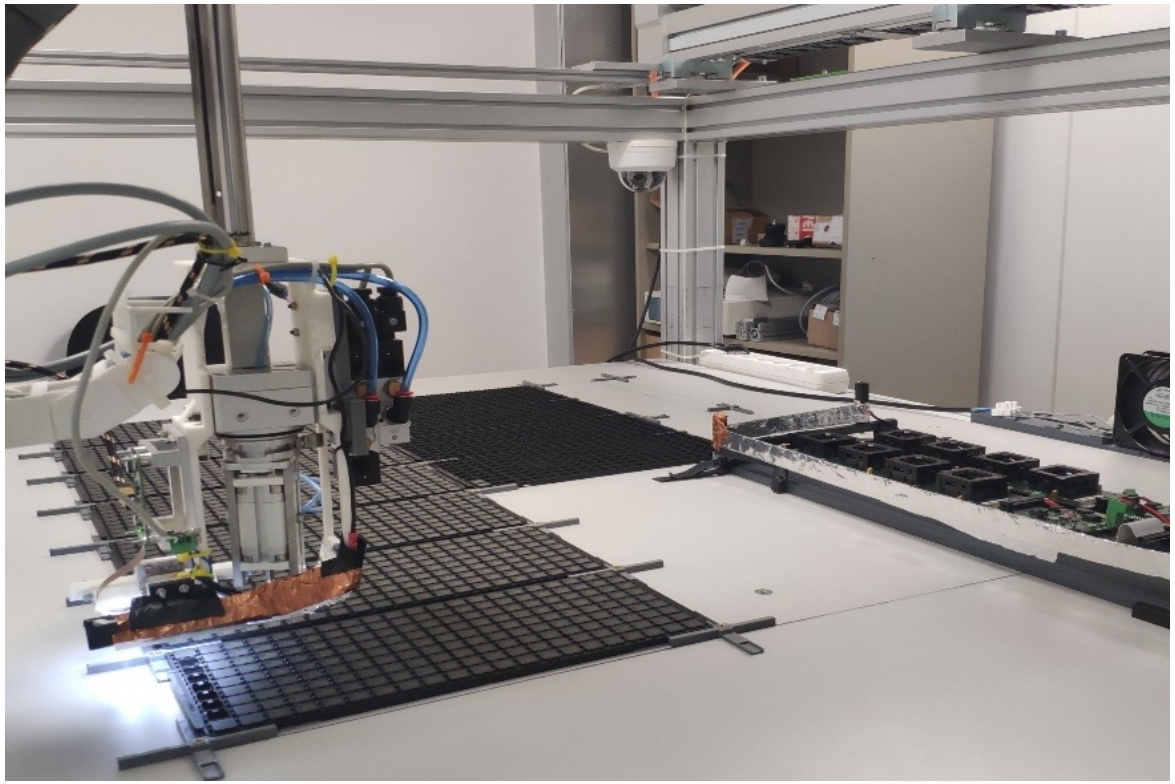
- Fast clustering algorithm
  - One channel ≥ $\mathrm{Thr}_{\mathrm{High}}$
  - Channel ≥ $\mathrm{Thr}_{\mathrm{Seed}}$ + Channel ≥ $\mathrm{Thr}_{\mathrm{Neighbour}}$
- Only send out reconstructed clusters
- Reduces data rate significantly





Electronics Production

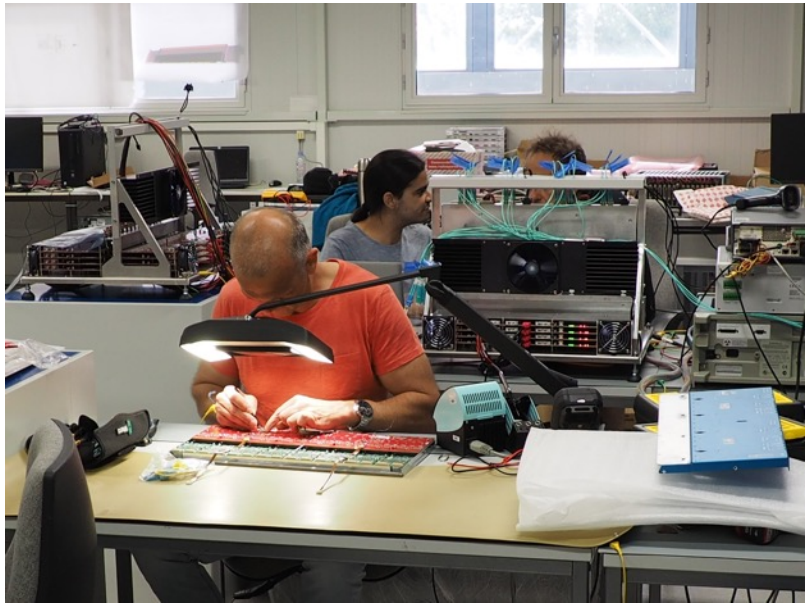
- ~23,000/8192 PACIFIC ASICs
- ~2500/2048 PACIFIC boards
- ~2500/2048 Cluster boards
- ~570/512 Master boards
- Extensive QA during production
- Unique barcodes on every part
- Everything traceable in data base

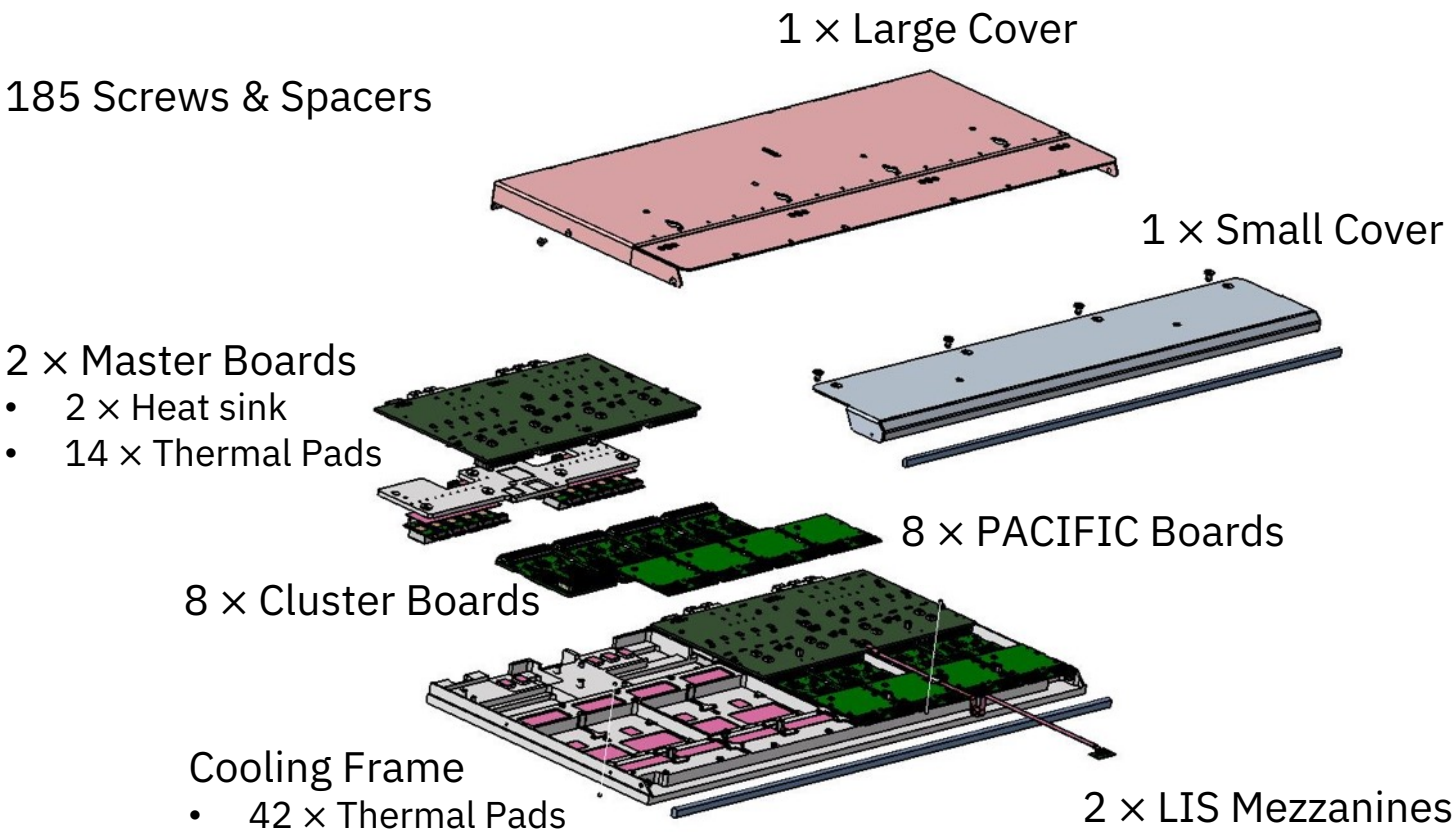


Automatic testing of PACIFIC ASICs

Frontend Assembly

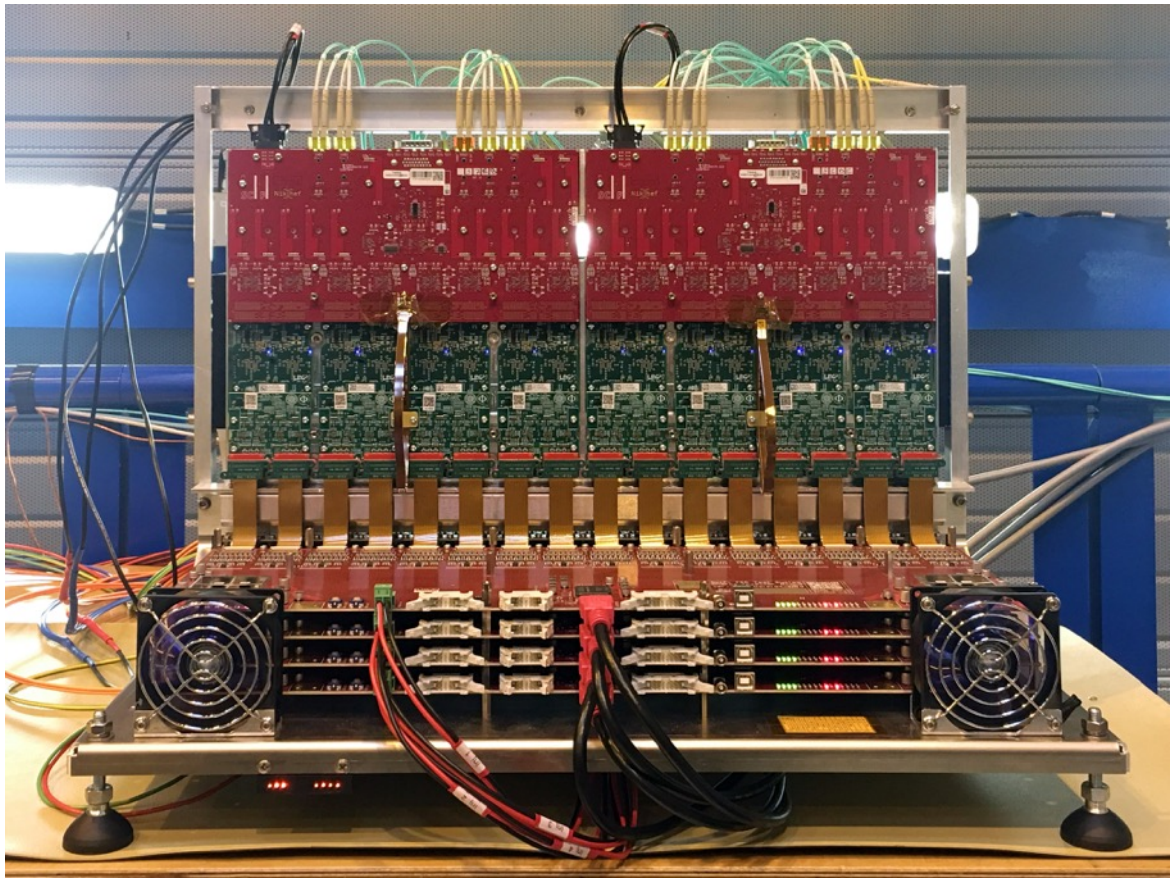
- Fully assembled frontend electronics: Readout Box (ROB)
- All 256 ROBs assembled





Readout Box QA

- Dedicated frontend tester to test fully assembled ROBs
- Full functional test
- Control & configure ROB
- Inject charge into every channel independently (2048 channels)



Frontend tester equipped with one ROB

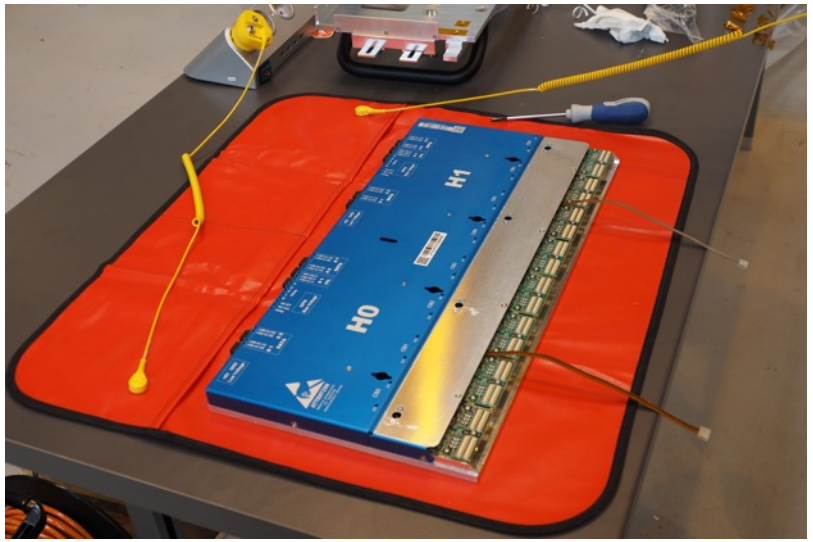
Detector Assembly

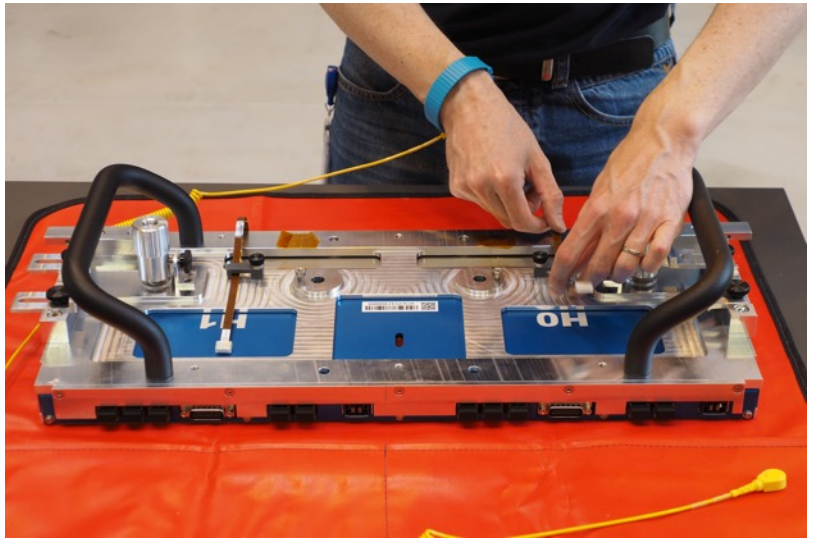
- Assembly in dedicated hall at LHCb site (LHC Point 8)

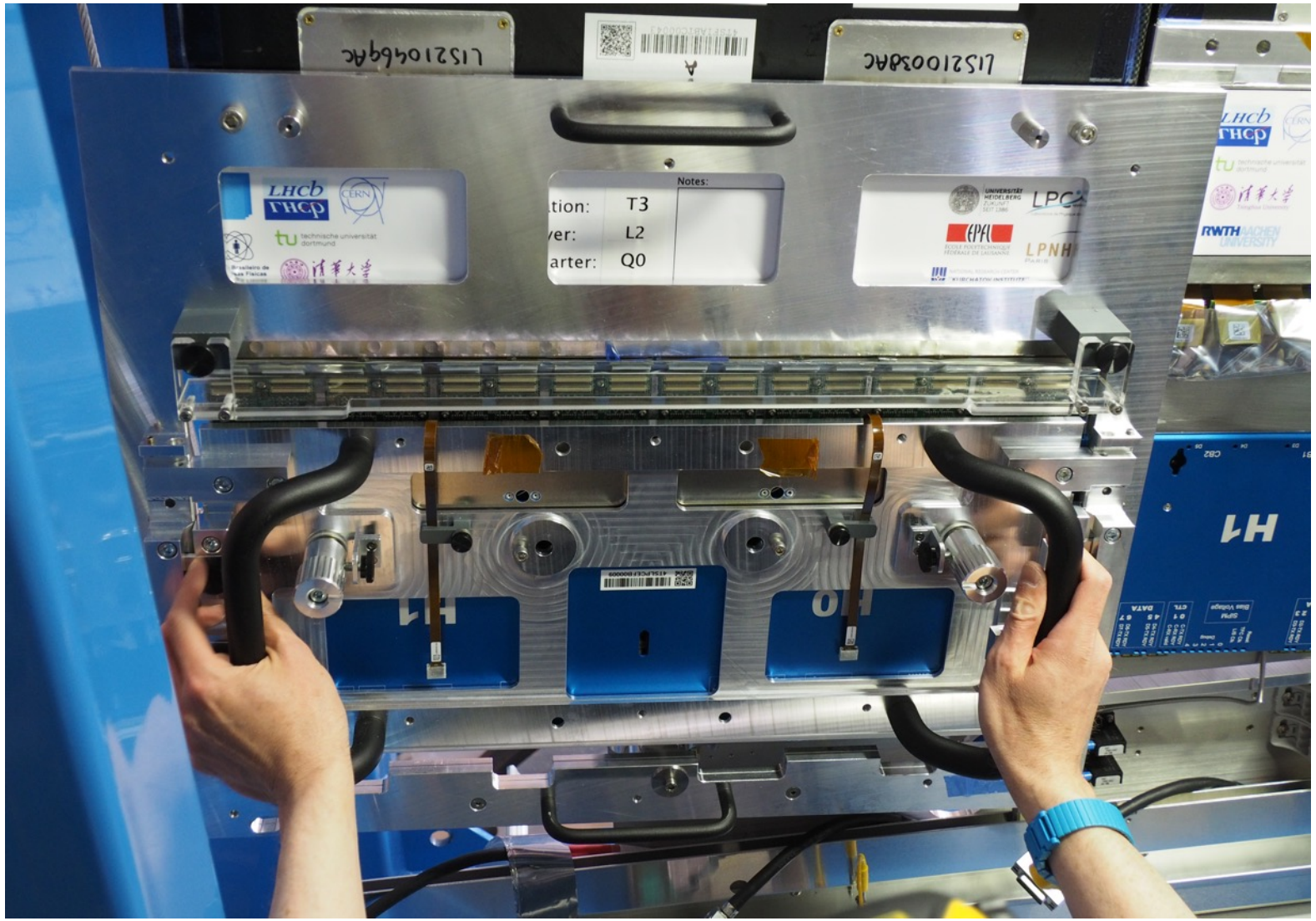
C-Frame Assembly

Module Installation

Readout Box Installation

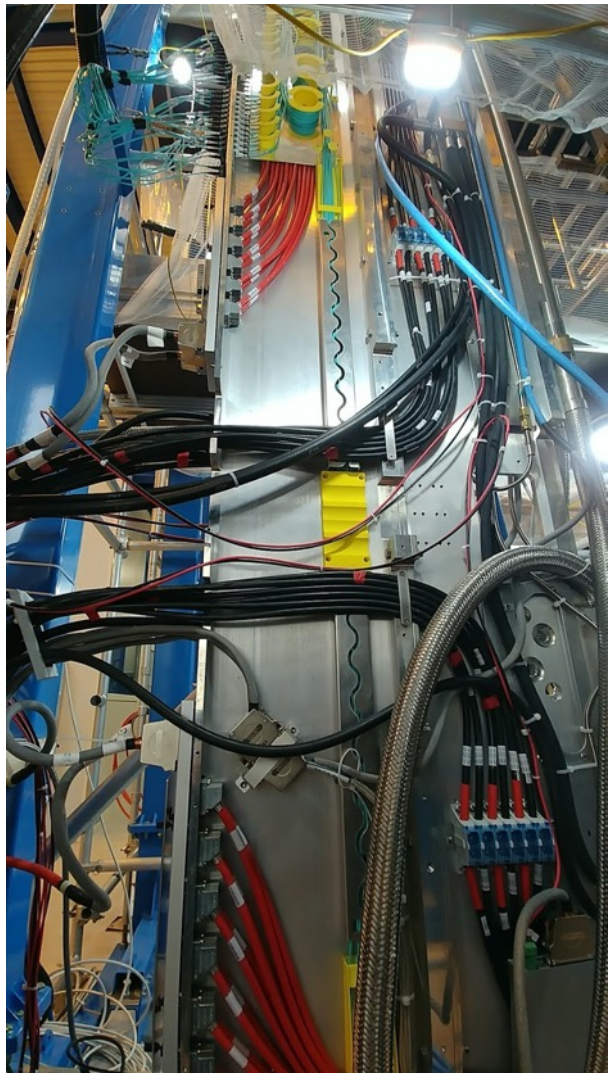


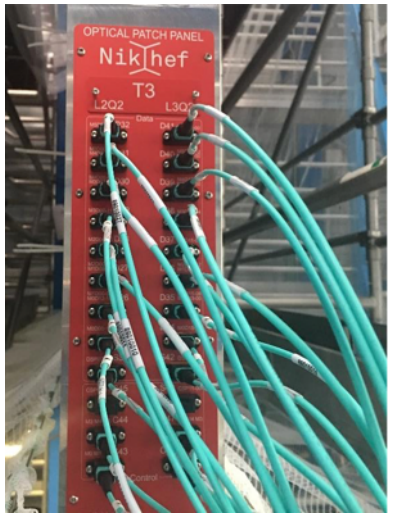




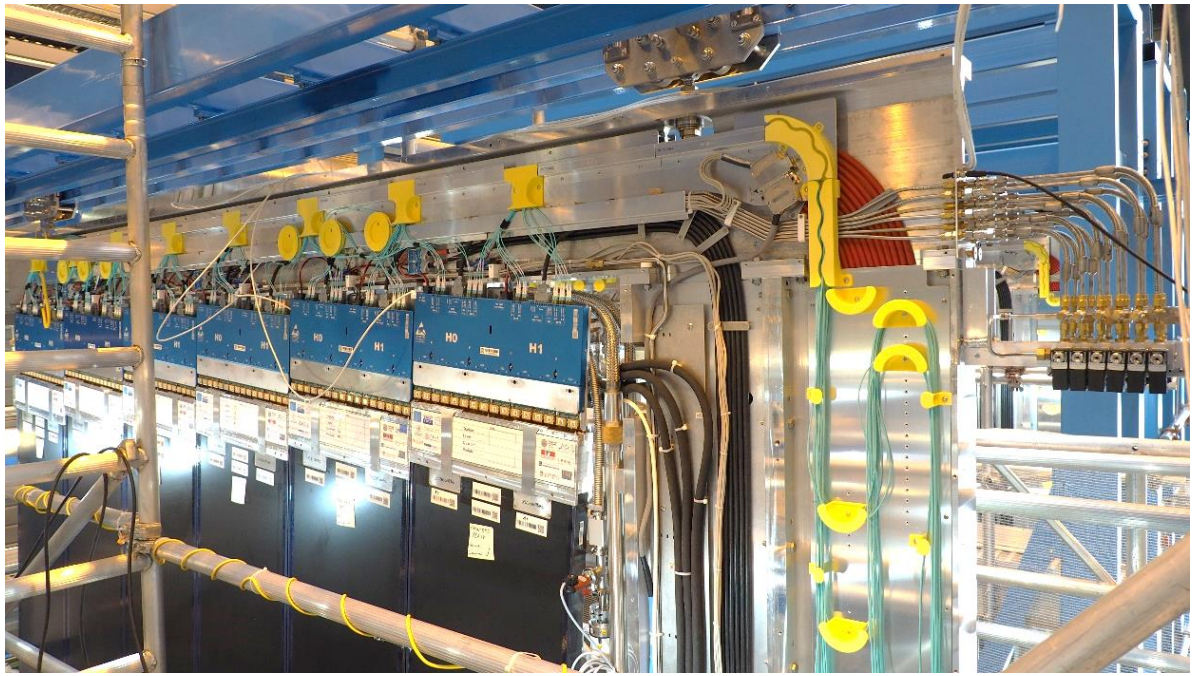
Cabling

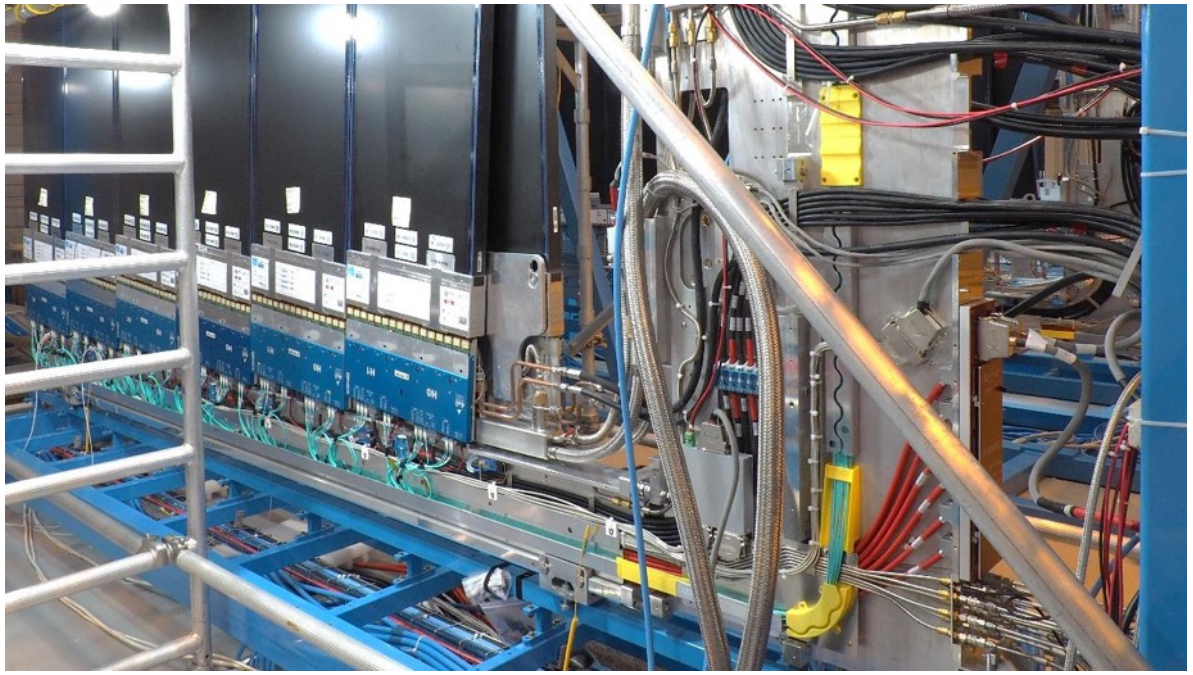
- Connect all cables on C-Frame
  - 384 SiPM connectors
  - 384 data + 48 control links
  - 48 LV (12 channels)
  - 48 HV (96 channels)
- Inspect & clean optical fibres before connecting
- Test LV & HV connections
- Keep track of mapping
- Label everything





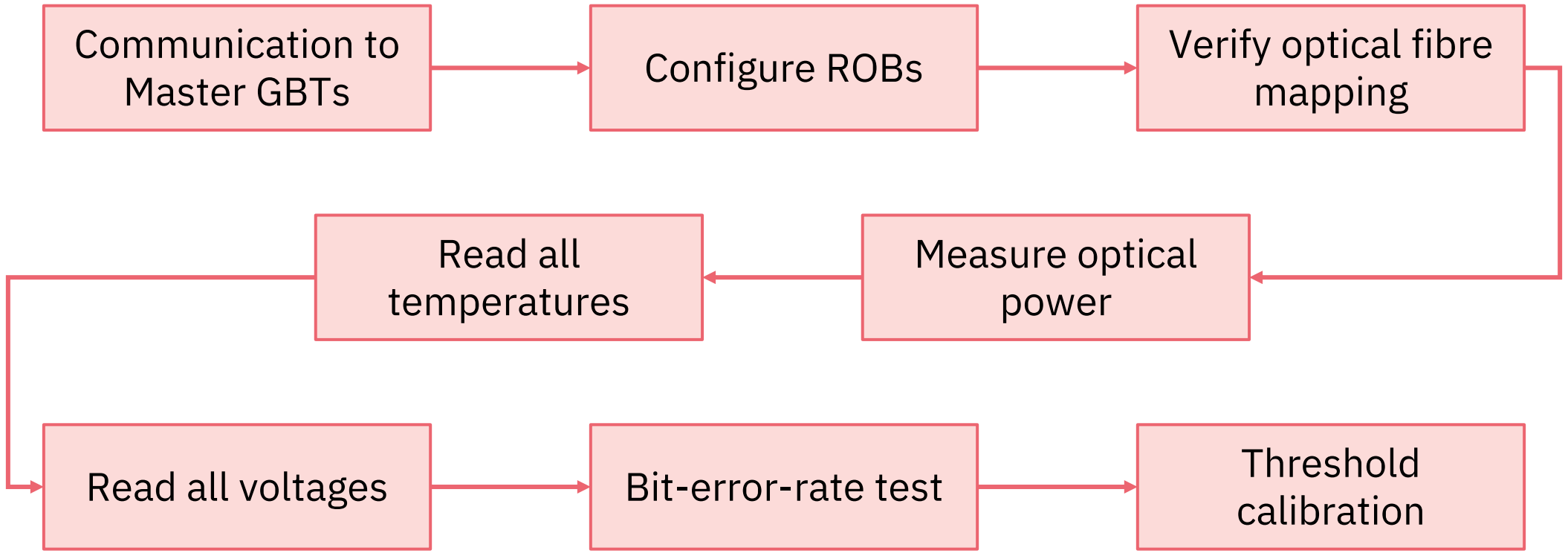
Complete C-Frame





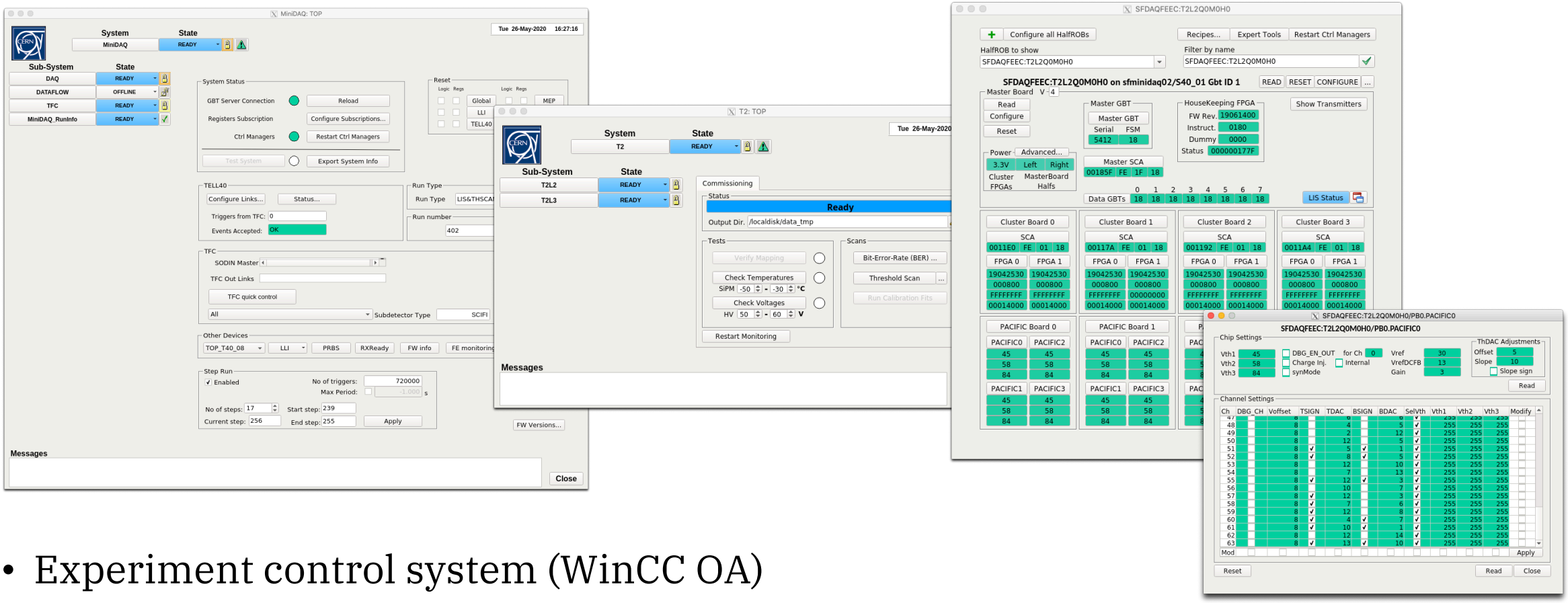
- C-Frame ready for commissioning of electronics

Electronics Commissioning



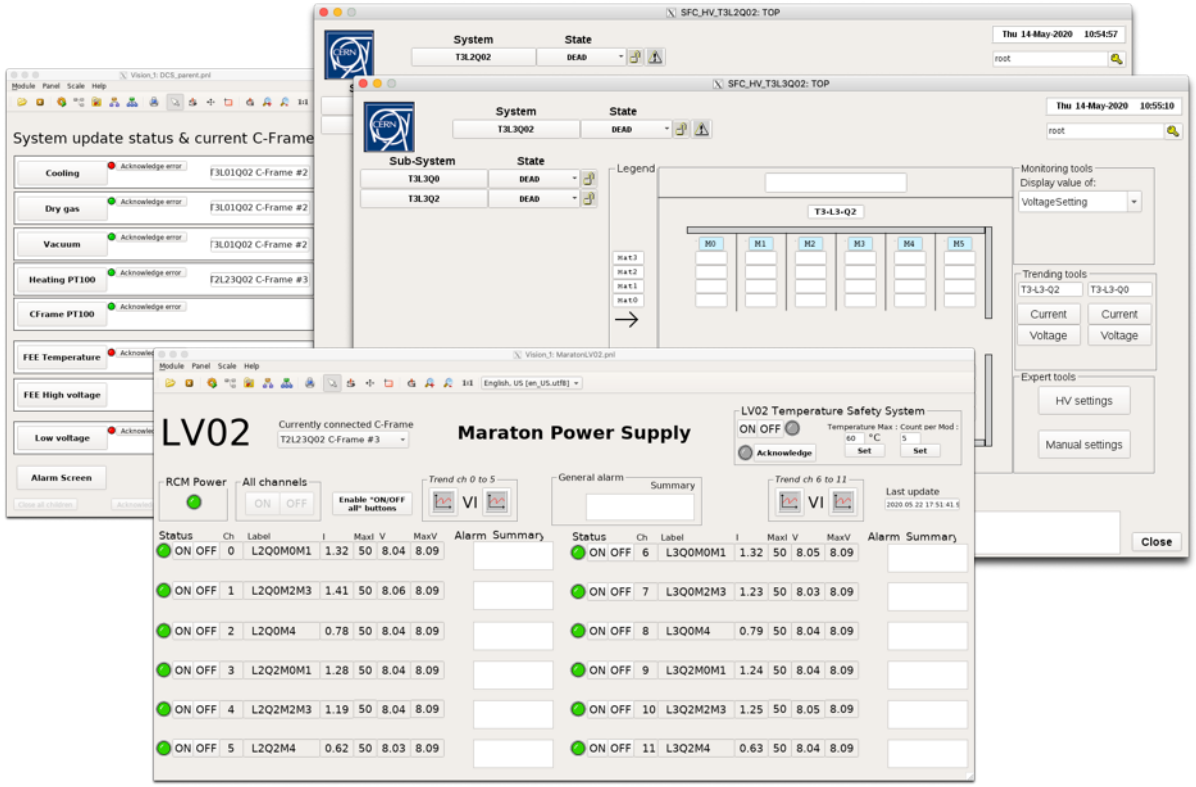
- Every step makes sure that the full system is operational
- Large & complex system → Need proper controls & monitoring

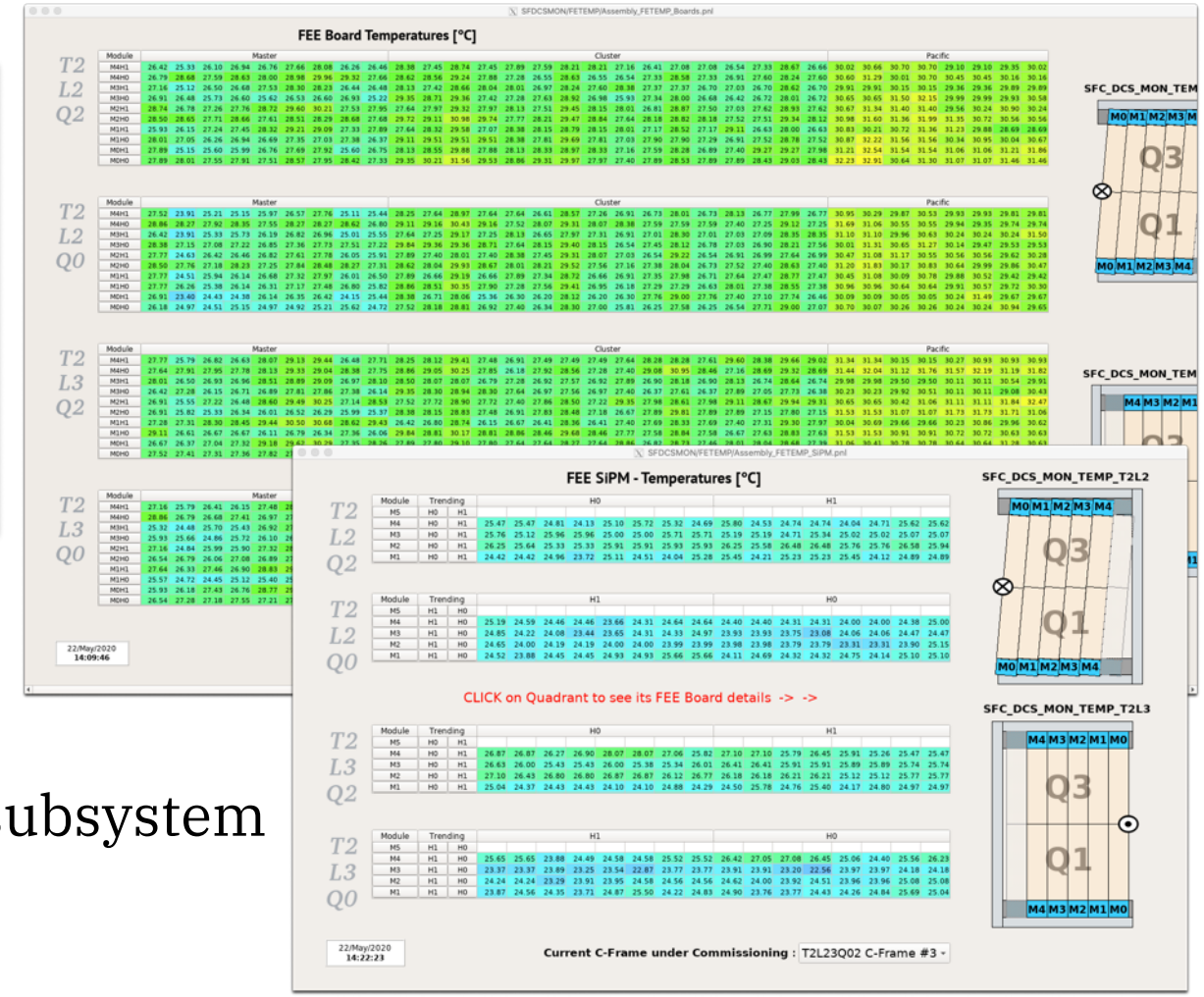
Controls & Monitoring



- Experiment control system (WinCC OA)
- Send commands to configure hardware, start data taking …
- Panels for users and experts

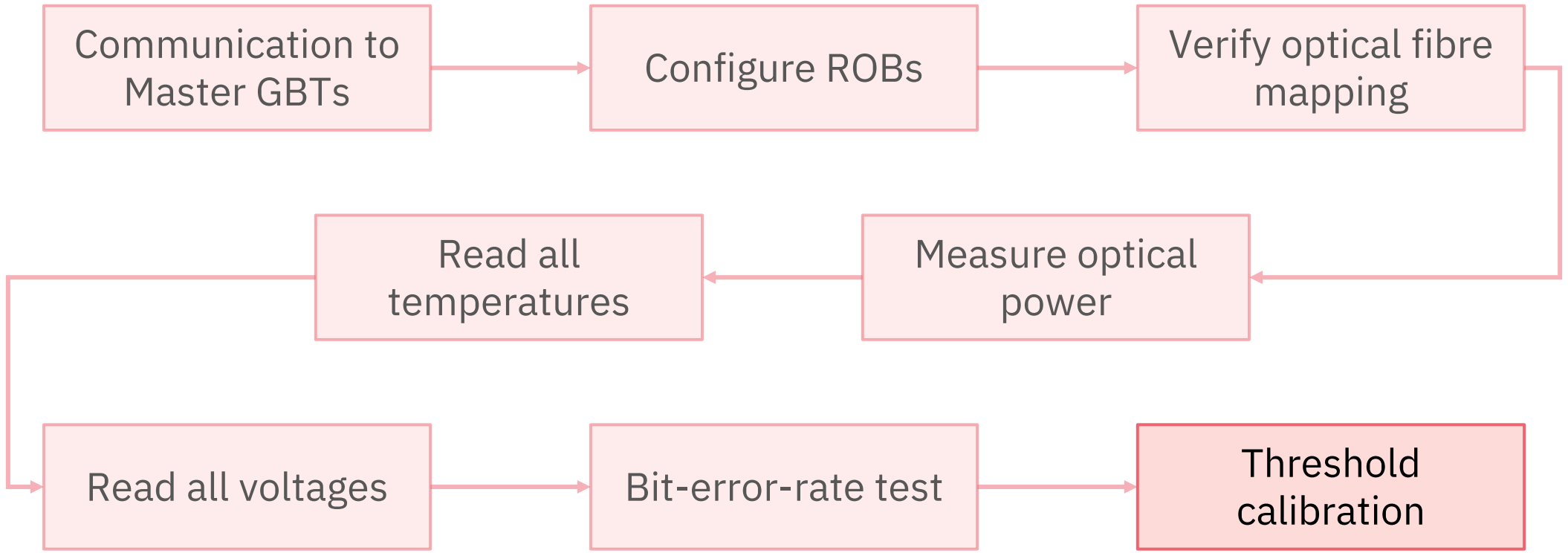
Controls & Monitoring





- Control and monitoring panels for every subsystem
  - Temperatures, Voltages, Currents …
- Trending and archiving of values

Electronics Commissioning



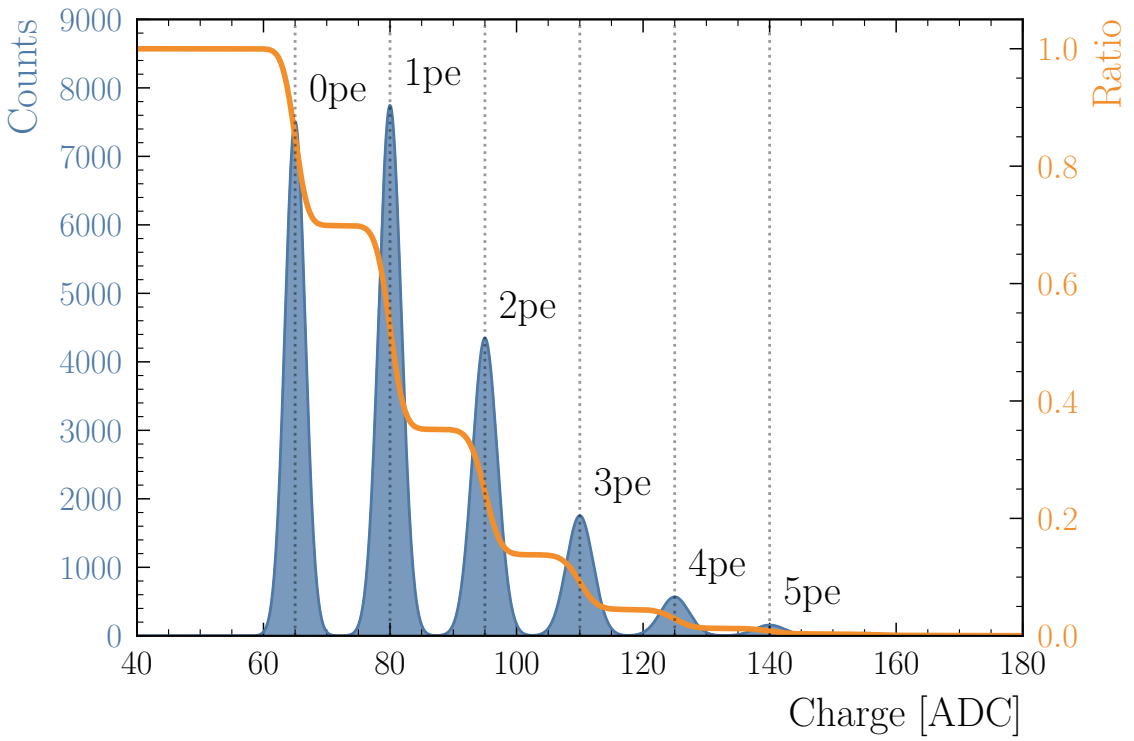
Threshold Calibration

- Convert signal from DAC values to photoelectrons (pe)
- PACIFIC can not measure full SiPM spectrum directly

Threshold scan:

- Set comparator threshold
- Inject pulsed light into fibre mat
- Count events over threshold
- Repeat for every DAC value (256)

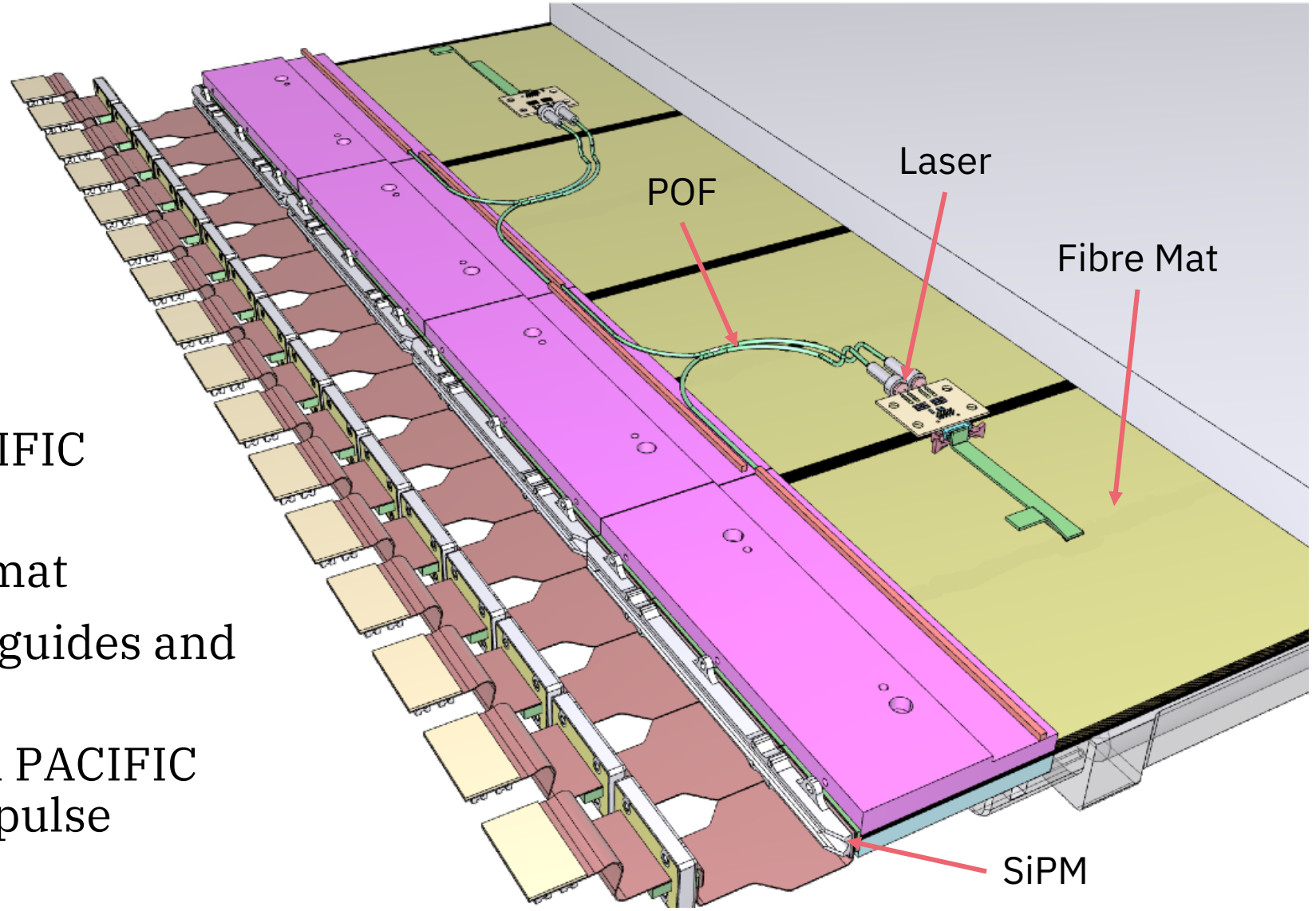
→ S-Curve (~integral of spectrum)



SiPM charge spectrum and corresponding threshold scan

Light Injection System

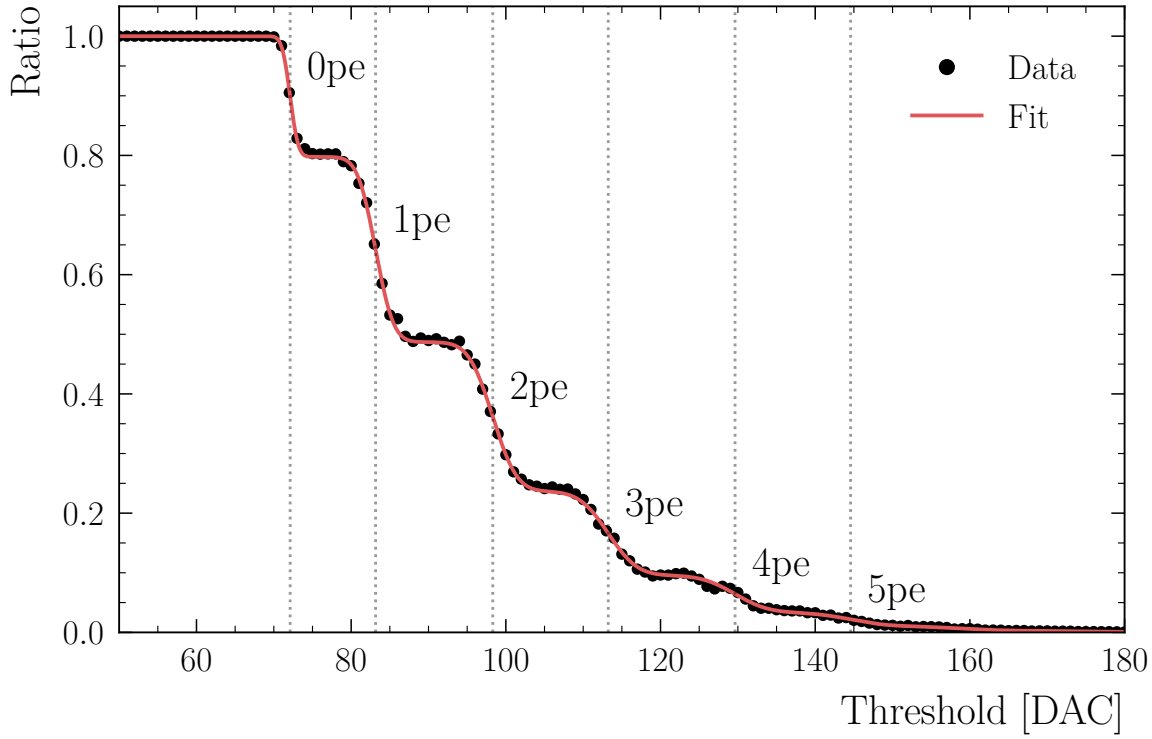
- Designed to calibrate PACIFIC comparator thresholds
- One laser diode per fibre mat
- Plastic optical fibre (POF) guides and distributes light over mat
- Adjustable phase between PACIFIC sampling window & laser pulse



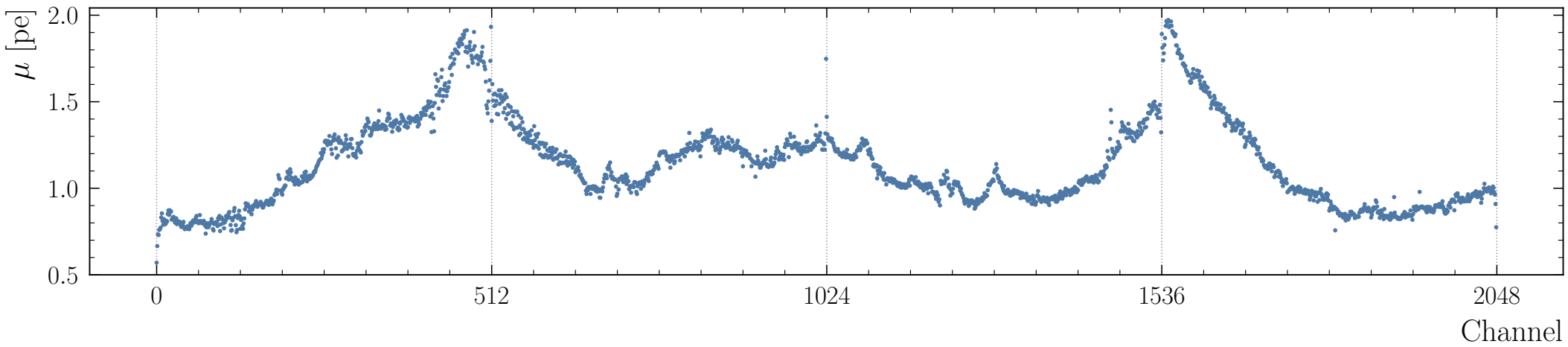
Calibration Procedure

1. Perform threshold scan for every channel, integrator, and comparator
   - 147,456 S-Curves per C-Frame
2. Fit S-Curves to determine calibration parameters
   - DAC values of photoelectron amplitudes
   - Light intensity
   - Gain
   - …

- Light intensity & gain are especially interesting for commissioning

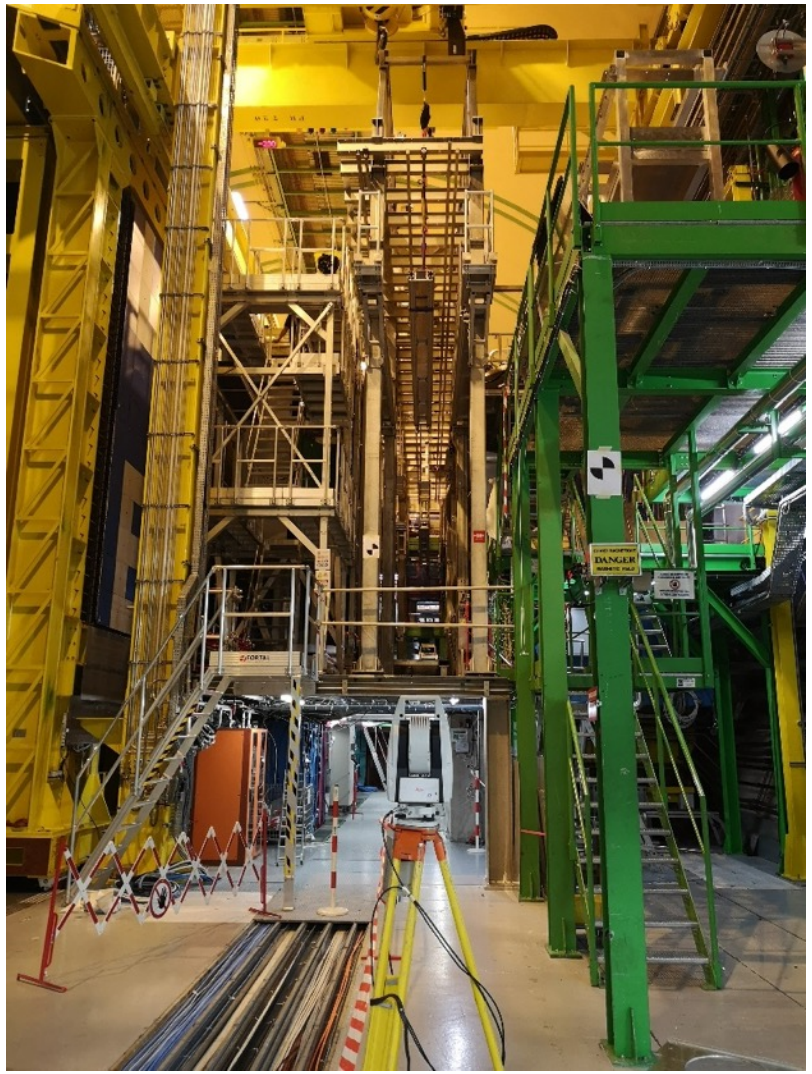


Calibration Result

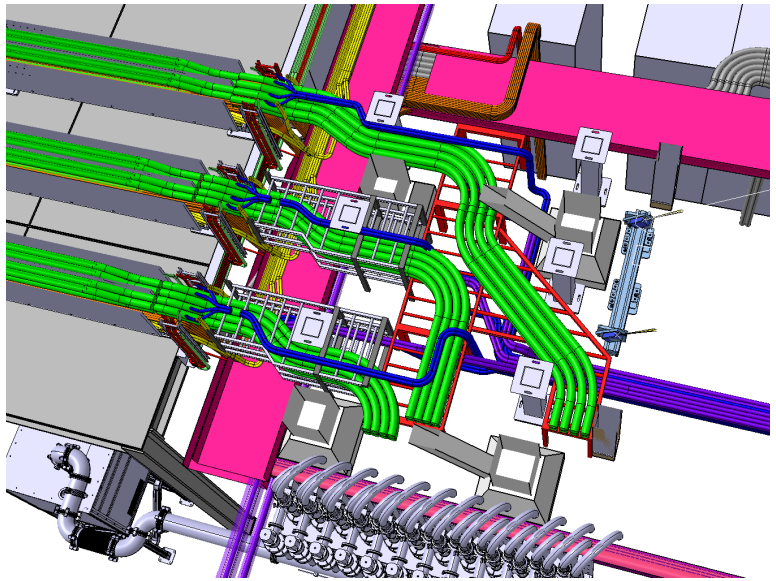


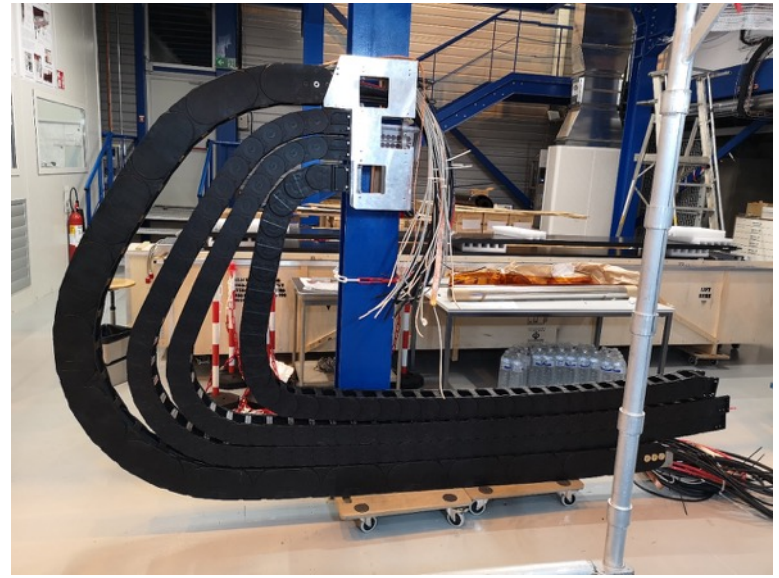
- Light intensity (μ) for one ROB (2048 channels)
- Structures originate from light distribution of the LIS
- Verify that all channels see light

Installation



- Dismantling of old detectors finished
- Progress on integration of all services
- Successfully transported and installed two bare C-Frames

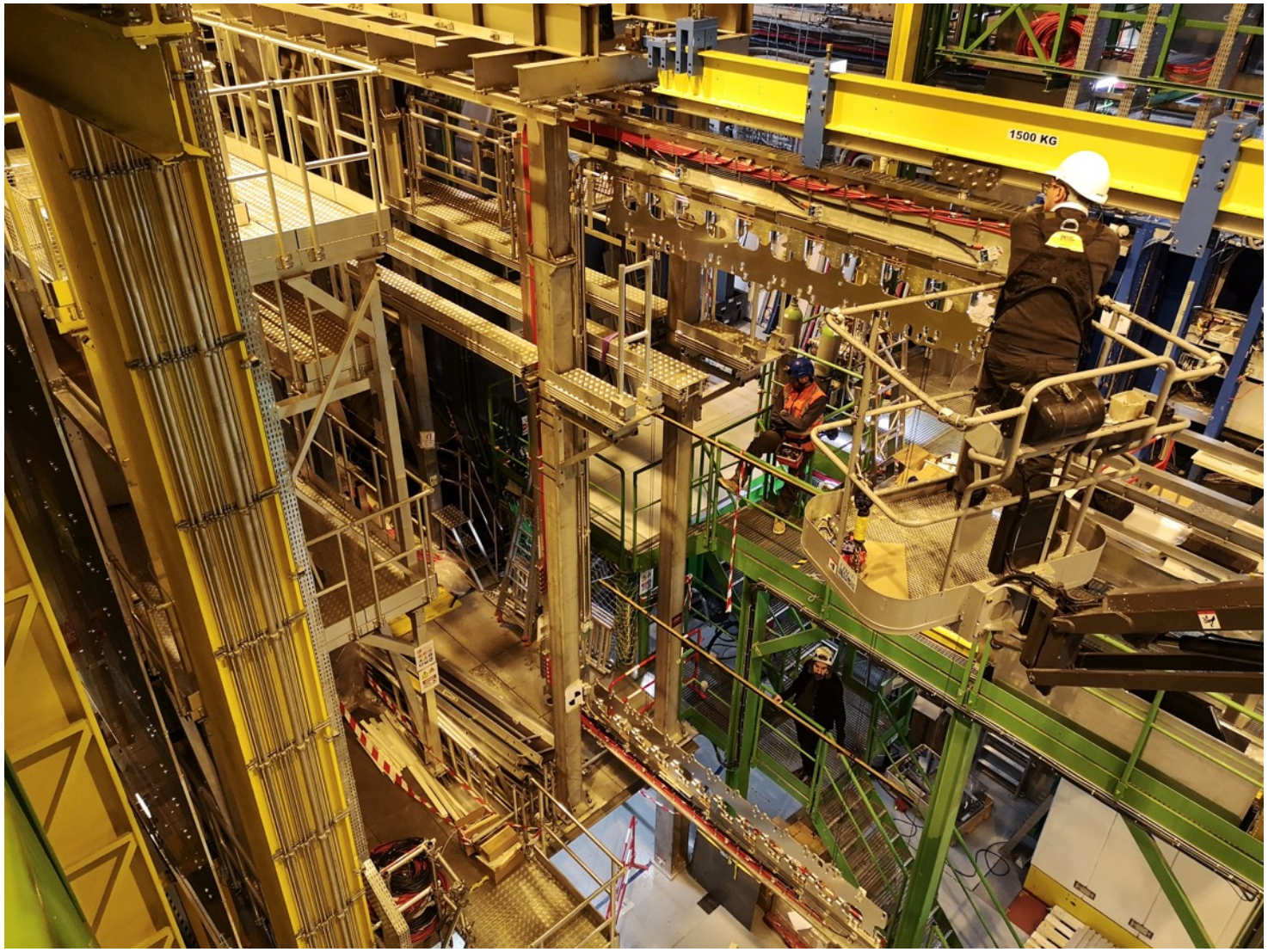


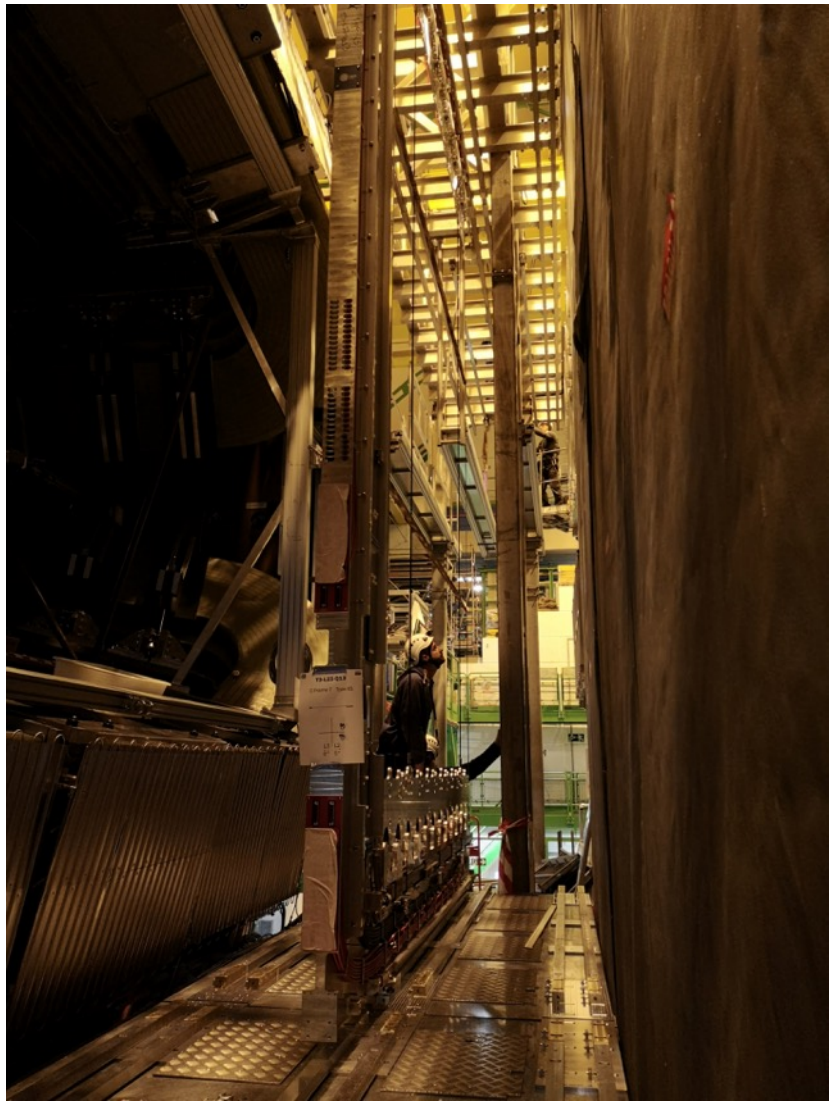


Transport to the Pit

- Test of the full procedure from transport to installation
- Two C-Frames without modules and electronics
- Special transport & storage cage

Installation in the Cavern





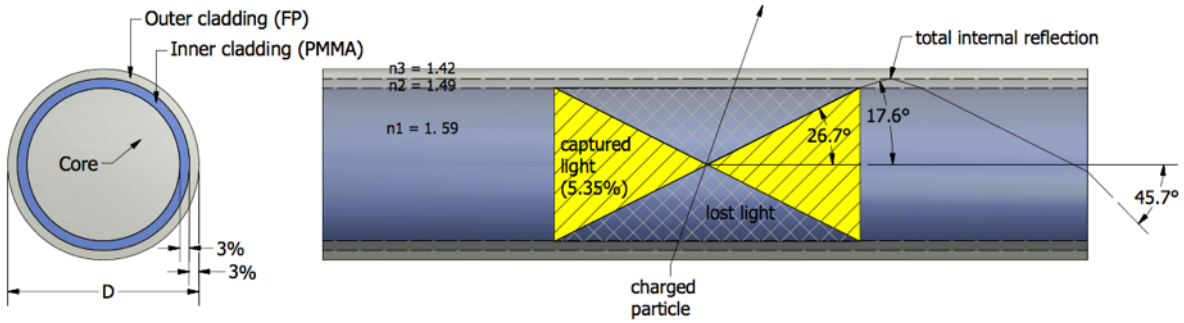
Summary

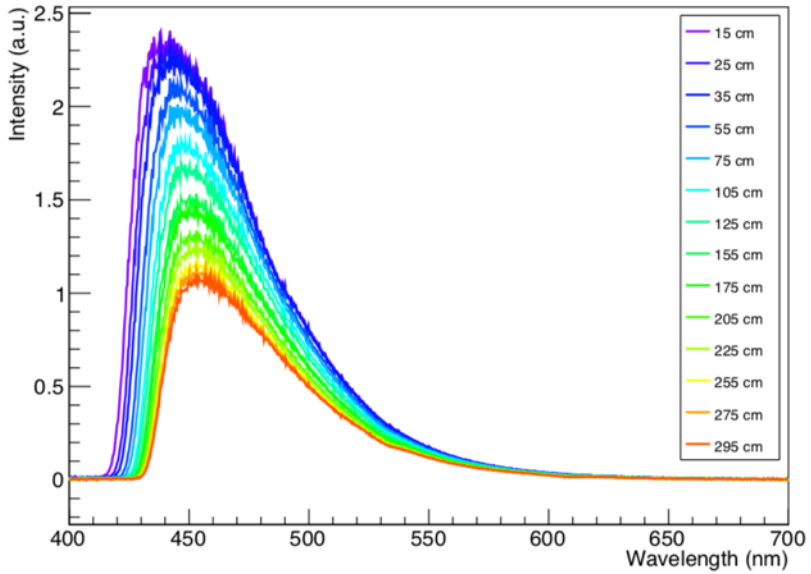
- The LHCb SciFi Tracker is the largest scintillating fibre tracker ever constructed
  - 340 m^2 active area
  - 524,288 channels

- Assembly of C-Frames progressing well
- First C-Frame fully commissioned
- Second C-Frame in last steps of commissioning
  - On halt from 12 March – 18 Mai due to CERN lockdown

Backup

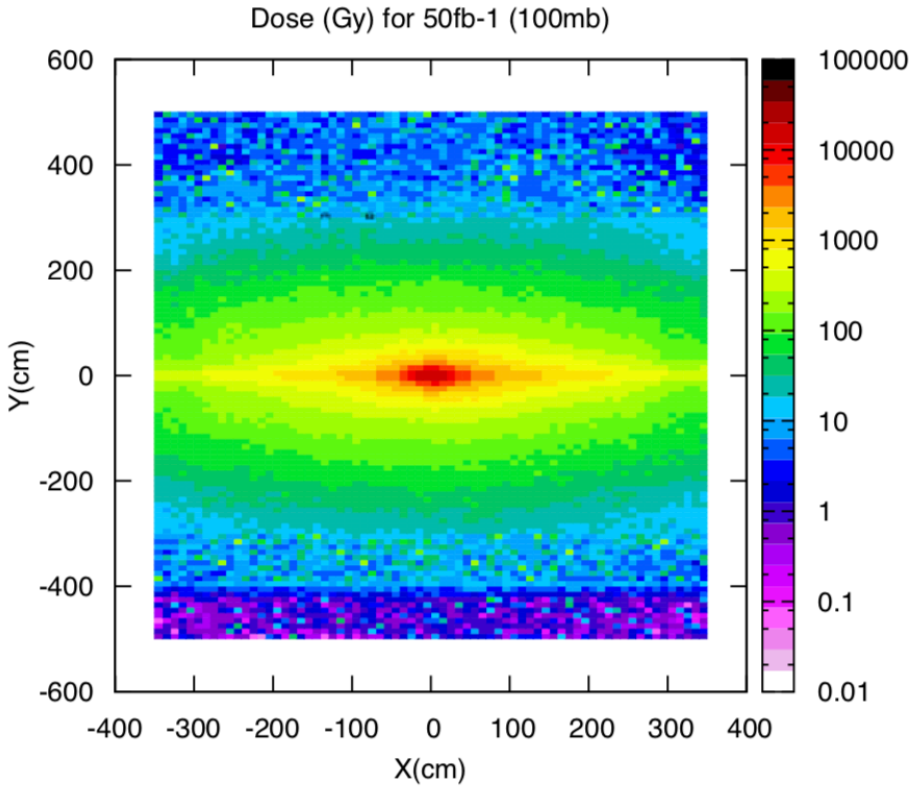
Scintillating Fibres

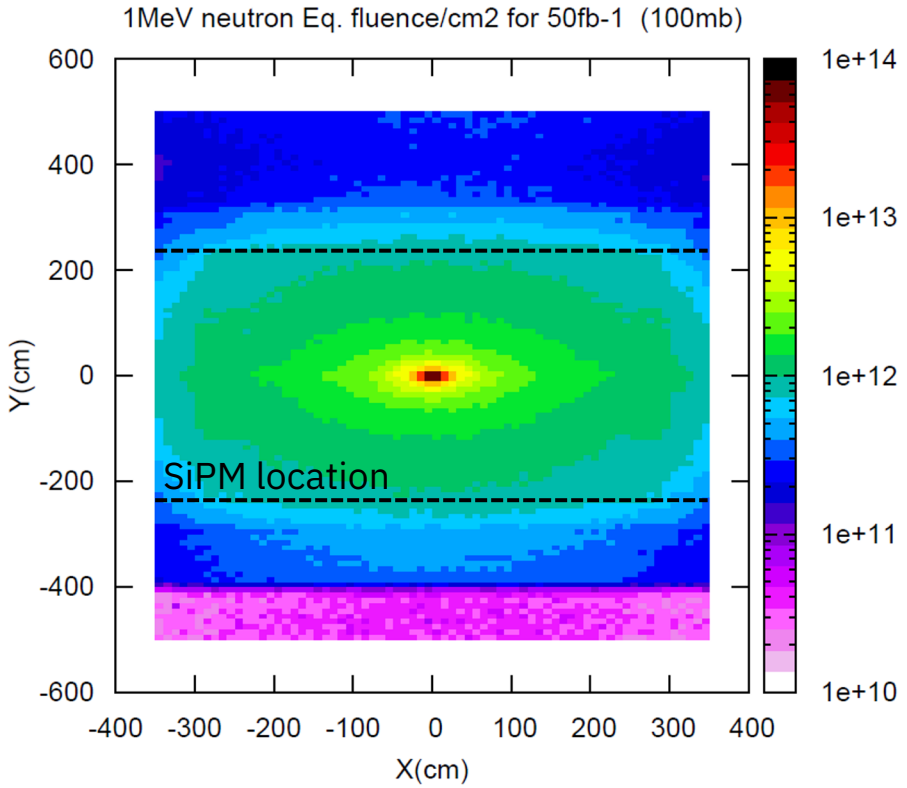




- Kuraray SCSF-78MJ
  - Base Polystyrene
  - Activator PTP
  - Wavelength shifter TPB
- 250 µm diameter
- Emission peak ~450 nm
- Decay time ~2.8 ns
- Attenuation length ~3.5 m

Radiation Environment

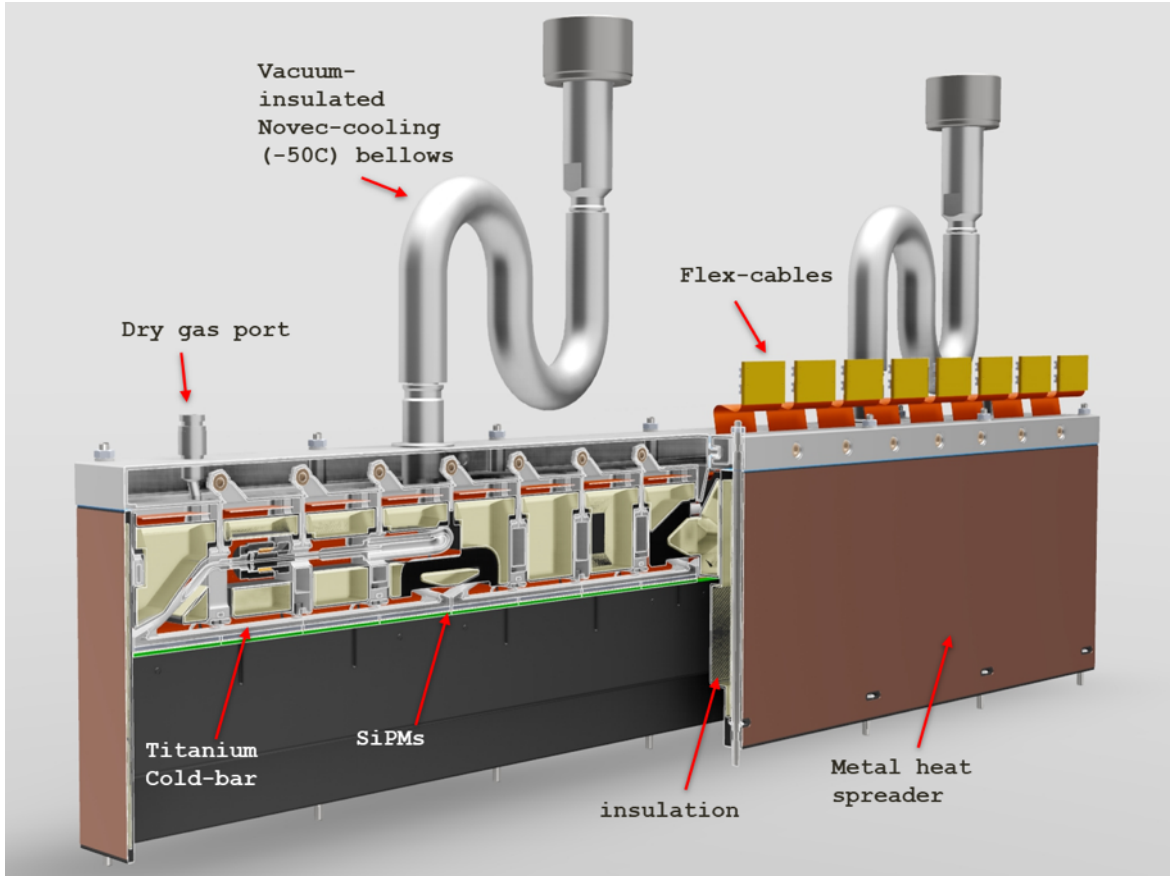




- 35 kGy in the hottest region around the beam pipe

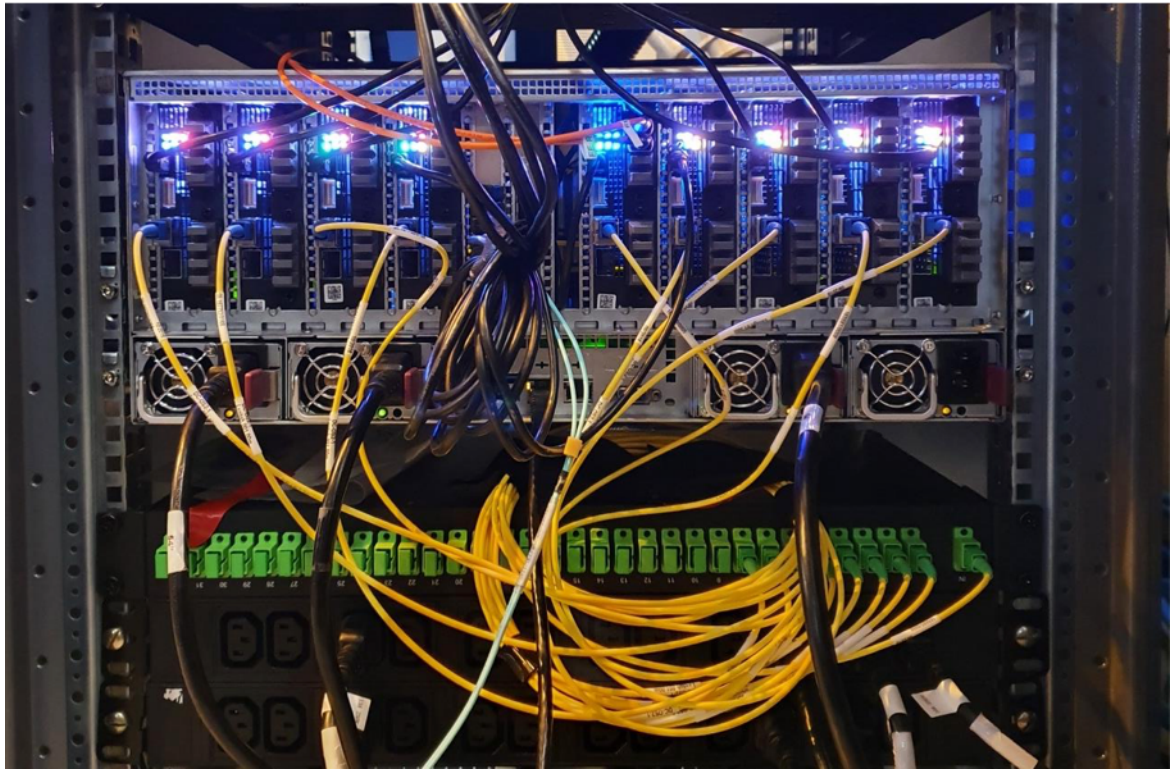
- $6 \cdot 10^{11}\ n_{eq} cm^{-2}$ at the SiPM location
- ~14 MHz/Ch dark count rate at -40 °C

Cold Box



- Insulation for the -40 °C cooled SiPMs
- 3D printed glass-reinforced Nylon structure
- SiPMs mounted on 3D printed titanium Cold Bar

Backend Electronics



Commissioning backend electronics

- 9 × PCIe40 readout cards in one server
- 8 × TELL40
  - Receive data from 48 optical links
- 1 × SOL40/SODIN
  - Distribute clock and triggers
  - Control frontend electronics

PCIe40 Readout Board

- Sends & receives information from up to 48 optical links
- Three configurations within LHCb

1. SODIN
   - Receives & distributes LHC clock
   - Send data to Event Builder
2. TELL40
   - Receives data from frontends
   - Assembles data belonging to the same collision into one event fragment
3. SOL40
   - Interface for timing, slow & fast control to the frontends

Calibration Fit Model

$$Ratio(x) = 1 - \sum_{k=0}^{N} A_k(\mu, \lambda) \cdot \frac{1}{2}\left[1 + \mathrm{erf}\left(\frac{x - p_k}{\sigma_k \sqrt{2}}\right)\right]$$

Photon Statistics:

- Generalised Poisson distribution
- $A_k(\mu, \lambda) = \frac{\mu \cdot (\mu + k \cdot \lambda)^{k-1} \cdot \exp(-\mu - k \cdot \lambda)}{k!}$
- μ: Mean number of detected photons
- λ: Mean number of crosstalk events

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Detector Response:

- Step positions
  - $p_k = p_0 + \sum_{i=0}^{k-1} gain_k$
  - $gain_k$: distance between steps
- Step width
  - $\sigma_k = \sqrt{\sigma_0^2 + k \cdot \sigma_1^2}$
  - σ_0: Electronic noise
  - σ_1: Variation in released charge

Initial Fit Parameters

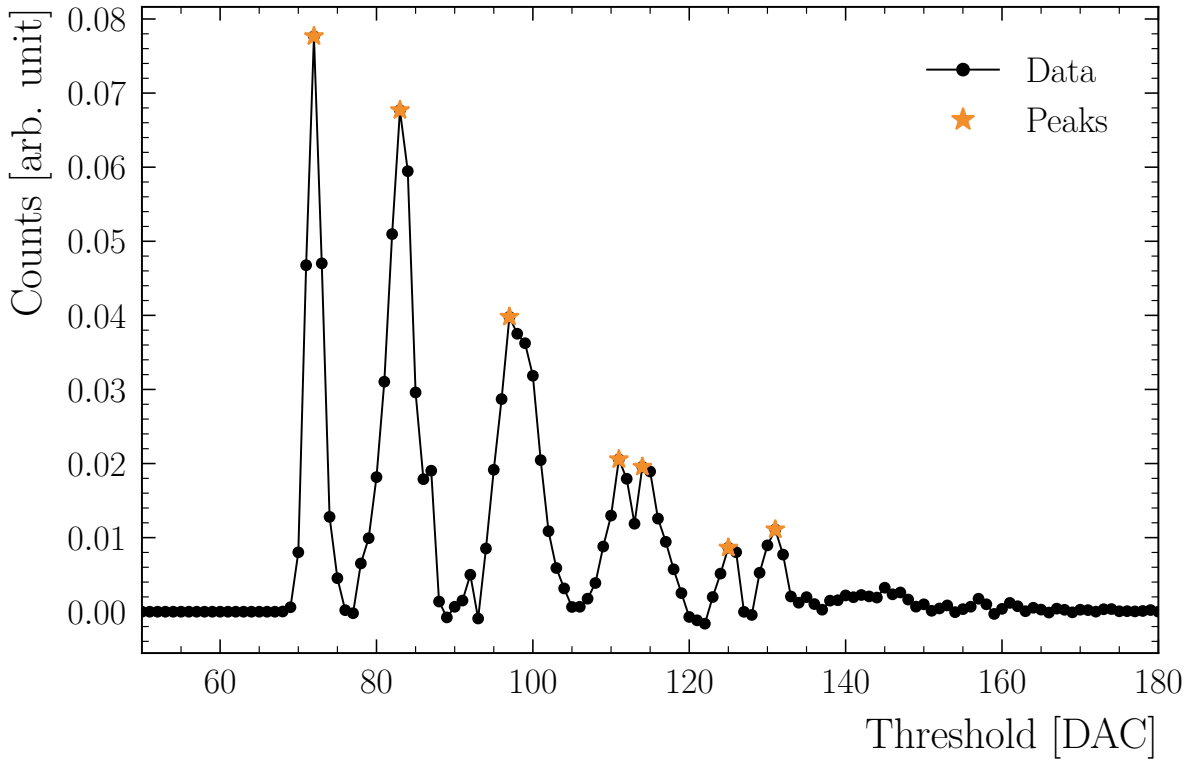
- Estimate initial parameters from peak spectrum (derivative of S-Curve)

1. Find peaks
2. Fit gaussians to peaks
   - Remove duplicates

   → Peak position and area
3. Poisson hypothesis test
   - Remove outliers

   → μ and λ
4. Determine p_0 and $gain_k$ from remaining peaks

→ Fit S-Curve



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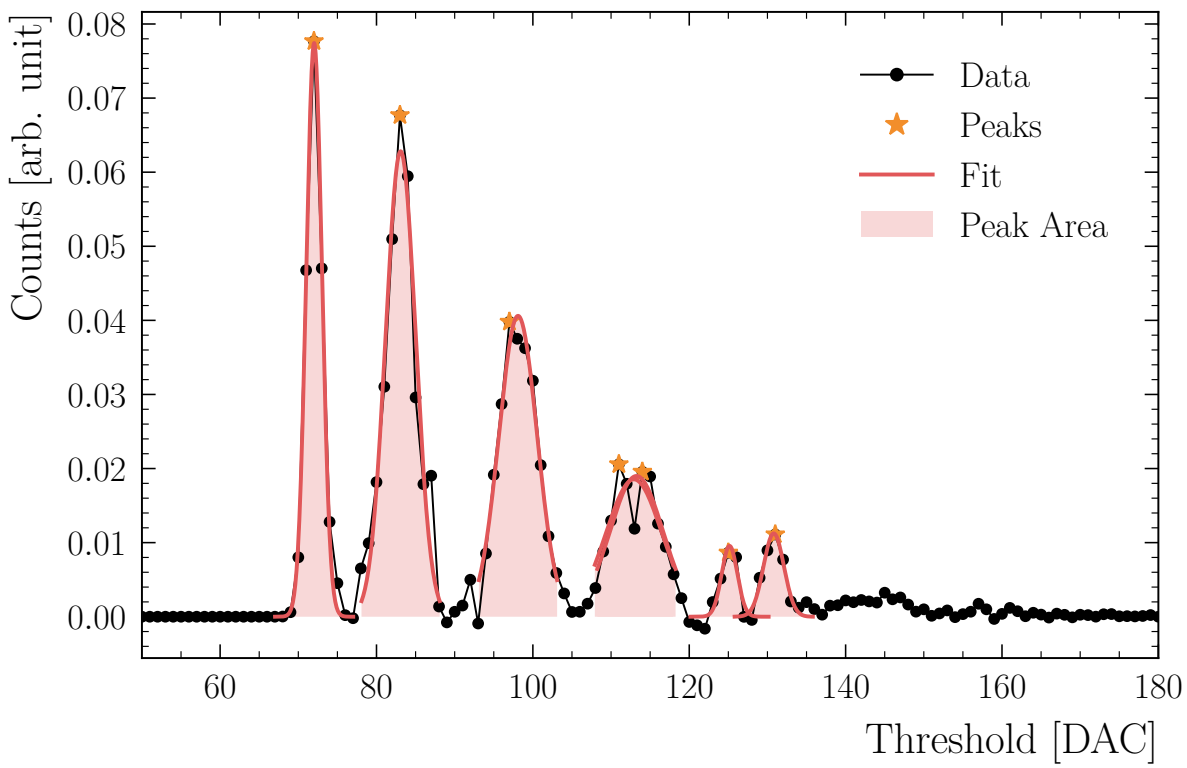

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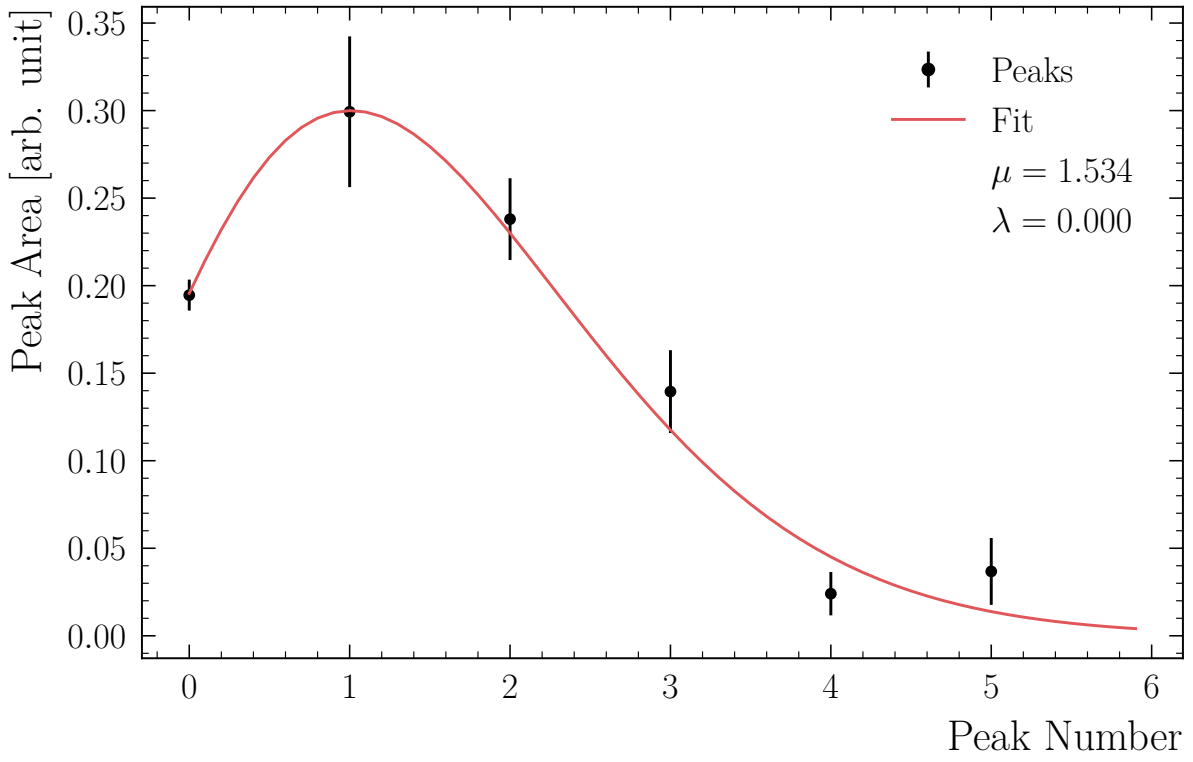

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