Test of LHCb SciFi readout electronics

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on behalf of LHCb collaboration

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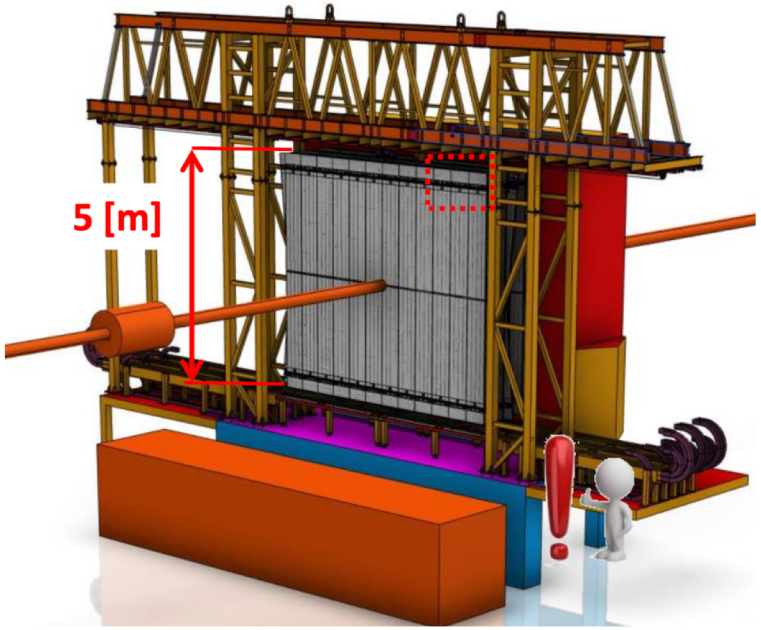
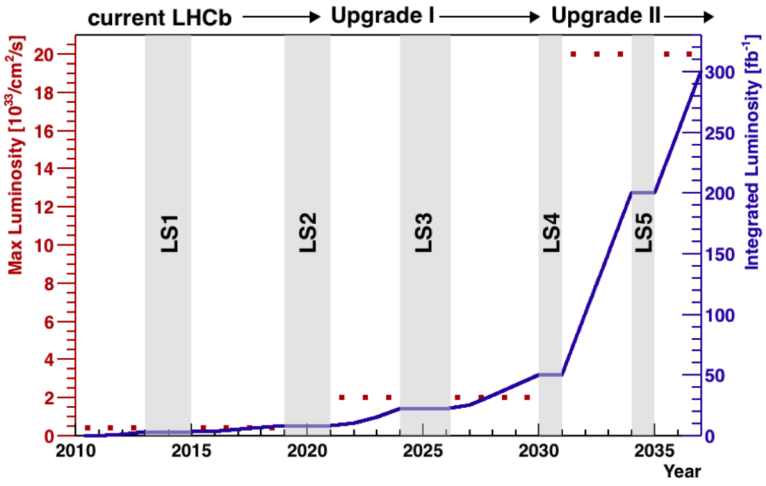
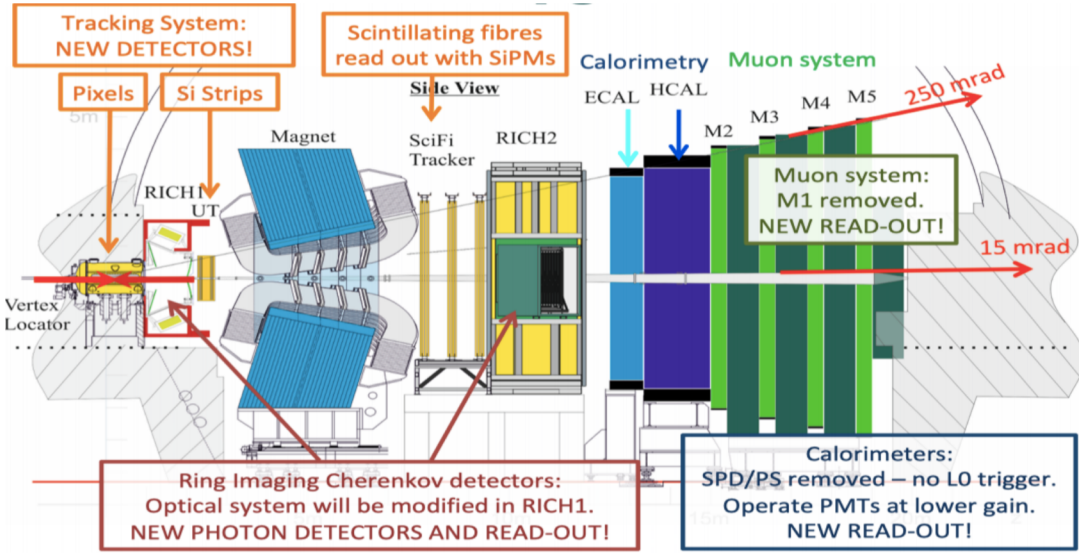
The 6th China LHC Physics Workshop



LHCb Upgrade 1

- Measurements limited by 1 MHz hardware trigger
  - rare decay, CPV, spectroscopy …
- LHCb Upgrade-1 during LS2
  - $\mathcal{L}_{inst} \sim 2\times10^{33}\,cm^{-2}s^{-1}$, accumulate 50 fb^{-1} in Run 3&4
  - Software trigger only, readout all detectors at 40 MHz
  - Tracking system: NEW DETECTORS





Upgrade downstream tracking

Current tracking

- 2 sub-systems:

  Inner Track, Outer Tracker

- Outer Tracker
  - 24 layers of 5mm gas drift tubes (2.5m straws)
  - Resolution~200 μm
- Inner Tracker
  - silicon strip sensors with 0.18-0.20 mm pitch
  - Resolution~50 μm
- Too high occupancy @ higher lumi.
- Need new electronics @ 40 MHz

Upgrade tracking

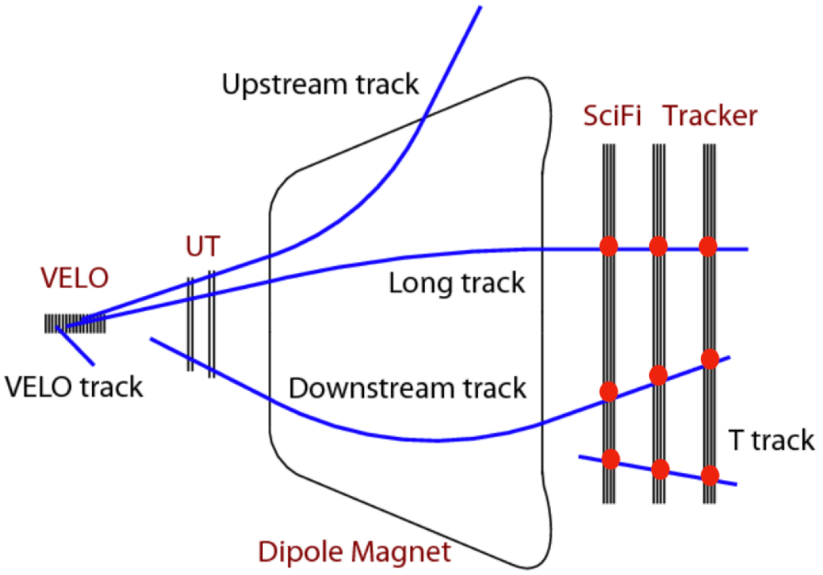
- new detector:

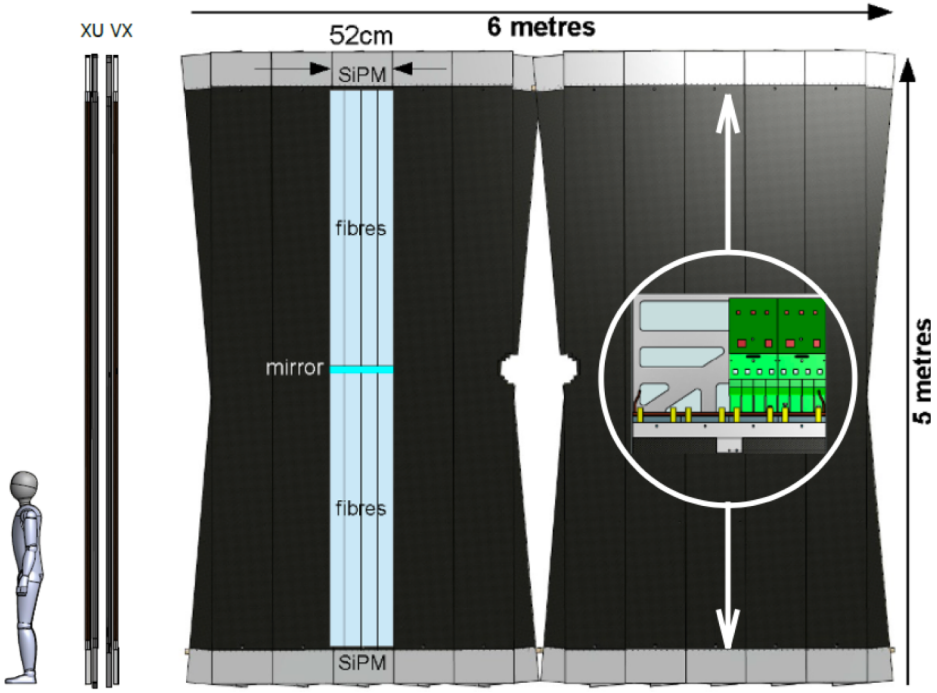
  One single tracking technology

- 12 fibre mat layers composed of scintillating fibres (l=2.5m, d=0,25mm) in 3 stations of X-U-V-X
- Single hit resolution <100 μm
- Single hit efficiency: 99%
- **Readout at 40MHz in accordance with software-only trigger**
- **Be able to run at higher luminosity**

Scintillating Fibre (SciFi) Tracker

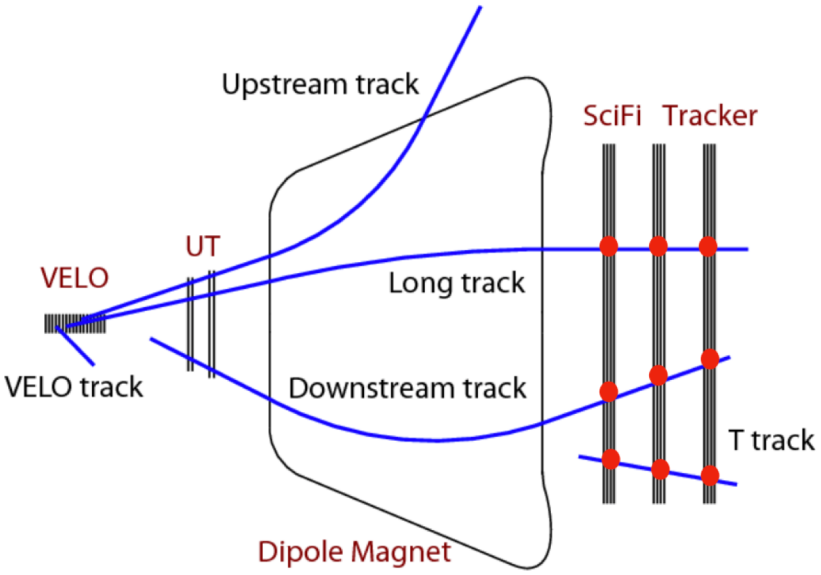
- 3 stations x 4 detector planes (x-u-v-x, 2 are tilted by ±5°)
- 24 modules per planes, top + bottom
- Scintillation light detected with Silicon Photomultipliers (SiPM)
- Large area, total of 6×5 m^2
- 2048 detector channels per module, **590k** channels in total

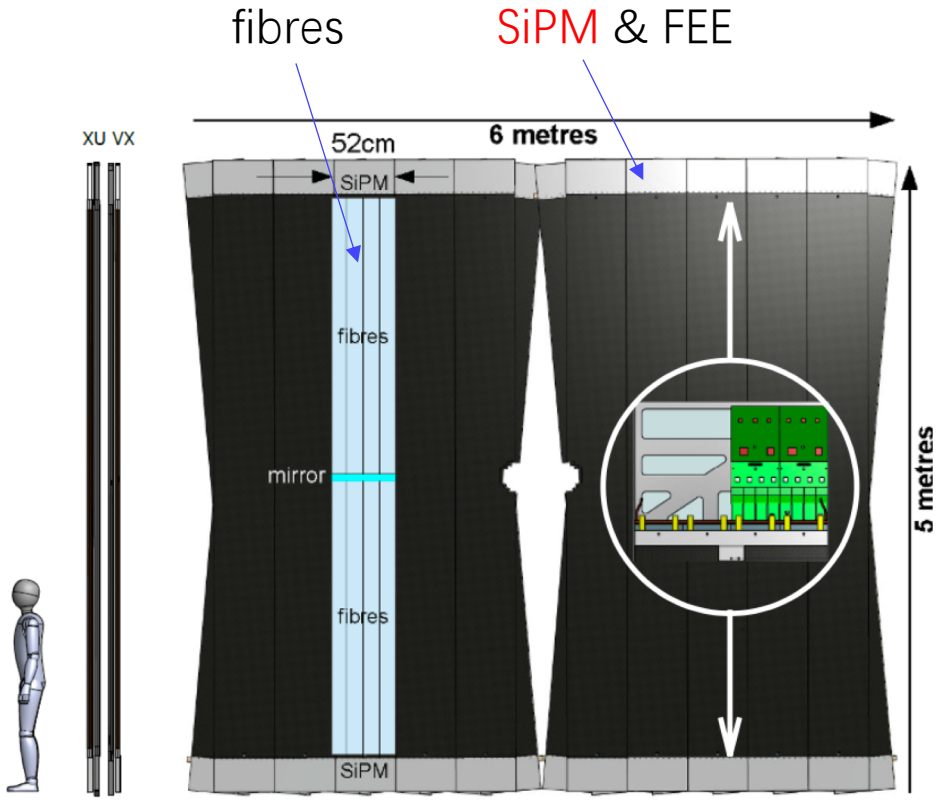




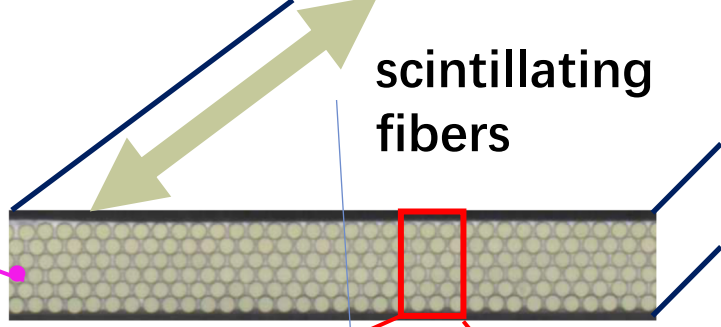
Scintillating Fibre (SciFi) Tracker

- 40 MHz readout
- Minimize material, X/X_0 < 1% per layer
- Radiation resist to 35 kGy
- Hit efficiency ~ 99 %
- Hit resolution < 100 μm



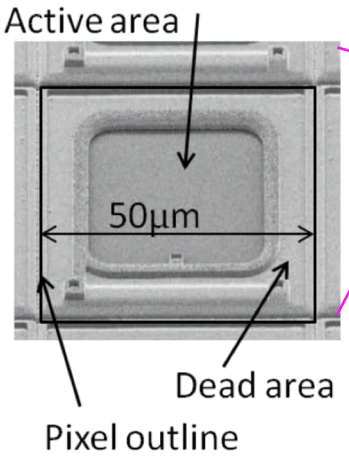


SciFi Detector Principle

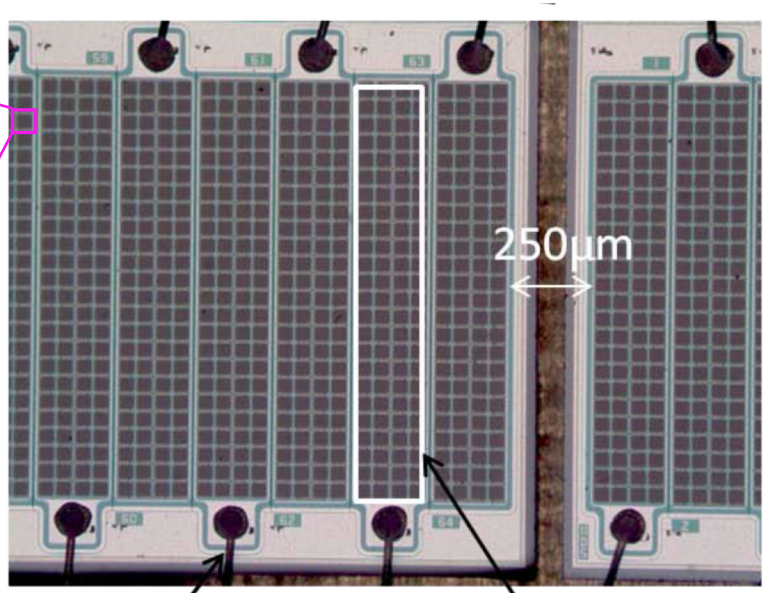


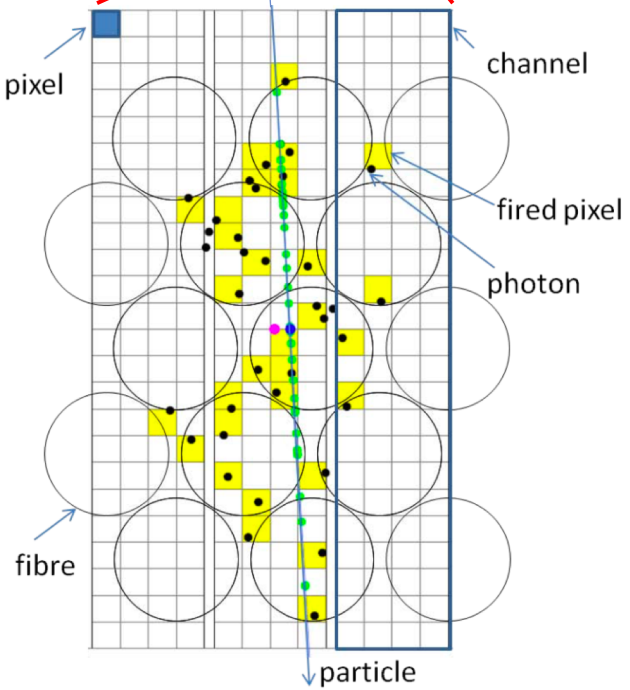
Fibre: 2.5m ×0.25 mm

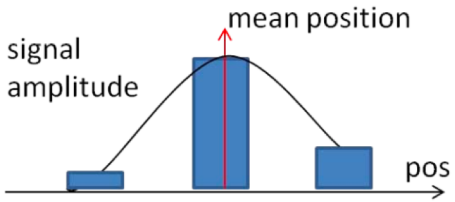
SiPM: Light Detector



SiPM array

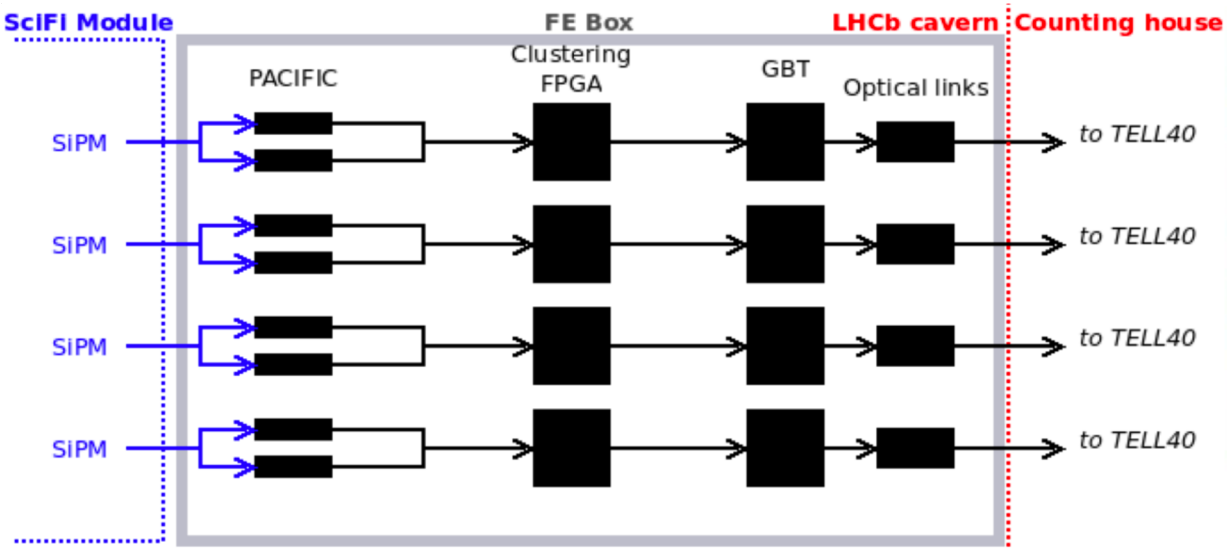


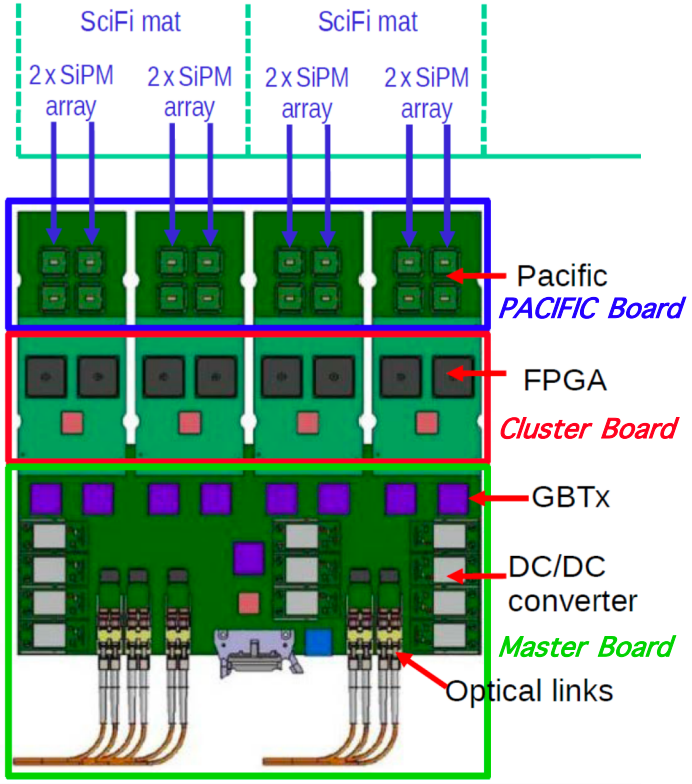




Grouping neighbor SiPM channels to improve spatial resolution <100 μm

Front-End Electronics

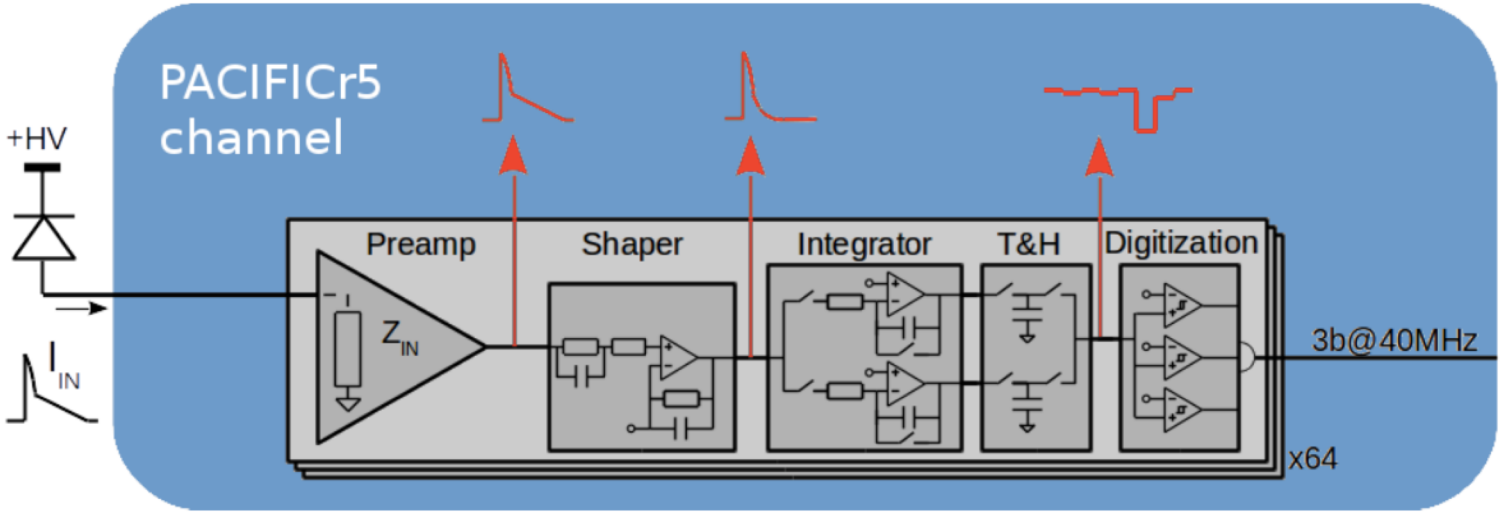




- SiPM are connected to the FE chip (PACIFIC) using a flex cable
- PACIFIC: 64 channel ASIC with the analog processing and digitization
- Clustering FPGA to handle the digital processing (zero-suppression)
- GBT: CERN ASICs (GBTx, GBT-SCA, GBLD) handling the electrical to optical conversion, the slow control and the timing
- TELL40: Standard data acquisition (DAQ) system board for LHCb

PACIFIC

- Low Power Asic for the sCIntillating FIbre traCker readout
- CMOS 130 nm technology
- 64 channel current mode input (10 mW/channel)
- Fast shaping to reduce spillover
- Double gated integrators to avoid dead time
- 2-bit/channel from 3 hysteresis comparators



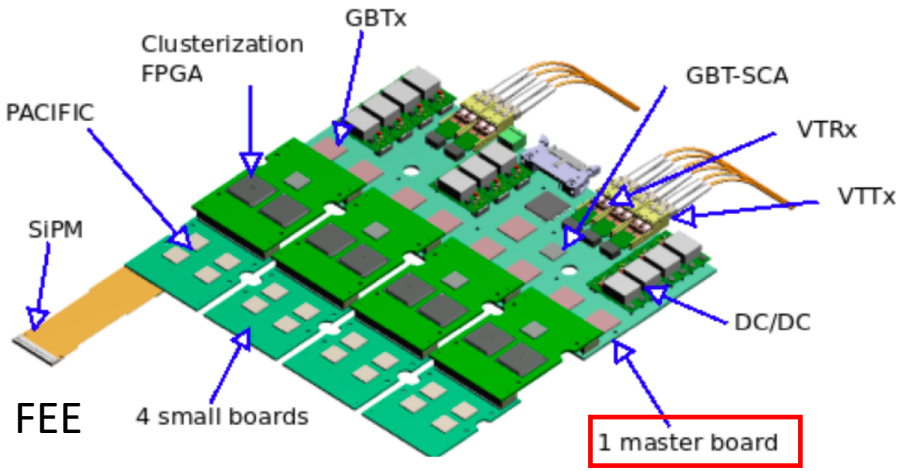
Preamplifier, Shaper, Integrator, Track & Hold, Digitization

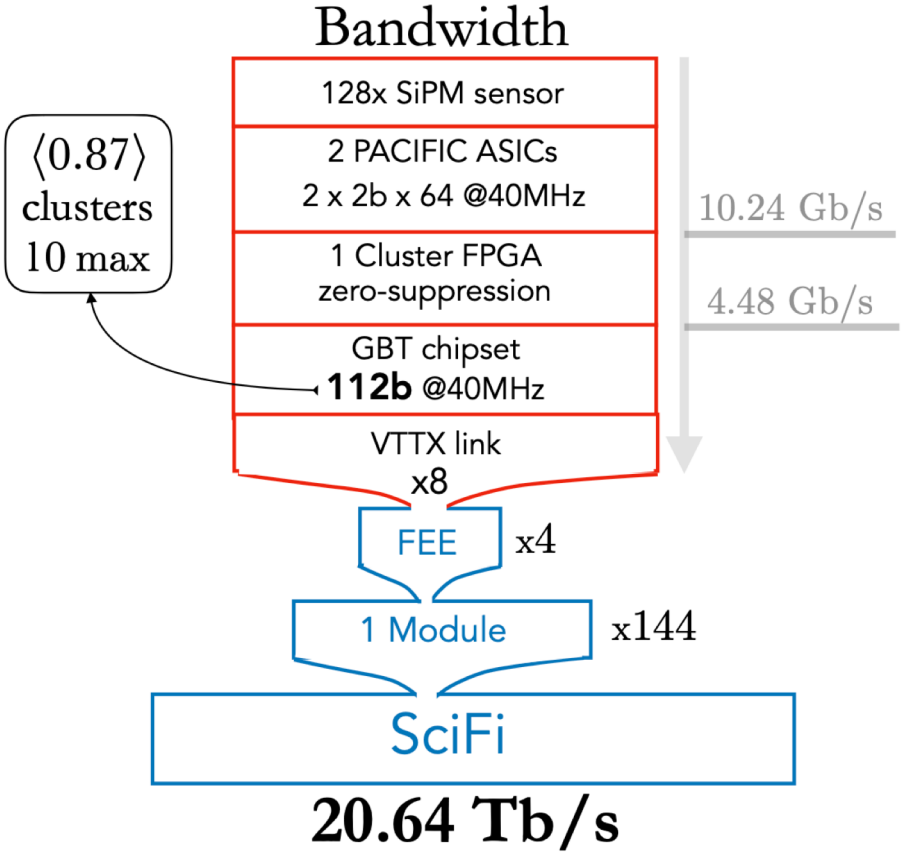
Cluster board

- Cluster building and zero suppression by FPGA on clusterization board
- Mostly no cluster size > 4 (from simulation)
- Simple barycenter computation
  - Algorithm: ($Q_{seed}>Q_1$ & $Q_{neig}>Q_0$) or $Q>Q_2$
  - Position from cluster barycenter

Master board

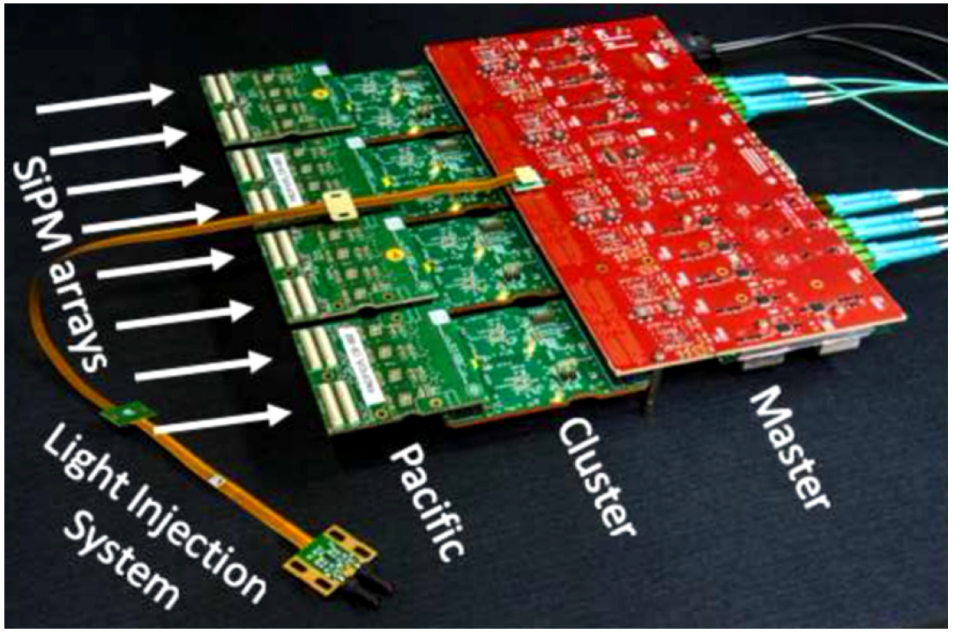
- Data transmission & Slow control & Timing
- 8+1 GBT chipset (data + control)

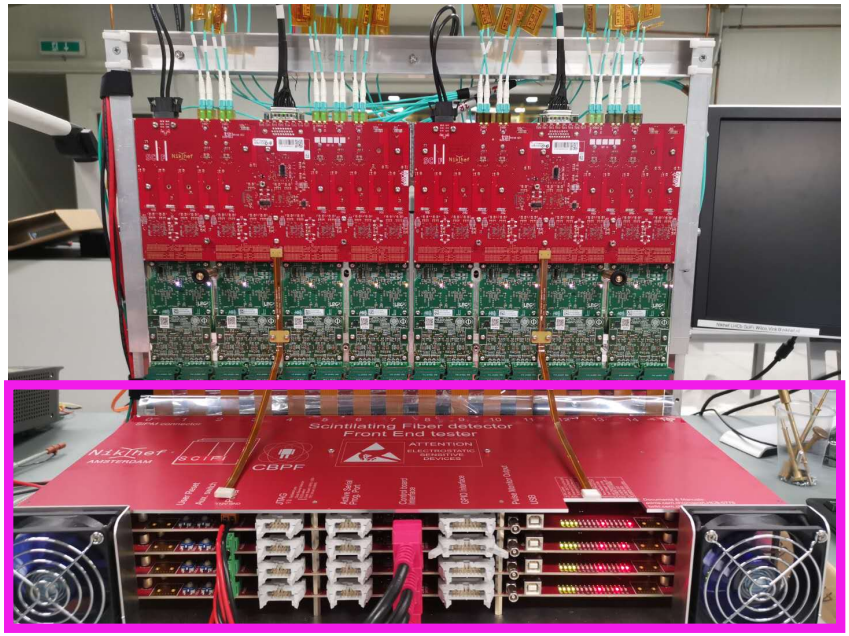




Commissioning

- Test FEE before installation, ~ 300 in total
- Test-system: 2048 (128×16) independent pulse generator to fully characterizes the RoB prior to the installation

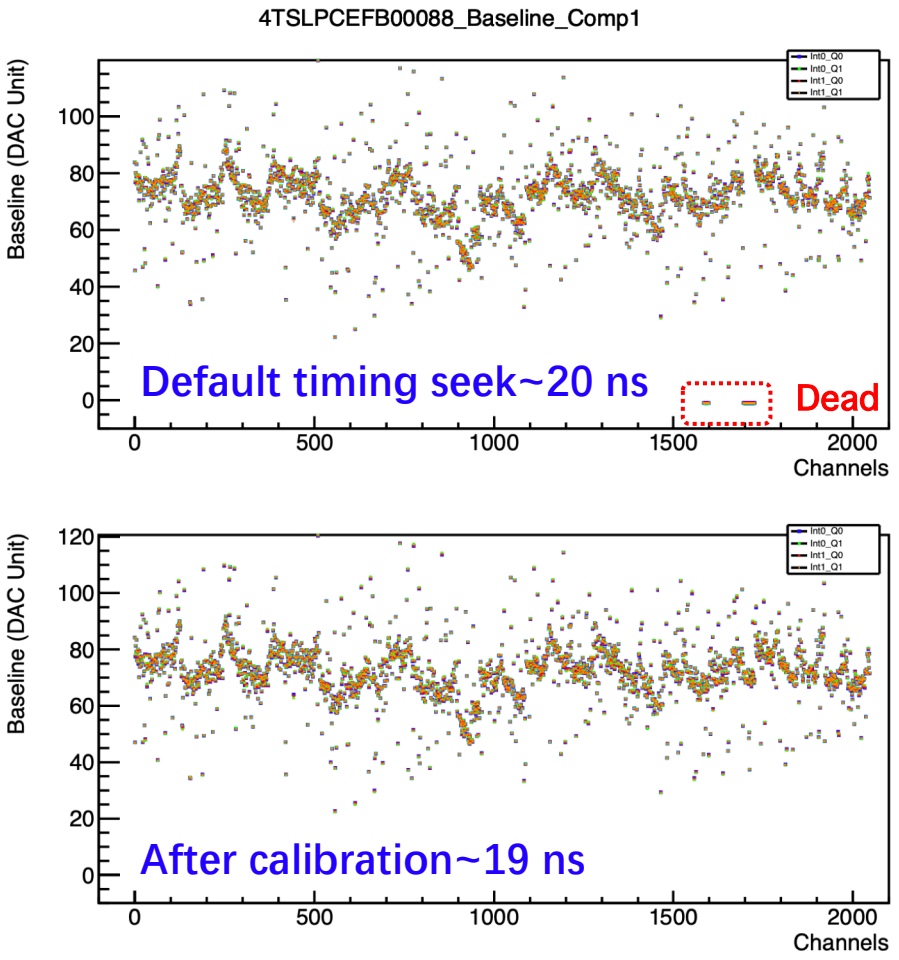




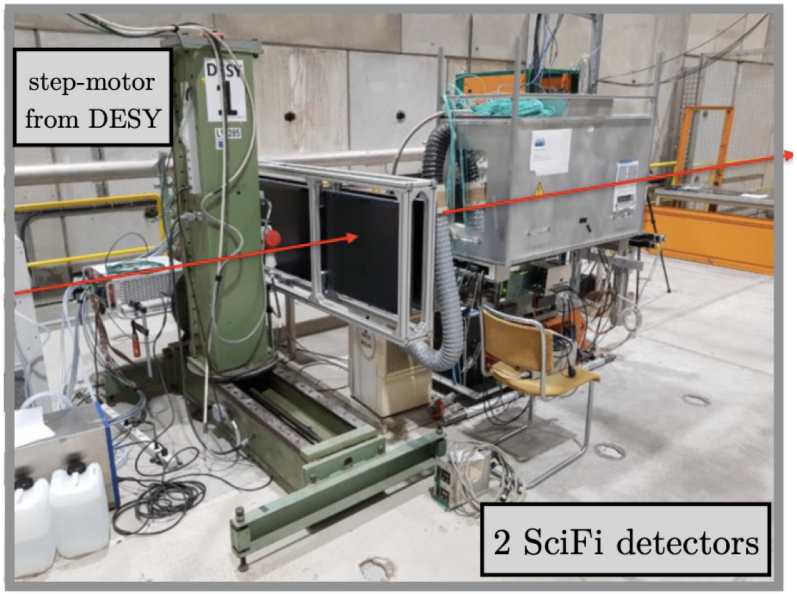
SciFi FEE tester

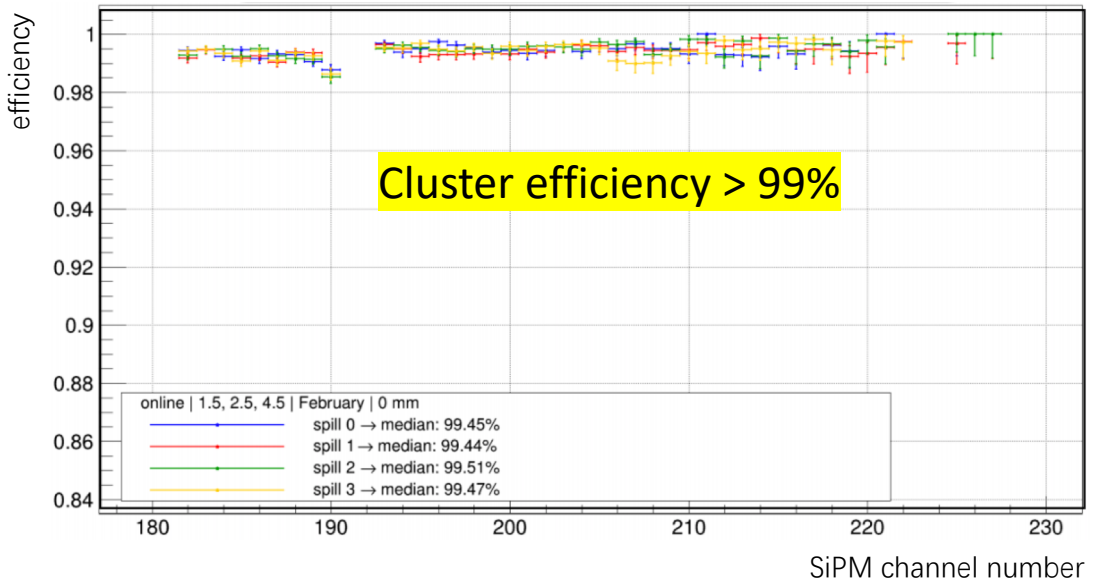
Commissioning

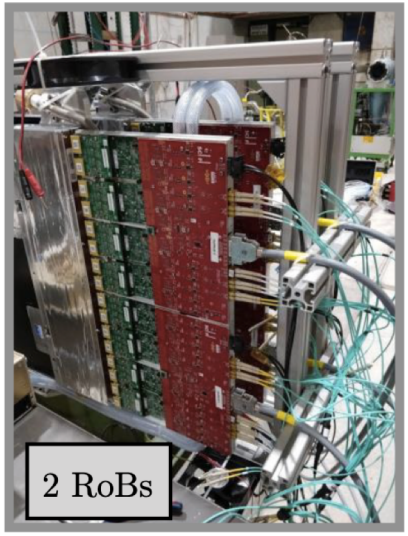
- FEE tester control system developed
- Read-out data analysis
- ~90 installed
- ~130 ready
- ~60 problems
  - PACIFIC dead channels
  - PACIFIC cross-talk
  - low gain
  - FPGA not programming
  - to be recover…



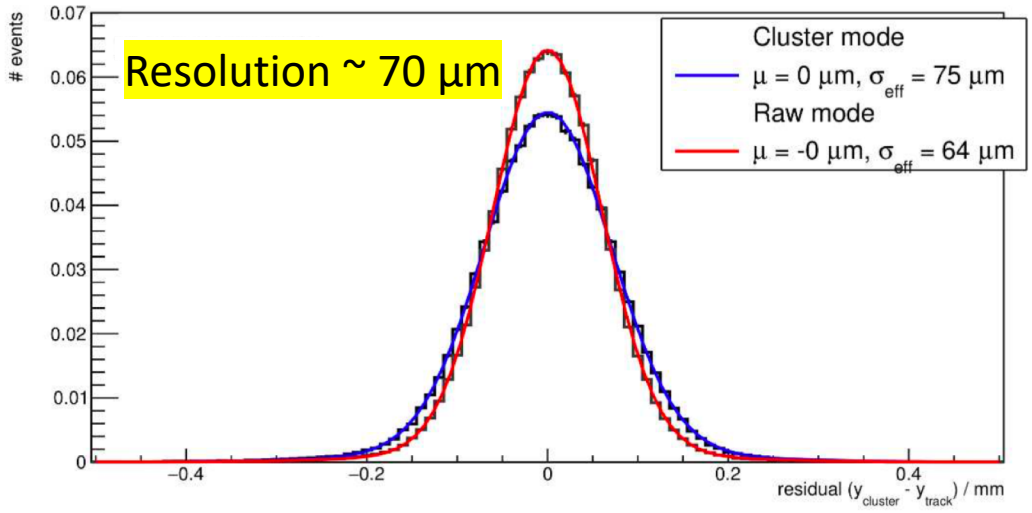
Test-beam @CERN & Performance







2 final Modules+FEE tested successfully with 450 GeV protons @CERN in July 2018



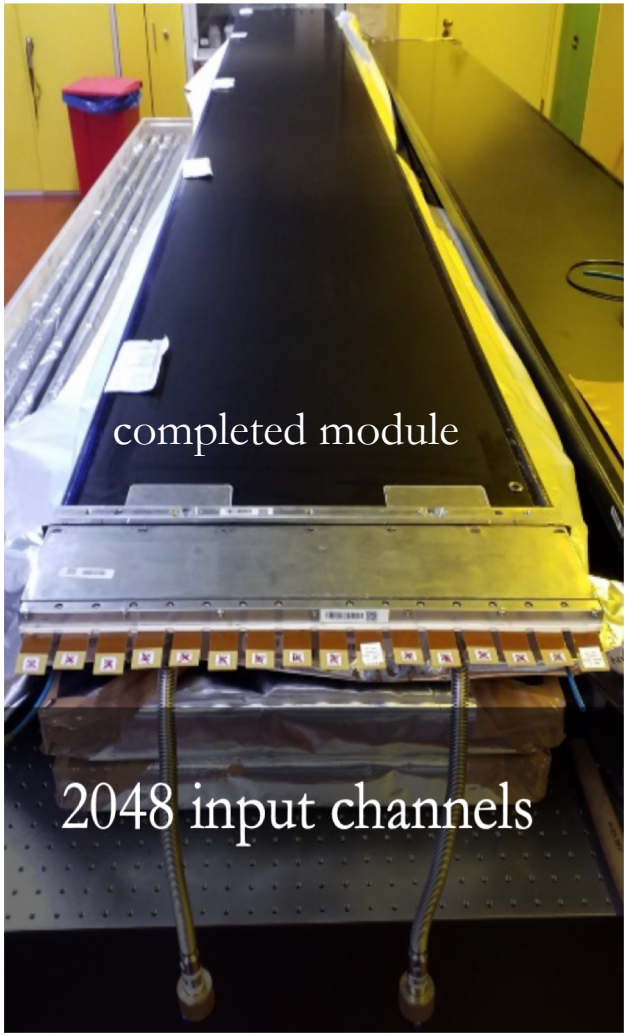
Summary

- LHCb SciFi team is finalizing the construction of the largest Scintillating Fiber tracker, able to run at 40 MHz
- Ø 0.25mm scintillating fibres, read-out with SiPMs
  - Hit position resolution ~ 70 μm, hit efficiency > 99%
- Satisfied all Tracker requirements, as cluster efficiency and spatial resolutions, FEE test mostly completed
- Successfully achieved desired performance in test-beam
- LHCb-China group contributions:
  - CCNU involved in PACIFIC QA test; Fiber test; TestBeam data analysis
  - UCAS involved in full front-end electronics test
  - Tsinghua involved in PACIFIC Carrier board design, tested 50% production; PACIFIC ASIC and Carrier Board QA system developed by Tsinghua; TestBeam & data analysis; SciFi assembling

Thanks for your attention!

Backup

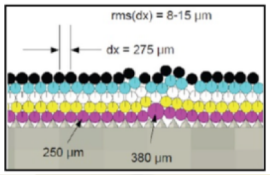
FEE Challenges and Requirements

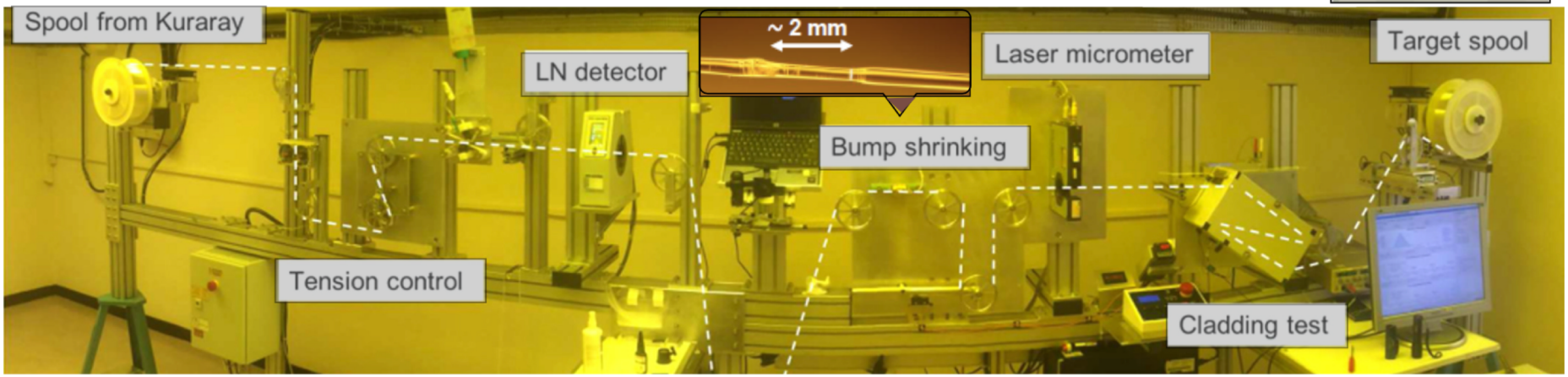


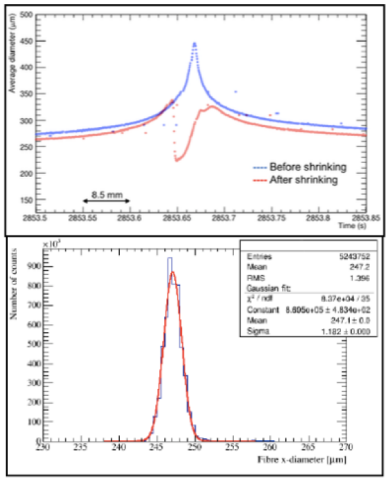
- 2048 channels @40 MHz per module, 288 modules needed
  - power consumption, high throughput
- large δ_{shape} SiPM signals (~18 p.e)
- signal exceeds 25 ns
  - fast shaping and integrators
- 14 MHz DCR/channel (-40 ^{0}C & radiation)
  - efficient noise reduction
- Clusterization Algorithm
- Optimizing bandwidth
- …

Scintillating fibers: Quality Assurance

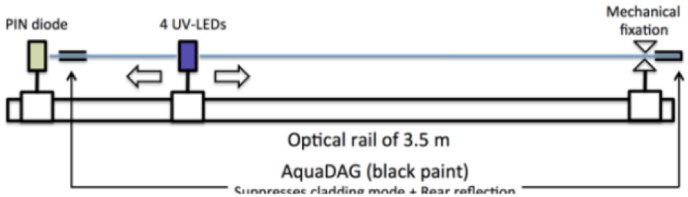
- Diameter monitoring & cladding integrity & bump shrinking > 350 μm





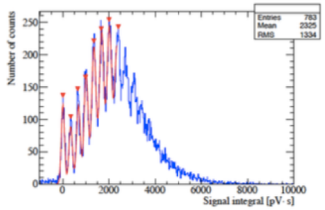


- Attenuation length

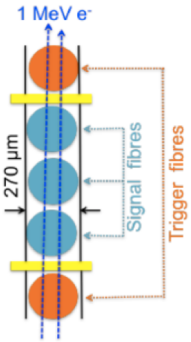


- Resistance to X-rays
- Minimum bending radius, decay time, natural aging *for a fraction of fibres*

- Ionization light-yield



10 p.e visible



Cold-box

- Each Cold-box houses 16 SiPMs cooled at **-400 C** by **Novec** 649 circulating in vacuum insulated lines
- Provides precise SiPM alignment
- Dry air flushing prevents ice formation (-700 dew point)
- 3D print Ti bar design copes termal expansion