SciFi – A Large Scintillating Fibre Tracker for LHCb

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on behalf of the

LHCb-SciFi-Collaboration

14th Topical Seminar on Innovative Particle Radiation Detectors, Siena

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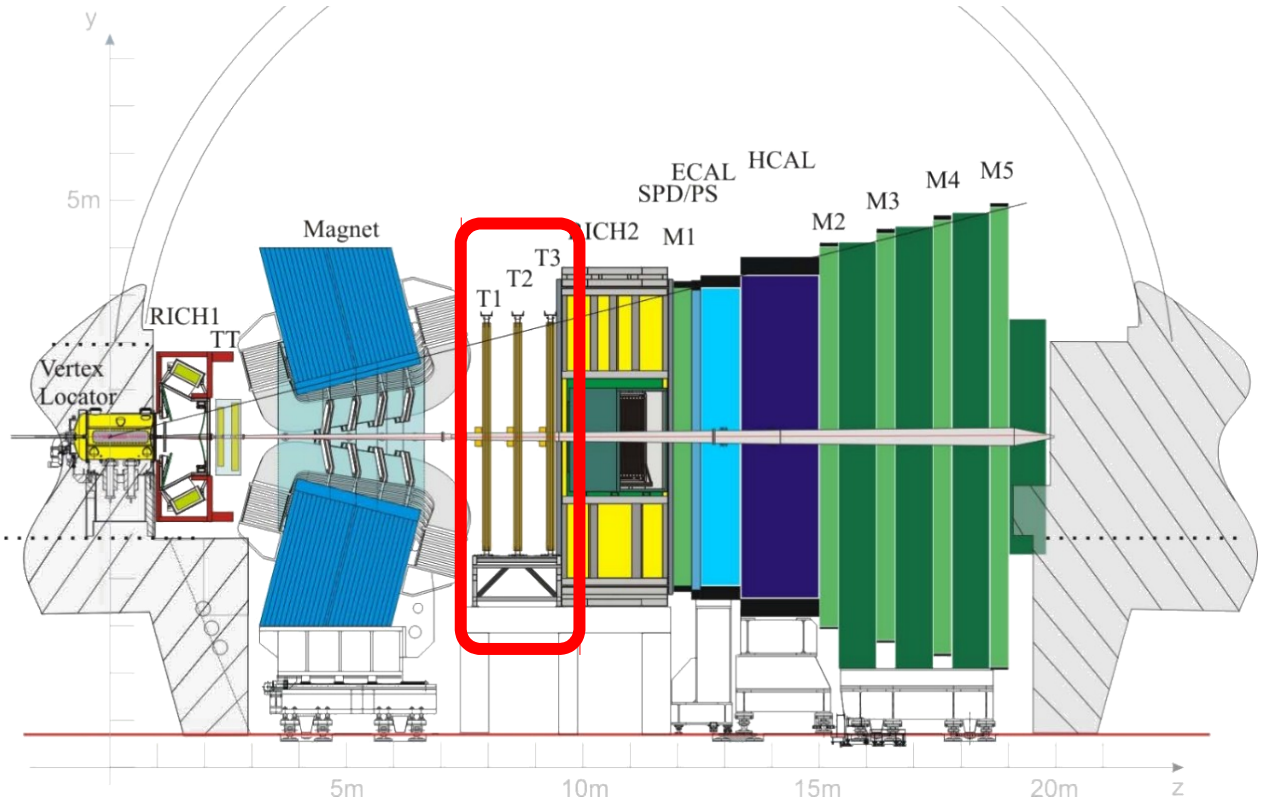
I. Physikalisches Institut

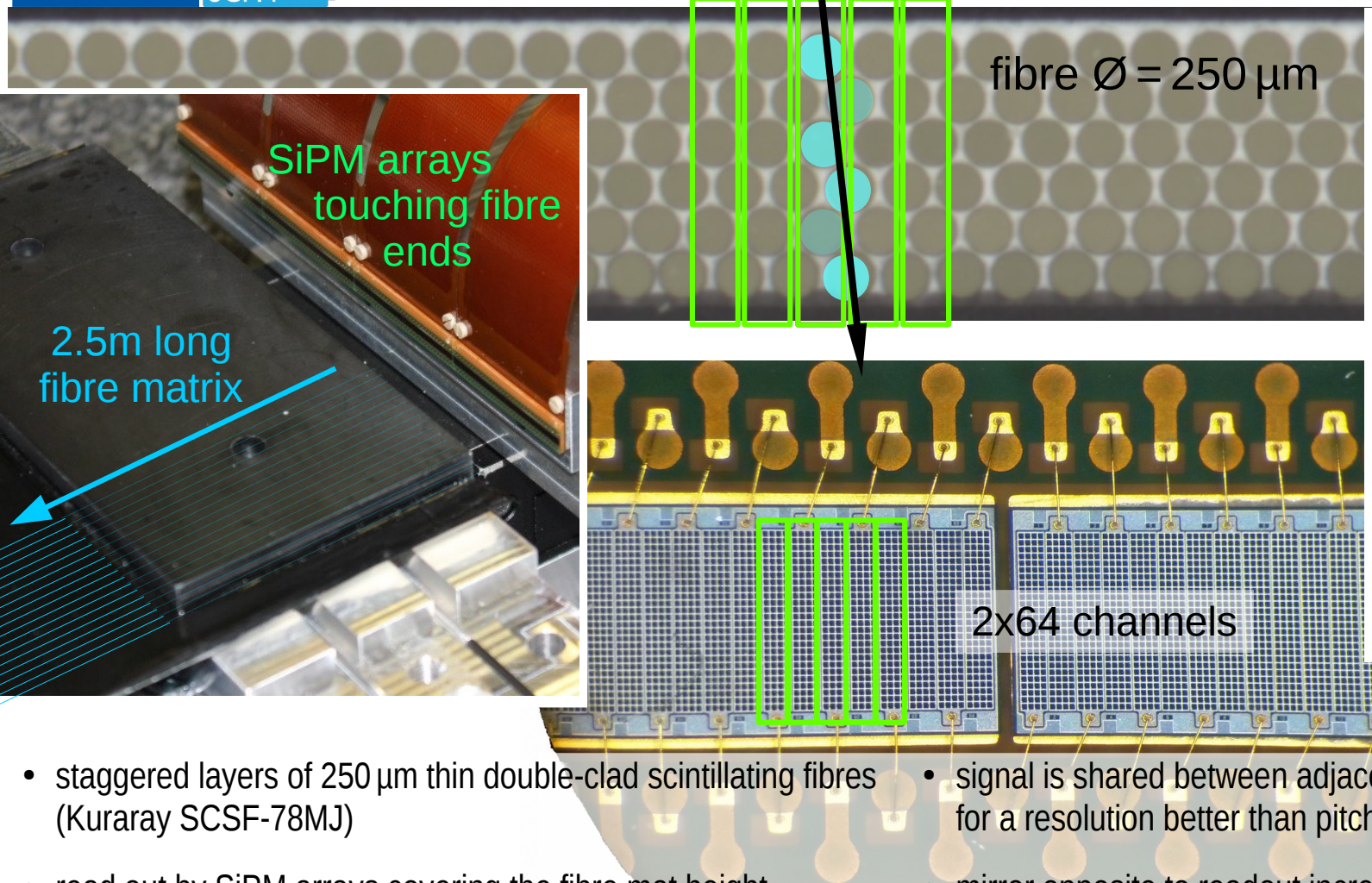
RWTH AACHEN UNIVERSITY

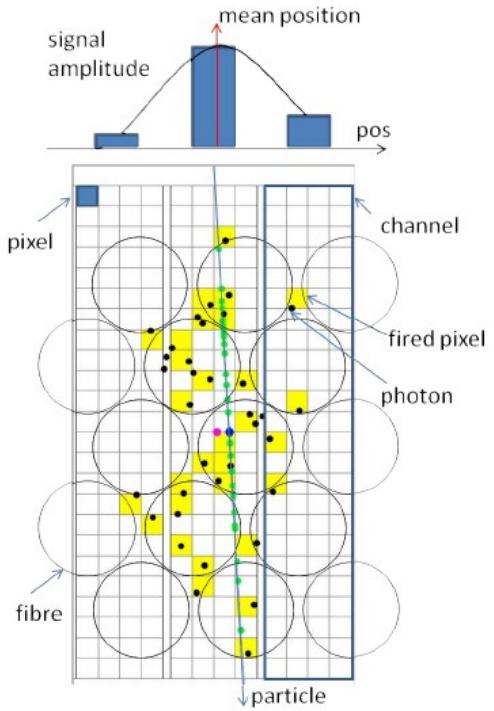
LHCb Detector Upgrade

- goal: 50 fb^{-1} integrated luminosity
  - increase the statistics significantly (rare decays)
  - limited by 1 MHz hardware trigger, and
  - limited by detector occupancy
- Major tracking upgrade during LS2 in 2020
  - 40 MHz detector readout → full software trigger
  - RICH: new photon detectors (→ talk by C. Gotti)
  - Calorimeter: remove SPD/PS, new readout
  - Muon System: remove M1, new readout
  - Tracking System:
    - new VELO (→ talk by M. Williams)
    - replace TT with new silicon micro-strip detector (→ poster by S. Coelli)
    - replace IT (silicon) & OT (straws) with SciFi tracker (scintillating fibres with SiPM array readout)



SciFi Principle

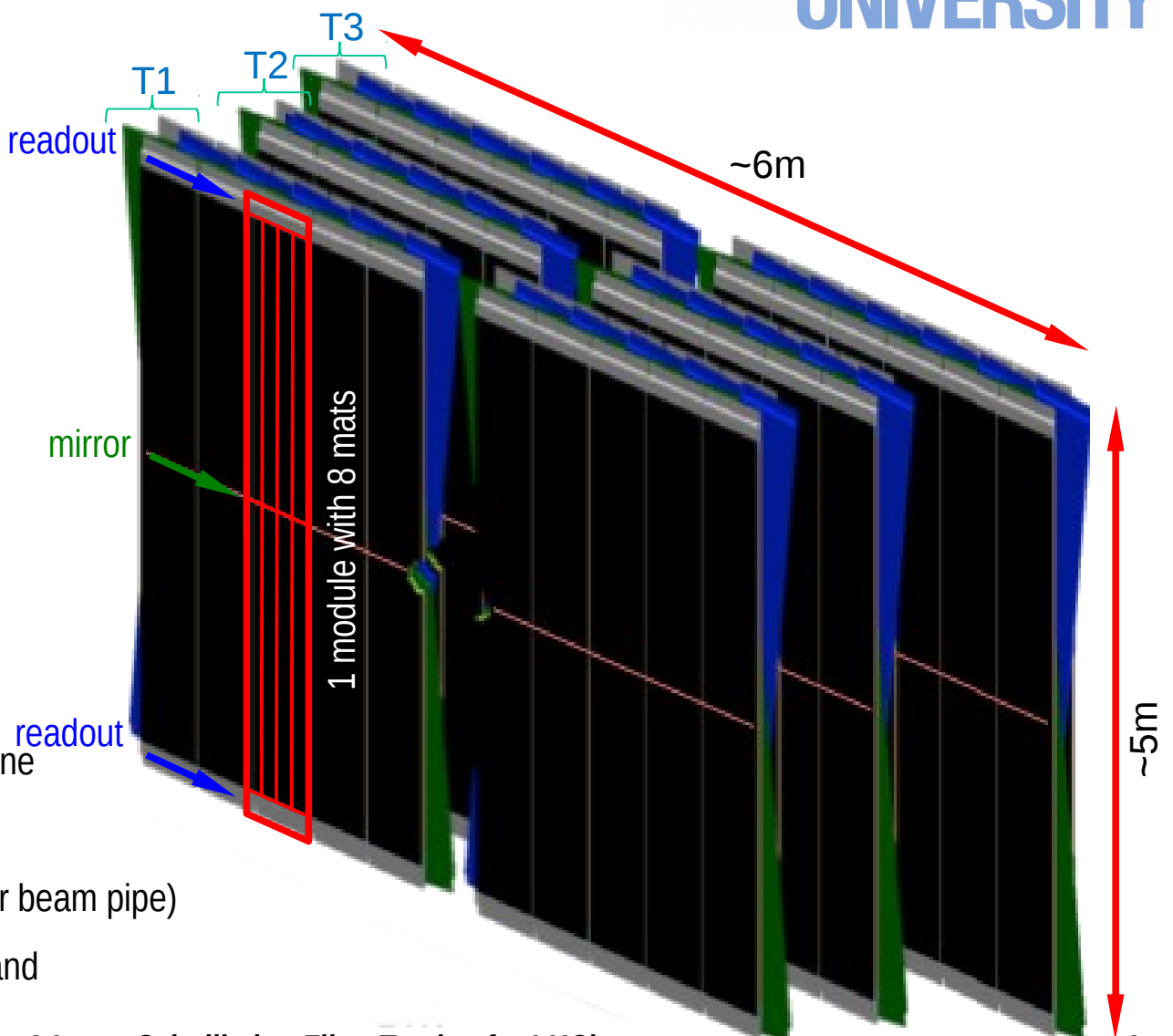




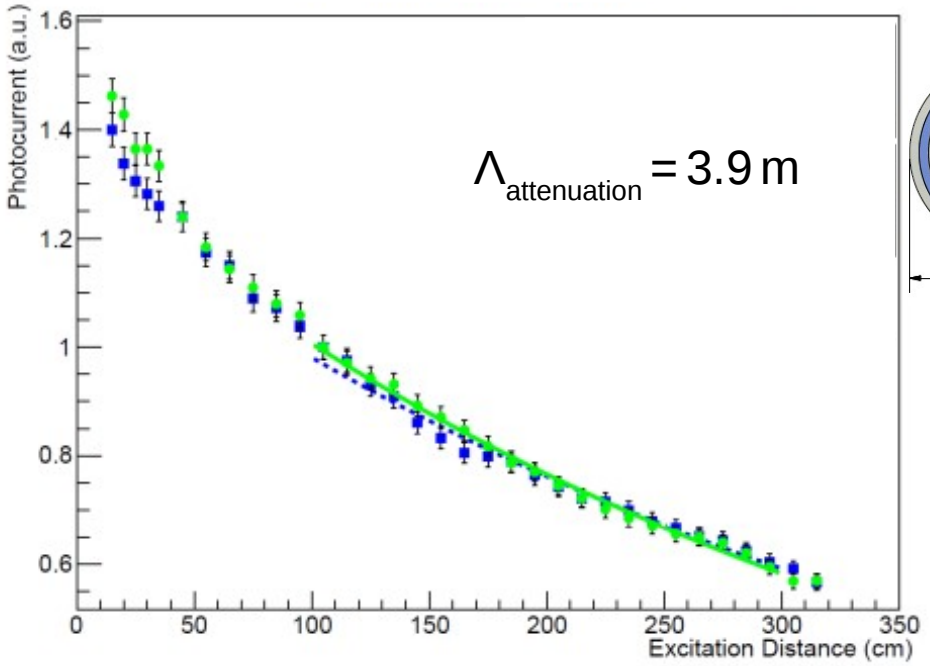
- staggered layers of 250 µm thin double-clad scintillating fibres (Kuraray SCSF-78MJ)
- read out by SiPM arrays covering the fibre mat height
- clustering with three threshold PACIFIC-ASIC
- signal is shared between adjacent array channels allowing for a resolution better than pitch / $\sqrt{12}$
- mirror opposite to readout increases the light yield by ≥ 65% close to mirror

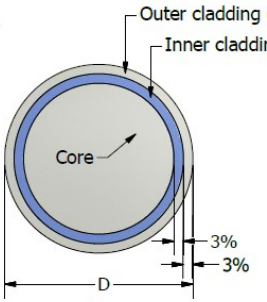
LHCb SciFi Tracker

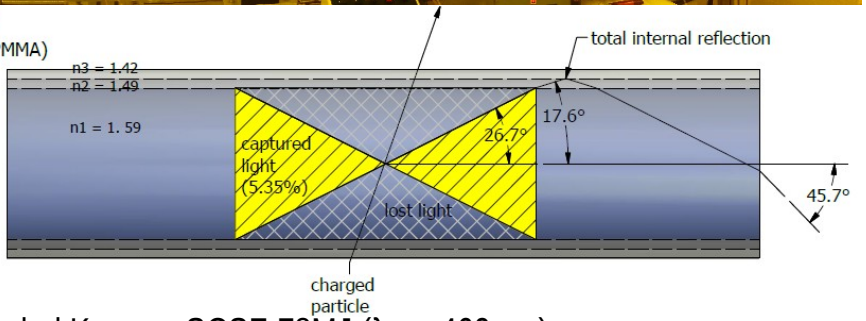
- 12 layers arranged in
  - 3 tracking stations each with
  - 4 planes of scintillating fiber modules (two planes tilted by ±5° stereo angle)
  - T1+T2: 10 modules per layer, T3: 12 modules
    - in total: 128 modules, 1024 mats + spares
  - 340 m^2 sensitive area
- requirements
  - single hit efficiency ~99%
  - material budget per layer ~1% X_0
  - single point resolution < 100 µm in bending plane
  - 40 MHz readout
  - radiation hardness (up to 35 kGy for fibres near beam pipe)
  - light injection system to calibrate overvoltage and discriminator thresholds



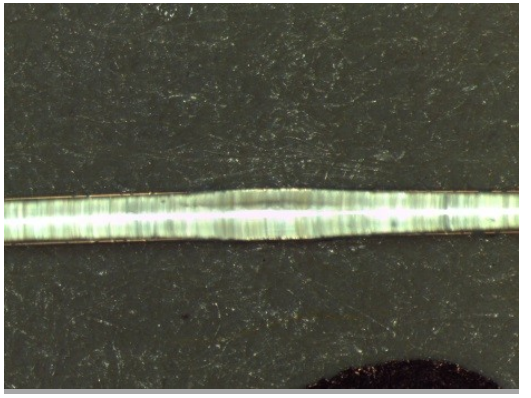
Fibres



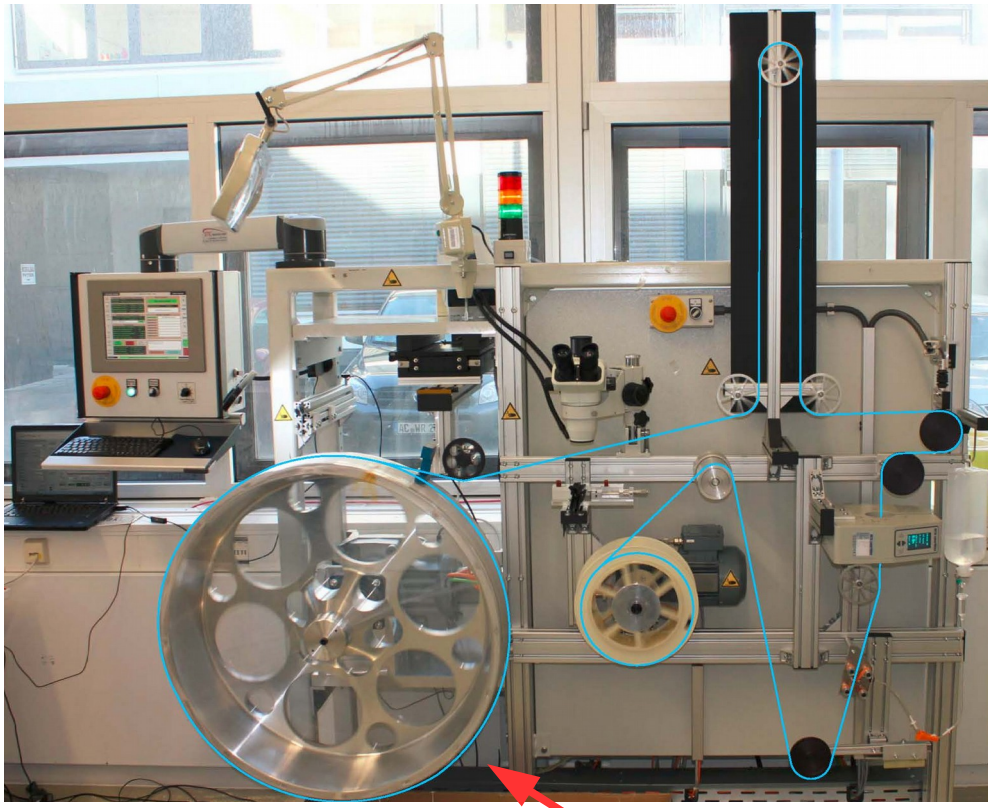




- 250 µm thin multi-clad Kuraray SCSF-78MJ (λ_{fibre}=460 nm)
- more than 10,000 km needed
- fibre QA at CERN → shipment to four mat production sites
  - bump detection and removal
  - diameter, light yield, and attenuation length measurement
  - radiation hardness tests

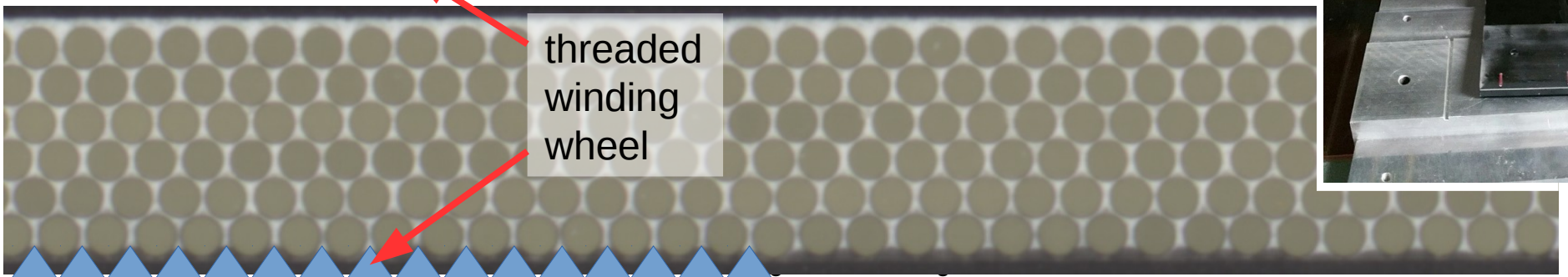


Fibre Mats



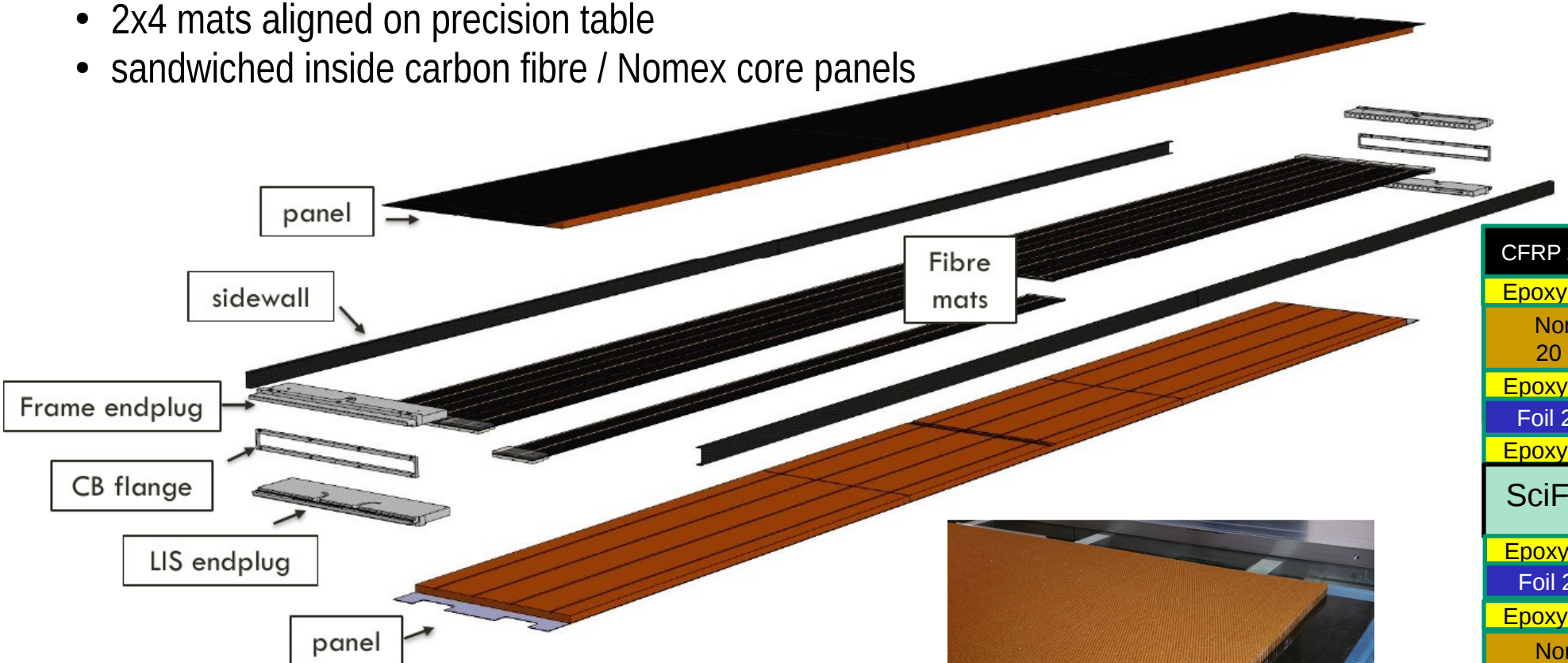
- 8 km of fibre per mat (242.4 cm long, 13.65 cm wide)
- Kapton lamination foil for mechanical stability and light-proofness
- glue alignment pins inherit precision of wheel to mat
- detailed QA at production sites: geometry and light yield

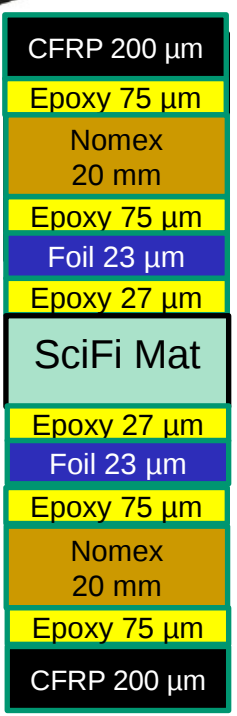
→ poster by S. Nieswand



Fibre Modules

- 2x4 mats aligned on precision table
- sandwiched inside carbon fibre / Nomex core panels



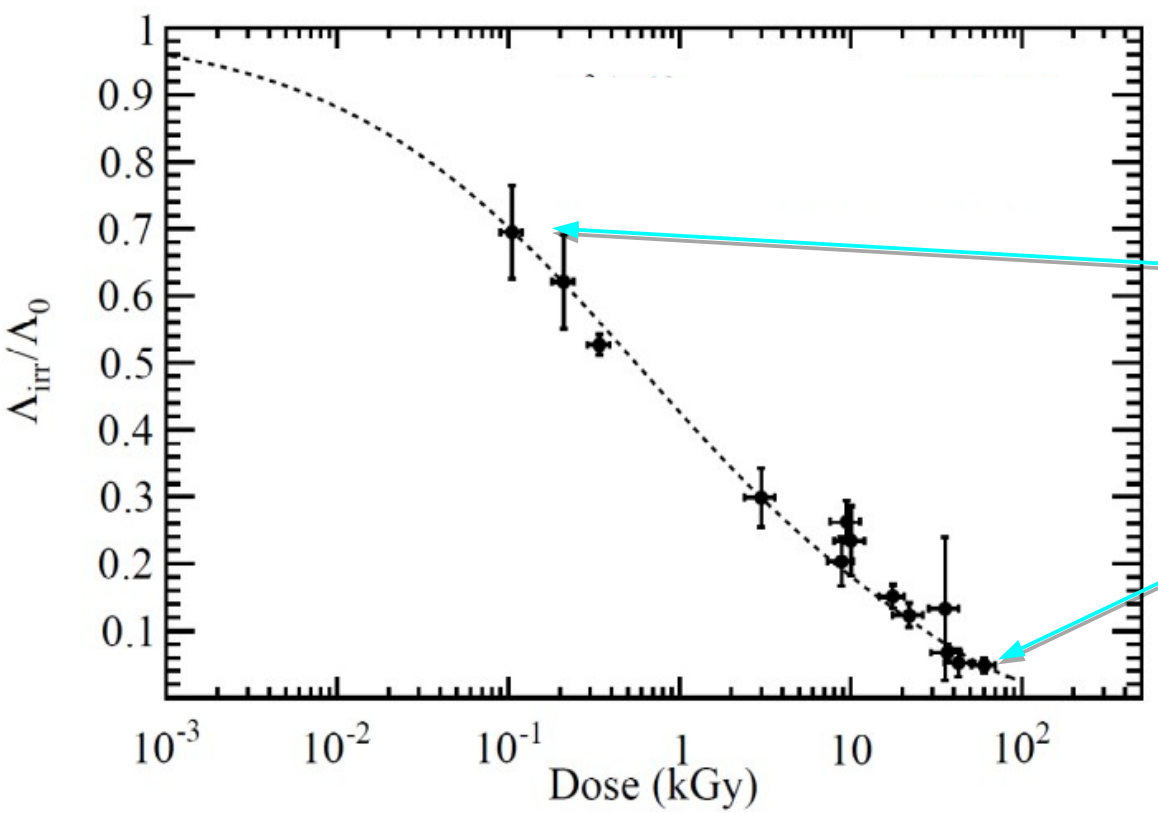


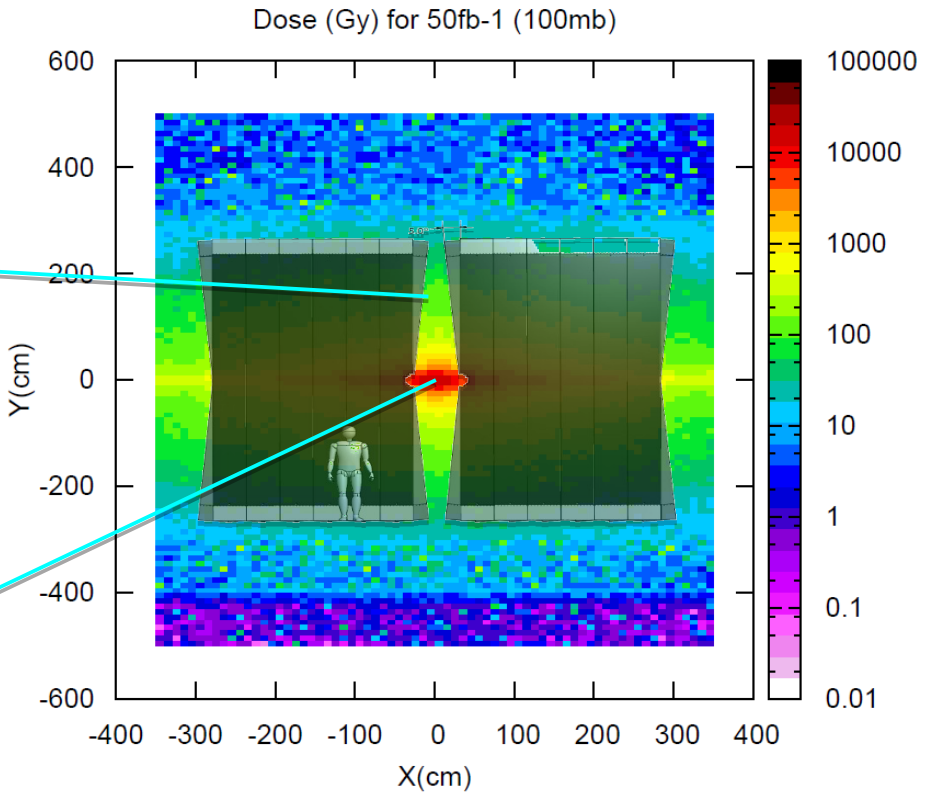
material budget

1.1% X0

Radiation Hardness

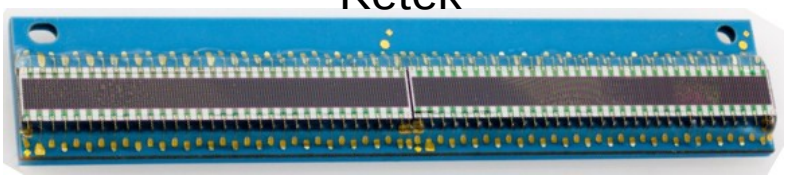
- light yield decreases with radiation dose (35 kGy near beam pipe over full lifetime, 60 Gy at SiPMs)
- expected signal reduction of 40% near the beam pipe



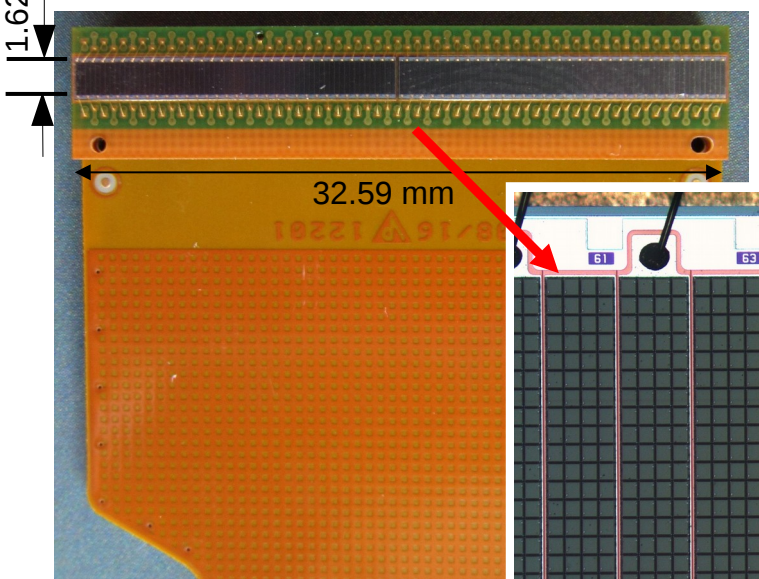


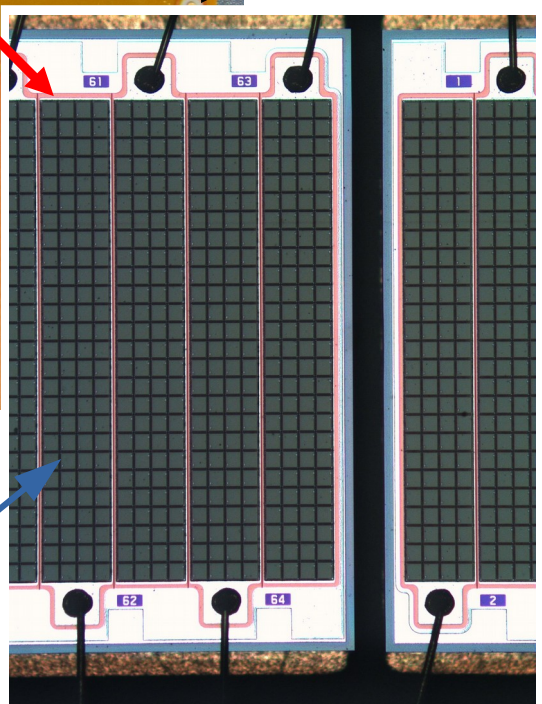
SiPM arrays

Ketek



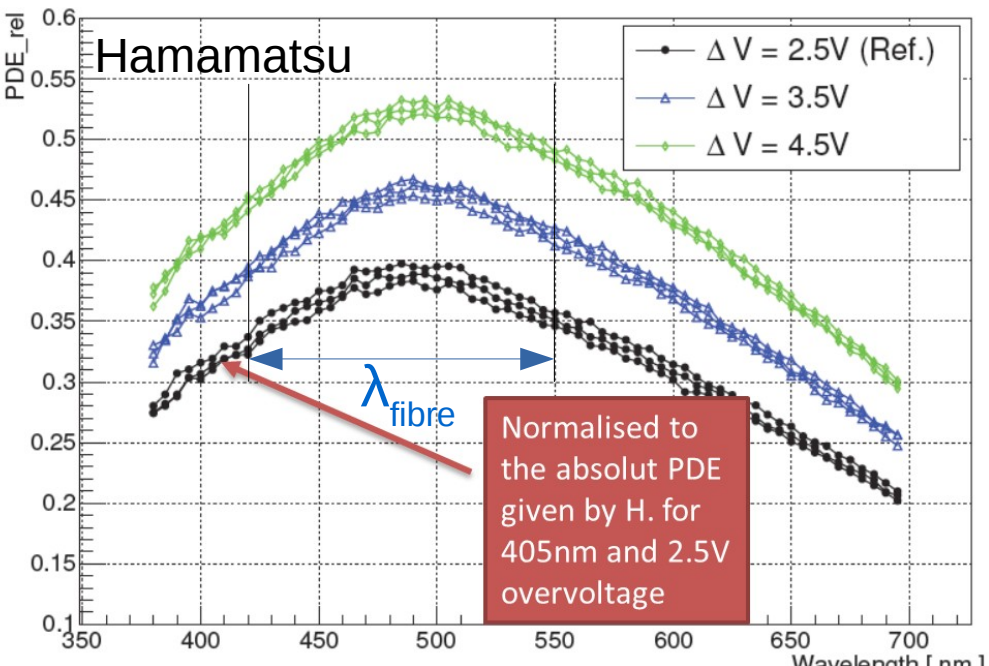
Hamamatsu



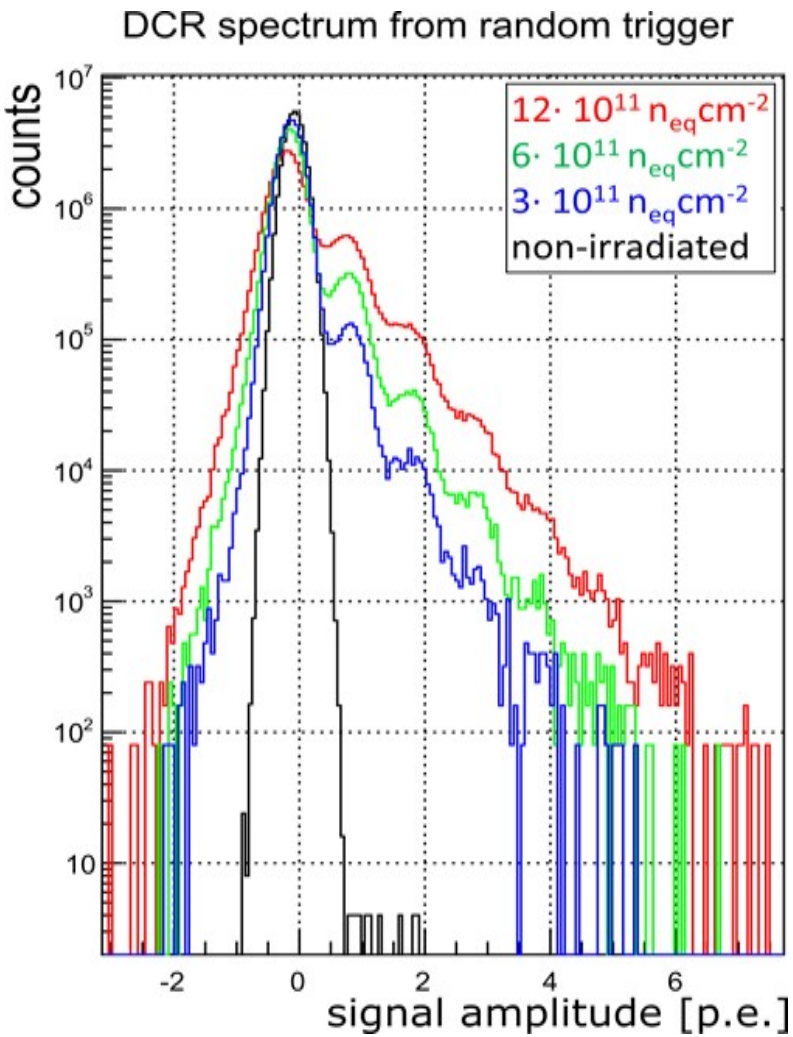


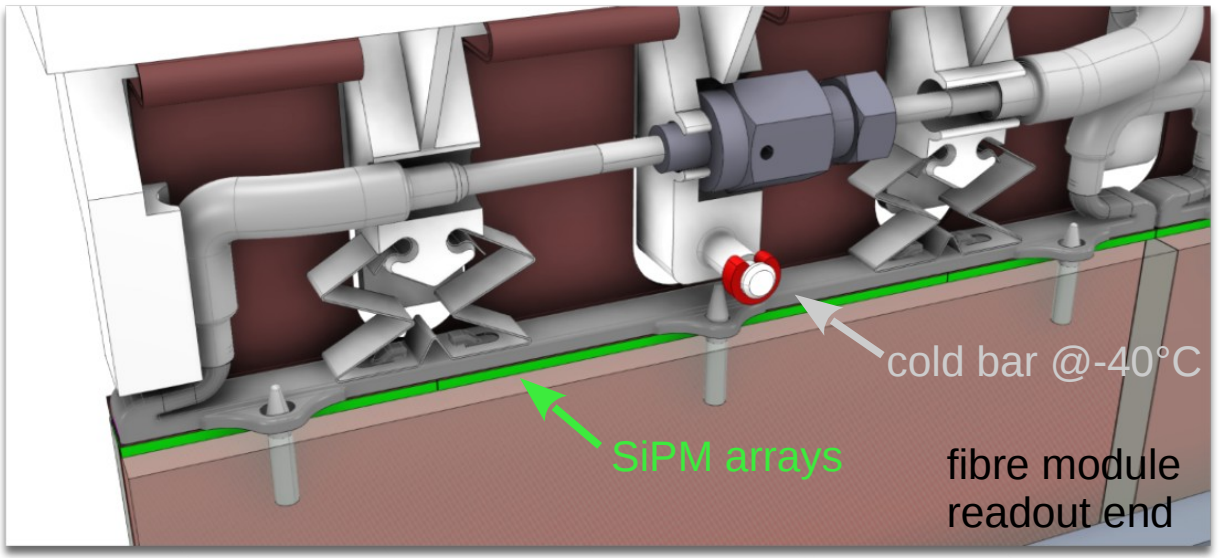
4 x 26 = 104 pixels per channel

- 128 (2x64) channel SiPM arrays
- 250 µm channel pitch (= fibre diameter)
- high photon detection efficiency ~45%
- low crosstalk probability < 10%
- neutron fluence $1 \cdot 10^{12}$ n_{eq}/cm^2 (1 MeV)
  - cooling needed to reduce noise
  - low temperature dependence
- small distance between fibres and silicon



Cooling

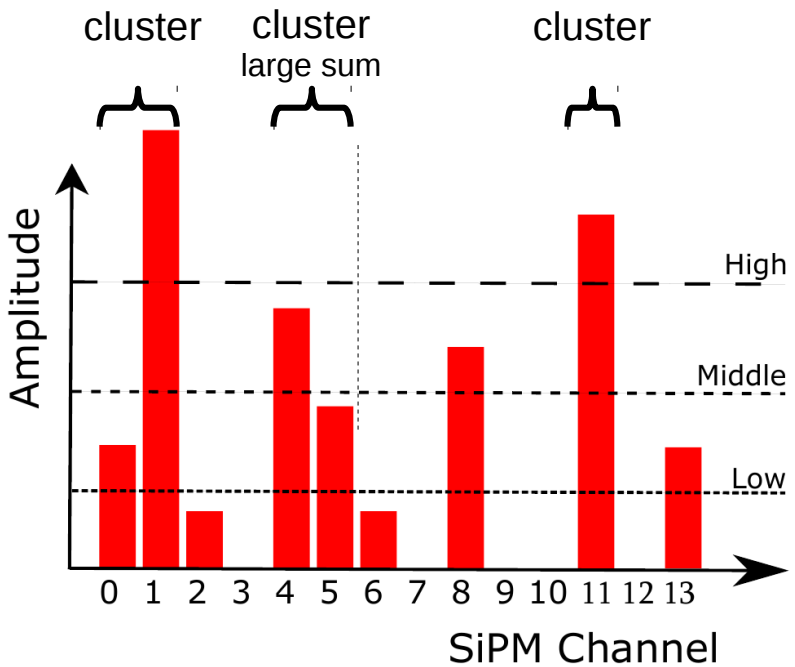




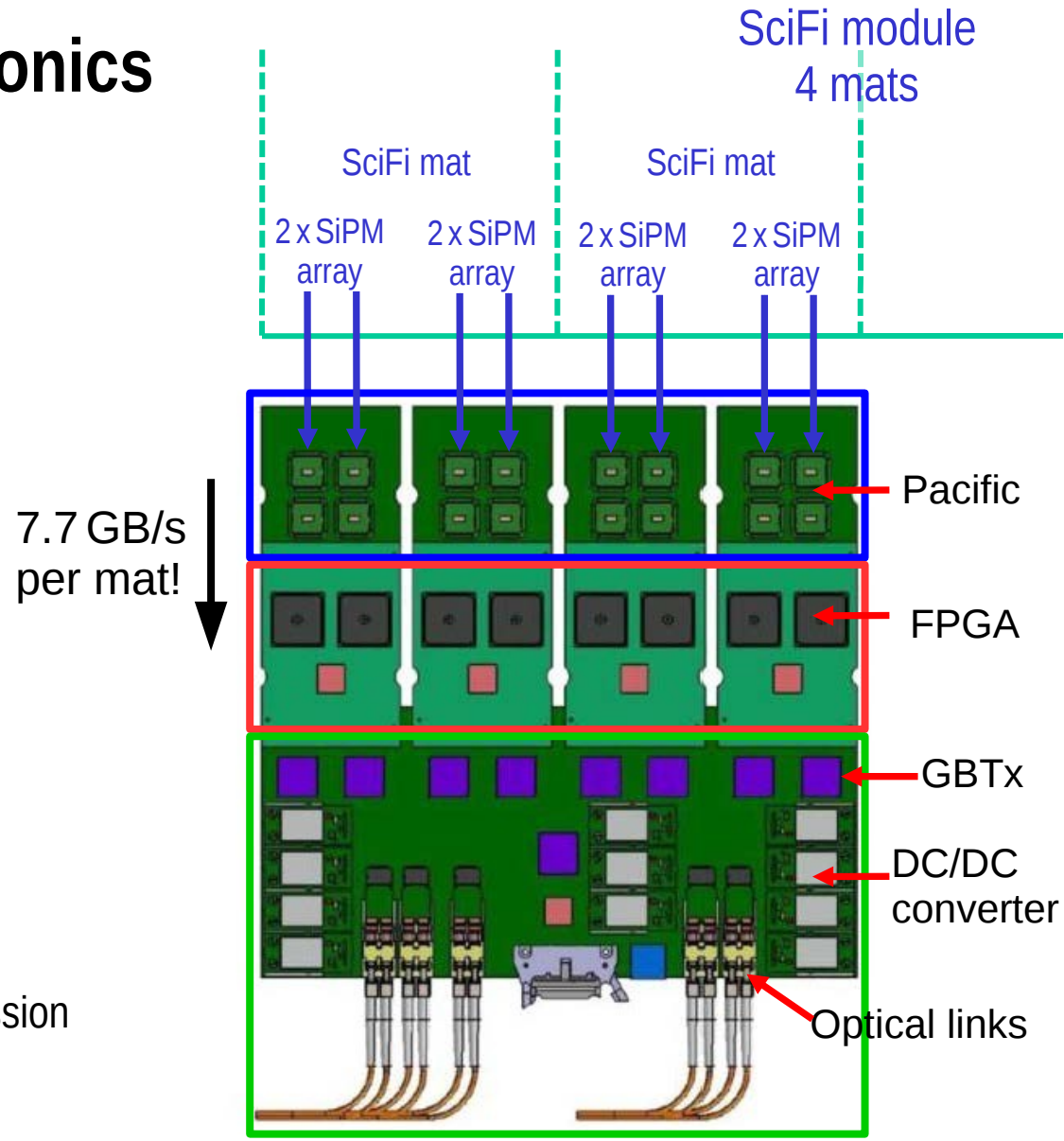
- SiPM dark count rate increases with radiation dose (60 Gy at end of LHC Run 3)
- reduction by factor 2 every ~10°C
- single phase Novek (649) cooling for SiPM arrays to -40°C

Electronics

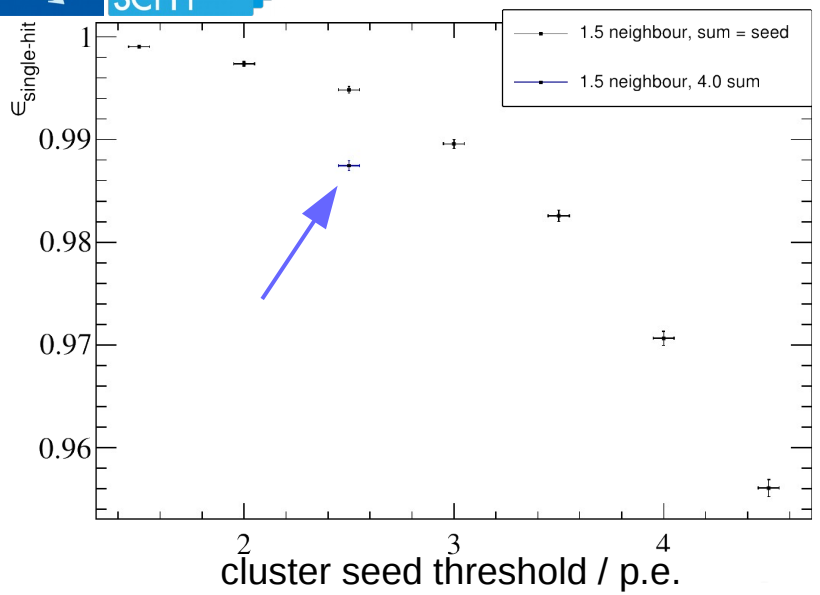
- PACIFIC: custom-made ASIC
  - → 64 channels, 3 threshold discriminator
  - → noise suppression

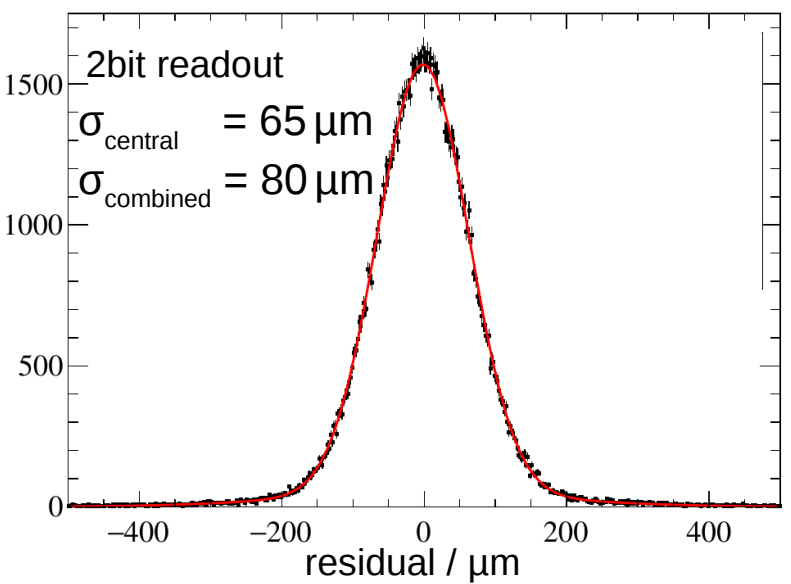


- clusterisation board: cluster building and zero suppression
- master board: transfer data and distribute signals
  - fast control, timing, clock, and slow control



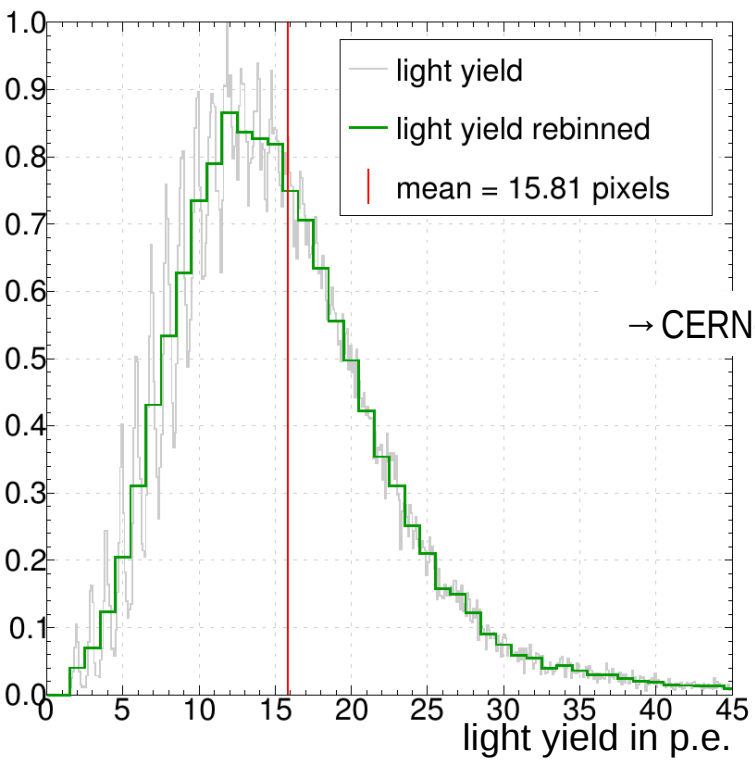
Test Beam Results





- SPS 180 GeV p/π^+ secondary beam
- light yield: 16 p.e.
- hit efficiency: 99%
- spatial resolution: 55-80 µm
  (depending on readout electronics, 12bit vs. 2bit)

} @mirror



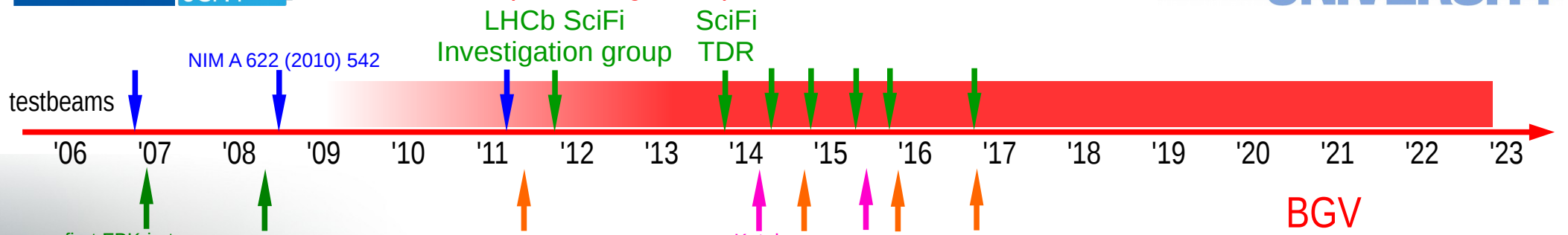
→ CERN-LHCb-PUB-2015-025

Summary

- large area (340 m^2) high resolution (80 µm) scintillating fibre tracker read out with 128 channel SiPM arrays
- 2.5 m long fibre mats with ≥16 p.e. light yield and 99% efficiency!
- production has started in 2016, ~80 mats already produced
- Installation in 2019, ready for LHC run 3 starting in 2021
- close collaboration of 18 institutes in 9 countries

Scintillating Fibre Trackers with SiPM readout

LHCb SciFi (2.5m long mats!)

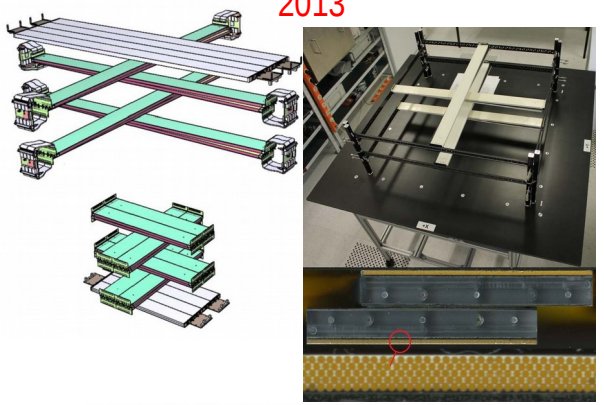


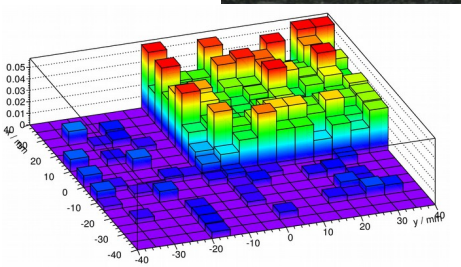
PERDaix

2010

muon tomograph

2013





BGV

Beam Gas Vertex monitor

2015