A new Scintillating Fibre Tracker for LHCb experiment

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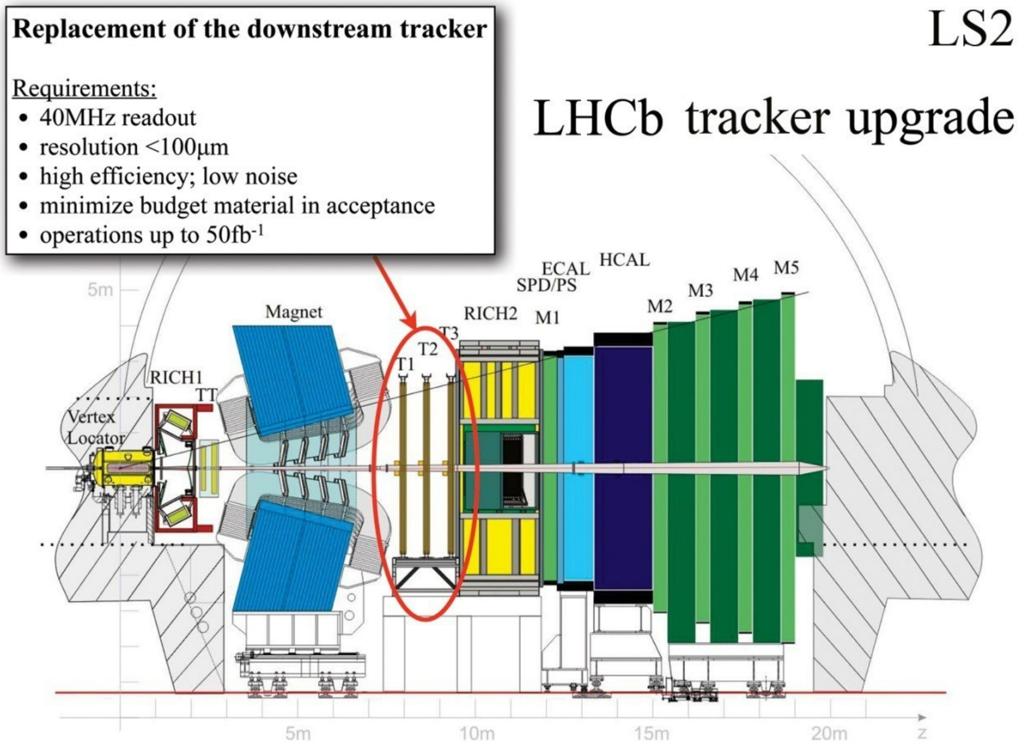
on behalf of the
LHCb-SciFi-Collaboration

Instrumentation for Colliding Beam Physics
BINP, Novosibirsk, 28th February 2017

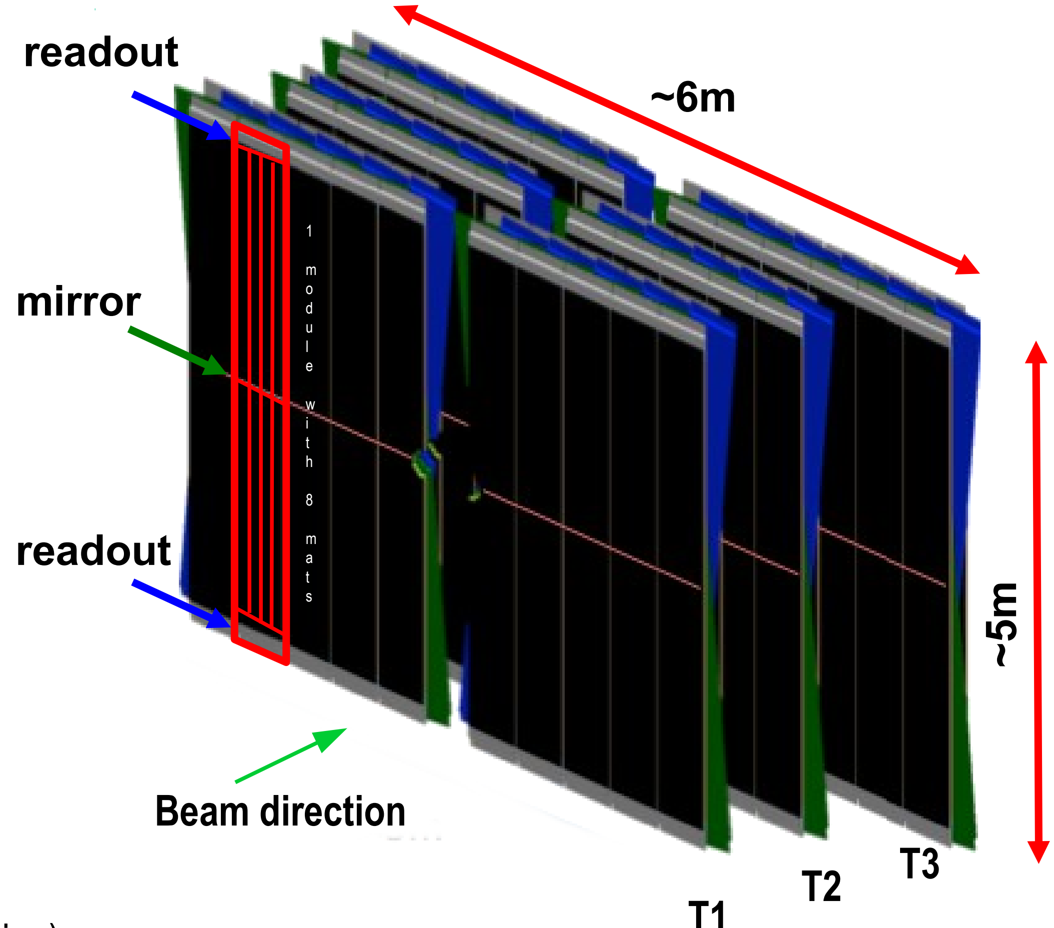
LHCb Detector Upgrade



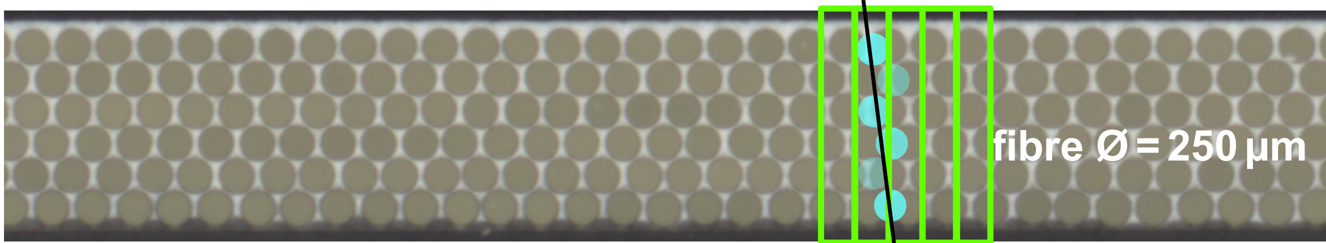
- Goal: 50 fb^{-1} integrated luminosity
  - increase the statistics significantly (rare decays)
  - limited by 1 MHz hardware trigger, and
  - limited by detector occupancy
- Major upgrade during LS2 in 2020 (see talk by Mark Williams)
  - new VELO
  - replace TT with new silicon micro-strip detector
  - replace IT (silicon) & OT (straws) with SciFi tracker (scintillating fibres, SiPM array sensors), to achieve
  - 40 MHz detector readout → full software trigger!
  - RICH: new photon detectors
  - Calorimeter: remove SPD/PS, new readout (see talk by Yury Guz)
  - Muon System: remove M1, new readout

LHCb SciFi Tracker

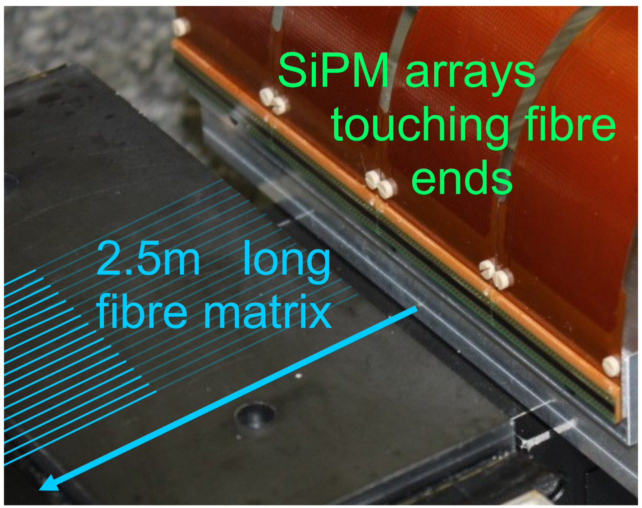
- Layout :
  - 12 layers arranged in 3 tracking stations
  - each station with 4 planes of scintillating fibre modules (two planes tilted by ±5° stereo angle)
  - T1+T2: 10 modules per layer, T3: 12 modules
  - in total: 128 modules, 1024 fibre mats + spares
  - 340 m^2 sensitive area
  - readout boxes with light injection system for calibration
- 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)

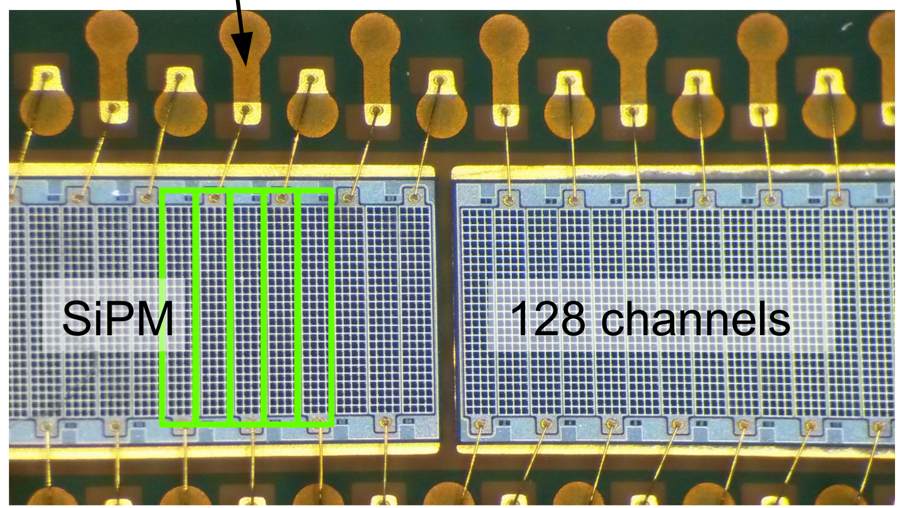


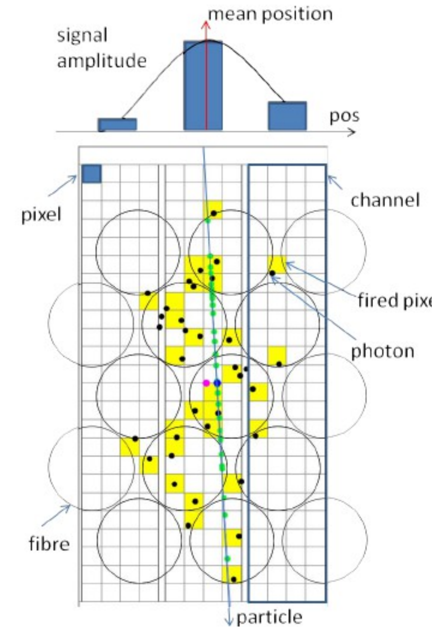
SciFi Principle



Six-layer fibre mat
1.4 mm thick

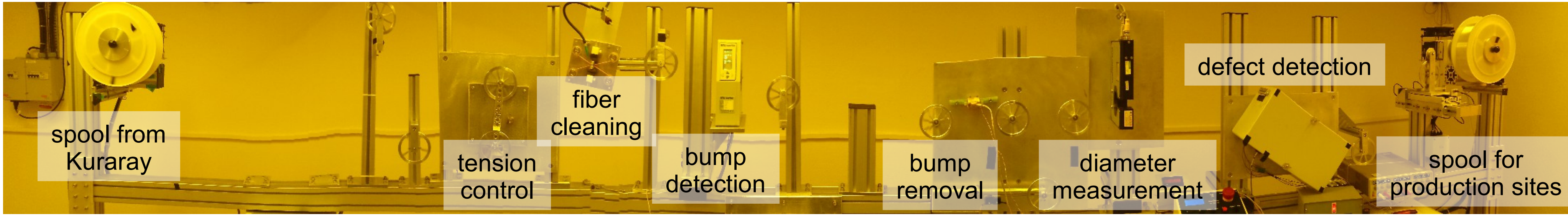


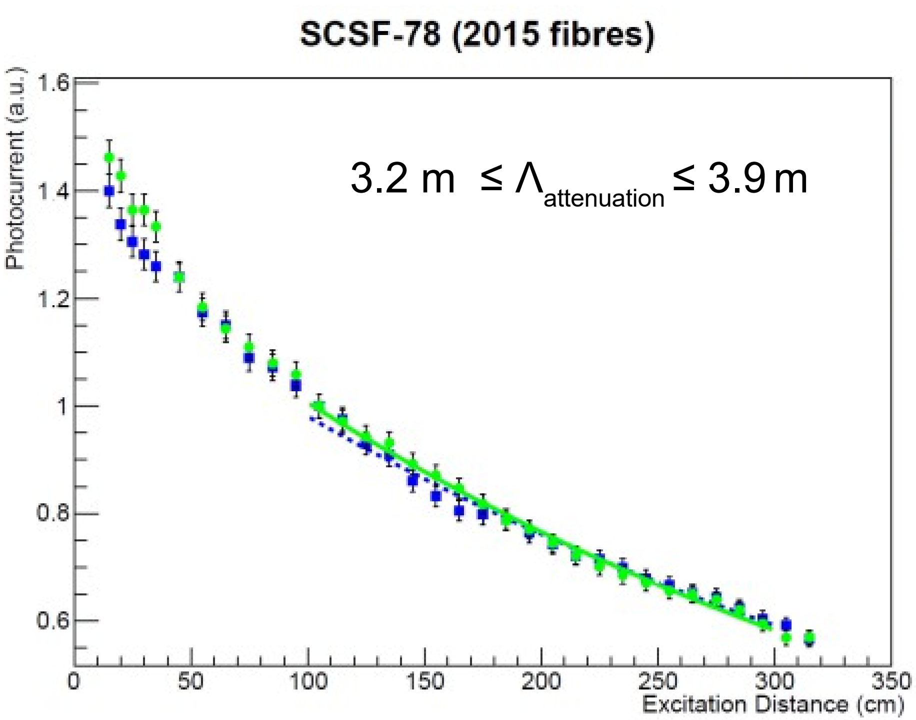


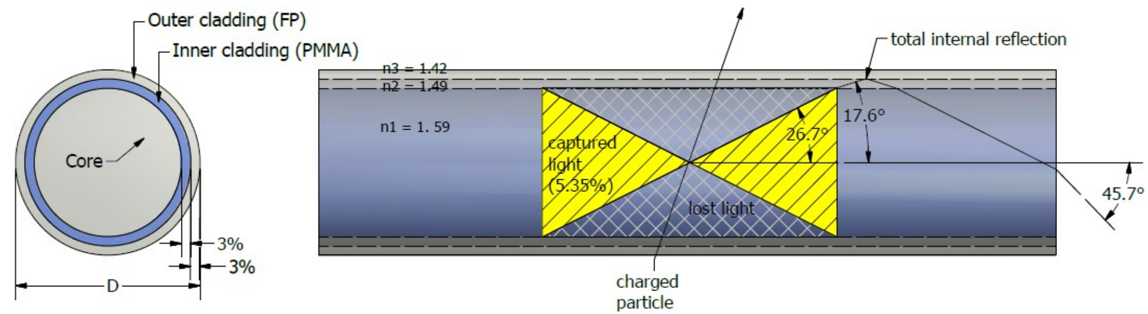


- Staggered layers of 250 µm thin, double-clad scintillating fibres, to form a 6-layered hexagonal packed mat
- Read out by the SiPM arrays covering one fibre mat end face
- Signal is shared between the adjacent SiPM array channels allowing for a resolution better than pitch / √12
- Mirror opposite to readout end increases the light yield by ≥ 65% for the hits close to the mirror

Fibres

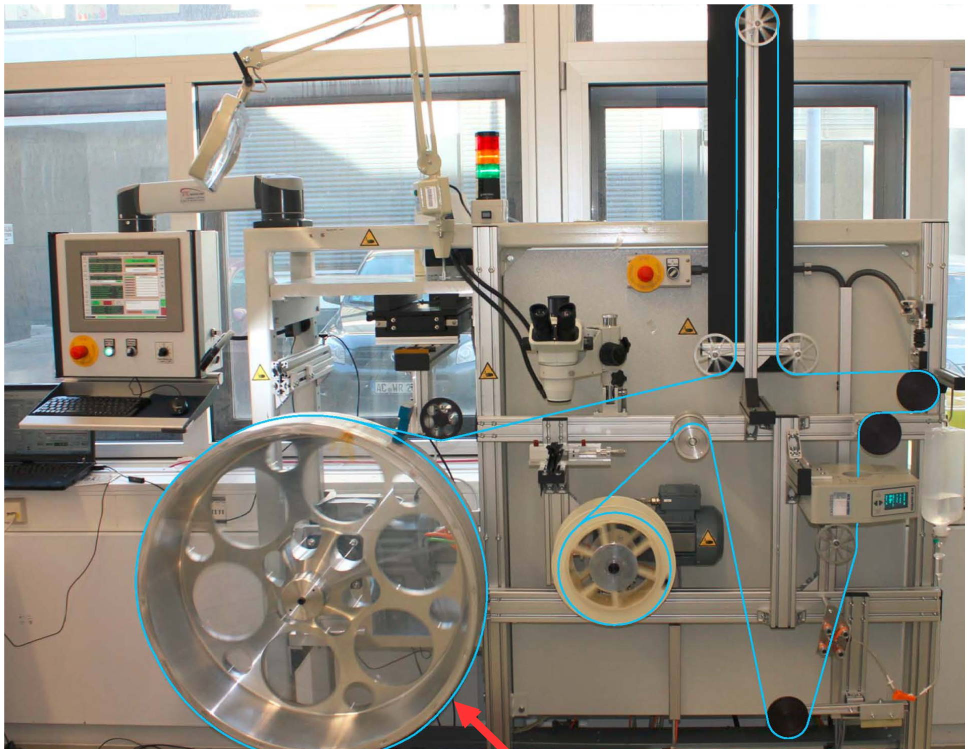




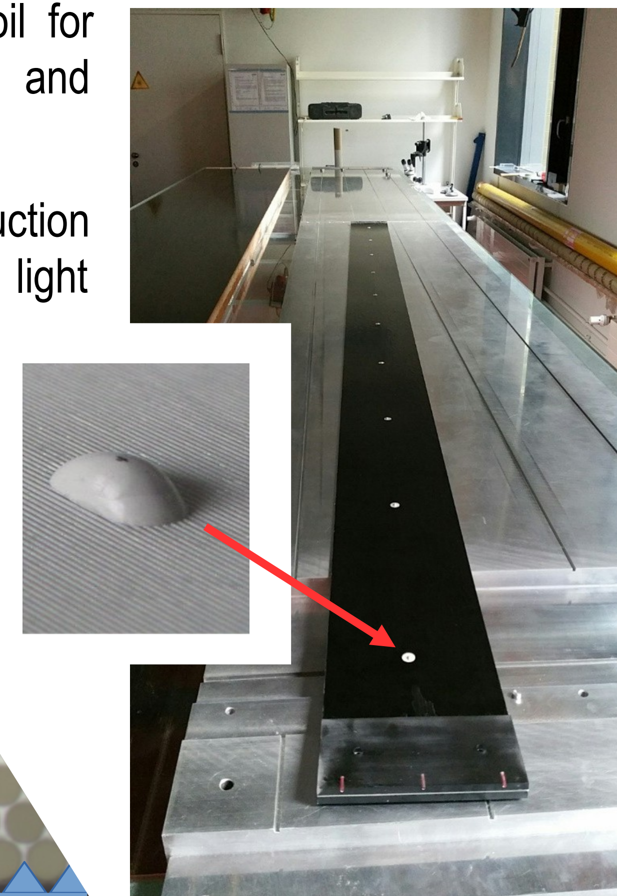


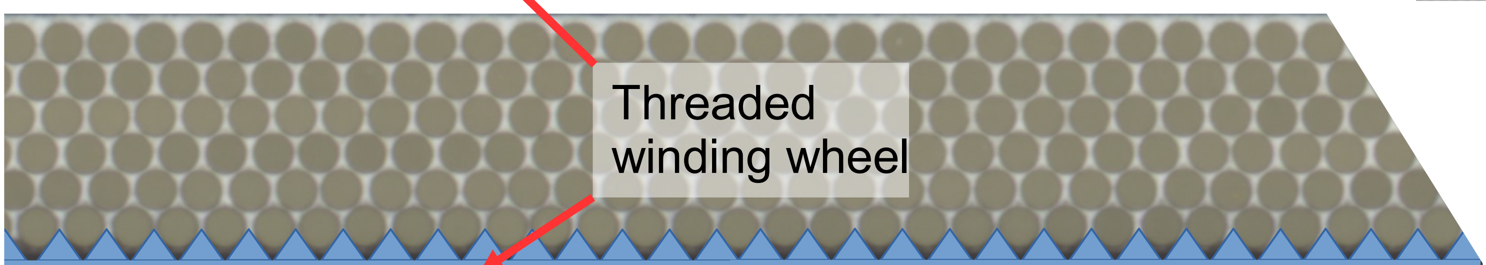
- **250 μm thin multi-clad Kuraray SCSF-78MJ (λ_{fibre}=460 nm)**
- **more than 10,000 km needed!**
- **fibre QA at CERN → shipment to four mat production sites**
  - **bump detection and removal**
  - **diameter, light yield, integrity, and attenuation length measurements**

Fibre Mats



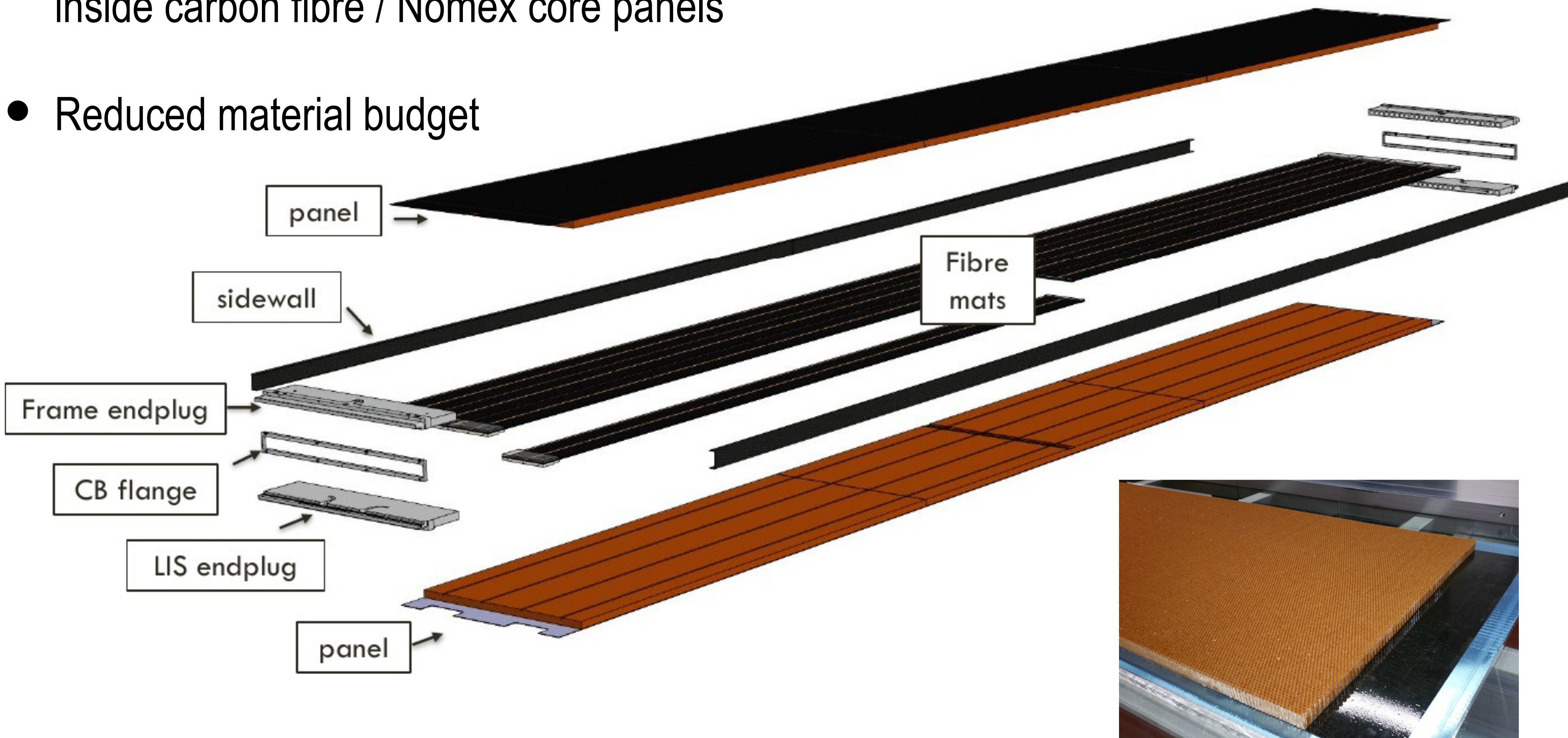
- 8 km of fibre per mat (242.4 cm long, 13.65 cm wide mat)
- Kapton lamination foil for mechanical stability and light-tightness
- Detailed QA at production sites: geometry and light yield
- Glue alignment pins inherit precision of the wheel to mats





Fibre Modules

- 2x4 mats aligned on precision vacuum table, sandwiched inside carbon fibre / Nomex core panels
- Reduced material budget



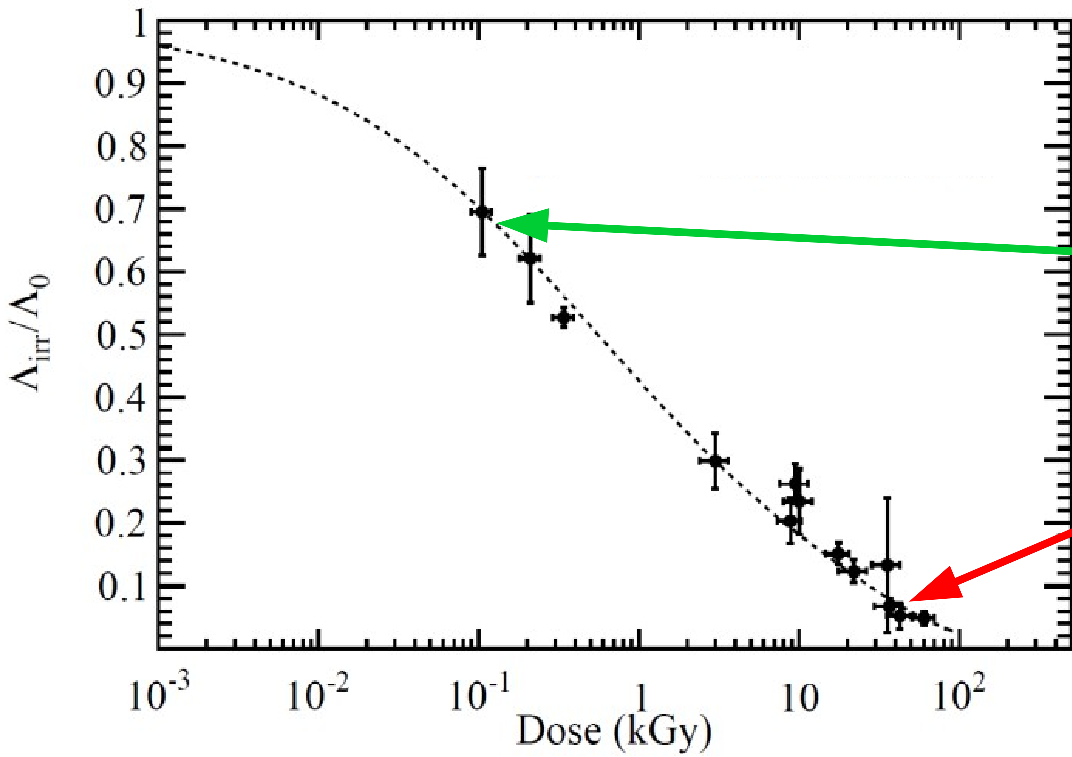
CFRP 200 µm
Epoxy 75 µm
Nomex 20 mm
Epoxy 75 µm
Foil 23 µm
Epoxy 27 µm
SciFi Mat
Epoxy 27 µm
Foil 23 µm
Epoxy 75 µm
Nomex 20 mm
Epoxy 75 µm
CFRP 200 µm

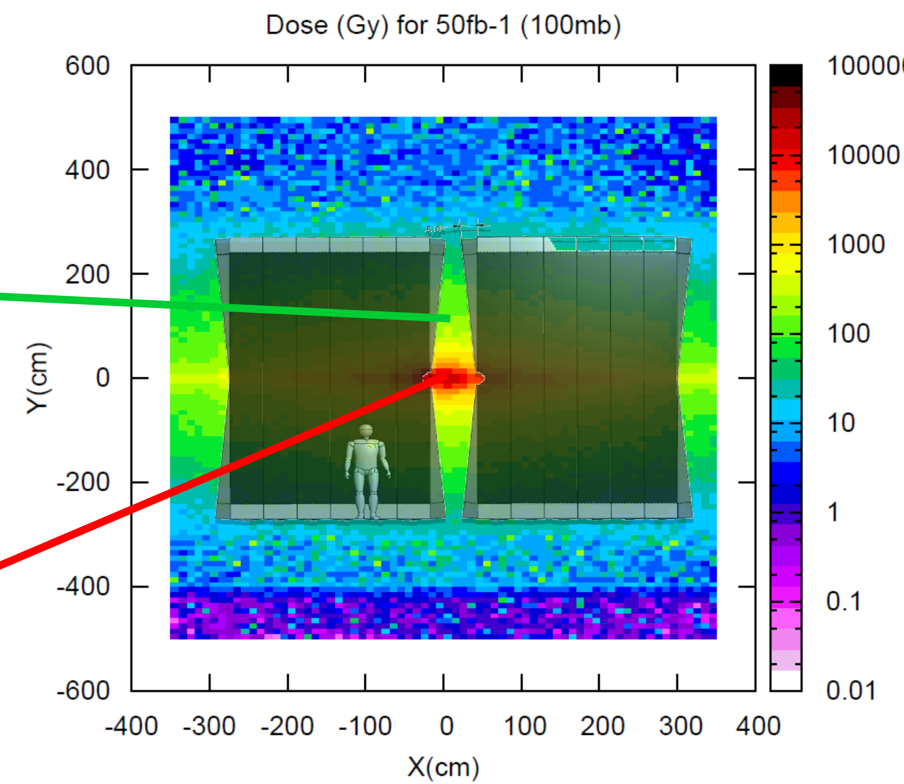
material budget

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

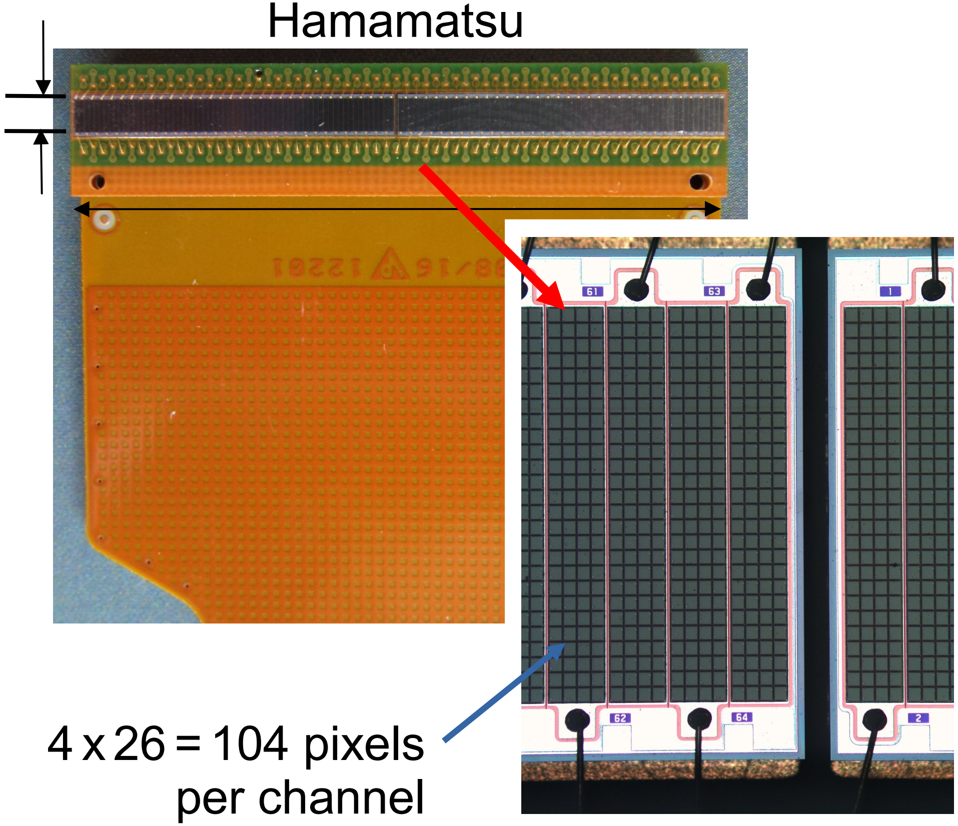




SiPM arrays

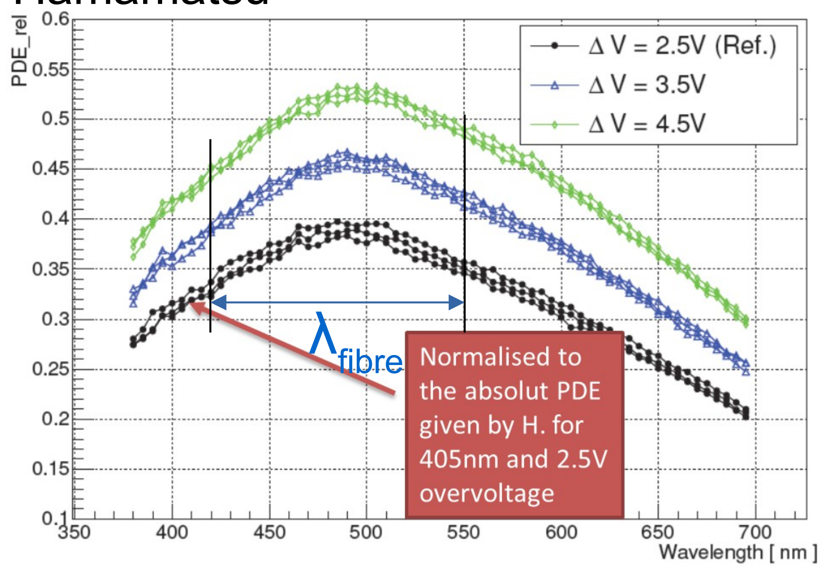
- 128 (2x64) channel SiPM arrays
- 250 µm channel pitch (= fibre diameter)
- high photon detection efficiency ~45%
- low crosstalk probability < 10%
- neutron fluence $1 \cdot 10^{12}$ n_{eq}/cm^2 (1 MeV)
  → cooling needed to reduce noise
- small distance between fibres and silicon

Hamamatsu



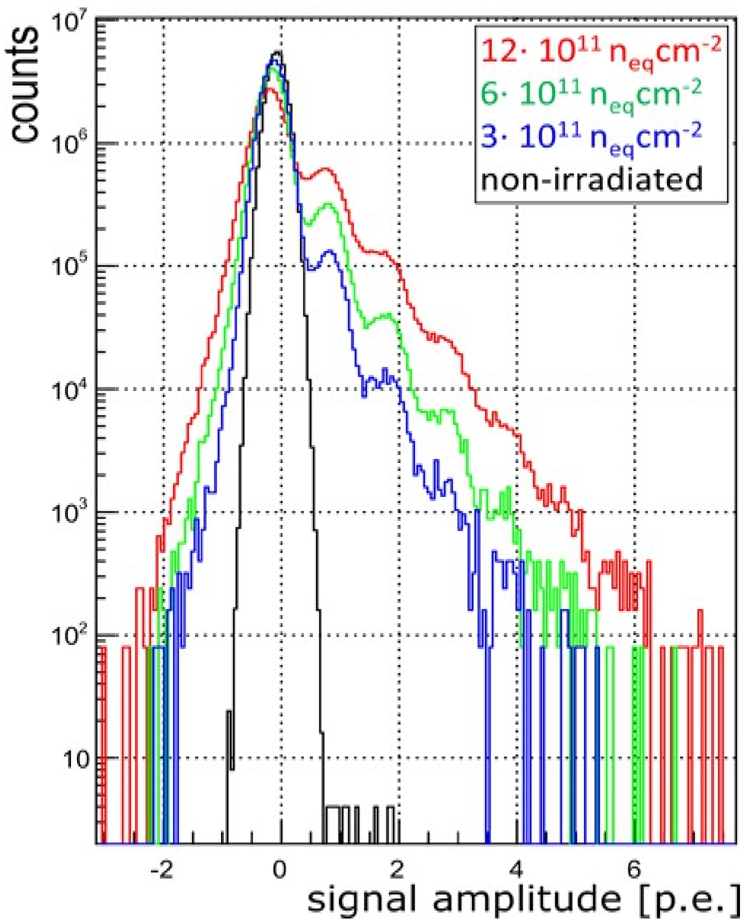
4 x 26 = 104 pixels per channel

Hamamatsu

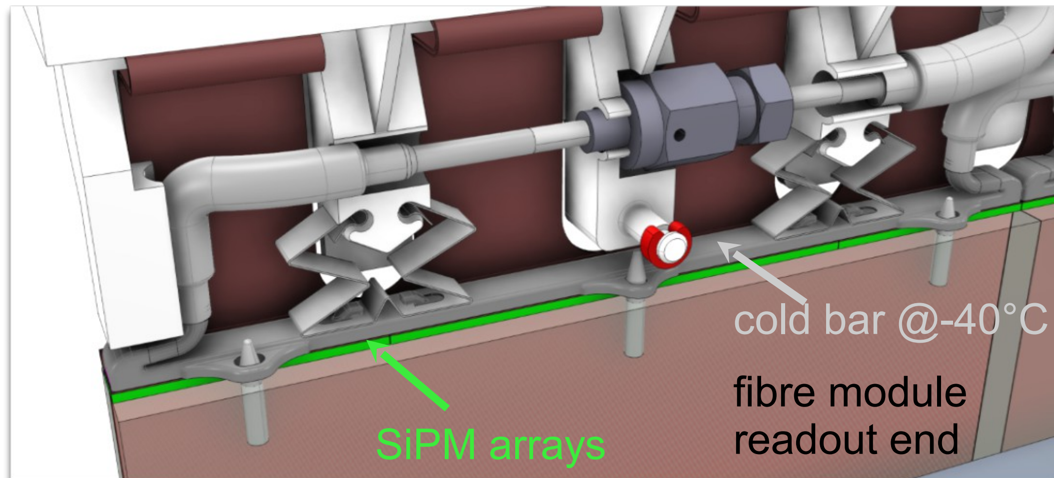


Cooling

DCR spectrum from random trigger



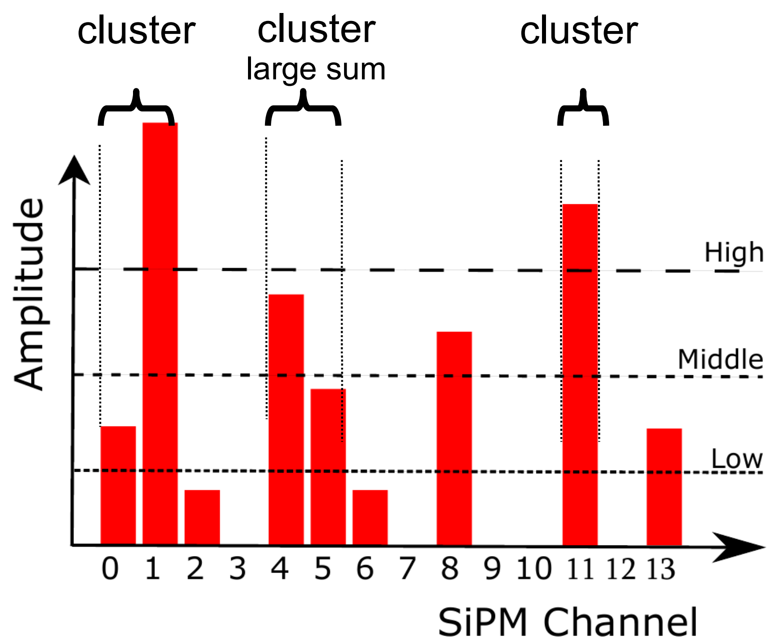
Inside the FE cold box



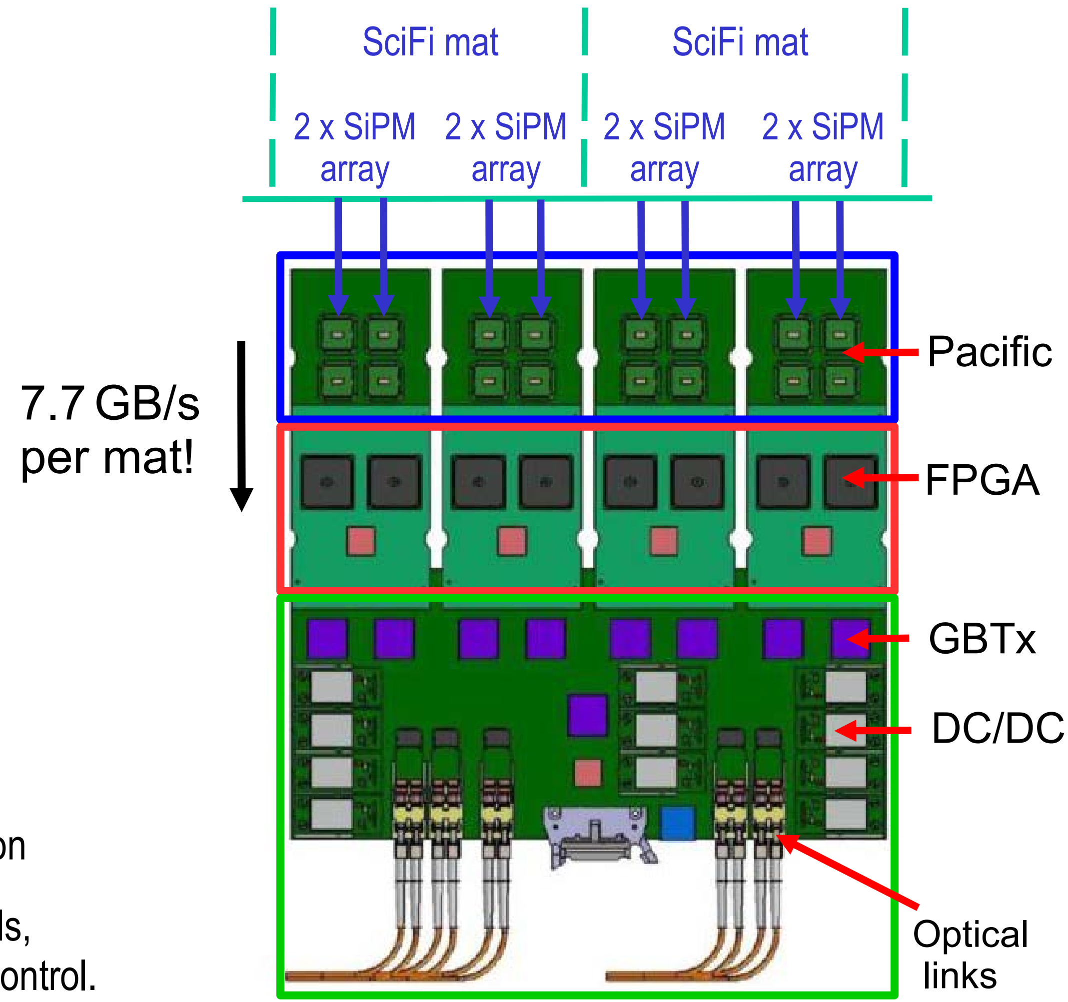
- SiPM dark count rate increases with radiation dose (60 Gy at the end of LHC Run 3)
- DCR reduction by factor 2 for every ~10°C cooling
- Single phase Novek (649) cooling for SiPM arrays down to -40°C

Electronics

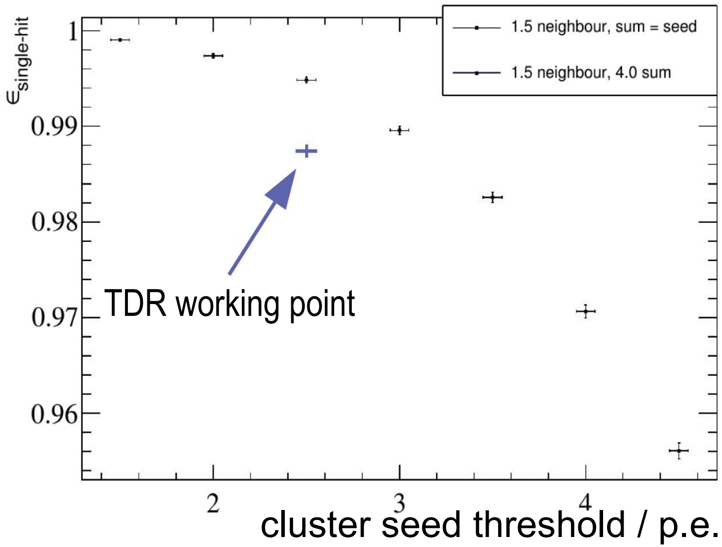
- PACIFIC: custom-made ASIC
  → 64 channels, 3 threshold discriminator
  → noise suppression



- Clusterisation board: cluster building and zero suppression
- Master board: transfers the data and distribute the signals, fast control, timing, clock, light injection pulse, and slow control.

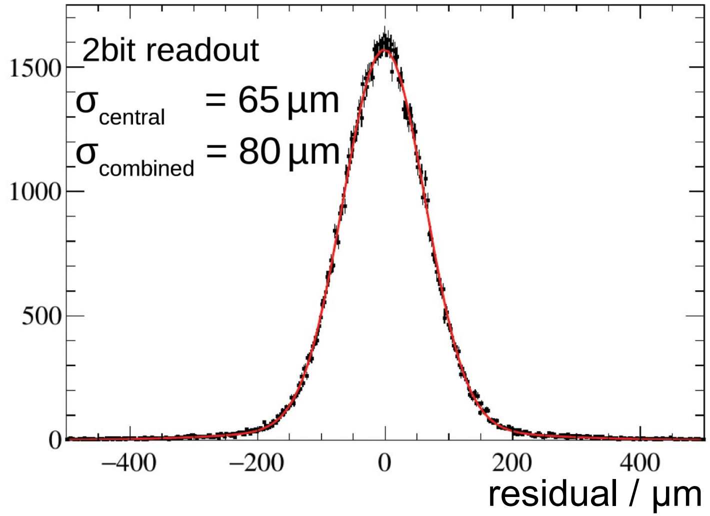


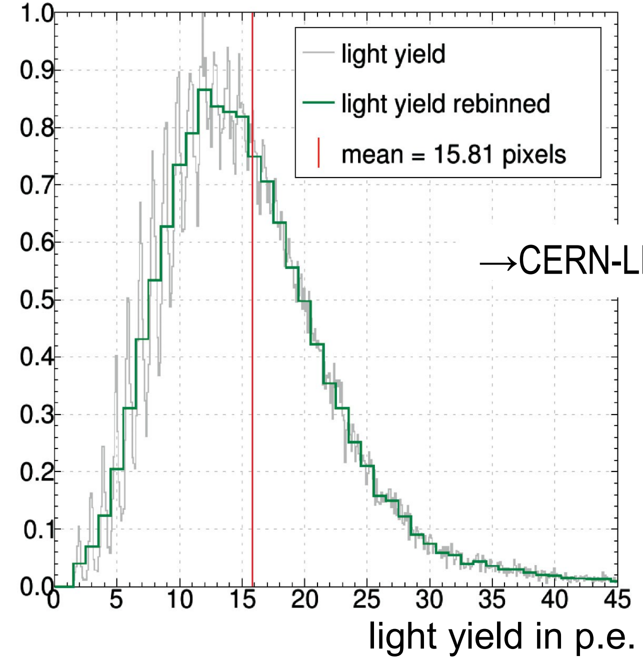
Test Beam Results



- Measured at SPS180 GeV p/π^+ secondary beam:
- Light yield: 16 p.e.
- Hit efficiency: 99%
- Spatial resolution: 80 μm

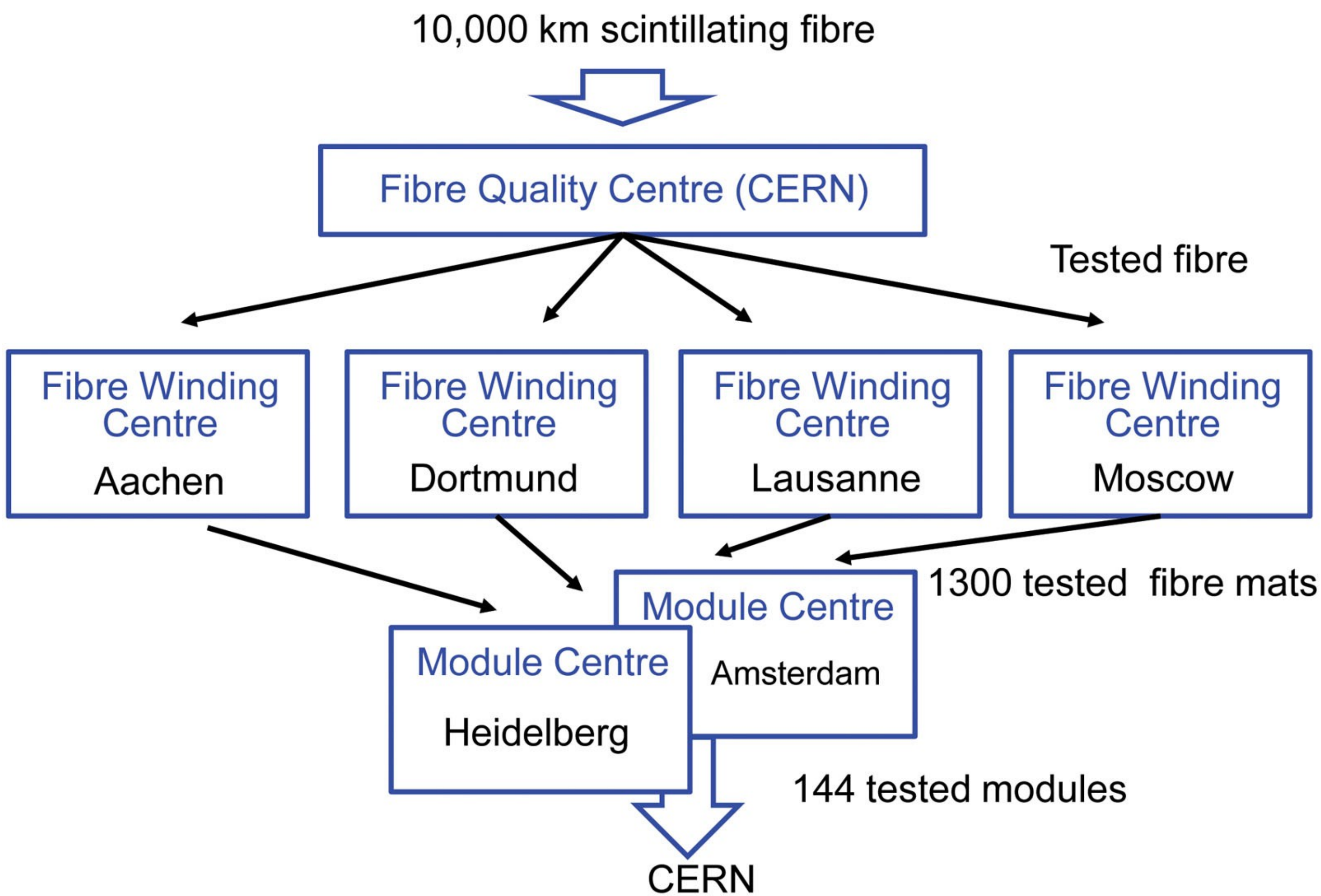
near the mirror



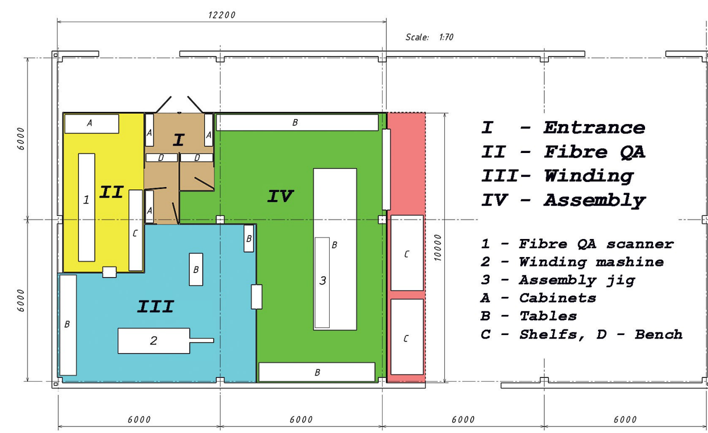


→CERN-LHCb-PUB-2015-025

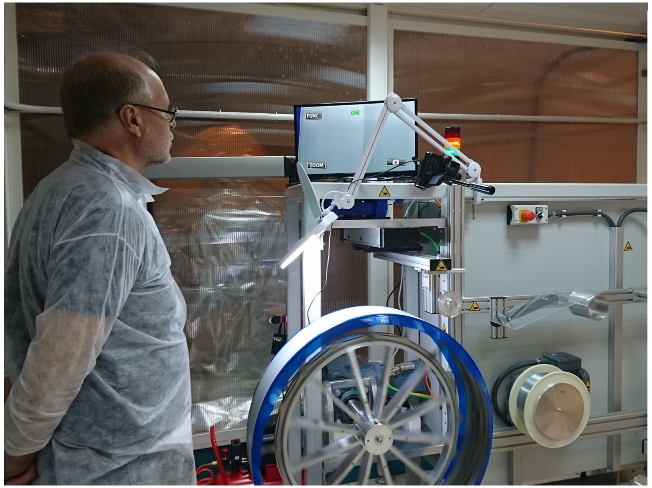
SciFi mass production centres

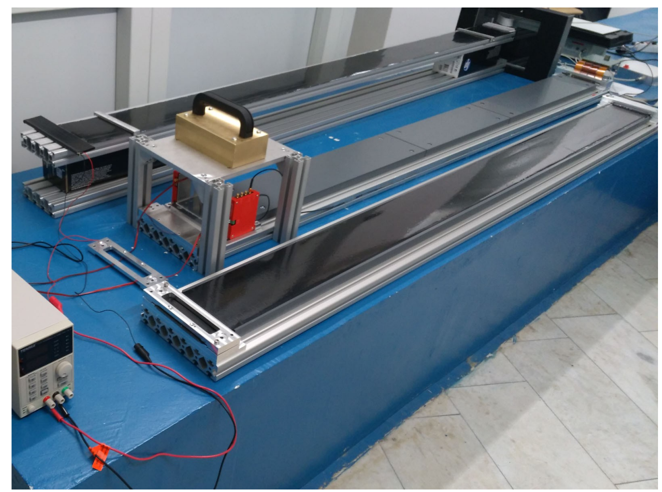


SciFi production centre at NRC KI



SciFi production centre at NRC KI





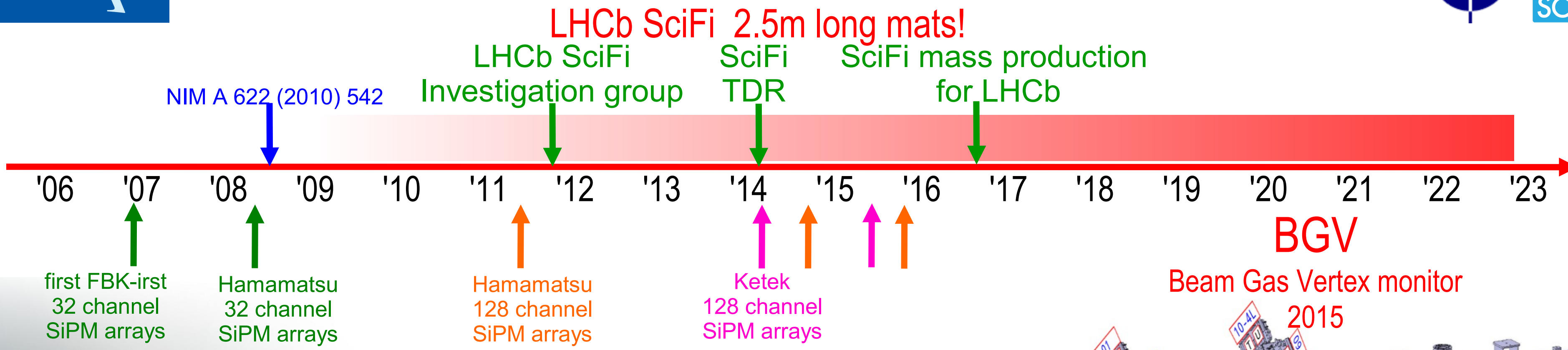
Summary

- 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, ~15% of mats are already produced.
- Installation in 2019, ready for LHC run 3 starting in 2021.
- Close collaboration of 18 institutes in 9 countries.

Thank you!

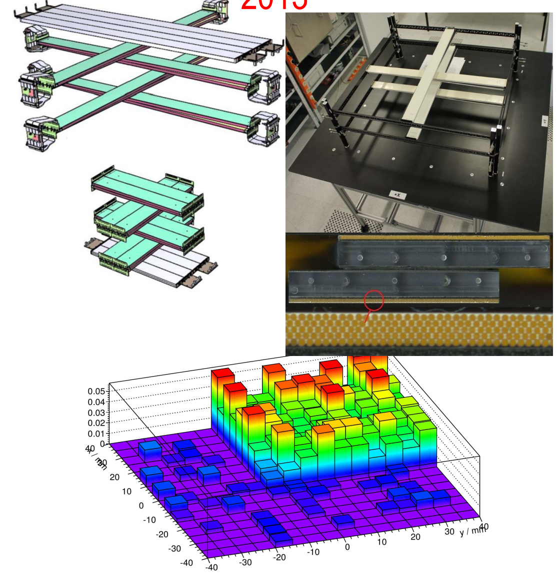
Backup slides

History of the Scintillating Fibre Trackers with SiPM readout



PERDaix 2010

muon tomograph, RWTH 2013



BGV
Beam Gas Vertex monitor
2015