Modular beam telescope based on scintillating fibres and silicon photomultipliers

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Scintillating fibres for tracking

The SciFi telescope
- Modular design
- Test beam at SPS

Future developments
- Timing and large area

A SciFi tracker for LHCb

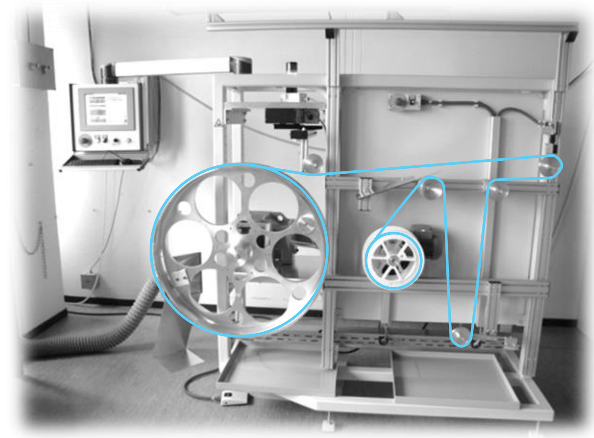
Large-scale SciFi technology application

- Placed downstream the magnet
- Total area of 340 m^2
- 11’000 km fibres (Ø250 μm, 2.8 ns decay time) arranged in mats
- 4000 Silicon Photomultipliers (SiPMs) 128-channel arrays for a total of 500k read-out channels

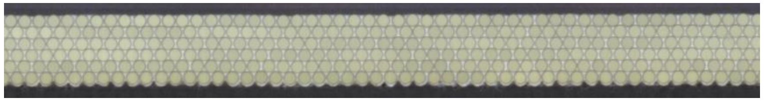
Some advantages of SciFi technology

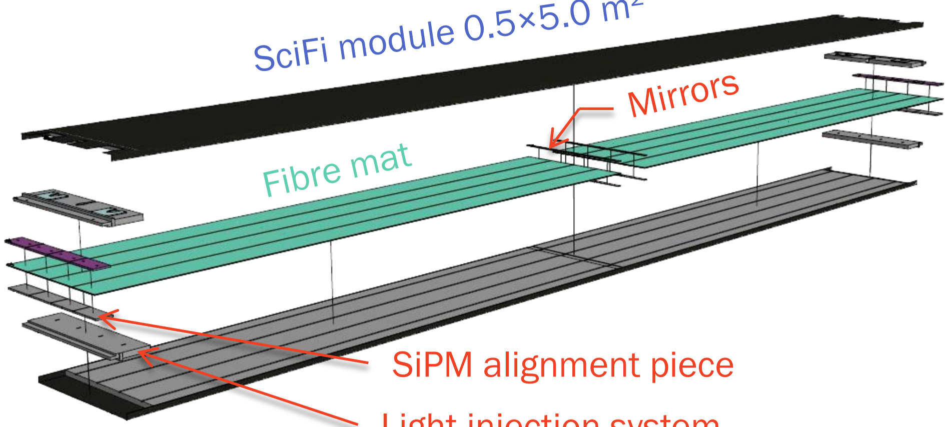
- Cover large area at relatively low cost and with high granularity
- No electronics and services in acceptance

Ø 250 μm blue emitting fibres from Kuraray (SCSF-78) wound on a custom machine



High quality mat:
2.5 m × 13 cm, 6 fibre layers

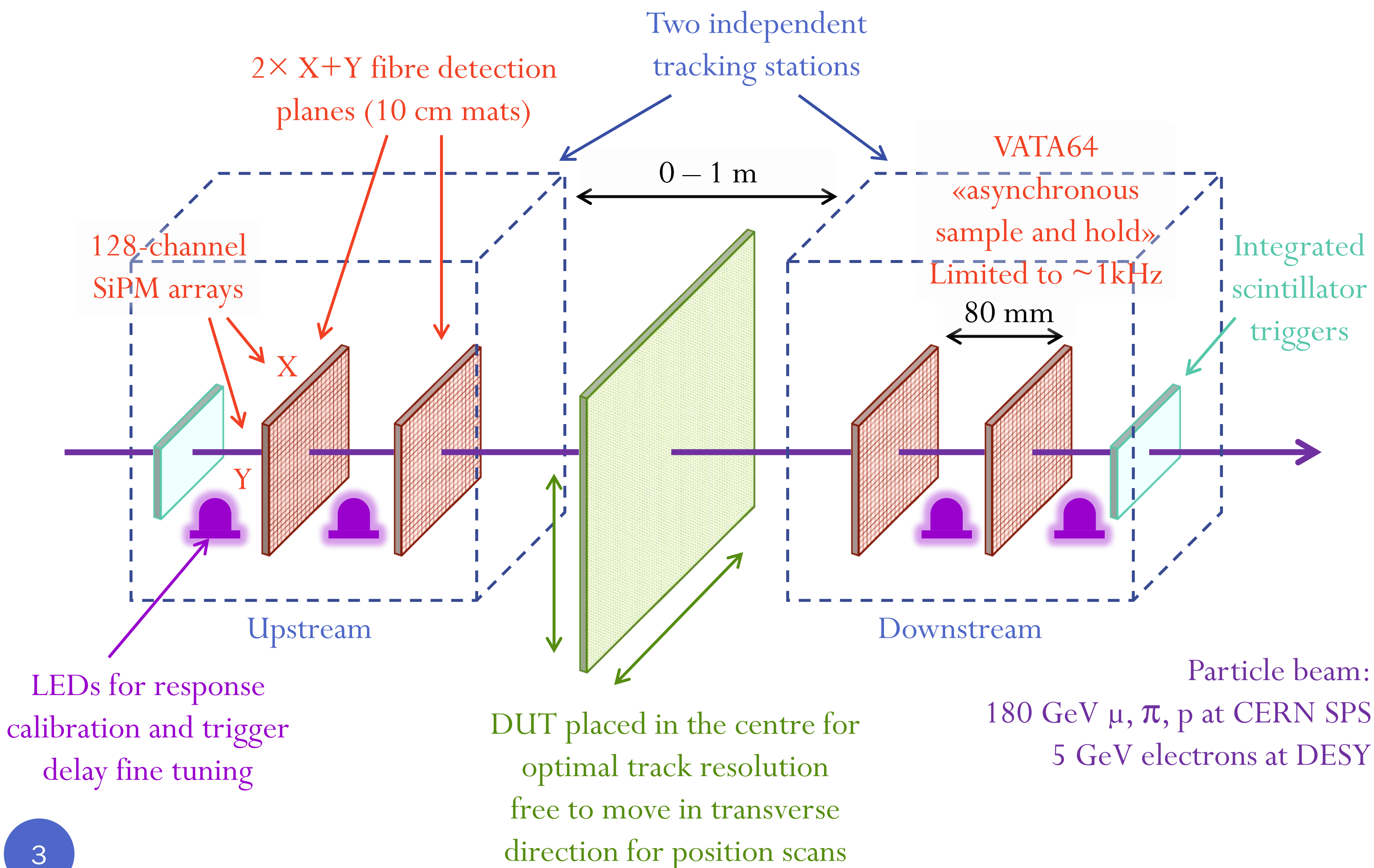




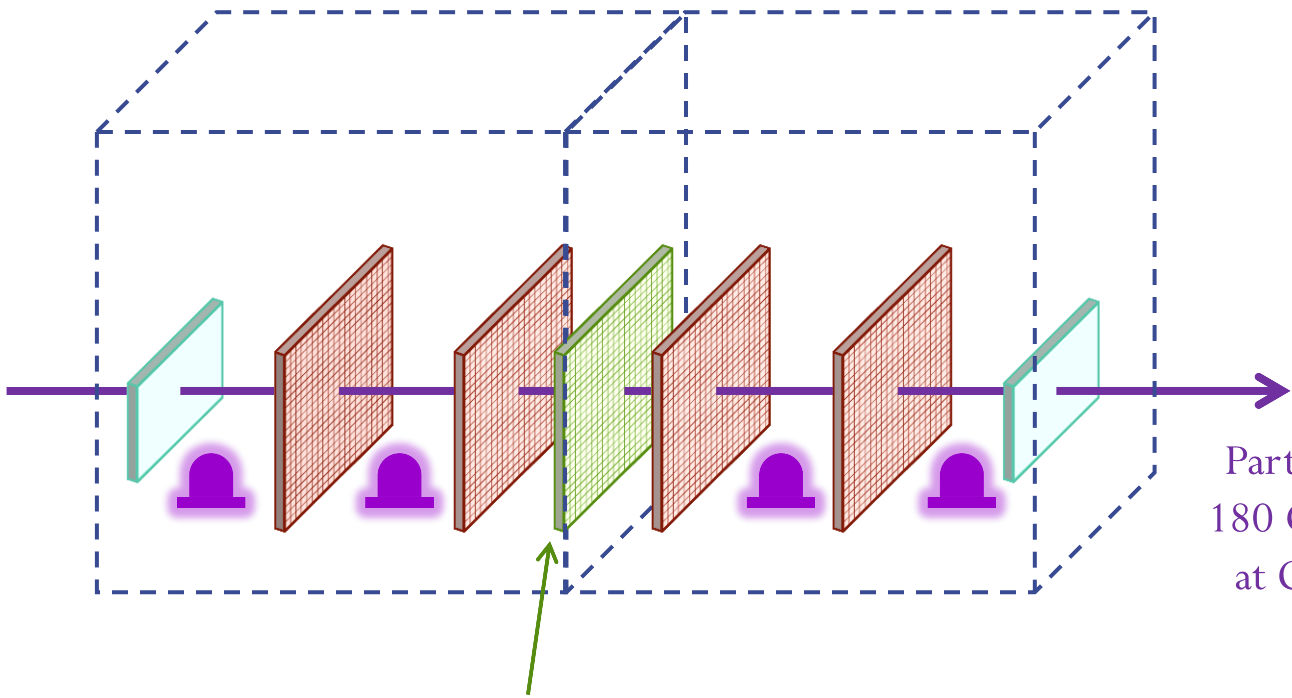
Related talk:

B. D. Leverington, *Test beam results of the LHCb Scintillating Fibre Tracker*.

Fibre-based telescope for beam test



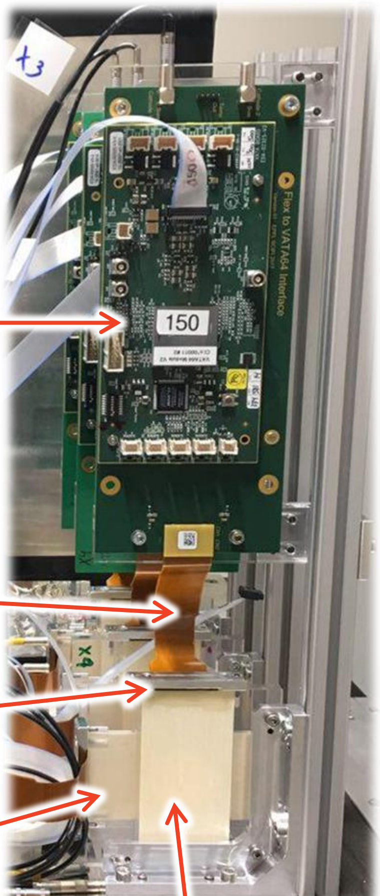
Setup of the latest test beam (Oct. 2017)

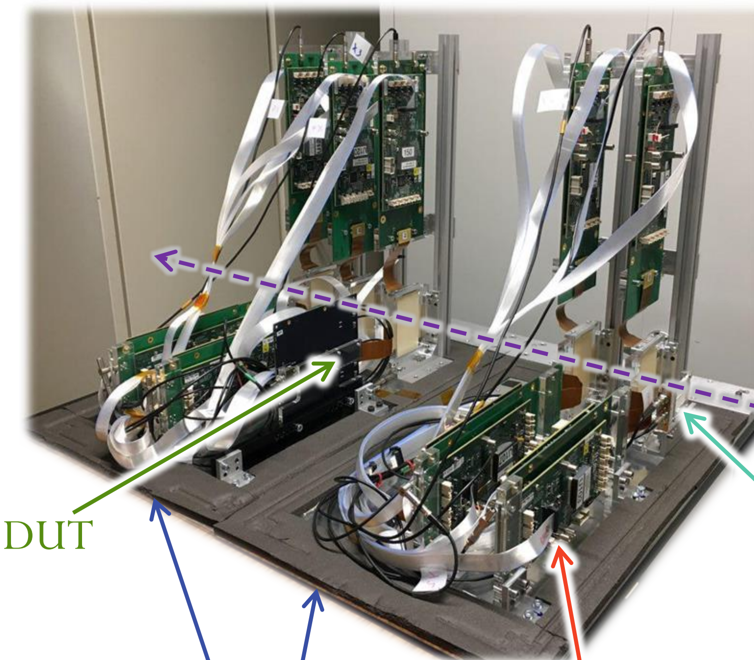


Particle beam:
180 GeV μ, π, p
at CERN SPS

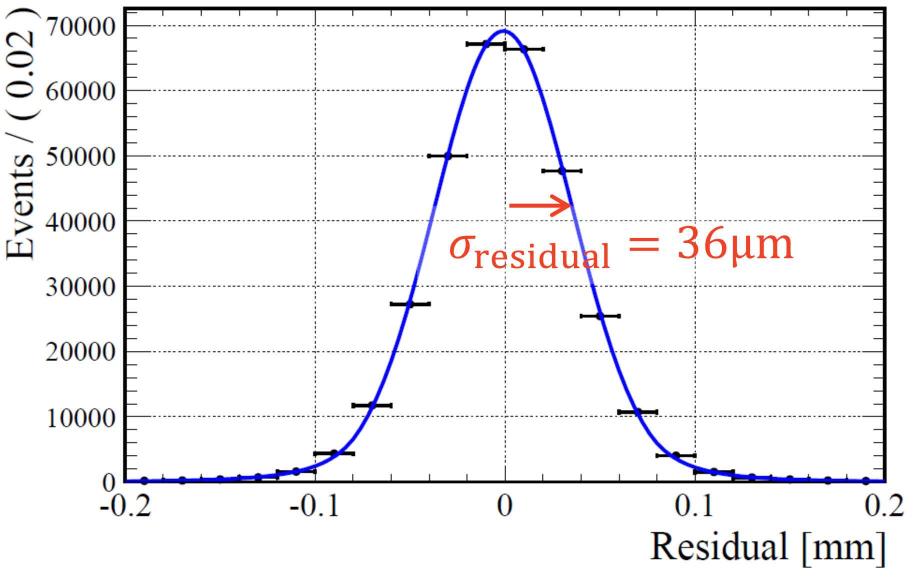
DUT: X+Y fibre mat of the same type as the tracking stations placed inside one of the stations

Setup of the latest test beam (Oct. 2017)





Track resolution and efficiency



Hit resolution σ_{hit}

- At the DUT: $\sigma_{Residual}{}^2 = \boldsymbol{\sigma_{hit}}^2 + \sigma_{track}{}^2$
- σ_{hit} same for all layers:

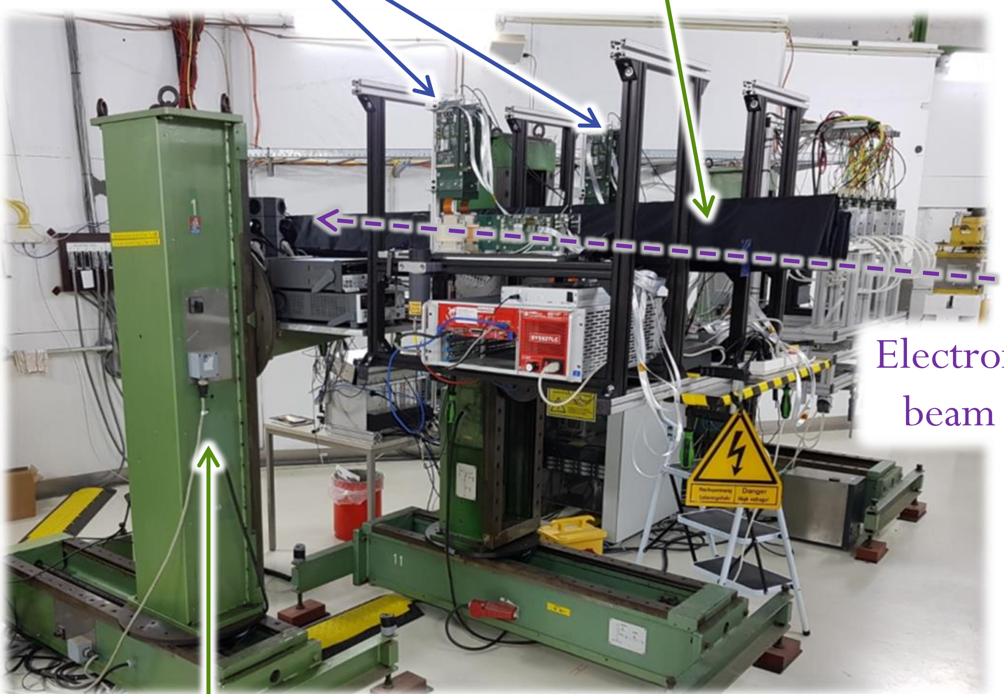
$$\boldsymbol{\sigma_{hit} = 32\mu m \implies \sigma_{track} = 16\mu m}$$

Hit detection efficiency ε_{hit}

- At the best hit resolution: $\varepsilon_{hit} = 99.6\%$
- Track finding efficiency ~98.6%
- Reduce the number of tracks with multiple scattering: cut on track χ^2
- Reject events with high energy delta electrons

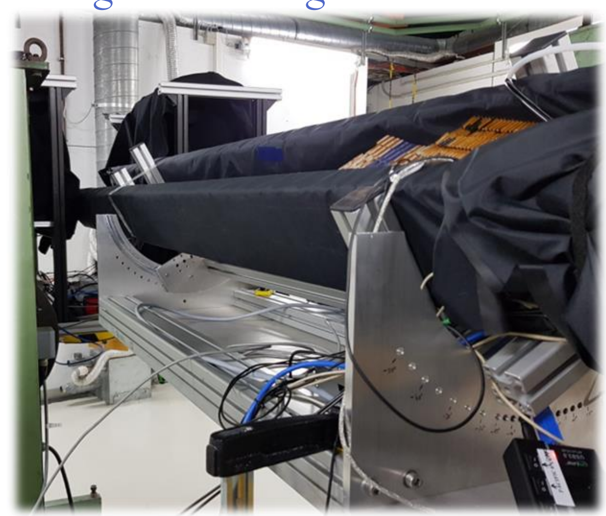
➢ At SPS: $\boldsymbol{\varepsilon_{track}}$ **= 50% used tracks**

Setup long module testing (f.ex. DESY)

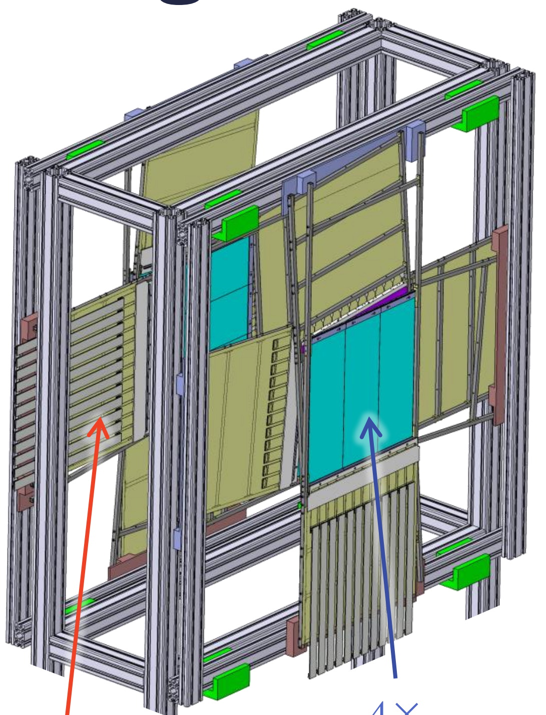


Front-view

Long module angular scan



Future developments
Large area device and timing



SHiP charm cross section experiment at SPS

Measurement of charm hadrons production cross-section of 400 GeV/c protons on SHiP target

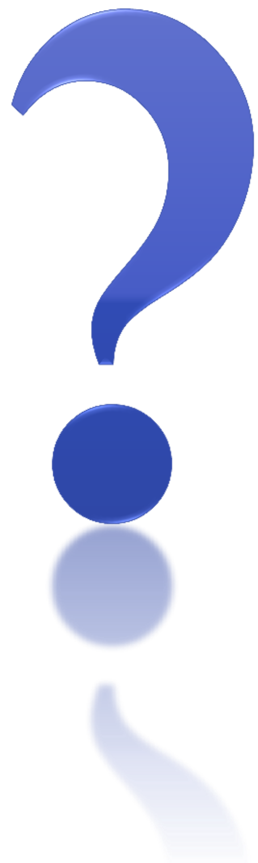
- Tracking systems including SciFi modules
- Fibres and SiPMs of the same type as LHCb SciFi
- STiC front-ends synchronized with beam trigger (~10 kHz)
- Hit time resolution expected <1 ns, ~300 ps for the track using all planes. Limitations: small number of photons (~20), scintillator decay time 2.8ns
- Hit resolution <50 μm expected

Integrate timing in the telescope to measure timing resolution for (large area) DUTs, rate increased up to 1 MHz

Summary

- Development of a beam telescope base on the same technology as the LHCb SciFi tracker with sufficient track resolution to characterize SciFi modules.
- Used successfully at SPS & DESY test beams to test large area fibre modules.
- Next improvements/developments:
  - Integrate timing measurement with the replacement of read-out electronics with STiC.
  - Development of a 400×400 mm^2 SciFi tracking system with 8 planes and timing measurement.

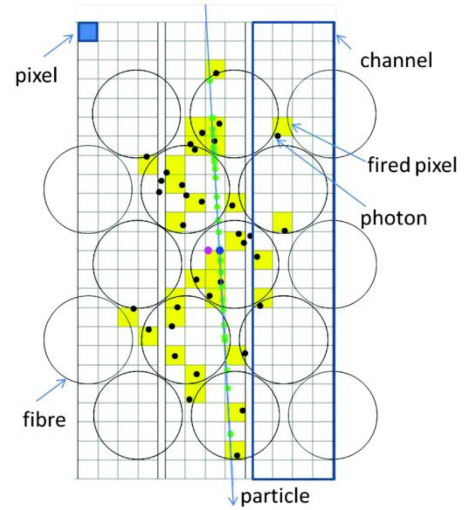
Thank you for your attention !

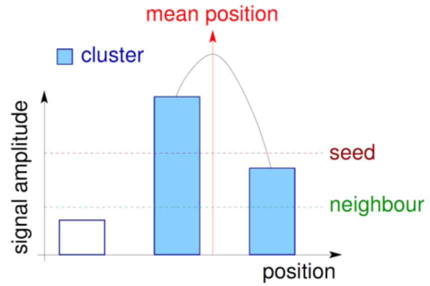


Hit position measurement and track reconstruction

Hit position calculation

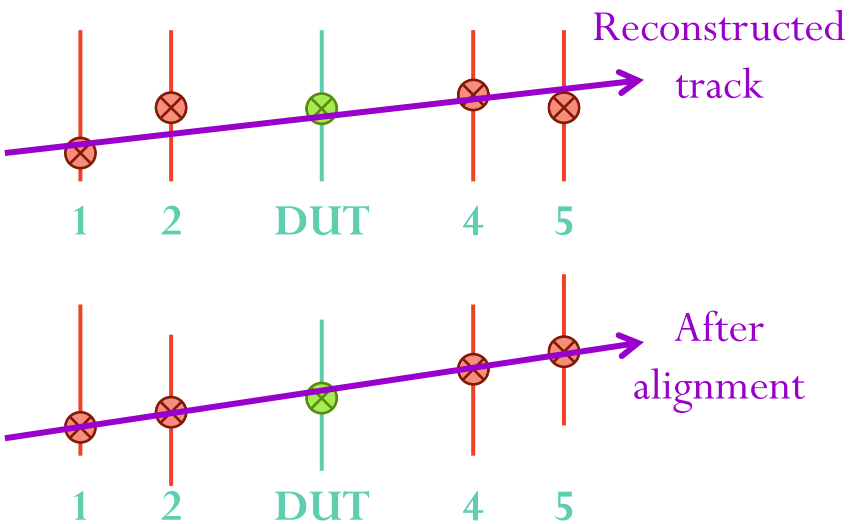
- Signal shared by several channels
- ➢ Clustering algorithm to calculate the barycentre and to suppress noise



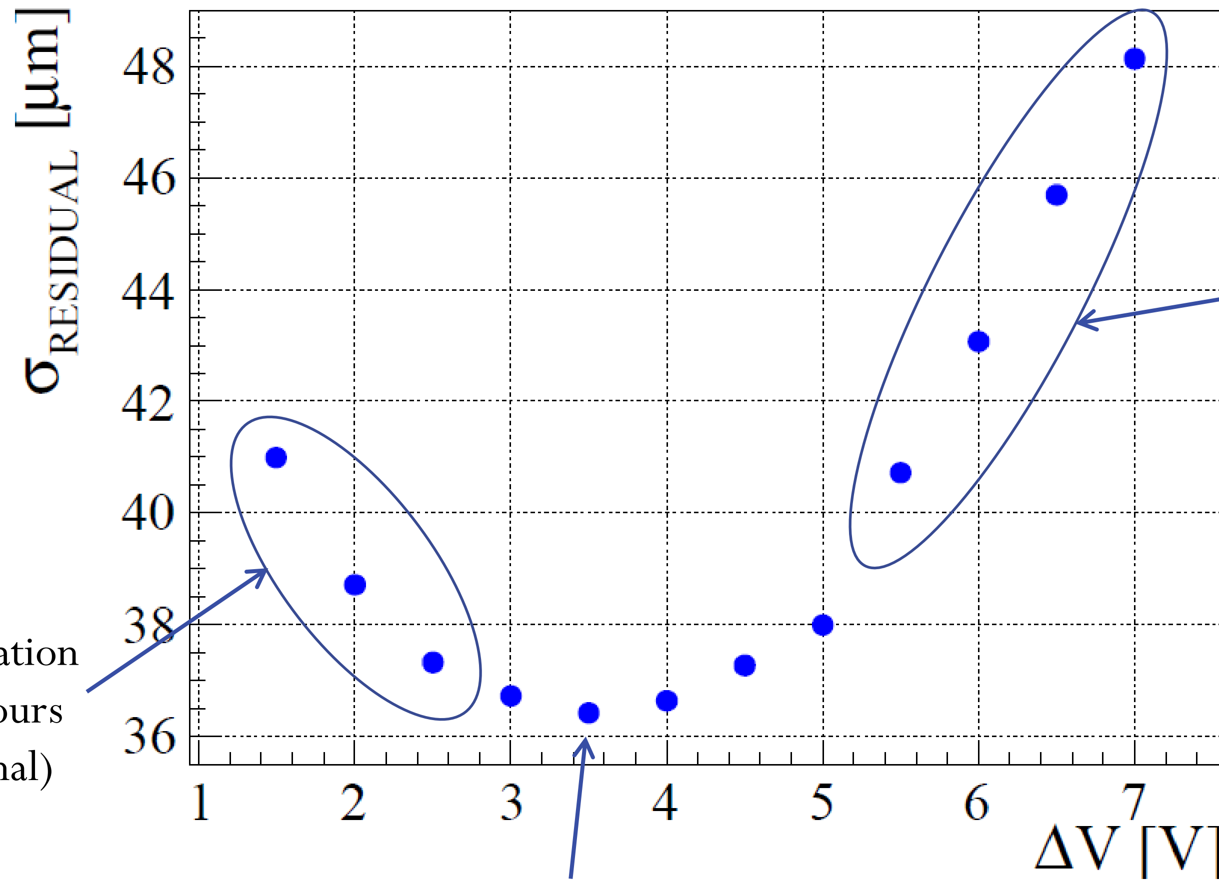


Planes alignment

- Alignment in the transverse direction using *Millepede*
- ➢ Set-up allows very good preliminary alignment (order of 200 μm correction)



Telescope optimisation (ΔV)



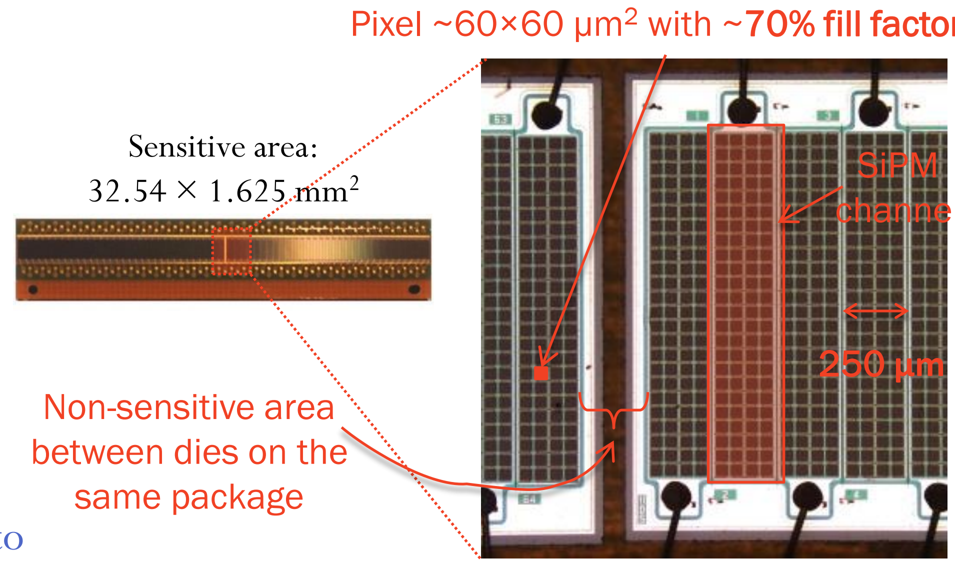
Correlated and random noise from the SiPM (fluctuation in signal amplitude in the cluster)

Loose information from neighbours (too few signal)

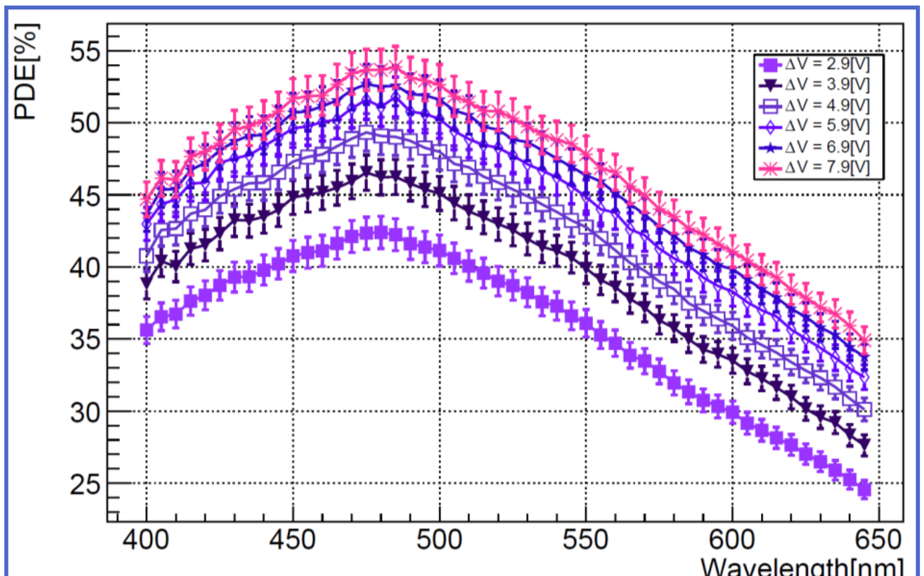
SiPM over-voltage optimised for the best hit resolution

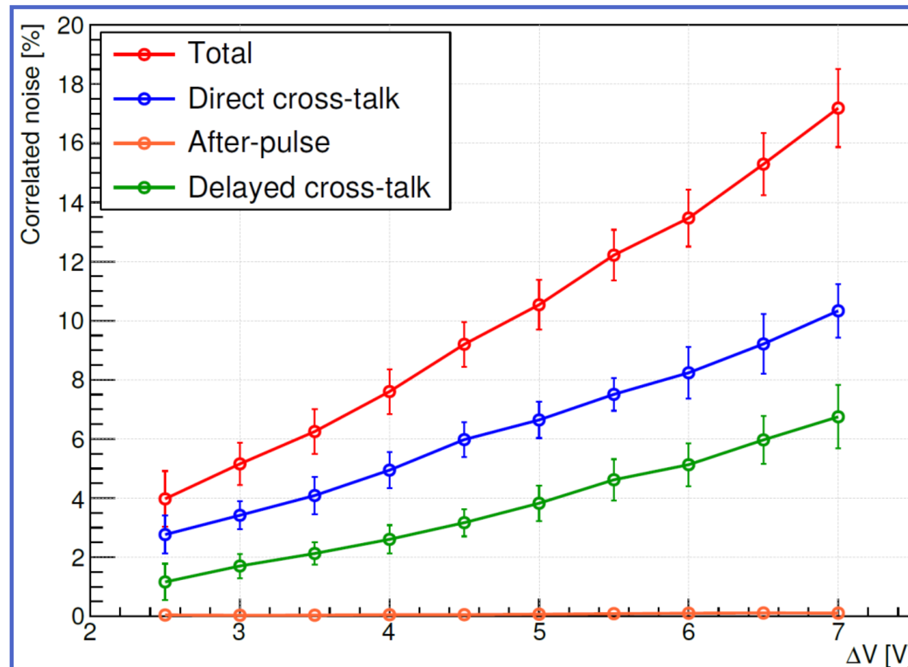
SiPMs

Customised SiPM array produced by Hamamatsu for the SciFi tracker optimised for the LHCb SciFi tracker



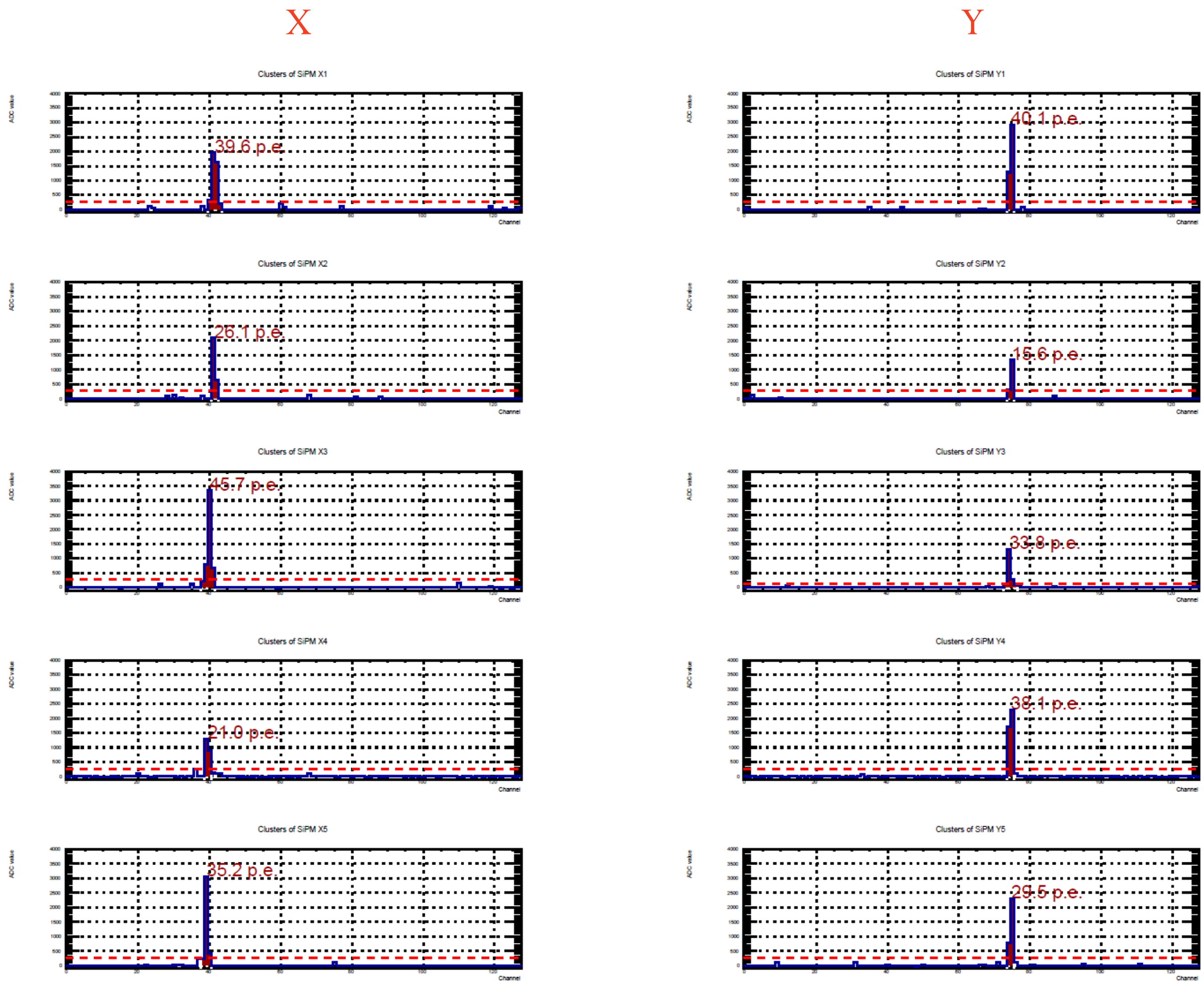
High photo-detection efficiency (necessary due to low amount of light from the fibres)



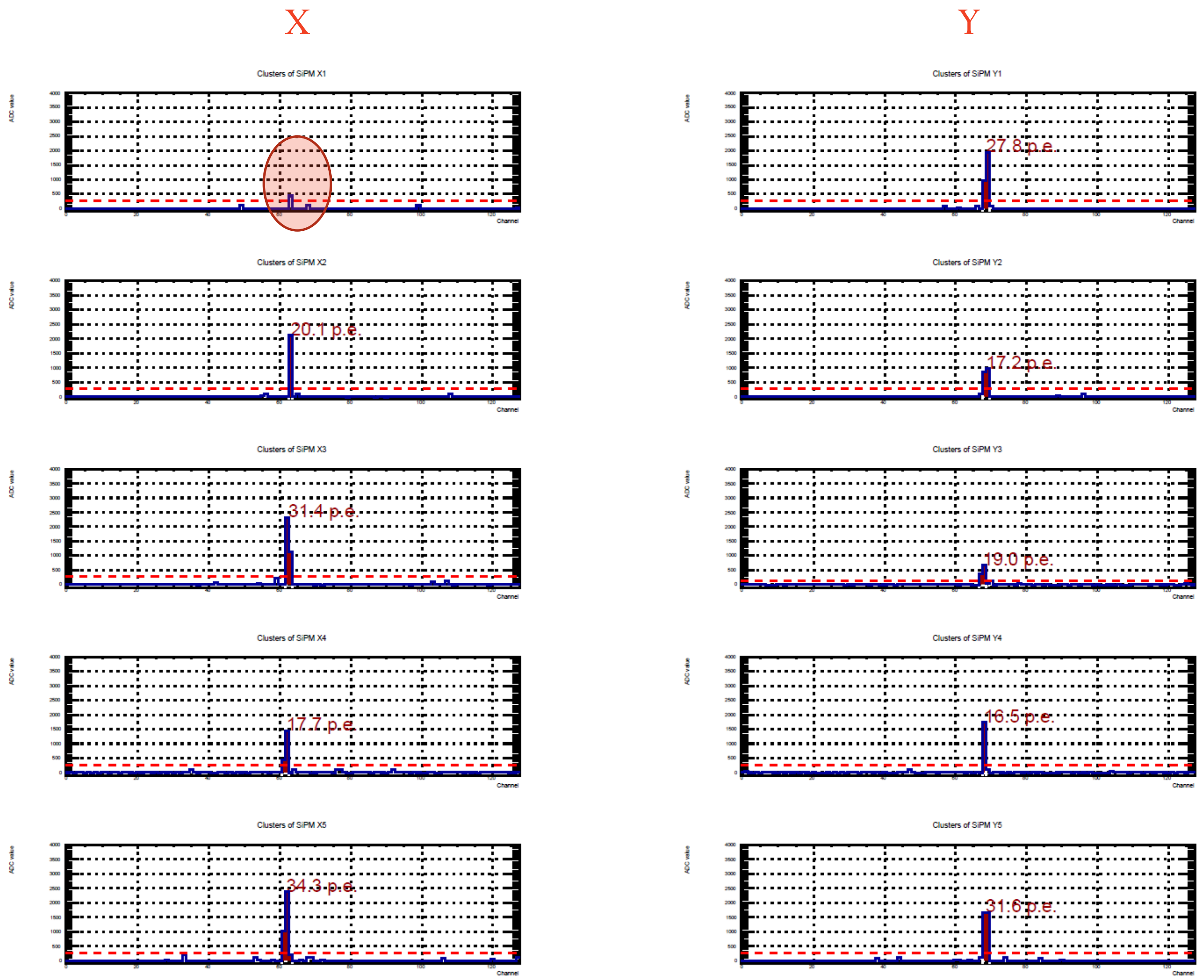


Low correlated noise (essential with the expected high DCR) over a wide operation range

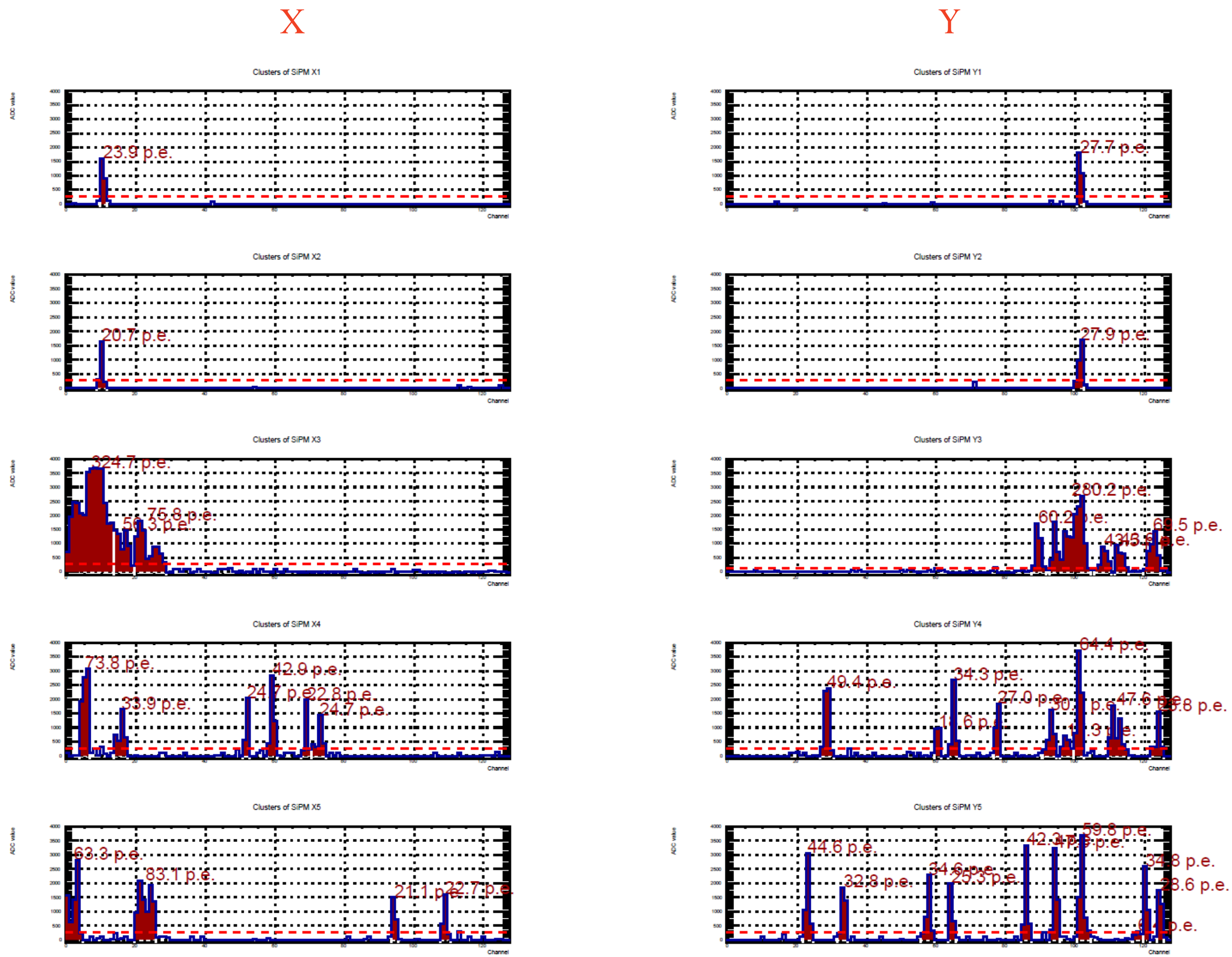
Event display (SPS) – accepted event



Event display (SPS) – rejected event



Event display (SPS) – rejected event



QA for Scintillating fibres

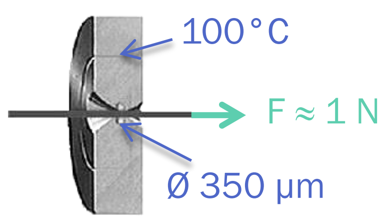
Fibres are produced by Kuraray (300 km every two weeks) and delivered at CERN where quality assurance tests are performed.

Goal of QA:

1. Acceptance test regarding optical and scintillation properties:
   - Attenuation length with UV LEDs
   - Scintillation yield with beta source
   - Irradiation tests with X-ray source
2. Removal of fibre sections out of mechanical specification ensuring high quality fibre mat production
   - Fibre defects (large diameter fluctuation) «bump» identified with laser micrometre scanner
   - Bump shrinking with heating element or cutting

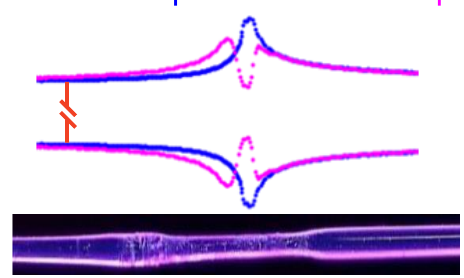
Bump shrinking by heating

Bump shrinking is fully automatic and it preserves fibre strength, cladding and 85% light transmission.

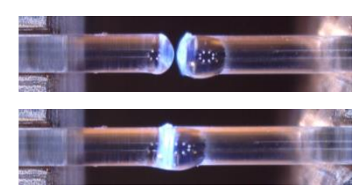


Example:

Before 415 μm → After 337 μm



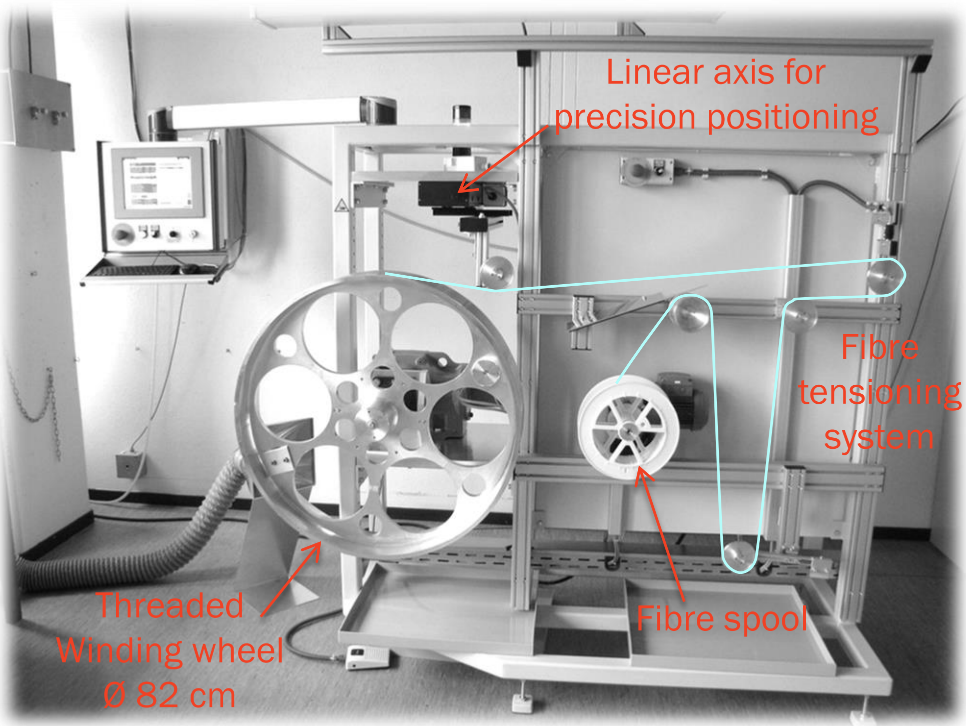
Fibber Bumps larger than 500 μm must be cut away and the fibre re-glued (~15 min, 1-2×/spool).



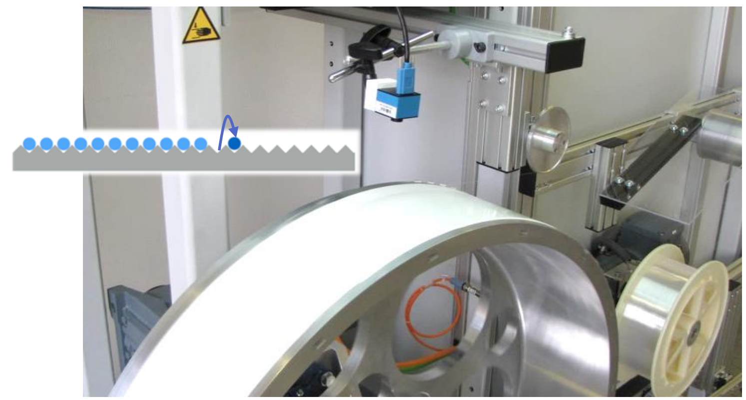
Fibre mat winding

~**1200 mats** required for the SciFi tracker
Aimed production rate: 4 mats/week/site

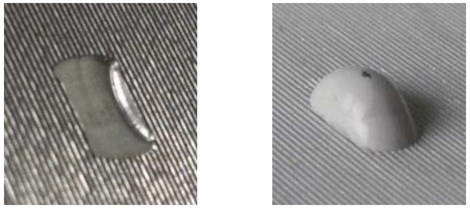
- Four production centres: RWTH Aachen and TU Dortmund (DE), EPFL (CH) and Kurchatov Institute (RU)
- Custom winding machine produced by an industrial company (one per winding centre)
- Fibre mat of 2.5 m length × 13 cm width, 6 fibre layers with a total of 7 km of fibres
- Mat winding takes 4h (1 per day)



Visual monitoring to detect fibre jumps

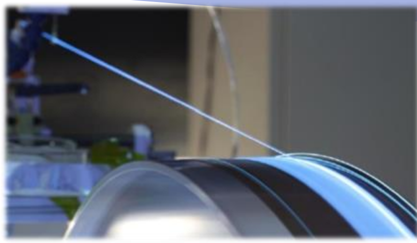


Alignment pin groove in the wheel, filled with glue during winding, allows precision positioning at later production steps



Mat production steps

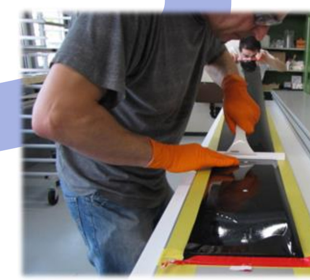
1. **Winding**



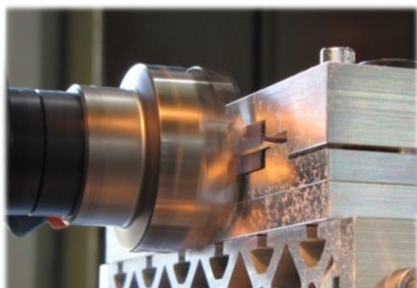
2. **Glue curing** with wheel rotating for 12h in an area with controlled humidity and temperature

3. **Cutting and unforming**

4. **Foil lamination** with black 25 μm thick capton foil (both sides, ensures light tightness) and **end piece gluing**

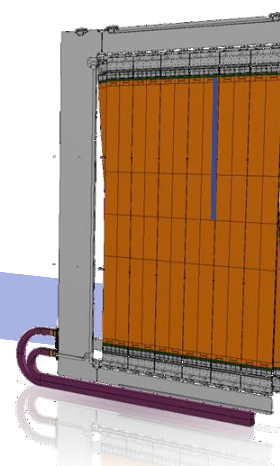


5. **Optical cut** with a milling machine (polishing with a diamond head)



6. **Mirror gluing**

7. **QA tests** with optical scanner and β-source (light yield homogeneity)



8. **Delivery** to Heidelberg and Nikhef for module assembly
+ integration of SiPMs, cooling and FE electronics