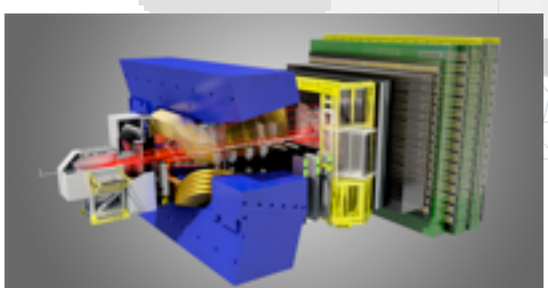
LHCb Upgrade Tracking TDR: Scintillating Fiber Tracker

Fred Blanc (EPFL)

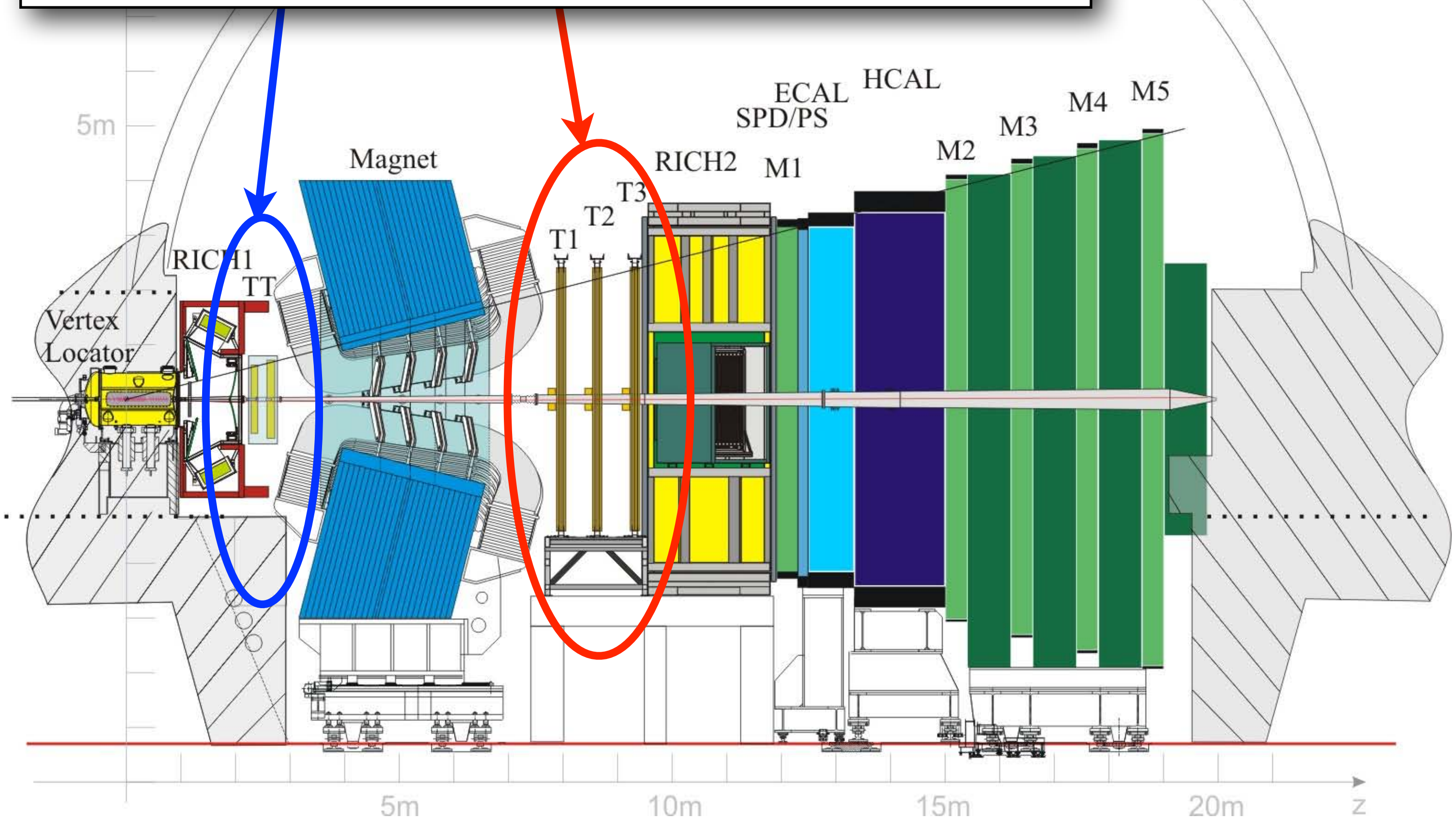
LHCC detector upgrade review
04/03/2014



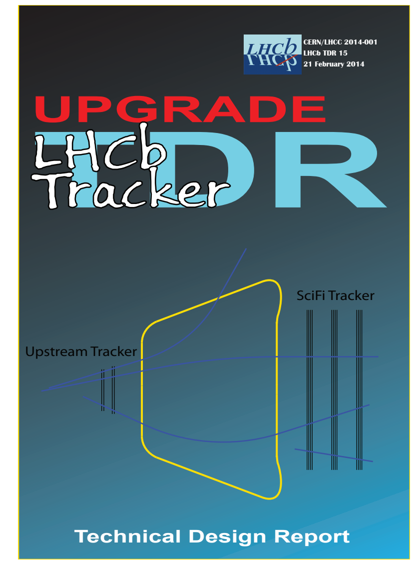
LHCb Tracker Upgrade

Replacement of the LHCb Tracker:

- **TT → Upstream Tracker (⇒ cf. talk by S.Stone)**
- **IT+OT → SciFi Tracker (⇒ this talk)**
  250μm scintillating fibres read out with Silicon Photomultipliers (SiPM)



LHCb Tracker Upgrade TDR
CERN/LHCC 2014-001
LHCb TDR 15



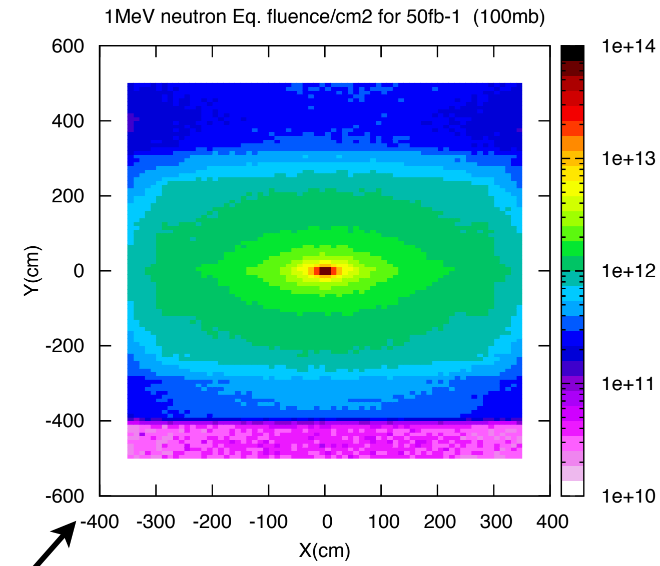
SciFi Tracker: participating institutes

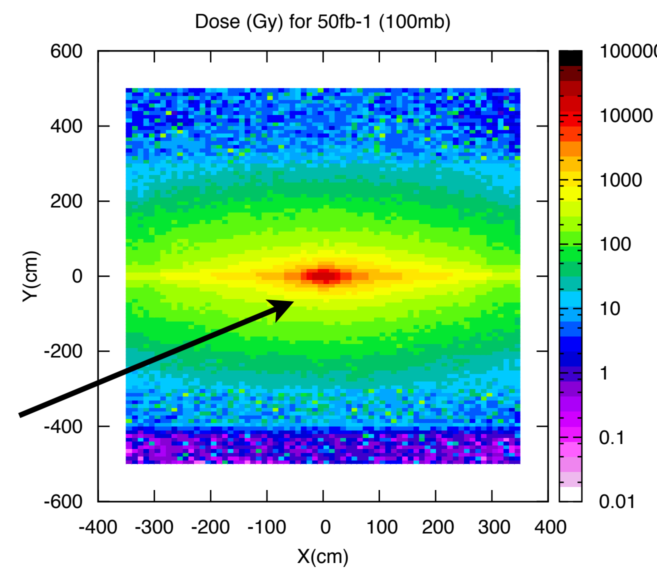
- Brasil (CBPF)
- China (Tsinghua)
- France (LPC, LAL, LPNHE)
- Germany (Aachen, Dortmund, Heidelberg, Rostock)
- Netherlands (Nikhef)
- Poland (Warsaw)
- Russia (PNPI, ITEP, INR, IHEP, NRC KI)
- Spain (Barcelona, Valencia)
- Switzerland (CERN, EPFL)
- UK (Imperial College)

Requirements

- Detector performance
  - high hit efficiency
  - low noise cluster rate (<10% of signal at any location)
  - < 100μm resolution in bending plane
  - $X/X_0 \leq 1\%$ per detection layer
- Constraints
  - 40MHz readout electronics
  - geometrical
  - radiation environment:
    - ≤ 80Gy at the location of the photo-detectors
    - ≤ 35kGy peak dose for the scintillating fibres
  - cooling down to –40ºC

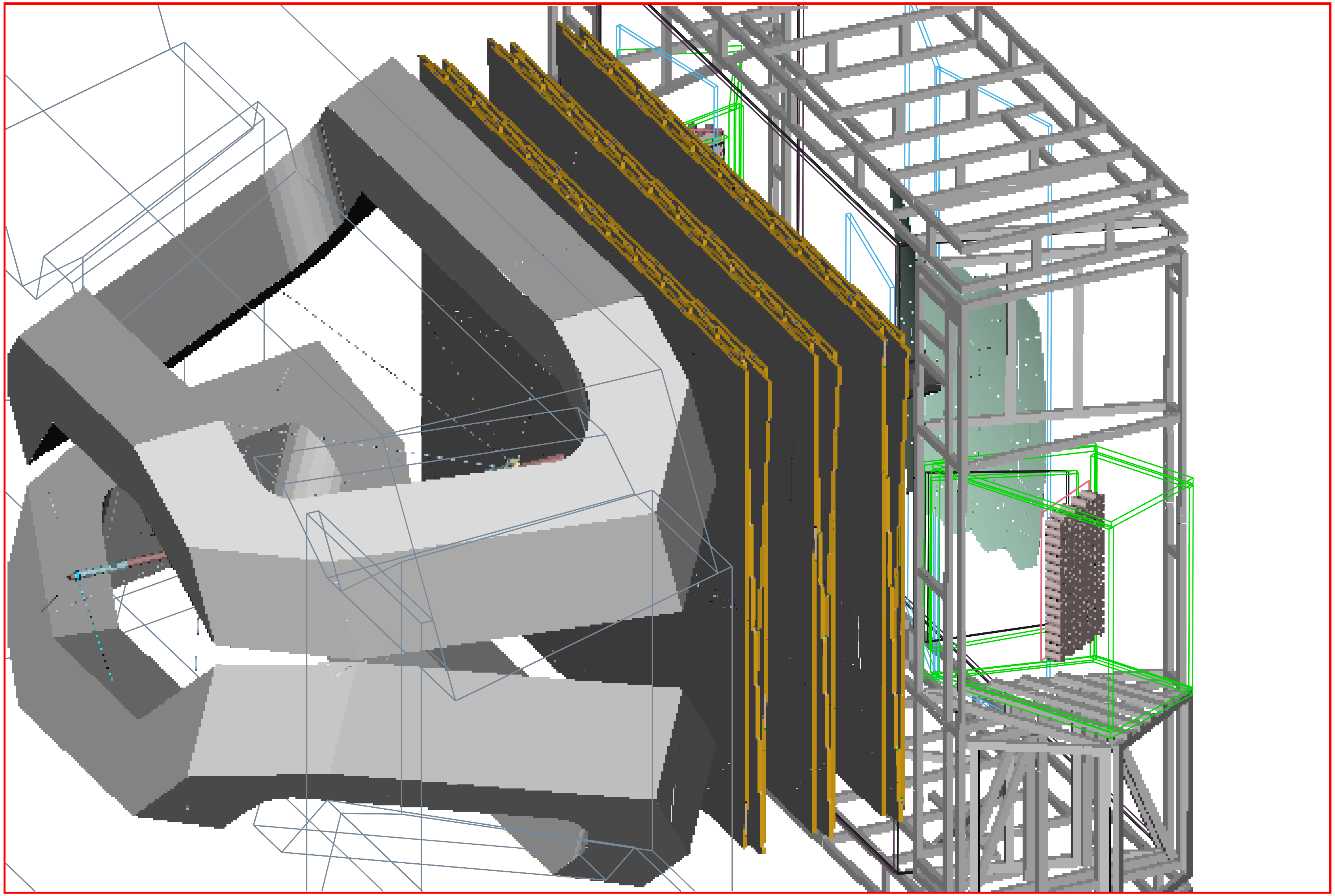
LHCb FLUKA simulation





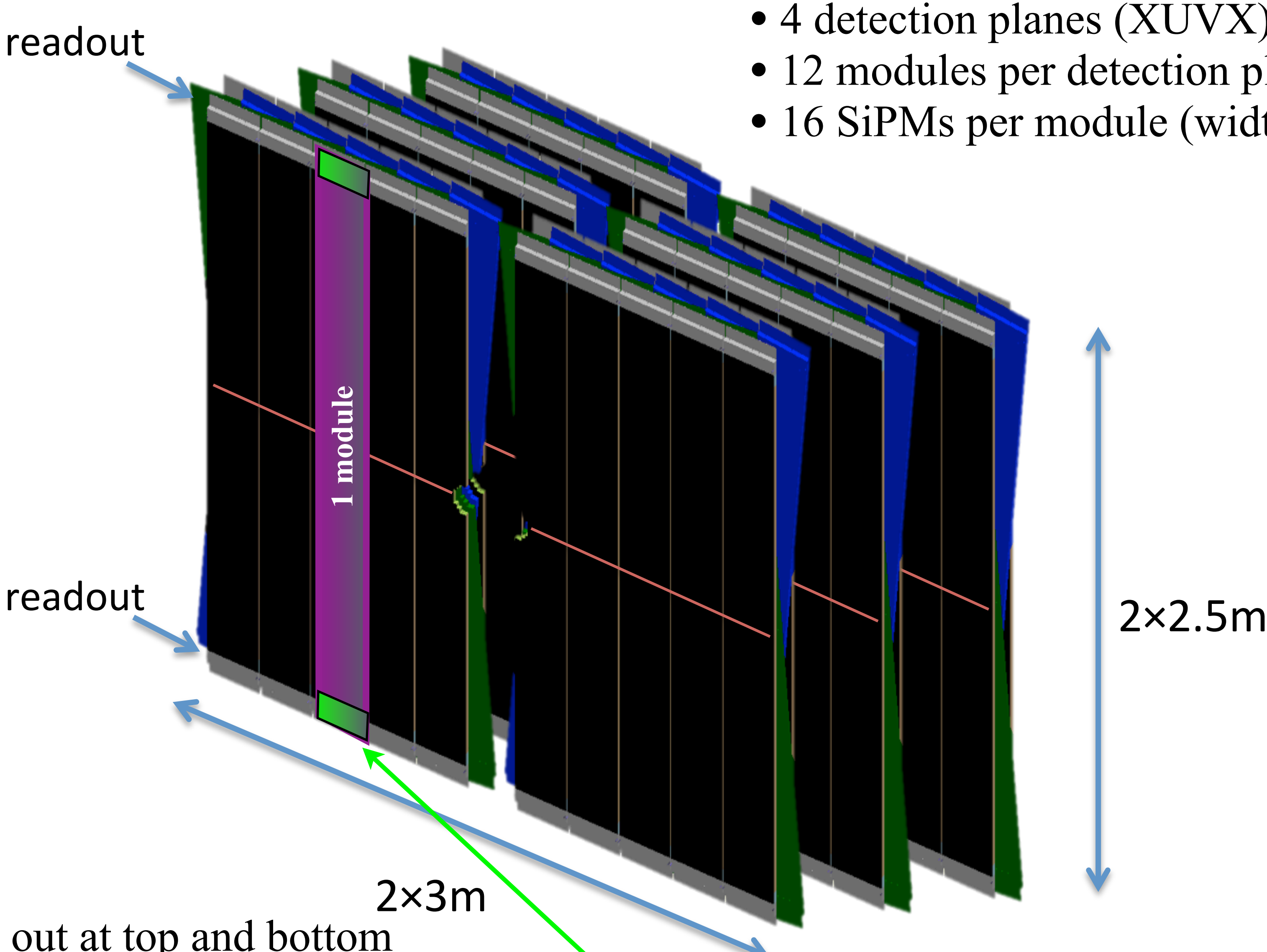
SciFi Tracker general layout

- General description of the detector geometry



SciFi tracker stations layout

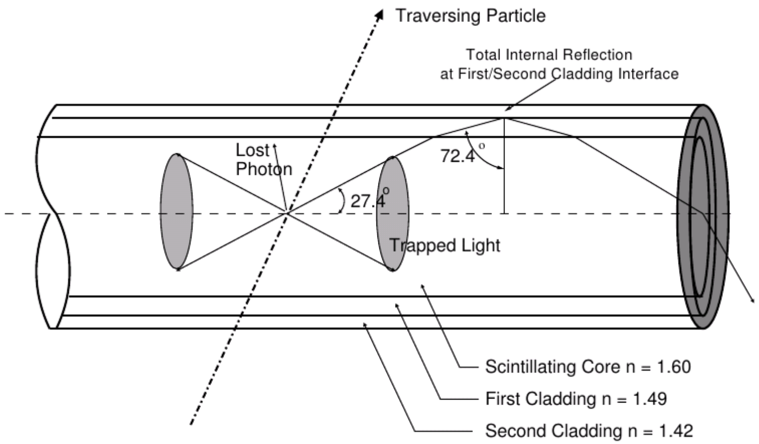
- 3 stations
- 4 detection planes (XUVX) per station
- 12 modules per detection plane
- 16 SiPMs per module (width ~530mm)



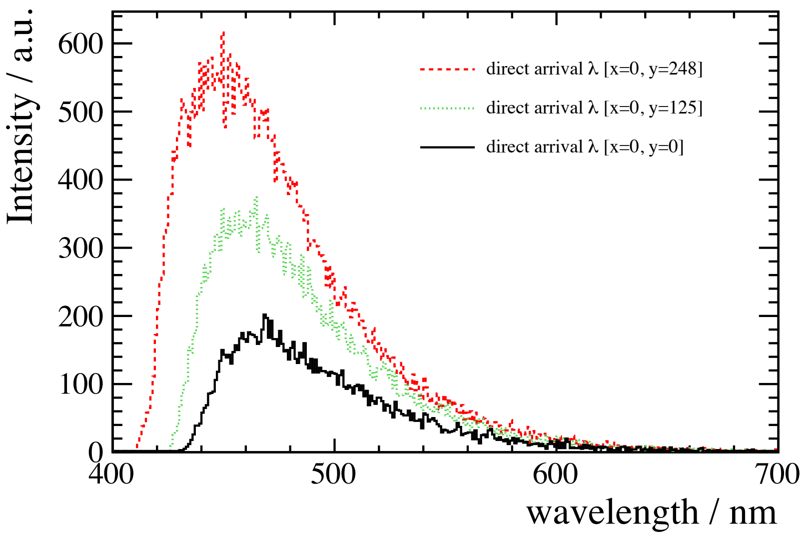
- Fibers read out at top and bottom
- SiPMs + FE electronics + services in a “Readout Box”

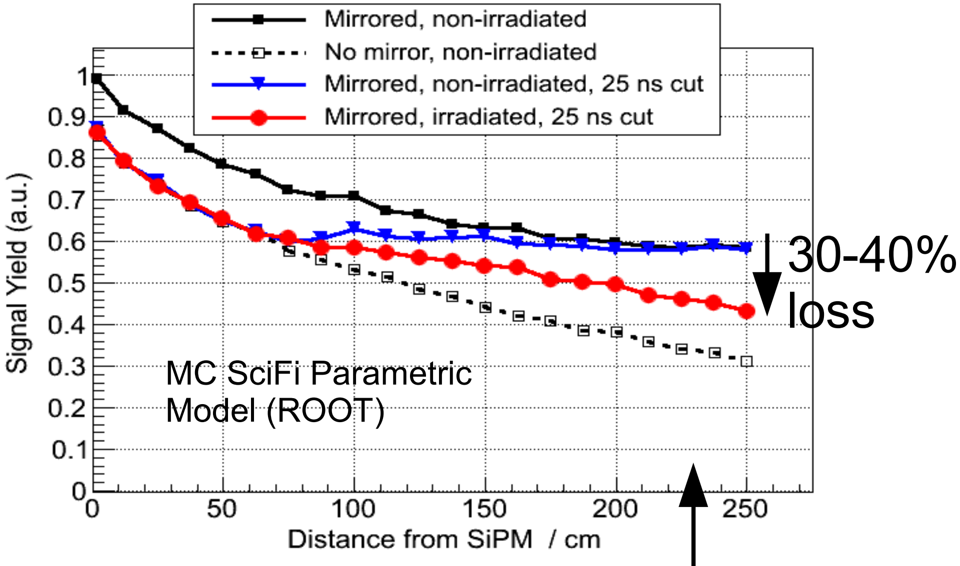
Scintillating Fibres

- Double-cladded scintillating fibers (Kuraray, SCSF-78, ⌀250μm)



- Radiation hardness studies:
  ⇒ fast damage
  ⇒ recovery (annealing)
  ⇒ shift spectrum to the green

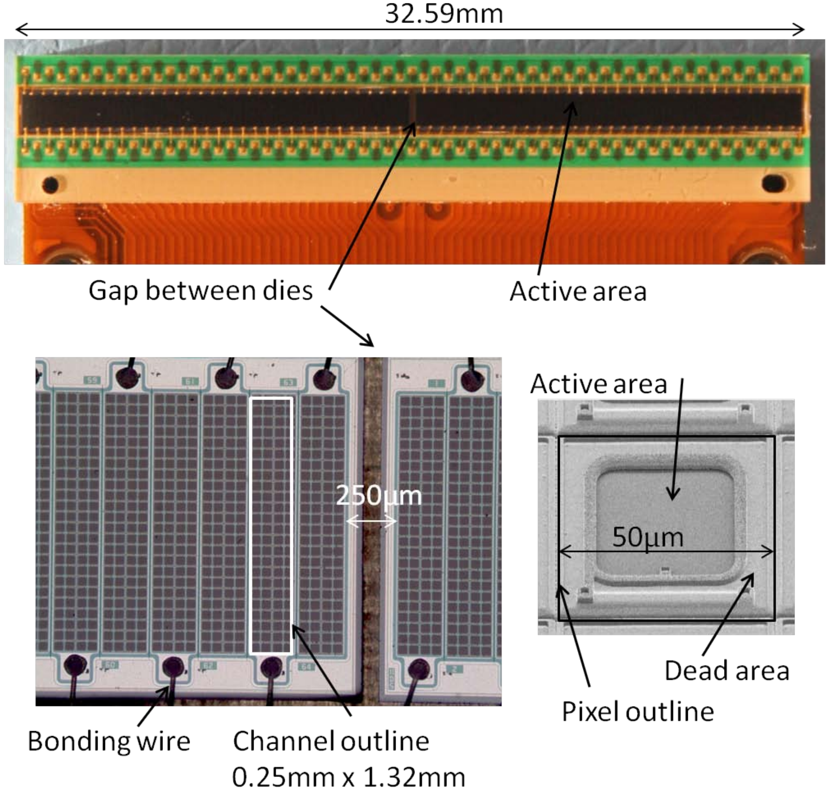


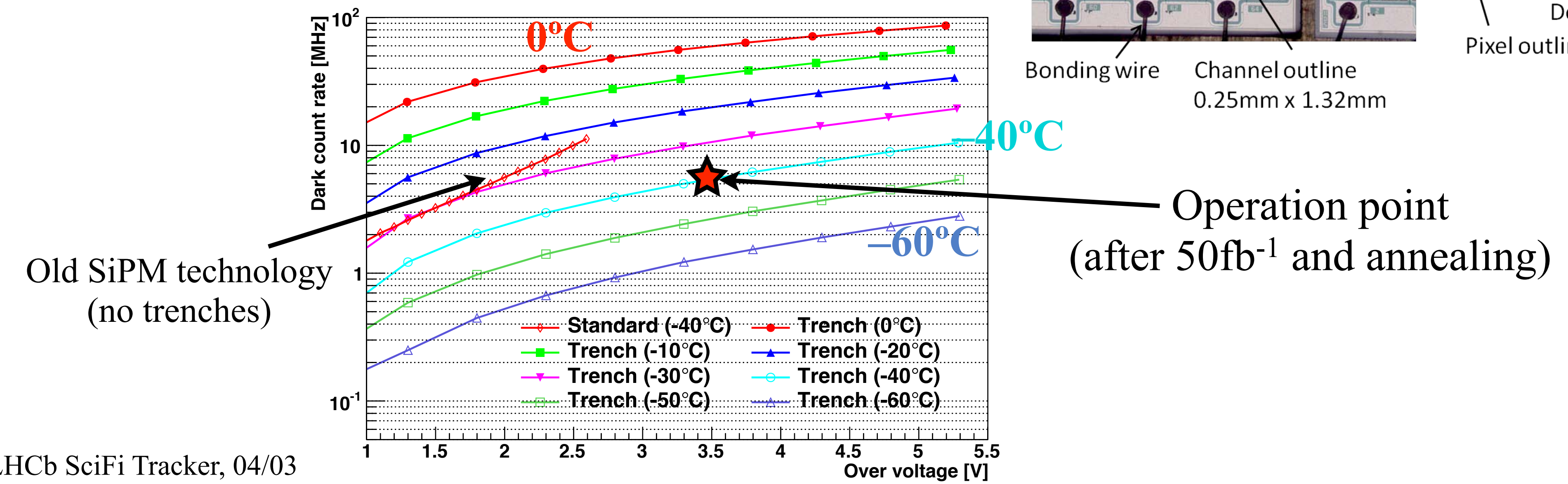


- Expect 30-40% light loss near the beam pipe after 50fb^{-1}

Silicon photo-detectors (SiPM)

- Multichannel SiPMs are well suited for this application:
  - fast signal response
  - fast recovery
- Good understanding of signal and noise characteristics
  - x-talk, after pulsing, etc…
- Radiation damage
  - cooling required (–40ºC)

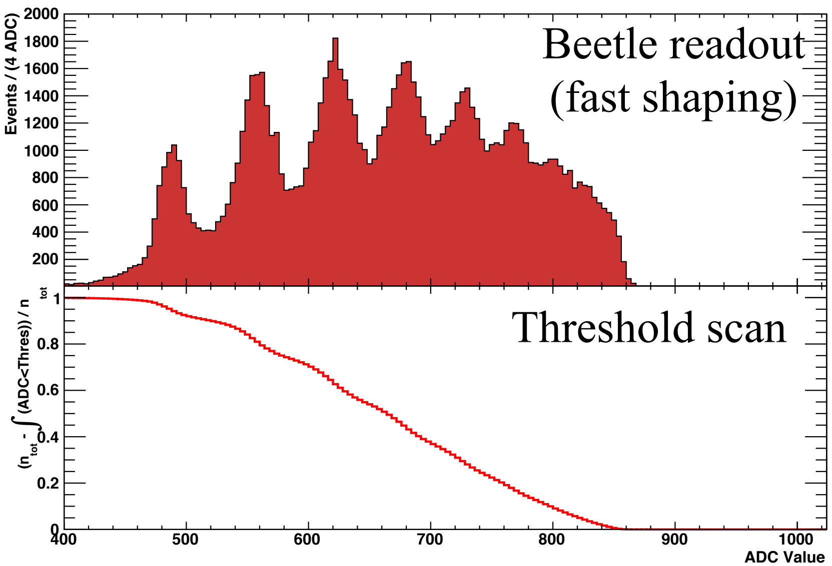


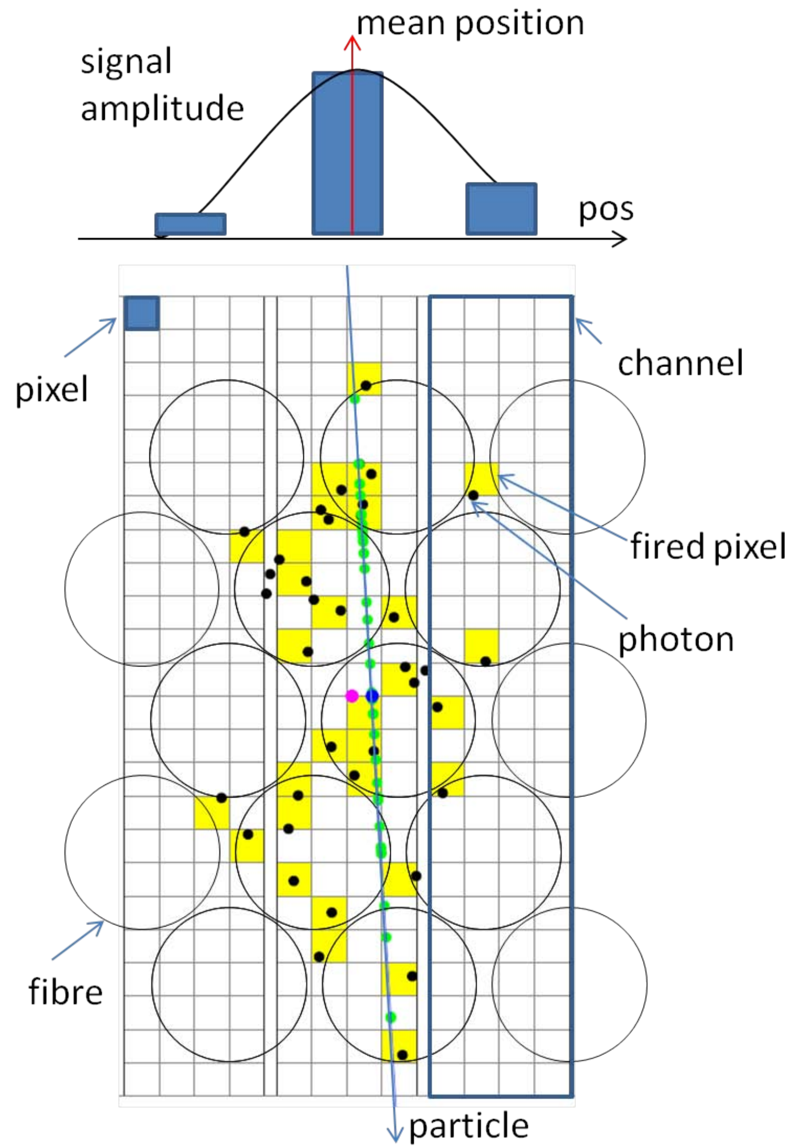


Silicon photo-detectors

- Clustering algorithm
  - based on 3 thresholds
  - used for implementation in the FE electronics

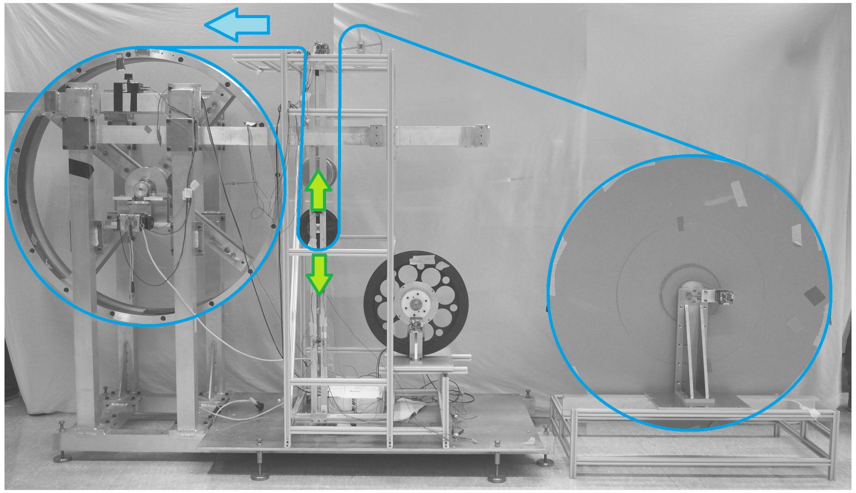
- Calibration strategy
  - threshold scans

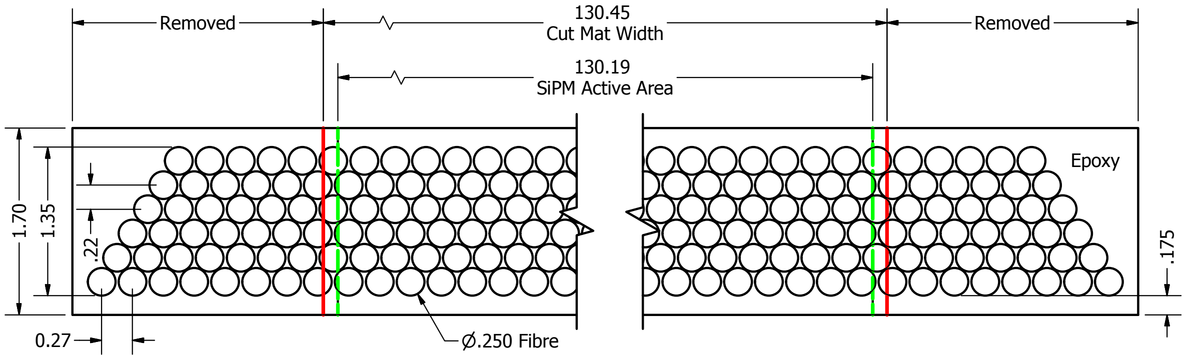




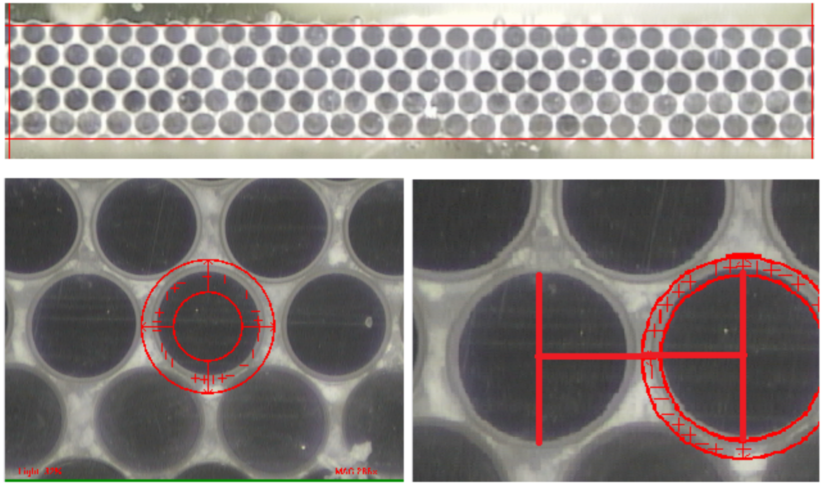
Detector modules: fibre mats

- Fibre mats
  - 2.5m×13.5cm × 5(6) layers
  - cylindrical winding (custom made setup)





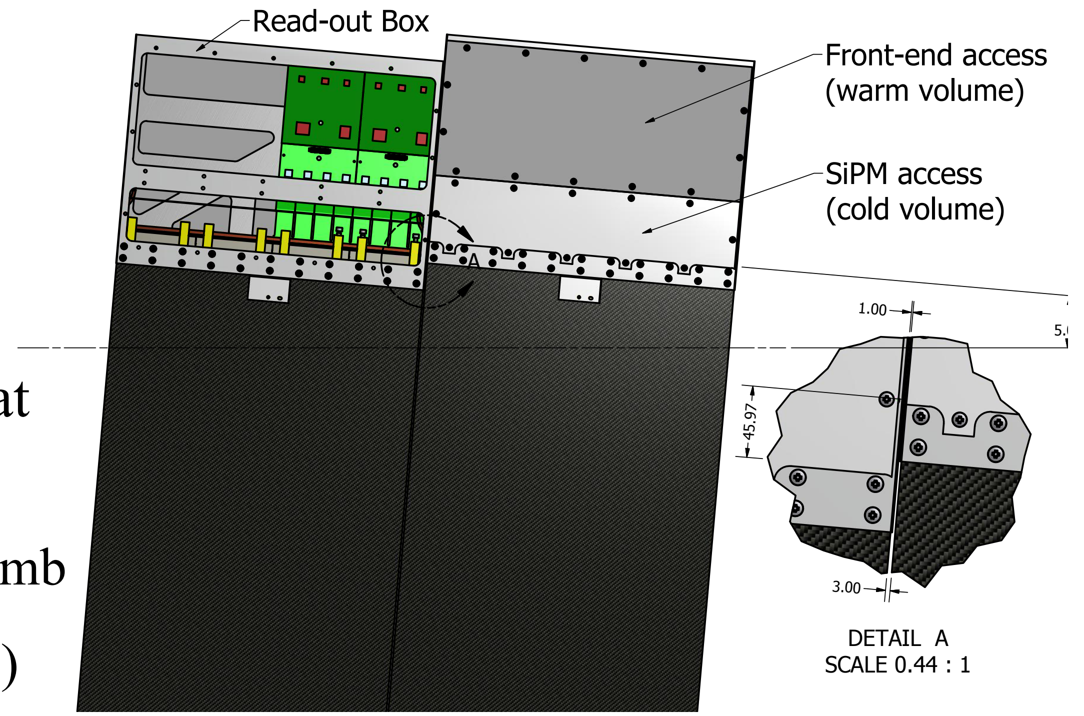
  - casting
  - alignment
  - cutting
  - mirror at end of fibre (aluminised mylar foil)

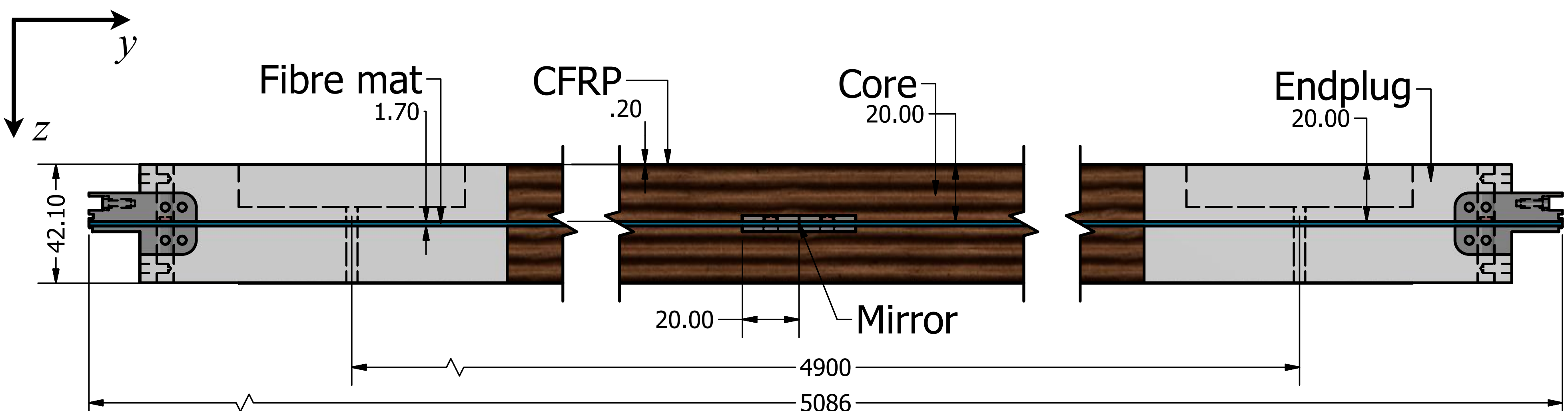


Fibres relative position within 16μm (5th layer)

Detector modules and fibre panels

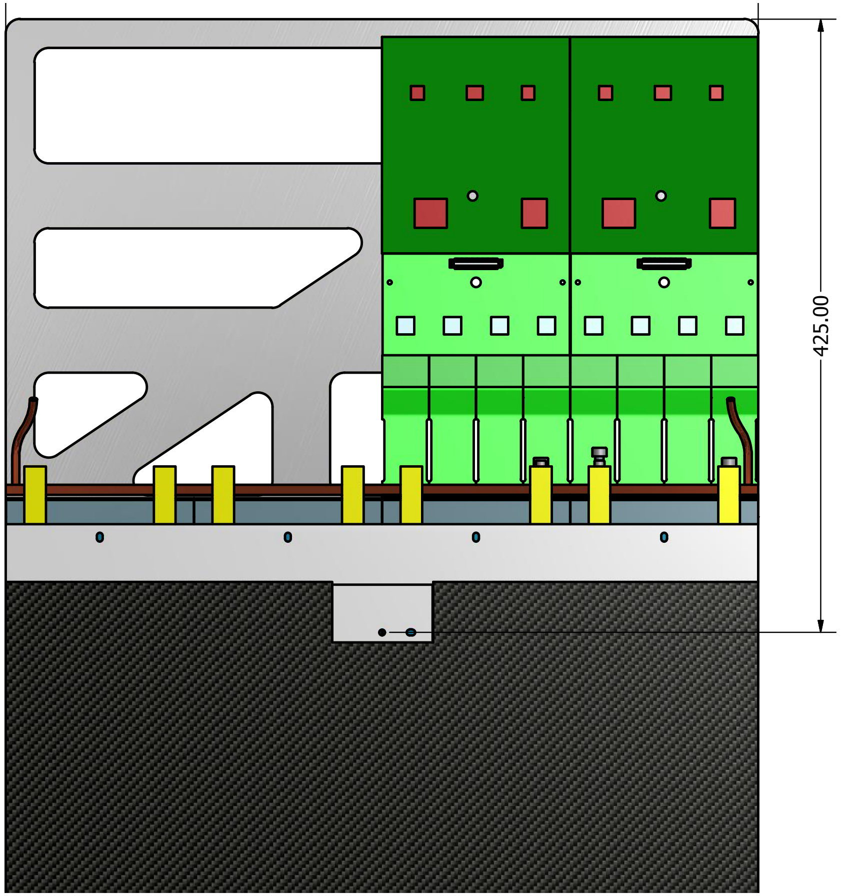
- Module consists of
  - 5×0.53 m^2 panel
  - 2 readout boxes
- Fibre panel
  - 1.7mm scintillating fibre mat in sandwich of
    - 20.0mm Nomex® honeycomb
    - 0.2mm carbon fibre (CFRP)



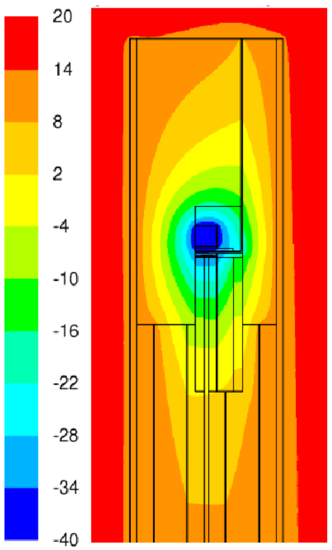


Readout Box

- Readout Boxes at both ends of the modules
- Each box contains
  - SiPMs (16)
  - FE electronics
  - cooling
  - services

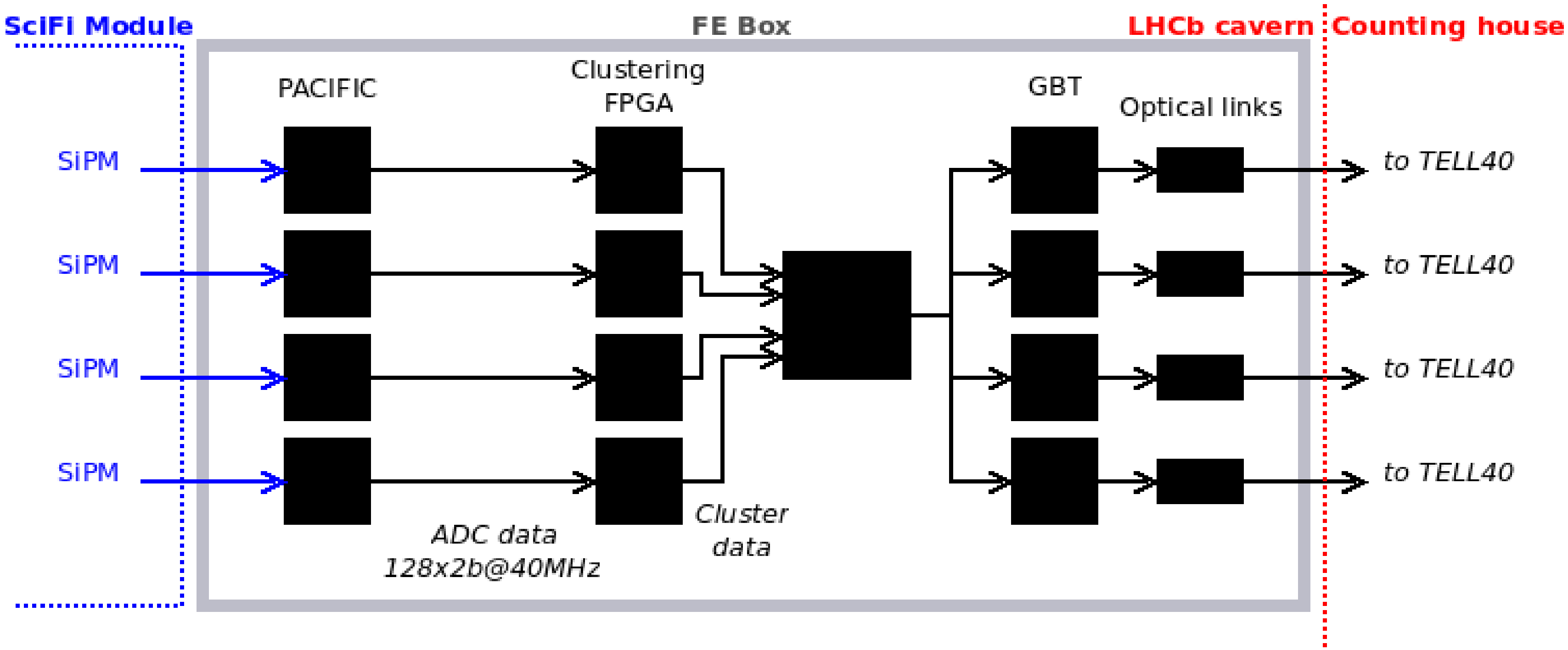


- SiPM cooling simulation used in the design of the Readout Box



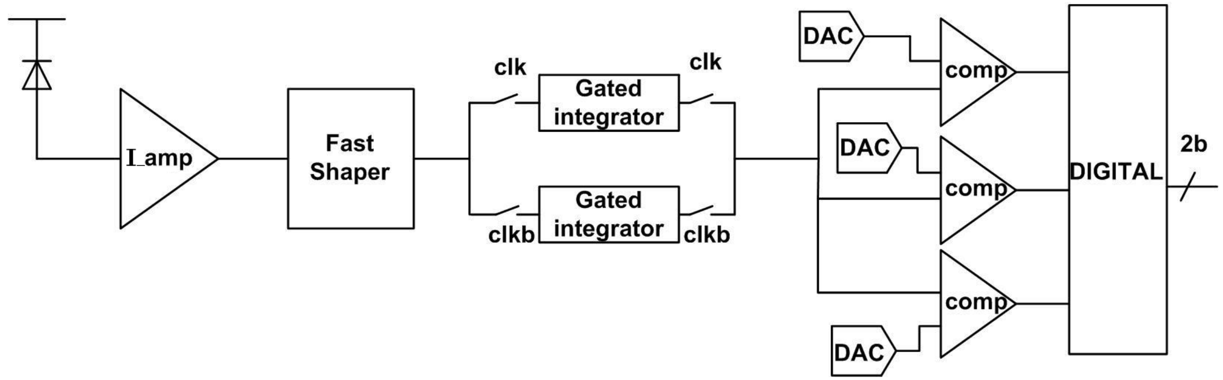
Front-end electronics

- Baseline solution:
  - one FE chip (PACIFIC) per SiPM (128 channels)
  - one dedicated chip for clustering
  - one “concentrator” chip / 4 SiPM to optimise bandwidth
- Allows to readout the 590k channels at 40MHz

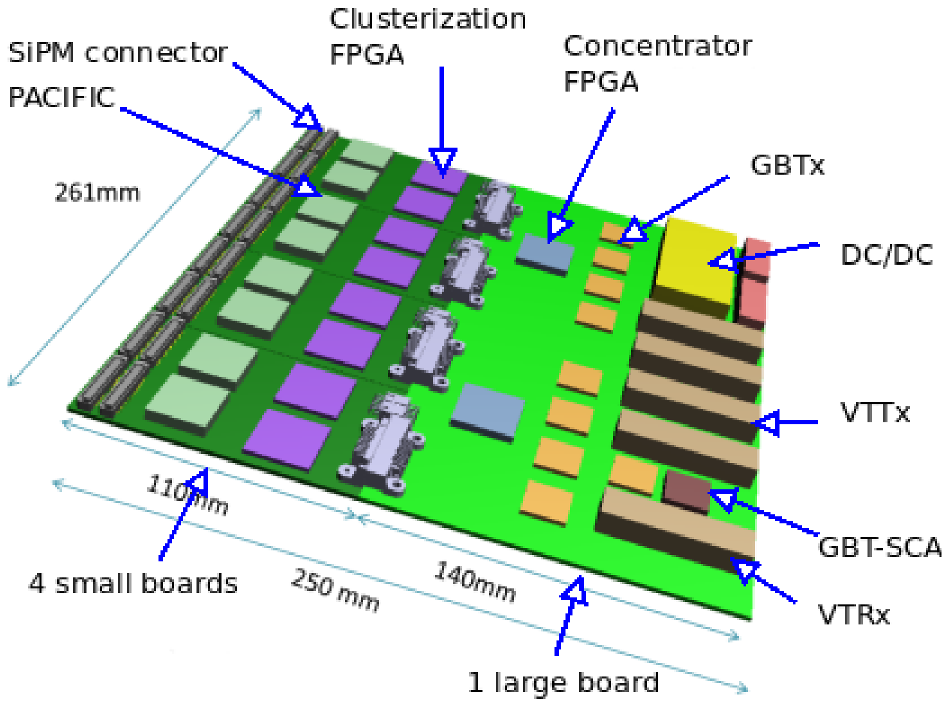


Front-end electronics

- Dedicated ASIC chip (PACIFIC):
  - fast shaper; 2 gated integrators; 3 threshold comparators (2bits)

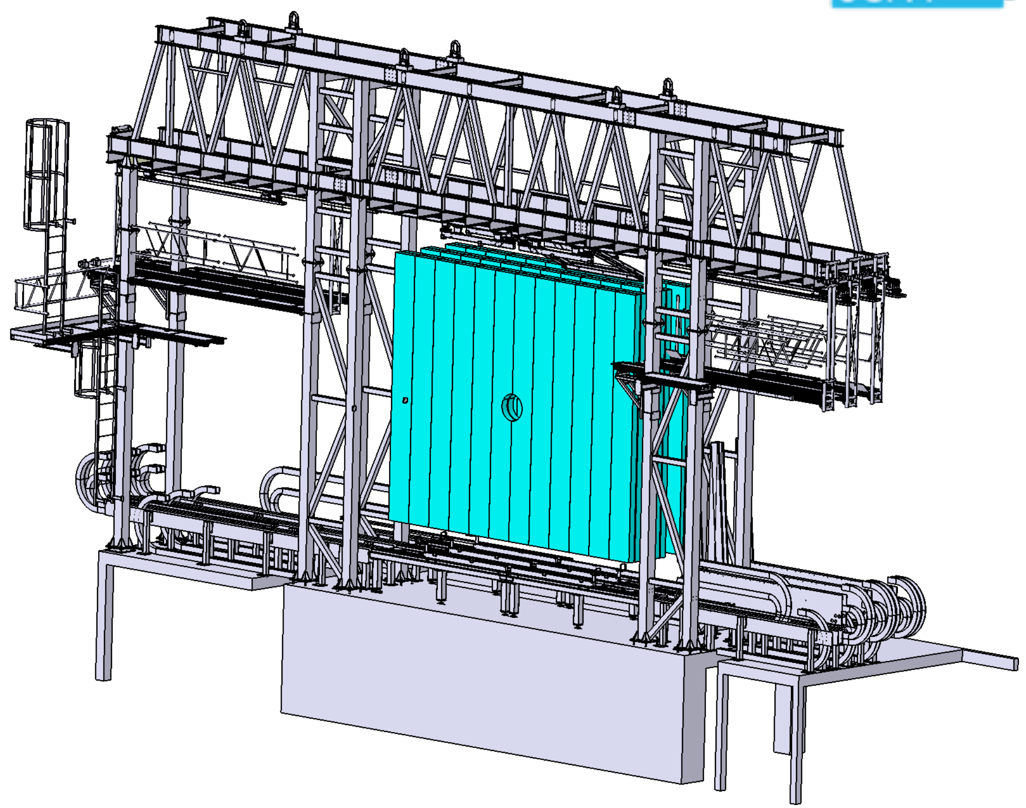


- FE board

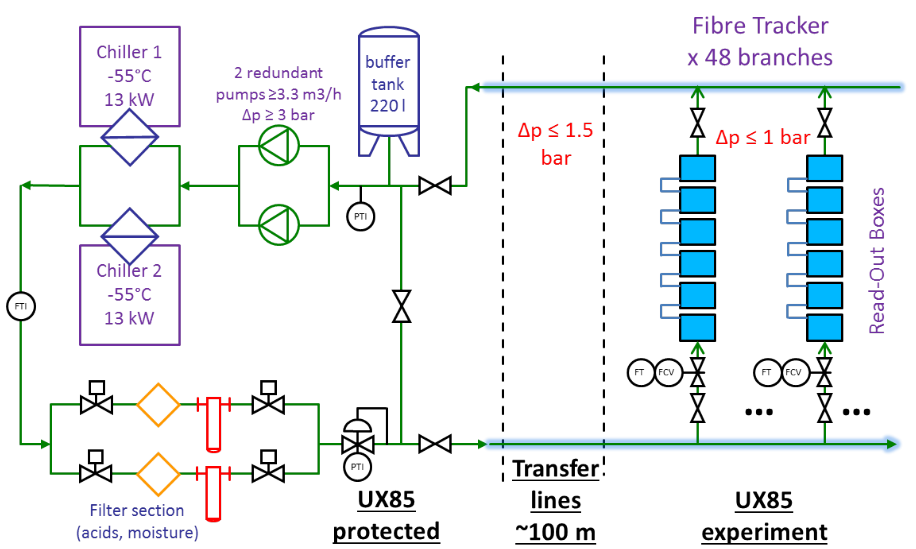


Detector infrastructure

- Support structure and frames
  - use existing "bridge" and access infrastructure



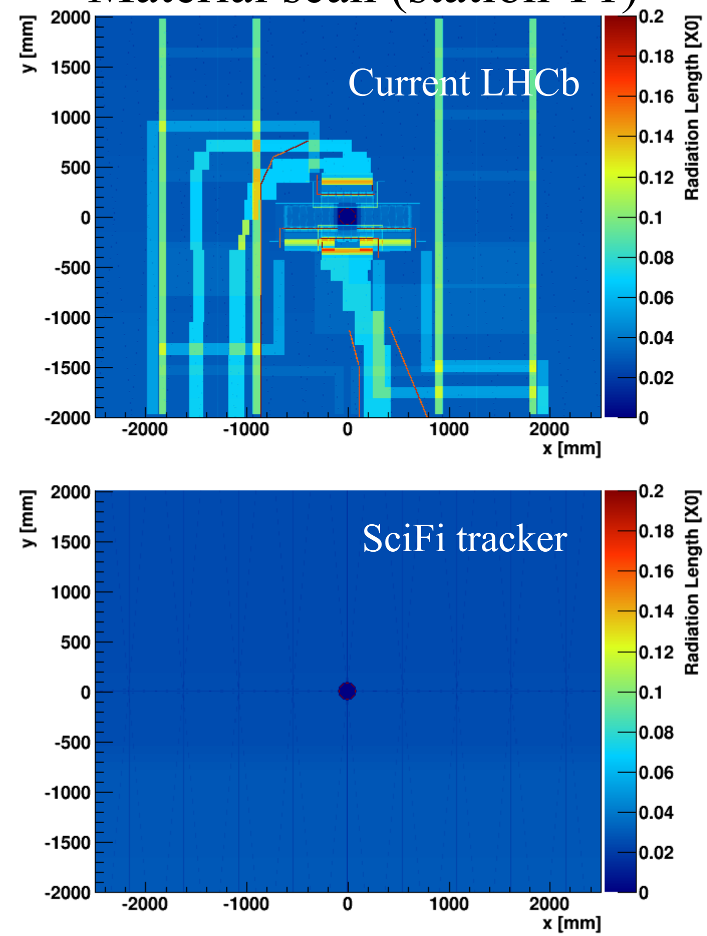
- SiPM cooling
  - mono-phase liquid → -40ºC
- Electronics cooling
  - demineralised water

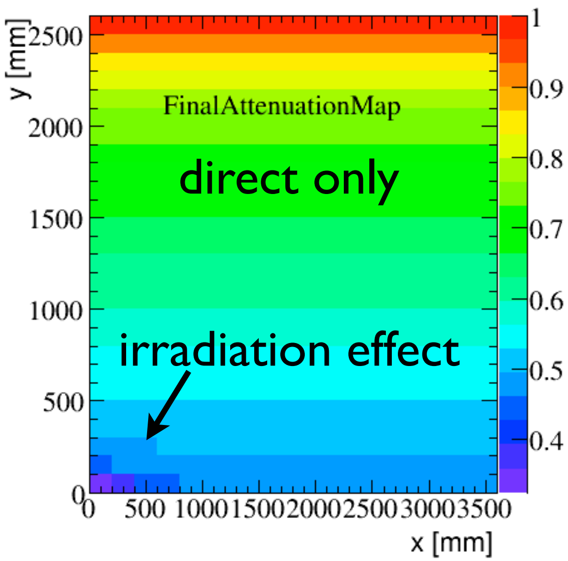


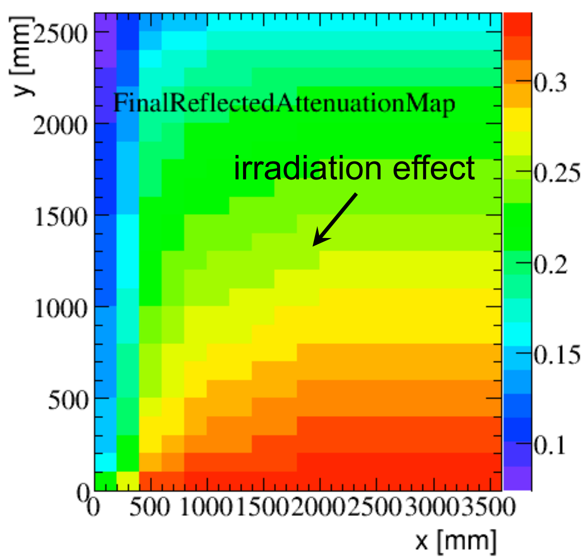
SciFi Tracker simulation

- Simulated a detailed and realistic description of the detector
  - with dead regions
  - light attenuation (after $50 fb^{-1}$)
  - light reflection from mirror
  - shaping time

Material scan (station T1)







  - SiPM response and signal digitisation

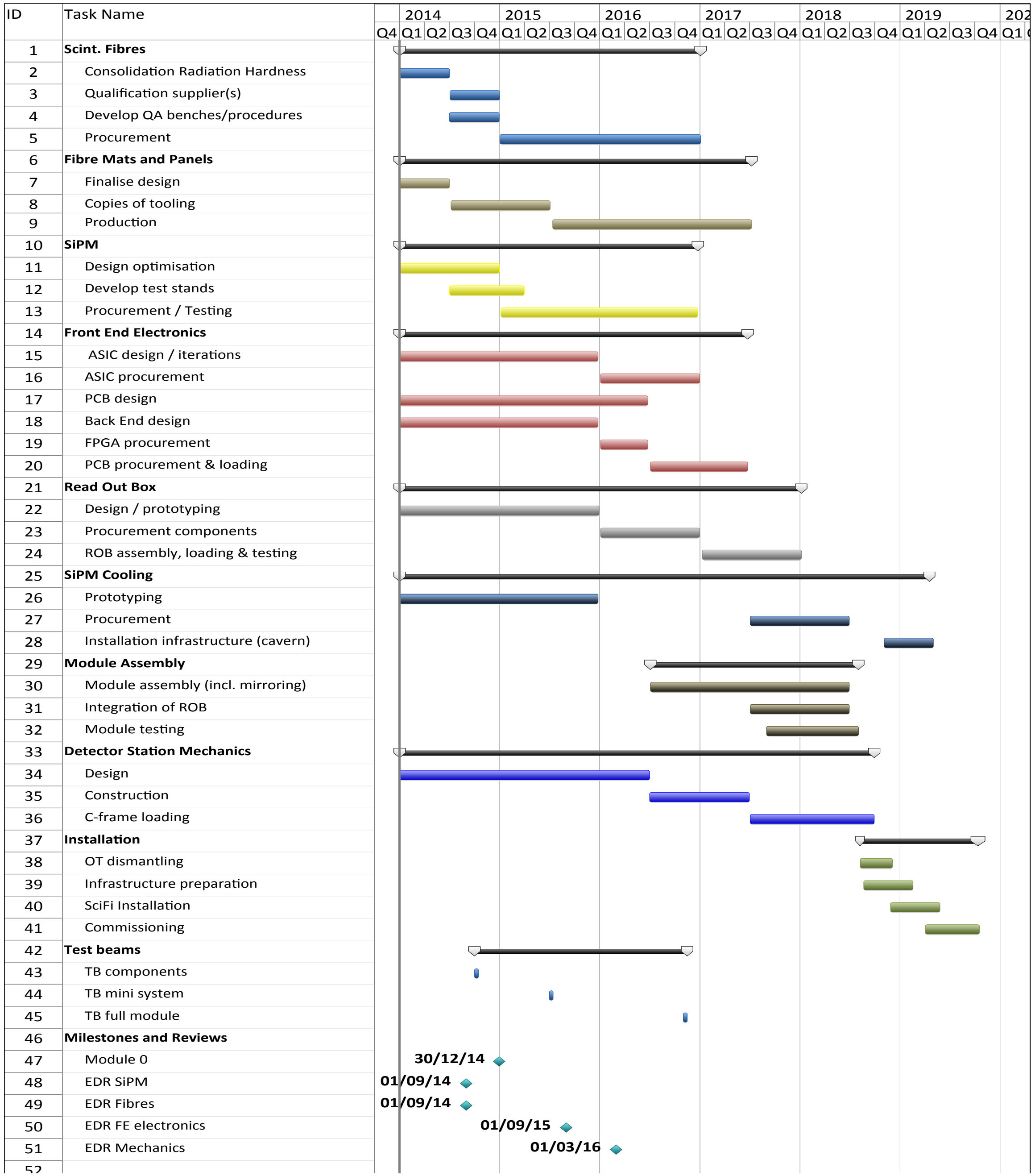
SciFi Tracker project organisation

- 21 participating institutes, from 10 countries
- Division of responsibilities:

Table 1.18: Division of responsibilities between the participating institutes.

Task(s)		Institute(s)
Detector	SiPM assembly	EPFL
	SiPM QA	CERN, EPFL, NCBJ
	Fibre QA	CERN, NCBJ, RWTH, TUD, HD
	Fibre mat production	Russia, RWTH, TUD, HD
	Panel & module construction	Russia, RWTH, TUD, HD
	Read-out box	CERN, EPFL, LPC, NIKHEF, RWTH
	Module testing (including electronics)	CBPF, NIKHEF
Electronics	PACIFIC ASIC	UB, IFC, LPC, NIKHEF, HD
	Front-end boards	EPFL, LPC, NIKHEF, RWTH, HD
	Tell40 board software	LPNHE, TUD
Infrastructure	Frames	CERN, EPFL, NIKHEF
	Cooling	CERN, RWTH
General	Installation	All institutes
	Non-read-out electronics, DAQ, ECS	All institutes
	Integration	All institutes
	Commissioning	All institutes
	Software	All institutes

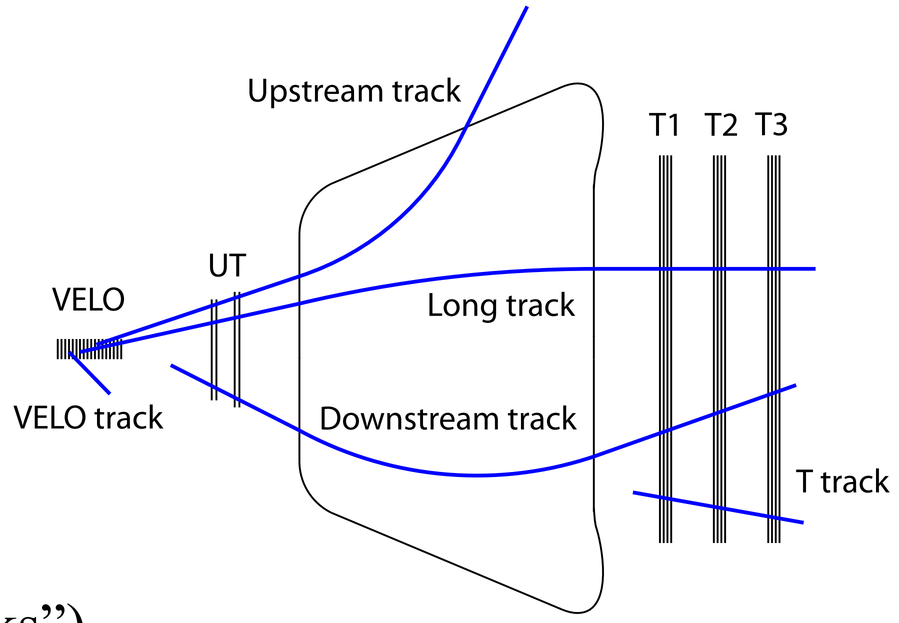
SciFi Tracker schedule



(TDR, Fig. 3.64)

Tracking performance

- LHCb simulation for 14TeV, 25ns bunch crossing, and ν=3.8 and ν=7.6 ($1\text{–}2\times10^{33}$ cm^{-2}s^{-1})
- SciFi tracker simulated for fully irradiated detector
- Test reliability and robustness of the tracking performance
  - efficiency
  - ghost rate
  - clone rate
  - timing



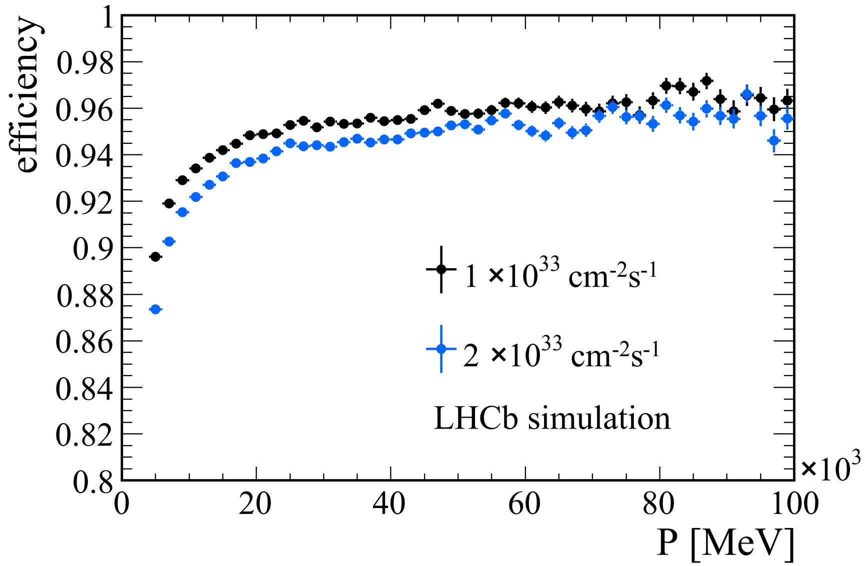
- Present here results for
  - forward tracking ("long tracks")
  - seeding ("T tracks")

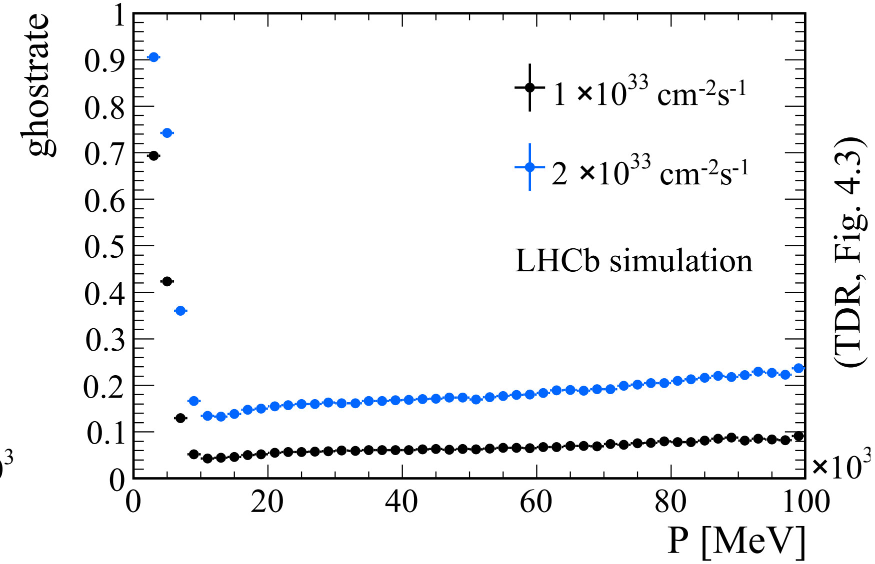
Forward tracking (long tracks)

- Forward tracking efficiency is 1 – 4% lower than current tracker at ν=2, but significantly better than current tracker at ν=3.8 or 7.6

	Current LHCb [%]	Upgrade LHCb [%]	
	$\nu = 2$	$\nu = 3.8$	$\nu = 7.6$
Ghost rate	13.1	14.7	25.5
Reconstruction efficiency			
long	90.9	86.9	84.5
long, $p > 5\,\text{GeV}/c$	95.4	92.9	91.5
b-hadron daughters	93.9	91.9	90.6
b-hadron daughters, $p > 5\,\text{GeV}/c$	96.1	95.1	94.2

Efficiency and ghost rate for long tracks, with track χ^2 cut (TDR, Table 4.4)





(TDR, Fig. 4.3)

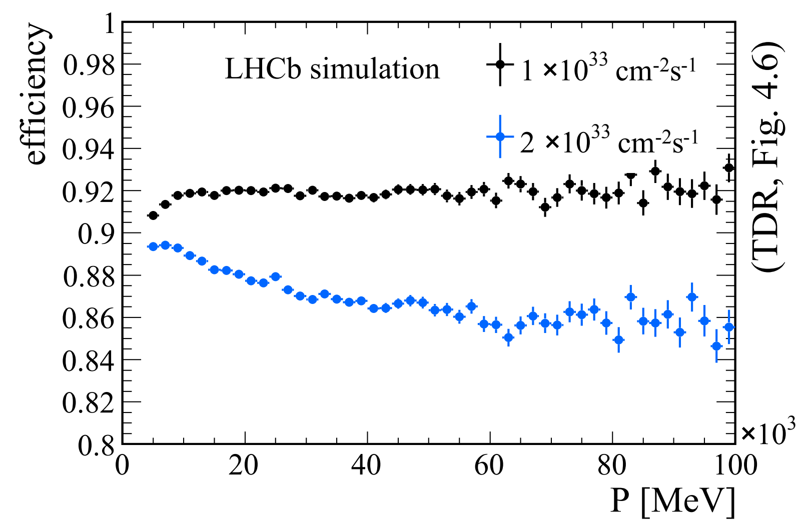
Seeding (T tracks)

- Lower seeding efficiency than in current LHCb tracker:
  - due to higher occupancy, and
  - no vertical (y) segmentation in the SciFi Tracker

	Current LHCb [%]	Upgrade LHCb [%]	
	$\nu = 2$	$\nu = 3.8$	$\nu = 7.6$
Ghost rate	5.2	7.4	19.6
Reconstruction efficiency			
long	96.1	85.3	82.6
long, $p > 5\,\mathrm{GeV}/c$	96.6	91.7	88.4
b-hadron daughters	96.9	89.3	87.6
b-hadron daughters, $p > 5\,\mathrm{GeV}/c$	97.2	92.4	90.4

Efficiency and ghost rate for T tracks (TDR, Table 4.6)

- Further improvements expected from:
  - optimisation of the acceptance coverage near beam pipe
  - tuning of the software algorithm



(TDR, Fig. 4.6)

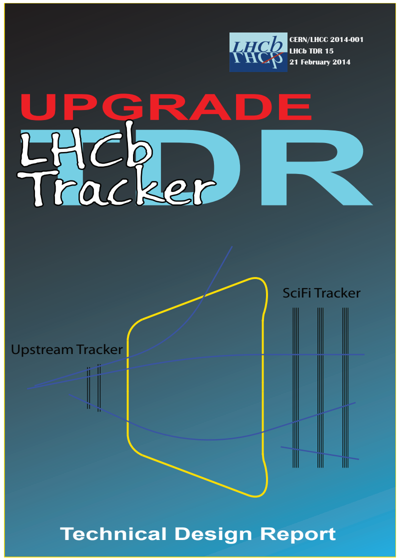
Summary

- LHCb SciFi Tracker
  - SciFi technology never used at this scale and radiation level
  - ambitious, exciting, and motivating project!

- R&D studies show this detector provides the necessary performance for the upgrade of the LHCb detector
  - further optimisation of the design are still ongoing

- Installation planned for Long Shutdown 2

- Further details may be found in the LHCb Tracker TDR



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