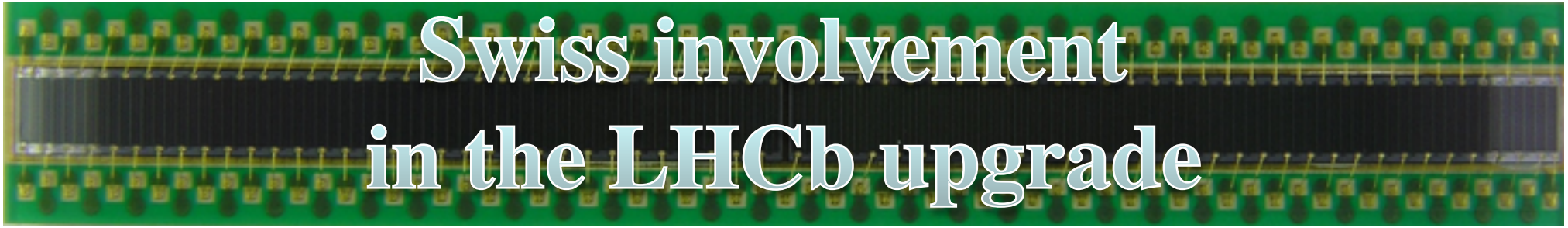

Swiss involvement in the LHCb upgrade

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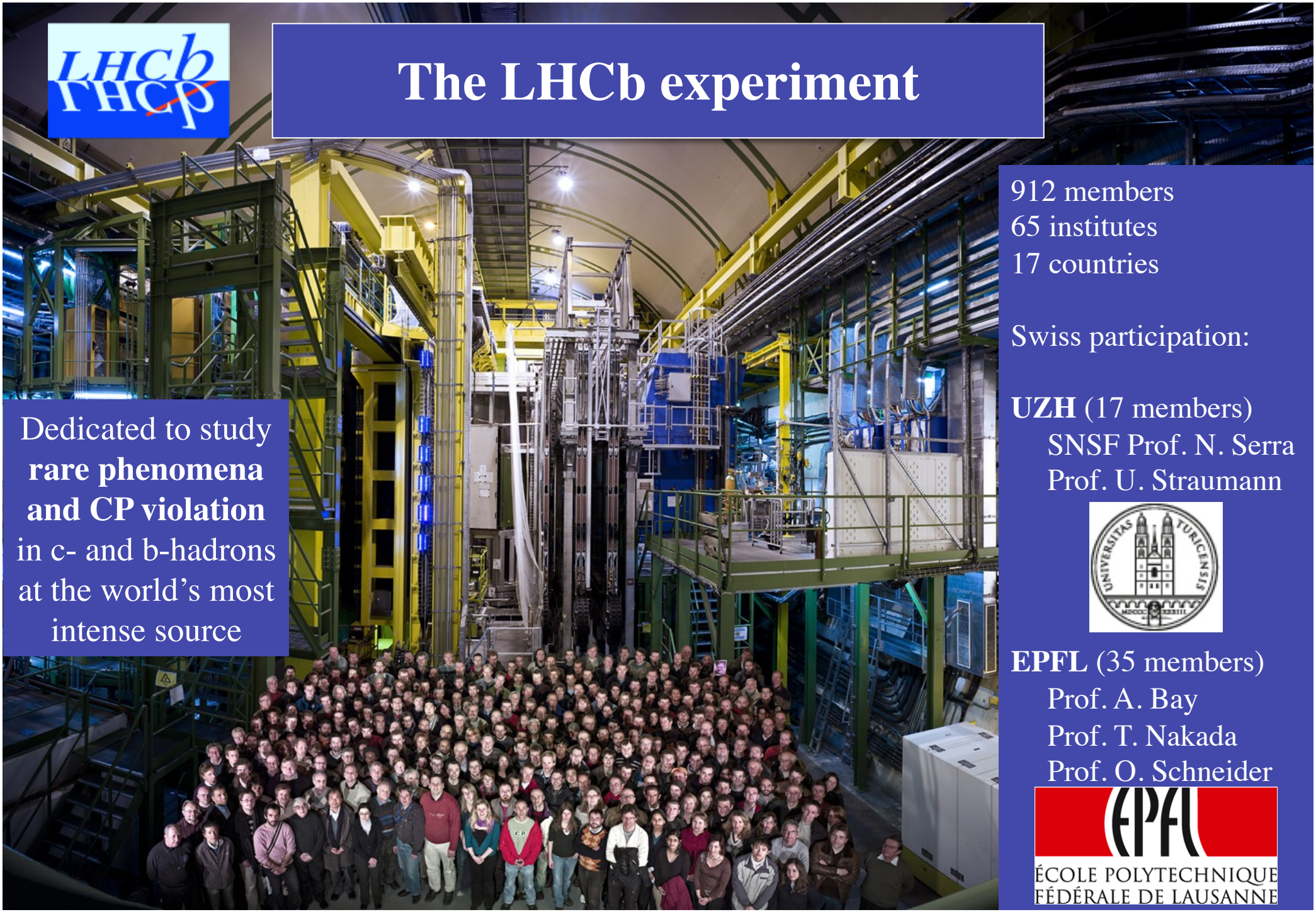
Prepared with the help of several colleagues. Thanks.

The LHCb experiment



Dedicated to study **rare phenomena and CP violation** in c- and b-hadrons at the world's most intense source

912 members
65 institutes
17 countries

Swiss participation:

UZH (17 members)
SNSF Prof. N. Serra
Prof. U. Straumann

EPFL (35 members)
Prof. A. Bay
Prof. T. Nakada
Prof. O. Schneider

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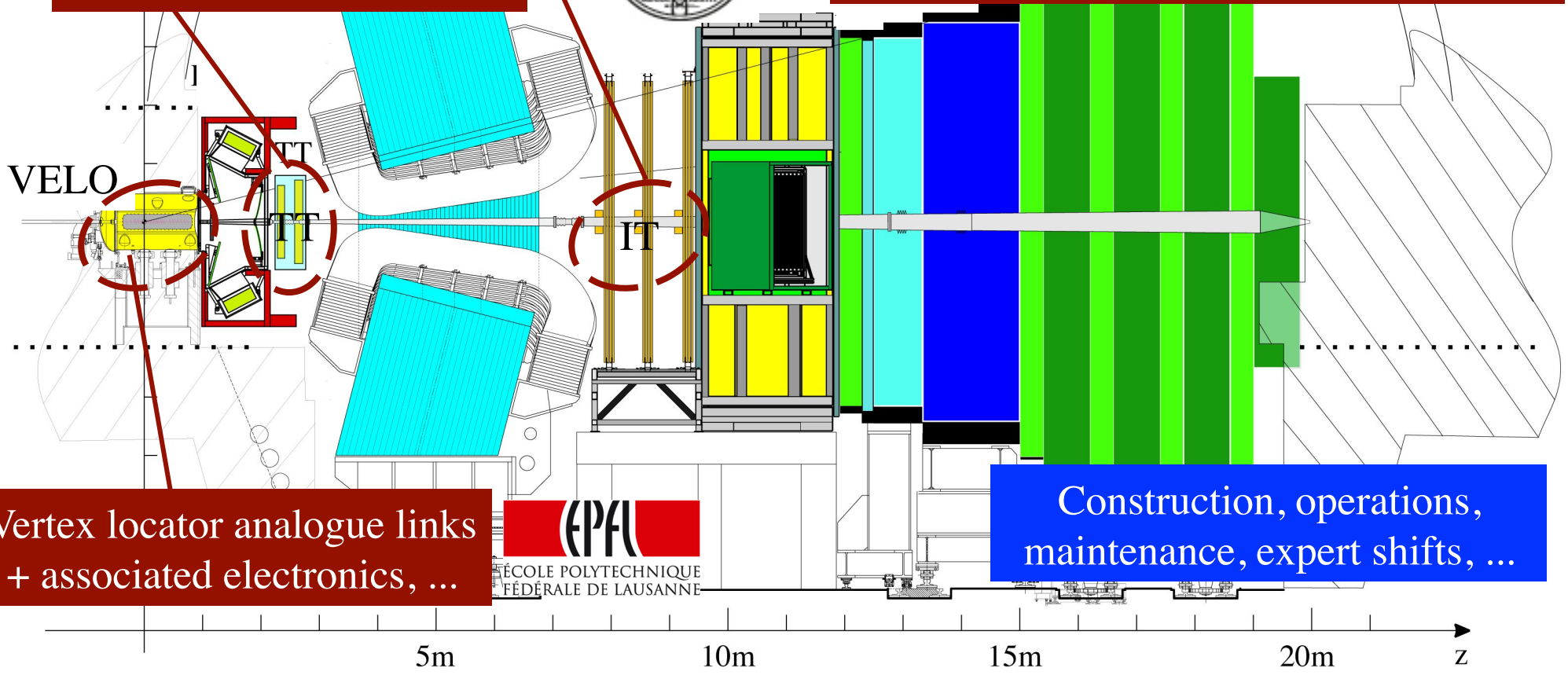
Swiss contribution to LHCb detector

Silicon Tracker:

– Inner Tracker (IT)
–Tracker Turicensis (TT)

Common readout board TELL1
(off-detector electronics)
+ common optical readout system
+ trigger and DAQ

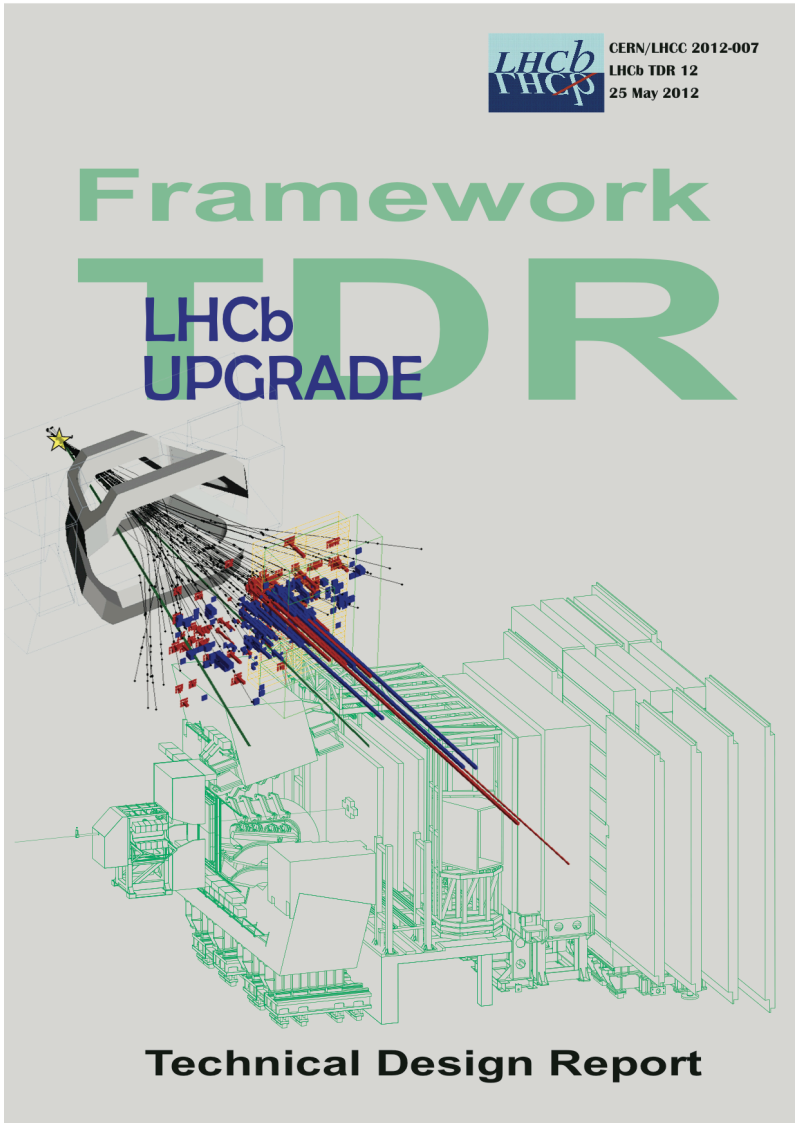


Vertex locator analogue links
+ associated electronics, ...

Construction, operations,
maintenance, expert shifts, ...

LHCb upgrade

- March 2011:
  - Letter of Intent for the LHCb upgrade
    CERN-LHCC-2011-001 / LHCC-I-018
- May 2012:
  - Framework Technical Design Report
    for the LHCb upgrade
    CERN-LHCC-2012-007, LHCb TDR 12
- November 2012:
  - CERN research board approved
    the LHCb upgrade to be part of the
    long-term exploitation of LHC



Statistical sensitivities (key measurements)

Discussed by Ch. Elsasser this morning

Type	Observable sensitive to New Physics	LHCb 2018	Upgrade ($50\ \text{fb}^{-1}$)	Theory uncertainty
B_s^0 mixing	$2\beta_s\ (B_s^0 \to J/\psi\phi)$	0.025	0.008	~ 0.003
	$2\beta_s\ (B_s^0 \to J/\psi f_0(980))$	0.045	0.014	~ 0.01
	$A_{\text{fs}}(B_s^0)$	0.6×10^{-3}	0.2×10^{-3}	0.03×10^{-3}
Gluonic penguin	$2\beta_s^{\text{eff}}(B_s^0 \to \phi\phi)$	0.17	0.03	0.02
	$2\beta_s^{\text{eff}}(B_s^0 \to K^{*0}\bar{K}^{*0})$	0.13	0.02	< 0.02
	$2\beta^{\text{eff}}(B^0 \to \phi K_S^0)$	0.30	0.05	0.02
Right-handed currents	$2\beta_s^{\text{eff}}(B_s^0 \to \phi\gamma)$	0.09	0.02	< 0.01
	$\tau^{\text{eff}}(B_s^0 \to \phi\gamma)/\tau_{B_s^0}$	5 %	1 %	0.2 %
Electroweak penguin	zero of $A_{\text{FB}}(B^0 \to K^{*0}\mu^+\mu^-)$ vs $q^2 = m_{\mu\mu}^2$	6 %	2 %	7 %
	$S_3(B^0 \to K^{*0}\mu^+\mu^-; 1 < q^2 < 6\ \text{GeV}^2/c^4)$	0.025	0.008	0.02
	$A_{\text{I}}(K\mu^+\mu^-; 1 < q^2 < 6\ \text{GeV}^2/c^4)$	0.08	0.025	~ 0.02
	$\mathcal{B}(B^+ \to \pi^+\mu^+\mu^-)/\mathcal{B}(B^+ \to K^+\mu^+\mu^-)$	8 %	2.5 %	~ 10 %
Higgs penguin	$\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	0.5×10^{-9}	0.15×10^{-9}	0.3×10^{-9}
	$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	~ 100 %	~ 35 %	~ 5 %
Unitarity triangle angles	$\gamma\ (B \to D^{(*)}K^{(*)})$	4°	0.9°	negligible
	$\gamma\ (B_s^0 \to D_s^{\mp}K^{\pm})$	11°	2.0°	negligible
	$\beta\ (B^0 \to J/\psi K_S^0)$	0.6°	0.2°	negligible
CP violation in charm	$A_\Gamma = [\tau_{\text{CP}}(D^0) - \tau_{\text{CP}}(\bar{D}^0)]/[\ldots + \ldots]$	0.40×10^{-3}	0.07×10^{-3}	–
	$\Delta A_{\text{CP}} = A_{\text{CP}}(K^+K^-) - A_{\text{CP}}(\pi^+\pi^-)$	0.65×10^{-3}	0.12×10^{-3}	–

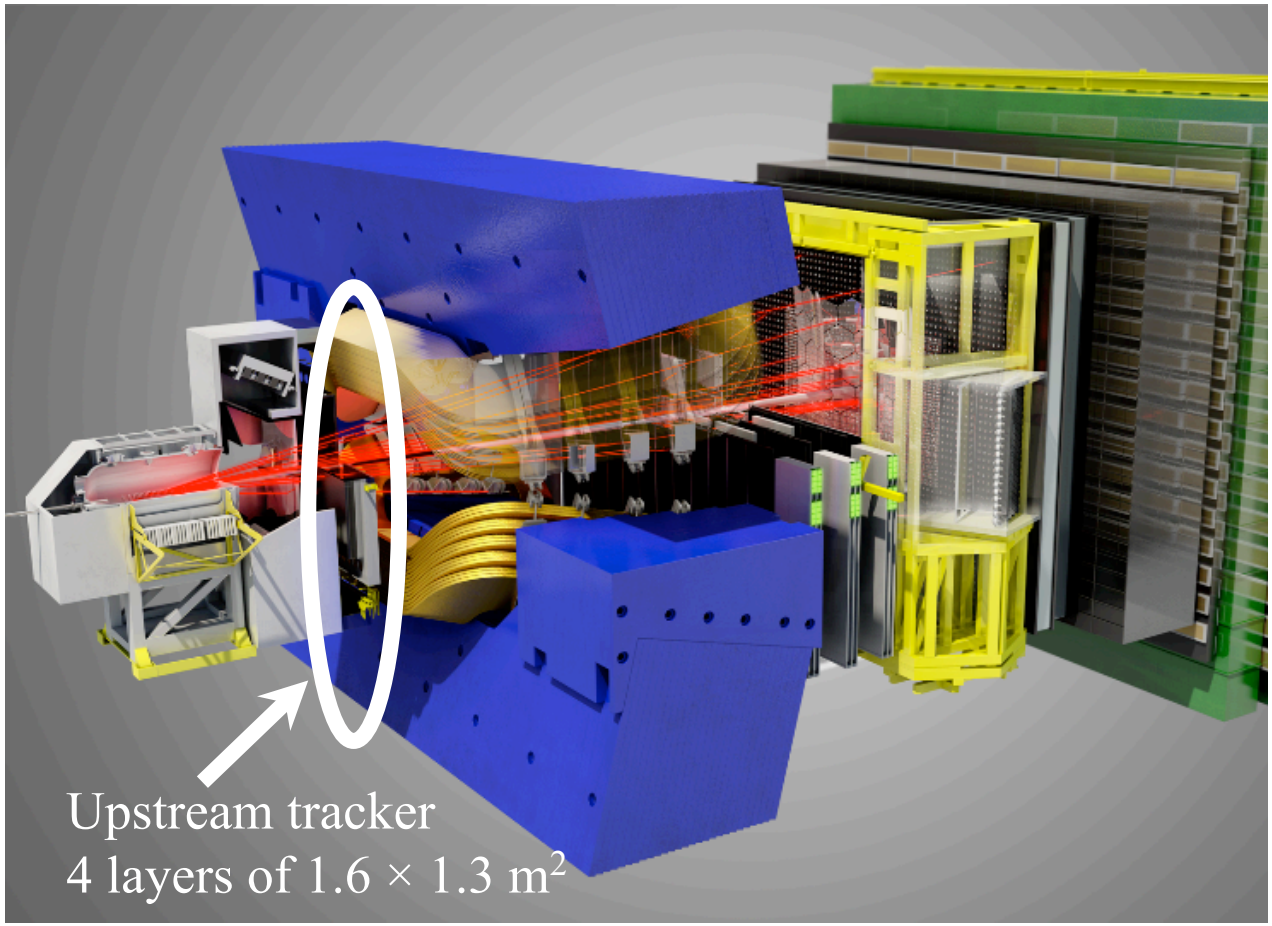
LHCb collaboration and A. Bharucha et al., "Implications of LHCb measurements and future prospects", arXiv:1208.3355 [hep-ex], Eur. Phys. J. C 73 (2013) 237

LHCb upgrade

- Goal
  - collect at least 50 fb^{-1} with up to 10 times more signal event rate
    - increase luminosity by factor 5 (over design)
    - improve current trigger efficiency by factor 2 for hadronic modes
- Plan
  - run at $L = (1–2) \times 10^{33}\ cm^{-2}\ s^{-1}$
    - already possible from machine point of view
  - trigger on displaced vertex at earliest stage
    - **read out full detector at 40 MHz**
- Hardware to be replaced
  - all front-end electronics
  - Si devices (vertex detector + tracking stations)
  - RICH photodetectors
- LHCb upgrade has to be done in "one go"

Tracker upgrade

- Upstream tracking station before the dipole magnet



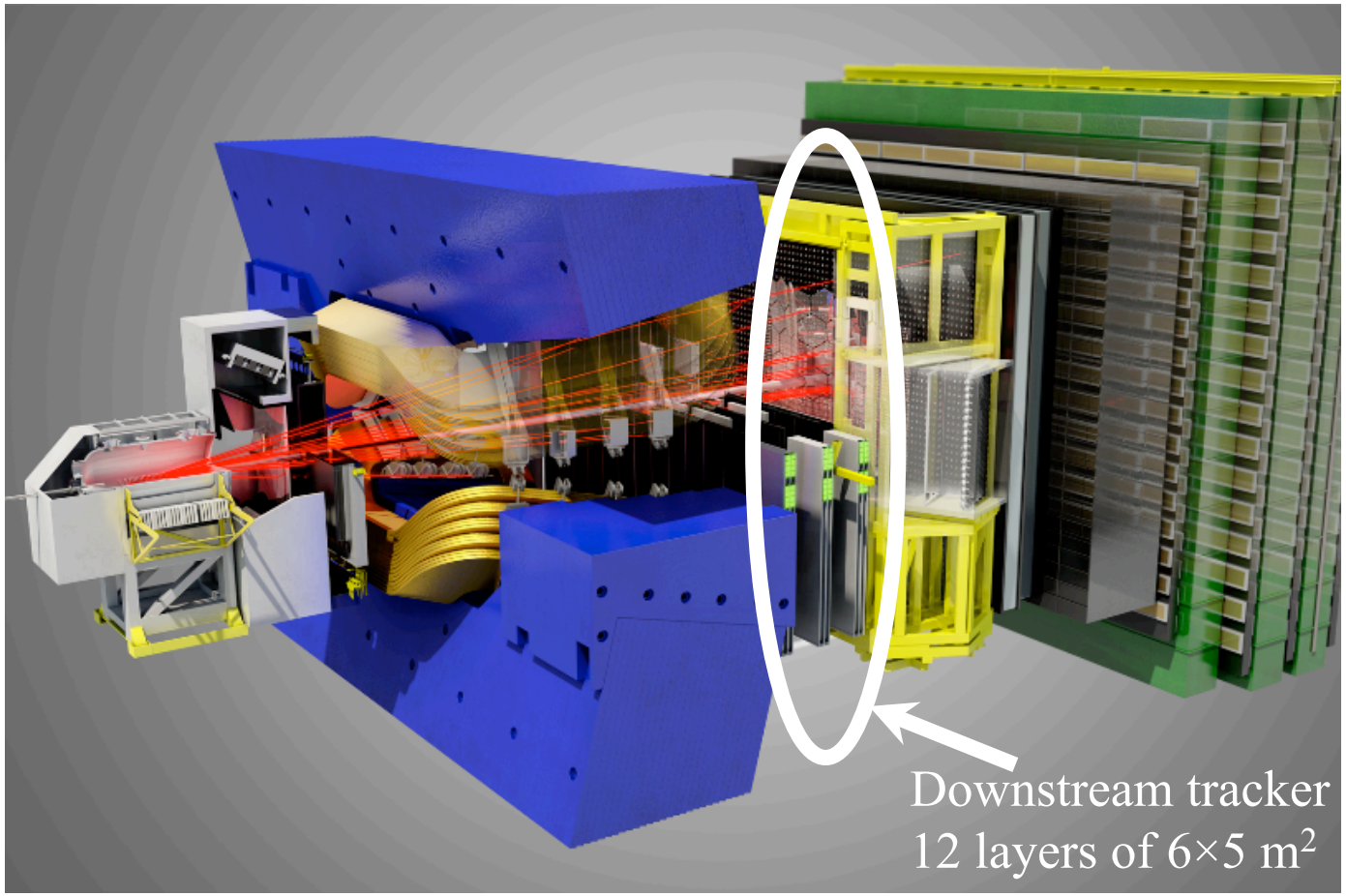
— Large surface Si strip detector
  - current detector designed and construction by UZH group

— 40 MHz readout requires replacement of detector modules
  - opportunity to re-optimize layout (very forward acceptance, strip segmentation)
  - main motivation is to speed up track reconstruction in high-level trigger
  - UZH leading effort to optimize pattern recognition algorithms, also investigating use of GPUs

— **UZH group starting to get involved in detector design / construction**

Tracker upgrade

- Downstream tracking stations after the dipole magnet

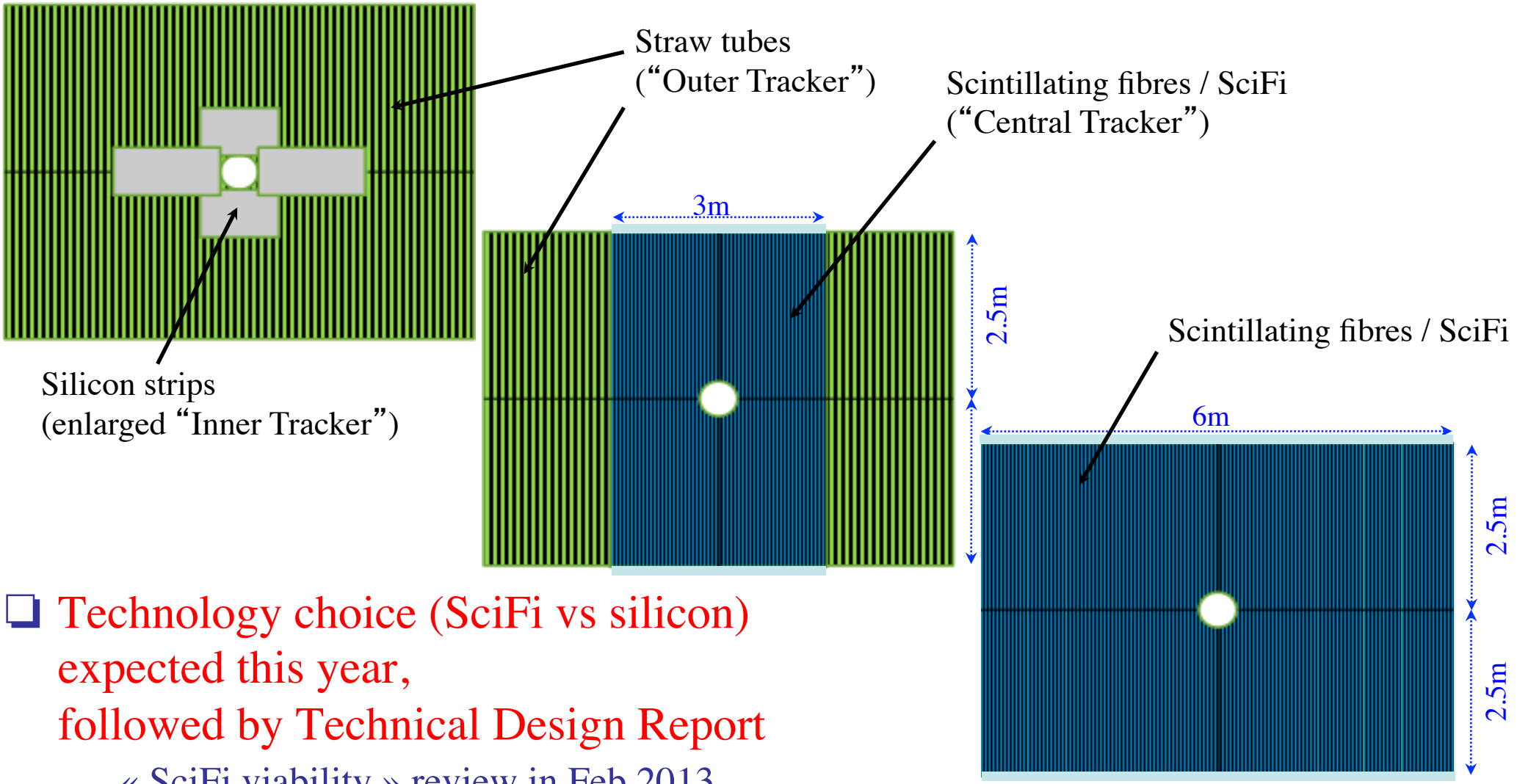


— Requirements

- High hit detection efficiency (≥ 98–99%)
- Spatial hit resolution at the level of 60–100 μm
- Small material budget in the acceptance
- Readout electronics to operate at 40MHz

— **The EPFL group has proposed a new technology for LHCb: Scintillating Fibres (SciFi) read out with Silicon Photo-Multipliers (SiPMs)**

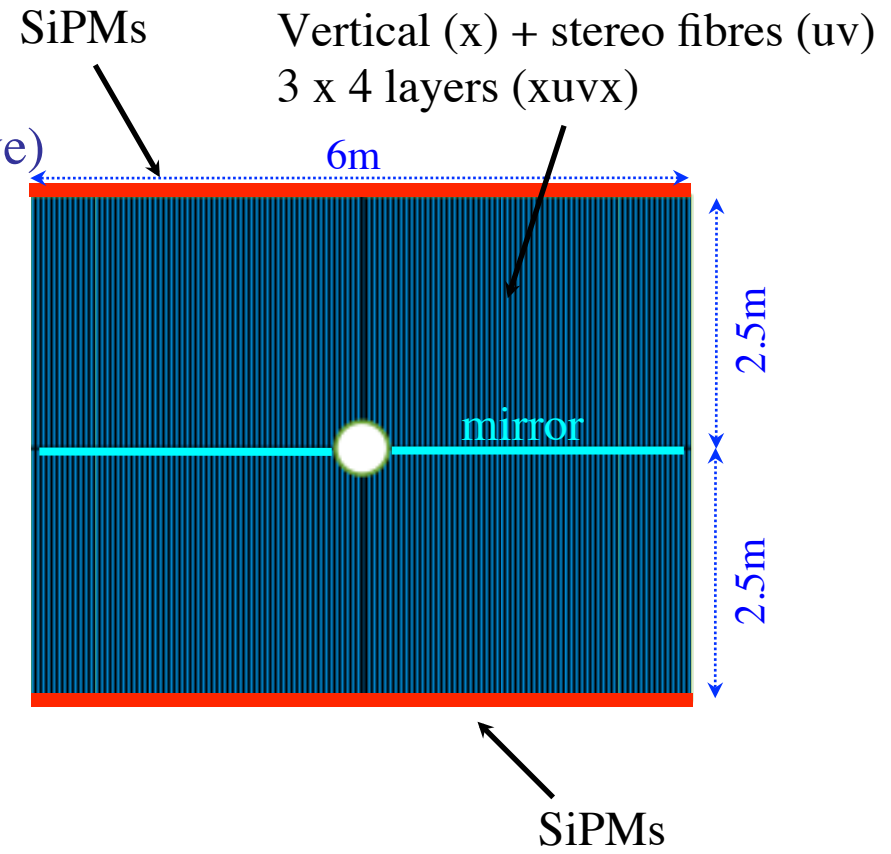
Options for dowstream tracker upgrade



- Technology choice (SciFi vs silicon) expected this year, followed by Technical Design Report
  - « SciFi viability » review in Feb 2013 concluded that there is no show-stopper

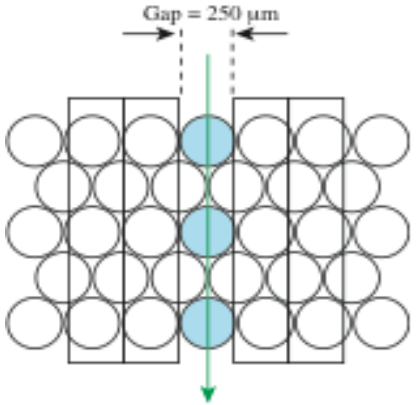
Full SciFi option

- Advantages
  - large area can be covered with small pitch to cope with high occupancy (silicon expensive)
  - SiPM readout outside of the acceptance, very little material in the acceptance
    - « only » passive scintillating fibres, which serve both as detecting medium and light guides
  - fast tracking algorithm for triggering (avoid CPU-costly left-right ambiguities due to drift time in straw tubes)
  - reduction of maintenance requirements
  - single technology for entire tracking stations



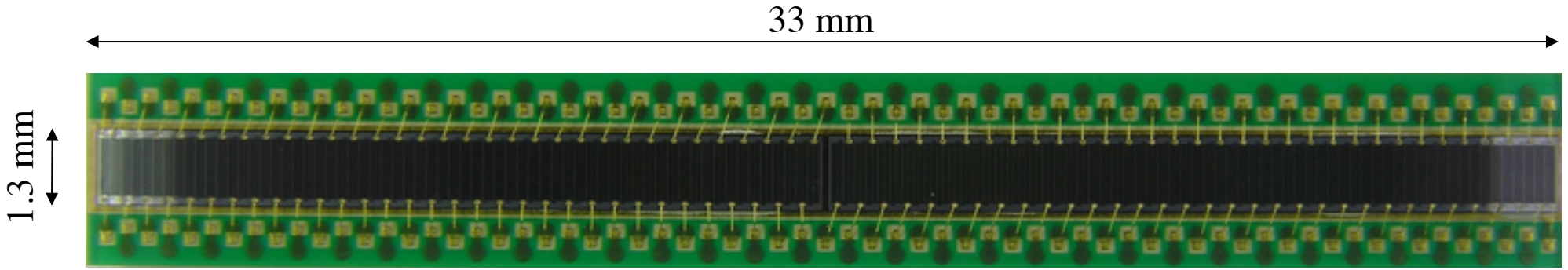
- Challenges / issues needing R&D
  - hit detection efficiency vs noise, resolution, mechanical precision
  - will the SciFi technology perform as required after the radiation dose received in the LHCb upgrade (50 fb^{-1}) ?

Fibres and SiPM

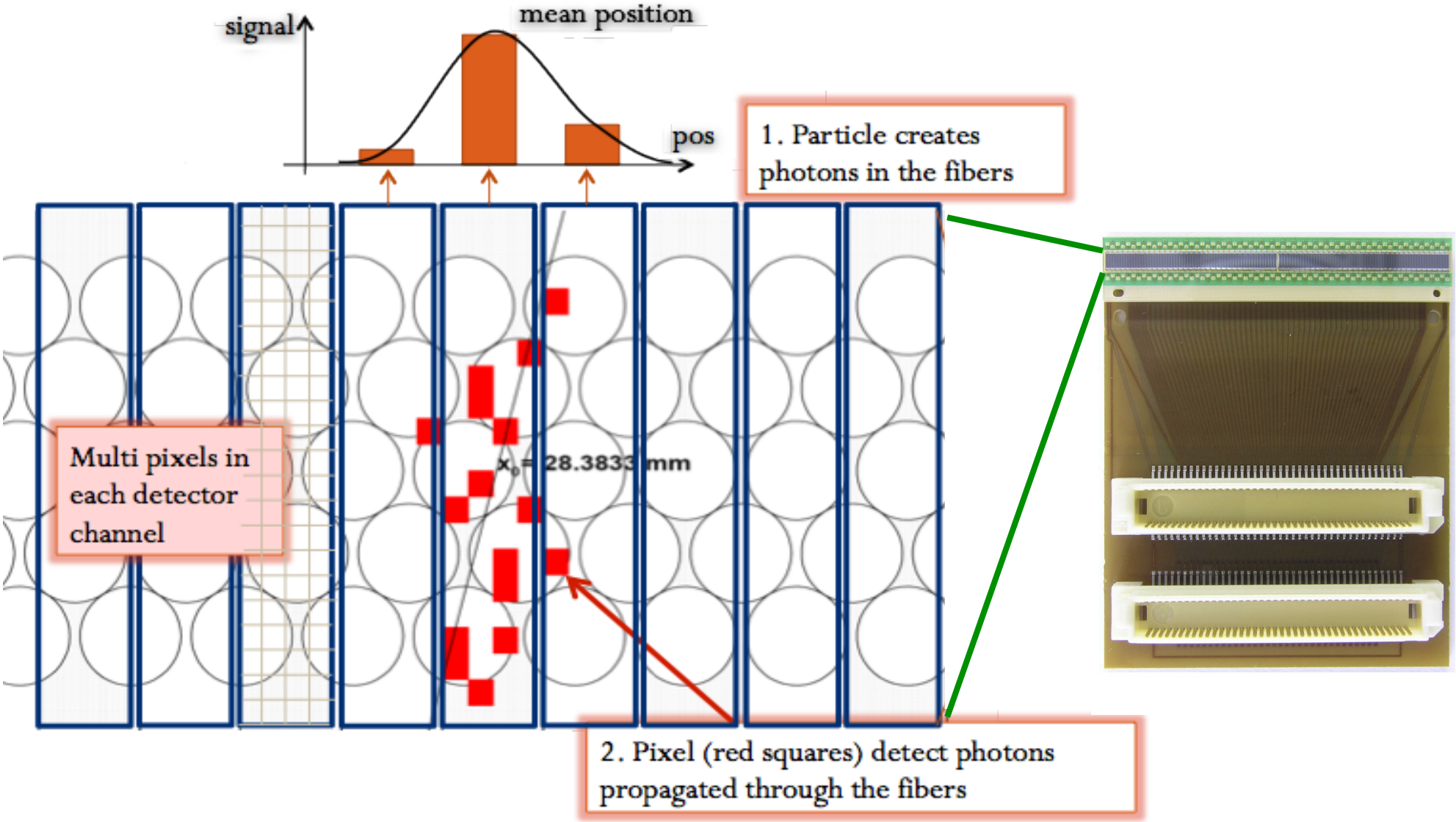


- 250 µm diameter scintillating fibres
  - — arranged in multiple (5) layers for sufficient light collection

- Light detection with multi-channel SiPM
  (SIPM also called MPPC = Multi-Pixel Photon Counter)
  - — each channel (0.25 × 1.3 mm^2) has 4×24 pixels (pixel size = 55µm)
  - — each pixel is an avalanche photo-diode (operating in Geiger mode)
  - — 128 (2 × 64) channels grouped in a ~33 mm array



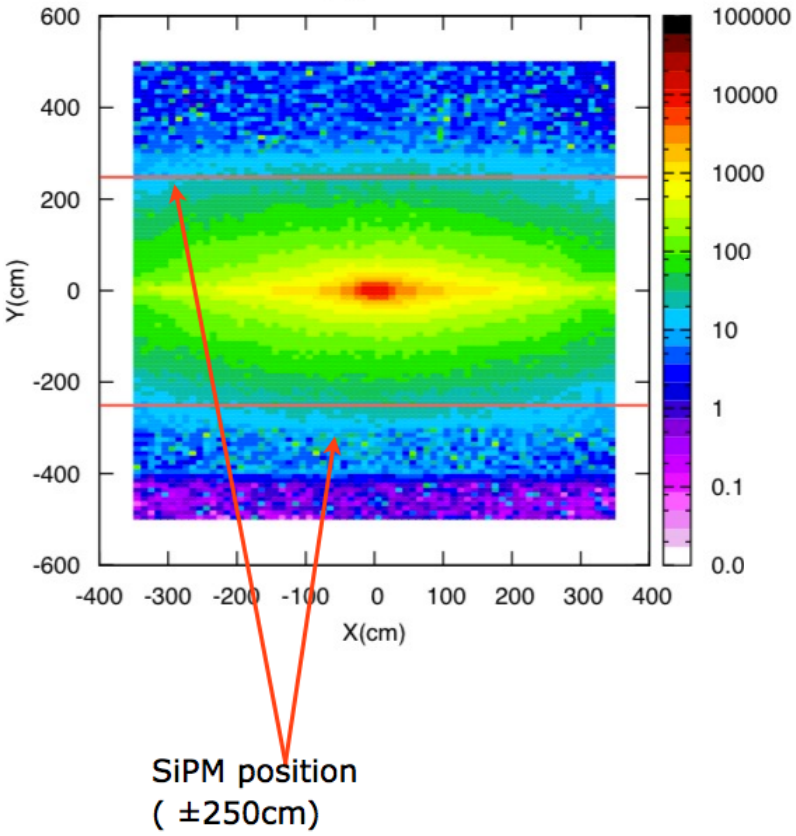
Signal cluster detection



Radiation issues

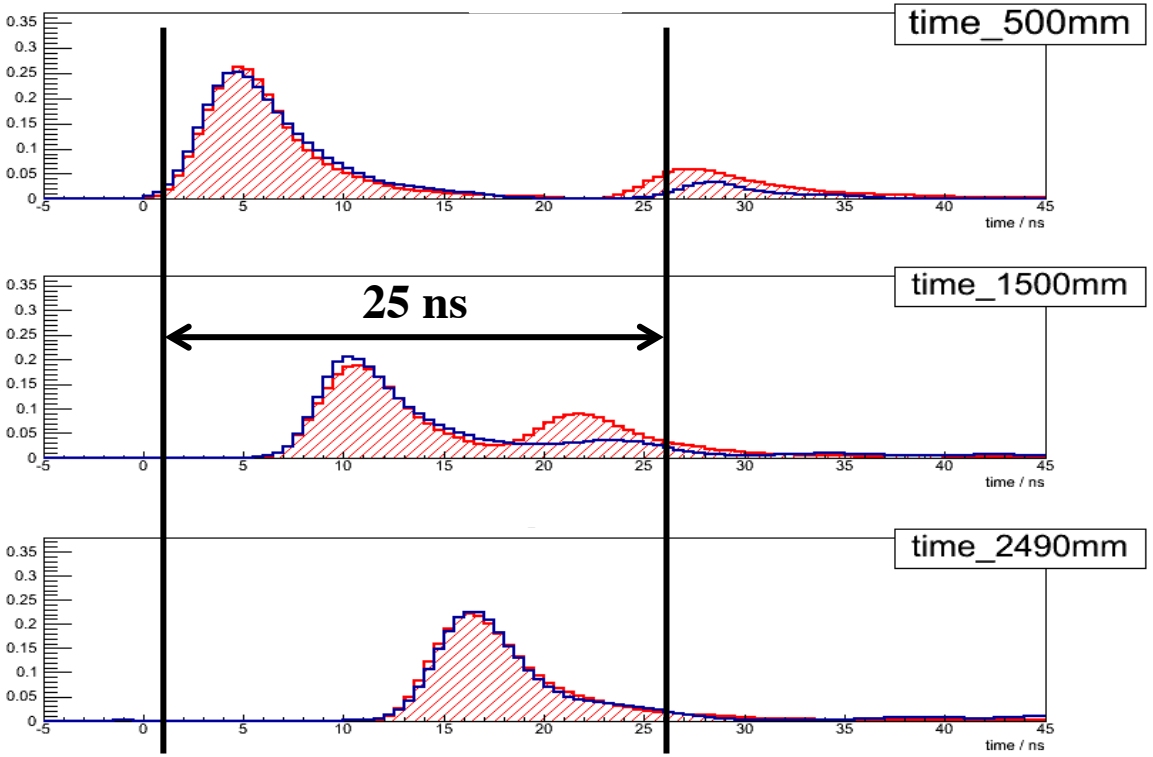
- SiPM:
  - ~10^{12} neutrons per cm^2, factor ~2 reduction with shielding
  - need to operate at low temperature (–40 °C)
- Fibres:
  - 30 kGy in hottest region (close to beam pipe)
  - scintillating dye expected to be radiation resistant
  - scintillating light shifted towards larger wavelength (green) with dose
    - impact on SiPM specifications
  - attenuation length degrades with dose
    - 400 cm at 0 Gy → 52 cm at 22 kGy

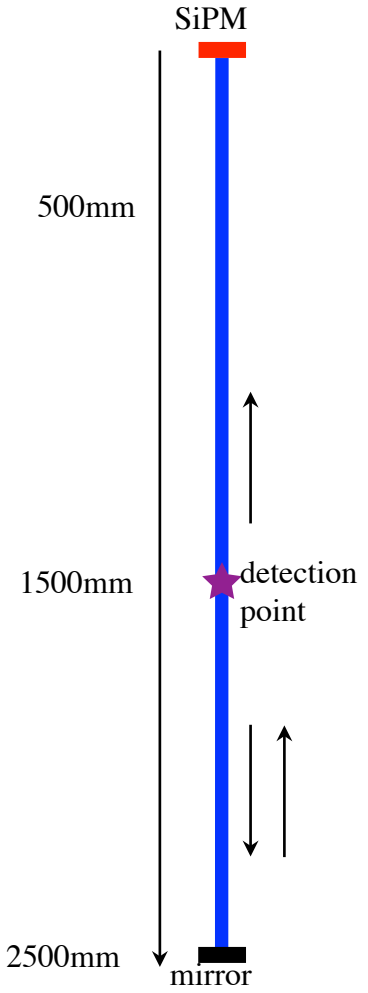
Dose (Gy) from charged particles after 50 fb^{-1} (FLUKA simulation)



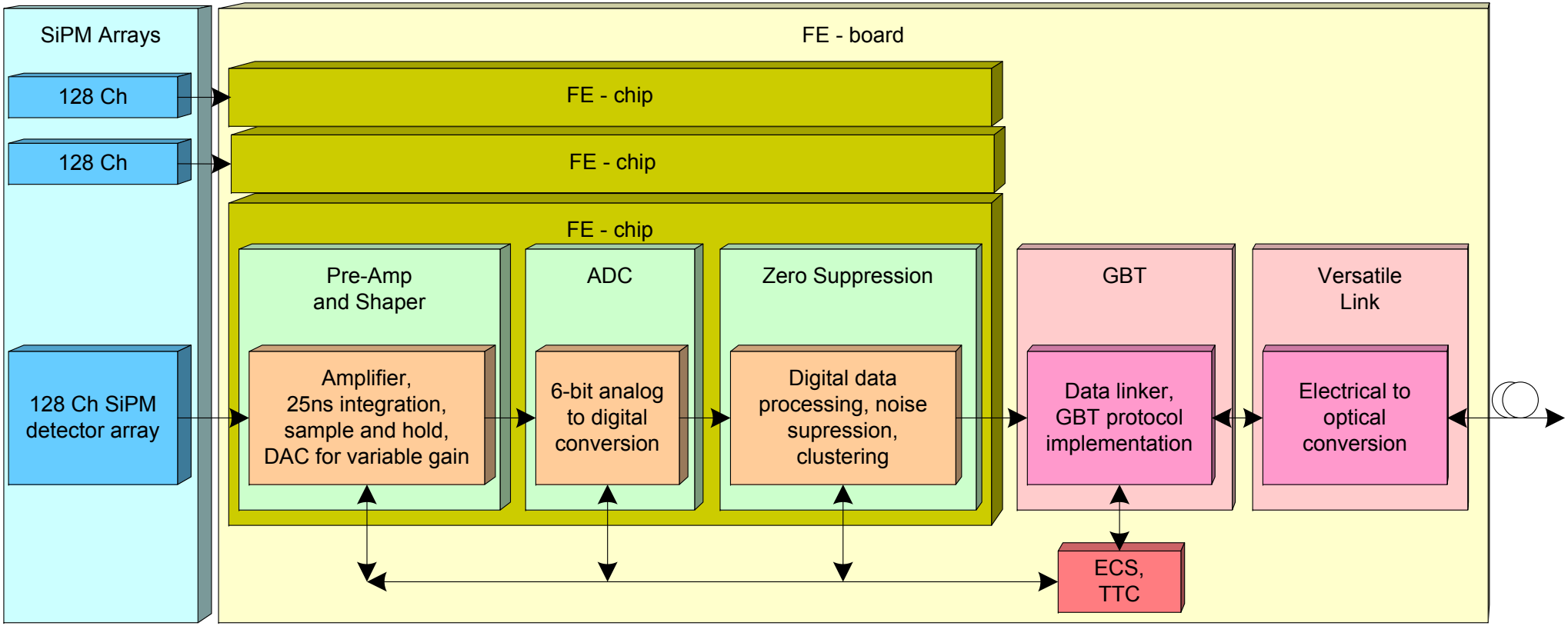
Light detection timing

- Baseline fibre: Kuraray SCSF-78MJ
  - 2.8 ns scintillation decay time
  - light yield: ~1600 photons/mm/MIP × 5.35% capture
    ⇒ 10's of photons
  - 5.3 ns / m propagation time



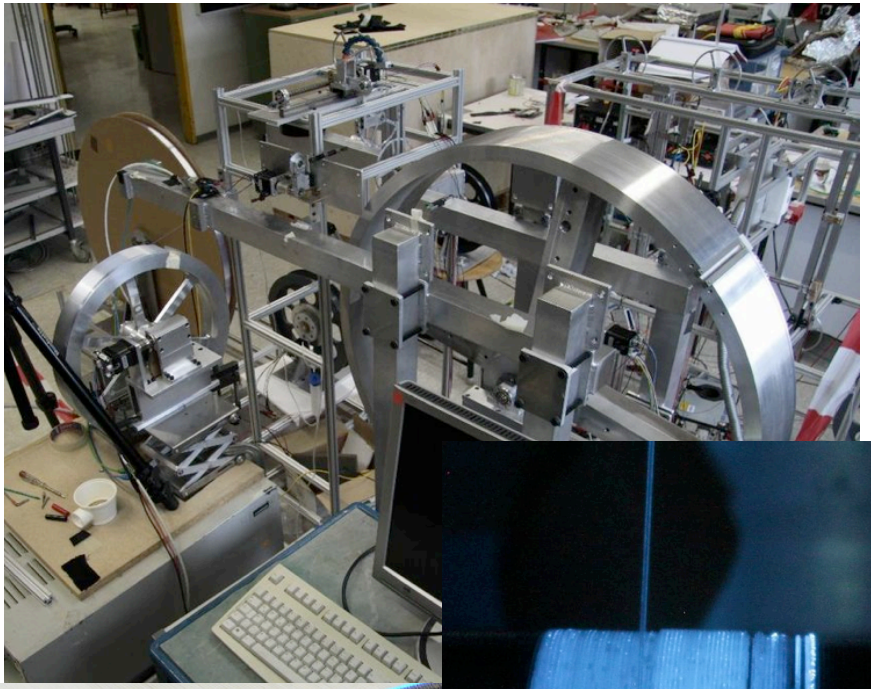


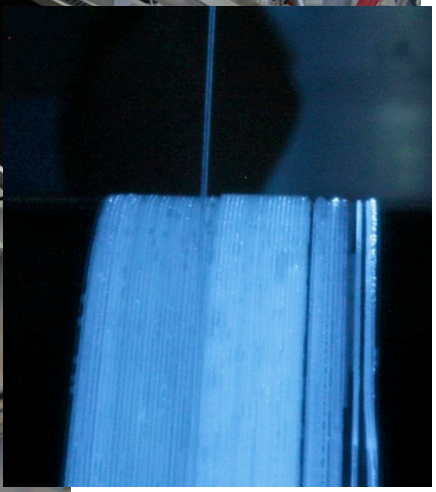
Readout electronics

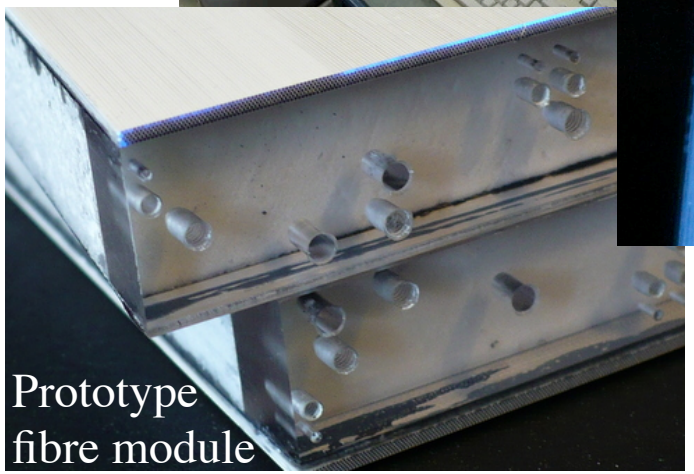


Fibre mat production

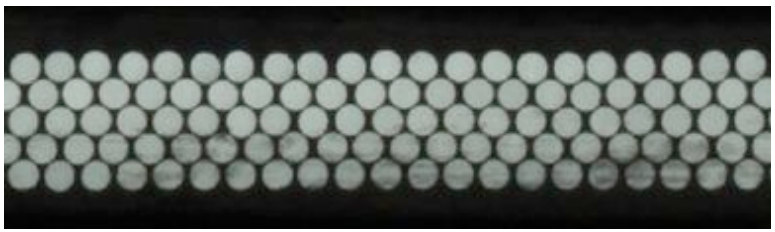
- "Wheel method"
  - Lay down fibres on a 96 cm diameter rotating cylinder
  - 280 μm pitch imposed by grooves
  - each layer glued to the previous one
  - fibre mat taken off the wheel before glue is dry
  - mat can be cut to desired dimensions and glued to supporting structure
- Mechanical tolerances (over fibre length):
  - < 50 μm in x
  - < 300 μm in z







Early 5-layer prototype

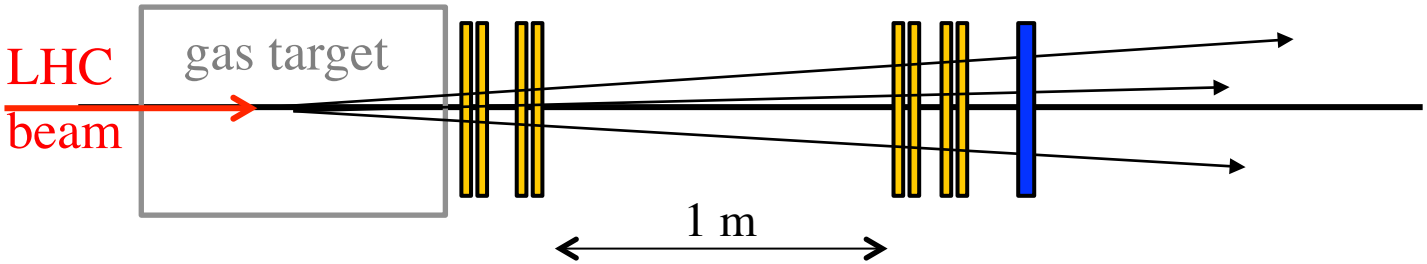


Swiss R&D activities

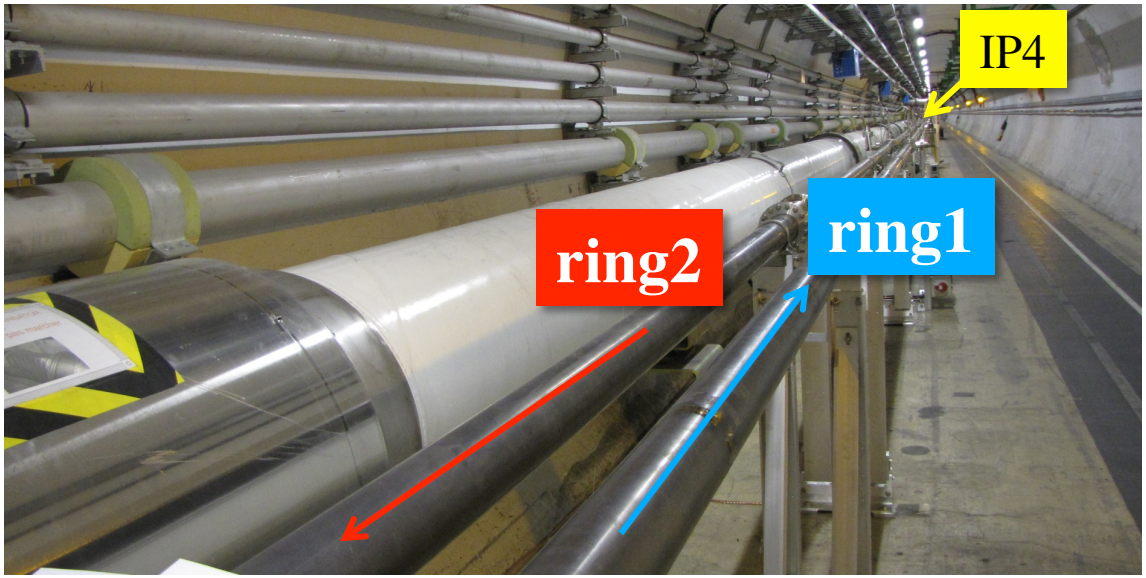
- R&D towards the demonstration of the feasibility of the SciFi proposal
  - Development of SiPMs with Hamamatsu
    - optimisation of photon detection efficiency (incl. active area)
    - improvement of radiation hardness
    - from single-channel to 128-channel device
  - Radiation studies
    - understand LHCb environment (simulation, in situ measurements, shielding tests, ...)
    - SiPM irradiation (in LHCb, in the lab, ...) and characterization (noise, ...)
    - simulation (and measurement) of light propagation in fibres
  - Front-end readout electronics
    - intermediate solution for prototypes (use of current Beetle chip)
    - design of final electronics at 40 MHz
  - System design studies
    - construction of prototype modules with fibres, SiPM, cooling, readout, ...
- LHCb-wide coordination of SciFi R&D (Fred Blanc, EPFL)

Beam gas vertexing (BGV) at LHC

- CERN/EPFL/Aachen « collaboration » to build a BGV demonstrator at LHC ring 2 during LS1 (2013–2014):
  - inject gas in beam pipe and measure tracks from beam gas-collisions (concept successfully used in LHCb vertex detector during run 1)



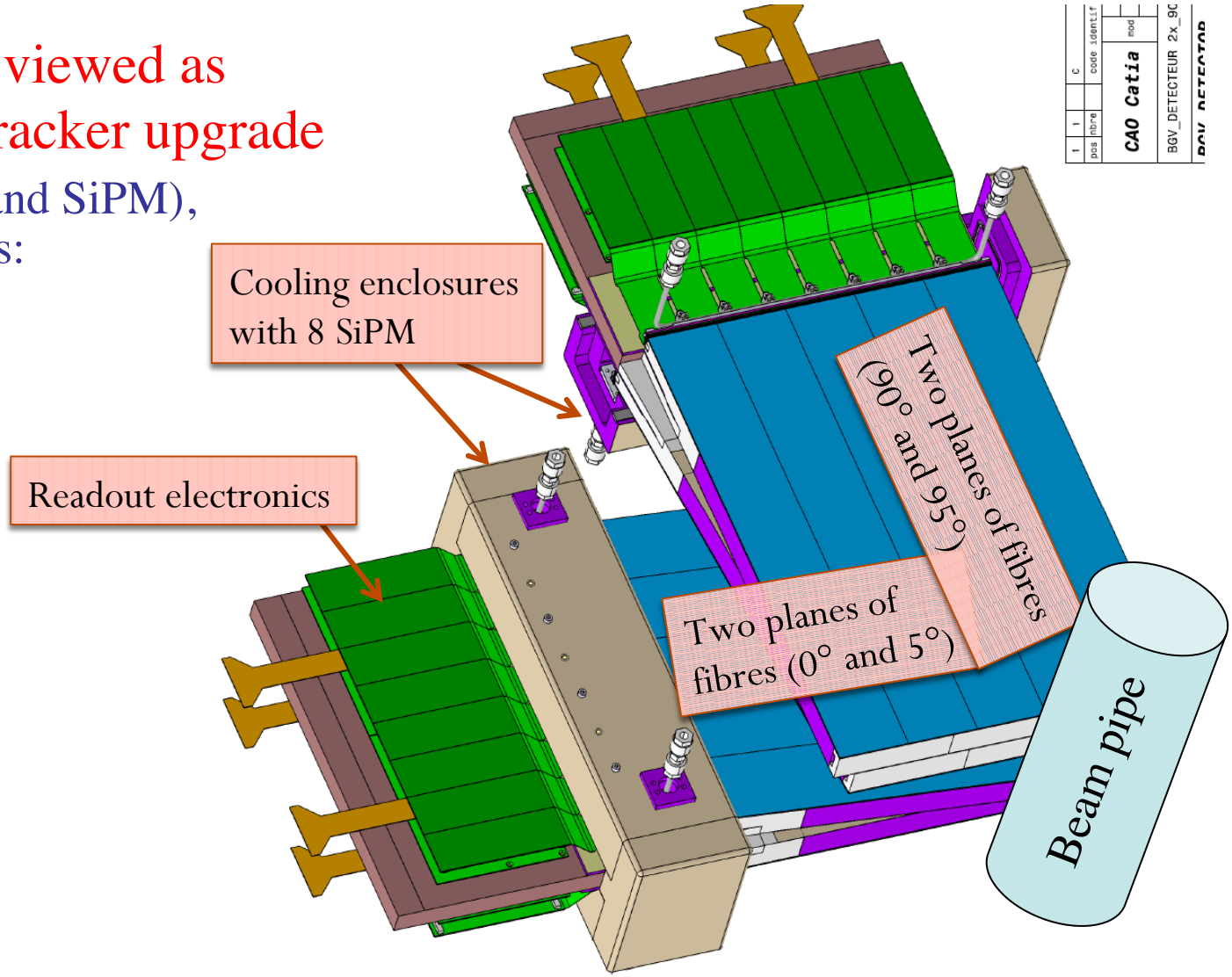
  - image beam profile
    → extract beam emittance (knowing beta function from machine optics)
  - use SciFi modules + SiPM



- Large synergy between BGV and LHCb tracker upgrade

BGV modules = prototypes

- BGV modules can be viewed as prototypes of LHCb tracker upgrade
  - same detector (fibres and SiPM), but much shorter fibres: ~35 cm vs 250 cm
- We will soon gain valuable experience
  - design
  - construction
  - cooling
  - readout
  - operation in radiation environment



Swiss upgrade construction effort

- Next steps:
  - technology choice for downstream tracking (SciFi vs Si) by LHCb
  - Technical Design Reports
    - final design, updated cost. definition of responsibilities
    - several LHCb countries interested, in addition to CH
      - upstream: IT, PL, US
      - downstream: CERN, CN, DE, ES, FR, GB, NL, PL, RU
- Involvement of Swiss groups:
  - SiPM and corresponding readout electronics
  - other items to be defined soon
- Intended Swiss resources for LHCb upgrade:
  - 4 MCHF for tracking upgrade (70% from SNSF)
  - 8.5 technicians for tracking upgrade + ST maintenance (2 from SNSF)
  - scientists ...

Summary

- LHCb upgrade: fully exploit flavour physics potential of LHC
- Swiss groups in LHCb
  - committed to the LHCb upgrade, concentrating on the tracker
  - proposed SciFi + SiPM for the downstream stations
    - first time such technology would be used in high radiation environment of LHC
- LHCb tracker upgrade:
  - SciFi+SiPM R&D well advanced
    - SiPM developed and characterized, prototypes built
    - valuable experience will be gained in real environment (BGV project at LHC)
  - LHCb decision expected this year
  - Installation in long shut-down 2 (2018)
    - schedule is tight as usual, but many LHCb groups joined the project