LHCb Silicon Detectors

Mark Tobin

About me

(1) Born in Hartlepool.

(2) MPhys @ University of Liverpool.

PhD @ University of Liverpool.

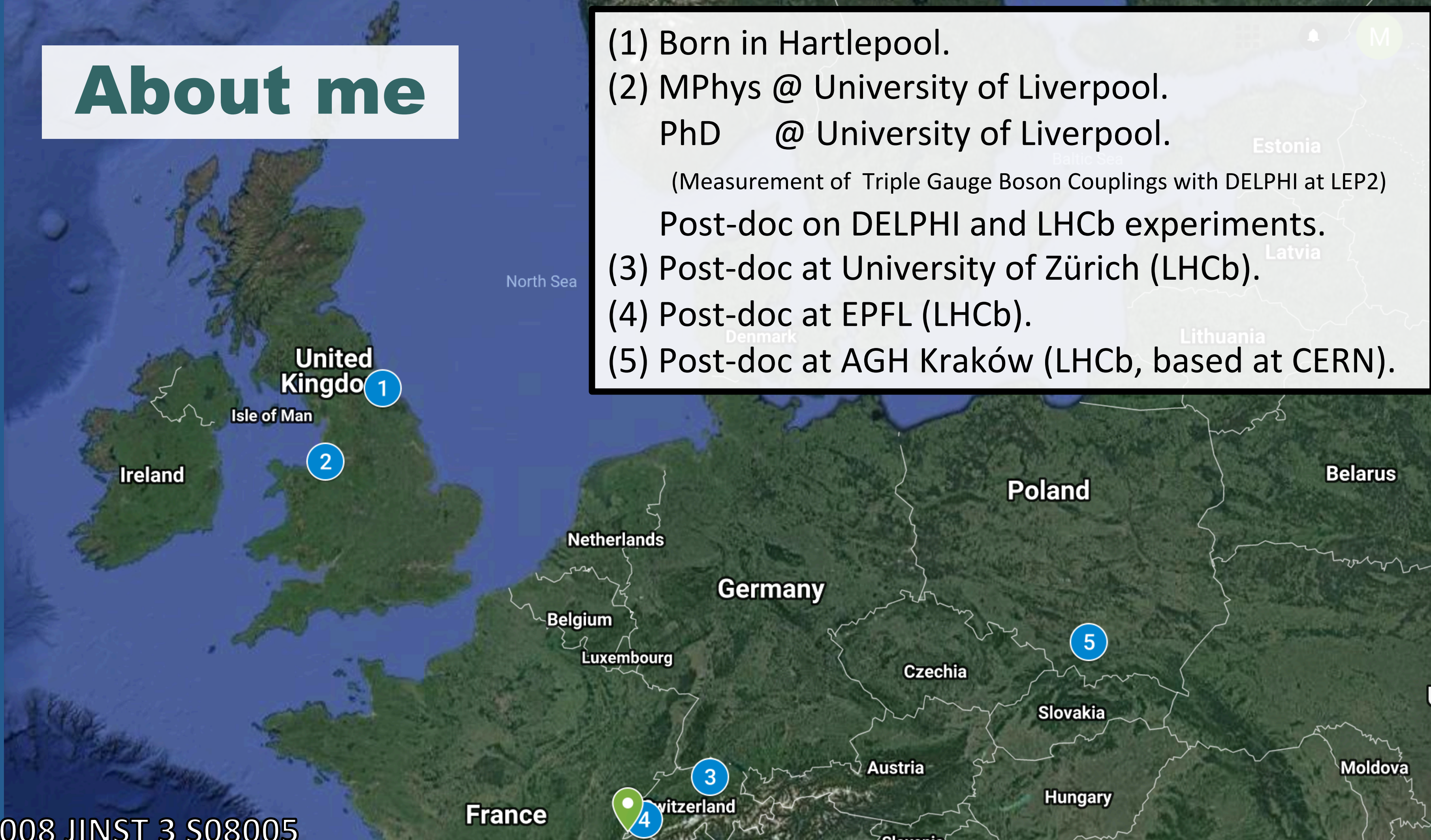
(Measurement of Triple Gauge Boson Couplings with DELPHI at LEP2)

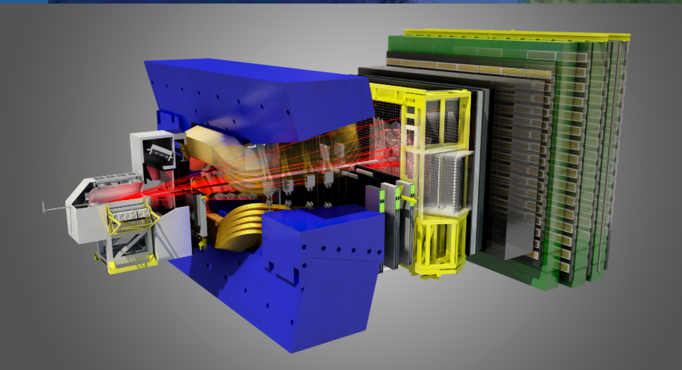
Post-doc on DELPHI and LHCb experiments.

(3) Post-doc at University of Zürich (LHCb).

(4) Post-doc at EPFL (LHCb).

(5) Post-doc at AGH Kraków (LHCb, based at CERN).





2008 JINST 3 S08005

Curriculum Vitae (since PhD)

time

University of Liverpool (post-doc).

- LHCb VErtex LOcator (VELO).
  - Module reception tests at CERN.
  - Installation & testing of low voltage system.
  - Commissioning of full detector system.

University of Zurich (post-doc).

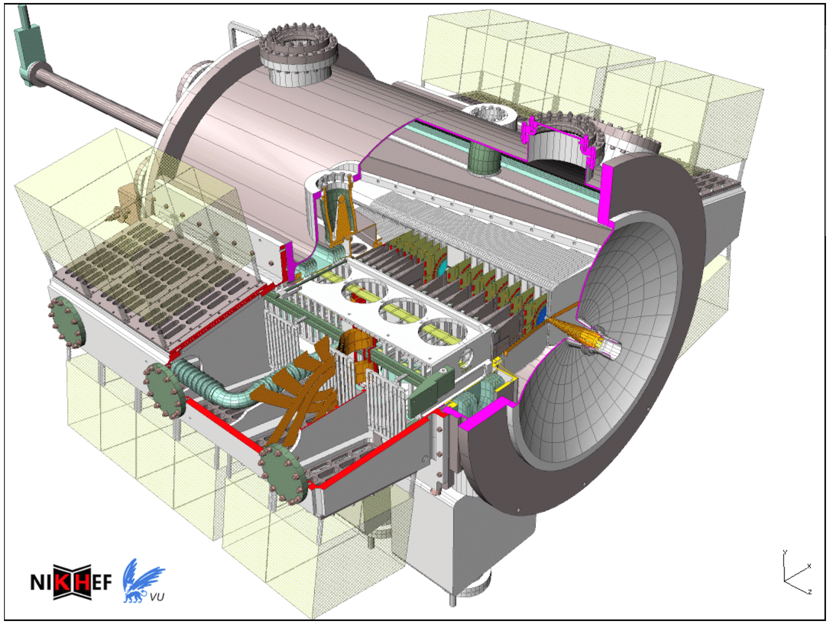
- LHCb Silicon Tracker (ST).
  - Commissioning & operation of system.
  - Online monitoring of data.
  - Module testing after detector repairs.
  - Deputy project leader.

EPFL-Lausanne (post-doc).

- LHCb Silicon Tracker.
  - Commissioning of detector for Run 2.
  - Monitoring of radiation damage in sensors.
  - Project leader.
- LHCb Scintillating Fibre (SciFi) Tracker.
  - Characterisation of irradiated SiPMs.
  - Editor of LHCb Upgrade Tracker TDR.
  - Test beam co-ordinator.

AGH-Krakow (post-doc).

- LHCb Upstream Tracker.
  - Experimental control software.



VERTEX LOCATOR (VELO)

J. Instrum. 9 (2014) P09007

LHCb VELO

Reception tests at CERN.

- Visual inspection of modules.
- Problem with construction jig.

Test beams at SPS.

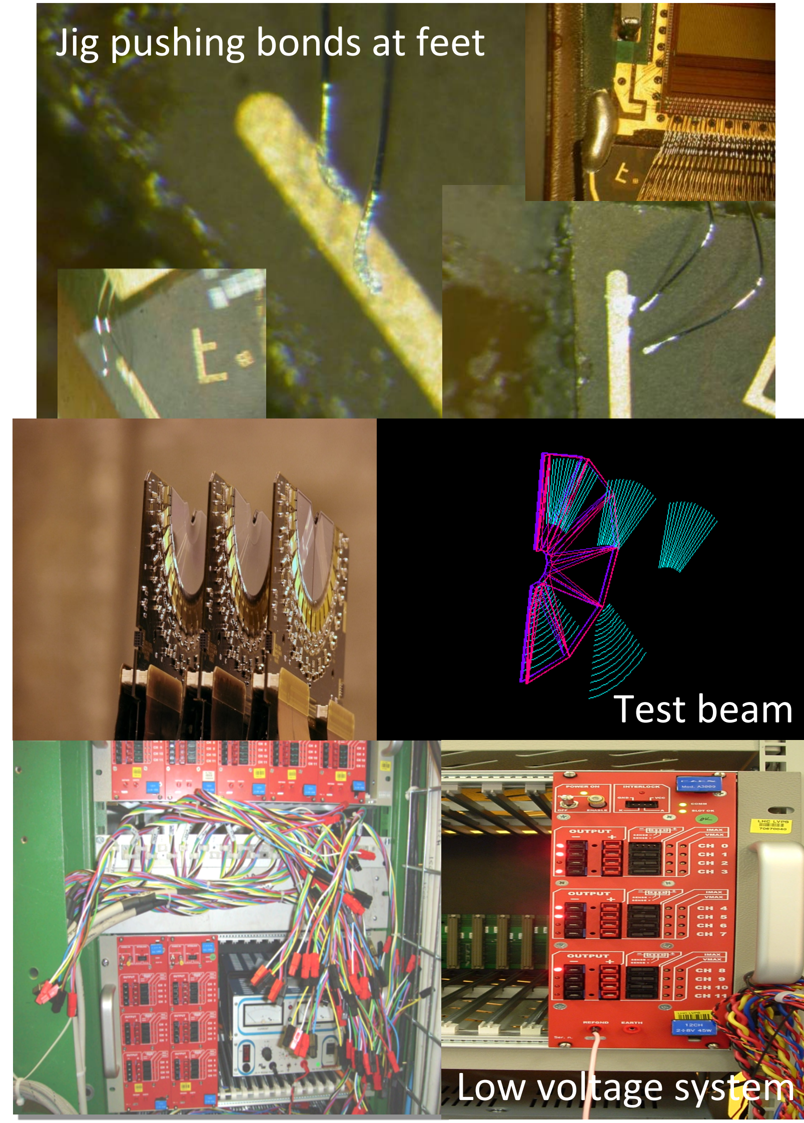
- Pre-production modules.
  - Full offline software chain used.
  - Study performance of sensors.
- Partially equipped detector half.
  - System test of full read-out chain.

Low voltage system.

- Installation team of 3 people.
- Testing of CAEN LV modules.
  - Linearity of supplies, interlocks, etc.
- Integration in full system.

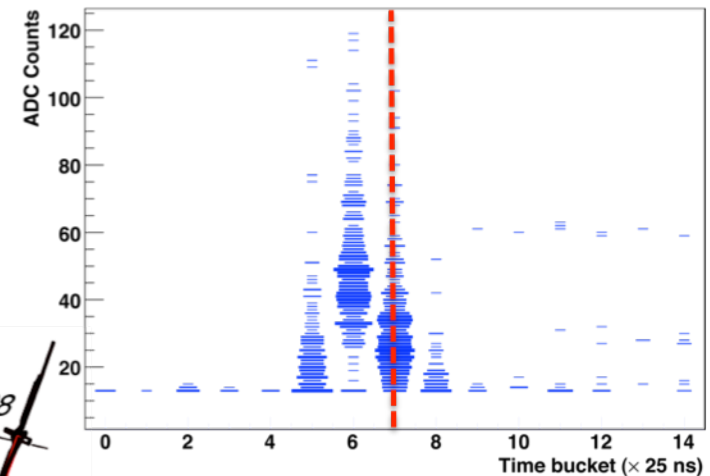
Detector commissioning.

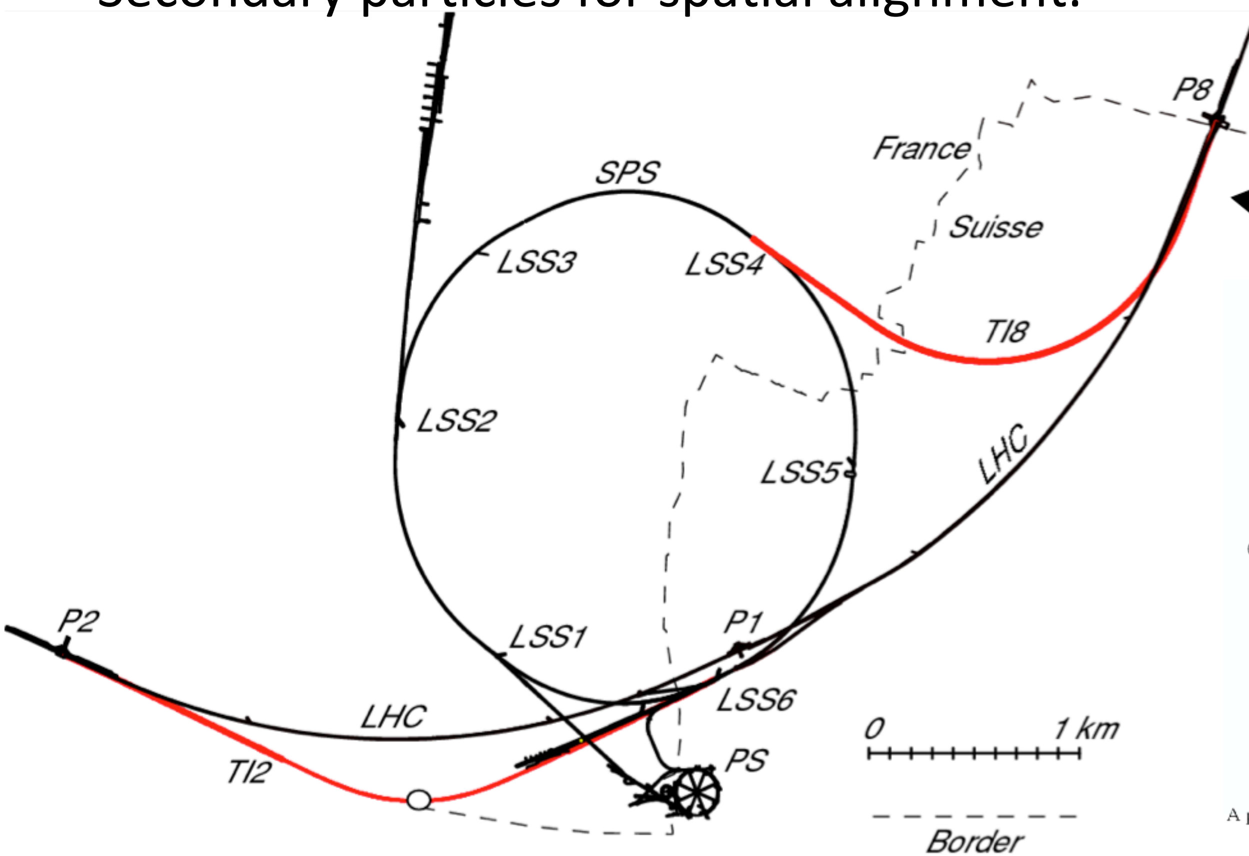
- Module powering & read-out tests.
- Preparation for LHC injection tests.



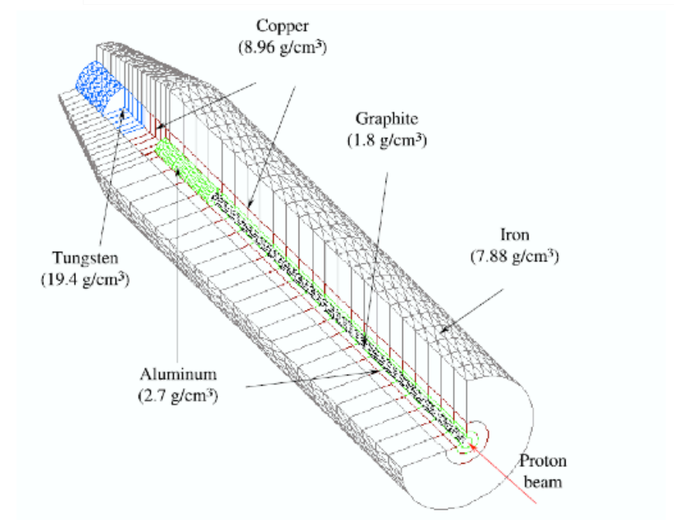
Commissioning

- Installation in 2008 → test services (LV, HV, read-out, etc.)
- Forward geometry → low rate cosmic muons.
- Use particles from LHC injection tests.
  - Beam stopper 350 m from LHCb.
  - 10^9 protons every 48 seconds.
- Time alignment (internal + w.r.t beam).
- Secondary particles for spatial alignment.





TED

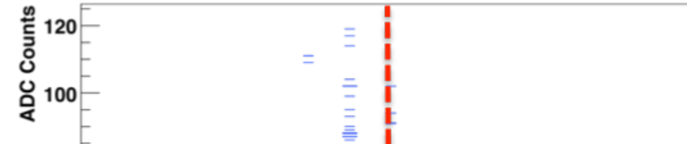


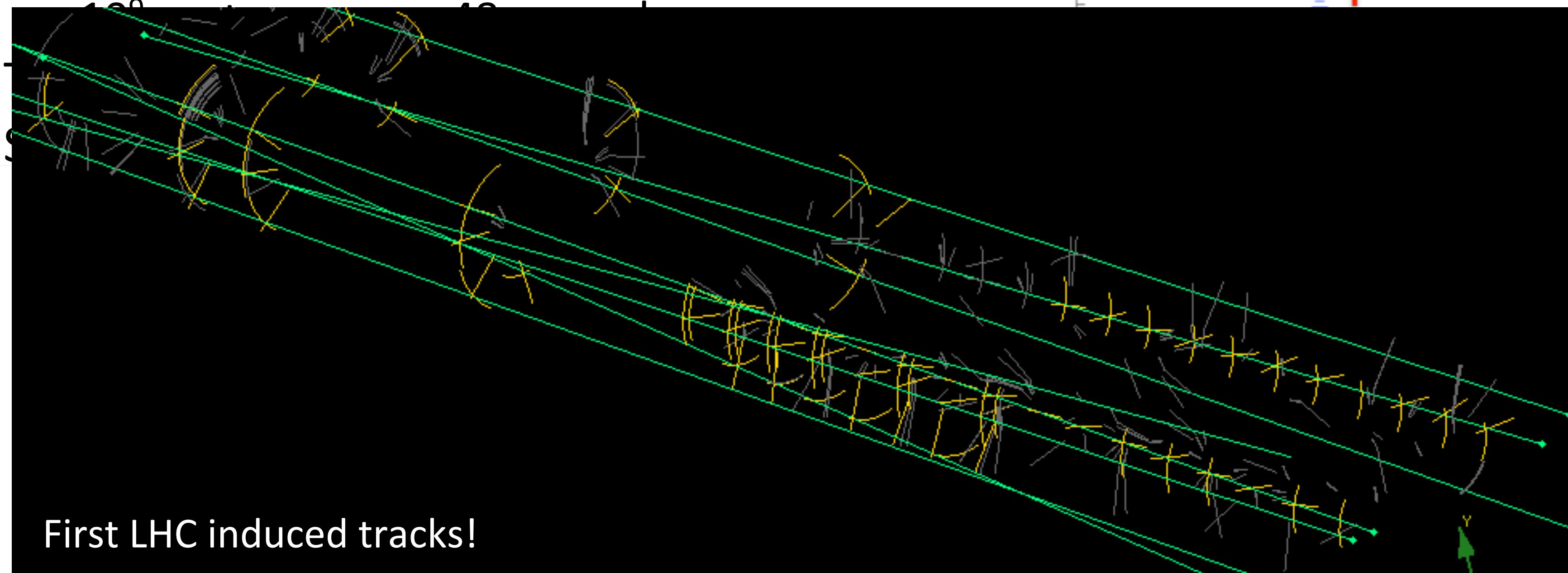
A perspective view of the FLUKA geometrical representation of the TED beam-dump.

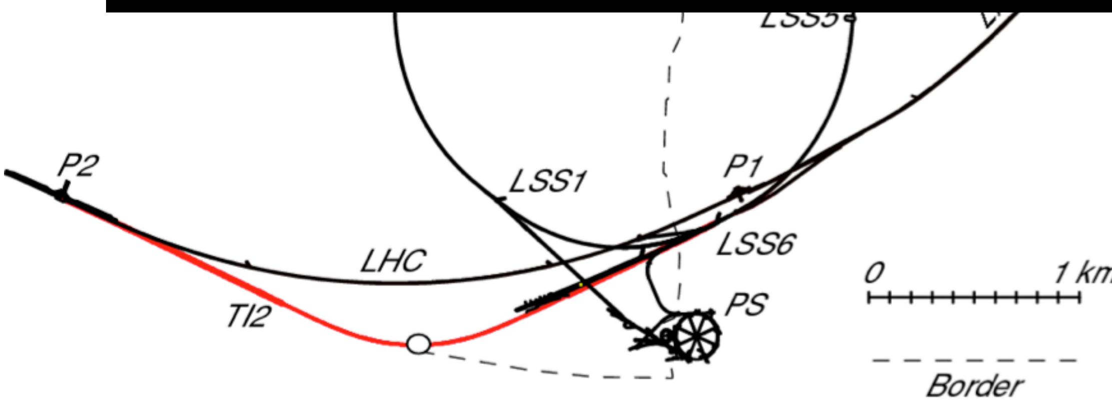
Commissioning

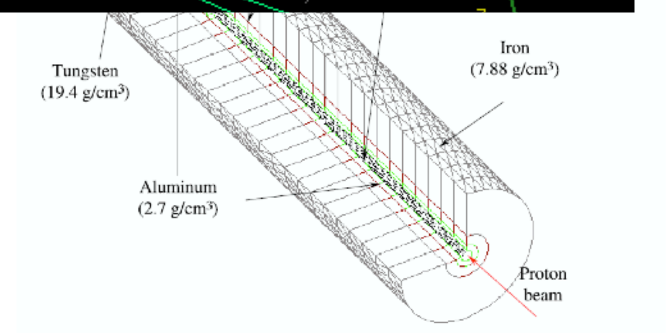
NIM A604, 1 (2009)

- Installation in 2008 → test services (LV, HV, read-out, etc.)
- Forward geometry → low rate cosmic muons.
- Use particles from LHC injection tests.
  - Beam stopper 350 m from LHCb.

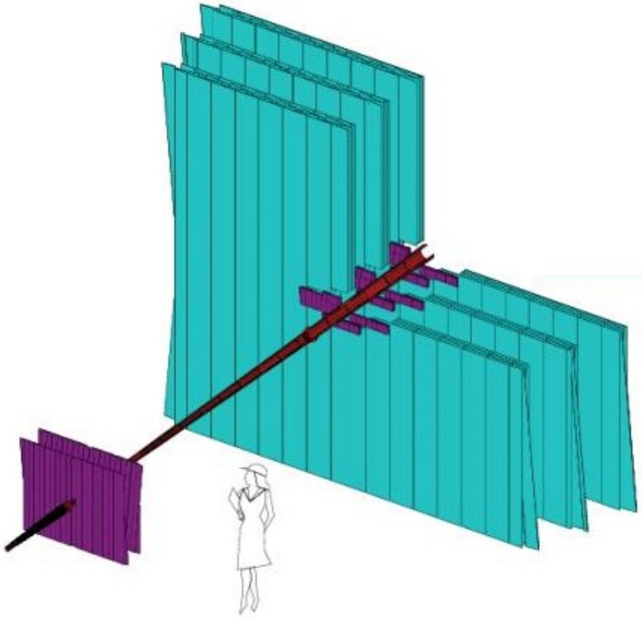








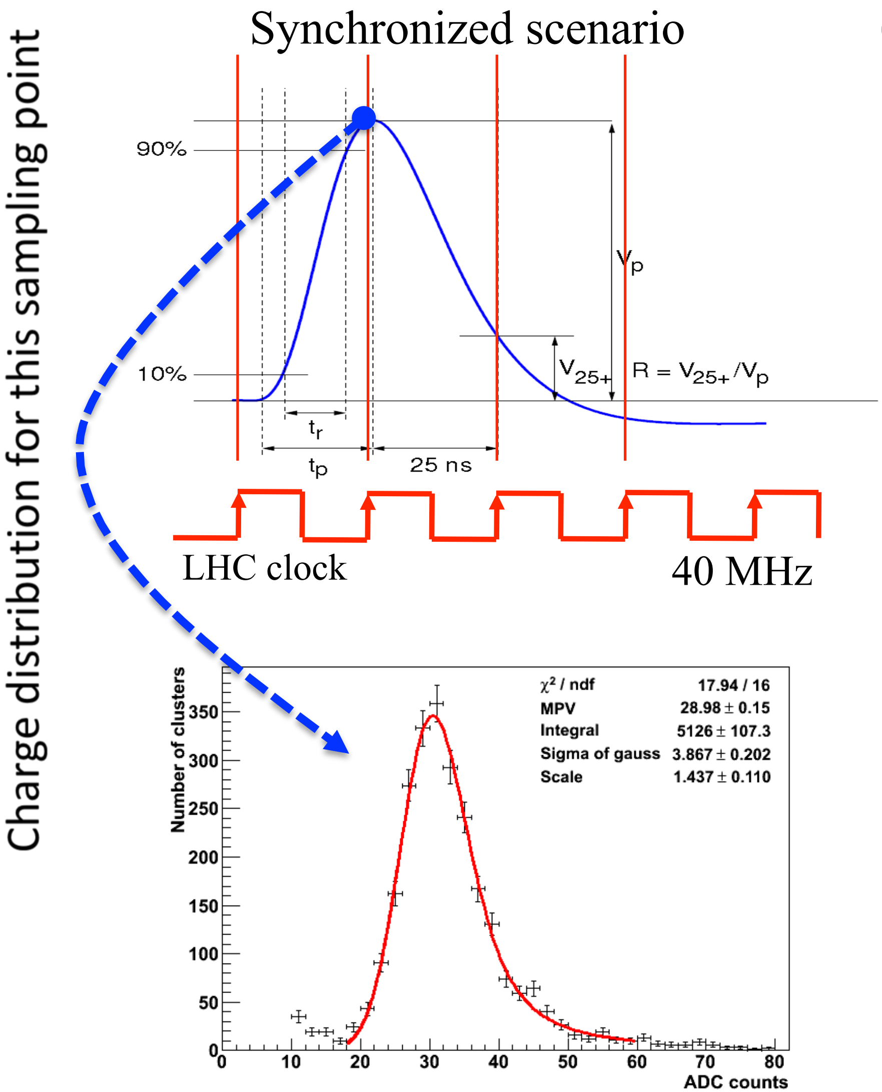
A perspective view of the FLUKA geometrical representation of the TED beam-dump.



SILICON TRACKER

Int. J. Mod. Phys. A 30 (2015) 1530022

Time Alignment



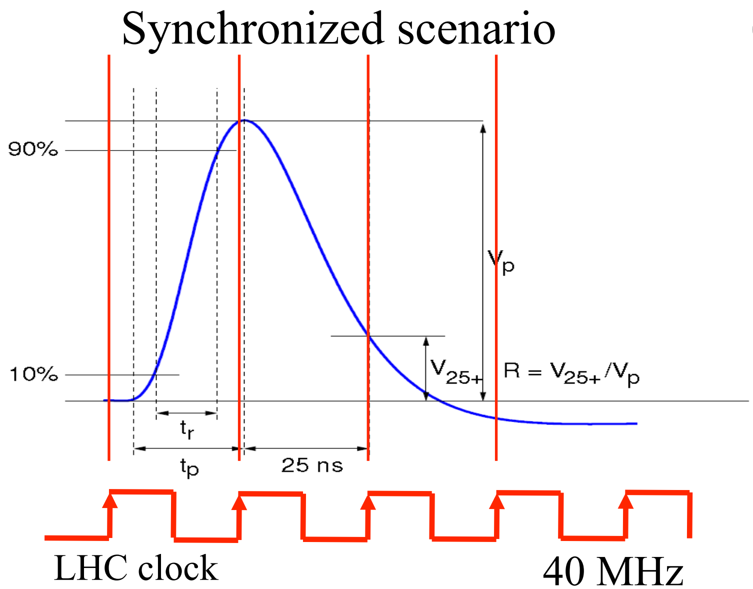
Optimize charge collection:

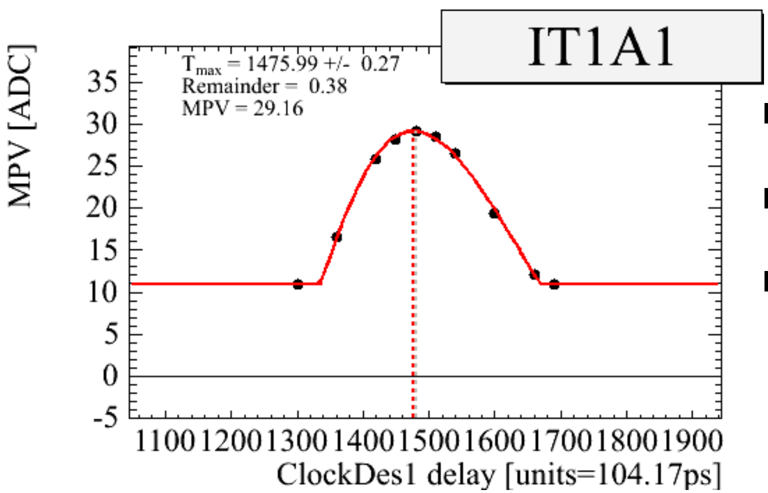
- Different length cables.
- Time of flight different for each station.

Perform time delay scan.

- Read out successive samples spaced by 25ns
- Fit Landau ⊗ Gaussian to charge distribution for each sample.
- Shift sampling point

Time Alignment





Optimize charge collection:

- Different length cables.
- Time of flight different for each station.

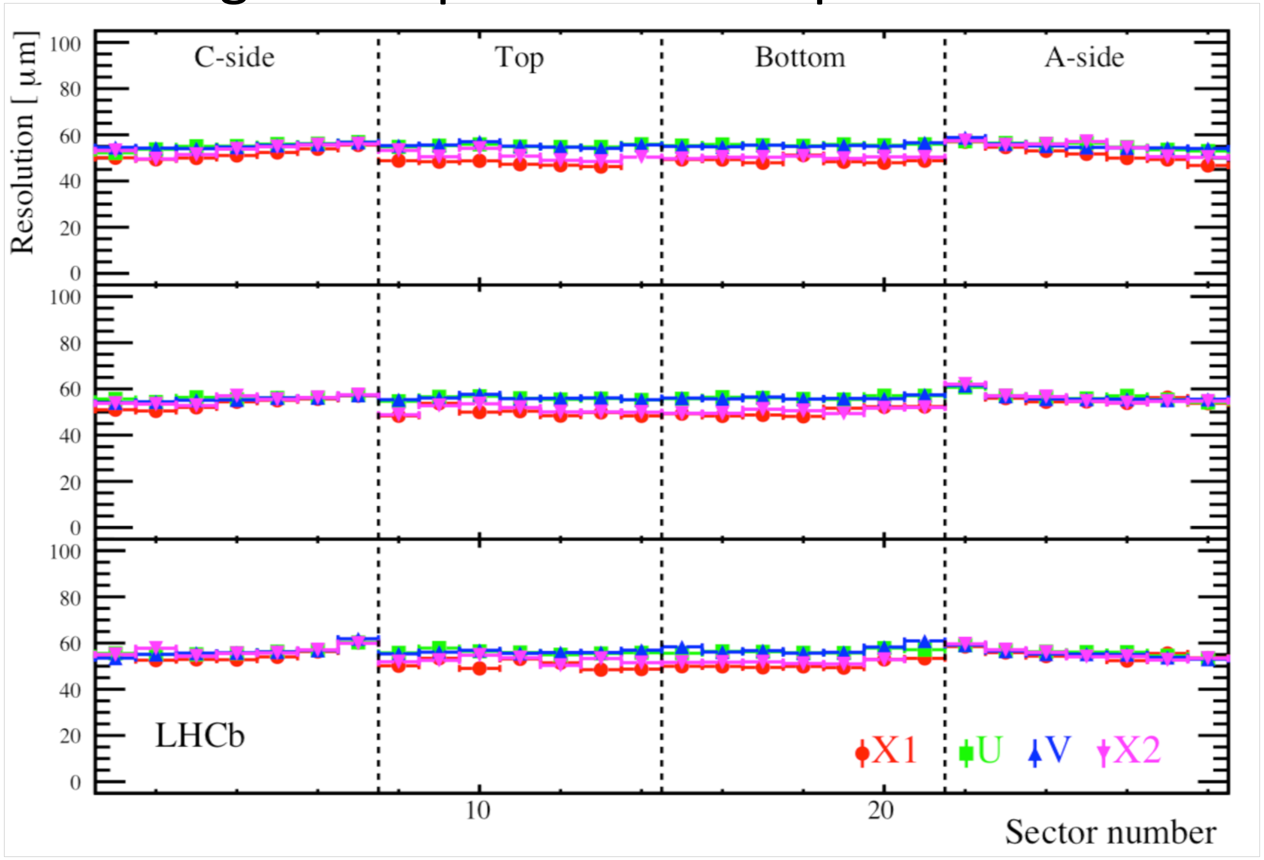
Perform time delay scan.

- Read out successive samples spaced by 25ns
- Fit Landau ⊗ Gaussian to charge distribution for each sample.
- Shift sampling point
- Plot MPV vs sample time.
- Fit pulse shape.

Internal Time Alignment < 1 ns

Alignment and resolution

- Use tracks from VELO+T stations.
- Global χ^2 minimisation based on Kalman track fit residuals
  - W.D. Hulsbergen, Nucl. Inst. Meth. A600, 471 (2008).
- Additional mass constraint applied to vertices from $D^0 \rightarrow K^+\pi^-$.
  - J. Amoraal et al., Nucl. Inst. Meth. A714, 48 (2013).
- Alignment precision ≈ 10 µm.



Hit resolution:

✧ **52.6 µm (TT, 2011)**

✧ **53.4 µm (TT, 2012)**

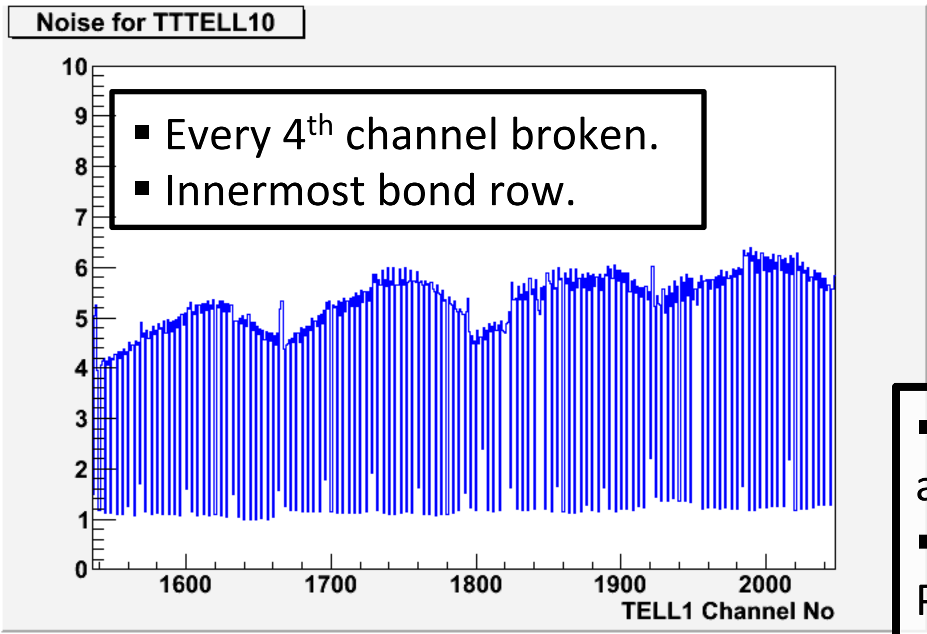
✧ **47.9 µm (TT, MC)**

✧ **50.3 µm (IT, 2011)**

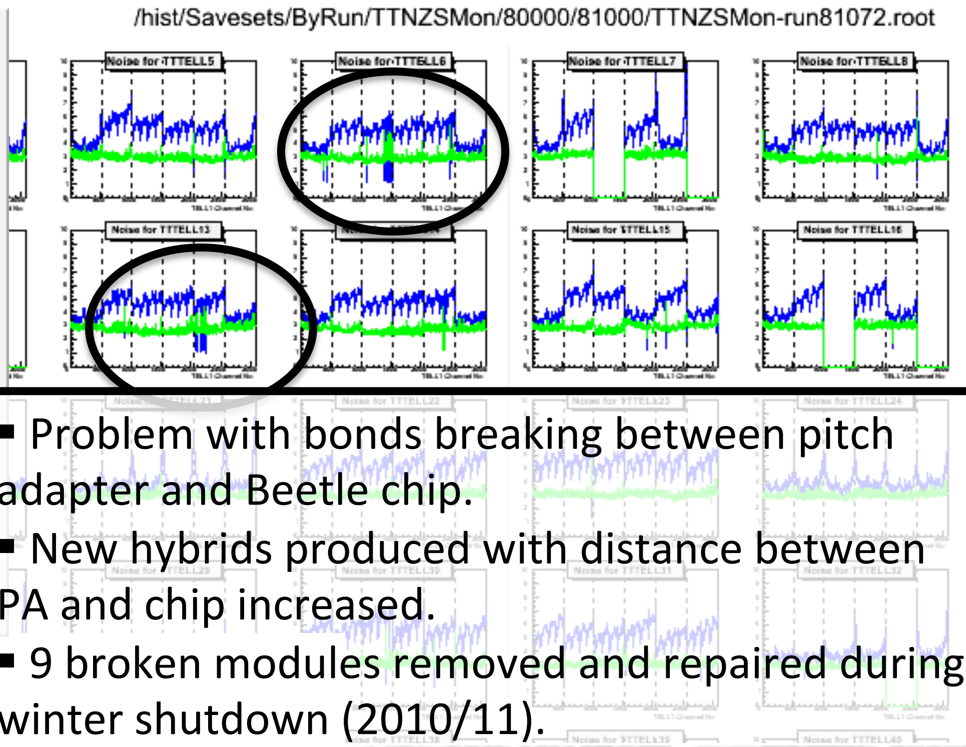
✧ **54.9 µm (IT, 2012)**

✧ **53.9 µm (IT, MC)**

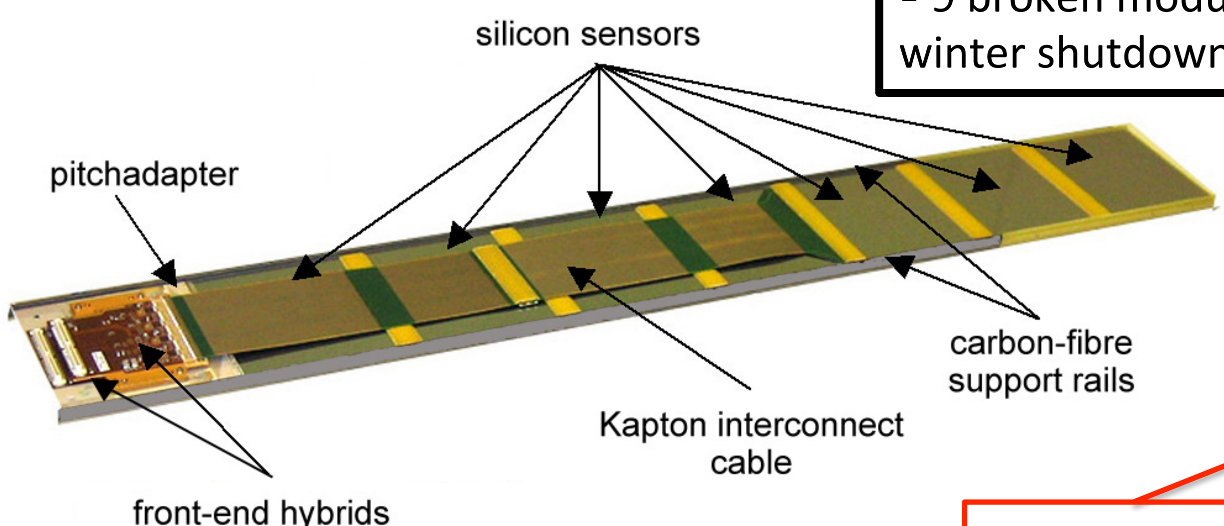
Broken bonds in TT

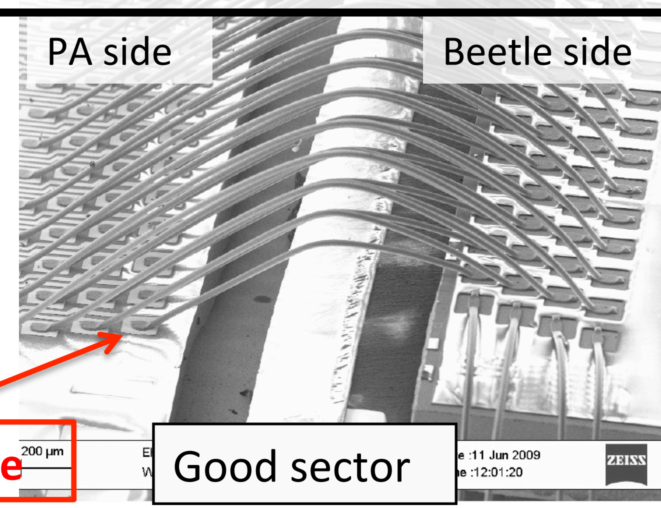


- Every 4th channel broken.
- Innermost bond row.

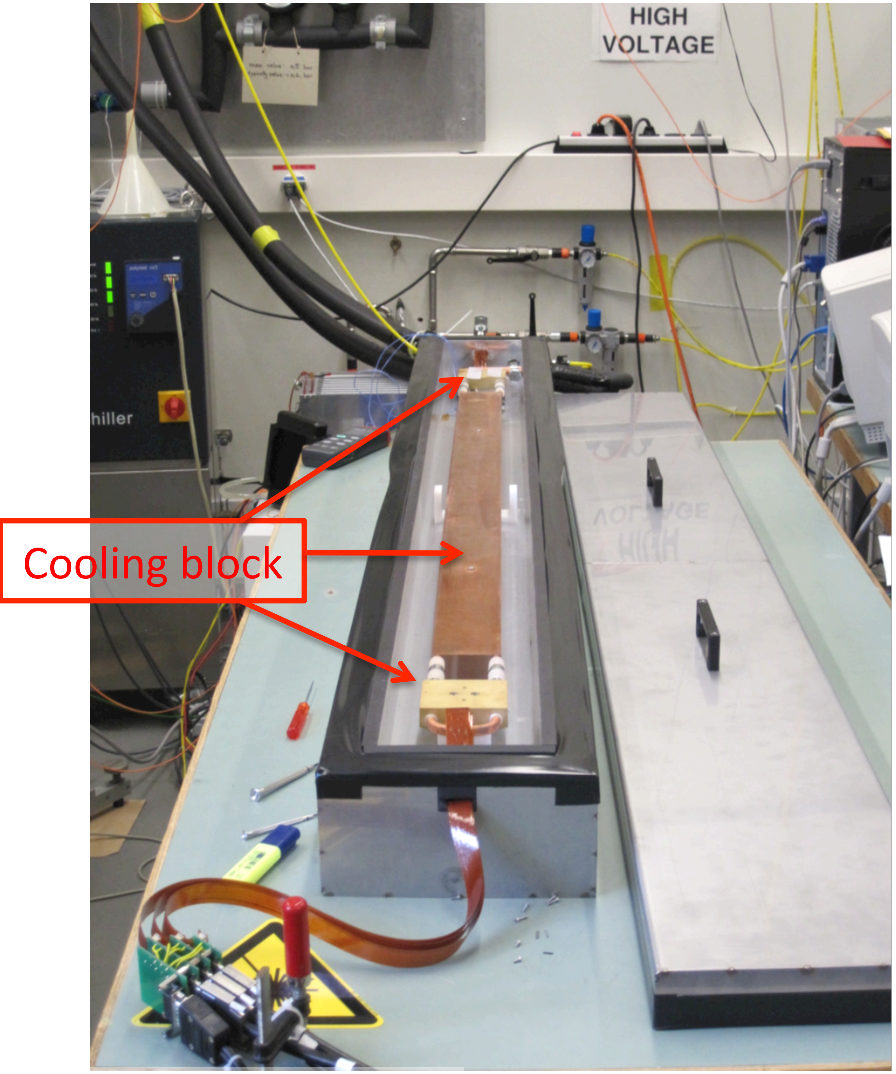


- Problem with bonds breaking between pitch adapter and Beetle chip.
- New hybrids produced with distance between PA and chip increased.
- 9 broken modules removed and repaired during winter shutdown (2010/11).

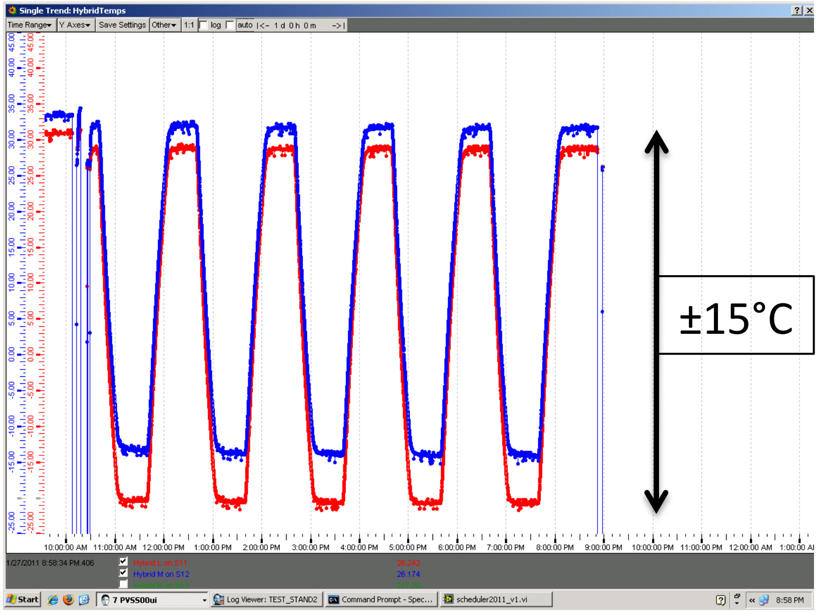




Module testing in Zürich

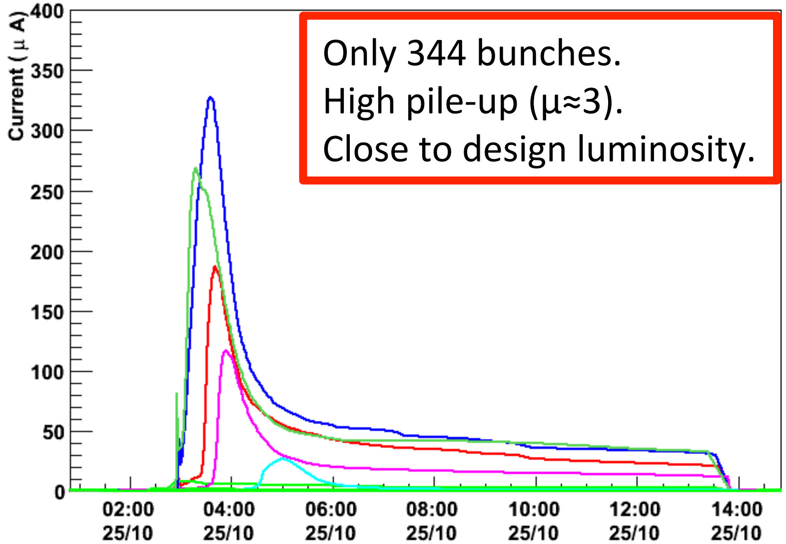


Read out half module



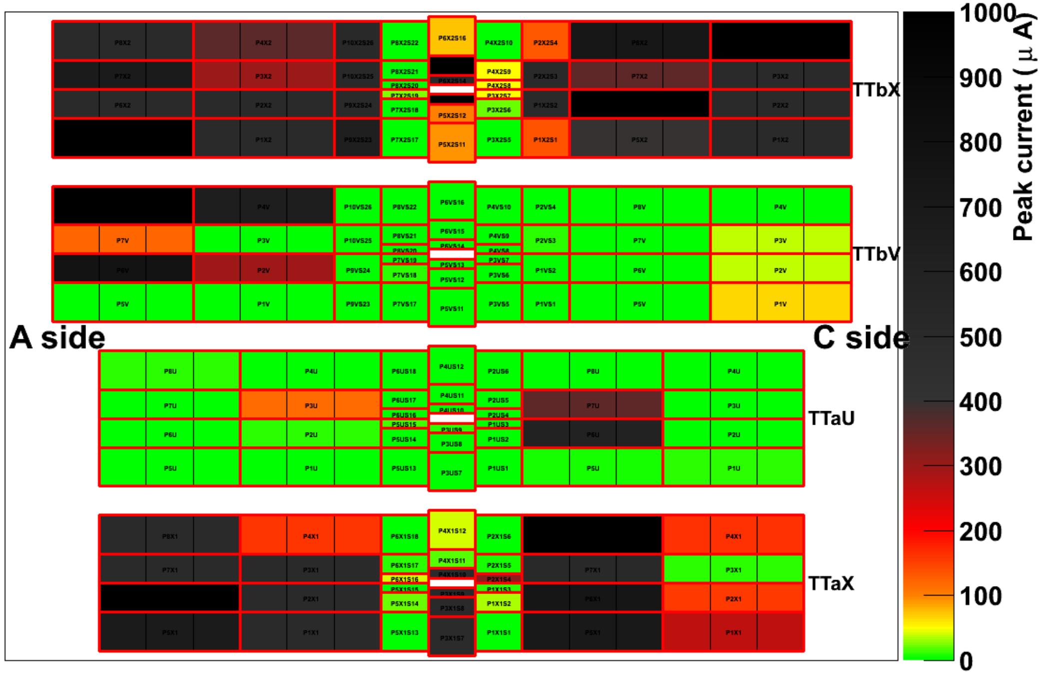
- Set-up burn-in stand for module testing.
  - Also used for master student projects.
- Electrical tests of bare hybrids.
- Developed module testing programme.
  - Stress tests of repaired modules.
  - Temperature cycling.
  - Measure current-voltage curves
- Modules successfully re-installed.

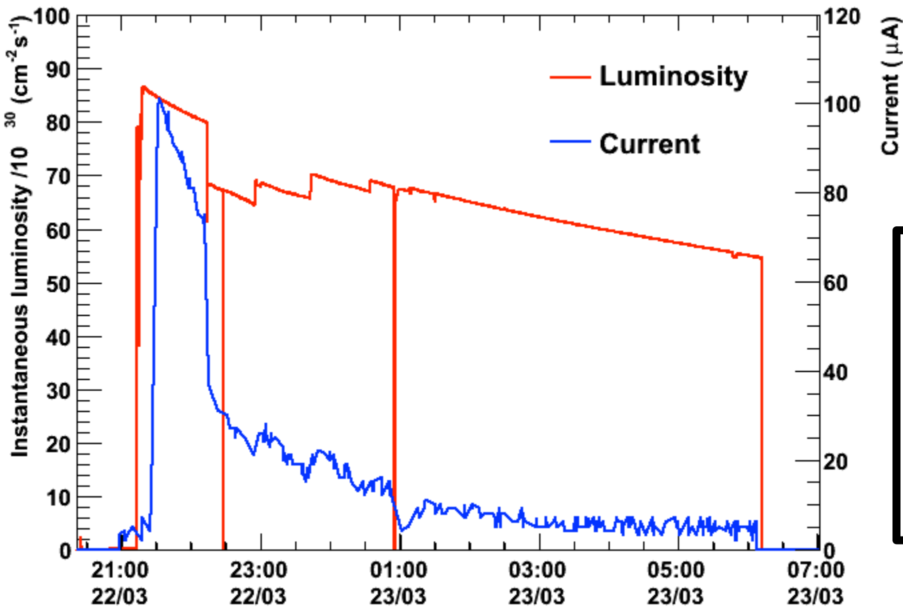
HV problems

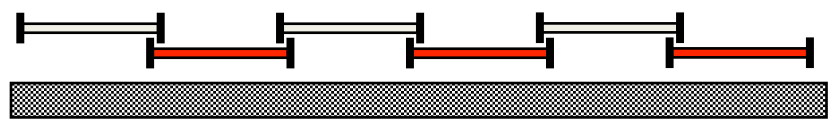


Only 344 bunches.
High pile-up (μ≈3).
Close to design luminosity.

Large currents observed with beam.

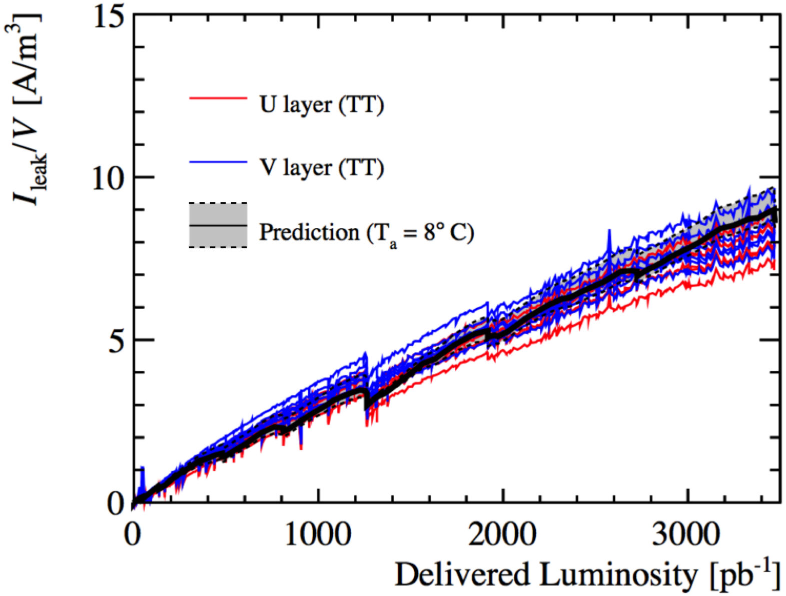


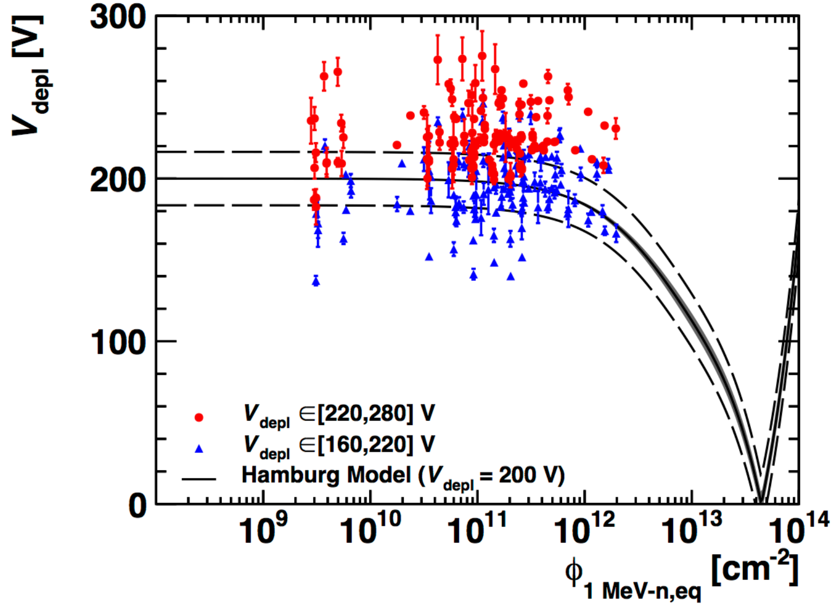




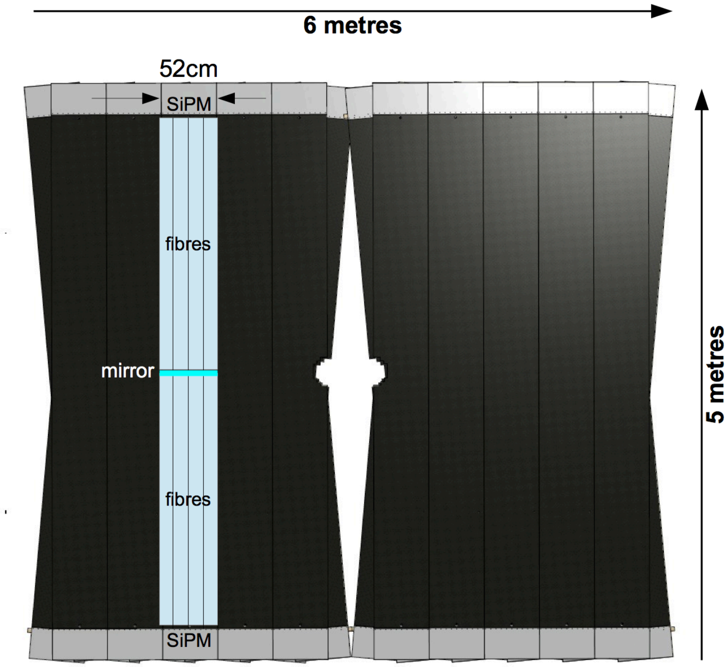
- Located in sectors closest to insulation wall.
- Correlated with instantaneous luminosity.
- Potential show-stopper for high luminosity.
- Installation of Kapton shielding and changes to operation procedures cured problem.

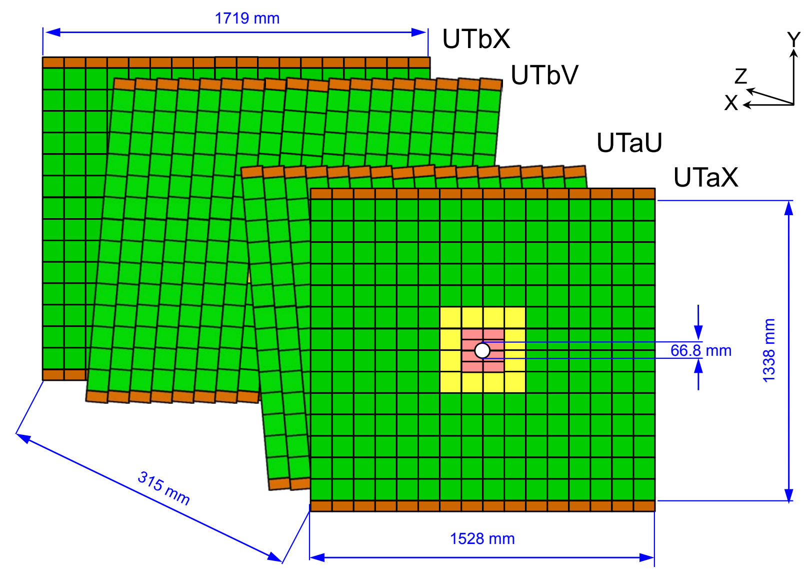
Radiation damage studies





- Monitor changes in leakage currents.
- Monitor changes in depletion voltage
  - Dedicated charge collection efficiency scans.
- Compare results with predictions.

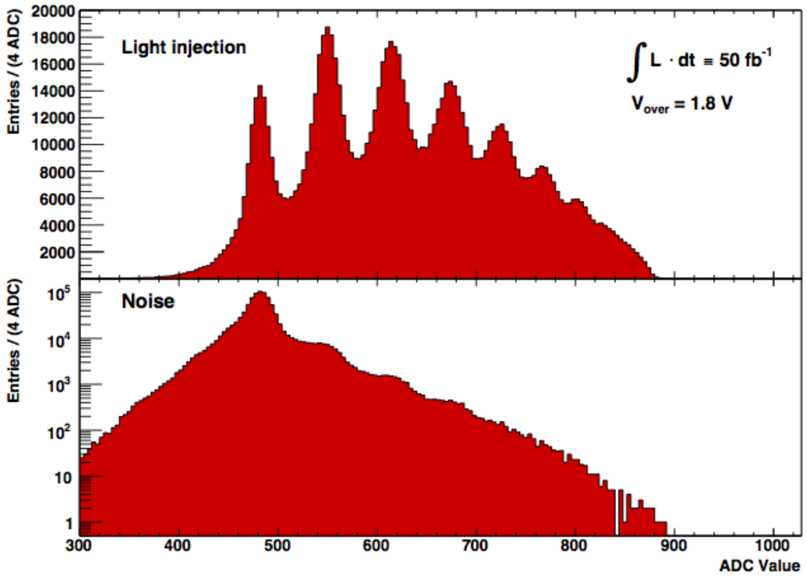


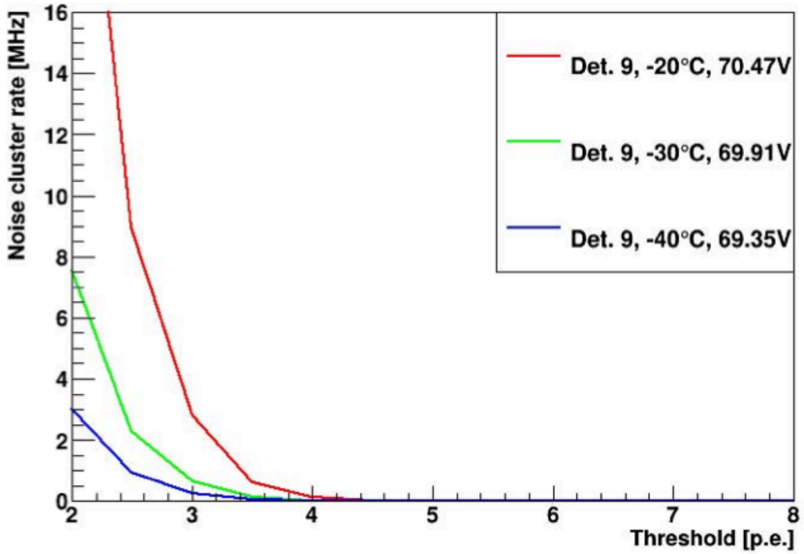


LHCB TRACKER UPGRADE

CERN/LHCC-2014-001; LHCb TDR 015 (2014)

LHCb Upgrade: SciFi Tracker



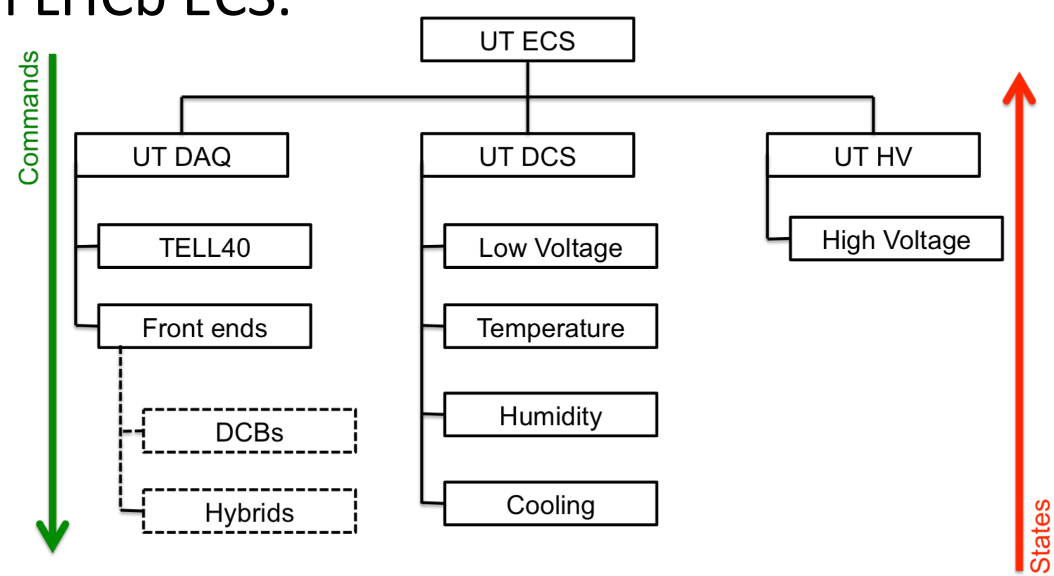


- Characterisation tests of irradiated SiPMs.
  - Irradiated at neutron-reactor to equivalent of 50 fb^{-1}.
- Adapted VELO read-out system.
  - Fast shaping of signals.
  - Required attenuation of signals by a factor of 200.
- Measure noise cluster rates, signals, etc.

LHCb Upgrade: Upstream Tracker

- New silicon microstrip detector.
  - Finer segmentation, reduced material, closer to beam.
- Replace all electronics.
  - Read out full detector at 40 MHz.
  - New read-out ASIC (SALT).
  - PEPI electronics (control and data signals).
- New experimental control system (ECS).
  - Testing electronics and data processing.
  - Integration with central LHCb ECS.

- SCADA system (WinCC-OA).
- Finite-state machine hierarchy.
- JCOP framework



Lessons learned

Low Voltage Tests

- Crucial to test cables and power supplies with dummy load.
- Designer assumed boards could supply -ve voltages… had to swap some cables

Software

- Use online/offline software with real data as early as possible.
- Test beam with was crucial to debug VELO geometry.

LHC injection tests

- Opportunity to see real tracks in forward detector.
- Initial time and spatial alignment.

Online Monitoring

- Critical for data quality and detector performance.

Radiation monitoring

- Make IV and CCE scans from the beginning.
- Define and test procedure

Broken bonds

- Changed design of hybrids (original bond heights very different in VELO & ST).
- Encapsulate bond wires (should be tested).

Knowledge transfer

- Keep detailed logs of everything.
- Huge amount of time wasted to correlate (historical) information from different systems and databases.
- Document all procedures (people leave).

Research plan

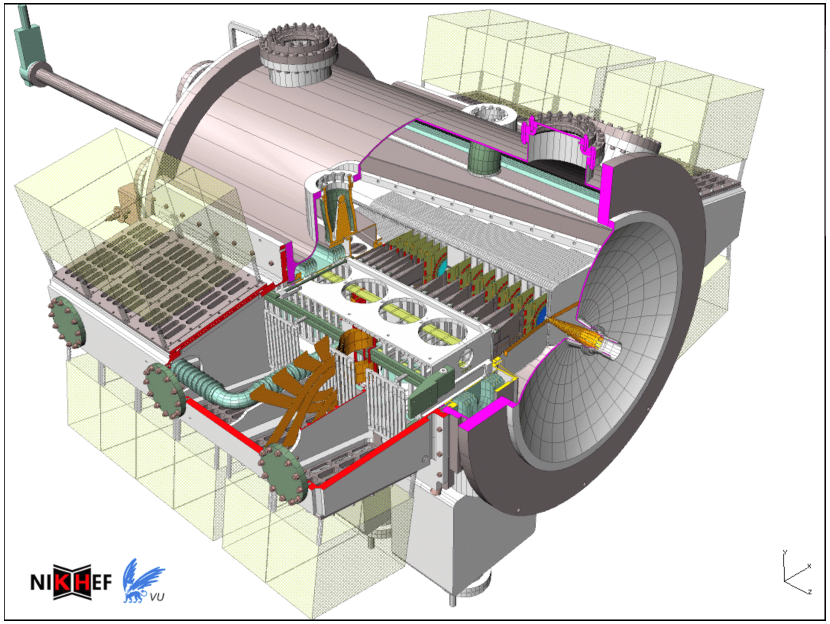
- Local commissioning.
  - Development of ECS software and tools.
  - Perfect read-out and data processing.
  - Stave testing and installation at CERN.
  - Develop monitoring and calibration procedures.
- Global commissioning.
  - Integration of UT after installation in cavern.
  - High rate tests of read-out with other sub-systems.
- Final commissioning.
  - TED shots – initial time alignment of detector.
  - First beams – time and spatial alignment of detector.
  - Data quality and detector performance studies.
- Future commissioning.
  - LHCb phase 2 upgrade → develop 4-D tracking detectors?

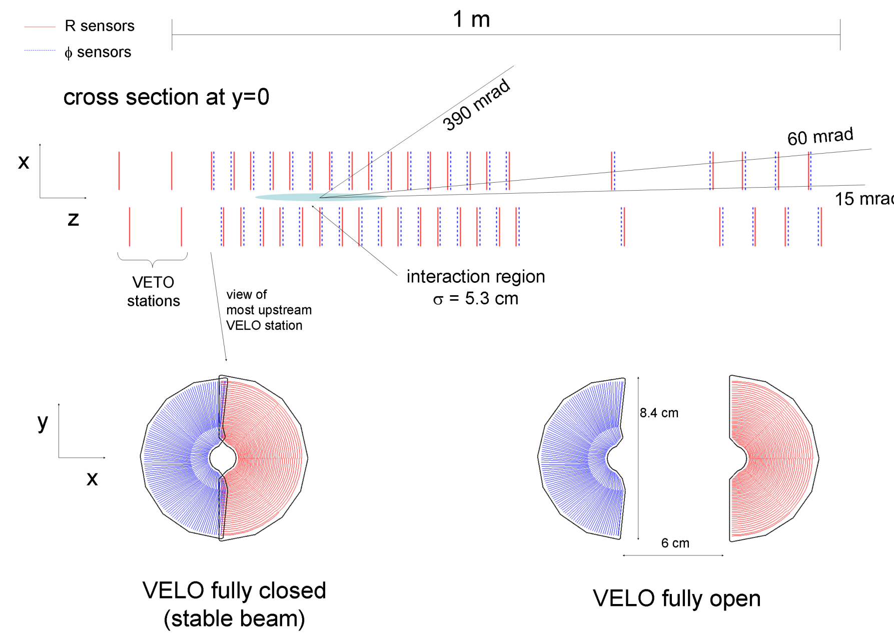
Summary

- LHCb Vertex Locator.
  - Design, construction and commissioning.
  - Quality assurance of modules and LV system.
- LHCb Silicon Tracker.
  - Commissioning of detector system for Run 1&2.
  - Radiation damage studies.
  - Responsible for detector operations during Run 1&2.
  - Project management (deputy & PL).
- LHCb SciFi Tracker.
  - Development of silicon photo-detectors.
  - Technical Design Report.
- LHCb Upstream Tracker
  - Design and implementation of control software.
  - Responsible for online monitoring of data.

BACK UP

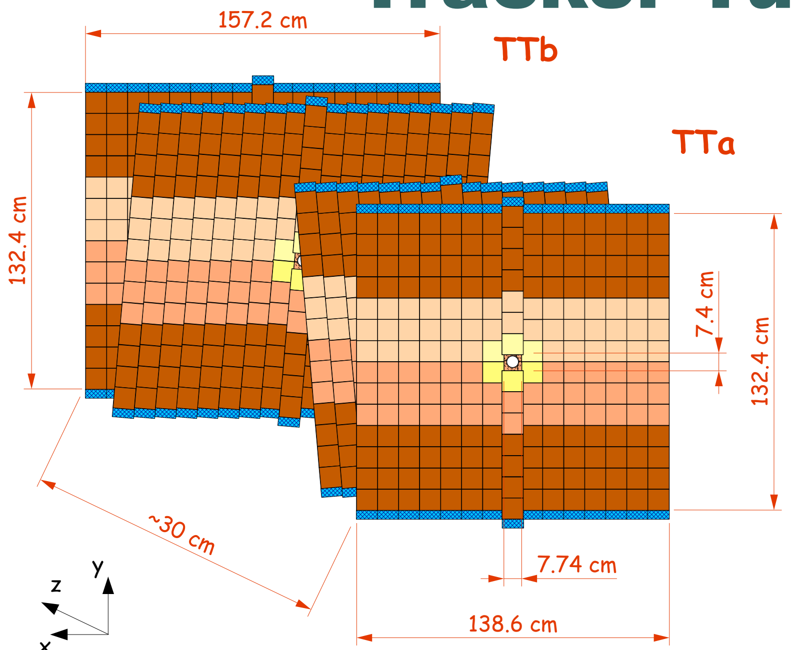
VErtex LOcator (VELO)

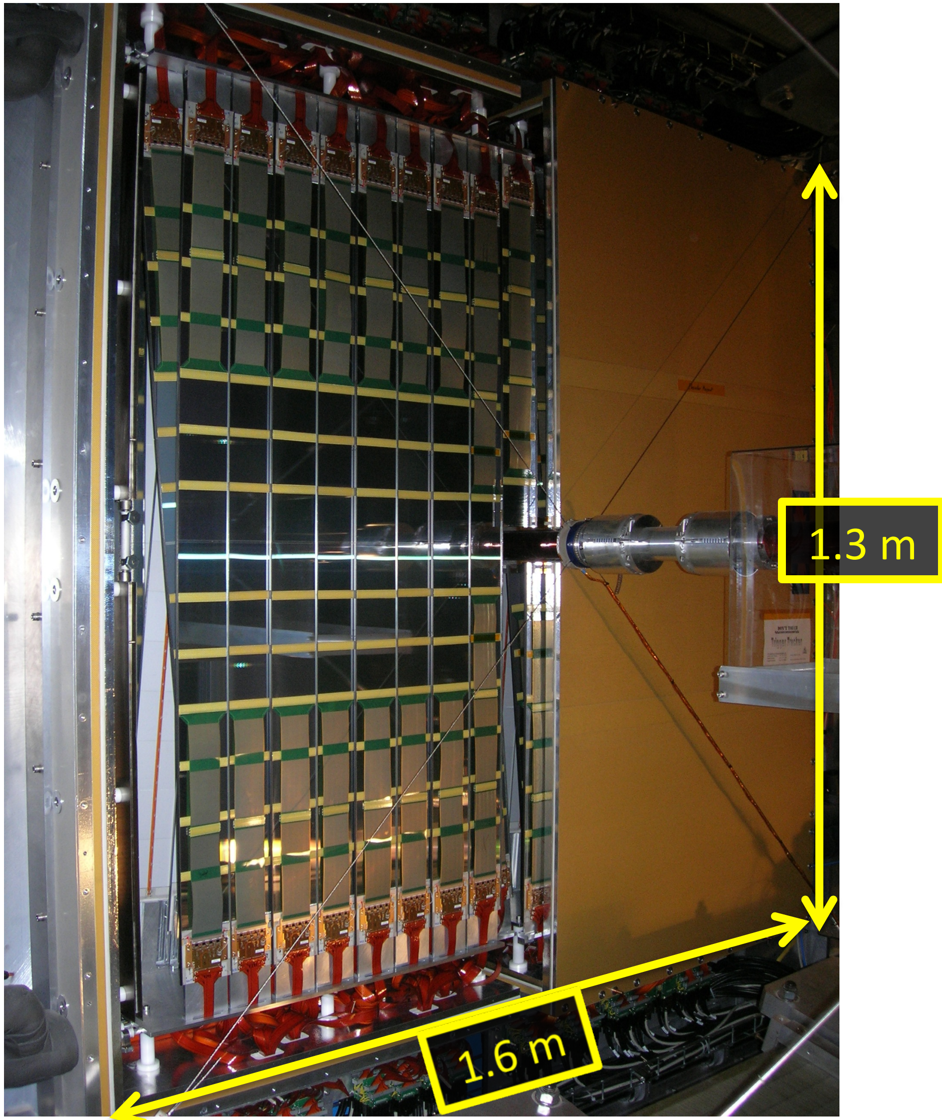




- Two retractable halves.
  - 5 mm from beam when closed, 30 mm during injection.
- 21 R-ϕ modules per half.
- Operates in secondary vacuum.
- 300 μm aluminium foils separates detector from beam vacuum.
- Cooling using bi-phase $C0_2$ system.
  - Operates @ -30°C, Sensors @ -10°C.

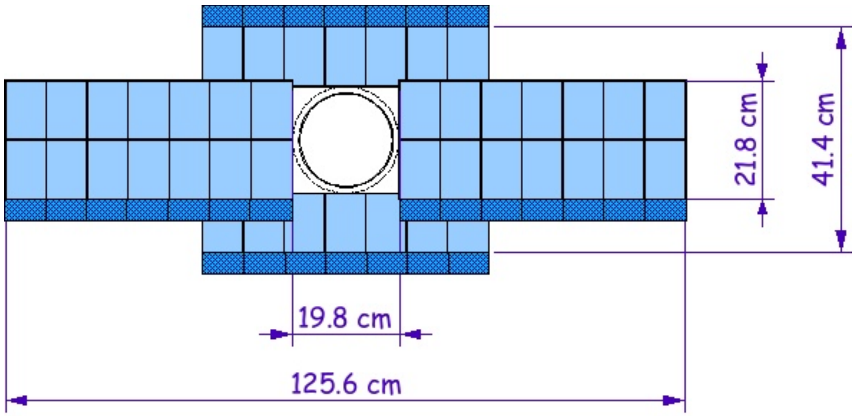
Tracker Turicensis (TT)

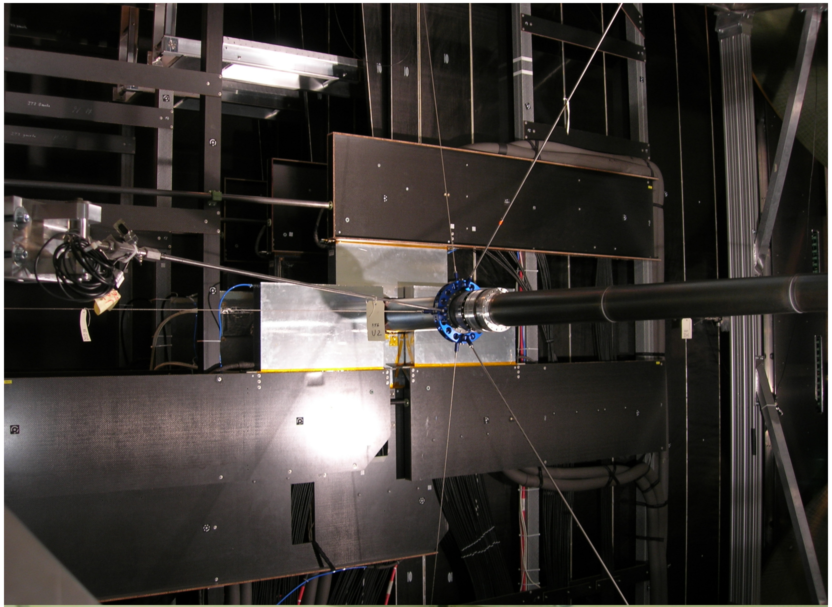


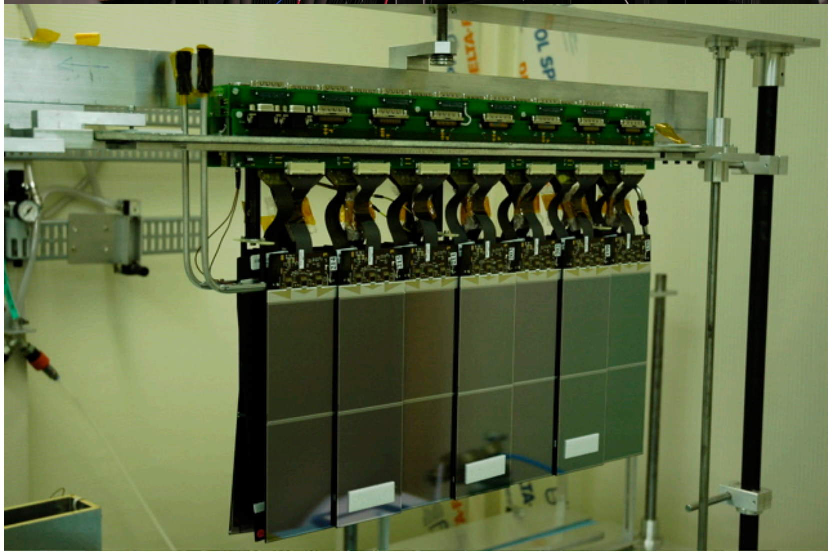


- Silicon micro-strip detectors.
  - p^+-on-n from Hamamatsu Photonics K.K.
- Four planes (0°, +5°, -5°, 0°).
- Pitch: 183 µm; Thickness: 500 µm.
- Long read-out strips (up to 37 cm).
- 143360 read-out channels.
- Total Silicon area is 8 m^2.
  - Covers full acceptance before magnet.
- Cooling plant operates at 0°C.
  - Sensors @ 8°C.

Inner Tracker (IT)

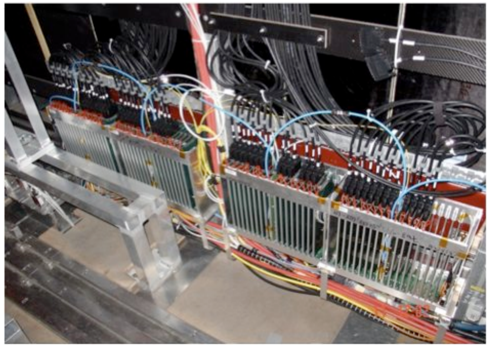






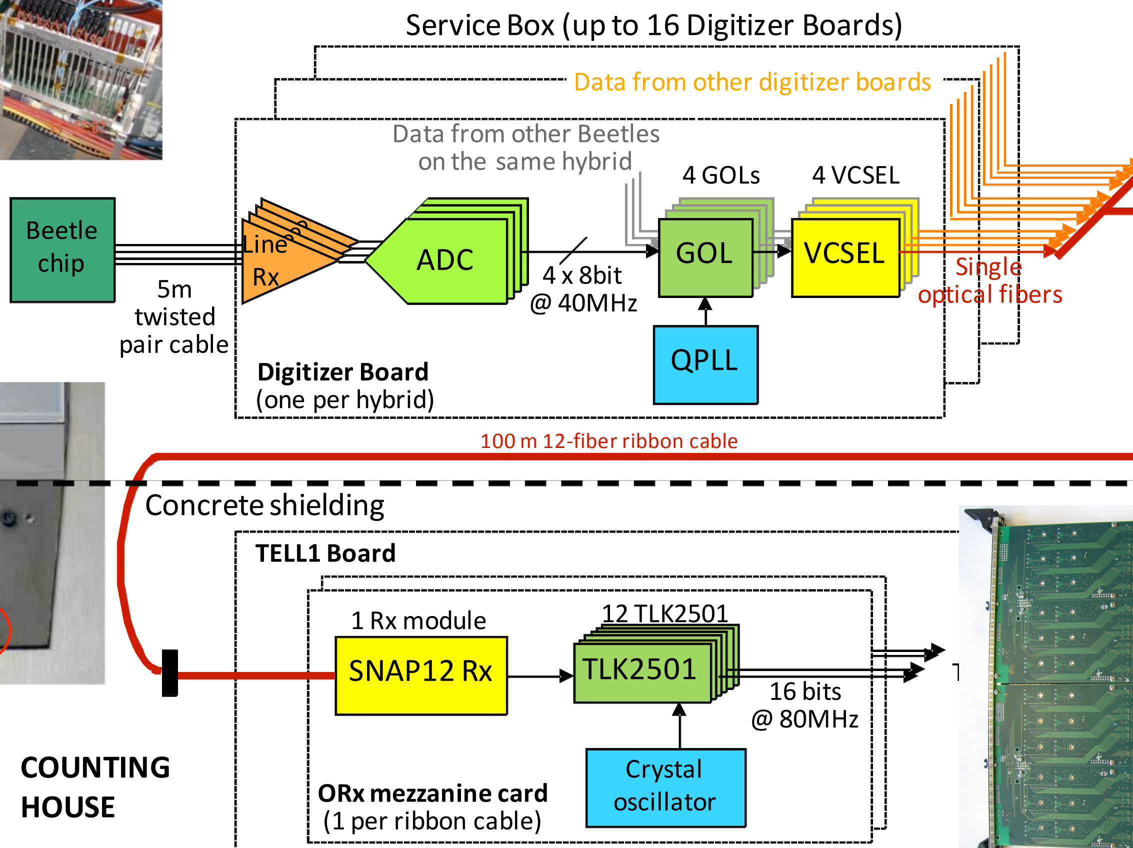
- Silicon micro-strip detectors.
  - p^+-on-n from Hamamatsu Photonics K.K.
- Three stations in z.
  - Four boxes in each station.
  - Four planes (0°, +5°, -5°, 0°)
- Pitch: 198 µm
- Thickness: 320 or 410 µm
- 129024 read-out channels.
- Total Silicon area is 4.2 m^2.
  - Covers region around beam with highest flux.
- Cooling plant operates at 0°C.
  - Sensors @ 8°C.

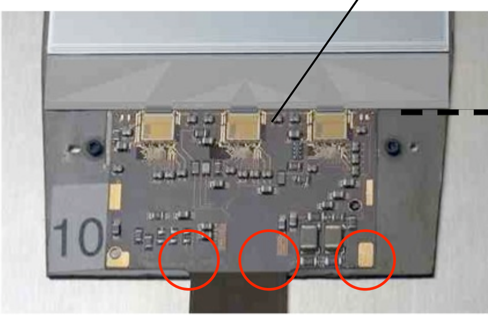
read-out chain

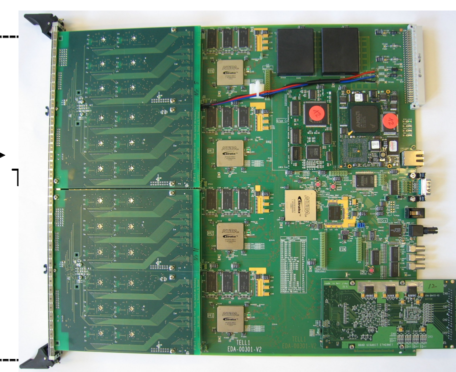


Digitization: Service box near detector 15 krad in 10 years

Optical link



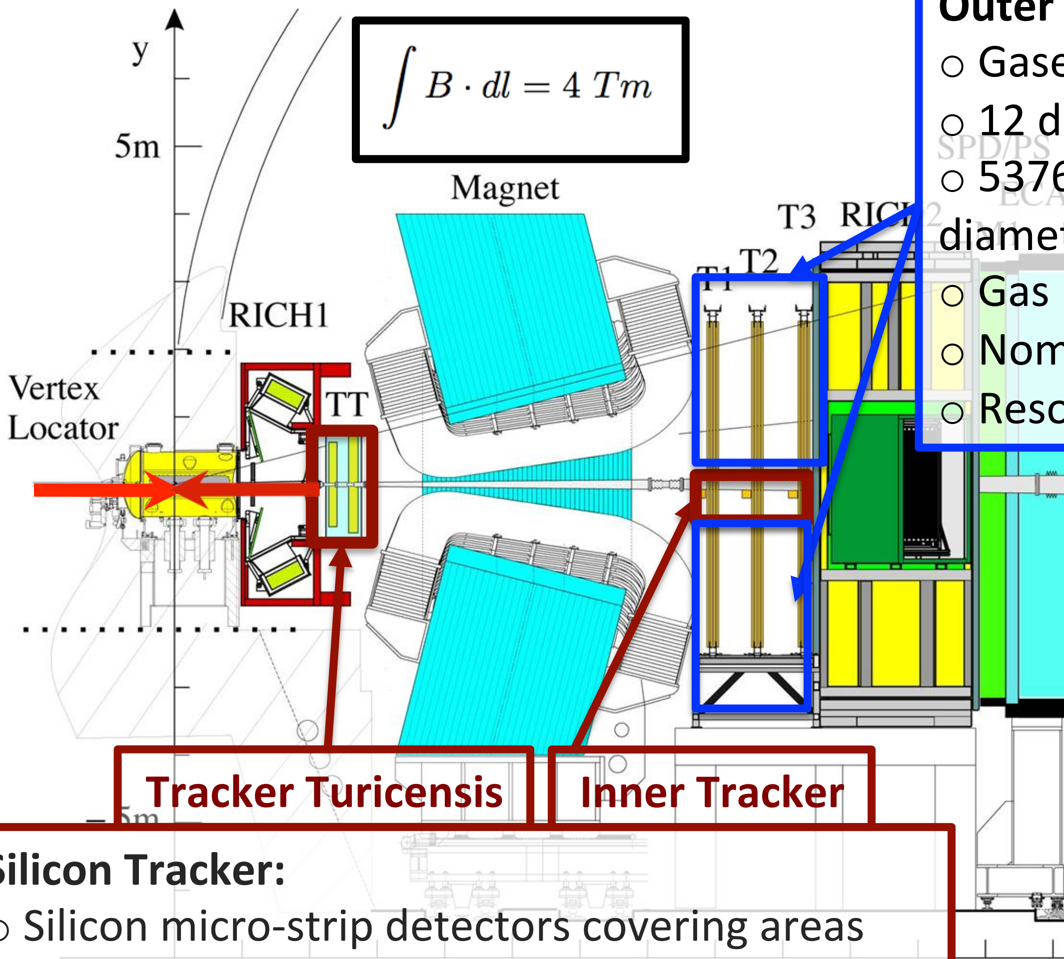




Front end on detector < 1 Mrad in 10 years

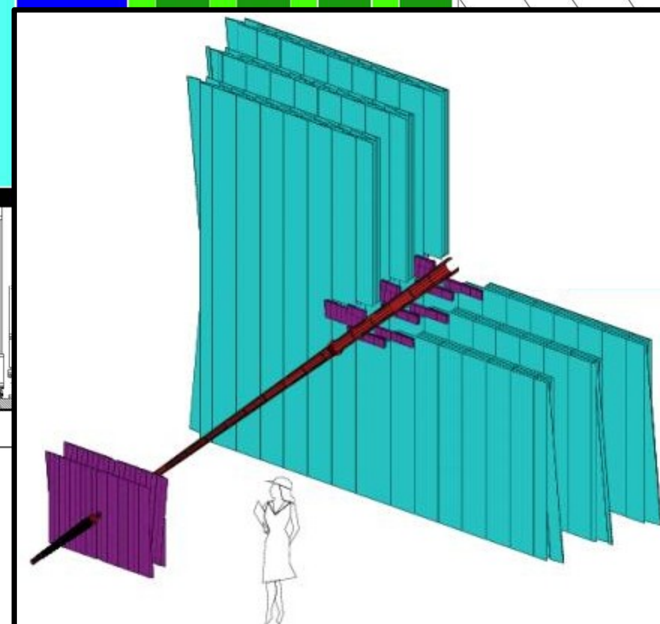
Tell1 read-out boards in counting House: Zero Suppression

Current Tracker



Outer Tracker:

- ○ Gaseous straw tube detector.
- ○ 12 detection layers (~ 4 x 6 m^2).
- ○ 53760 straw tubes (2.4 m long, 4.9 mm diameter).
- ○ Gas mixture: $Ar/CO_2/O_2$ (70%/28.5%/1.5%).
- ○ Nominal operating voltage is 1550 V.
- ○ Resolution ≈ 200 μm.

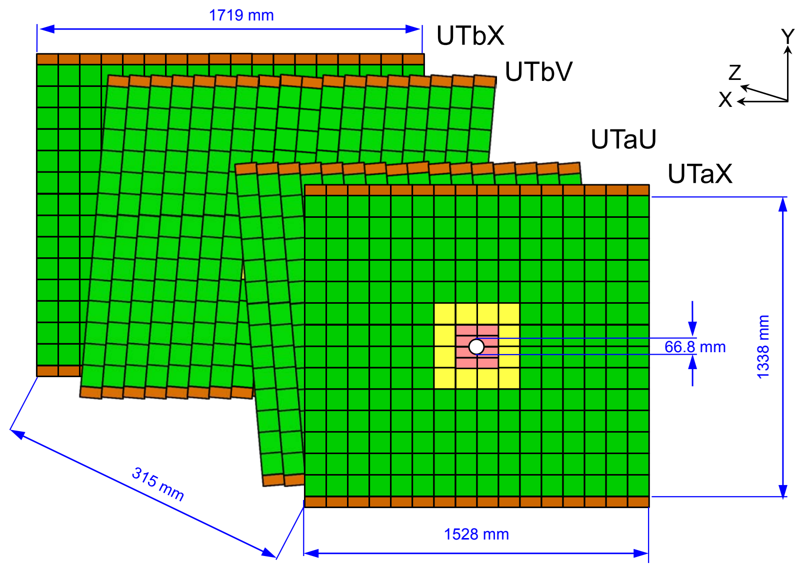


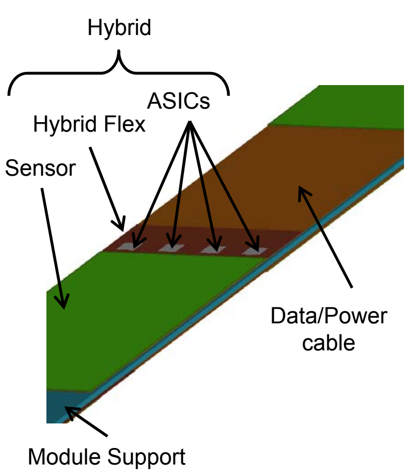
Silicon Tracker:

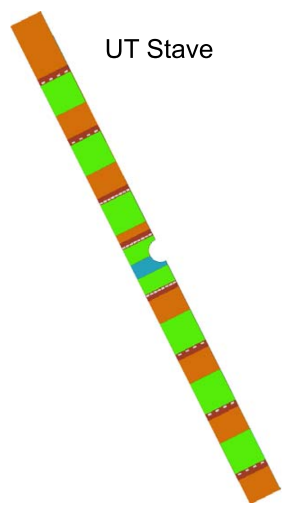
- ○ Silicon micro-strip detectors covering areas closest to the beam pipe.
- ○ Pitch: 183 μm (TT), 198 μm (IT).
- ○ Thickness: 500 μm (TT), 320/410 μm (IT)
- ○ Strips up to 37 cm long.
- ○ Resolution ≈ 50 μm.

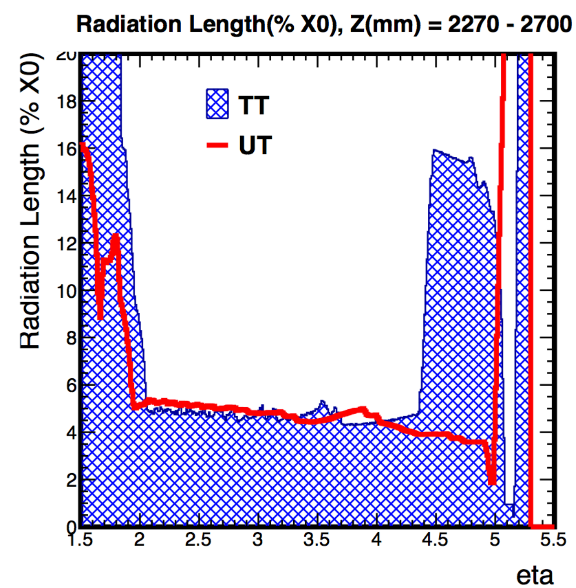
Upstream Tracker (UT)

- Replace TT with new silicon strip detector.
  - Four layers (x, u, v, x) as now.
- Finer segmentation around beam-pipe.
  - Increased occupancy.
- Reduce material.
  - Thinner sensors.
  - 500 µm → 300 µm.
- Move sensors closer to beam.
  - Optimise shape of inner sensors.
  - Increase acceptance at large η.
- New read-out chip (SALT).



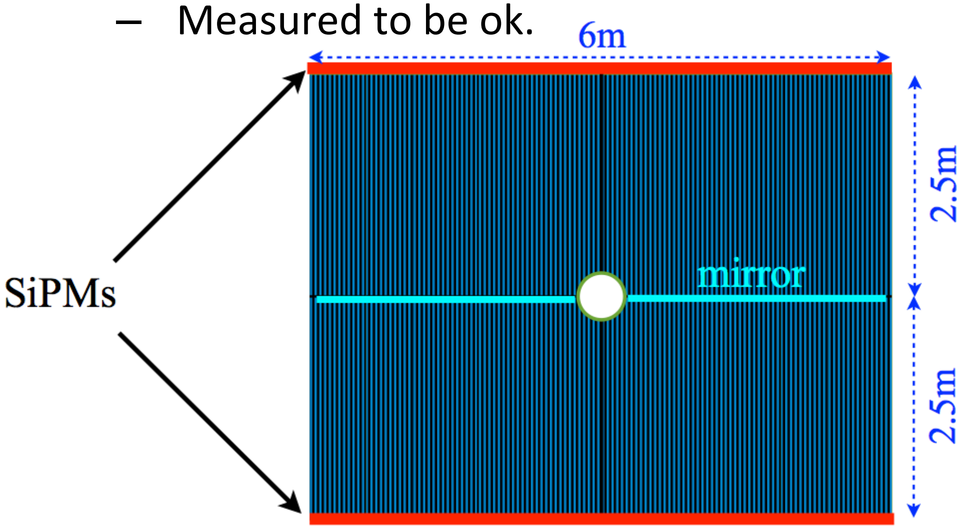




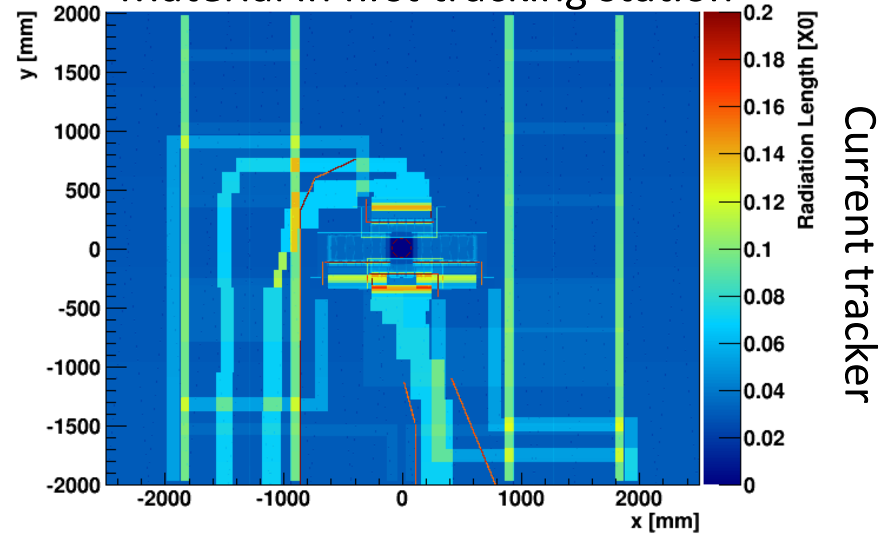


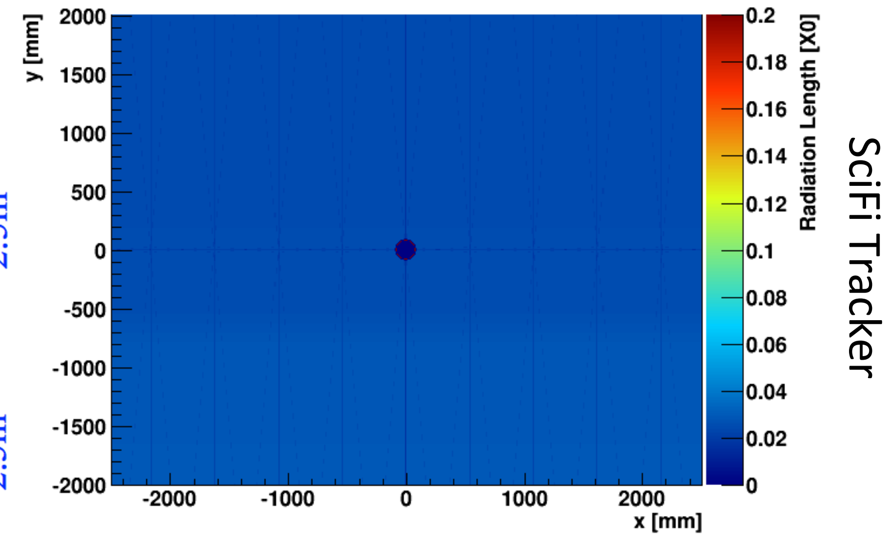
SciFi Tracker

- Replace IT+OT with single technology.
  - Occupancy too high in OT.
  - Electronics embedded in IT modules.
- Scintillating fibres read out with SiPMs.
  - 2.5 m long, 250 μm diameter.
  - Keep 12 layers (x, u, v, x) x 3
- SiPMs outside acceptance.
  - Radiation damage from neutrons.
  - Require cooling to -40°C.
- New ASIC for read-out (PACIFIC).
- Radiation hardness of fibres.
  - Measured to be ok.



Material in first tracking station





SciFi Tracker