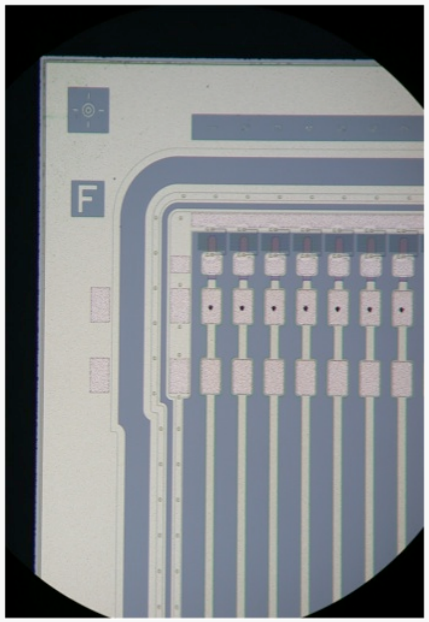
First Operational Experience from the LHCb Silicon Tracker

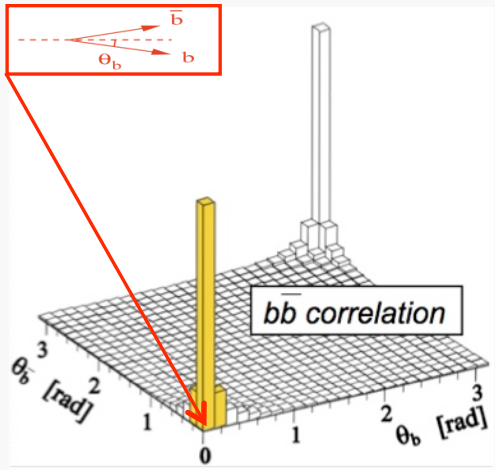
7th International Hiroshima Symposium on Development and Application of Semiconductor Tracking Devices

- The LHCb Silicon Tracker
- Installation and Commissioning
- Operation with particles
- Summary

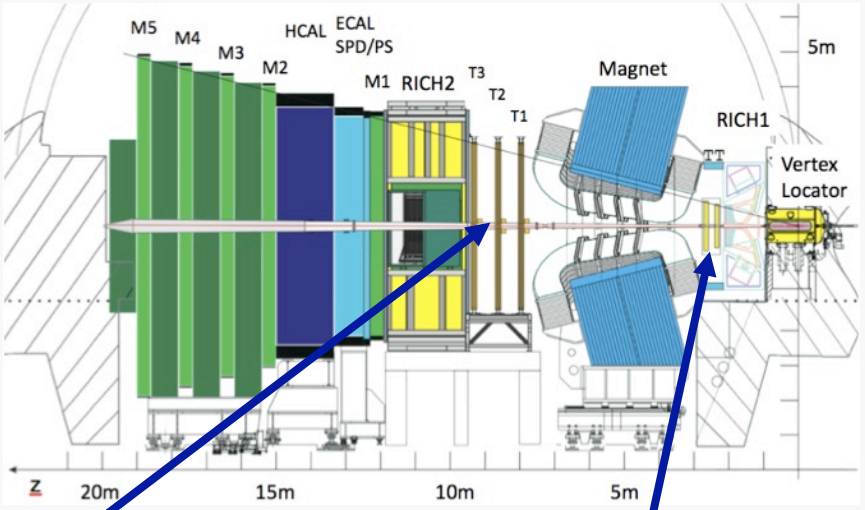
Abraham Gallas for the LHCb Silicon Tracker Group

The LHCb Silicon Tracker





LHCb: single-arm forward spectrometer

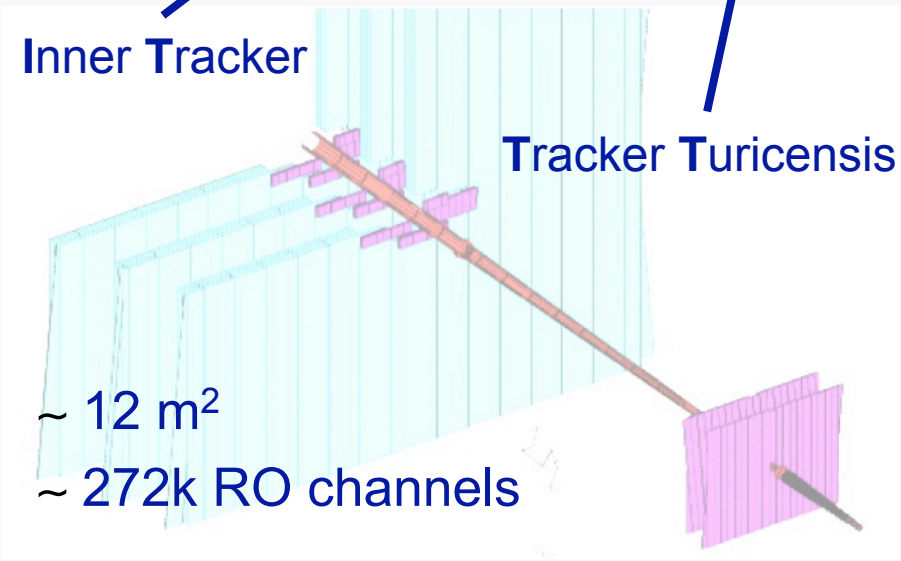


Silicon Sensors:

- p-n silicon strip sensors (HPK)
- 1-4 sensors bonded together → up to 37 cm long strips

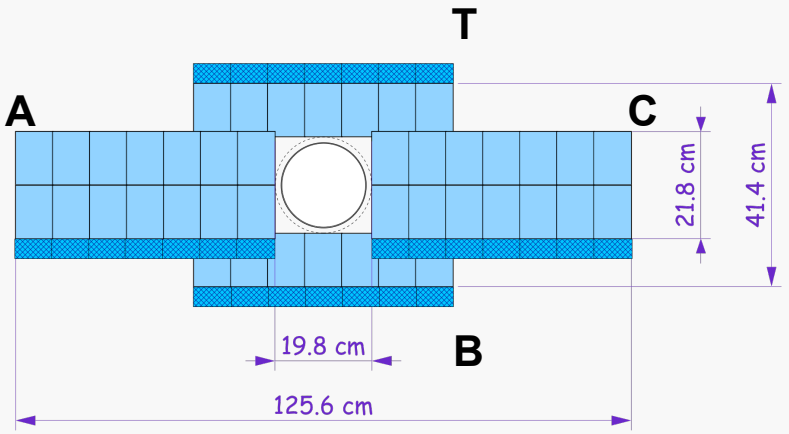
Radiation Dose:

- IT : 5 x 10^{13} 1 MeV n/cm^2 eqv after 10 years
- TT: 8 x 10^{13} 1 MeV n/cm^2 eqv after 10 years
- Operation @ ~ 5°C

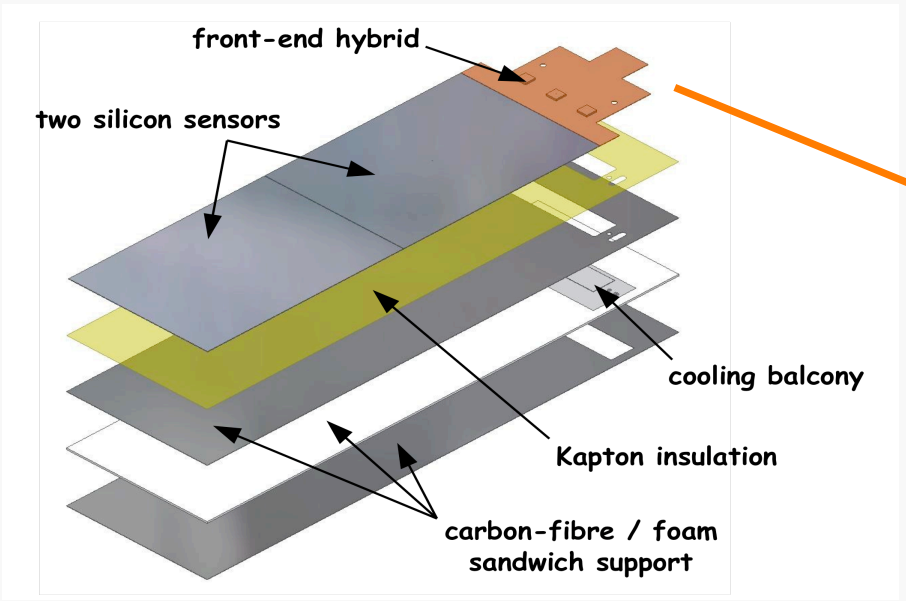


IT Layout

- **3** Stations with **4** Boxes
  - (**T**op, **B**ottom, **A** side, **C** side)
- Each box has 4 layers (0°, +5°, -5°, 0°)
- Top/Bottom boxes 1 sensor ladders
- Side boxes 2 sensor ladders
- 320, 410 μm thicknesses
- 198 μm pitch, w/p = 0.25
- Sensor size: 110 x 78 mm

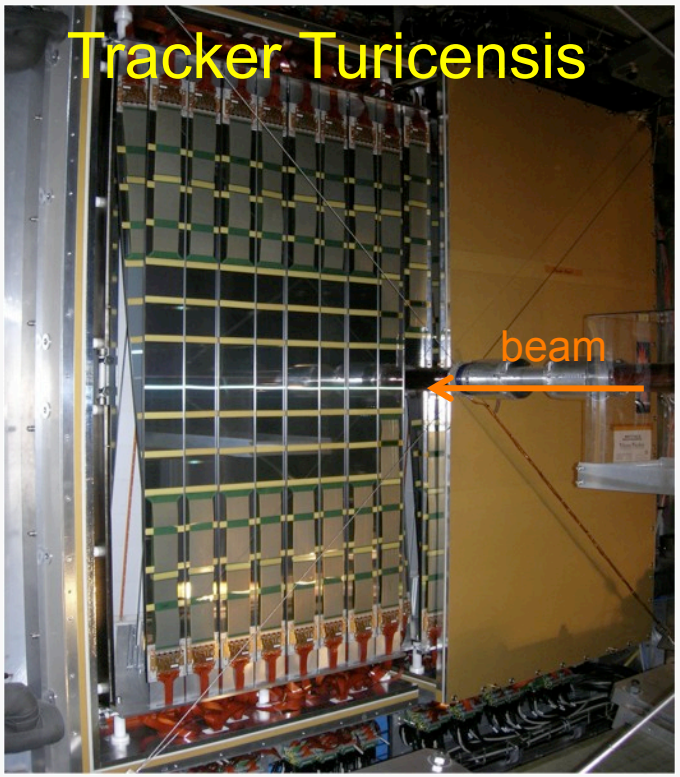


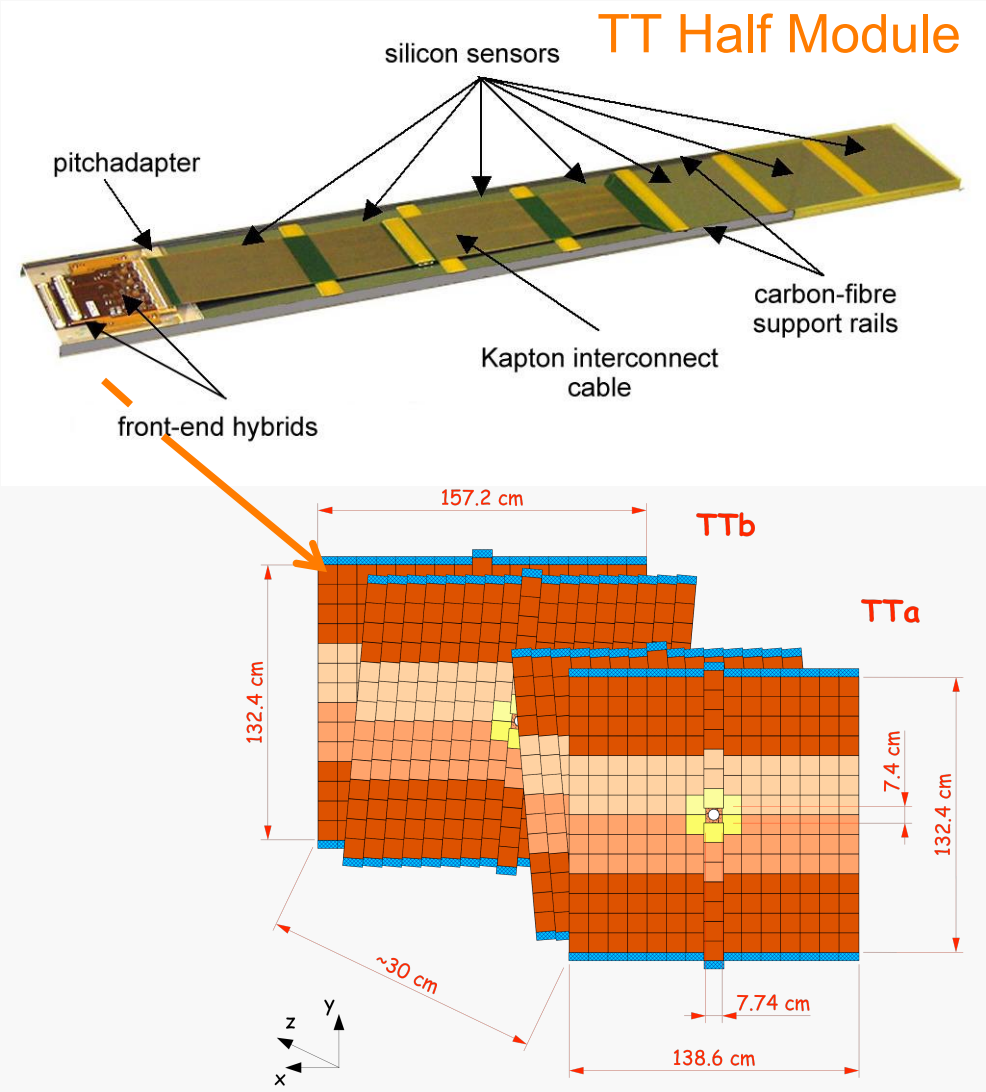
IT Module



TT Layout

- **4** Layers (0°, +5°, -5°, 0°)
- **128** half-modules with **7** sensors
- 500 μm thickness
- 183 μm pitch, w/p = 0.25
- Sensor size: 96.4 x 94.4 mm

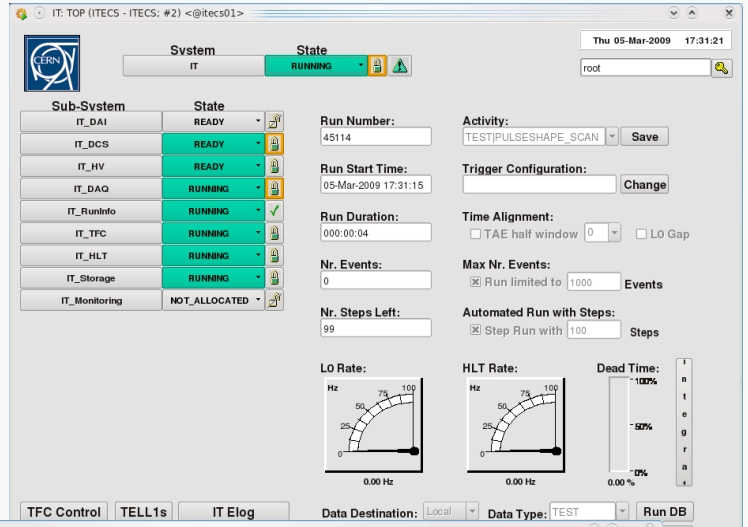


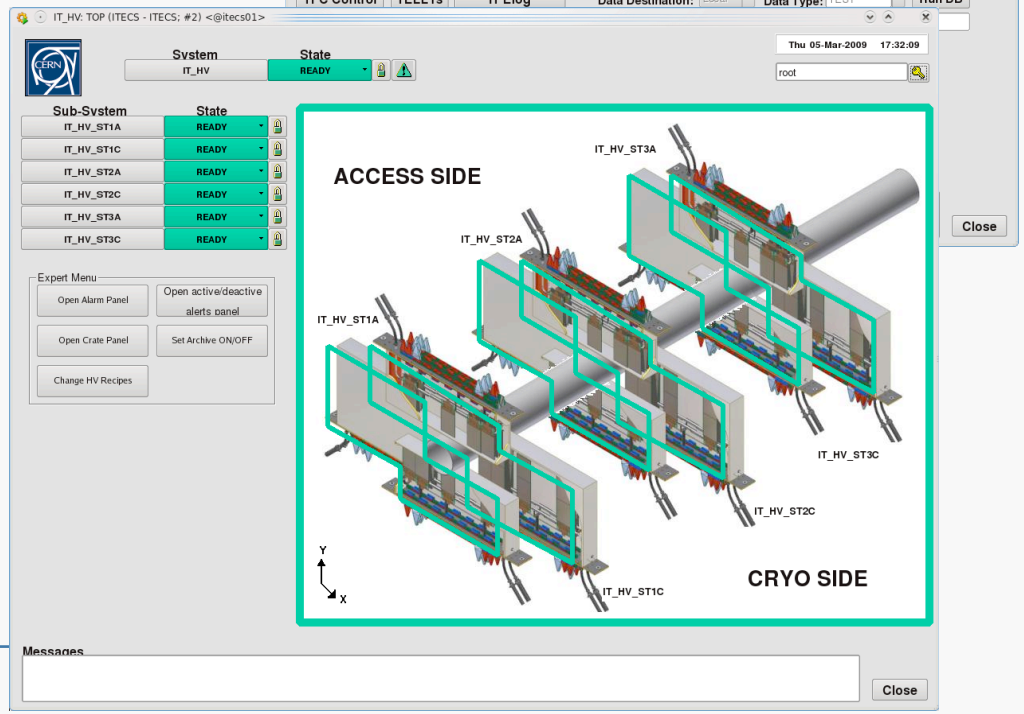


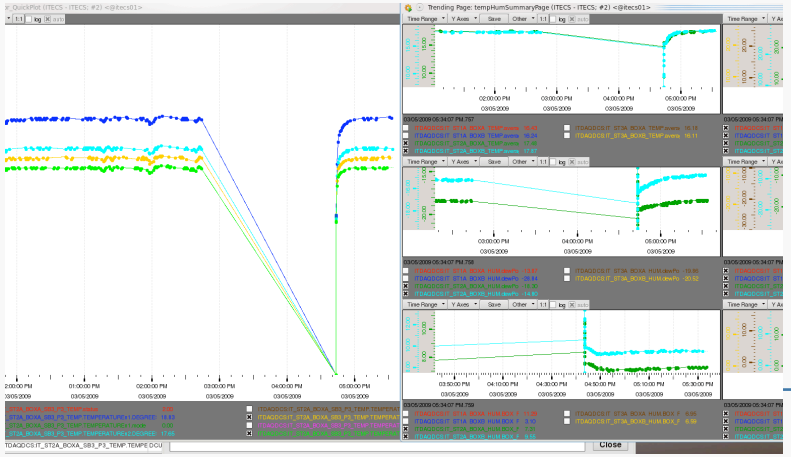
Silicon Tracker ECS

ST Experiment Control System:

- Expert system based on a hierarchical FSM paradigm
- Allows distributed and multi-platform control
- Controls and/or monitors:
  - HV, LV power supplies and regulators
  - DAQ electronics
  - Cooling
  - Environmental parameters (T,H, ...)
- Corrective actions triggered automatically by warnings
- Devices to be configured: ~ 7.5k
- Devices permanently monitored: ~ 6.6k
- Implemented using PVSS II SCADA and the SMI++ toolkit
- Trending and archiving capabilities

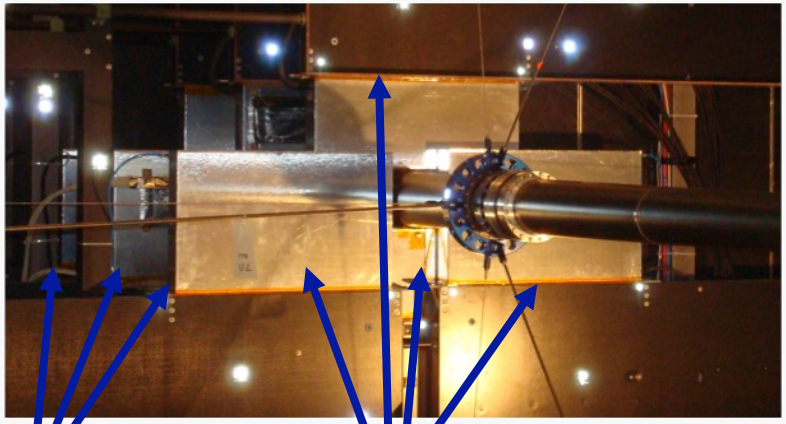






Detector Installation

Inner Tracker



Tracker Turicensis

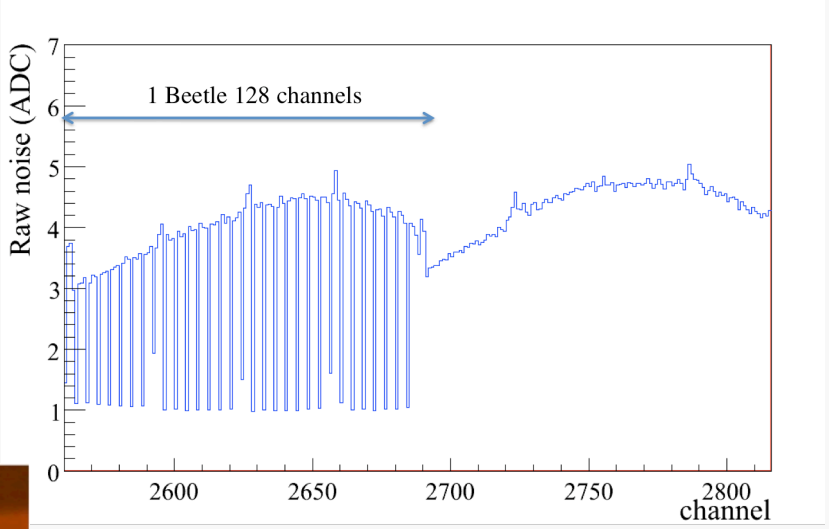
Commissioning Lessons

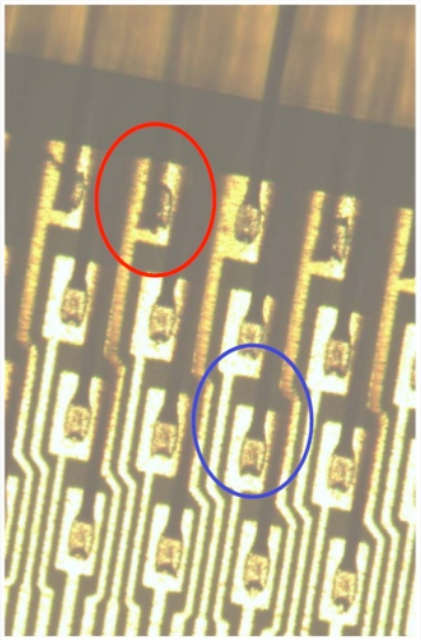
- Oscillations in the LV power supplies:
  - Filter out with capacitors
- Failing voltage regulators:
  - we did not test with all different load scenarios
    - ➢ replaced (~ 30 out of 1992)
- Optical fibre/laser diode problems:
  - measure optical power
    - ➢ bad alignment between the diode and the optical fiber due to overheating of diodes during soldering process
    - ➢ diodes below threshold replaced:
      - ✧ IT: 30 out of 1008
      - ✧ TT: 95 out of 1152
- Internal swaps in optical fiber bundle, bad connections, ….

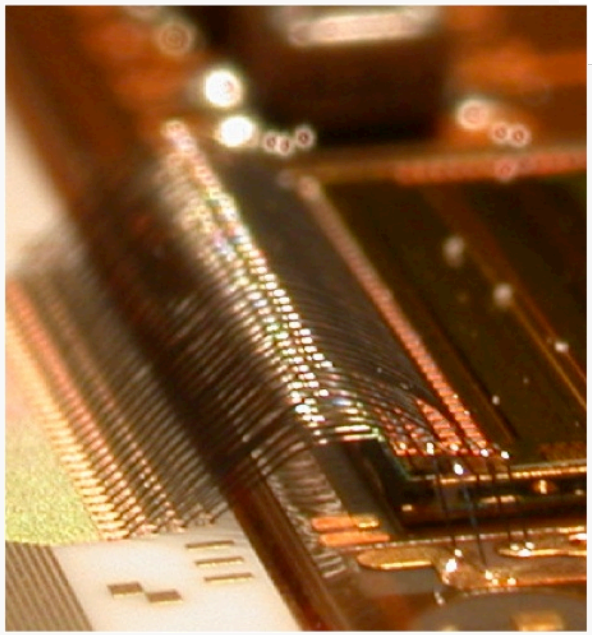
Commissioning Bond Problems

Despite extensive module testing/temp cycling during module construction and QA:

- On 9 out of 280 TT-hybrids bond wires on front-end chip (Beetle) input broke at the heels
- 7 hybrids exchanged during the shutdown
- Detected via noise pattern inspection
- Affects innermost of four bond rows







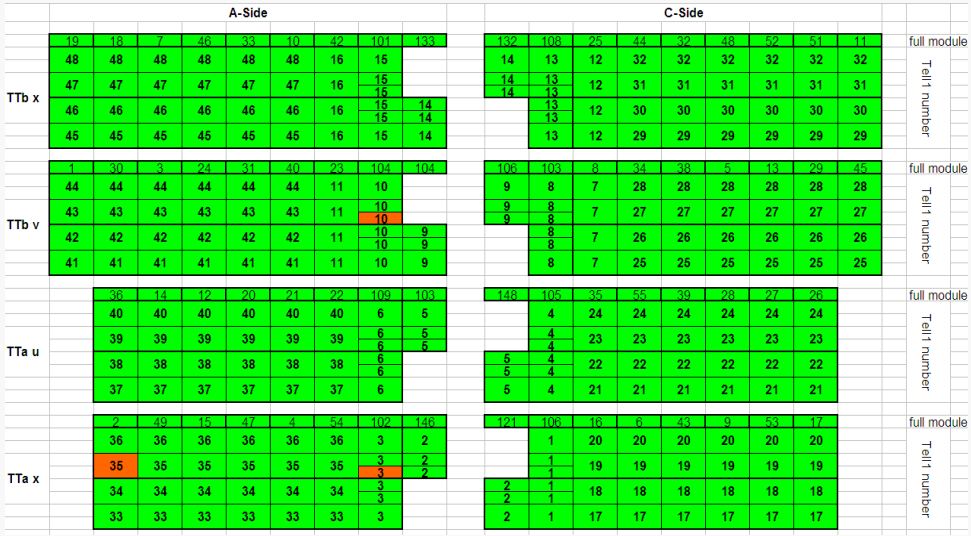
- ➢ One module with broken bonds has been extensively tested
- ➢ 2 hybrids examined with SEM
- ➢ So far the damage could not be reproduced in lab (i.e. temp variations etc...)
- ➢ The majority of the broken bonds appeared ~ 2 month after the installation of the modules was finished
- ➢ This year only 1 hybrid started to show the problem
- ➢ Under further investigation

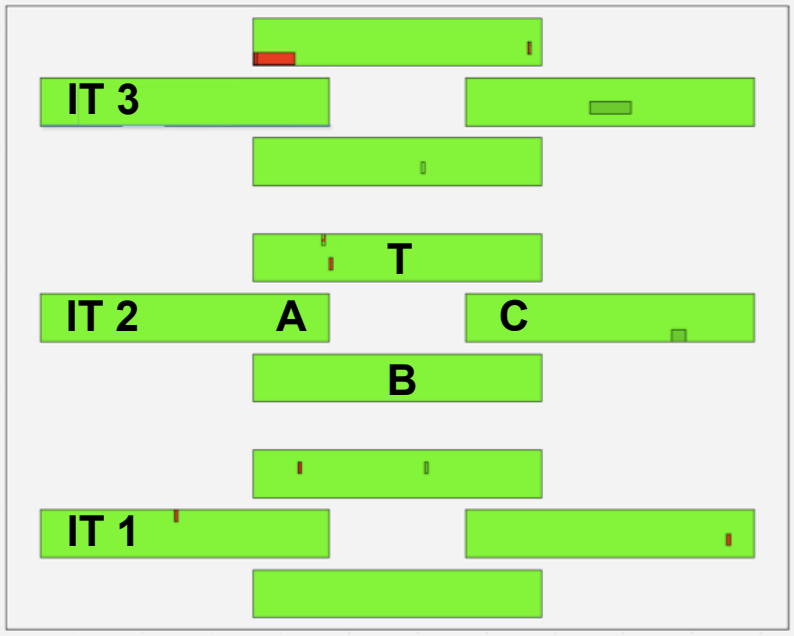
Commissioning Status

TT-Station:

broken bond wires
1 broken Beetle port (32 chs)

➔99.75 % working channels!!





IT-Stations:

/ slightly noisier

Beetle ports not working

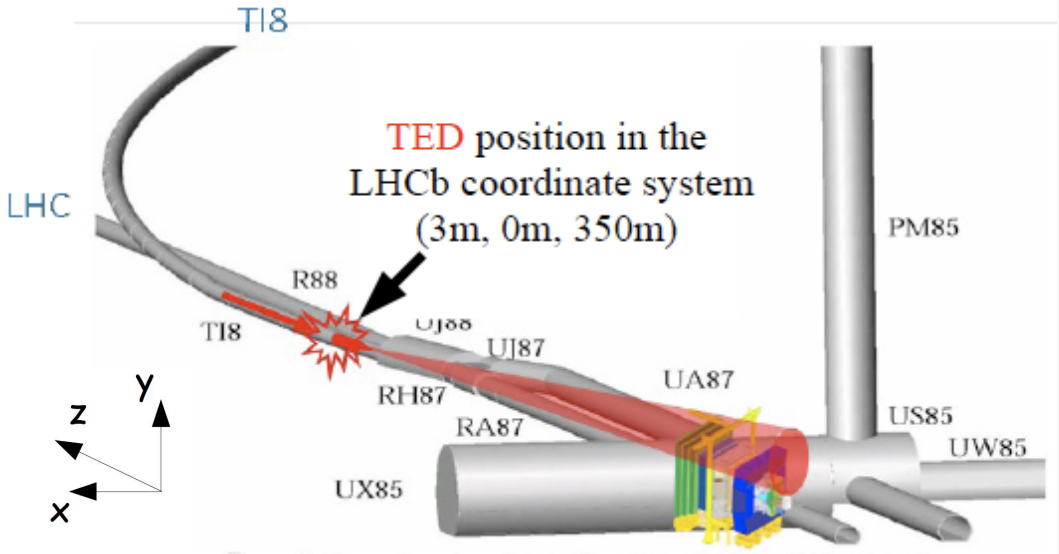
➔99.3 % working channels!!

ST commissioning with particles

Cosmic events are very rare due to the projective geometry of LHCb

“TED” events

- LHC beam injected in the transfer line and stopped in a beam dump 350 meters behind the LHCb detector, in 2008 & 2009
- very high particle density:
  - ~ 4000 clusters in the IT
    (~ 20x more than B meson event)
  - detectors fully illuminated with particles.
  - muons, <p> ~ 10 GeV/c (MC)
  - Magnet off
- Internal fine time alignment
- Spatial alignment
- Study performance of the detector



ST commissioning with particles

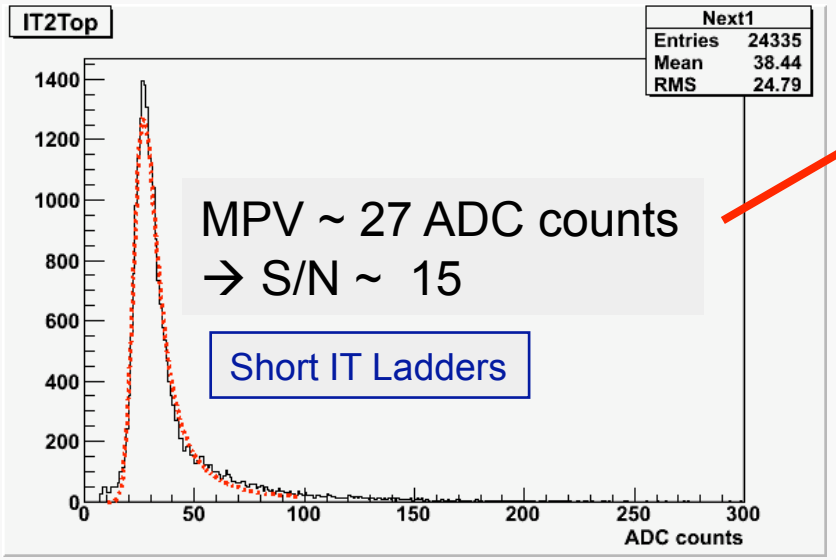
- LHC synchronization tests (TED runs) were performed in Aug-Sep 2008 and Jun 2009
- **2008 TED** runs:
  - The LHCb detector was in nominal position
  - LHCb data taking was ~ 6 hours
  - 5.3k tracks reconstructed in the Inner Tracker
  - Time and spatial alignment was performed
- **2009 TED** runs:
  - The LHCb detector was in an open position: the Inner Tracker was opened by ~ 50 cm
  - Most of the electronics related faults during 2008 run had been fixed
  - Data taking for LHCb was ~ 72 hours
  - ~ 50k (12k @ low intensity) tracks reconstructed in the Inner Tracker

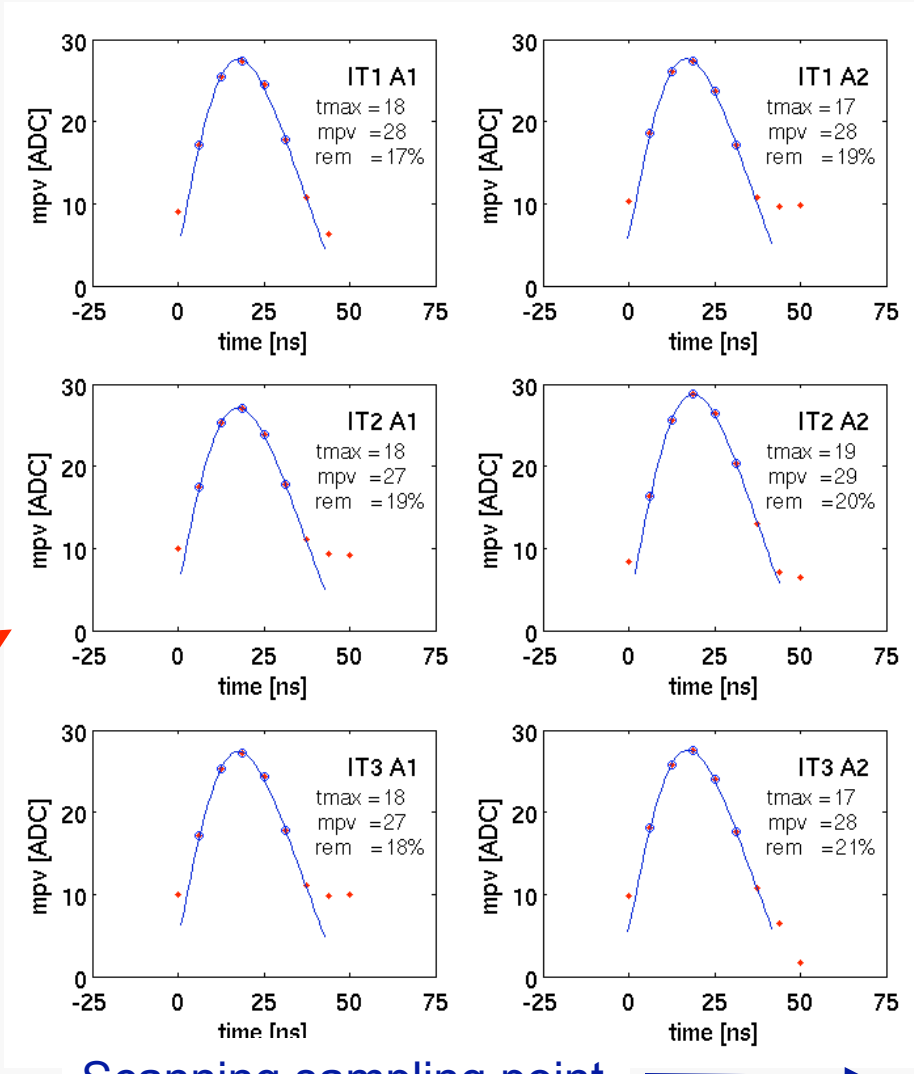
TED events: IT time alignment

- Cable lengths for different parts of the detector differ
- Different stations have different time of flight of particles

➔ Need to adjust timing delays of individual detector elements

➔ Timing delay scans (charge measurement vs clock delay)

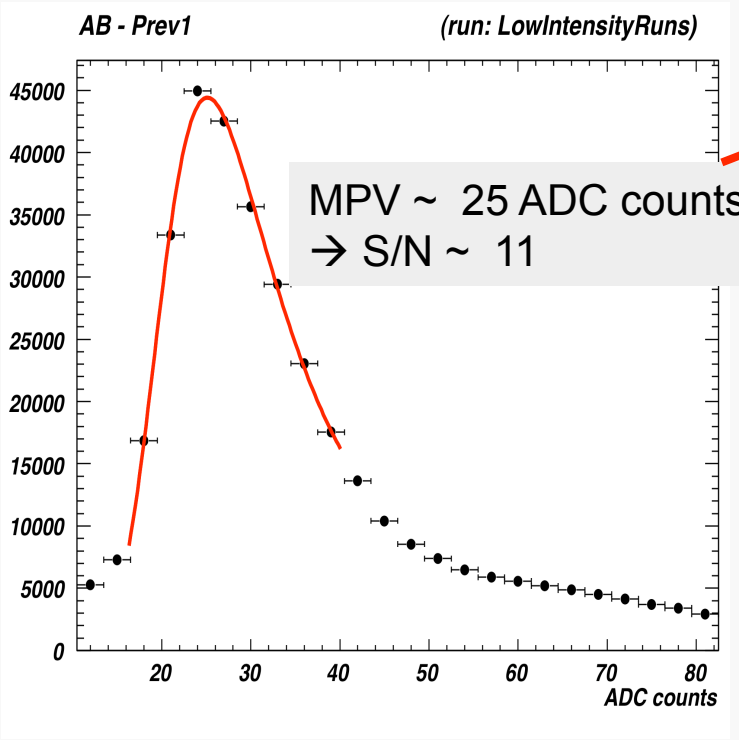


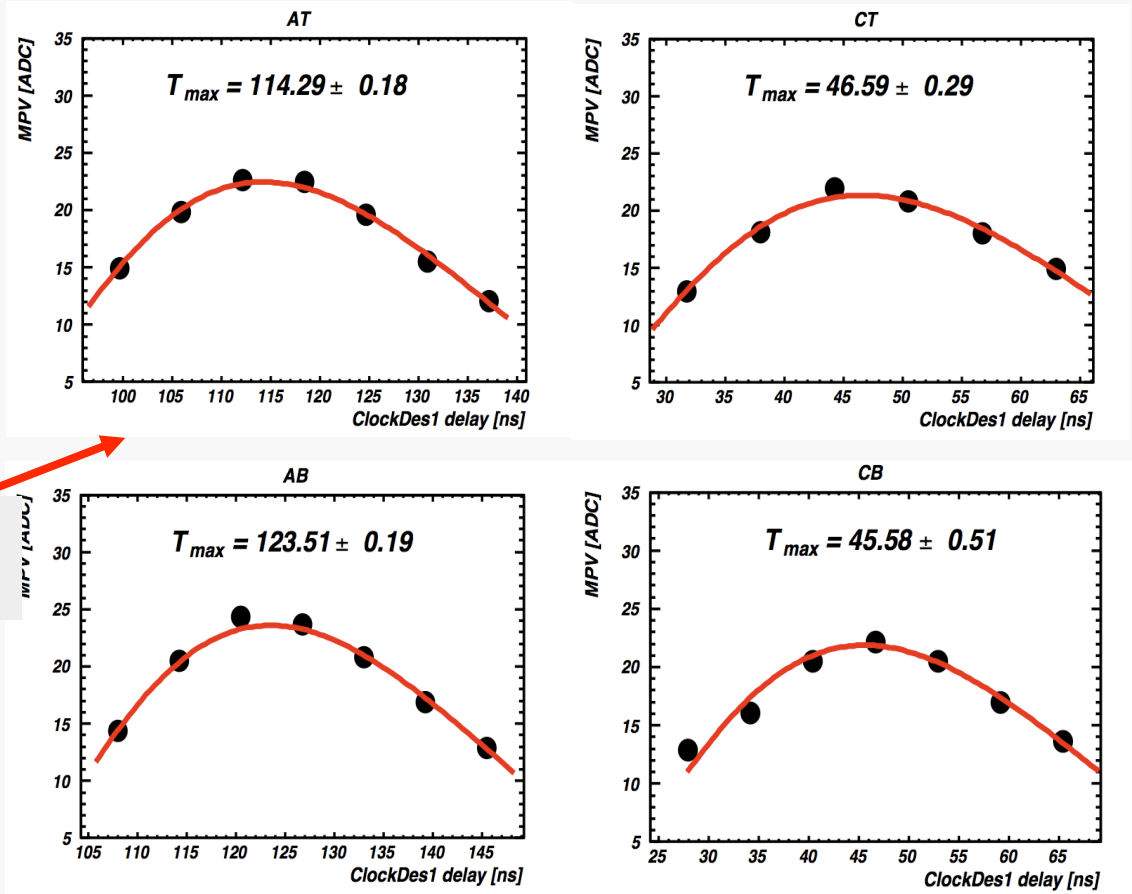


TED events: TT time alignment

- Need to adjust the timing delays of the four quadrants of the TT stations.

➔ Timing delay scans (charge measurement vs clock delay)

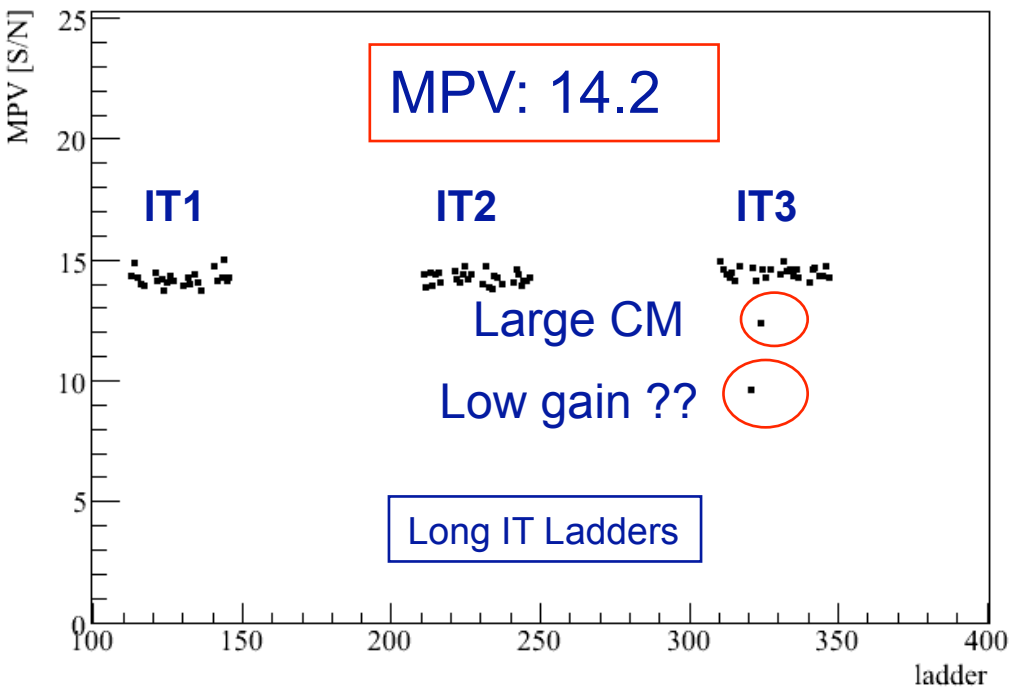




Scanning sampling point ➔

TED events 2009

MPVs: IT C side



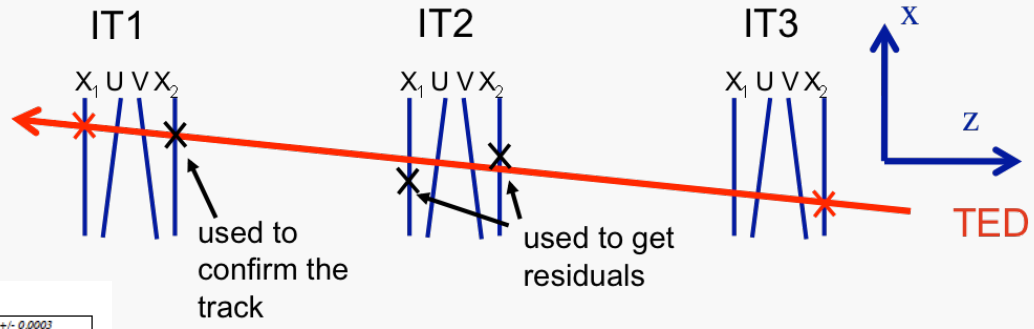
Landau fits per ladder with the optimal timing:

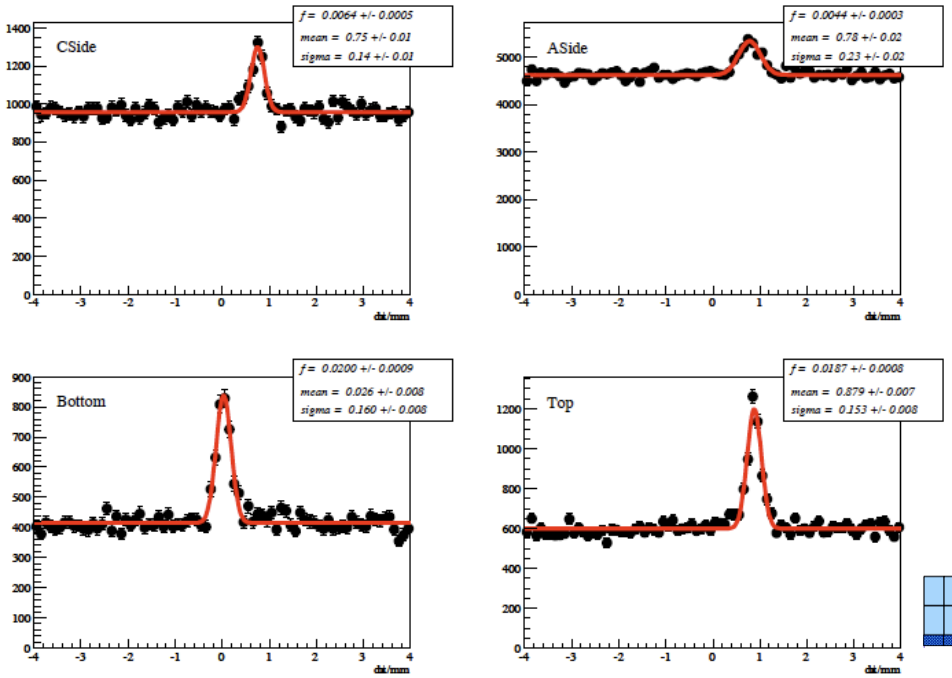
- S/N ratio 14÷15 in most cases
- Few outliers due to large CM / low gain,…

IT: Spatial alignment

"TED events": occupancy too high for standard track finding.

Survey ➔Pre-Alignment ➔Alignment

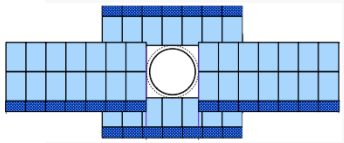




Estimate of x position of the IT2 station boxes

Simple pre-alignment tracking

- Draw a line with hit in 1st layer of IT1 and 4th layer of IT3
- Line should point towards TED
- Confirm track with another hit in IT1 or IT3
- Residuals in IT2



Survey

Box photogrammetry (~ 1-2 mm)

Layer survey (~ 50 μm)

Only x layer surveyed

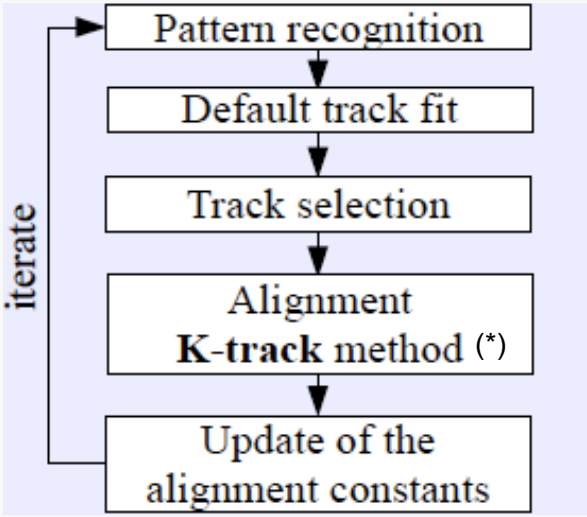
Ladder survey (precision: ~ 50 μm)

Only x ladders surveyed

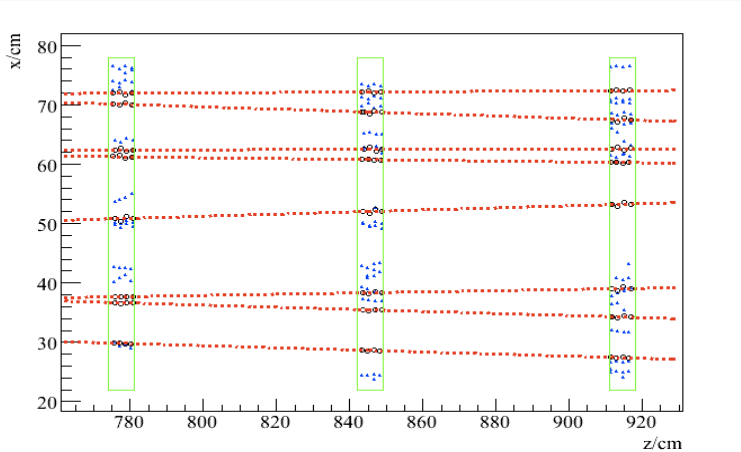
IT: Spatial alignment

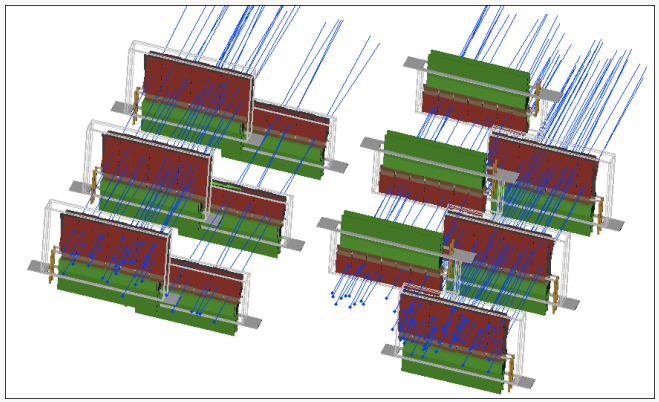
Alignment:

- Use TED runs with lowest occupancy
- Standalone IT reconstruction pointing towards TED
- Alignment of:
  1. Boxes in X, Y translation and Z rotations
  2. Layers in X translation and Z rotation
  3. Ladders in X translation



- Strategy: Evolving χ^2 */dof* of reconstructed IT tracks for track selection with iteration
- Ladders were aligned to ~ 20 μm precision with 2008 TED data. Will improve in 2009 TED





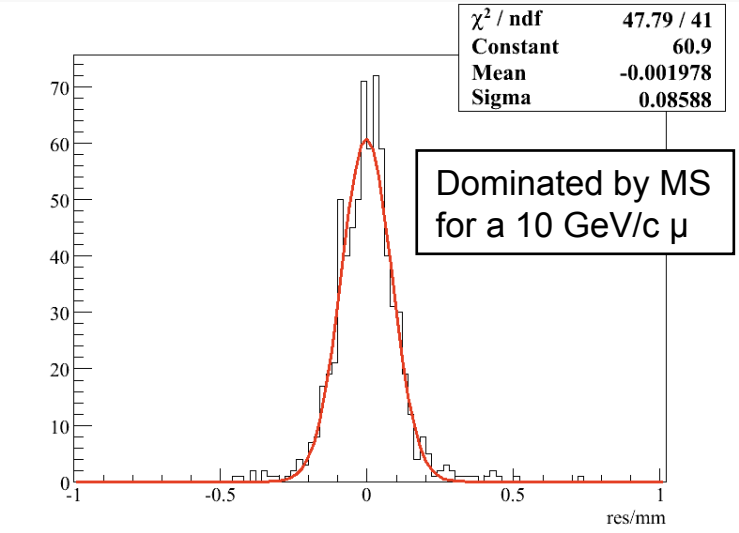
(*) NIM A600: 471-477, 2009

IT: Spatial alignment validation

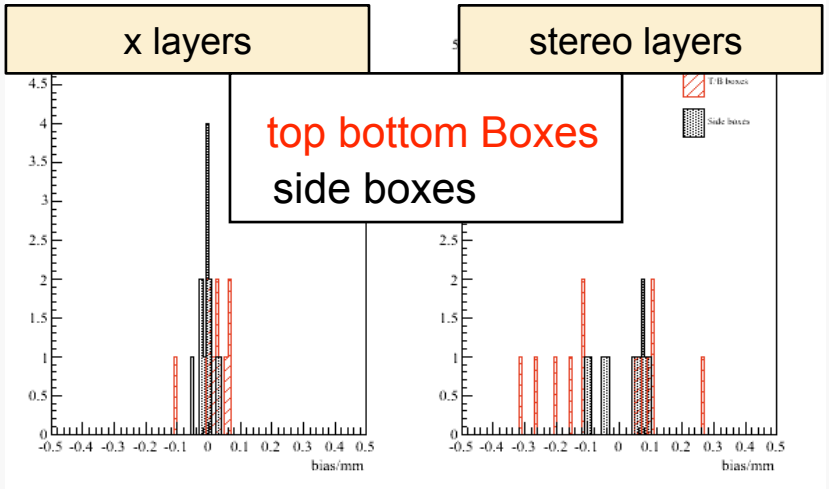
Procedure

- Alignment done using TED runs with the lowest occupancy
- Use different event sample to estimate the layer/ladder bias

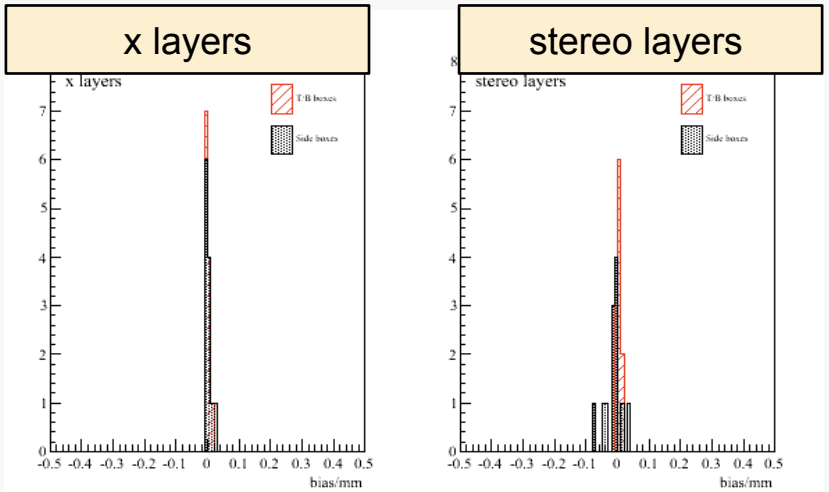
Fit gaussians to residual distributions of all 12 layers and plot the mean (layer bias)



Before alignment



After alignment

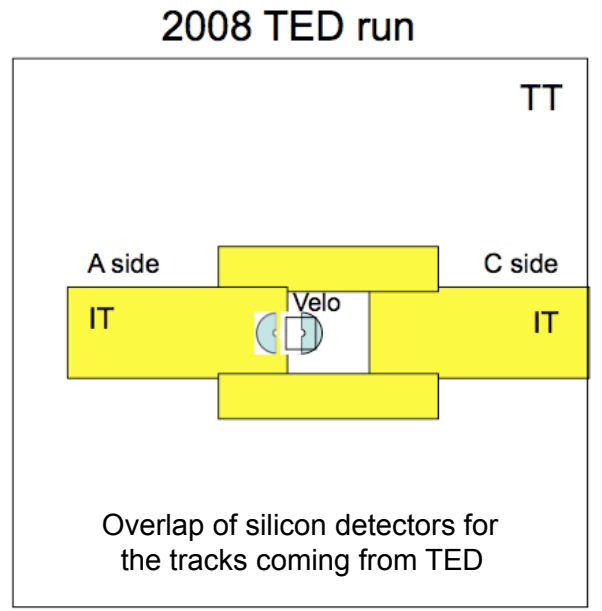


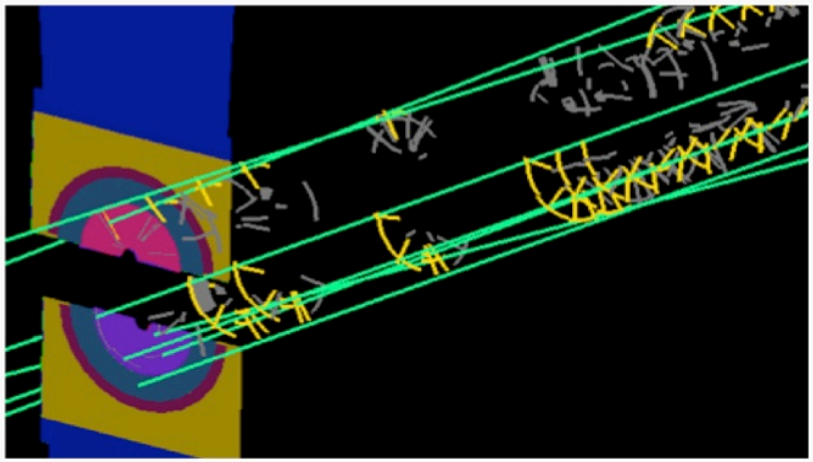
TT: Spatial alignment

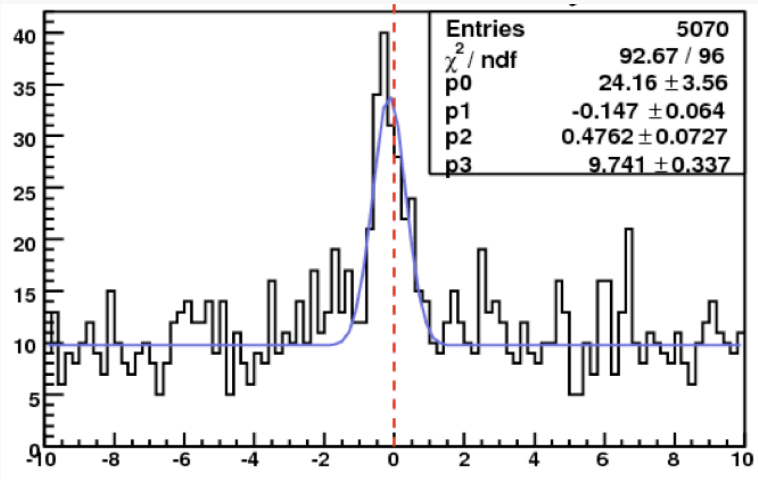
"TED" events

- No standalone TT track reconstruction, TT has only 4 layers (X,U,V,X)
- Track candidates from the VELO extrapolated to the TT:
  - Search for hits in the TT (min 3 hits in 4 layers)
- VELO acceptance very limited -> small region of TT illuminated by VELO tracks around beam pipe -> no individual module alignmen
- Survey ➔ Align full station in x and y rotation

Survey: Full station (500 μm) Module support (50 μm) Sensor metrology assembly (10 μm)



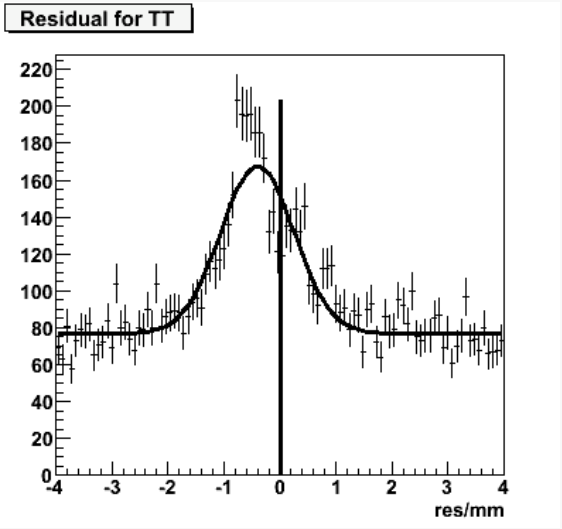
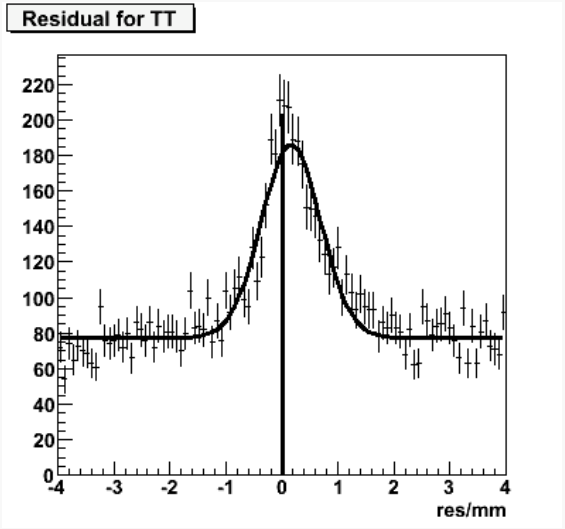
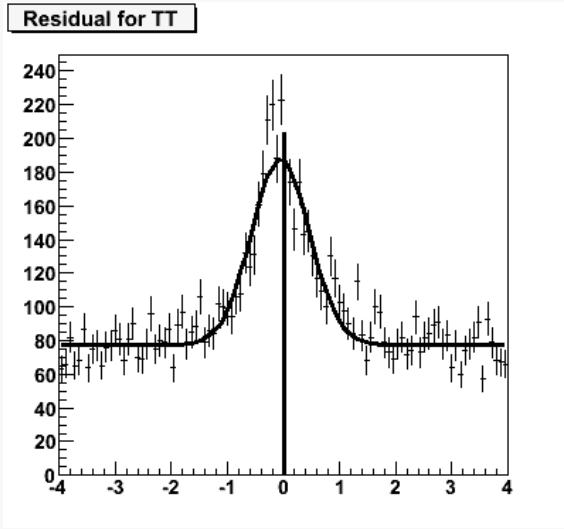




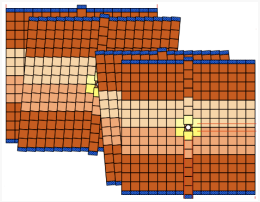
Extrapolate VELO Track candidates ➔ **Residuals in TT (TT a/U)**

TT: Spatial alignment

Residuals of TT hits to extrapolated VELO tracks

Nominal	Survey	Aligned
		
Mean: -0.404 mm Width: 0.655 mm	Mean: 0.162 mm Width: 0.526 mm	Mean: -0.053 mm Width: 0.519 mm

Only alignment of full station

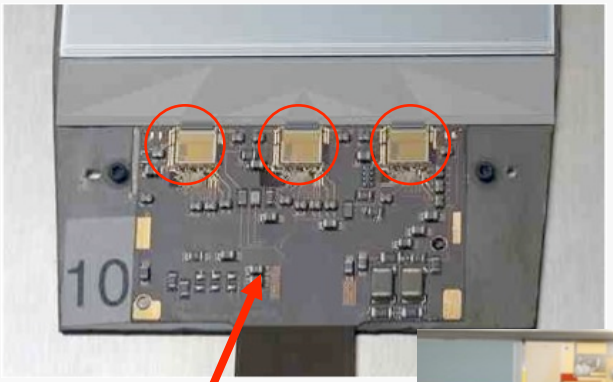


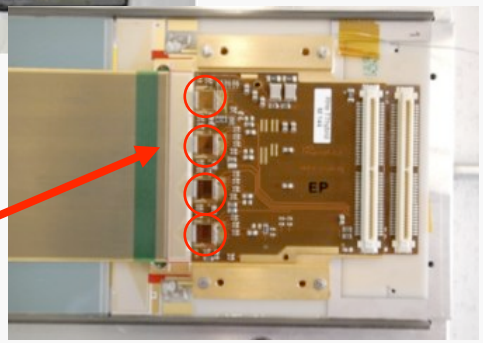
Summary

- The LHCb Silicon Tracker is a silicon strip detector for the high density particle region near the LHC beam pipe and in front of the bending magnet
- Installation in the LHCb cavern of the detectors and ancillary systems has been completed by summer 2008
- Commissioning in LHCb revealed several minor design weaknesses that have been fixed in the meantime
- Initial time alignment, and first studies of spatial alignment have been done with particles during the TED runs.
- At the moment > 99% of the detector is fully operational
- Internal and global alignment of the ST ongoing. IT aligned to 20 μm
- Ready for next data taking with particles this winter.

Back-up slides

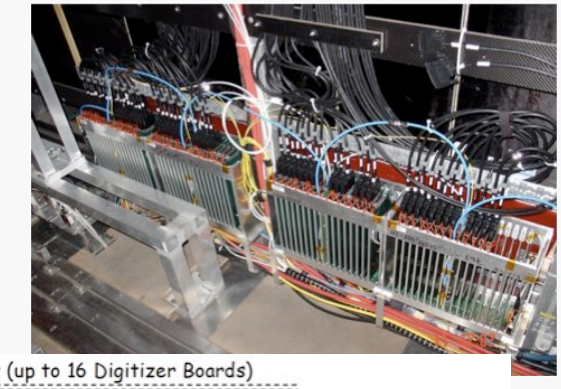
Read-out Electronics

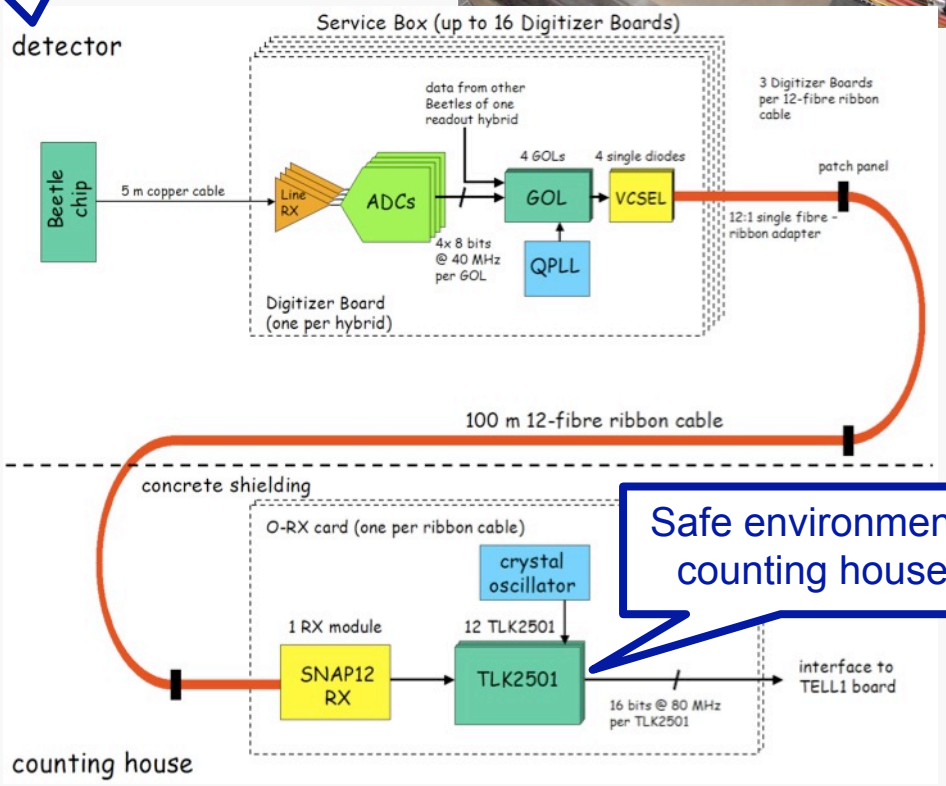




near detector
< 1 Mrad in 10yrs

near detector
~ 15krad in 10 yrs

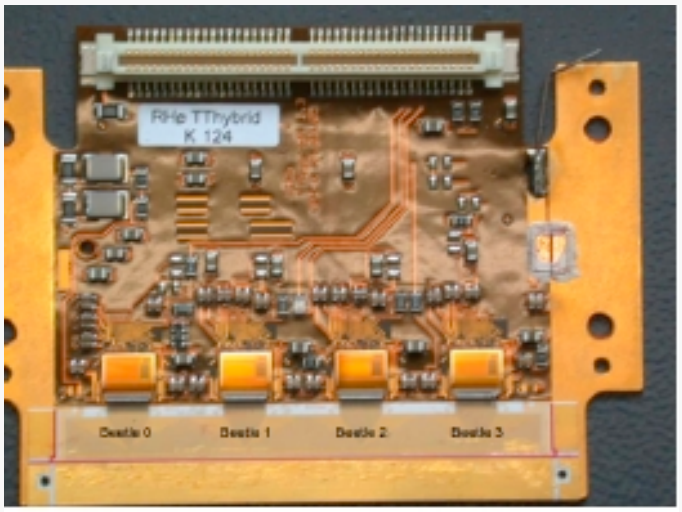


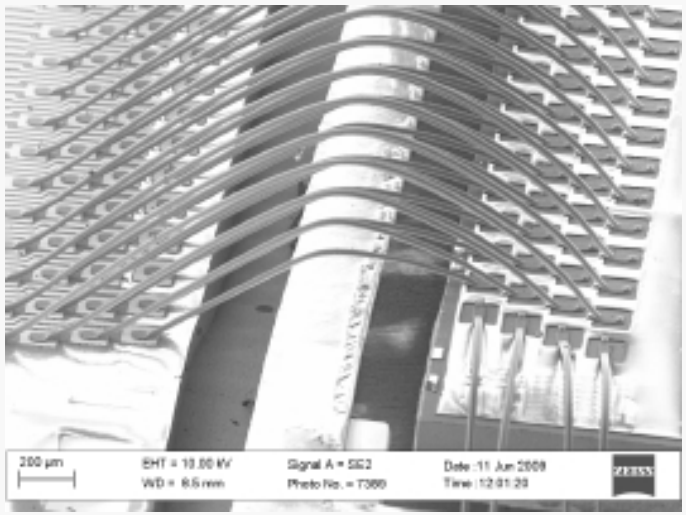


- 3 (4) Beetle readout chips IT(TT)
- rad hard 0.25 μm CMOS
- 40MHz, 128 channels
- multiplexed onto 4 ports
  - 36 cycles to read 1 event
  - 1.1 MHz readout
- Pipelined 160 bunch crossing

Broken bonds SEM studies

Investigation with a Scanning Electron Microscope of 2 hybrids with broken bonds: K124, M175.





In general:

- Affects always and only the innermost of the four bond rows between the readout chip (Beetle) and the pitch-adapter.
- For most hybrids, almost all broken bonds are broken on the pitch-adaptor side, but for at least one hybrid almost all broken bonds are broken on the Beetle side.
- Out of the two hybrids we put under the SEM, on one we see cracks on almost all not-broken bonds, but on the other one we do not see any cracks on the not-broken bonds.

Broken bonds SEM studies

Broken bond