Commissioning and Performance of the LHCb Silicon Tracker

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on behalf of the LHCb Silicon Tracker group

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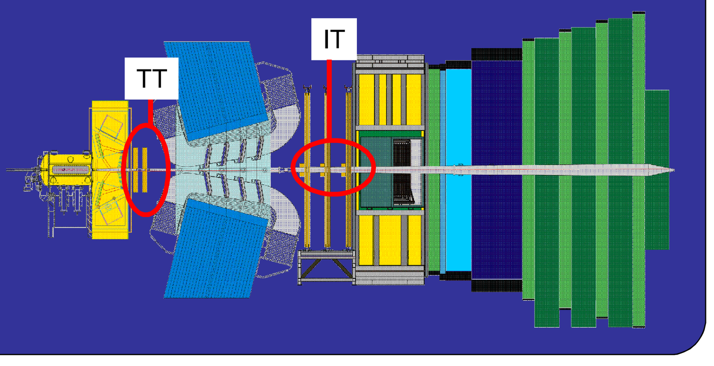
The LHCb experiment

- Single-arm, forward spectrometer (6m x 5m x 20m).
- Acceptance of 10-300(250) mrad in (non-)bending plane, optimized for *B* decays.
- Excellent tracking and particle identification.
- High-precision measurements of CP violation and rare decays of *B* hadrons.
- Proton-proton interactions at 40 MHz bunch spacing.

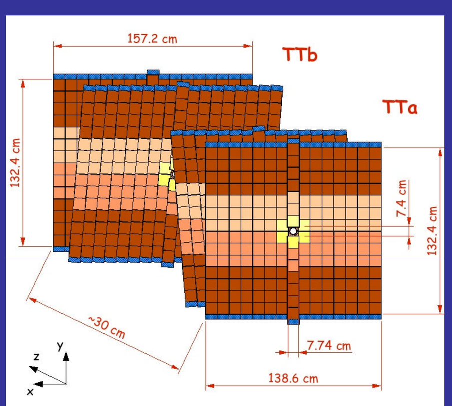


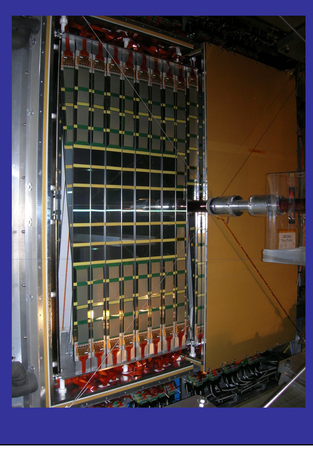
The Silicon Tracker

- Two detectors (TT and IT), both with p-on-n silicon-strip sensors.
- Similar readout electronics with front-end electronics operating at 40 MHz.
- Both detectors are operated below 5 ℃ to minimize radiation damage.
- Up to 4 (6 inch) sensors bonded together to form longer readout strips (readout sectors).
- Zero-suppression (clustering) performed on common off-detector readout board (TELL1).

Tracker Turicensis (TT)

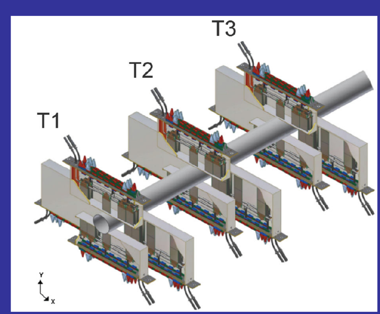
- 150 cm x 130 cm planar station.
- 4 layers (two with ±5° stereo angle).
- Upstream of dipole magnet
- Covers the full LHCb acceptance.
- 64 modules with 14 sensors each.
- Readout of 1,2,3 and 4 sensor sections.
  - Max strip length 37 cm.
- Strip pitch: 183 μm.
- Sensor thickness: 500 μm.
- 143k readout channels.
- Active area: 7.8 m².





Inner Tracker (IT)

- 120 cm x 40 cm cross-shaped region around beam pipe.
- 3 stations with 4 boxes each.
- Each box has 4 layers (0°,+5°,–5°,0°).
- Downstream of dipole magnet
- 1% of acceptance (but 30% of particles)
- Readout of 2-sensor (long) and 1-sensor (short) modules.
  - Max strip length: 22 cm.
- Strip pitch: 198 μm.
- Sensor thickness: 320 μm and 410 μm.
- 129k readout channels
- Active area: 4.2 m².

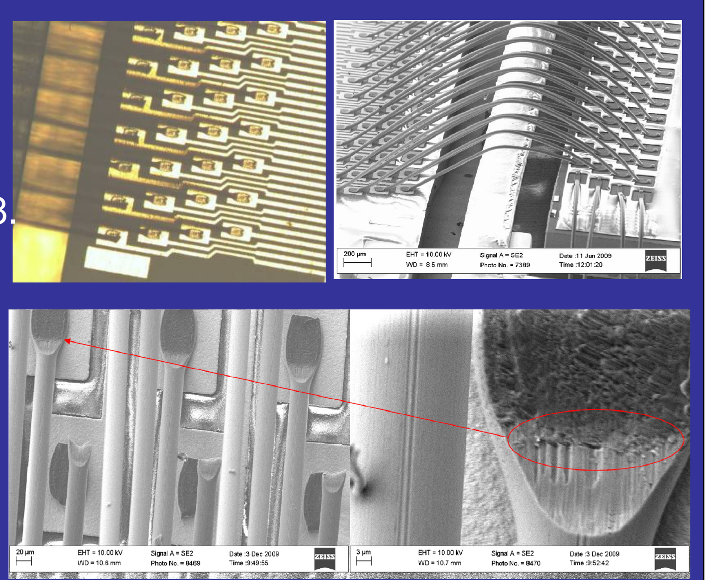


Commissioning

- Installation of ST completed in summer 2008.
- Extensive commissioning without beam (comparing noise levels): many readout problems fixed
- Most problem fixed by replacing faulty components (e.g. electronics board, patch panel, cable).

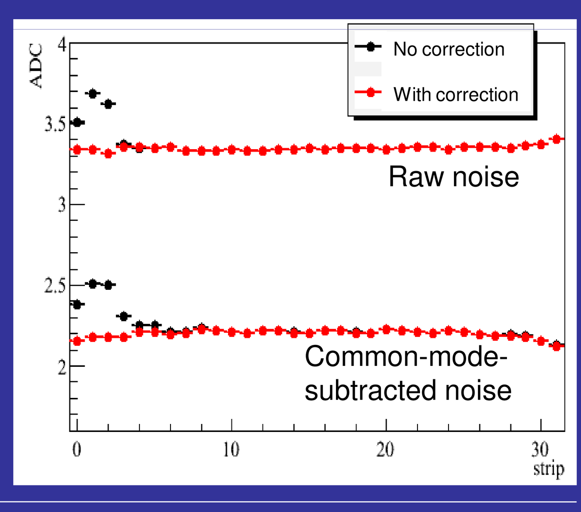
Broken bonds (TT)

- Broken between FE-chip (Beetle) and pitch adapter.
- Only innermost bonds broken (staggered bonding).
- Majority of bonds break on pitch adapter side.
- 9 readout sectors affected (total 280), starting June 2008.
- Many investigations (not reproducible in lab).
- Low loop height innermost bonds is not ideal.
- Heel cracks seen on good bonds but mainly on wrong (Beetle) side.
- Material fatigue probably induced by stress on wire (vibrations, thermal cycling).
- Number of new broken bonds is decreasing.
- No new broken bonds since July 2009.



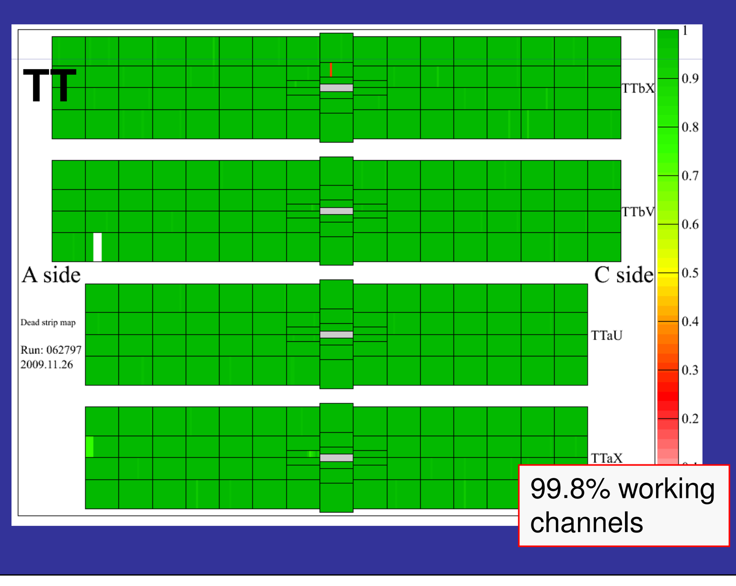
Header cross talk

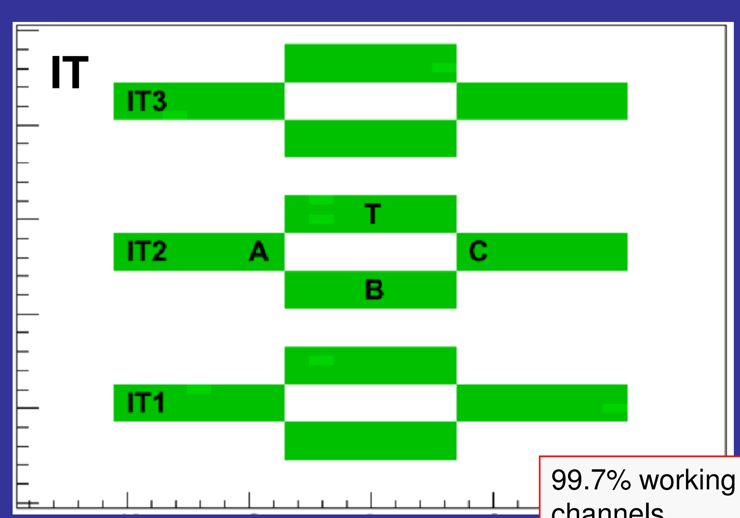
- FE-chip (Beetle) sends analog data via four output ports.
- Data for each port (32 channels) preceded by 4 header bits (header bits are encoded as analog signals).
- Cross talk observed from header bits into first channels.
- Header cross talk depends on length of output cable.
- Effect can be corrected for in LHCb readout board (TELL1) before zero-suppression.
- Correction mainly depends on last two header bits (first two bits are constant).
- Correction can be applied on the first 6 strips in each port.



Number of working channels

- Based on noise levels November 2009.





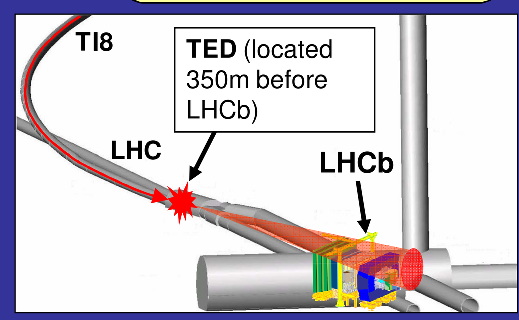
LHC injection tests

Injection tests
- Aug/Sep 2008
- June, Oct/Nov 2009

Injection tests very useful for ST commissioning!

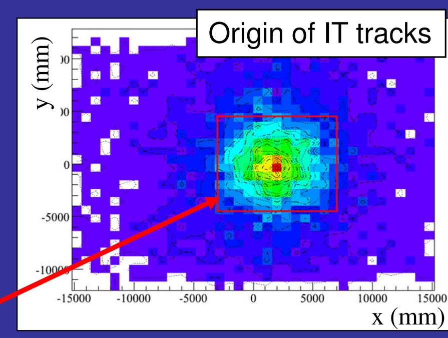
→ Acceptance for cosmics not ideal.

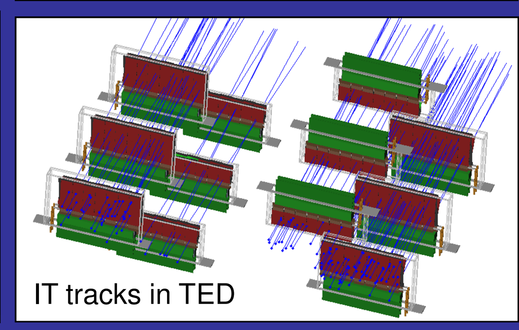
- Beam dump (TED) before injection to LHC ring.
- Secondary particles (mainly ~10 GeV muons) pass LHCb.
- Particles are coming in "wrong direction" compared to collisions.
- Useful exercise for timing (few ns) and spatial alignment.
- Very high occupancies (at 5x10⁹ protons): 6% (IT), 10% (TT).
- LHCb dipole magnet off.



Fighting combinatorics

- Use low occupancy (~3%) runs.
- Start from initial pre-aligned detector.
- Iterate track finding and alignment with evolving track χ^2 cuts.
- Require tracks to point back to TED.





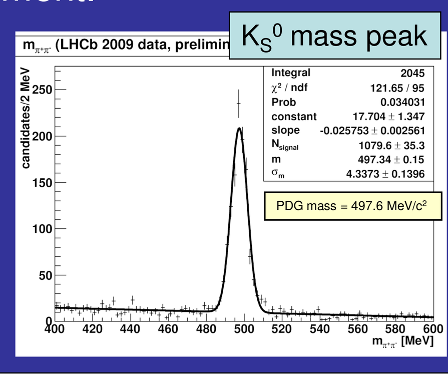
Beam gas & First collisions

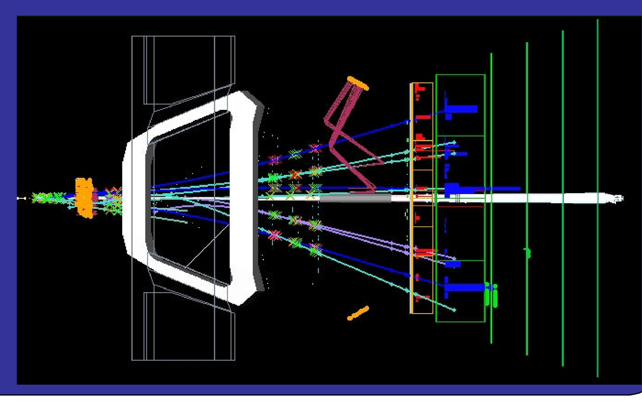
- Collected 540k events with all detectors at 450 GeV.
- Collected 3k events with dipole magnet off.
- Fine-time alignment done with first stable beam (Dec 6).
- A wealth of data for spatial alignment.

Highlights from 2009

- Nov 23: First collisions at 450 GeV.
- Dec 6: Collisions w/ stable beam (~1 Hz).
- Dec 12-13: High intensity runs (~50 Hz).

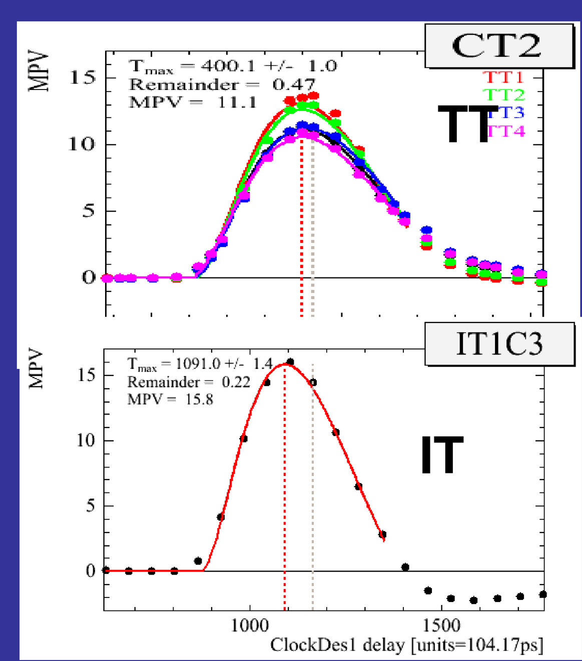
- First mass peaks at right place.
- Found K_S^0, Λ and φ peaks.
- Resolution will improve with better alignment.





Time alignment

- Initial time alignment done (and practiced) with TED data.
- Fine-timing (< ns) done with first stable beam (Dec 2009).
  - Only zero-suppressed data → not full pulse shape.
  - Measured S/N between 16.8 and 11.1 (depending on capacitance).
- Fine-timing will be redone for 2010 run
  - Cooling temperature changed from 15°C to 5°C,
  - FE (Beetle) chip settings changed (slightly higher S/N)



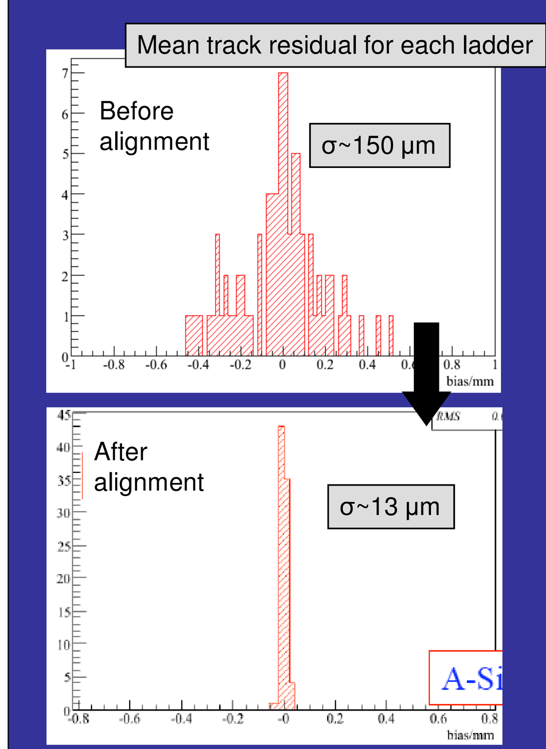
Method

- Take non-zero-suppressed data w/ different trigger delays.
- Find one-strip clusters (no bias from capacitive coupling).
- Follow pulse shape in previous and next readout.
  - Allows to plot full pulse shape (including undershoot).
- Determine MPV in cluster charge (S/N) distribution.
- Plot MPV versus delay to get the full pulse shape.

Collision data

Sector type	TT1	TT2	TT3	TT4	IT Long	IT Short
S/N	14.5	13.7	11.1	11.9	15.4	16.8

Spatial alignment



IT alignment with TED data

- Use detector survey as starting point.
- Use standalone tracking in IT (total ~16k isolated tracks).
- IT boxes in different positions during TED runs.
  - Internal alignment within boxes remains valid.
- Closed-form alignment with Kalman fitted tracks (NIM A600: 471-477, 2009)
- Alignment of boxes (2 translations and 1 rotation), layers (1 translation and 1 rotation) and ladders (1 translation).
- Ladder alignment precision ~13 μm.

IT alignment with collision data

- Use TED alignment as starting point.
- Use tracks starting from interaction point with p > 6 GeV, χ^2/dof < 7.
- Ladder alignment precision ~15 μm.
  - Not yet aligned for all degrees of freedom.
  - Unbiased residuals indicate additional residual misalignment.
  - E.g. still working on alignment between boxes using overlaps.
- Understand differences between magnet-on and magnet-off data.

TT alignment

- Only 4 layers → no standalone track reconstruction.
- TED data only used for aligning of full TT station in 2 dof.
- Beam collision data used for first module alignment with tracks starting from interaction point.
- Greatly improves unbiased residual: 75 μm (MC: 51 μm).