The LHCb Silicon Tracker Performance in pp Collisions at the LHC

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LHCb Silicon Tracker

Installation completed in June 2008.
Long programme of commissioning:
- Running detector without beam.
- Test readout.
- Cosmic data taking.
- Rate extremely low.
- LHC injection tests.
  - Protons dumped on beam stopper 350m from LHCb.
  - First tracks seen.
  - Initial time and spatial alignment of detector.
- Proton-proton collisions.
  - Final time alignment of detector.
  - Spatial alignment.
  - Study detector performance.
  - Radiation damage.

Common project: 5 institutes, ≈ 50 people.
Tracker Turicensis

- Silicon micro-strip detectors.
- Four planes (0°, +5°, -5°, 0°).
- Pitch: 183 μm; Thickness: 500 μm.
- Long readout strips (up to 37 cm).
- 143360 readout channels.
- Total Silicon area is 8 m².
  - Covers full acceptance before magnet.
- Detectors operate at 0°C.
Silicon micro-strip detectors.
Three stations in z.
  - Four boxes in each station.
  - Four planes (0°, +5°, -5°, 0°)

Pitch: 198 μm
Thickness: 320 or 410μm
129024 readout channels.
Total Silicon area is 4.2 m².
  - Covers region around beam with highest flux.

Detectors operate at 0°C.
Silicon Tracker Status

- 99.77% working channels.
- Repairs possible for electronics outside detector box.

**Noise cluster rate \( \approx 10^{-5} \)**

(VCSEL=Vertical-cavity surface-emitting laser)

- 98.22% working channels
  - 2 modules are not configurable.
  - 1 module with High Voltage problem.
  - 5 dead VCSEL diodes.
- Access for repairs is difficult.
  - Close to beam pipe
**Synchronized scenario**

- **LHC clock:** 40 MHz

**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 $\otimes$ 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 $\times$ Gaussian to charge distribution for each sample.
- Shift sampling point
- Plot MPV vs sample time.
- Fit pulse shape.

Internal Time Alignment $< 1 \text{ ns}$
Use tracks from VELO+T stations.

Global $\chi^2$ minimisation based on Kalman track fit residuals.

– W. Hulsbergen (NIM A600, 471)

More details in Raphael Märki’s talk about alignment.

Data shown is from 2010.

Expected resolution $\approx 50 \, \mu m$. 

**Spatial Alignment**

**TT:** $62 \, \mu m$

**IT:** $58 \, \mu m$
Clusters from tracks (p > 5 GeV):

- Signal to Noise:
  - IT: 16.5 (Long), 17.5 (Short).

- Within 10-20% of expectation.
Hit Efficiency

- Measure efficiency with tracks.
  - \( p > 10 \text{ GeV} \),
- Search for hits in window around track.
- Efficiency varies as function of window size.
  - 2.5 mm (TT) 1 mm (IT)
- Efficiency = #found / #expected.

Overall Efficiency:
- \(99.30\%\) (TT)
- \(99.65\%\) (IT)
Intrinsic Charge Sharing

Method:
- Calculate cluster centre-of-gravity, $\eta$.
- Plot vs fractional position of track, $x$.
- Fit error function.
  - Sigma gives charge sharing width

Results:
- Width: 3.5 to 5.0 μm.
- Increases with track angle.
Comparison with Simulation

- Many effects measured with data:
  - Capacitive coupling between strips.
  - Charge sharing.
  - Lorentz angle.
  - Gain.
  - LHCb-PUB-2010-016
- Effects are modelled in simulation.
- Excellent agreement between data and MC.
Radiation damage

LHCb Integrated Luminosity at 3.5 TeV

- Expected Radiation Dose (10 years):
  - IT: $5 \times 10^{13}$ 1 MeV neutron equivalent.
  - TT: $8 \times 10^{13}$ 1 MeV neutron equivalent.
- Monitor change in leakage currents.
  - IT: $\Delta I(10^\circ C) = 0.103 (0.031) \mu A/\text{pb}^{-1}$
  - TT: $\Delta I(8^\circ C) = 0.065 \mu A/\text{pb}^{-1}$
- Expect type inversion after 1-2 years.
- Monitor changes in depletion voltage
  - Charge Collection Efficiency.
Radiation damage

- Change in leakage current.
  - $\Delta I_{\text{leak}} = \alpha \phi_{\text{eq}} V$
  - assume $\alpha = 4 \cdot 10^{-17} \text{A/particle/cm}^2$.

M. Moll et al., NIM A426, p. 87 (1999)

- Can extract 1-MeV equivalent fluence.
  - Measured vs expected radiation dose (for 2010).

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Leakage current evolution in TT

- Results within expectations

![Graphs showing leakage current evolution in TT](image-url)
Leakage current in TT

Peak Current (µA)

Integrated luminosity (1/pb)
Current evolution in IT

![Graph showing current evolution over delivered luminosity](image)

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Conclusions

- Detectors are in good shape.
  - 99.77% and 98.22% are fully operational for TT and IT.

- Detector performance is within expectations.
  - Time aligned to 1 ns precision.
  - Signal to noise ratio measured to be:
    - 13-15 (TT) 16.5 or 17.5 (IT)

- Studying the effects of radiation damage.
  - Results compatible with expectations.

  **LHCb Silicon Tracker is performing well.**
BACK UP
Readout chain

Digitization: Service box near detector 15 krad in 10 years

Service Box (up to 16 Digitizer Boards)
- Data from other digitizer boards
- Data from other Beetles on the same hybrid

ADC
- 4 x 8bit @ 40MHz
- 4 GOLs
- 4 VCSEL
- QPLL

TELL1 Board
- 1 Rx module
- SNAP12 Rx
- 12 TLK2501
- 16 bits @ 80MHz
- TLK2501
- Crystal oscillator

Optical link
- Patch panel
- 100 m 12-fiber ribbon cable
- Single optical fibers

House: Zero Suppression

From Matt Needham talk at Vertex 2010

Readout

Front end on detector < 1 Mrad in 10 years

Tell1 readout boards in counting

Positioning

Concrete shielding

Beetle chip
5 m twisted pair cable
HV problems

- Observed HV channels tripped during collisions.
- Current peaks in many channels after stable beams.
  - Rise time minutes, decay time hours, luminosity dependent.
- Lowered HV from 350V to 300V.
  - reduces current.
- Lowered temperature from 5°C to -15°C
  - higher current peaks, broken bonds.
- Affected channels have current peaks during ramp without beam
  - Not true after long time without beam.

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Luminosity dependent

- Effect dependent on instantaneous luminosity.
- Luminosity levelling in LHCb can lead to large spikes in current if step size is large.
Location of HV problems

HV problems @ 1.20x10^-32 and 350 V at T=-15C

HV Partition

HV Partition

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Broken bonds

- 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.
- Broken modules removed and repaired during winter shutdown.