Performance of the LHCb Silicon Tracker

Greig Cowan

On behalf of the LHCb Silicon Tracker group

HSTD-8, 7th December 2011

- 1 LHCb tracker
- 2 Operational experience
- 3 Alignment
- 4 Detector efficiency and resolution
- 5 Radiation damage
- 6 Summary

LHCb detector

- Forward arm spectrometer. $b/\bar{b}$ production correlated in forward/backward direction.
- Access to $B_u, B_d, B_s, B_c, \Lambda_b$.
- Excellent tracking and momentum res for good mass res. $\delta p/p \sim 0.4\%$.

LHCb detector

- Forward arm spectrometer. $b/\bar{b}$ production correlated in forward/backward direction.
- Access to $B_u, B_d, B_s, B_c, \Lambda_b$.
- Excellent tracking and momentum res for good mass res. $\delta p/p \sim 0.4\%$.

Tracking at LHCb

- 1 Charged particles get kick from dipole magnet - momentum information.
- 2 Reconstruct primary and secondary vertices.
- 3 Extrapolation to RICH, CALO and Muon systems for particle ID.

See following talk from P. Collins for details about the VELO

Tracker Turencisis (TT)

- Four planes of **p-on-n** “HPK” silicon ($0^\circ, +5^\circ, -5^\circ, 0^\circ$).
- $500\mu\text{m}$ thick, $183\mu\text{m}$ pitch.
- Long strips, up to 37cm .
- Total area 8.2m^2 , 143k strips.
- Complete station is 7% of a radiation length.
- Temperature: 8°C for sensors, 0°C coolant.
- Digitisation in off-detector service box.

Inner tracker (IT)

- Four planes of **p-on-n** silicon per box ($0^\circ, +5^\circ, -5^\circ, 0^\circ$).
- $320\mu m$ or $400\mu m$ thick, $198\mu m$ pitch.
- $11cm$ or $22cm$ strips.
- Total area $4m^2$, 130k strips.
- 3 stations each have 4% of a radiation length.
- Temperature: $10^\circ C$ for sensors, $0^\circ C$ coolant.
- Digitisation in off-detector service box (outside acceptance).

Operational status

TT

- 143360 readout channels.
- **99.77%** working channels.
- 3 ports disabled.

IT (more difficult to access)

- 129024 readout channels.
- **98.22%** working channels.
- 10 ports disabled.
- 2 modules not configurable.
- 1 module with HV problem (will be fixed during winter).

Timing calibration (1)

Optimise charge collection

- Different cable lengths for different detector parts.
- Time of flight different per station.
- Trigger and control signals must be synchronized for the entire LHCb detector.

Time delay scan for each service box

- Read out samples spaced by 25ns .
- Fit Landau $\otimes$ Gaussian to charge distribution for each sample.
- Shift sampling point by $-6, +6, +12\text{ns}$.

Synchronised scenario

Timing calibration (2)

Optimise charge collection

- Different cable lengths for different detector parts.
- Time of flight different per station.
- Trigger and control signals must be synchronized for the entire LHCb detector.

Time delay scan for each service box

- Read out samples spaced by $25ns$.
- Fit Landau $\otimes$ Gaussian to charge distribution for each sample.
- Shift sampling point by $-6, +6, +12ns$.

- Plot MPV vs sample time.
- Fit pulse shape to extract optimal timing.

Collision data used to internally align TT and IT with resolution $< 1ns$

Spatial alignment

- Tracking stations aligned using tracks which have been fitted with a Kalman filter
W. Hulsbergen (NIM A600, 471).
- χ^2 minimization of all track residuals using mass constraints.
  - i.e., use $J/\psi \rightarrow \mu\mu$ or $D^0 \rightarrow K\pi$ daughter tracks.
  - Fix their origin and the invariant mass of the J/ψ or D^0 to known value.
  - Compute new tracks and residuals which go into χ^2 minimization.
- Metrology survey constraints are used to fix certain degrees of freedom.

Signal-noise performance

- Measure S/N for clusters assigned to tracks with $p > 5\text{GeV}$.

- S/N results:
  - TT: 12-15
  - IT (long): 16.5
  - IT (short): 17.5
- Within 10-20% of expectations from test beam.

Hit efficiency

- Use daughter tracks from $D^0 \rightarrow KK$ decays.
- Gives us a very pure sample of tracks, $p_{track} > 10\text{GeV}$.
- For each track, extrapolate where we expect them in the silicon. Use isolation criteria.
- Within some search window, $\epsilon = \frac{\# \text{hits found}}{\# \text{hits expected}}$.
- Two sectors have high common mode noise ($\epsilon > 98\%$).

Intrinsic charge sharing

- Multi-strip clusters due to charge sharing.
- Interstrip track position: x .
- Centre of gravity: $\eta = C_R(x)/(C_L(x) + C_R(x))$.

TT, $0.01 < dx/dz < 0.02$

- Convolve error function with Gaussian in x (for mis-alignments) and η (due to sharing).
- Perform 2D fit allows us to extract the charge sharing width (σ_f) and track resolution.
- Black curve shows 1D cluster position shape: $f(x; \sigma_f) = \frac{1}{2} \left(1 + \operatorname{erf} \left(\frac{x - 1/2}{\sqrt{2}\sigma_f} \right) \right)$.

Radiation damage (1)

LHCb Integrated Luminosity at 3.5 TeV in 2011

- LHCb designed to operate at lower luminosity than ATLAS/CMS!

Radiation damage (2)

- Measure change in the leakage current and extract fluence.
  - $\Delta I = \alpha \phi_{eq} V$, $\alpha = 4 \times 10^{-17}$ A/particle/ cm^{-2}
- Compare to what is expected from simulation:

- Highest expected radiation dose (10 years):
  - TT = 5×10^{14} 1MeV neutron equiv.
  - IT = 9×10^{12} 1MeV neutron equiv.

Leakage current evolution (TT)

- Signs of annealing taking place during LHC technical stops.
- Current behaving as expected.

Leakage current evolution (IT)

- Evolution of current with delivered luminosity behaving as expected.

Summary

- LHCb silicon tracker is operating successfully at the LHC.
    - $> 99\%$ and $> 98\%$ operational for TT and IT.
    - Will use winter technical stop to perform some small improvements.
  - Radiation damage being studied and is compatible with expectations.
  - Performance is excellent.
    - Time alignment $< 1ns$.
    - S/N is ~ 14 (TT), ~ 17 (IT).
    - Spatial alignment to $\sim 16\mu m$.
    - Hit efficiency is $> 99\%$ for IT.
- ⇒ **Excellent physics performance of LHCb!**

Backup: Tracker readout chain