Performance of the LHCb Silicon Tracker with first data

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Outline

• The LHCb Silicon Tracker

• Commissioning and status

• Performance with first data (TED runs)
  • Time Alignment
  • Spatial Alignment

• Summary
Dedicated b physics experiment at the LHC
Detector is a single forward arm spectrometer

Muons Calorimeters
RICH2 Tracker
Magnet
RICH1
VELO

Inner Tracker (IT)
Tracker Turicensis (TT)

IT + TT
common project
Silicon Tracker
Tracker Turicensis

- Four planes of Silicon ($0^\circ$, $+5^\circ$, $-5^\circ$, $0^\circ$)
- 500 $\mu$m thick, 7-sensor long ladders.
- Pitch 183 $\mu$m
- Strip lengths up to 37 cm, Capacitance 56 pF
- Area of 8.2 m$^2$ covered by Silicon
- 143 k strips
3 stations after the magnet
- Station consists of 4 boxes
- Box contains 4 layers (0°, 5°, -5°, 0°)
- Readout pitch 198 μm
- 320 μm, 1 sensor ladders
- 410 μm, 2 sensor ladders
- Area of 4 m² covered
- 336 ladders, 130 k readout strips
Tracker Turicensis

- TT 99.7 % of channels functional
- IT 99.7 % of channels functional
- Noise cluster rate $\sim 10^{-4}$ (with a S/N threshold of 4)
Commissioning Lessons

To achieve this status took a lot of work (before + after the winter shutdown)

• Oscillations in the LV power supplies:
  • Filter out with capacitors

• Failing voltage regulators:
  • Did not test with all different load scenarios
  • Replaced (~ 30 out of 1992)

• Low optical power readout links
  • Bad alignment between the diode and the optical fiber
  • Replaced in IT: 30 out of 1008 diodes, TT: 95 out of 1152

• Internal swaps in optical fiber bundle, bad connections, ….
Commissioning with Cosmics

Low rate of cosmics due to the forward geometry of LHCb

IT Cosmic

IT 2008 cosmic running
2.6 million calorimeter triggers
3 cosmics going through 3 IT boxes
~ 1000 through 1 IT box
First signals + coarse timing

TT Cosmic

TT 2009 cosmic running
Few cosmics 2008 (trigger is far away)
Scintillator trigger close to RICH1
First coincidences (TT/RICH)
Commissioning with Beam

- $2 \times 10^9$ protons extracted from SPS and dumped on a tungsten beam-stopper (the ‘TED’) 350 m downstream of LHCb
- Spray of $\sim 10$ GeV muons in the detector, occupancies 10× that in normal running
- $\sim 6$ hours running September 2008, 72 hours running June 2009
- Wealth of data for time and spatial alignment and performance studies
  - e.g. 2009 run 50000 tracks in the IT
IT Time Alignment

• Different cable lengths for different detector parts
• Time of flight different per station
• Time delay scans (collected charge vs sampling time)

Short IT Ladders

MPV ~ 27 ADC counts

Scanning sampling time

Detector internally time aligned with accuracy better 1 ns
TT Time Alignment

Adjust timing delays of four quadrants of TT
Plot signal versus sampling time

MPV ~ 25 ADC counts

Scanning sampling time
First Step:
Validate survey using histogramming method
Adjust box + layer positions in x
Boxes adjusted by 700 μm (consistent with survey precision)

Pairs of hits in T1 x, T3 x [define] line
Require to point to TED
Interpolate to hits in T2
Calculate distance to hits + histogram
Box survey verified good to 700 μm
Layer survey verified good to 140 μm
IT Spatial Alignment

• Use TED events with lowest occupancy + select isolated tracks (16 k total)
• IT alignment with closed form Kalman Filter Method (NIM A600: 471-477, 2009)
• Alignment of Boxes (TxTyRz), Layers (TxRz), Ladders (Tx)
• Repeat pattern recognition at each step/iteration
  • Evolving pattern recognition and $\chi^2$ cuts with iteration
• Independent data sample for validation
• Study unbiased residuals per ladder
• Mean of distribution (bias)
• $\sigma$ of distribution (resolution)

Bias 13 $\mu$m

$x$: 80 $\mu$m

Resolution consistent with ~ 10 GeV muons

Probability of $\chi^2$

A-Side tracks

Stereo 150 $\mu$m
Detailed studies of charge deposition made. Landau fit per ladder to extract S/N.

S/N long ladders ~ 14.5
S/N Short ladders ~ 15.5
Consistent with testbeam expectations at 5 % level

A-Side clusters on tracks
Knee partly due to two particle clusters
IT Efficiency

- Use tracks to measure ladder efficiency
- Measured efficiency 97.8%
- Inefficiencies dominated by modules close to detectors edge (alignment/acceptance problems) + known problem modules

Efficiency 97.8%
TT Spatial Alignment

TT only has four layers

- Standalone tracking not possible
- Alignment needs seeds from either Vertex Locator or IT
- Residual distributions show clear correlations with Velo/IT tracks
TT Spatial Alignment

Residuals of TT hits to extrapolated VELO tracks

- **Nominal**
  - Mean: -0.404 mm
  - Width: 0.655 mm

- **Survey**
  - Mean: 0.162 mm
  - Width: 0.526 mm

- **Aligned**
  - Mean: -0.053 mm
  - Width: 0.519 mm

Full station alignment only (limited overlap Velo-TT)
Summary

LHCb Silicon Tracker is commissioned and fully operational

• ~99.7% detector channels in IT + TT functional

• TED running has allowed first studies of detector performance
  • Internal time alignment with 1 ns accuracy
  • IT ladders internally aligned with a precision of 15 microns
  • IT efficiency measured to be ~ 98% with tracks
  • S/N in line with expectations from testbeam

For sure many challenges ahead, but we are looking forward to colliding beams
Backup
Readout Electronics

- 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

near detector
~ 15krad in 10 yrs

near detector
< 1 Mrad in 10 yrs

Safe environment counting house

Service Box (up to 16 Digitizer Boards)

Concrete shielding

control panel

EPFL
MC Studies

Unbiased residual IT

Efficiency

Residual TT

Ghost rate