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for the LHCb Silicon Tracker Group

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- Production and Testing
- Commissioning
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The LHCb Silicon Tracker

LHCb: single arm forward spectrometer

Silicon Sensors:
- p-n siliconstrip sensors (HPK)
- 1-4 sensors bonded together → up to 37cm long strips
- 183µm and 198µm pitch, w/p=0.25,
- 320,410 and 500µm thicknesses
**TT-Station and Inner Tracker**

- **TT-station:**
  - 4 layers in a single detector box volume (2 with ±5° stereo angle)
  - Support and readout hybrids outside of the acceptance

- **Inner Tracker:**
  - 4 individual detector boxes / station
  - 4 layers/station,
  - 3 stations

- Liquid C$_6$F$_{14}$ cooling system → operation at ~5°C
- Lightweight foam for thermal insulation + Al foil for electrical shielding
- 270k readout channels, 280 + 336 readout sectors (modules) and 12m$^2$ of silicon
Silicon Tracker Modules

- **Inner Tracker Module:**
  - Sensors
  - Kapton
  - Carbon Fibre
  - AIREX
  - Carbon Fibre

- **TT-Module:**

  - pitchadapter
  - silicon sensors
  - front-end hybrids
  - Kapton interconnect cable
  - carbon-fibre support rails
  - Kapton flex cable

  - 512 signal + 2 GND + 2 HV strips
  - backplane (GND): Copper mesh
  - 9 μm
  - 16 μm
  - 112 μm
Readout Electronics

- 3 (4) “Beetle” readout chips
- Radiation hard 0.25µm CMOS
- 40MHz, 128 channels
- Multiplexed onto 4 readout ports
  - 36 cycles to read 1 event
  - 1.1MHz readout
- Pipelined 160 bunch crossings

On detector: < 1 Mrad in 10 years
Near detector ~15 krad in 10 years
Safe environment counting house

Concrete shielding

100 m 12-fibre ribbon cable

5 m copper cable

36 cycles to read 1 event

1.1 MHz readout

Pipelined 160 bunch crossings
Module Production

• ~400 Inner Tracker and ~150 TT-Station modules have been produces in two production sites

• sensor edges → mechanical stops

• vacuum jig

• TT-modules: glued with expoxy in groove on Carbon/Glass fibre side rails

• Inner Tracker-modules: glued with silicone on flat Kapton coated CF-Support

• sensor-sensor alignment

  ~100µrad rel. rotation

  ~7µm relative shift
• aging against infant mortality:
  • 36-48h temperature cycling
    • 40°C and -5°C (Inner Tracker Modules)
    • 25°C and 5°C (TT-Modules)
  • electrical “burn-in”
    • regular front-end read out
    • sensor bias voltage stability tests

2 Modules out of 410 Inner Tracker modules actually “died” during the “burn-in”
• tracked down to weak isolation of some hybrid vias
• modified the gluing technique to prevent further losses
Testing: Shorted and Open Channels

using the internal Beetle test-pulse to detect:
→ shorted/broken channels (typically on pitch adapter) via change load capacitance and hence the Beetle response

![Image of shorted channel and open channel](image_url)
Problems Spotted

Readout Electronics:
- ADC bandwidth: typo in datasheet (corrected in 2002) → required additional low pass filter
- “fixed” all 600 readout boards

Silver Glue:
originally used in GND (Inner Tracker) and sensor bias connection (TT-Station):
- degrading quality
- replaced by
  - bond wire
  - soldered wire
Detector Assembly

- TT-Station
- Inner Tracker
**Commissioning Status**

**TT-Station:**
- broken bond wires
- large bias current

→ > 99% working channels!!

**Inner Tracker:**
- large / bit larger noise
- problems due to:
  - voltage regulator problems
  - connector problems
  - optical fibre/laser diode problems
  - ADC problems

→ to be fixed when access (in the following weeks. (similar already done in the TT-Station)
→ ~96% of the Inner Tracker is fully functioning
Nothing new, but: Isn’t it anyhow “surprising” and hence worth mentioning?

- whatever can go wrong, will go wrong. Certainly more than you imagine 😊

**e.g.**

- Oscillating power supplies:
  - we didn’t test with all different cable lengths / load scenarios
  → additional capacitors
- Oscillating slow control ADCs (DCU) due to non adjusted input range:
  - we didn’t test the readout circuit with all different load scenarios
  → adjust voltage divider
- Failing voltage regulators:
  - we didn’t test with all different load scenarios
- Failing press fit connectors (after transport damage?):
  → re-solder
- Swapped channels in patch panels, leaking cooling pipes, ....
Cosmic events:
- very rare due to geometry of LHCb
  - used for coarse time alignment

“TED events”:
- LHC (SPS) beam directed on a beam dump in the transfer line 300m “behind” LHCb
- the only “beam” induced particles seen so far
- very high particle density
  - ~ 4000 clusters in the Inner Tracker per event (~20x more than in nominal physics events)
- internal fine time alignment
- spatial 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)

MPV = 27 ADC counts
→ S/N ~ 14
"TED events": Track density is too high for standard track finding

→ track candidates in expected direction from hits in first and last layer → hit residuals middle box

• Simulation (low occupancy beam bas events)
  • 80µm (1.4*binary resolution)
  • 50µm misalignment → 80µm
  • 100µm misalignment → 130µm

σ ~ 130 µm
Δ ~ 0.6 mm

σ ~ 270 µm
Δ ~ 0.5 mm
Inner Tracker Cosmic Events

- “Cosmic events”:
  - LHCb geometry is “not very favourable”
  - from 1.1 million cosmic triggers (special stand alone tracking with very tight noise cuts)
    - 44 track candidates that cross two stations
    - 2 track candidates that cross all three stations

<table>
<thead>
<tr>
<th>station</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>residual [mm]</td>
<td>-0.5</td>
<td>-1.0</td>
<td>-1.5</td>
</tr>
<tr>
<td>Hit residuals:</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
  - Nominal geometry: \( \sigma = 310 \mu m \)
  - Survey geometry: \( \sigma = 270 \mu m \)
  - “TED data alignment”: \( \sigma = 220 \mu m \)

Reconstructed cosmic track with 10/12 hits!
TT-Station Spatial Alignment

• “TED events”:
• TT-Station has only 4 layers \((x,u,v,x)\) → no stand alone tracking is possible

→ track candidates from the VELO are extrapolated to the TT → hit residuals

TT-layers:

extrapolate VELO track candidates → Residuals in TT layer (TT a/U)

• Expected resolution of extrapolation to TT: \(300\mu m\)
• Hit residuals observed in TT: \(500\mu m\)
• Offsets:

\(\sigma \sim 500\mu m\)

\[
\begin{array}{l|l}
\text{Entries} & 5070 \\
\chi^2/\text{ndf} & 92.57/96 \\
p0 & 24.16 \pm 3.56 \\
p1 & -0.147 \pm 0.064 \\
p2 & 0.4762 \pm 0.0727 \\
p3 & 9.741 \pm 0.337 \\
\end{array}
\]
Summary

• The LHCb Silicon Tracker is a silicon strip detector for the high density particle region near the beam pipe and in front of the bending magnet

• O(600) modules have been produced and extensively tested at two main production sites:
  • Zuerich
  • Lausanne/CERN

• successful installation was followed by commissioning with the “usual surprises”

• at the moment, > 97% of the detector is fully operational
  → to be further improved in this shutdown

We are looking forward to follow up the first commissioning with particles with circulating/colliding beams in … late spring?
More Testing

**Pinholes:** sensor implant is shorted to the AC coupled readout strip

- IR light (i.e. traditional light bulb)
  - photo current
  - preamplifier saturation
  - spot pinhole as showing low noise

**Scratches:** on readout strip on the sensor:
- discharge also saturates the front-end

Both Inner Tracker and TT-Modules have < 1‰ of bad strips (open/short/pinhole)
Sensor Bias Voltage Testing

TT @ 5°C
900 IV-curves

Sensor bias current
- Sensor bias leakage current
- Sensor bias breakdown voltage

Sensor bias voltage:

Onset of high voltage breakdown
→ increased noise in first/last strip

500V
Despite extensive module testing/temp cycling:

- on 6 TT-hybrids bond wires on Beetle input broke
- detected via noise pattern
- affects innermost of four bond rows

→ one module has been removed and is extensively tested
→ so far the damage could not be reproduced in lab (i.e. temp variations etc.)
→ accidental damage excluded
→ under further investigation