The LHCb Silicon Tracker, design and test results.

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for the LHCb Si-Tracker

• Introduction
• Inner Tracker design
• TT-Station design
• Preliminary test results
LHCb Introduction

LHC: “b-factory” with $10^{12} b\bar{b}$/year @14 TeV, lumi=$2\cdot10^{32}$ cm$^{-2}$s$^{-1}$ (compared to $10^7$ at $\Upsilon(4S)$)

LHCb: single-arm spectrometer dedicated to B-physics:

CP violation and other rare phenomena in the B-system
The LHCb Experiment

tracking detectors:
VELO, TT-Station, Inner- and Outer Tracker

[Diagram of LHCb Experiment]

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LHCb Silicon Tracker

12.5m² active area  (4.3m² IT + 8.2m² TT)
~310k readout channels
use: “same” silicon sensors
    same readout chip, hybrid, readout link, etc.
modules of 1, 2 or 3 sensors
Why Silicon?

**Inner Tracker**

- fine granularity $\rightarrow$ tolerable occupancy (<1%) in region of large particle density ($\sim 10^5 \text{ cm}^{-2}\text{s}^{-1}$)
- good hit finding efficiency ($\sim 100\%$)
- good spatial resolution ($dp/p \sim 3\% @ 20 \text{ GeV}$)

**TT-Station**

- $p_T$ info in L1 trigger
- fast readout
- good spatial resolution
  - little mismatching in online track reconstruction
  - better minimum bias retention than mixed silicon and straw tubes
**Inner Tracker Layout**

- **IT**: 1.3% of sensitive area
- 20% of tracks

**Inner Tracker:**
- silicon strips
- 4.5m

**Outer Tracker:**
- straw tubes
- 6m

- 4 individual boxes per station
- 4 layers per station: (2 stereo layers)

⇒ 336 IT modules: 11 and 22cm long
Inner Tracker Modules

readout hybrid with 3 Beetle chips

module (ladder) with 2 SI sensors

overlapping of adjacent modules
Inner Tracker Design

• cross shaped station consists of individual boxes
• each box houses 28 ladders (4 layers)
• operation at ~5°C
  • cooling plate with embedded cooling pipes
  • balconies + CF support (AmocoK1100/Mitsubishi K13C2U) conduct cooling for hybrid and sensors
• box enclosure lightweight isolation foam + Al foil for electrical shielding
• cover – and cooling plate provide rigidity
• 4 layers in 2 half stations, 2 layers $\pm 5^\circ$ stereo angle
• 11cm, 22cm and 33cm long modules
• all readout hybrids at the edge outside of the acceptance
• inner modules connected via Kapton interconnect cable
TT-Station Design

• modules are connected to 11 (12) sensor long ladders supported by carbon fibre rails

• box provides electrical and thermal insulation
• cooled to ~5°C
TT-Station: Kapton Cable

up to 55cm long interconnect cables in TT:
- cable capacitance adds to readout chips load capacitance

measurements on “D0-like” prototype cables 42cm and 54.5cm
50µm Kapton, no backplane, 91µm pitch, 15µm width, 7µm thick Cu

- interstrip capacitance 0.17 pF/cm
- good agreement with simulation 0.154 pF/cm
**TT-Station: Kapton Cable**

- pick-up noise can be kept small in laboratory measurements (depending on grounding)
- prefer to have more solid GND connection for robustness
  → use thin copper mesh as backplane

**Simulations:** \( C_{\text{tot}} < 0.5 \text{ pF/cm} \) possible for 100\( \mu \text{m} \) substrate

→ test measurements in preparation
Readout Chain

Beetle (1.2) readout chip:
- 40MHz clock, 128 channels
- multiplexed 4x32
  → 900ns readout
- pipelined for 183 BX
- rad. hard 0.25µm CMOS
differential output via 5m twisted
  pair cable → amplifier, ADC etc.
  outside detector acceptance
digital signals multiplexed and sent
  via 100m optical fibre

good signal integrity demonstrated
  in “eye pattern”
Challenges of SI Detector

- moderate spatial resolution required (~70-80µm)
- moderate radiation environment 1 Mrad/10 years or 9×10^{12} cm^{-2} of 1-MeV Neutron equivalent

But:

minimize: R/O channels \(\Rightarrow\) large pitch \(O(200\mu m)\) (charge collection)
\(\Rightarrow\) long strips 33cm (noise)
minimize: material \(\Rightarrow\) “thin” sensors (little charge)
40MHz, fast readout \(\Rightarrow\) (noise)
Sensors

6” wafer, high resistivity n-bulk, p+ strips
crystal orientation <100>
designed for Inner Tracker tests:

LHCb sensors (320µm, 198/240µm pitch,
w/p 0.25 – 0.35)

33cm ladder in TT: use thicker sensors

CMS sensors (500µm, 180µm pitch, w/p=0.25)
GLAST (410µm, 228µm pitch, w/p=0.25)

→ charge collection with fast readout, ballistic deficit?
Sensor Characteristics

$1/C^2$ versus $V_{\text{bias}} \rightarrow$ depletion voltage

**LHCb sensors**
- Sensor 1
- Sensor 2
- Sensor 3
- Sensor 4
- Sensor 5

**GLAST sensors**
- Sensor 1
- Sensor 2
- Sensor 3
- Sensor 4
- Sensor 5

**CMS sensors**
- Sensor 1
- Sensor 2
- Sensor 3
- Sensor 4
- Sensor 5

**total strip capacitance**

**simulation**
Test Setup

test-beam and IR-laser
120GeV pions

testing of: 3 sensor ladders with CMS, GLAST, LHCb sensors
2, 1 sensor ladders with LHCb sensors
Pulseshape

fast readout in $O$ (charge collection time)
$\rightarrow$ observe time structure

- central and neighbouring strips show different time structure
- central strip is the latest
- reproduced in simulation with
  drifting charges +
  capacitive coupling +
  Beetle front end response

- Glast ladder ($V=200V$
  $Vfs=400mV$)
  - central strip
  - left neighbour
  - right neighbour
  - left neighbour -1
  - right neighbour +1
Signal Remainder

signal remainder 25ns after peak (BX every 25ns)
→ specification: remainder < 0.5 o.k.

test-beam:

V1, Vfs=400
V2, Vfs=400
V1, Vfs=100
V2, Vfs=100

laser setup:

remainder vs. detector capacitance (pF)

remainder vs. capacitance [pF]
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**Signal Remainder**

**signal remainder 25ns after peak (BX every 25ns)**

→ **specification:** remainder < 0.5 o.k.

**test-beam:**

![Graph showing signal remainder vs. detector capacitance](image)

- V1, Vfs=400
- V2, Vfs=400
- V1, Vfs=100
- V2, Vfs=100

**laser setup:**

![Graph showing laser setup capacitance](image)

- Vfs=1000 mV
- Vfs=400 mV
- Vfs=0 mV

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Cluster Shape

Cluster shape reflects the shoulders seen in pulseshape scan.

Shoulder 8-18% depending on ladder length, pitch and \( (w/p) \).
MPV S/N from Landau $\times$ Gaussian fit:

→ scaled to same thickness and same capacitance using measure Beetle front end response $\text{ENC} = 450 + 47 \times C / \text{pF}$

<table>
<thead>
<tr>
<th>Experiment</th>
<th>MPV</th>
<th>Capacitance (pF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LHCb</td>
<td>9.6</td>
<td>50.6</td>
</tr>
<tr>
<td>GLAST</td>
<td>10.4</td>
<td>41.3</td>
</tr>
<tr>
<td>CMS</td>
<td>10.8</td>
<td>37.6</td>
</tr>
</tbody>
</table>

agree within 12%
large pitch $\rightarrow$ charge loss observed for particles passing between two readout strips.

charge loss remains even for over-biased detector and long shaping times
Spatially Resolved Efficiency

Cluster finding adjusted to noise rate $< 1\%$

Despite charge loss in between strips:

$\Rightarrow \sim 100\%$ efficiency for thickness $\geq 400\ \mu\text{m}$. 
Summary

• LHCb Si-Tracker uses silicon modules with large pitch of ~200\(\mu\)m
  long strips up to 33 cm
  fast readout \(O(25\text{ns})\)

• presented the current design for TT-station and Inner Tracker

• preliminary test results show modules meet fully the expectations
  time resolved signal evolution in the Si+readout
  spatially resolved charge collection between strips