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 $10^{12}$ $\bar{b}b$/year

$pp@14$ TeV, lumi=$2\times10^{32}$ cm$^{-2}$s$^{-1}$

(compared to $10^7$ at $Y(4S)$)

full $B$ spectrum $B, B_s$

LHCb: single-arm forward spectrometer dedicated to $B$-physics acceptance: 15-300(250)mrad:

$\bar{b}b$ angular distribution

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

tracking detectors:

VELO, TT-Station, Inner- and Outer Tracker
LHCb Silicon Tracker

Inner Tracker

TT-Station

12.5m² active area
~310k readout channels
use: “same” silicon sensors
same readout chip, hybrid, readout link, etc.
modules of 1, 2 or 3 sensors

(4.3m² IT + 8.2m² TT)
Why Silicon?

Inner Tracker

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

TT-Station

\(P_T\) info in L1 trigger

• fast readout
• good spatial resolution
Why Silicon: L1-Trigger

How does the improved spatial resolution of Si-strips w.r.t. straw tubes improves the trigger?

L1: $P_T$ from VELO and TT track segment

(10-GeV track is deflected by $\sim 3.4$ mm at TT)

better resolution
$\rightarrow$ better hit matching
$\rightarrow$ better minimum bias retention
Inner Tracker Layout

IT: 1.3% of sensitive area
20% of tracks

Outer Tracker: straw tubes
Inner Tracker: silicon strips

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

336 IT modules: 11 and 22cm long

bending plane

4.5m
6m
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 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 ±5° 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

“D0-like” prototype cables 42cm and 54.5cm (Dyconnex)

- interstrip capacitance 0.17 pF/cm (simulation 0.154 pF/cm)
- pick-up noise can be kept small in laboratory (grounding!!)
- tests with thin copper mesh as backplane
  (simulation: $C_{\text{tot}} < 0.5$ pF/cm possible for 100µm substrate)

- test measurements including sensor+cable ongoing
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 (~70-80 µm)
- moderate radiation environment 1 Mrad/10 years or 9·10^{12} \text{ cm}^{-2} \text{ of 1-MeV neutron equivalent}

But:

- minimize: R/O channels \implies \text{large pitch } O(200 \text{ µm}) \text{ (charge collection)}
  \implies \text{long strips 33cm (noise)}
- minimize: material \implies \text{“thin” sensors (little charge)}
- 40 MHz, fast readout \implies (noise)
Sensors

6” wafer, high resistivity n-bulk, p+ strips
“standard” Hamamatsu design
designed for Inner Tracker tests:

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

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

⇒ charge collection with fast readout, ballistic deficit?
**Test Setup**

CERN test-beam and IR-laser

120GeV pions

testing of:
• 3 sensor ladders with CMS, GLAST, LHCb sensors (~ 30 cm)
• 2, 1 sensor ladders with LHCb sensors
• 1 CMS sensor + 60cm Kapton flex cable (laser only)
Pulseshape

fast readout in $O(\text{charge collection time})$

→ 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
Signal Remainder

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

**test-beam:**

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Capacitance (pF)</th>
<th>Remainder</th>
</tr>
</thead>
<tbody>
<tr>
<td>V1</td>
<td>100</td>
<td>0.15</td>
</tr>
<tr>
<td>V1</td>
<td>400</td>
<td>0.25</td>
</tr>
<tr>
<td>V2</td>
<td>100</td>
<td>0.35</td>
</tr>
<tr>
<td>V2</td>
<td>400</td>
<td>0.40</td>
</tr>
</tbody>
</table>

**laser setup:**

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

Graphs showing the relationship between capacitance and remainder for different voltages.
Cluster Shape

cluster shape reflects the shoulders seen in pulseshape scan

shoulder 8-18% depending on ladder length, pitch and (w/p)

![Cluster Shape Graph]

![Cluster Shape Diagram]
Signal / Noise

MPV $S/N$ from Landau $\otimes$ Gaussian fit:

$\rightarrow$ scaled to same thickness and same capacitance using measure Beetle front end response  

$ENC = 450 + 47 \times C \, /pF$

$LHCb : 9.6 \quad (C=50.6 \, pF)$

$GLAST : 10.4 \quad (C=41.3 \, pF)$

$CMS : 10.8 \quad (C=37.6 \, pF)$

{agree within 12%}
Spatially Resolved S/N

- **LHCb3 ladder**
- **GLAST ladder**
- **CMS ladder**

- large pitch → 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

- **LHCb3 ladder**
- **GLAST ladder**
- **CMS ladder**

Cluster finding adjusted to noise rate < 1.‰

Despite charge loss in between strips:

→ ~100% efficiency for thickness ≥ 400 µm
Summary

• LHCb Si-Tracker uses silicon modules with large pitch of ~200µm 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