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Silicon Strip Detectors for the LHCb Experiment

Olaf Steinkamp

Physik-Institut der Universität Zürich
Winterthurerstrasse 190 CH-8057 Zürich
olaf.steinkamp@physik.unizh.ch

LHCb Detector

Trigger Tracker
(TT)

Inner Tracker (IT 1-3)

Vertex Locator
(VELO)

VELO Layout

Detector design optimised for:

- Level-1 trigger algorithm using large-impact parameter tracks from B decay vertices
=> r/ϕ strip geometry for fast 2D tracking algorithm in rz plane
- precise reconstruction of B production and decay vertices
=> detectors installed inside LHC beam pipe
- also: main tracking device upstream of spectrometer magnet
=> 84 silicon sensors, 0.27 m^2 , 170k readout strips

VELO Mechanics

Detectors installed inside LHC vacuum chamber:

- separated from beam vacuum by 300 μm thick corrugated aluminium foil
- detector halves retractable for beam injection

Complex strip layout to optimise for occupancy and spatial resolution:

- active area from 8 mm to 42 mm
- thickness: 200 μm or 300 μm (tbd)
- r-measuring sensors:
 - strips divided into 45° sectors,
 - strip pitch increasing with radius from 40 μm to 100 μm
- ϕ -measuring sensors:
 - inner / outer region
 - strip pitch "naturally" increasing with radius from 36 μm to 97 μm
 - stereo angles of -20° resp. $+10^\circ$
- 2nd metal layer to route signals to f/e chips

VELO Radiation Environment

Innermost strips only 8 mm from LHC beam axis:

- expect up to 1.3×10^{14} 1-MeV equiv. neutrons / cm^2 / year
- extensive R&D program on irradiated silicon sensors

- main lesson learnt: use n-o-n detectors
 - work reasonably well even when underdepleted
- still: expect to replace detectors after a few years

Inner Tracker

Tracking downstream of magnet:

- 3 stations x 4 detection layers (xuvx)
- 1-sensor ladders above/below beam pipe
- 2-sensor ladders left/right of beam pipe

Silicon sensors (HPK):

- single-sided p-on-n
- 300 μm / 400 μm thick
- 108 mm long strips
- 384 readout strips
- 198 μm pitch
- 50 μm wide implants

=> 336 silicon ladders, 4.2 m², 130k readout strips

Trigger Tracker

CMS-OB2 sensors (HPK):

- p-on-n, 500 μm thick
- 91.57 mm long strips
- 512 readout strips
- 183 μm pitch
- 46 μm wide implants

=> 280 readout sectors, 7.9 m^2 , 143k readout strips

Level-1 trigger / tracking upstream of magnet:

- 4 detection layers
- 14-sensor ladders left/right of beam pipe
- 7-sensor ladders above/below beam pipe
- each ladder several readout sectors
- all hybrids outside of acceptance

Beetle Front-End Chip

Common development for LHCb silicon detectors:

- designed to meet LHCb trigger requirements
 - 0.25 μm CMOS, tested up to 40 Mrad
 - triple-redundant logic
 - 128 channels, analog pipeline
 - multiplexed readout via four analog ports
 - front-end amplifier optimised for speed and noise performance
- => adjustable shaping time !

VELO: 16-chip hybrid

Inner Tracker: 3-chip hybrid
(Trigger Tracker: 4-chips)

Silicon Tracker R&D

Main challenge: optimise detector for conflicting requirements of

- long readout strips $\Leftrightarrow$ large strip capacitances
 - fast shaping times to avoid overlapping events
- } NOISE !

Extensive R&D program to optimise:

- front-end amplifier
 - sensor thickness
- } silicon ladders of various lengths and thicknesses

Silicon Tracker R&D

Main lessons learnt:

- performance uniform over full length of readout strips
- significant cross talk from capacitive coupling between strips
- significant signal loss in central region between two strips

N.B.: radiation load after 10 years $< 10^{14}$ 1-MeV equiv. neutrons / cm²:

- expect no problem for sensor performance
- operating temperature $< 5^{\circ}\text{C}$ to suppress leakage currents & shot noise

Digital Optical Readout Link

Detector Box:
< 1 Mrad / 10 years

Service Box:
~10 krad / 10 years

Common development for most LHCb detectors (VELO: analog copper link)

Lessons learnt from R&D and engineering phase:

- try to keep things simple (not always possible !)
- use existing solutions where available
- develop common solutions where possible (politically not always easy !)
- n-on-n for best performance in harsh radiation environment
- significant charge loss in between readout strips for large pitch
- significant cross talk to neighbouring strips for long readout strips

Production & commissioning phase starting:

- many lessons to be learnt over the next couple of years ...