5th International Symposium on the
Development and Application of
Semiconductor Tracking Detectors
Hiroshima — June 14, 2004

Silicon Strip Detectors for the LHCb Experiment

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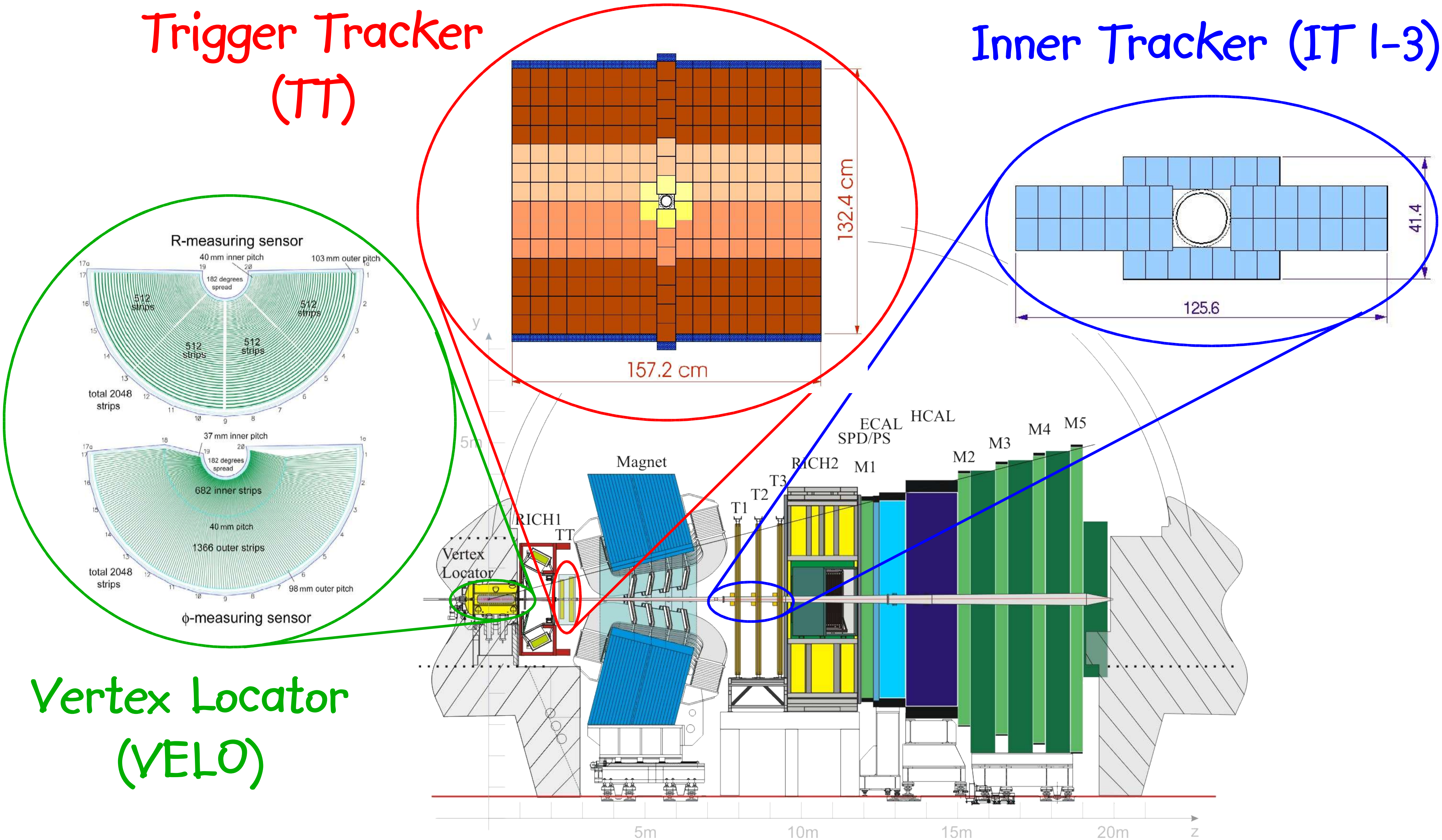
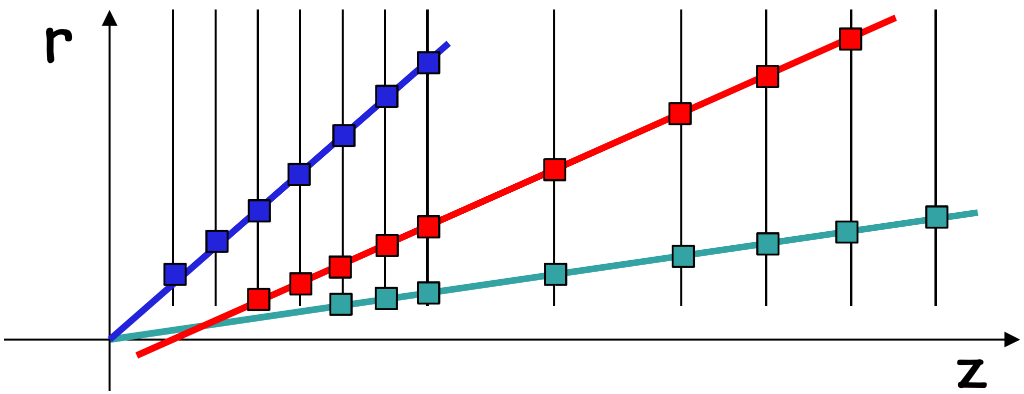
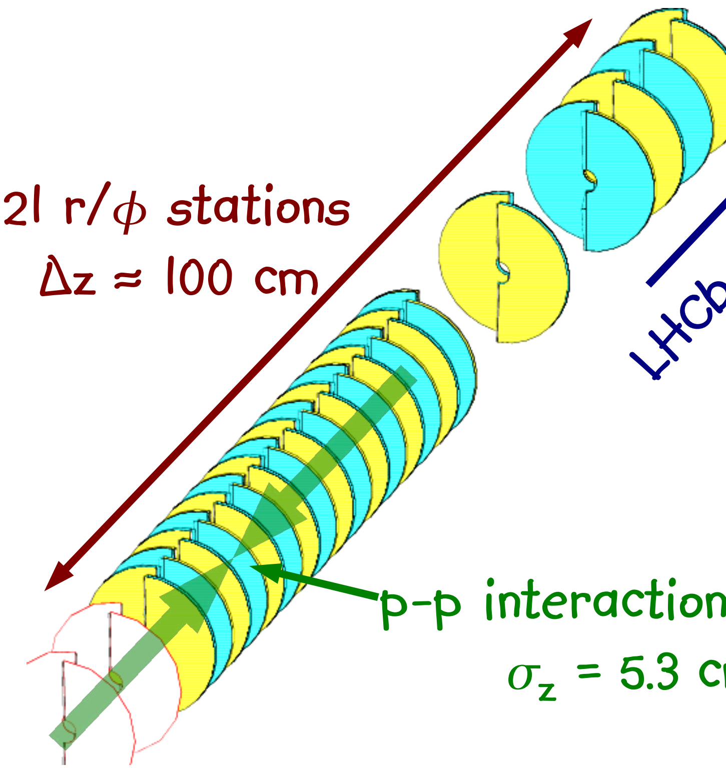
LHCb Detector



VELO Layout





Detector design optimised for:

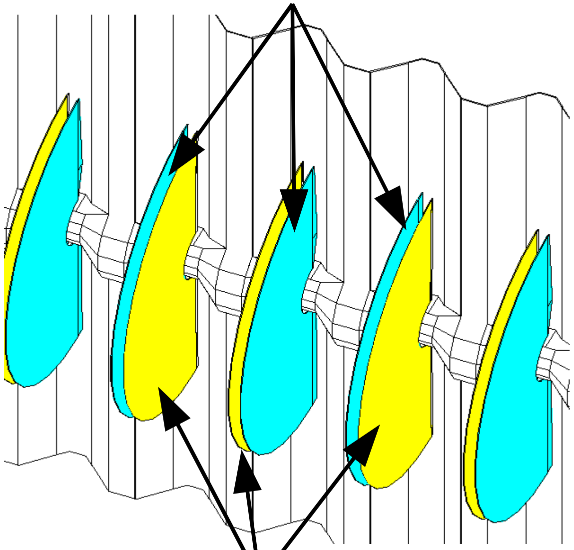
- Level-1 trigger algorithm using large-impact parameter tracks from B decay vertices
  => r/ϕ strip geometry for fast 2D tracking algorithm in rz plane
- precise reconstruction of B production and decay vertices
  => detectors installed inside LHC beam pipe
- also: main tracking device upstream of spectrometer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

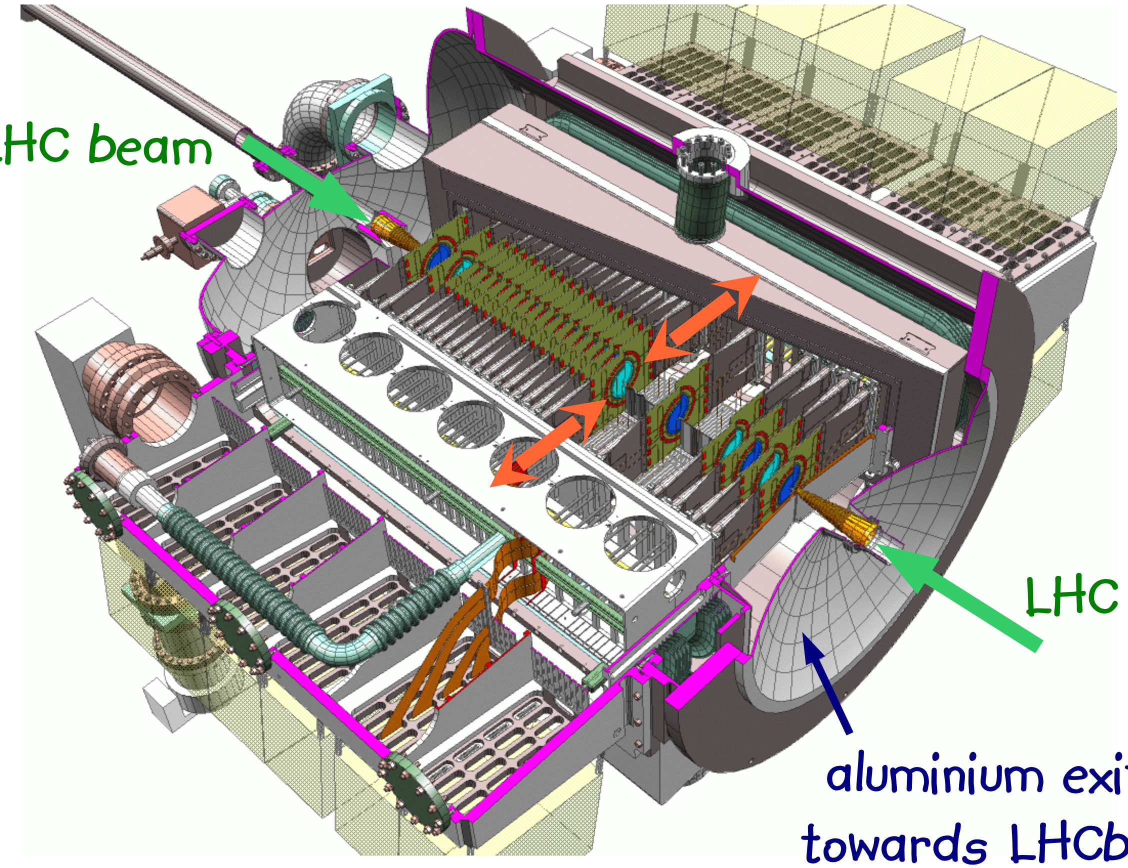
=> 84 silicon sensors, 0.27 m^2, 170k readout strips

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

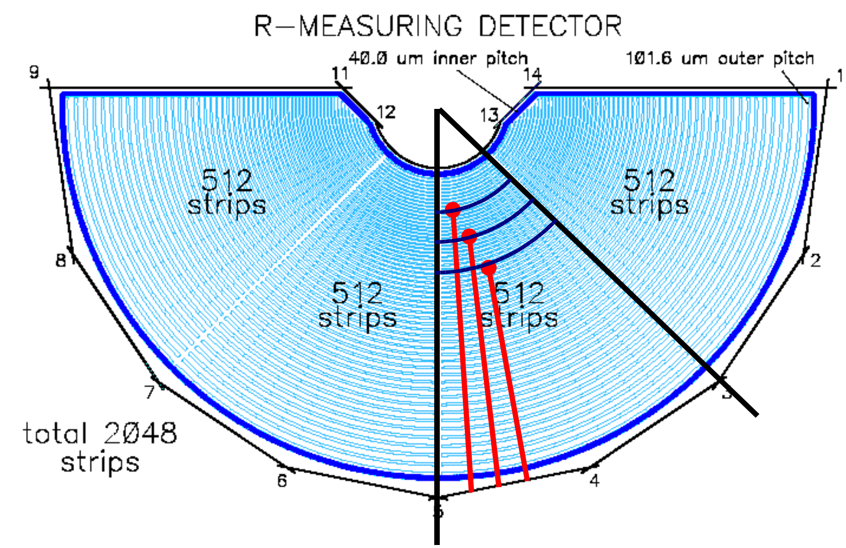


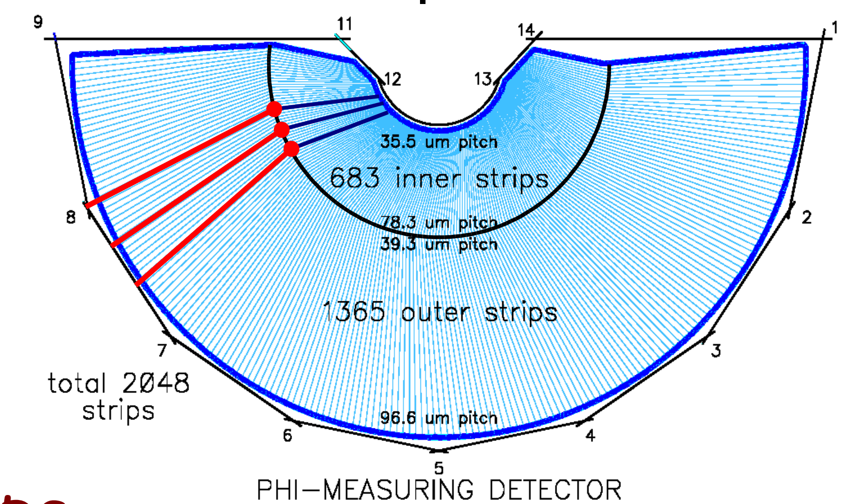


VELO Silicon Sensors

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°
- 2nd metal layer to route signals to f/e chips

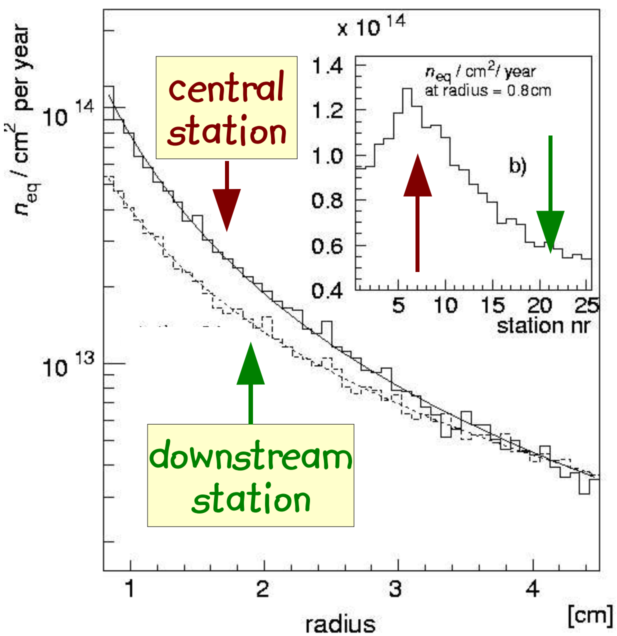


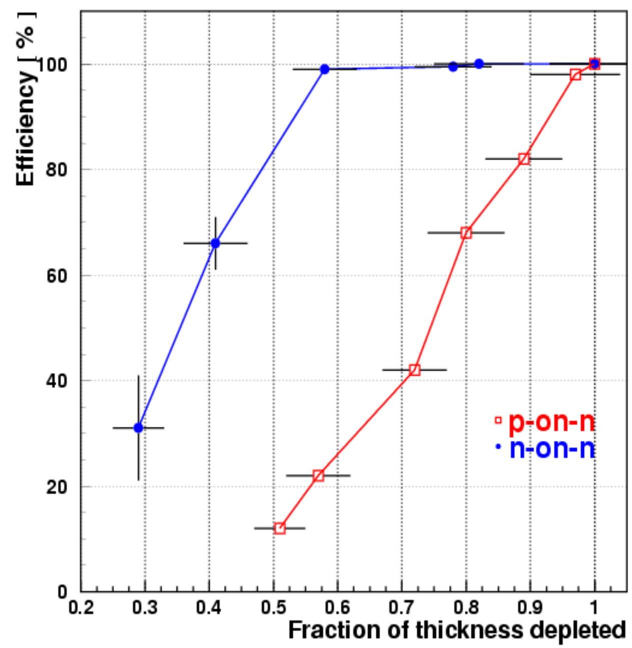


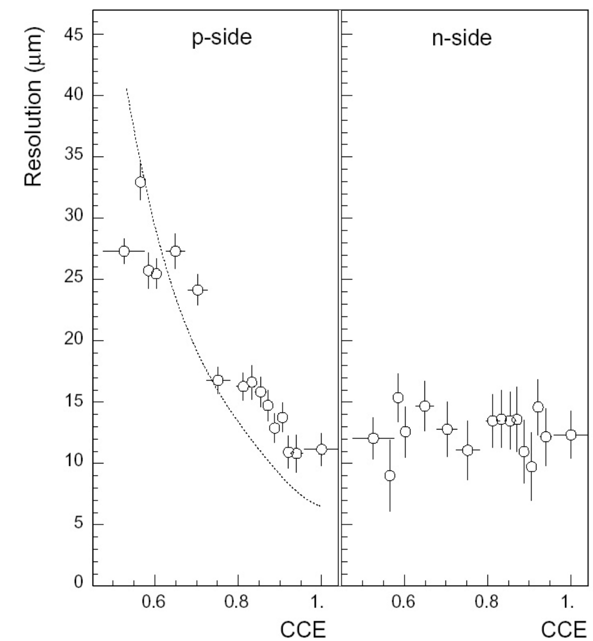
VELO Radiation Environment

Innermost strips only 8 mm from LHC beam axis:

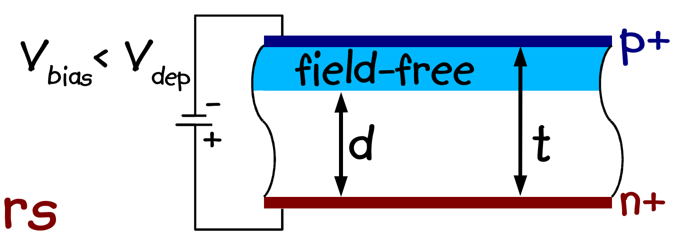
- expect up to 1.3 x 10^{14} 1-MeV equiv. neutrons / cm^2 / year
- extensive R&D program on irradiated silicon sensors



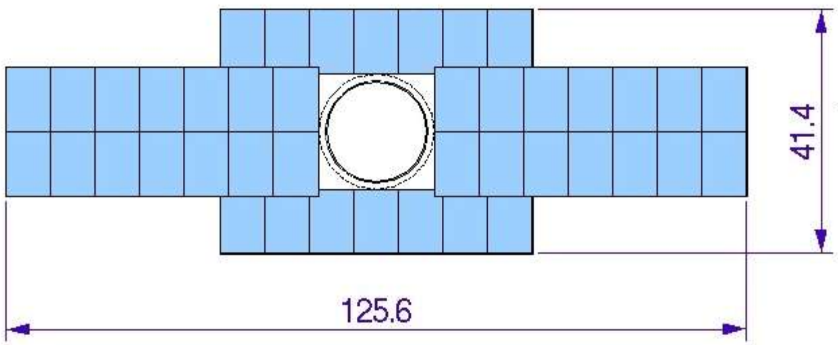




- main lesson learnt: use n-o-n detectors
  - work reasonably well even when underdepleted
- still: expect to replace detectors after a few years

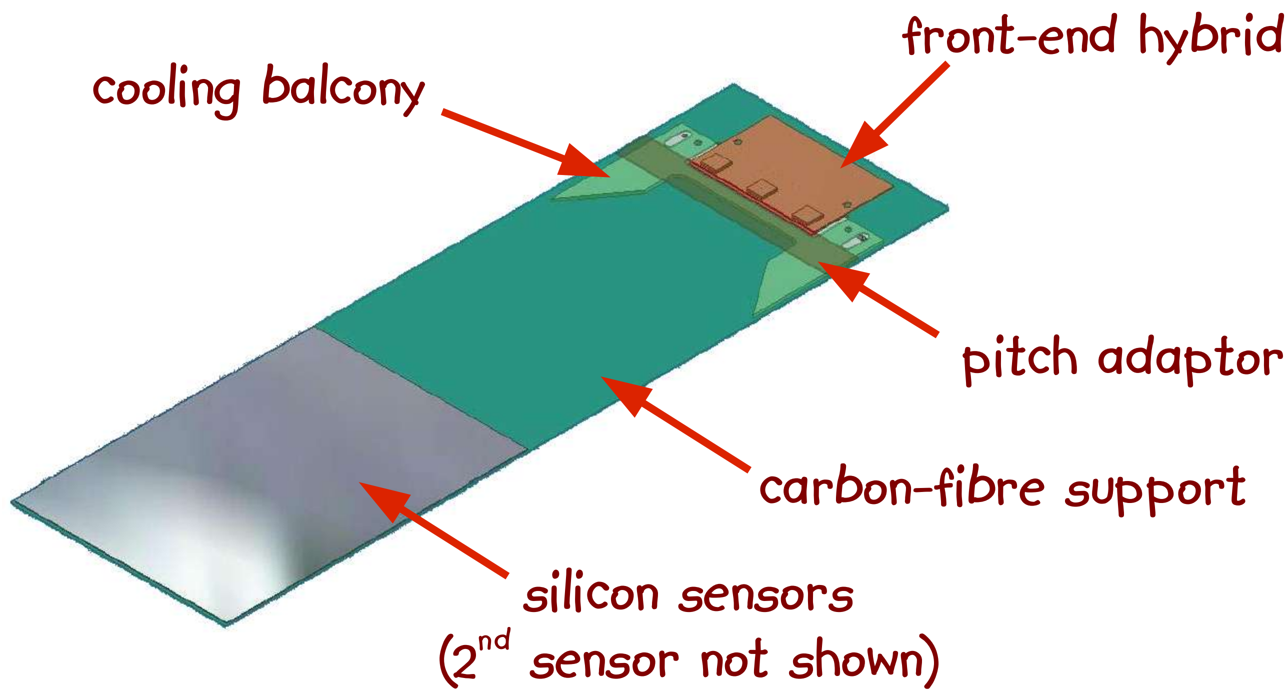


Inner Tracker



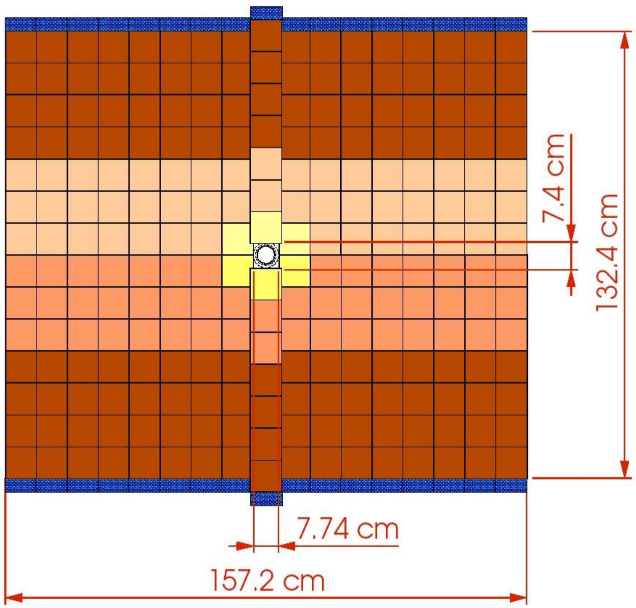
Tracking downstream of magnet:
- 3 stations x 4 detection layers (xuvx)
- 1-sensor ladders above/below beam pipe
- 2-sensor ladders left/right of beam pipe

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



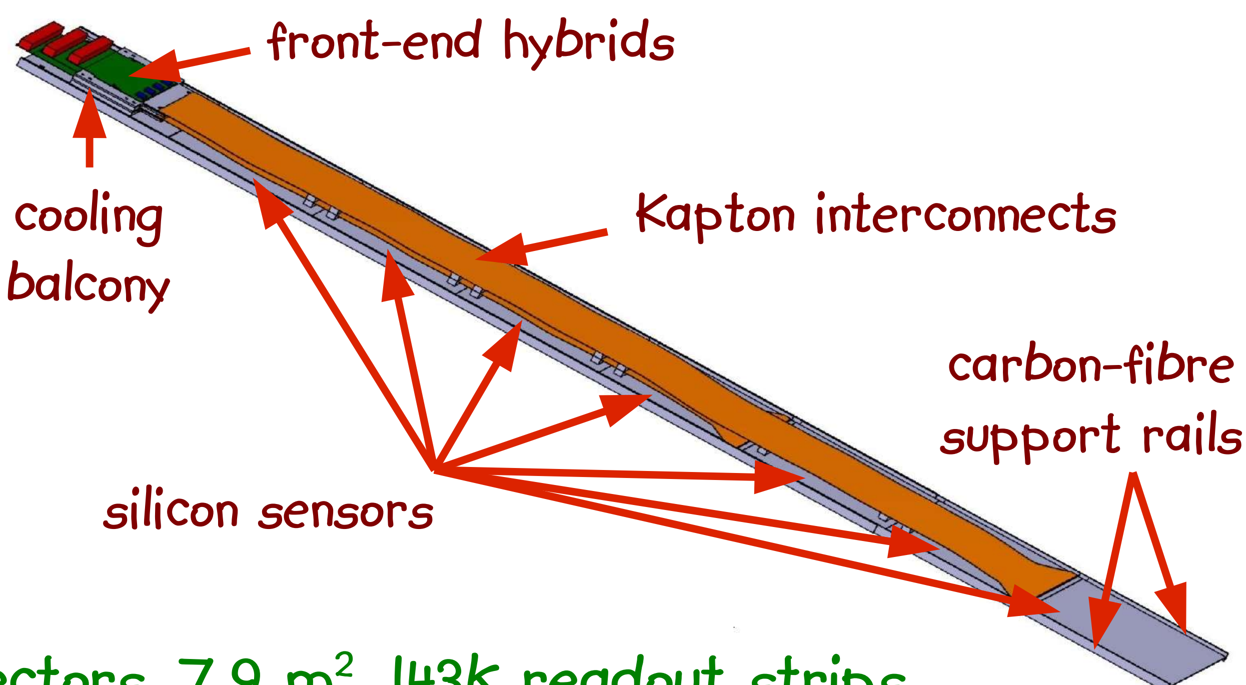
=> 336 silicon ladders, 4.2 m^2, 130K readout strips

Trigger Tracker



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



CMS-OB2 sensors (HPK):

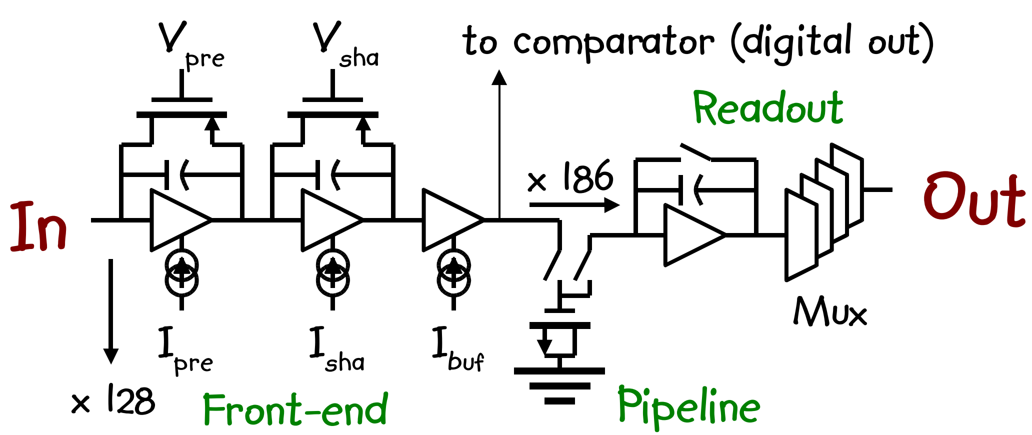
- p-on-n, 500 µm thick
- 91.57 mm long strips
- 512 readout strips
- 183 µm pitch
- 46 µm wide implants

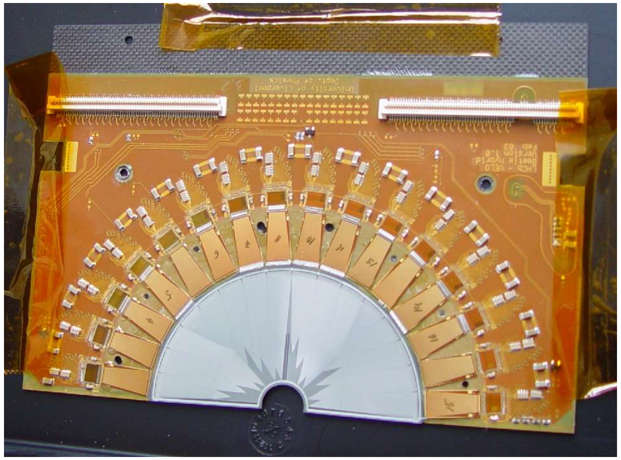
=> 280 readout sectors, 7.9 m^2, 143k readout strips

Beetle Front-End Chip

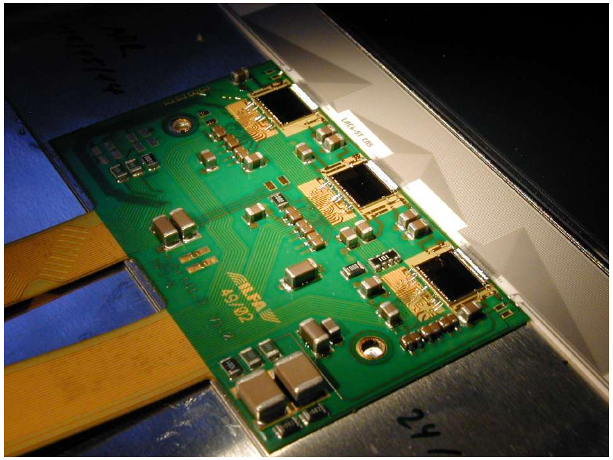
Common development for LHCb silicon detectors:

- 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 !



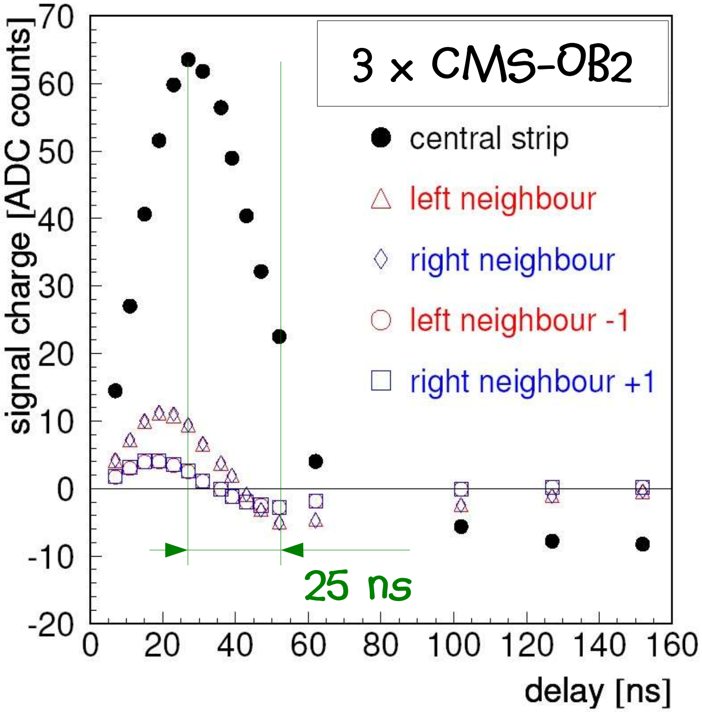


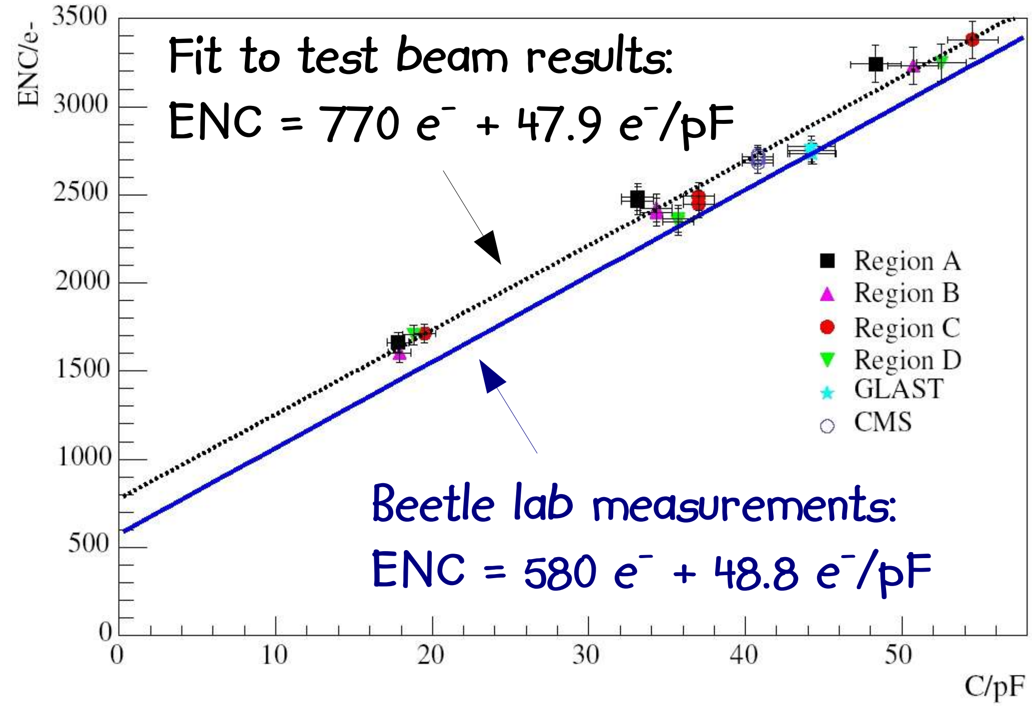
VELO: 16-chip hybrid



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

Silicon Tracker R&D





<u>Main challenge: optimise detector for conflicting requirements of</u>

- long readout strips <=> large strip capacitances
- fast shaping times to avoid overlapping events

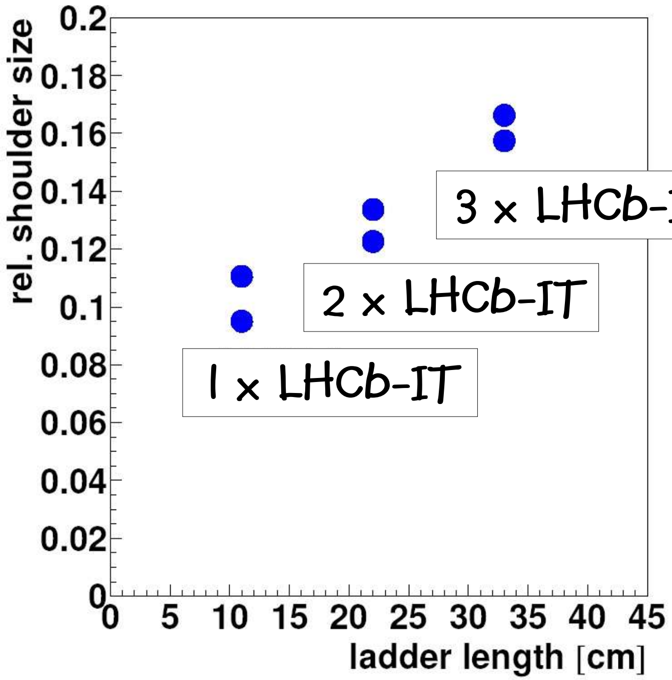
} NOISE !

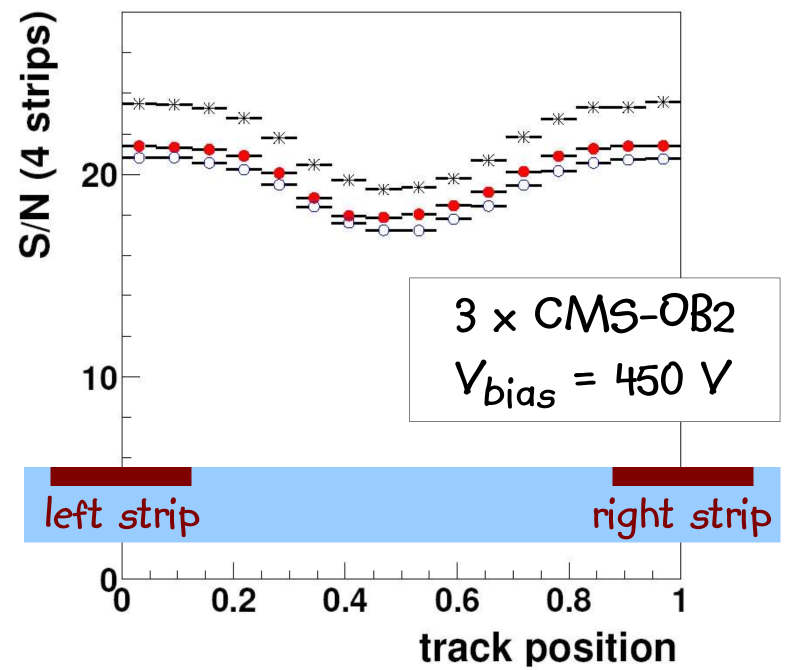
<u>Extensive R&D program to optimise:</u>

- front-end amplifier
- sensor thickness

} silicon ladders of various lengths and thicknesses

Silicon Tracker R&D





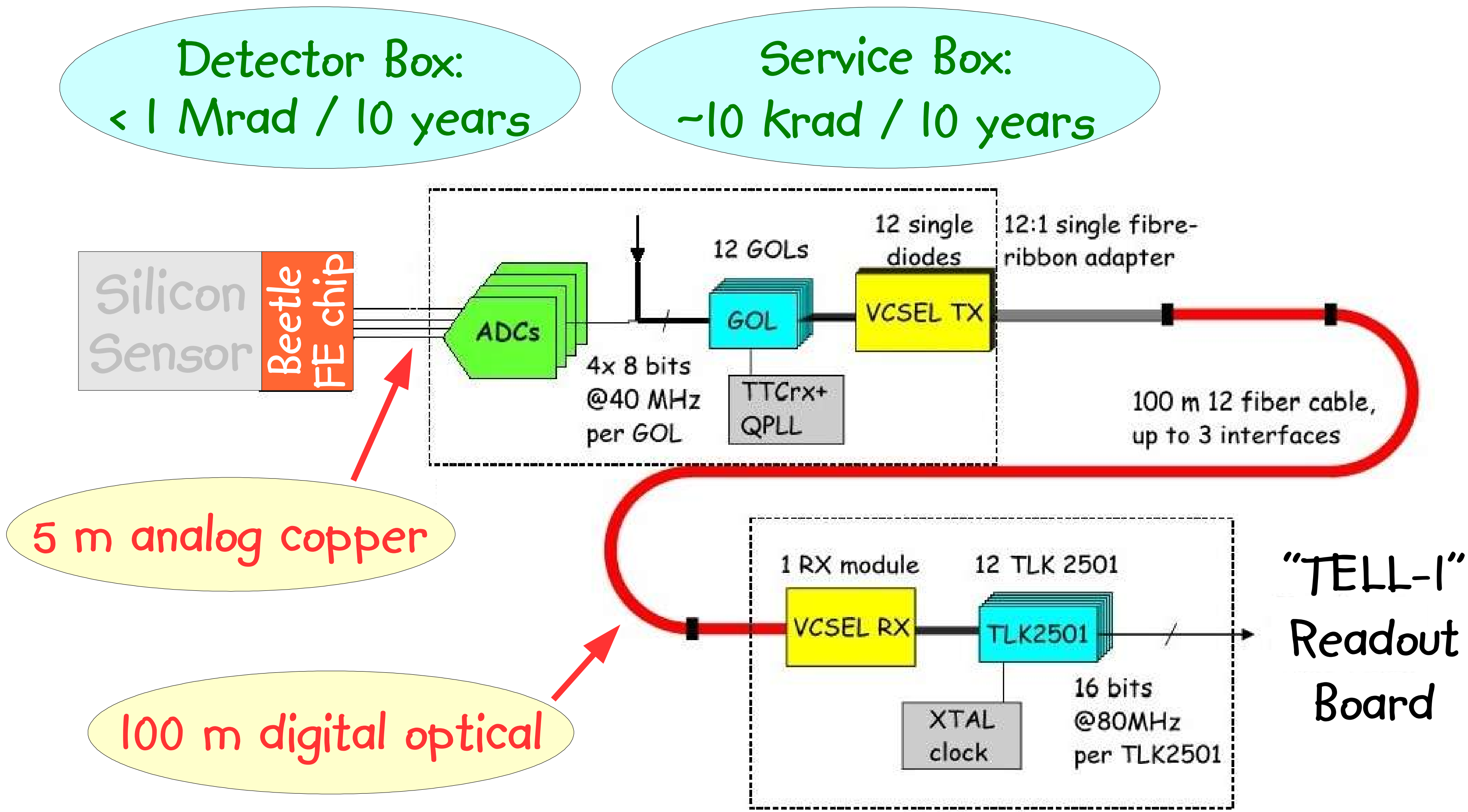
Main lessons learnt:

- 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 / cm^2:

- expect no problem for sensor performance
- operating temperature < 5°C to suppress leakage currents & shot noise

Digital Optical Readout Link



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

Summary

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 enviroment
- 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 ...