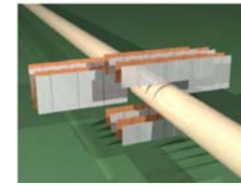
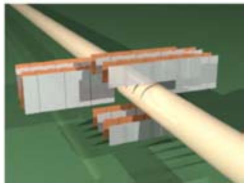


The LHCb Silicon Tracker, design and test results.

Helge Voss
for the LHCb Si-Tracker

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

LHCb Introduction

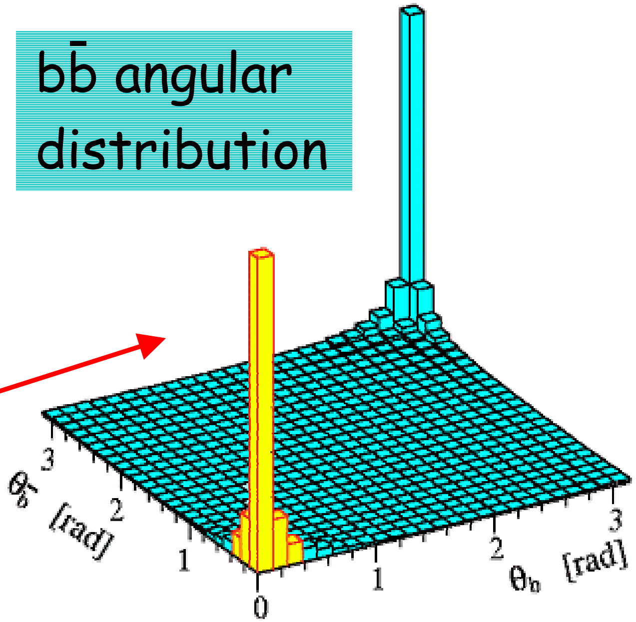


LHC: "b-factory" with 10^{12} $b\bar{b}$/year

pp@14 TeV, lumi=$2 \bullet 10^{32}$ $cm^{-2}s^{-1}$

(compared to 10^7 at Υ(4S))

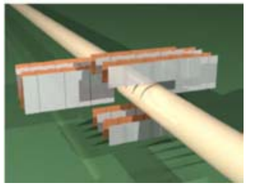
full B spectrum B, B_s



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

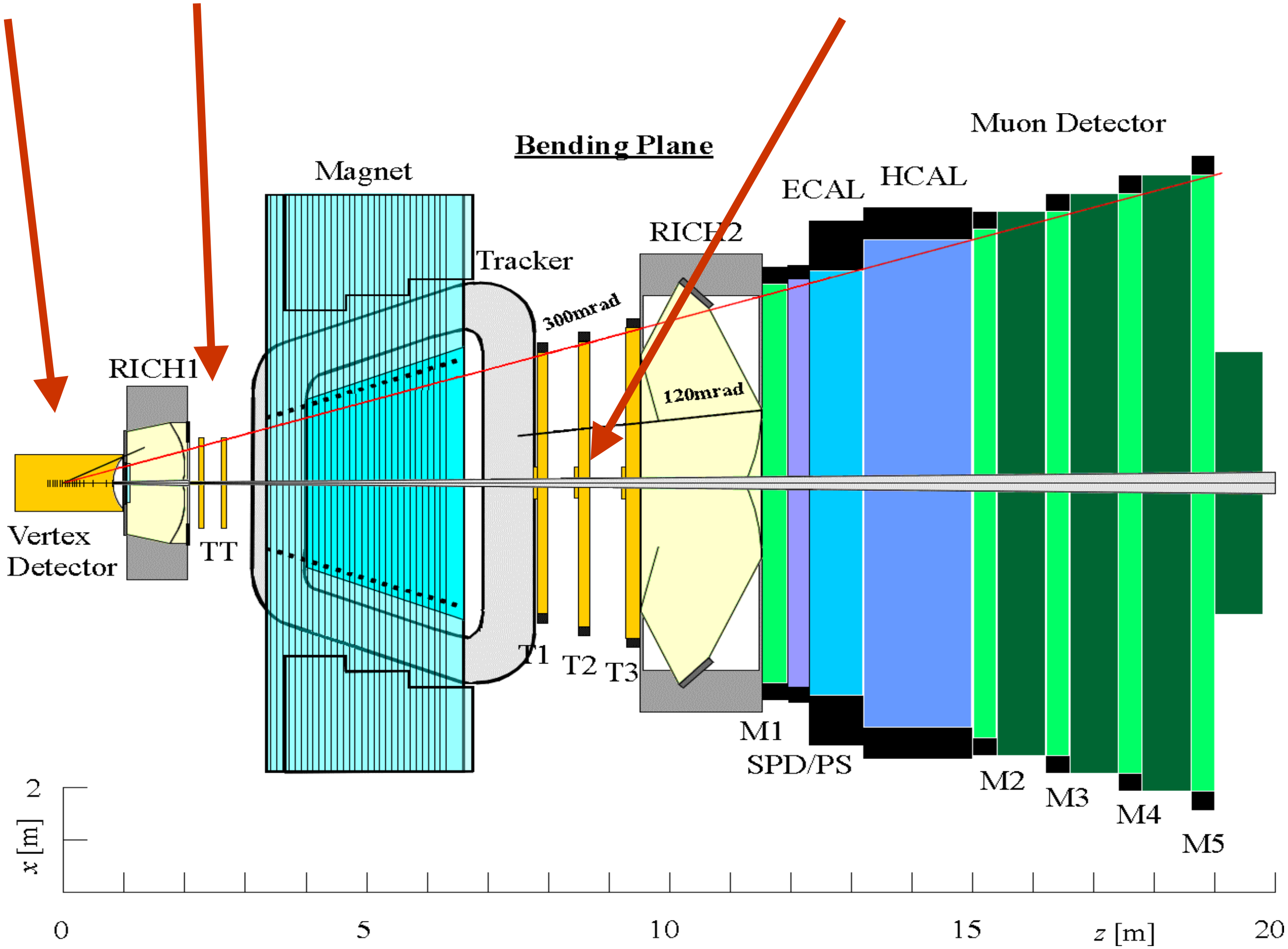
CP violation and other rare phenomena in the B-system

The LHCb Experiment



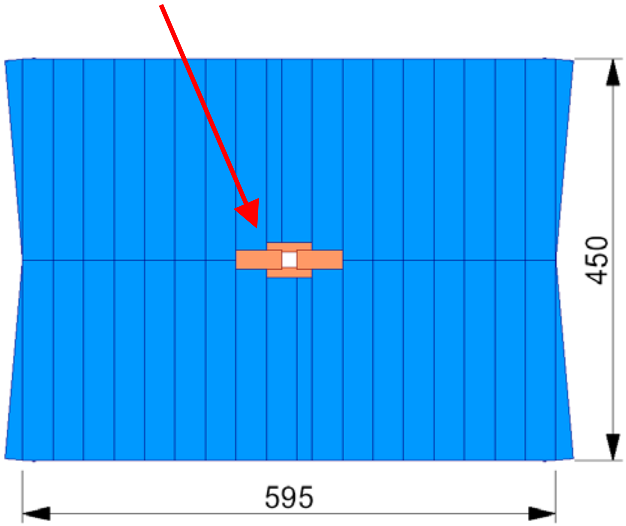
tracking detectors:

VELO, TT-Station, Inner- and Outer Tracker

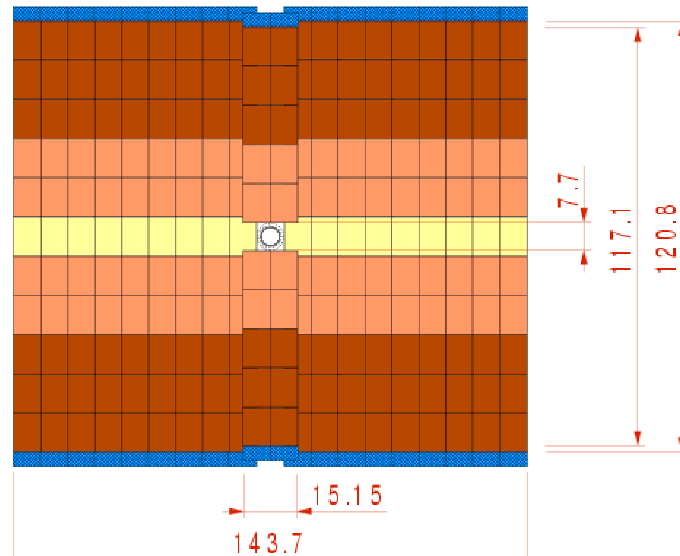


LHCb Silicon Tracker

Inner Tracker



TT-Station



12.5m² active area (4.3m² IT + 8.2m² TT)

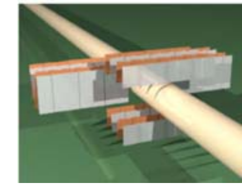
~310k readout channels

use: "same" silicon sensors

same readout chip, hybrid, readout link, etc.

modules of 1, 2 or 3 sensors

Why Silicon ?



Inner Tracker

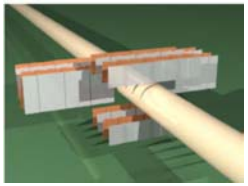
- fine granularity → tolerable occupancy (<1%) in region of large particle density (~ 10^5 $cm^{-2}s^{-1}$)
- good hit finding efficiency (~100%)
- good spatial resolution (dp/p ~ 3‰ @ 20 GeV)

TT-Station

P_T info in L1 trigger

- fast readout
- good spatial resolution

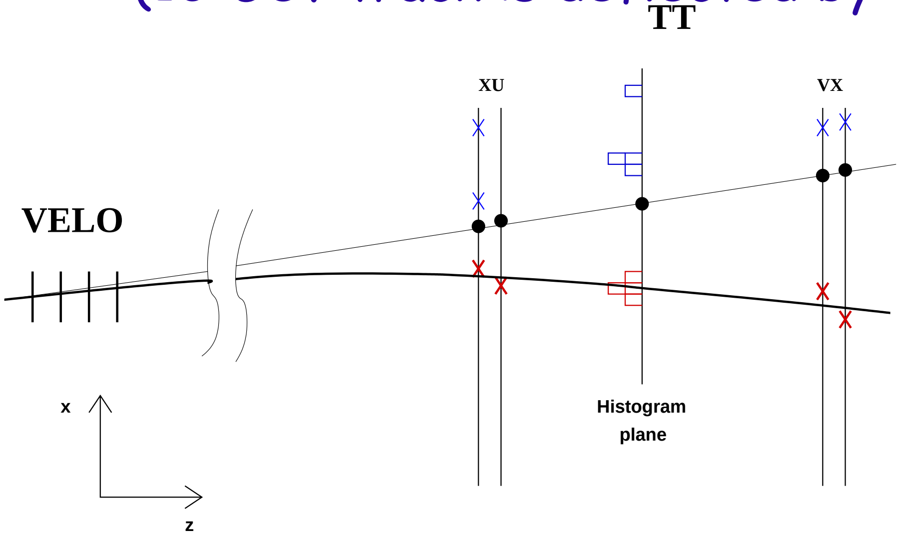
Why Silicon: L1-Trigger

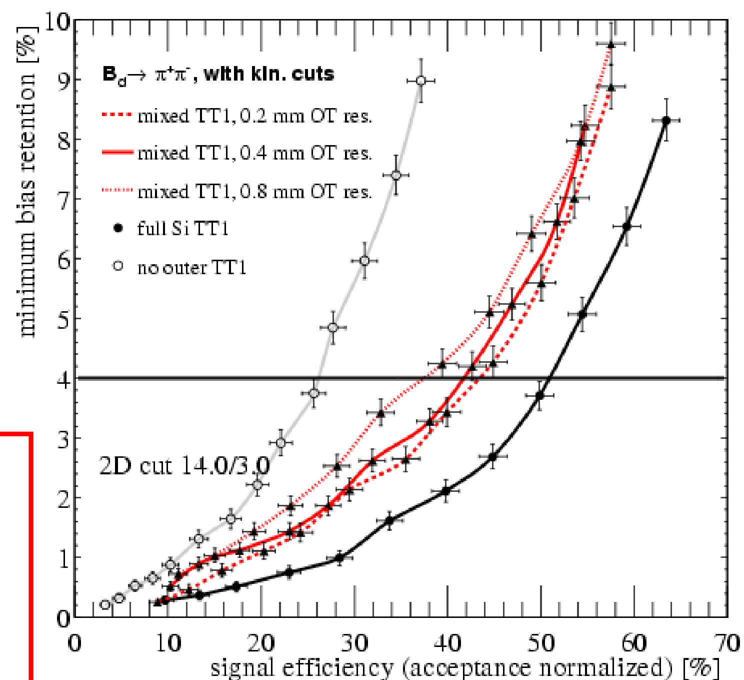


How does the improved spatial resolution of Si-strips w.r.t. straw tubes improves the trigger?

L1: P_T from VELO and TT track segment

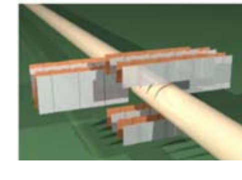
(10-GeV track is deflected by ~3.4 mm at TT)





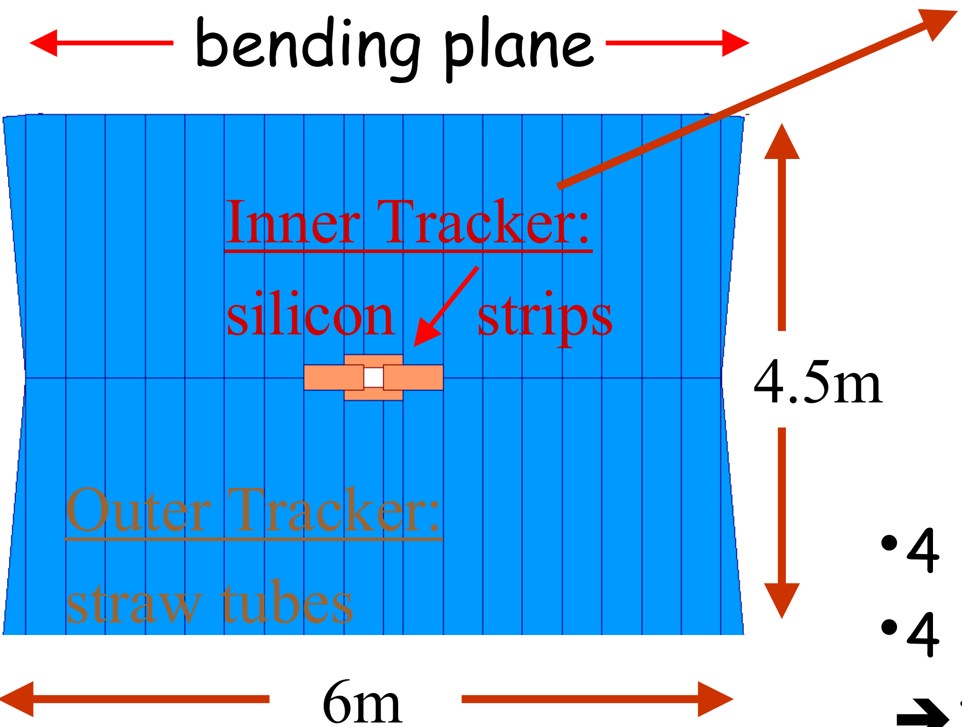
better resolution
→ better hit matching
→ better minimum bias retention

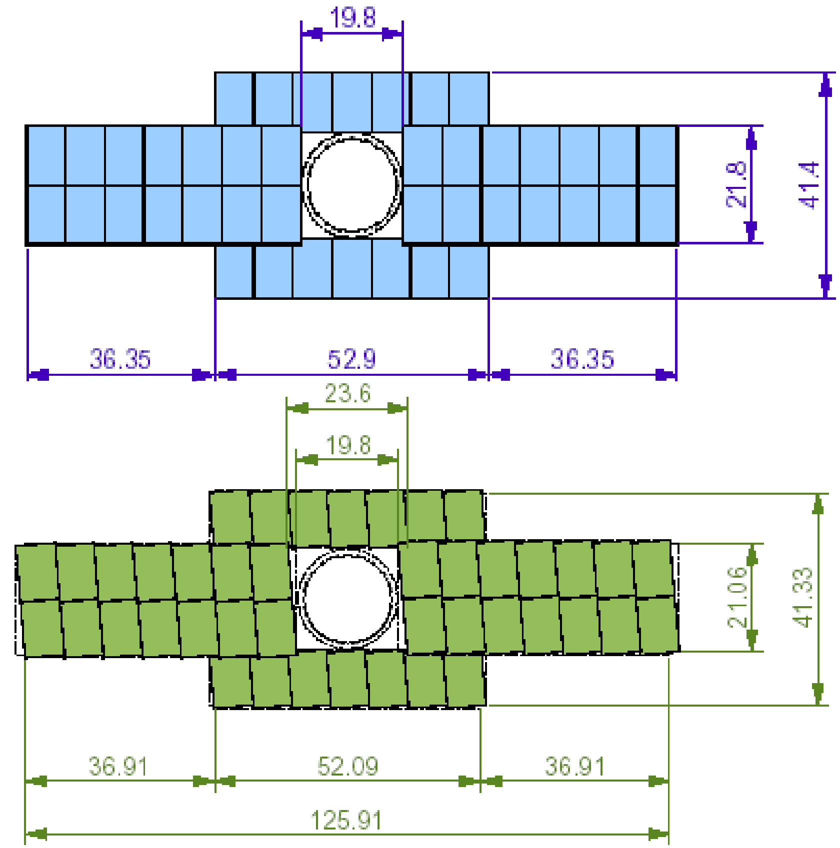
Inner Tracker Layout



IT: 1.3% of sensitive area

20% of tracks

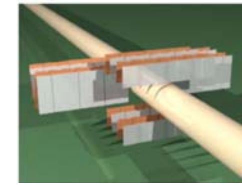




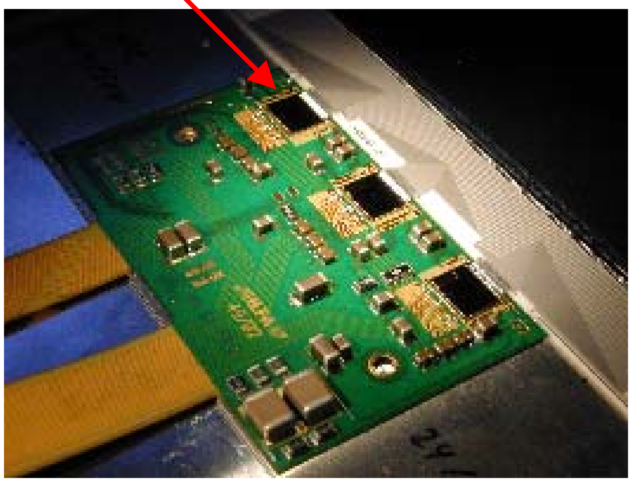
- 4 individual boxes per station
- 4 layers per station:(2 stereo layers)

➔336 IT modules: 11 and 22cm long

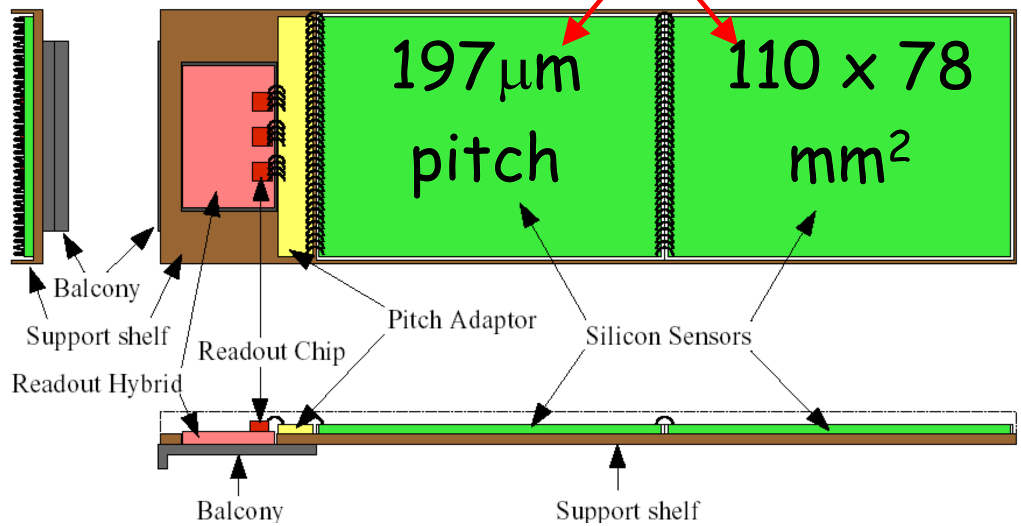
Inner Tracker Modules



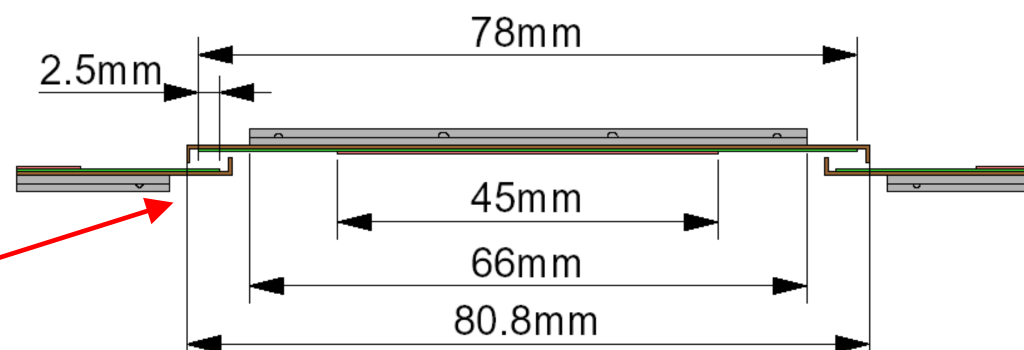
readout hybrid with 3 Beetle chips



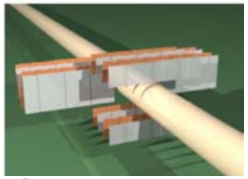
module (ladder) with 2 SI sensors



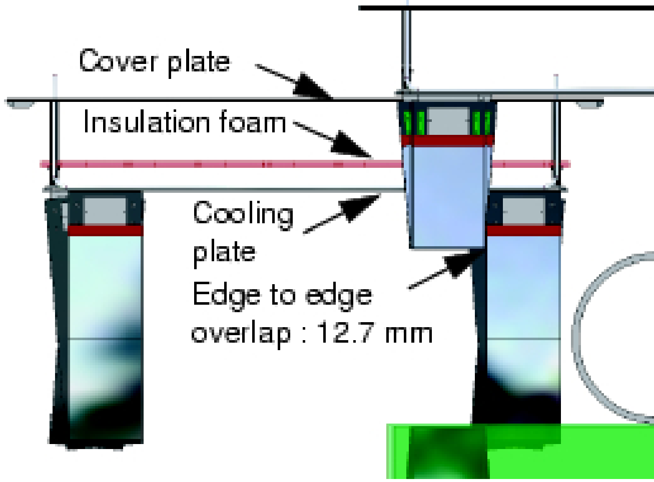
overlapping of adjacent modules

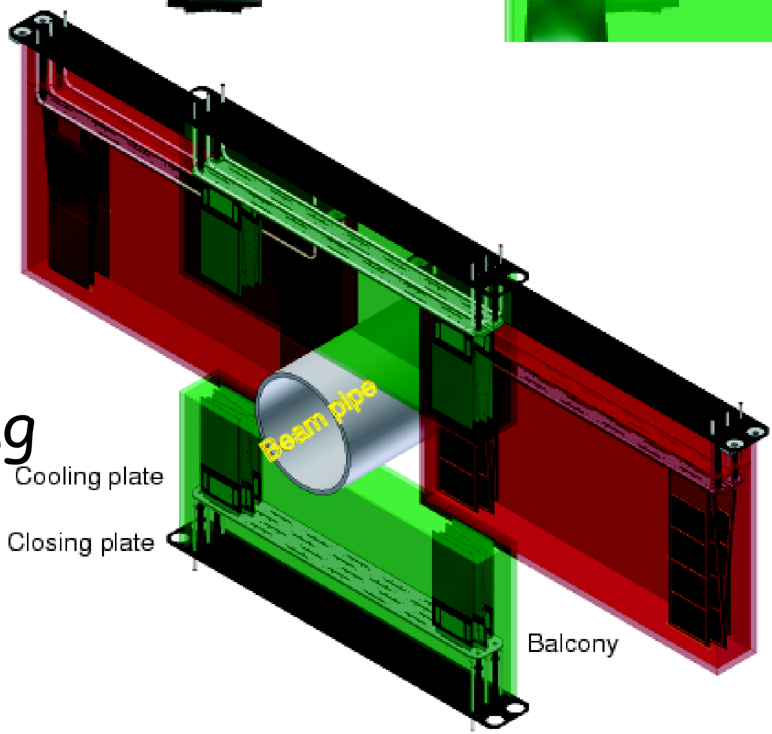


Inner Tracker Design

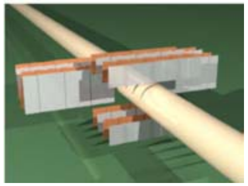


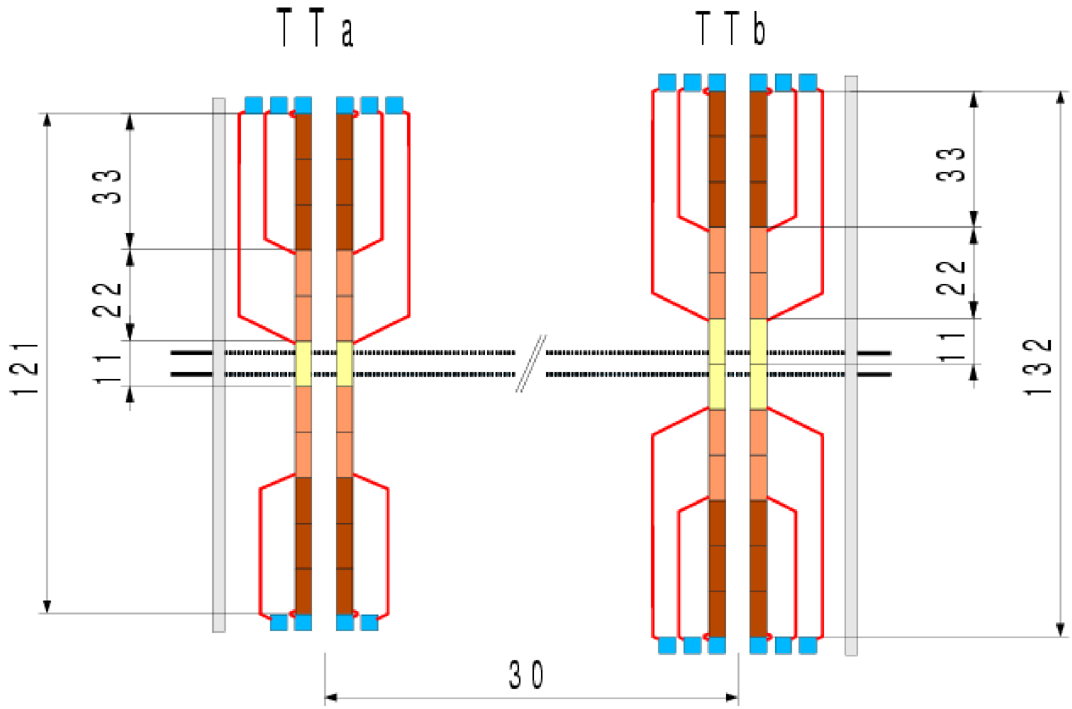
- cross shaped station consists of individual boxes
- each box houses 28 ladders (4 layers)
- operation at ~5°C
  - cooling plate with cooling pipes
  - balconies +
    CF support (AmocoK1100/Mitsubishi K13C2U) conduct cooling for hybrid and sensors
- box enclosure lightweight isolation foam + Al foil for electrical shielding
- cover – and cooling plate provide rigidity

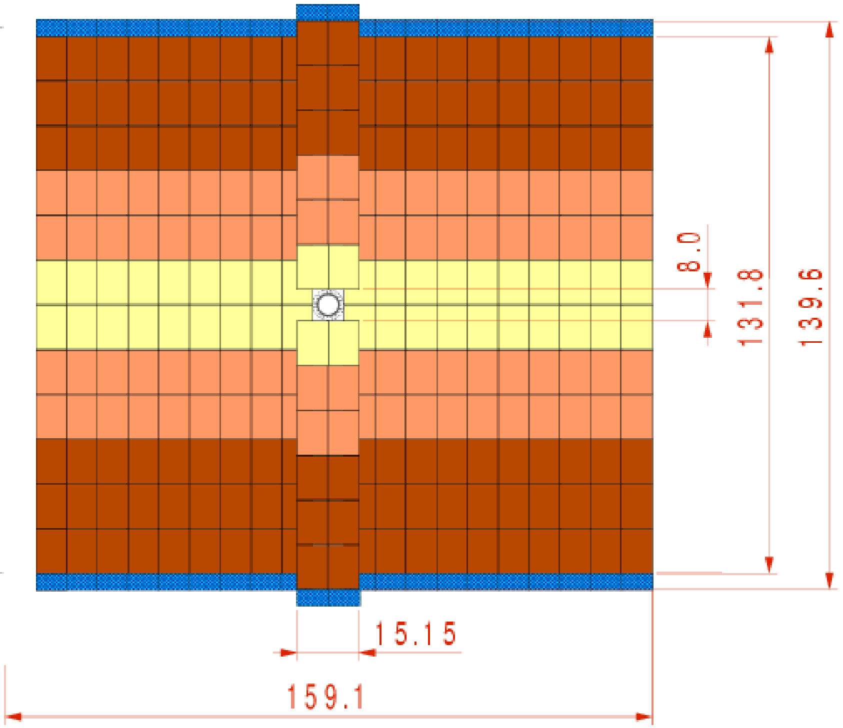




TT-Station Layout

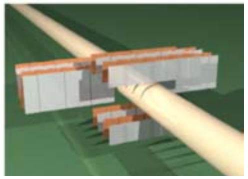




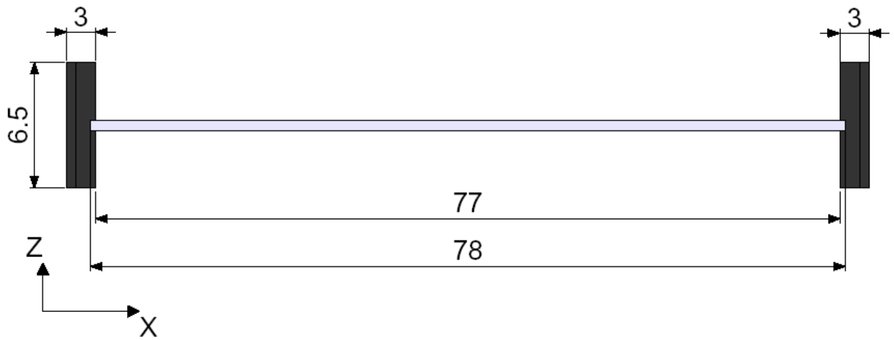


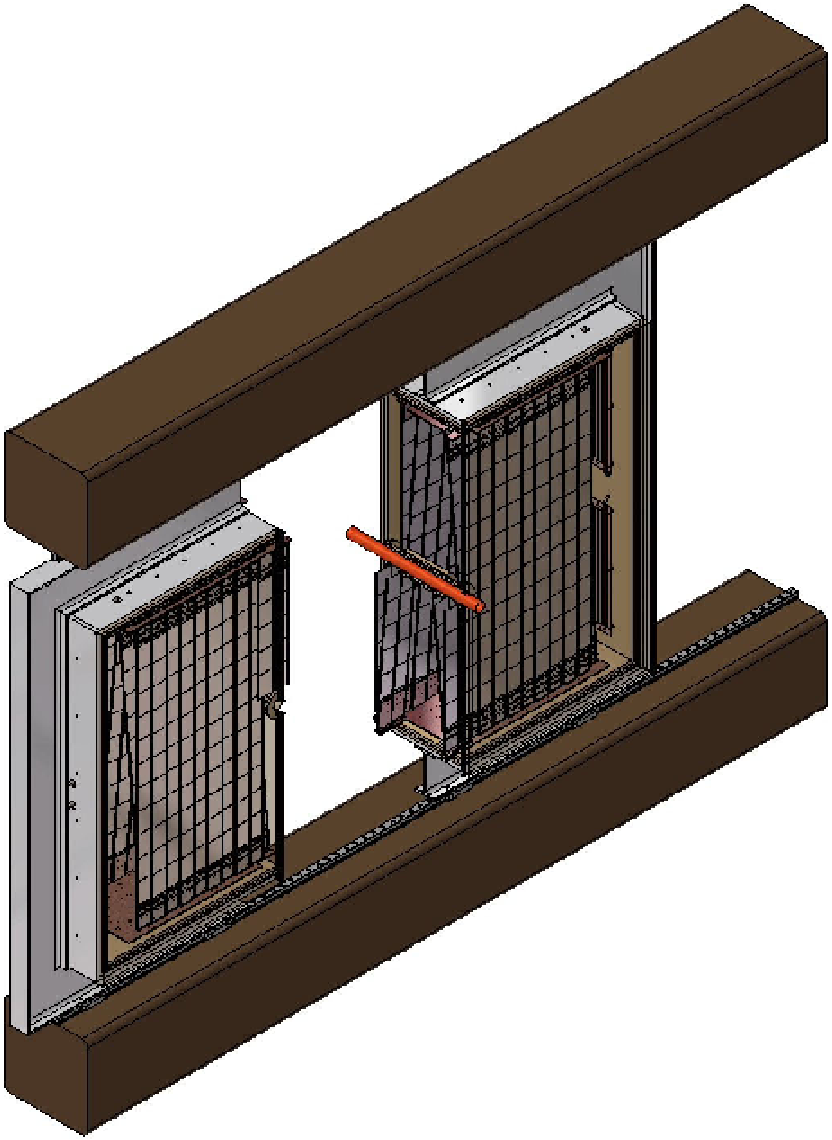
- 4 layers in 2 half stations, 2 layers ±5° stereo angle
- 11cm, 22cm and 33cm long modules
- all readout hybrids at the edge outside of the acceptance
- inner modules connected via Kapton interconnect cable

TT-Station Design



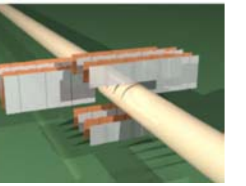
- modules are connected to 11 (12) sensor long ladders supported by carbon fibre rails





- 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

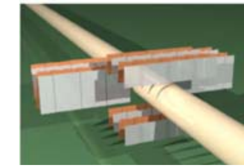
"D0-like" prototype cables 42cm and 54.5cm (Dyconnex)

- 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_{tot}<0.5 pF/cm possible for 100μm substrate)

➔test measurements including sensor+cable ongoing

Readout Chain

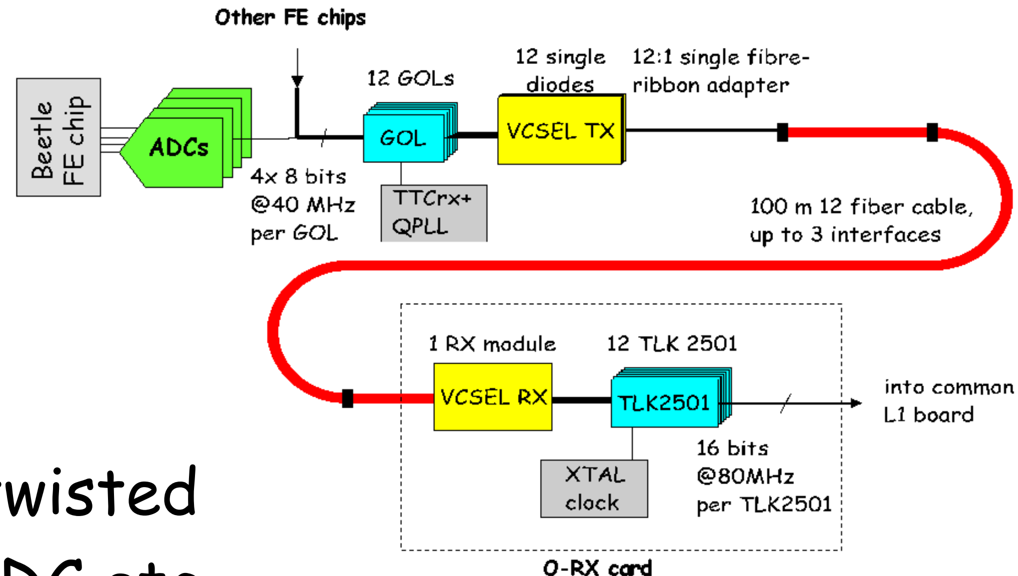


Beetle (1.2) readout chip:

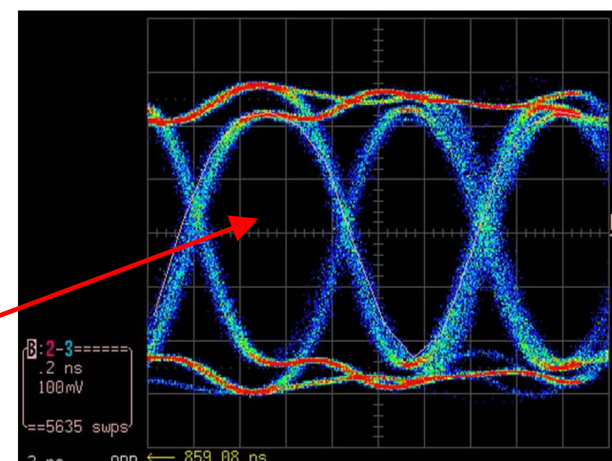
- 40MHz clock, 128 channels
- multiplexed 4x32
  - → 900ns readout
- pipelined for 183 BX
- rad. hard 0.25μm CMOS

differential output via 5m twisted
 pair cable → amplifier, ADC etc.
 outside detector acceptance

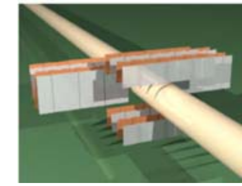
digital signals multiplexed and sent
 via 100m optical fibre



good signal integrity demonstrated in "eye pattern"



Challenges of SI Detector



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

But:

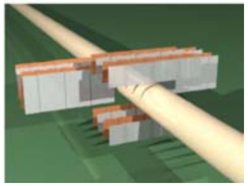
minimize: R/O channels ⇒ large pitch O(200μm) (charge collection)

⇒ long strips 33cm (noise)

minimize: material ⇒ "thin" sensors (little charge)

40MHz, fast readout ⇒ (noise)

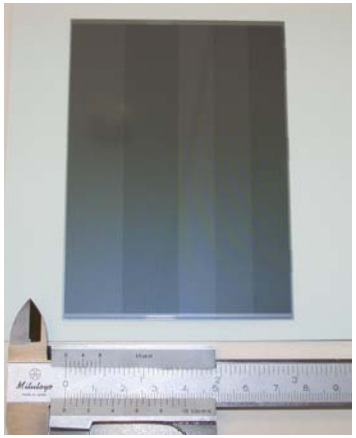
Sensors



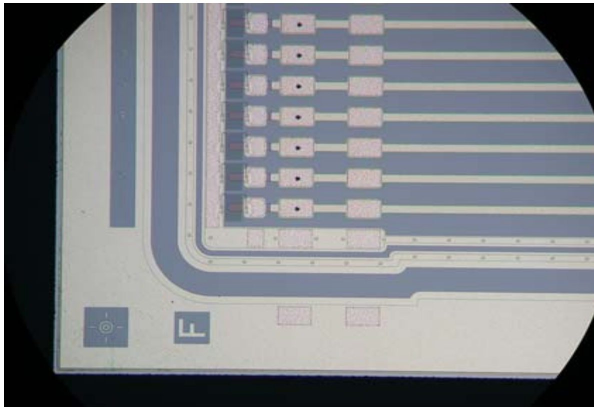
6" wafer, high resistivity n-bulk, p+ strips

"standard" Hamamatsu design

designed for Inner Tracker tests:



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



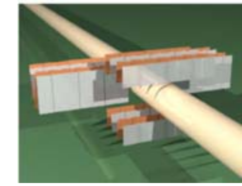
33cm ladder in TT: use thicker sensors

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

GLAST (410μm, 228μm pitch ,w/p=0.25)

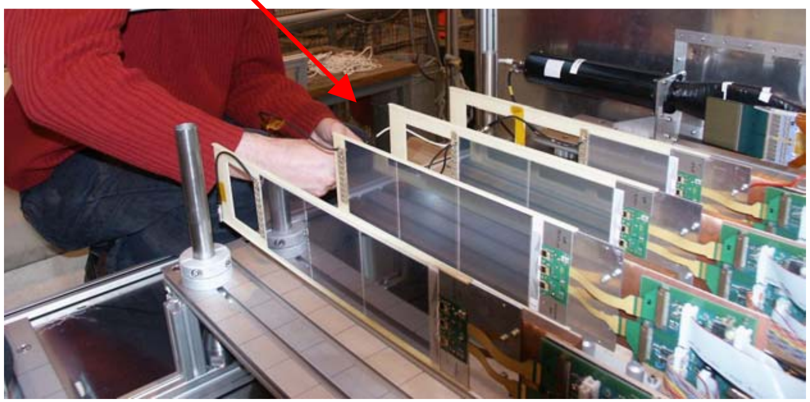
➔ charge collection with fast readout, ballistic deficit ?

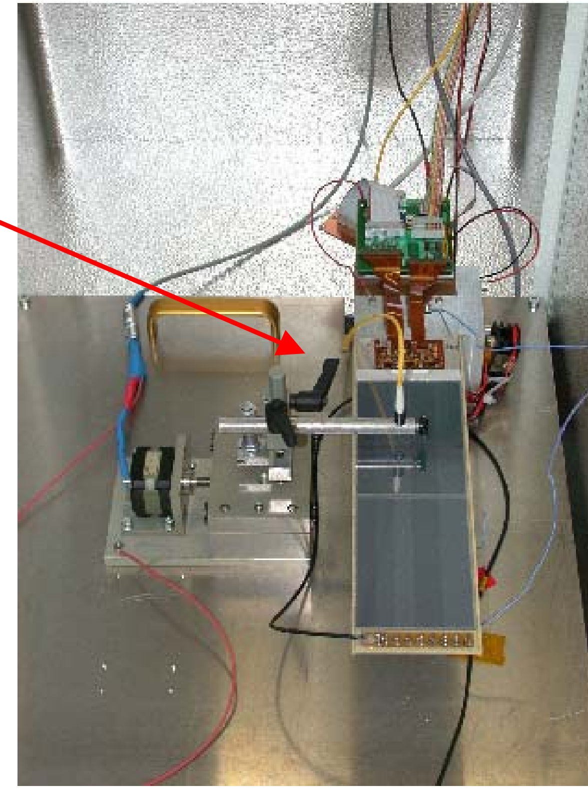
Test Setup



CERN test-beam and IR-laser

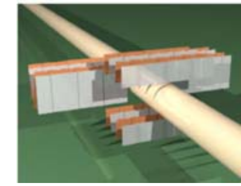
120GeV pions





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)

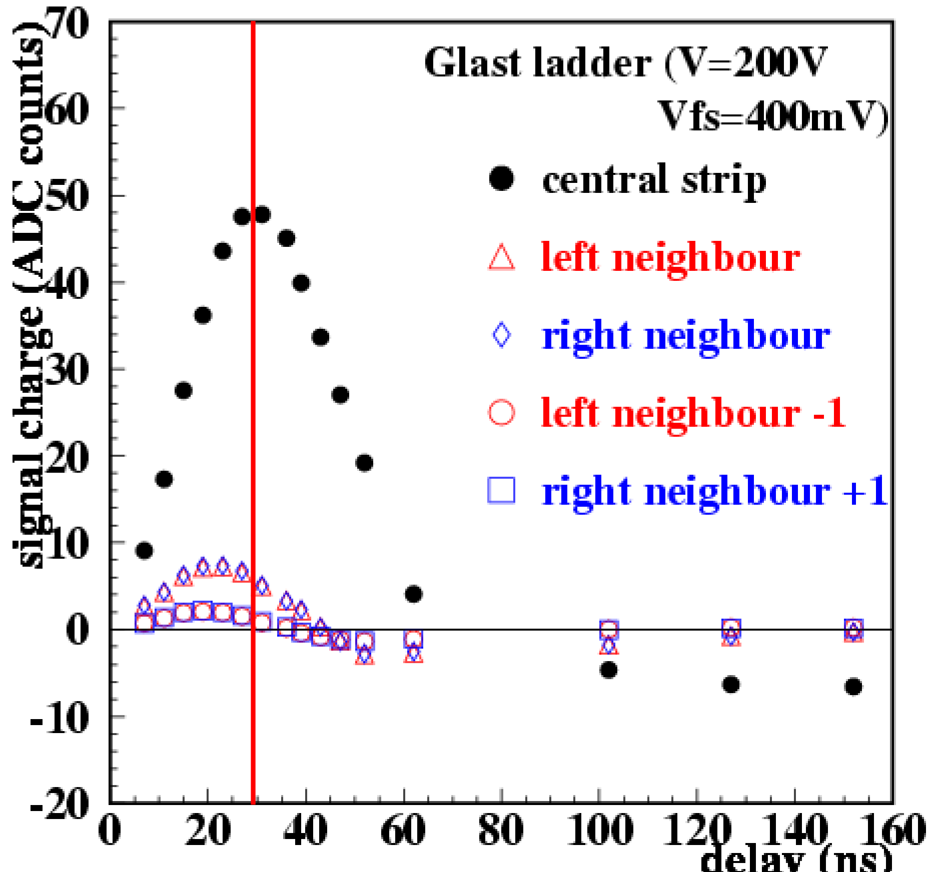


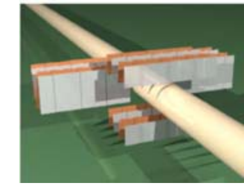
Pulseshape

fast readout in O(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



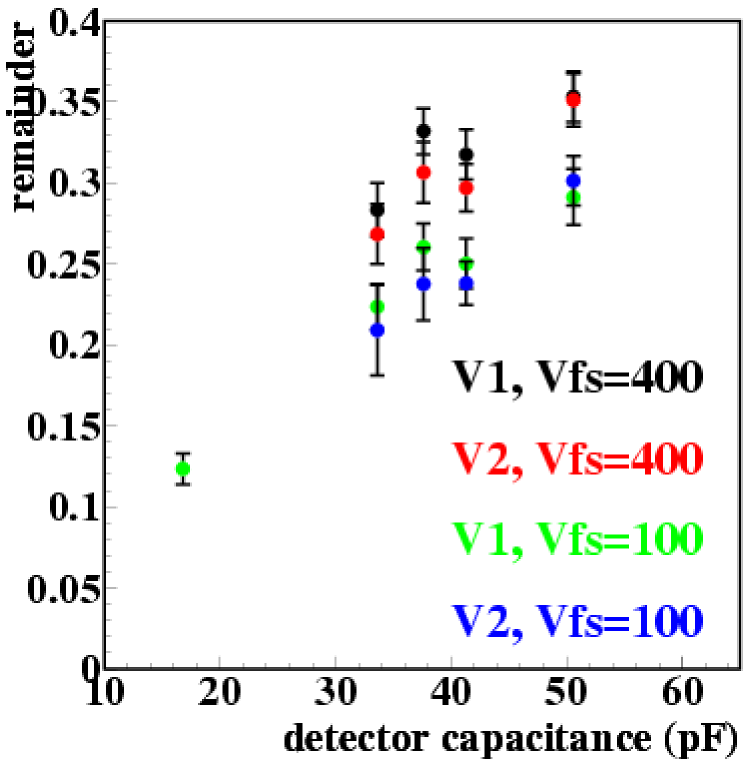


Signal Remainder

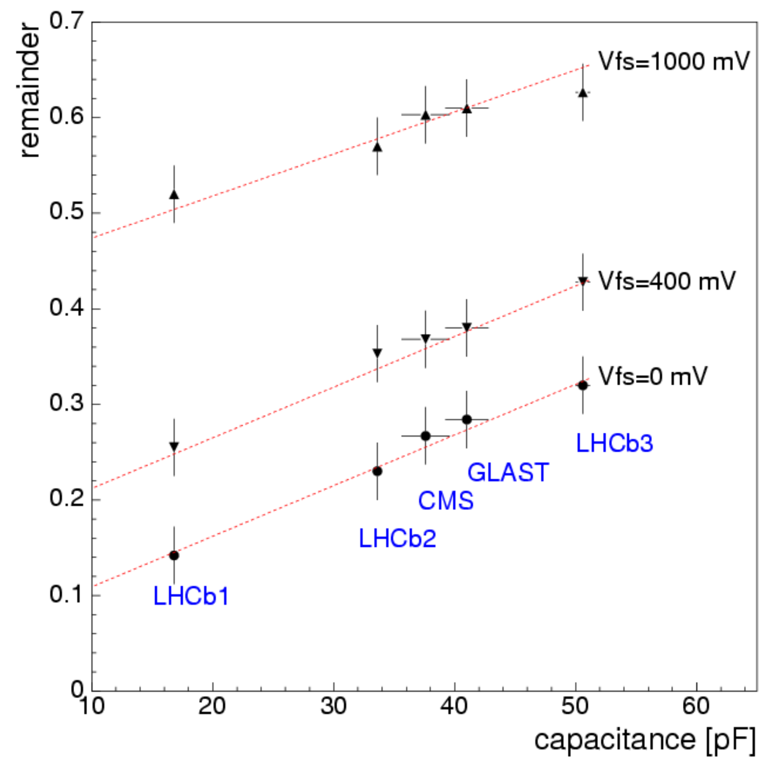
signal remainder 25ns after peak (BX every 25ns)

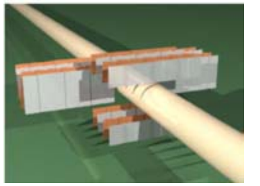
→ specification: remainder < 0.5 o.k.

test-beam:



laser setup:

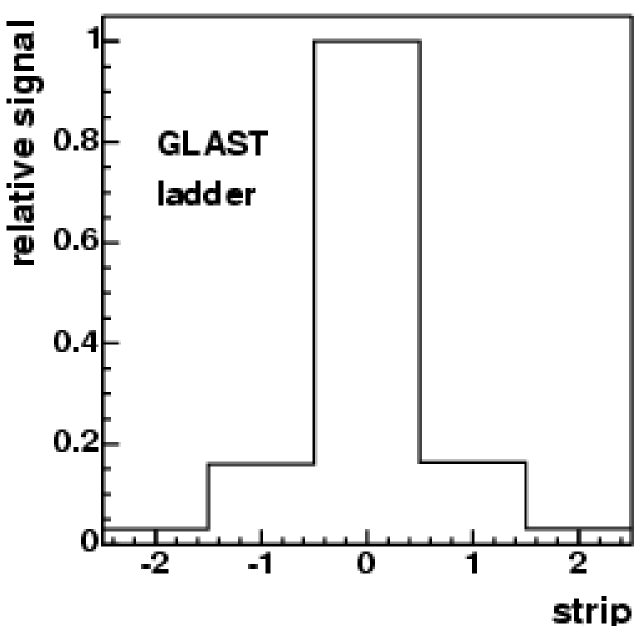


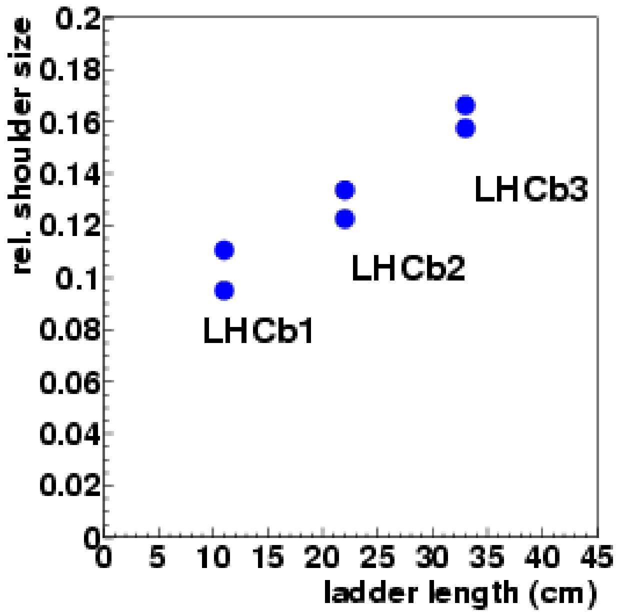


Cluster Shape

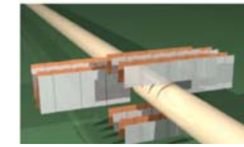
cluster shape reflects the shoulders seen in pulseshape scan

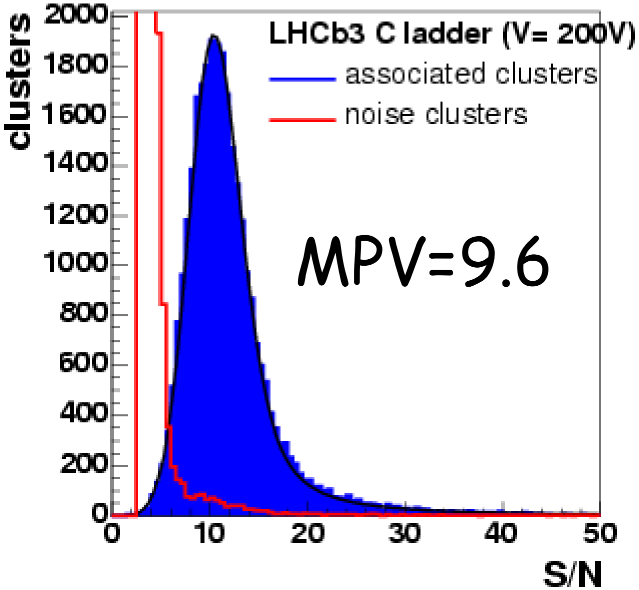
shoulder 8-18% depending on ladder length, pitch and (w/p)

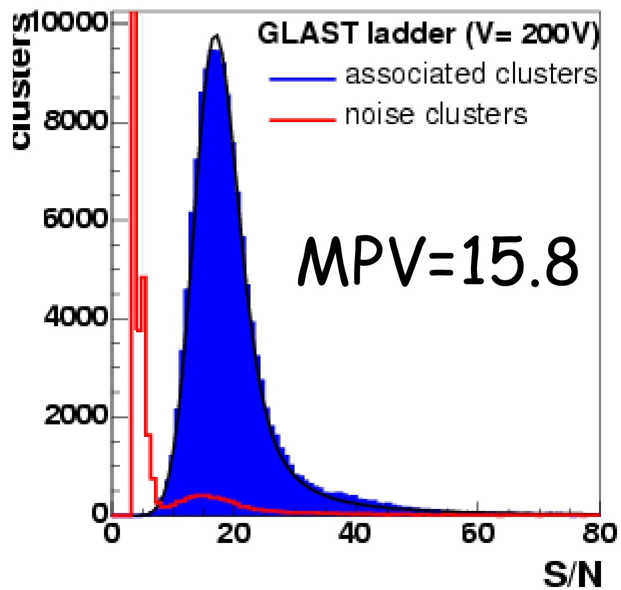


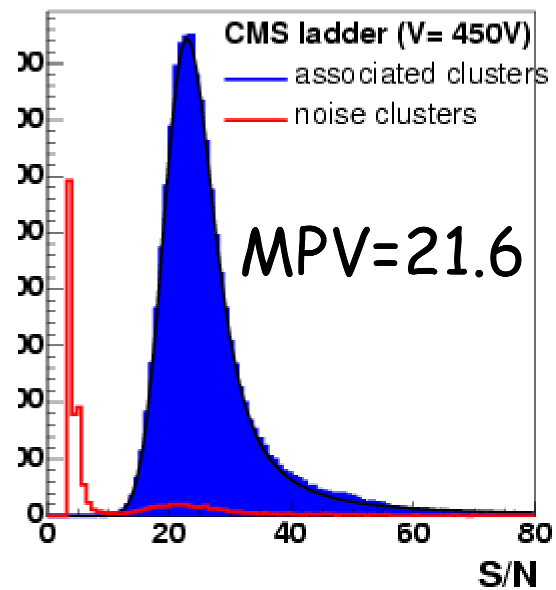


Signal / Noise







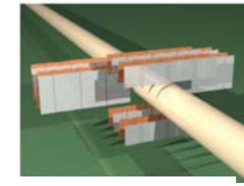


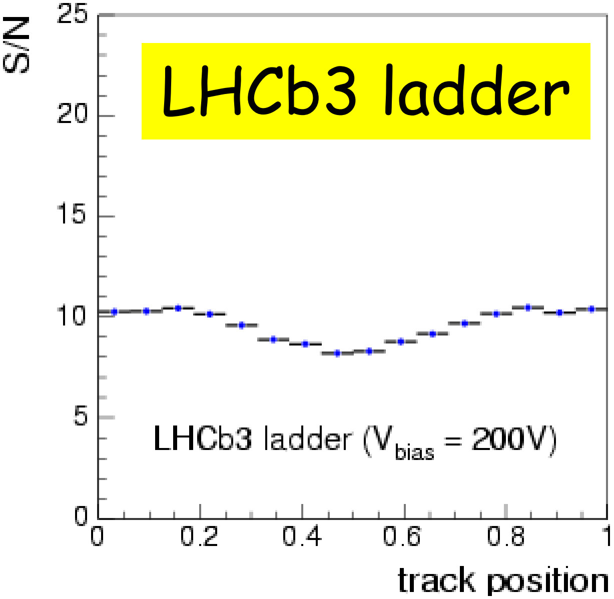
MPV S/N from Landau ⊗ Gaussian fit:

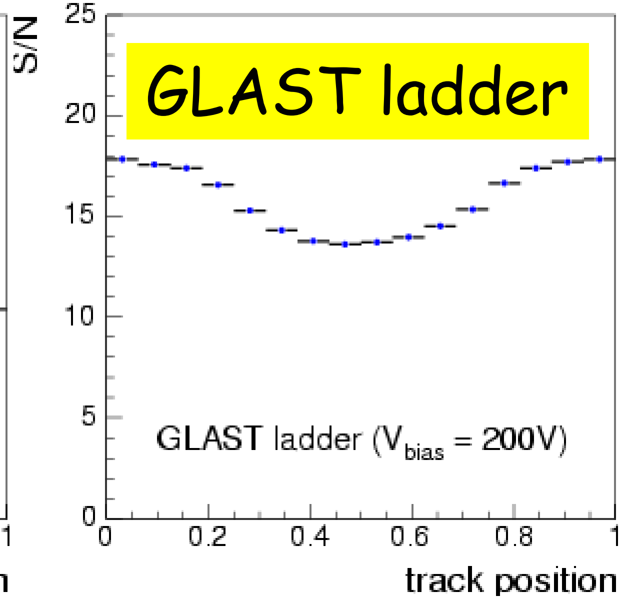
→ scaled to same thickness and same capacitance using measure Beetle front end response ENC = 450 + 47 * C /pF

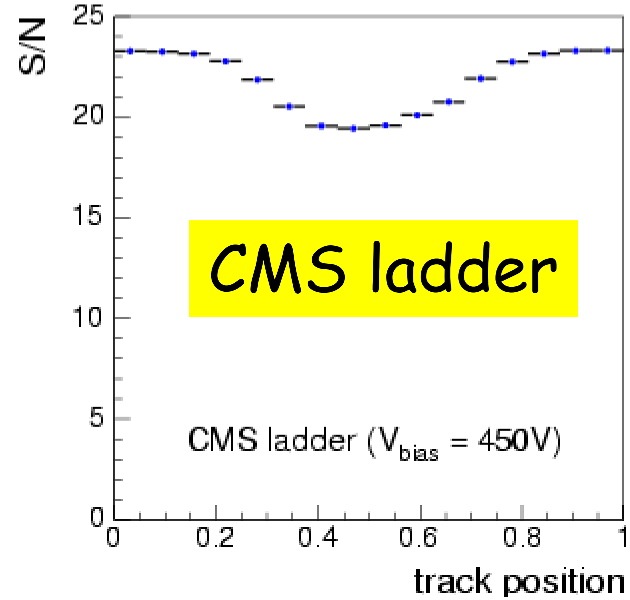
LHCb :	9.6	(C=50.6 pF)	agree within 12%
GLAST:	10.4	(C=41.3 pF)	
CMS :	10.8	(C=37.6 pF)	

Spatially Resolved S/N





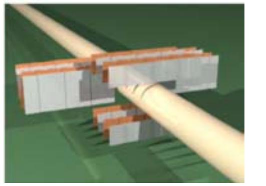




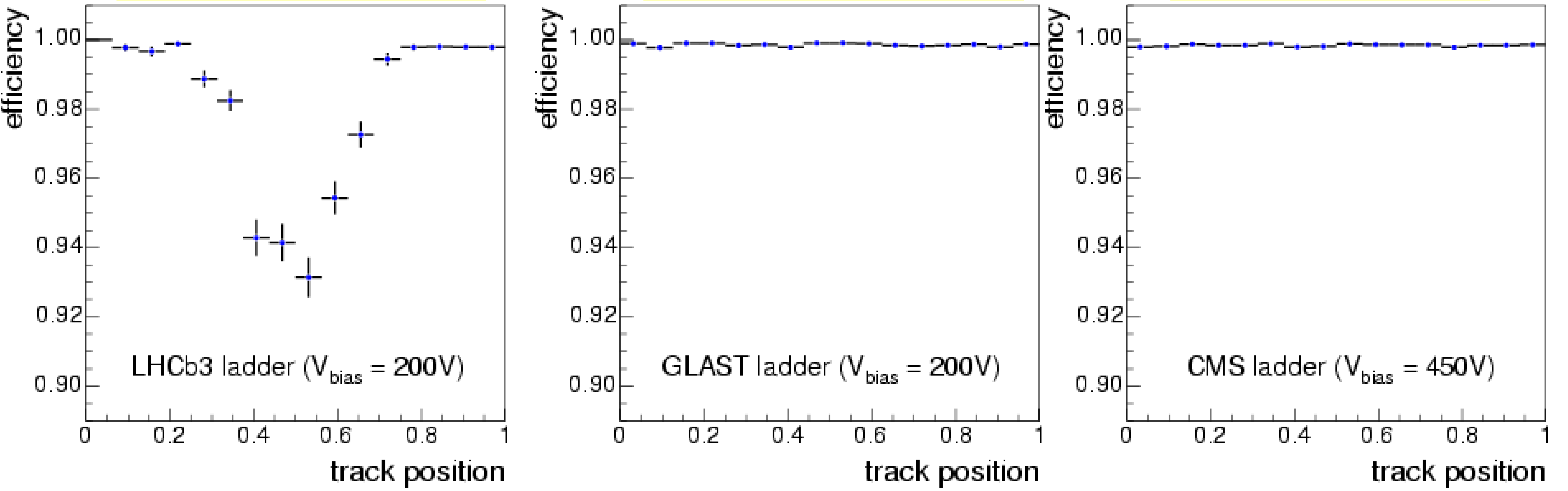
large pitch → charge loss observed for particles passing between two readout strips.

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

Spatially Resolved Efficiency



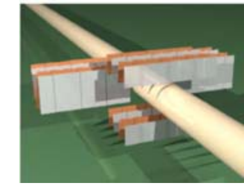
LHCb3 ladder | GLAST ladder | CMS ladder



cluster finding adjusted to noise rate < 1.‰

despite charge loss in between strips:

→ ~100% efficiency for thickness $\gtrsim$ 400 μm



Summary

- LHCb Si-Tracker uses silicon modules with
  - large pitch of ~200μm
  - long strips up to 33 cm
  - fast readout O(25ns)
- 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