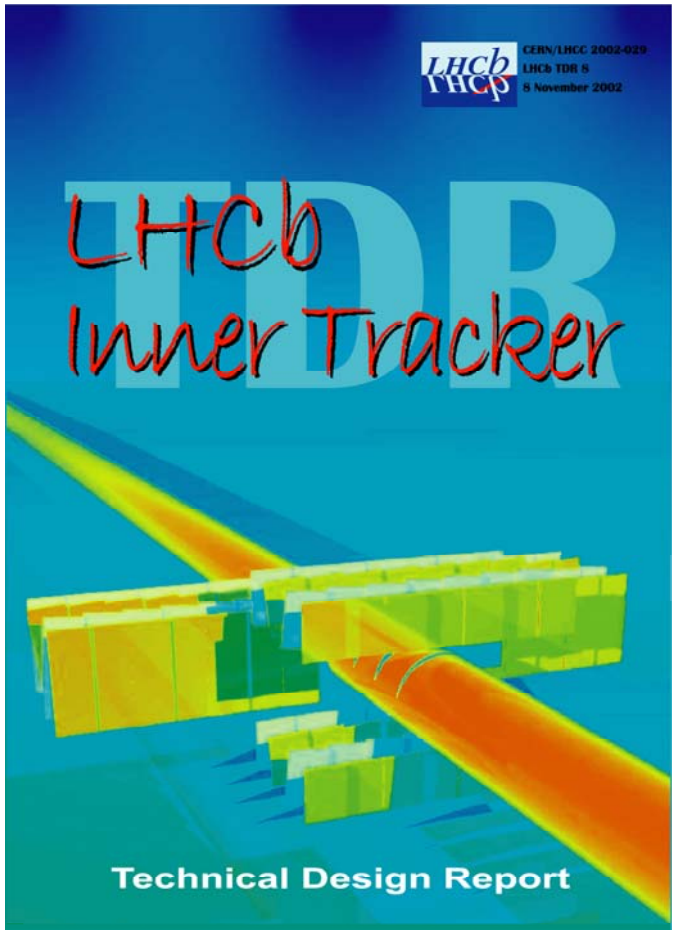
The LHCb Silicon Tracker



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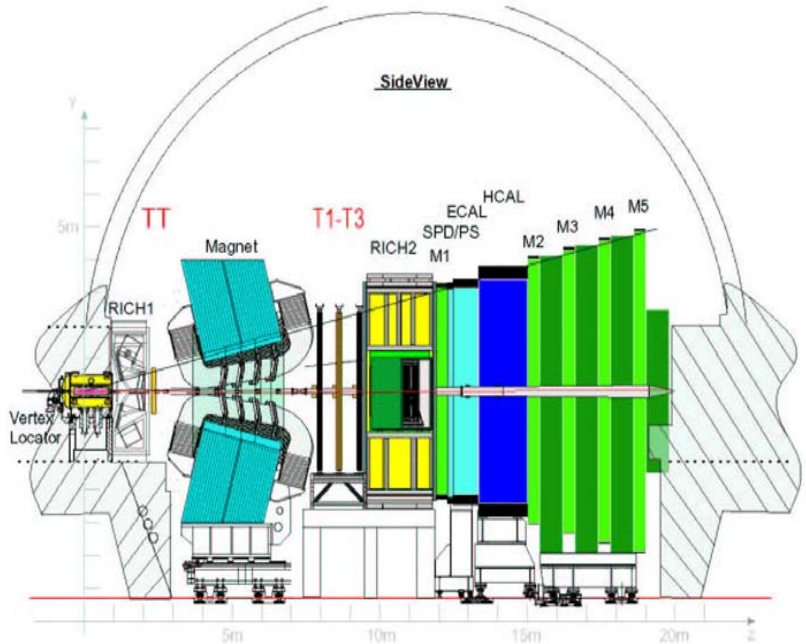
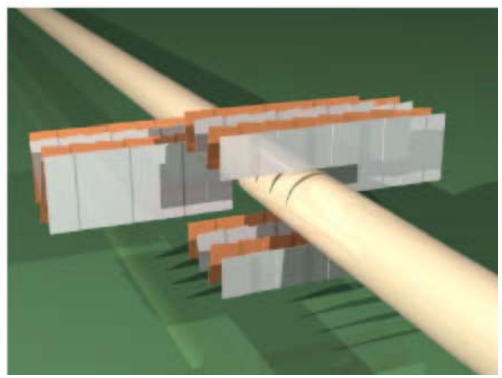
representing the
Silicon Tracker group
of LHCb

11th International Workshop on Vertex Detectors, Nov. 03-08, Hawaii 2002

The LHCb Silicon Tracker

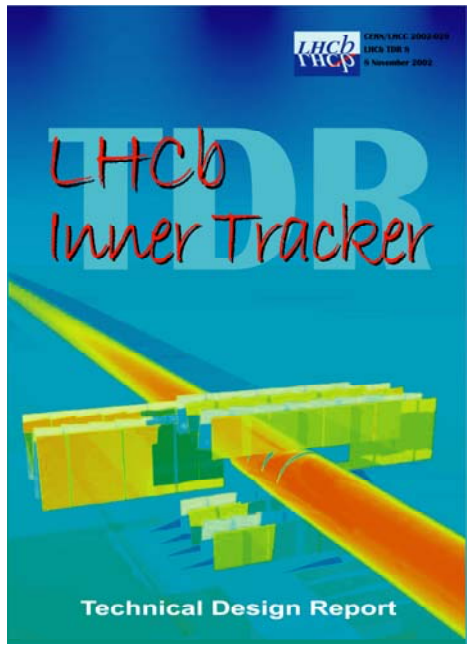
- LHCb dedicated b-physics experiment
- single forward spectrometer
- Silicon Tracker:
  - three inner tracking stations T1-T3 after magnet
  - one large area tracking station (TT) in front of magnet
  - total silicon area: 11 m^2
  - total number of R/O channels: ~300k





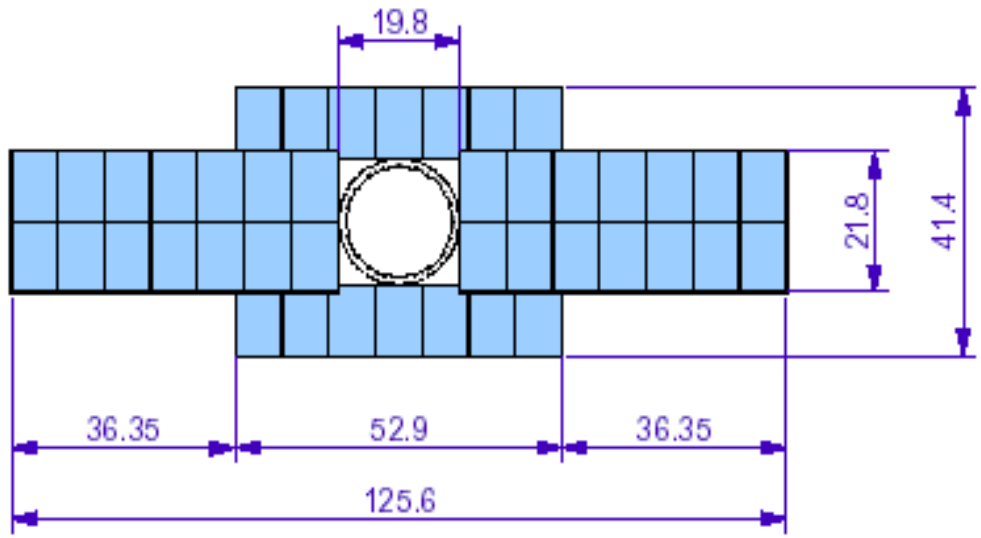
The LHCb Silicon Tracker: Requirements

- provide reliable and robust tracking in charged particle environment w/ rates of ~10^5 cm^{-2}/s
- achieve excellent momentum resolution of 3‰
  - keep occupancies at tolerable level of <2%
  - single hit resolution: ~70 μm
  - single hit efficiencies: nearly 100%
  - minimize dead material
  - data provided for L1 trigger
  - fast shaping/readout (FWHM 35ns)
- silicon strips reliable technology however:
  - employ wide pitch (~200μm) to reduce number of R/O channels
  - long silicon modules (ladders) -> high load capacitances ⇔S/N performance ?
  - goal: optimize noise and charge collection efficiency



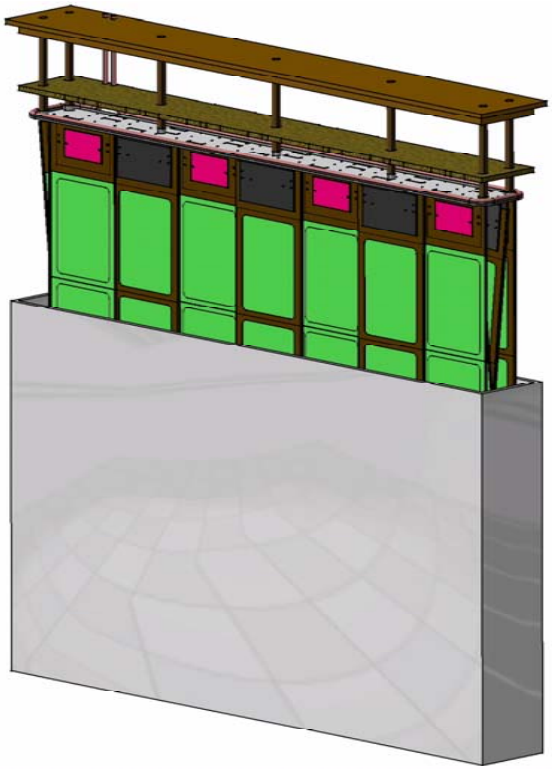
The LHCb Silicon Tracker: station design

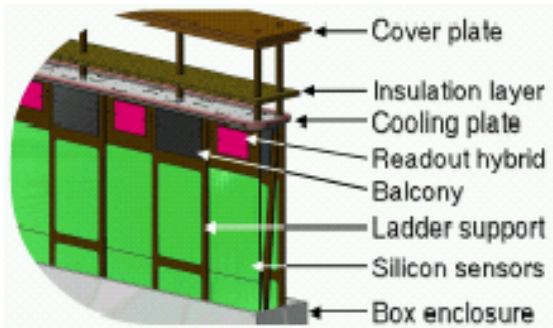
- three tracking stations along conical beampipe behind magnet
- four layers each with small angle stereo-view: 0°, ±5°, 0°
- up to 22 cm long silicon ladders
- conical beampipe => different layout in each station
- particle fluences higher in equatorial plane (bending plane of magnet)
- accomplished by four independent boxes arranged in cross geometry



The LHCb silicon tracker: detector design

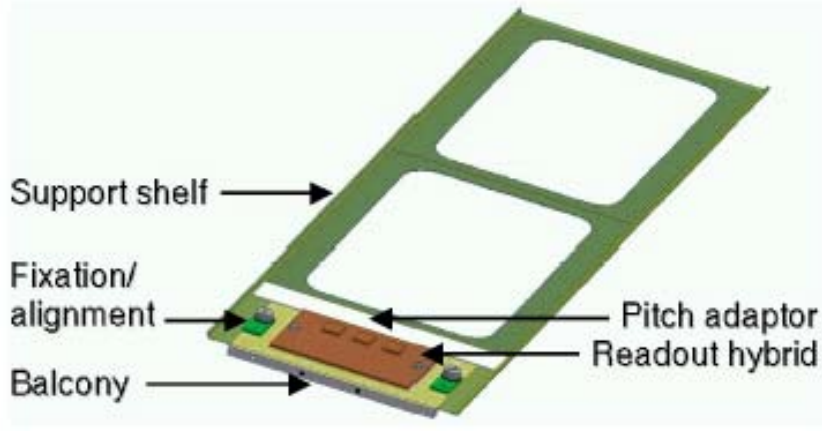
- each station has four independent boxes
- box houses 28 Si-ladders arranged in four planes
- ladder ends are mounted to a common cooling plate where coolant circulates
- enclosure of lightweight insulation foam material + thin Al-foil
  - light tightness
  - heat insulation
  - electrical shielding
- cover plate provides mechanical rigidity, cable feed-through
- silicon sensors will be operated at ~5°C
- ladders in nitrogen atmosphere

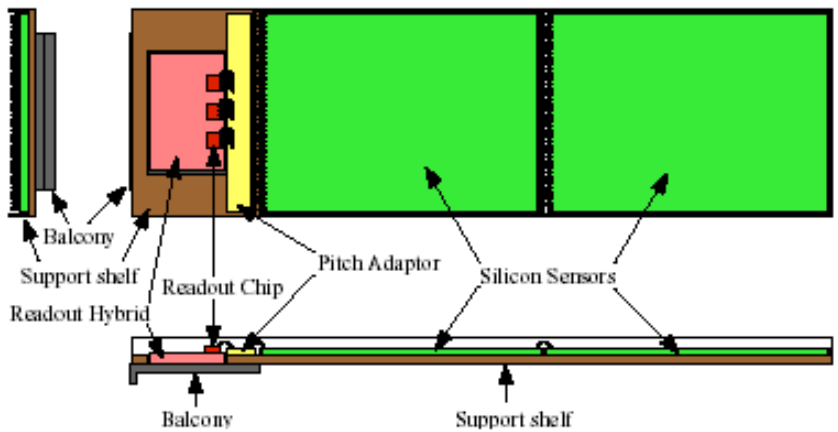




The LHCb silicon tracker: ladder design

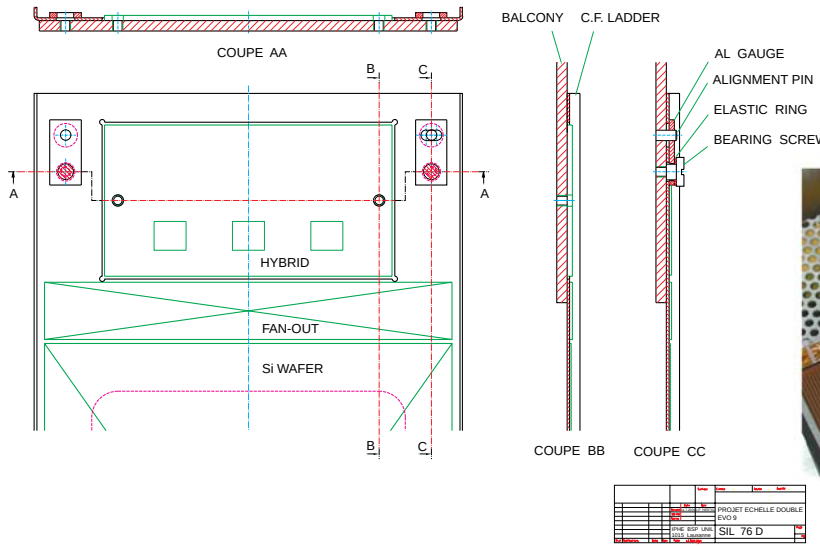
- two ladder types:
  - single sensor and two sensor ladders
    - ✓ aligned head-to-head
    - ✓ total active length of 22 cm
- silicon supported by U-shape carbon fiber composite shelf with high thermal conductivity
- ceramic substrate piece at ladder end
  - Kapton based printed circuit
  - three readout chips per ladder
- carbon fiber shelf mounted onto cooling balcony piece with precision holes and guide pins
- cooling balcony in direct contact with carbon support and ceramic for effective cooling

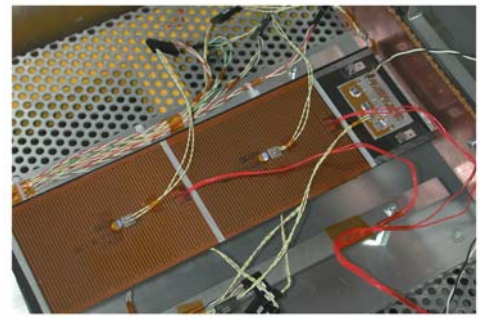


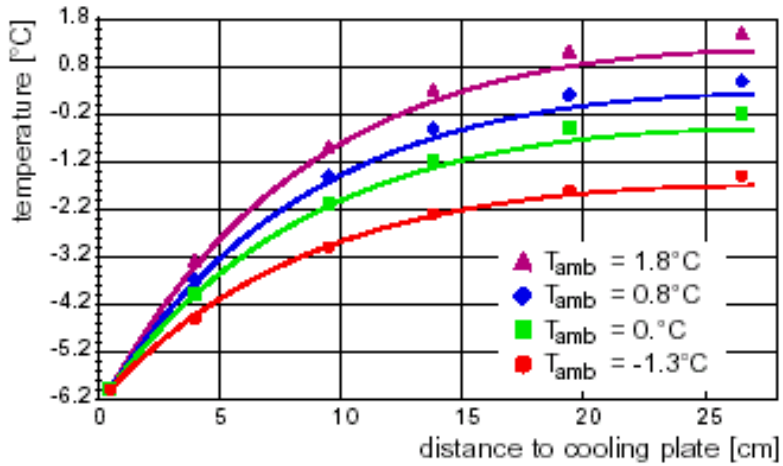


The LHCb silicon tracker: ladder design

- ladder requirements:
  - alignment 5μm, flat within 50μm
  - thermal conductivity >150 W/mK
  - mechanical stiffness
  - high radiation length
- first prototypes from Amoco K1100/Mitsubishi K13C2U composites produced
  - measured λ~200 W/mK
  - ladder flatness partially not yet satisfactory

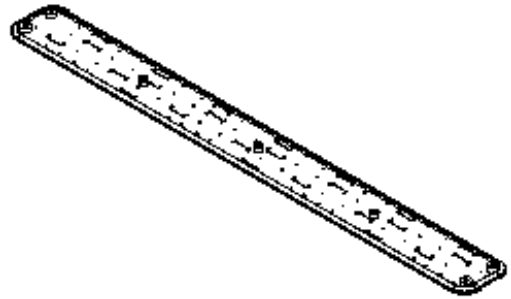


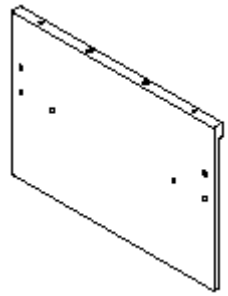


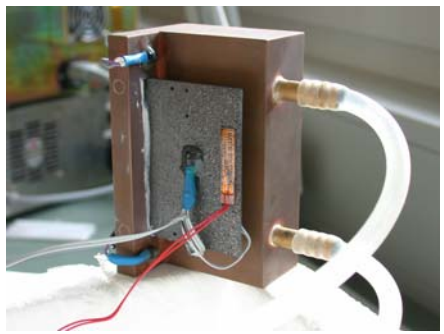


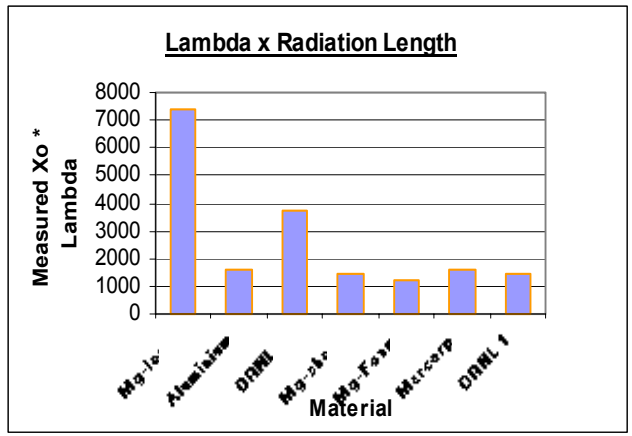
The LHCb silicon tracker: ladder design

- cooling plate
  - provides mounting surface for all ladders within one box
  - circulates liquid C6F14 as coolant
- cooling balconies
  - mounting & aligning of ladder support to cooling plate
- extensive R&D on lightweight materials:
  - ✓ MMC carbon fibers infiltrated with magnesium (X_0~17cm, λ~430 W/mK)
  - ✓ high density graphitic foams (X_0 up to 28 cm, λ up to 250 W/mK)
  - ✓ Carbon-carbon composites
  - ✓ figure of merit: $X_0 \cdot \lambda$



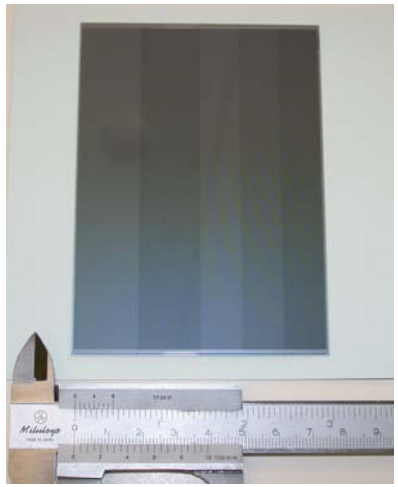


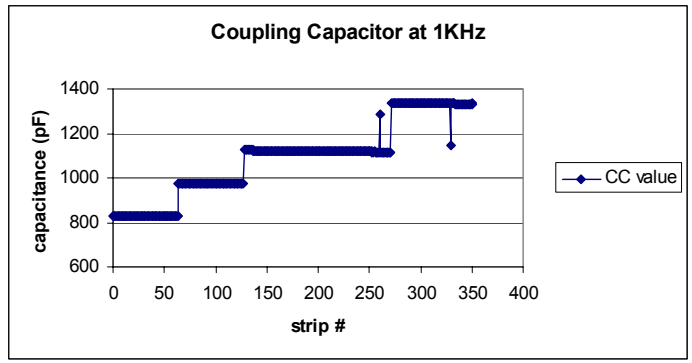


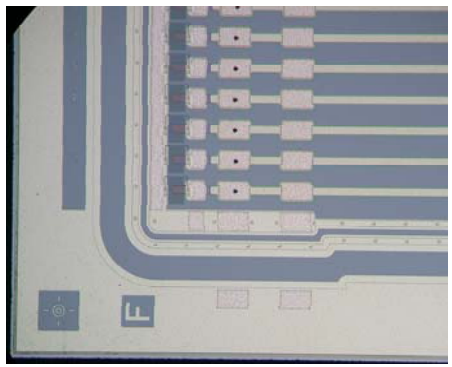


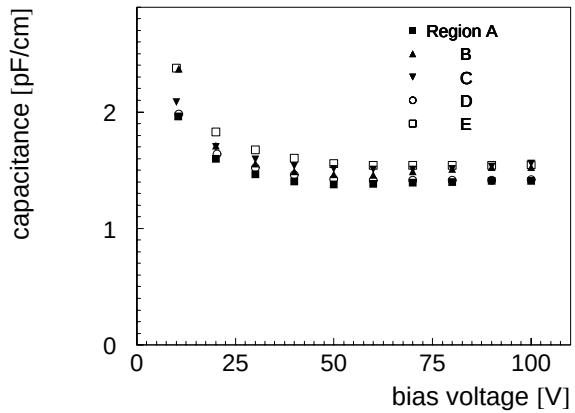
The LHCb silicon tracker: silicon sensors

- 6" p^+n single-sided silicon microstrip sensors
- dimension: 110x78 mm, 320μm thick
- pitch & w/p being optimized
  - multi-geometry sensor from Hamamatsu
  - two pitches: 198μm & 237.5μm
  - four different implant widths
- laboratory characteristics:
  - breakdown > 300V
  - total strip capacitances ~1.5 – 1.7 pF/cm depending on w/p
  - bad channels: <1%



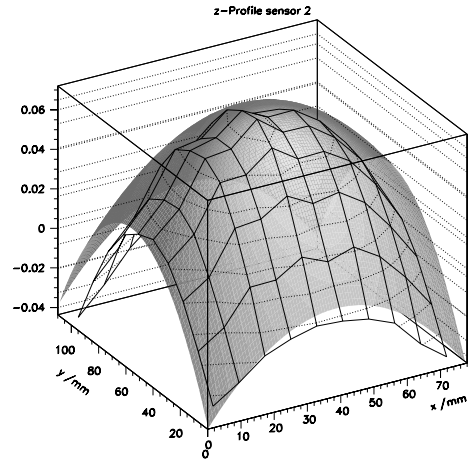


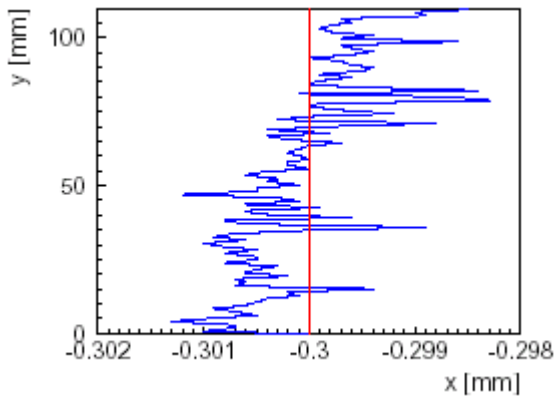




The LHCb silicon tracker: silicon sensors

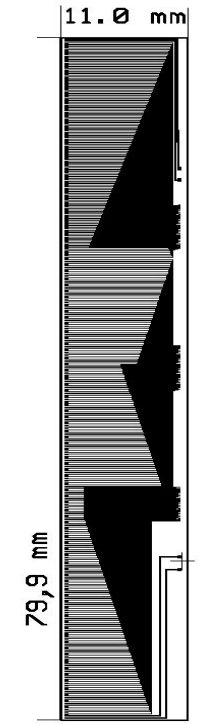
- metrology measurements with optical system
- flatness/planarity:
  - sensor warp ±50μm (specified ±25μm)
  - silicon shape well fit by parabolic shape
  - can probably live with that
- sensor dicing line
  - important since we use cut line for alignment
  - dicing line parallel within 5μm, accuracy 3μm

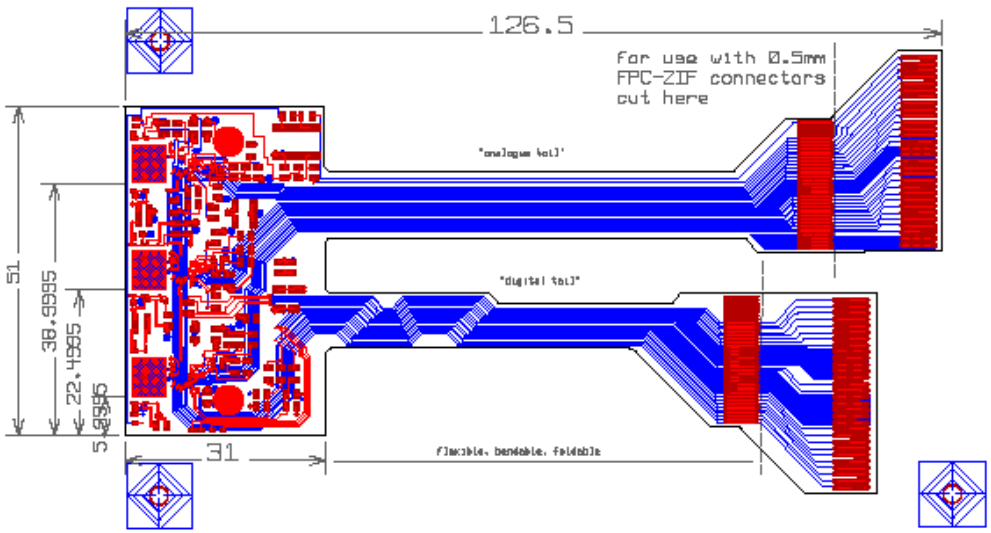


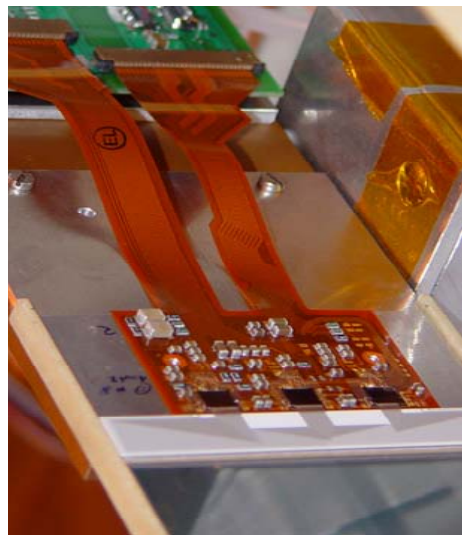


The LHCb silicon tracker: hybrid

- 4 layer kapton flex circuit laminated to ceramic (AlN) substrate
- careful design to avoid crossing of analog and digital signals
- two separate flexible tails for analog & digital lines
  - allows routing through cooling plate
  - 2nd tail can be folded over 1st tail to minimize feed-thru space
- pitch adapter necessary to match ~200μm wide pitch of sensors to 40μm pitch FE-Beetle bonding pad

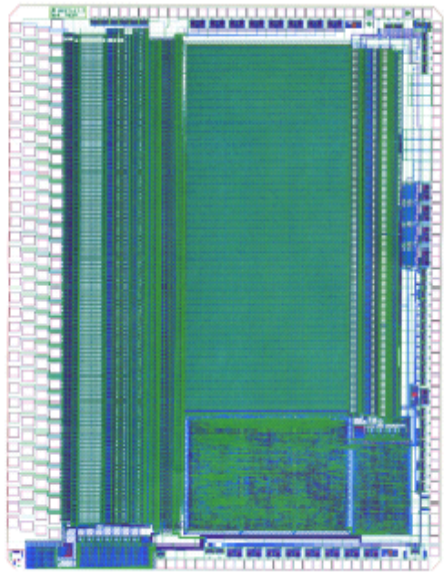


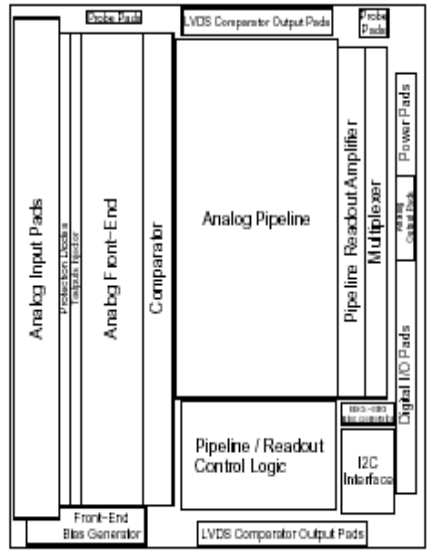


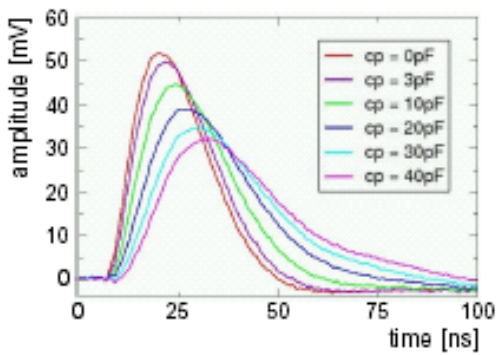


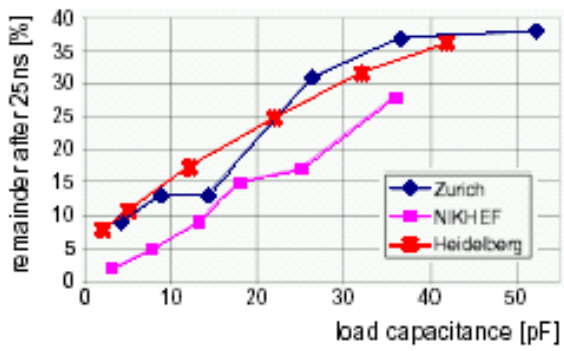
The LHCb silicon tracker: Beetle chip

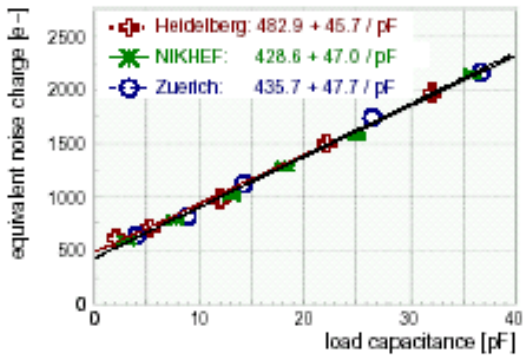
- Beetle (v1.2) readout chip
  - 0,25 μm CMOS, radiation hard, 40MHz clock
  - 128 channel preamplifier device with 160 BC deep pipeline
  - 32x multiplexed analog output for fast readout within 900ns
  - irradiated up to 45MRad (!), fully functional, no significant degradation observed
  - noise: 450e + 47e × C[pF] measured in three labs





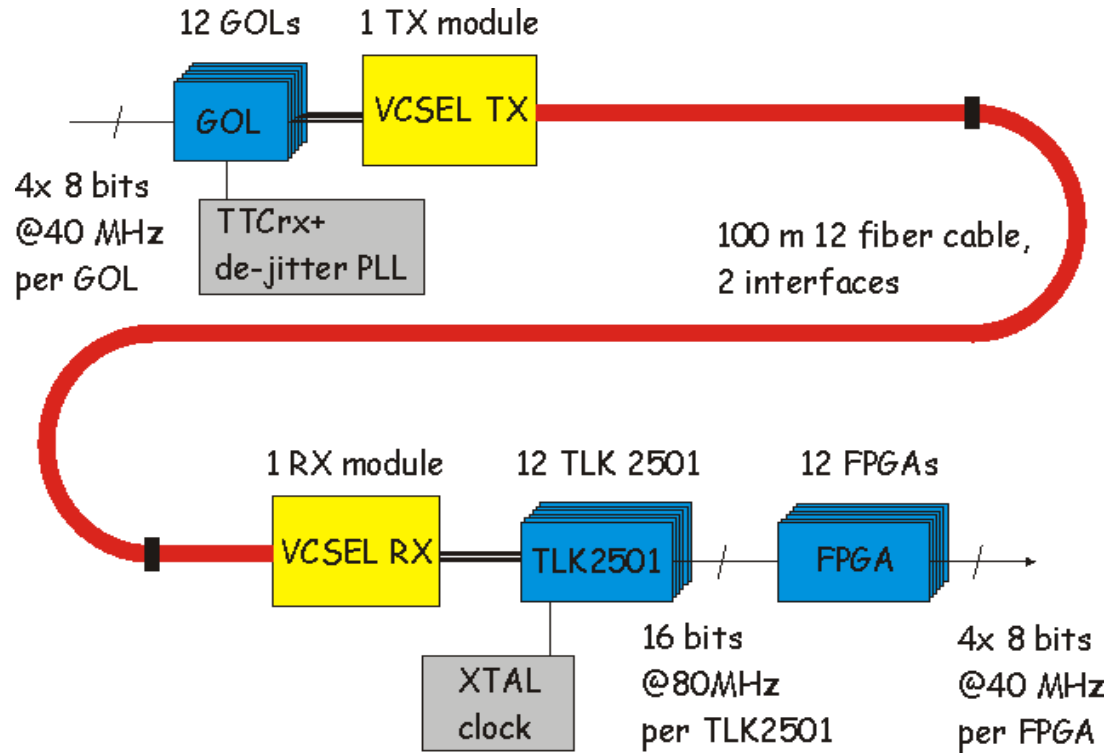


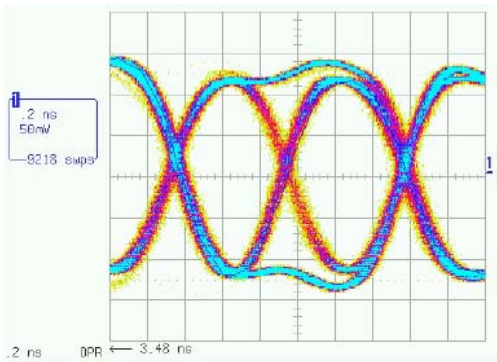


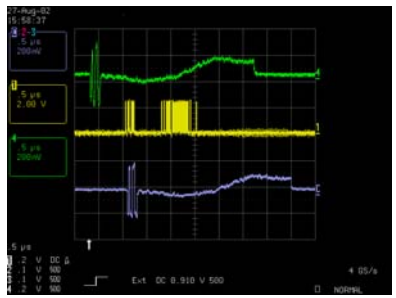


The LHCb silicon tracker: R/O chain

- Beetle analog data are sent to 8-bit FADC located outside the tracking volume
- CERN GOL capable of serializing 32-bit wide date at 40MHz
- 1.6 Gbit/s optical link over 100m to L1 electronics in hut
- one digital optical link:
  12 x 4 x 8 bits =
  48 analog channels (4 hybrids)
- will use COTS devices wherever possible
  - optical transmitter modules w/ VCSEL diodes
  - optical ribbon cable
- first prototype link lab setup ready
- eye pattern at receiving end
- bit error rate tests underway

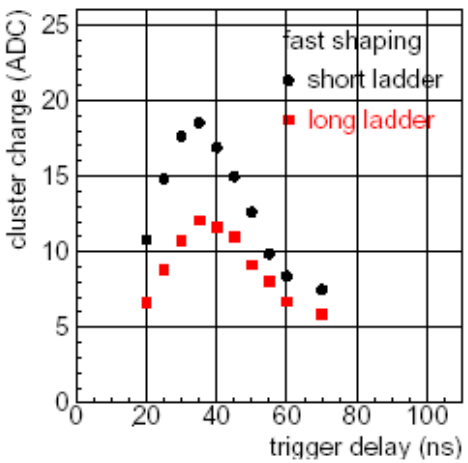


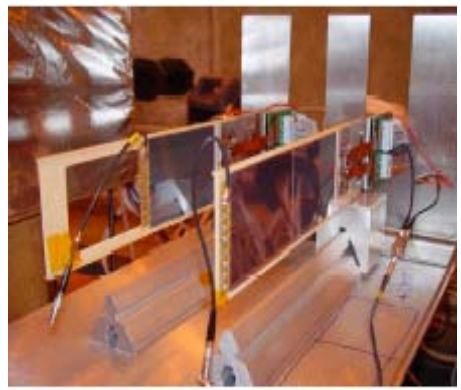




The LHCb silicon tracker: CERN testbeam

- May/June 2002 testbeam at CERN X7
  - Hamamatsu multi-geometry sensors
    - ✓ Region C: 198μm pitch w/p=0.35
    - ✓ Regions D & E: 240 μm pitch, w/p=0.3 & w/p 0.35
  - Beetle v1.1 R/O chip + hybrid
  - HERA-B silicon telescope + VDS DAQ
  - short ladder: 11cm strips, long ladder 22cm strips
  - fast shaping ~35ns FWHM

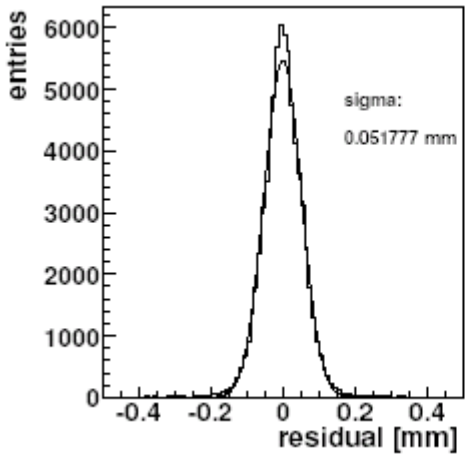




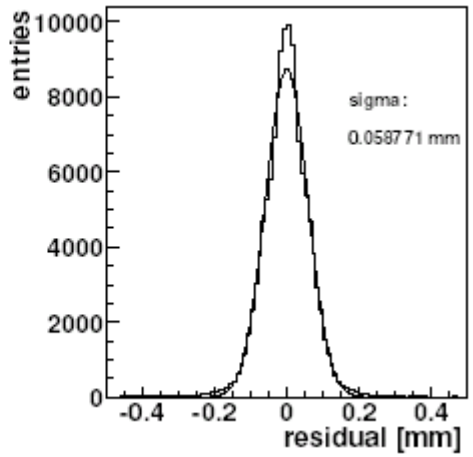
The LHCb silicon tracker: CERN testbeam cont'd

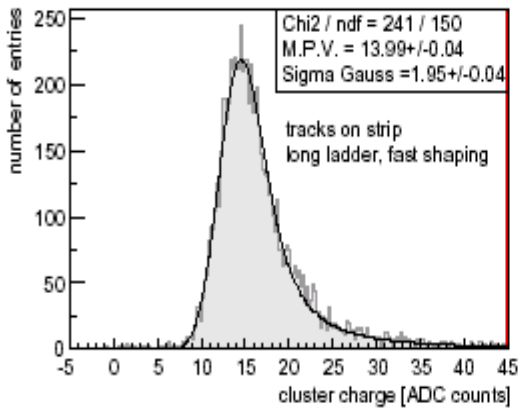
- achieved spatial resolution based on telescope track residuals ~52 (58) μm @ 200 (240) μm pitch is perfect for our purposes
- measured pulse height distributions for tracks 'on strips' & 'in between strips'
  - fit w/ landau ⊗ gaussian
  - most probable value as expected for tracks on strips
  - however, in between strips 7-20% charge loss
- S/N values of 10:1 for tracks on strips for long ladder is in good agreement w/ expected noise performance of Beetle 1.1

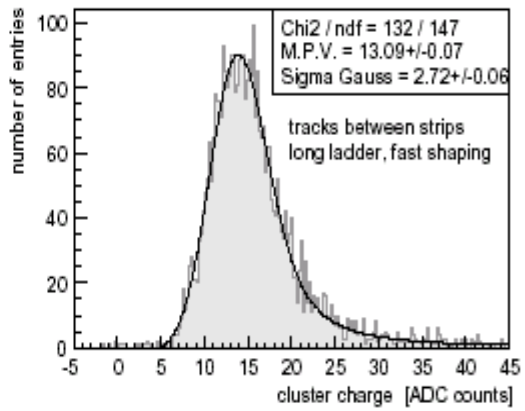
pitch 200 μm



pitch 240 μm



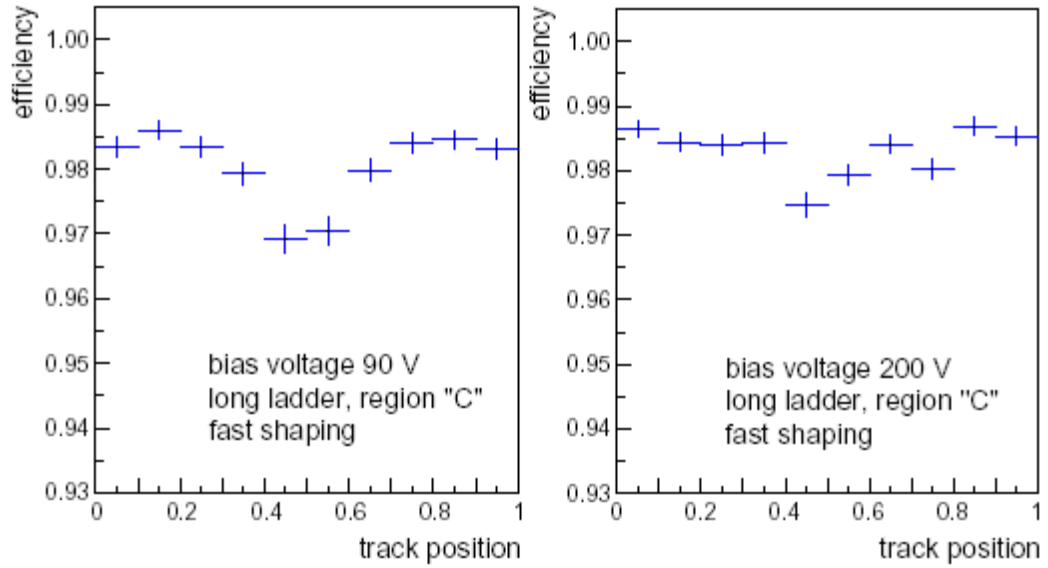


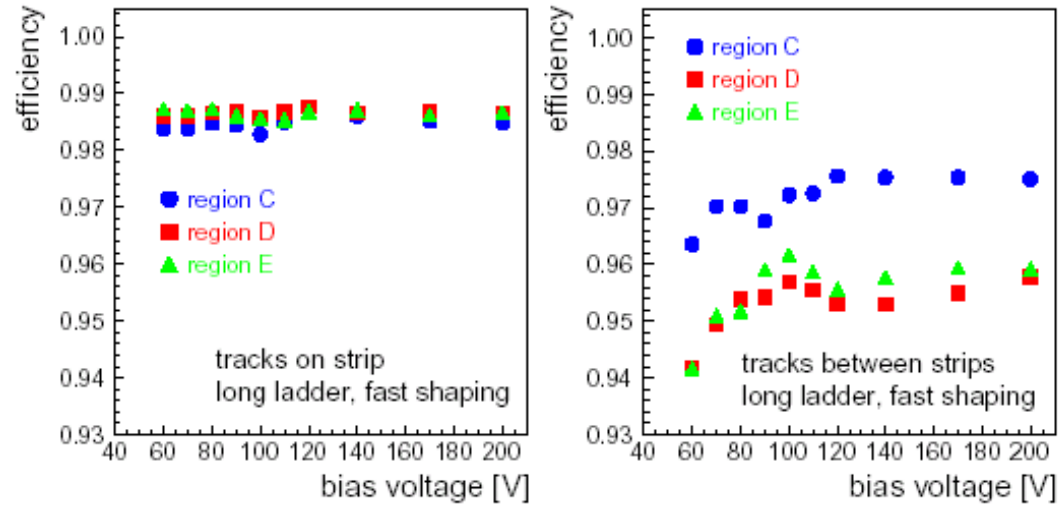


Region C of long ladder 200V bias

The LHCb silicon tracker: CERN testbeam cont'd

- hit efficiencies determined w/ adjusted clustering algorithm to give noise rate of 0.1% per strip and event (compare to 0.6% per strip and event for physics)
- efficiency 98-99% for tracks on strips, but 97% for tracks in between
- efficiencies slightly improve towards higher bias, indicating a ballistic deficit
- efficiency loss in regions D & E (with larger pitch) is more pronounced => prefer 200 μm pitch over 240 μm

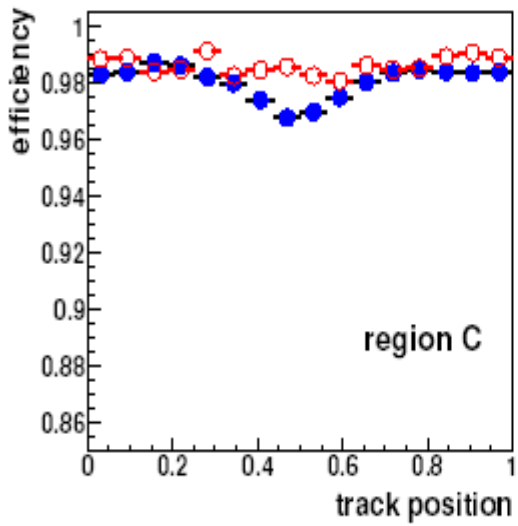


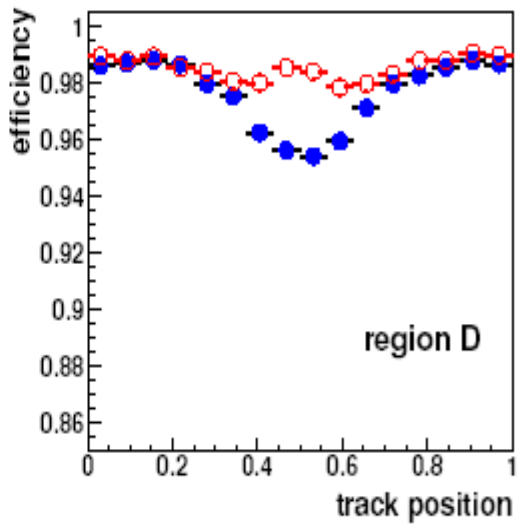


The LHCb silicon tracker: CERN testbeam cont'd

- further improvement if shaping time of Beetle is increased from FWHM~35ns to ~50ns
- efficiency loss in between strips gone
- however: slower shaping means more signal remainder after next BC
- tradeoff between occupancy and efficiency
- studies on tracking performance underway

closed circles: fast (standard) shaping
open circles: slow shaping





The LHCb silicon detector: Summary

- the LHCb tracking system employs wide pitch silicon strip detectors due to their robustness and good performance in a charged particle environment
- the silicon ladder and station design has rapidly evolved
- testbeam results on prototype ladders look promising, although some fine-tuning is needed
- the subcomponent TDR for the silicon tracker of LHCb will be submitted to the LHCC these days