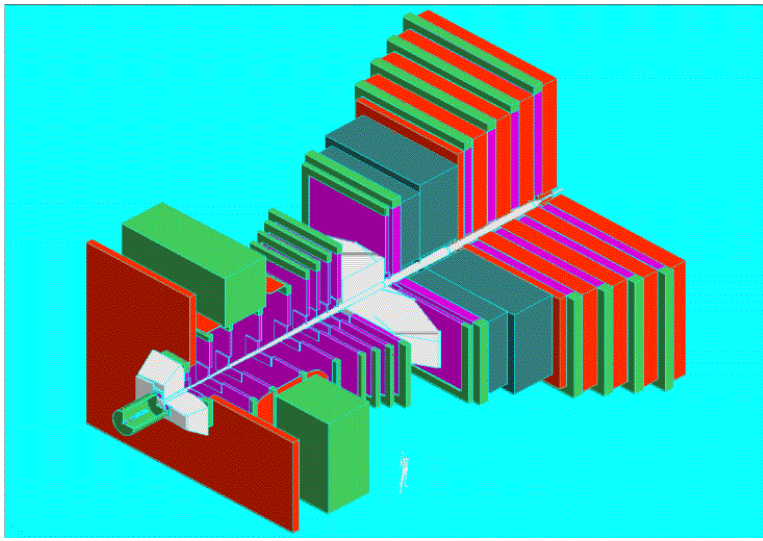
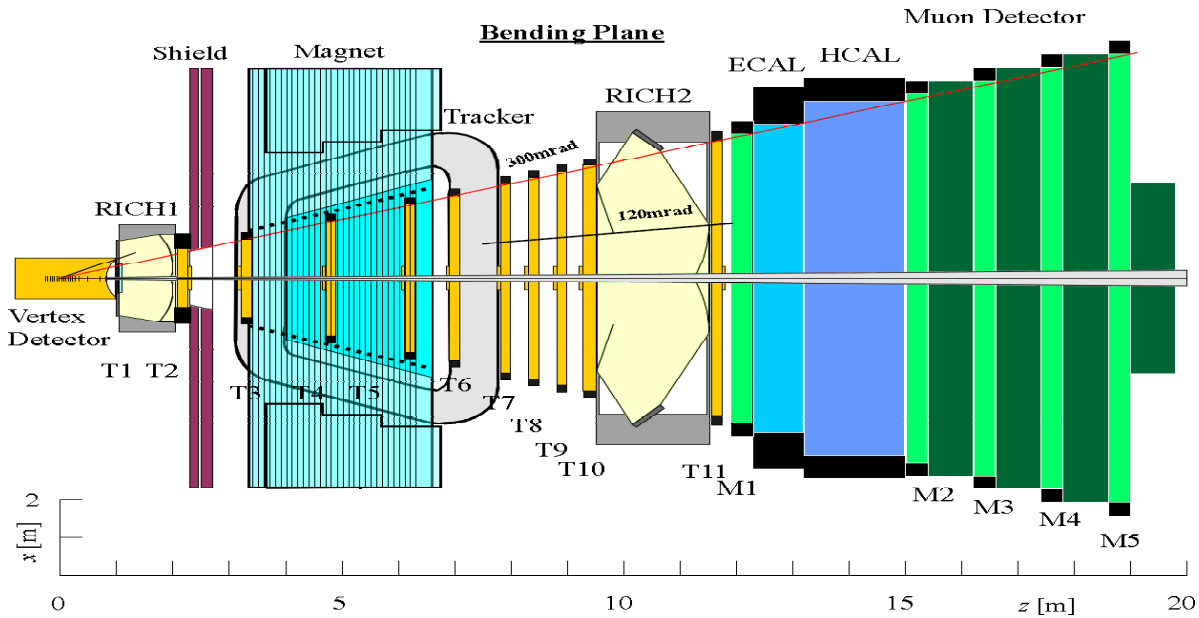
The LHCb experiment

- The LHCb experiment
  - dedicated b-physics experiment at LHC to study CP-violating phenomena
  - main challenges:
    - ✓ highly selective trigger to collect large samples of B decays in specific channels
    - ✓ charged particle identification (π/K) over wide momentum range
    - ✓ secondary vertexing and impact parameter
    - ✓ reliable and robust tracking and momentum measurements



The LHCb experiment

- forward single arm spectrometer with ±300mrad acceptance
- silicon strip based vertex detector stations for vertexing and L1-trigger
- two RICH detectors for effective particle ID
- tracking stations for momentum measurements
- preshower and em/had calorimeter
- muon system



The LHCb Tracker system

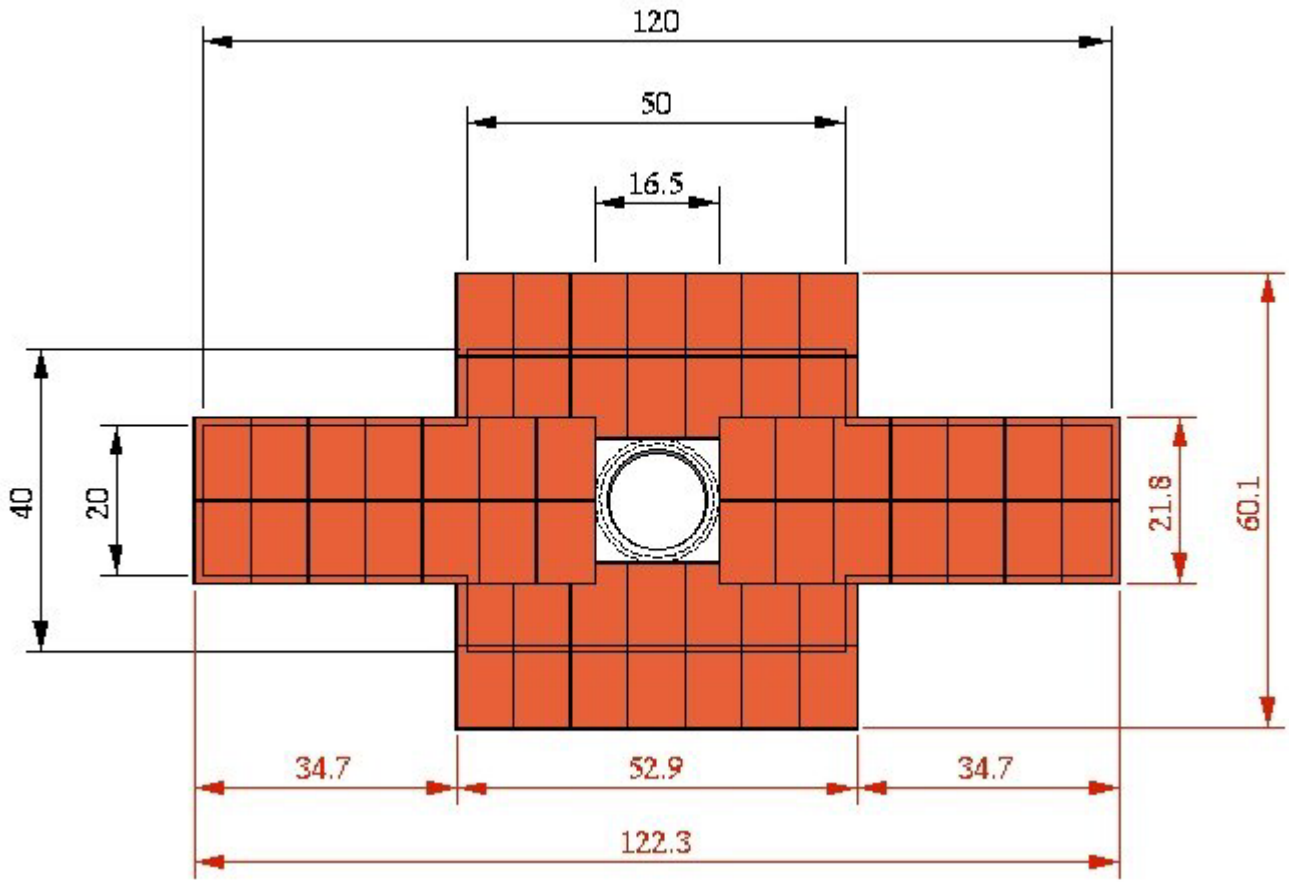
- general tracker requirements are:
  - robust and reliable track-finding and -following
  - provide precise momentum resolution of 3‰ translating into ~17MeV mass resolution for reconstructed B->ππ decays e.g.
  - provide track segments into RICH as input for particle-ID algorithms
  - tracking resolution dominated by multiple scattering => minimize mass
- keep occupancy at tolerable level
  - split tracker into inner and outer subsystem with different granularities
  - boundary between inner and outer tracker defined by particle rates and expected occupancy

The LHCb Inner Tracker

- detector technology for Inner Tracker driven by
  - sustain high charged particle rate of up to $10^6 cm^{-2} s^{-1}$
  - moderate position resolution of ~80μm sufficient
  - occupancy has to stay below 3%
  - minimize mass for radiation length budget
  - fast shaping time of 25ns
- use as tracker technology silicon strip detectors
  - reliable technology, however
    - ✓ employ wide pitch to reduce number of R/O channels
    - ✓ long silicon modules (ladders) -> S/N performance ?
  - goal: optimize noise, charge collection and efficiency

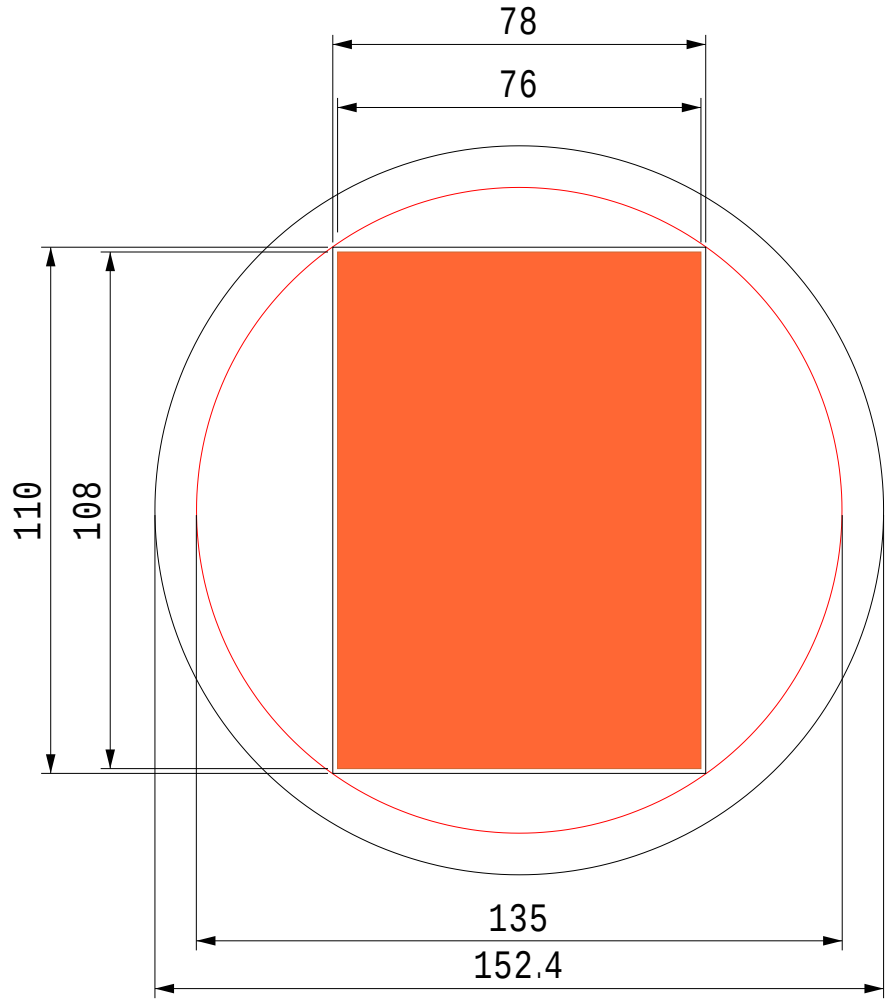
The LHCb Inner Tracker- Station layout

- nine tracking stations along conical beampipe
- four layers each with small angle stereo-view: 0°, ±5°, 0°
- up to 22 cm long silicon ladders
- total silicon area ~14 m^2
- 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



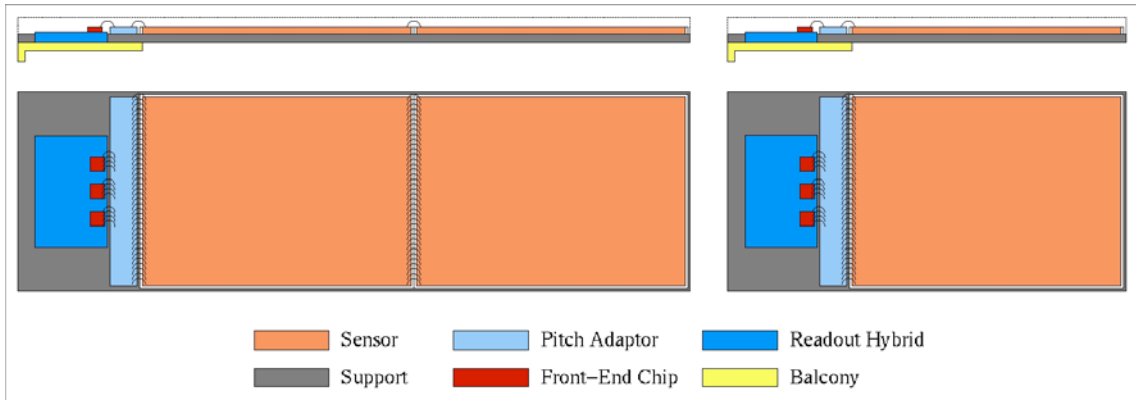
The LHCb Inner Tracker- Sensors

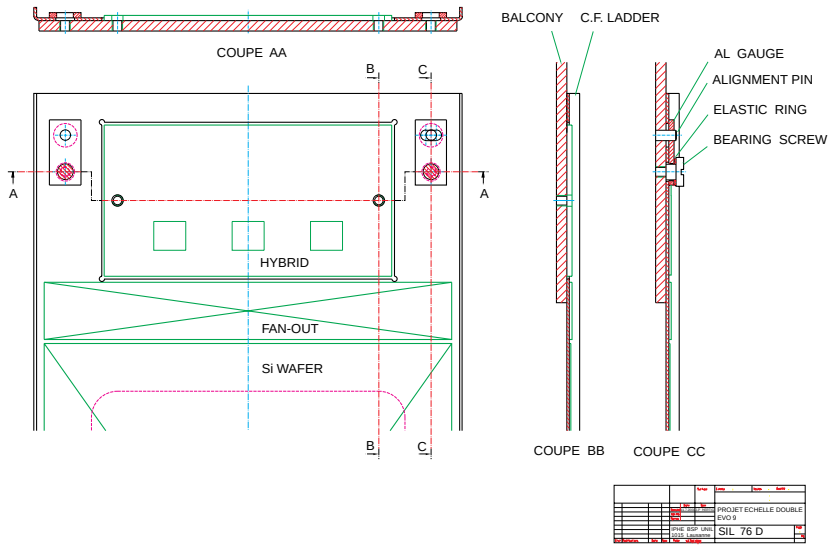
- use single sided p+n silicon sensors will be produced from 6" wafers
- physical length and width: 110 x 78 mm^2
- two options for pitch are discussed. Pitch will be matched to further R/O granularity
  - either: 198 μm => 384 strips
  - or: 237.5 μm => 320 strips
- a total of more than 1500 sensors + spares needed
- sensors have to be radiation hard up to charged hadron fluences of $5 \cdot 10^{13} cm^{-2}$



The LHCb Inner Tracker- Ladder design

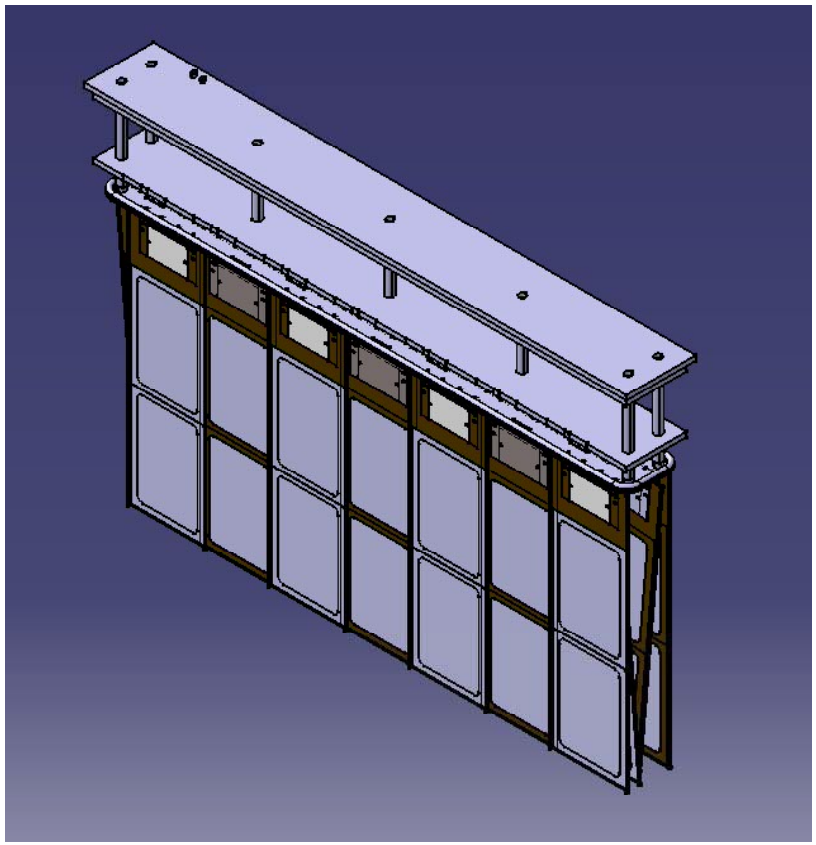
- two ladder types:
  - single sensor ladders (~280 needed)
  - two sensor ladders (~620 needed)
    - ✓ aligned head-to-head
    - ✓ total active length of 220 mm
- silicon supported by U-shape carbon fiber shelf with high thermal conductivity (Amoco K1100 composite)
- ceramic substrate piece at ladder 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





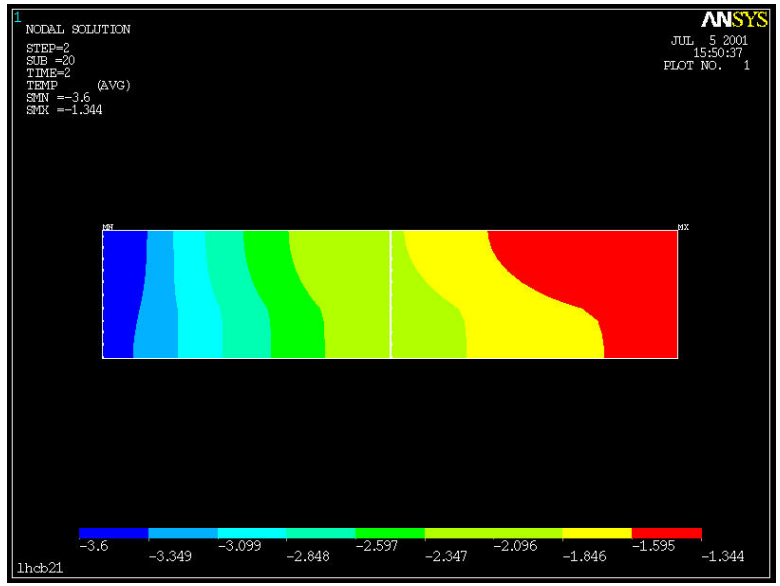
The LHCb Inner Tracker- station/box design

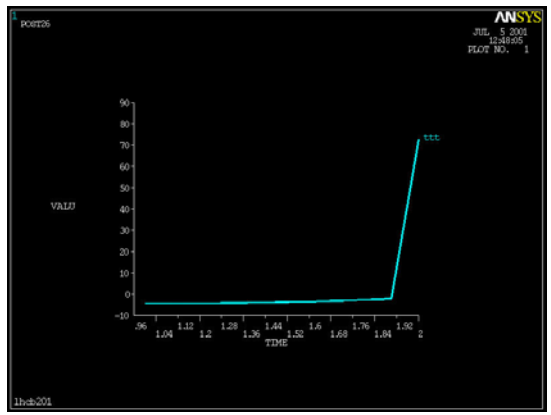
- one box (a quarter of the cross geometry) houses up to 28 ladders arranged in 4 planes
- ladder ends are mounted to a cooling plate where cooling passage runs
- enclosure of lightweight insulation foam material + thin Al-foil
  - light tightness
  - heat insulation
  - electrical shielding
- silicon sensors will be operated at -5°C
- ladders in cold nitrogen atmosphere



The LHCb Inner Tracker- thermal studies

- finite element calculations to optimize thermal performance of ladder
  - include power dissipation by chips and radiation damaged silicon
- silicon can be kept cold over course of 10 years of LHCb running
- however: for too high coolant temperatures risk of thermal runaway present
- minimize risk by additional convective cooling with nitrogen
- experimental studies to verify FEA analysis are underway

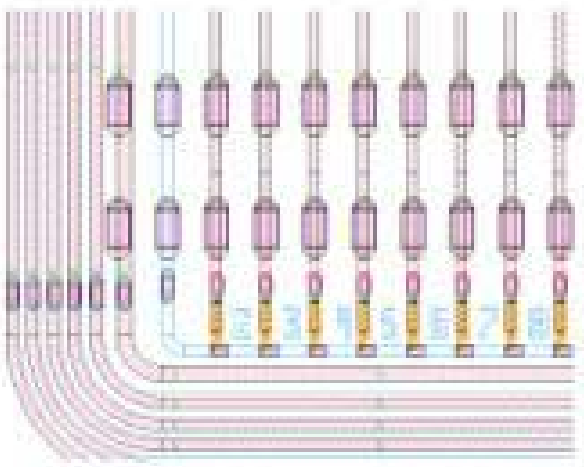


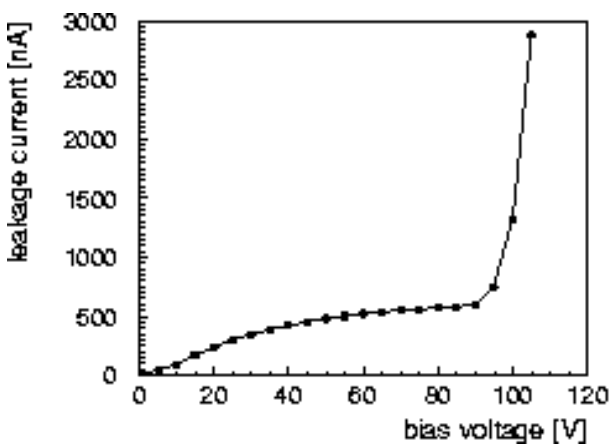


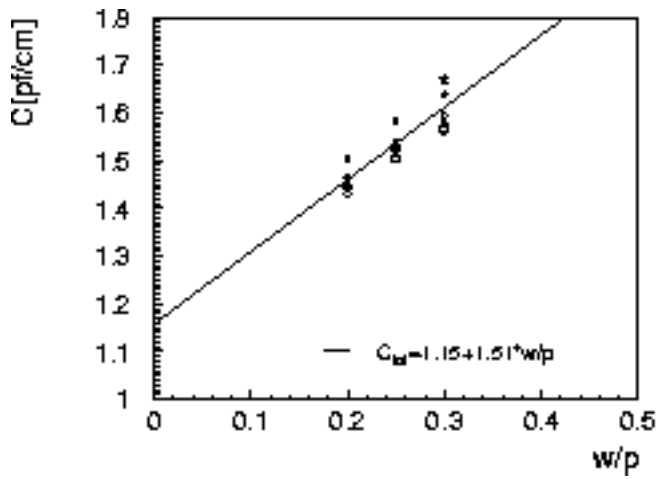
The LHCb Inner Tracker-first sensor prototypes

- multi-geometry sensors from SPA Detector in Kiev
  - p+n single sided
  - pitch 240μm
  - oxygenated on 4" wafers
  - three different width/pitch ratios
    - ✓ w/p= 0.2, 0.25, 0.3
  - two types of Al metal traces
    - ✓ overhang and underhang
- depletion voltage: 50-70V
- total capacitance: 1.3-1.6pF/cm
- Sensors fine but too low breakdown voltage

64 strips
66.6 mm long

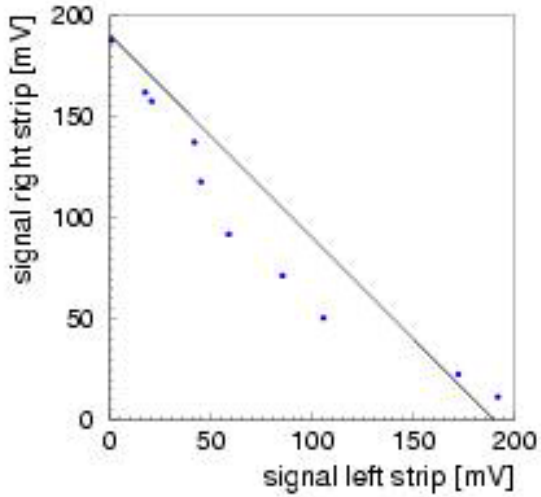


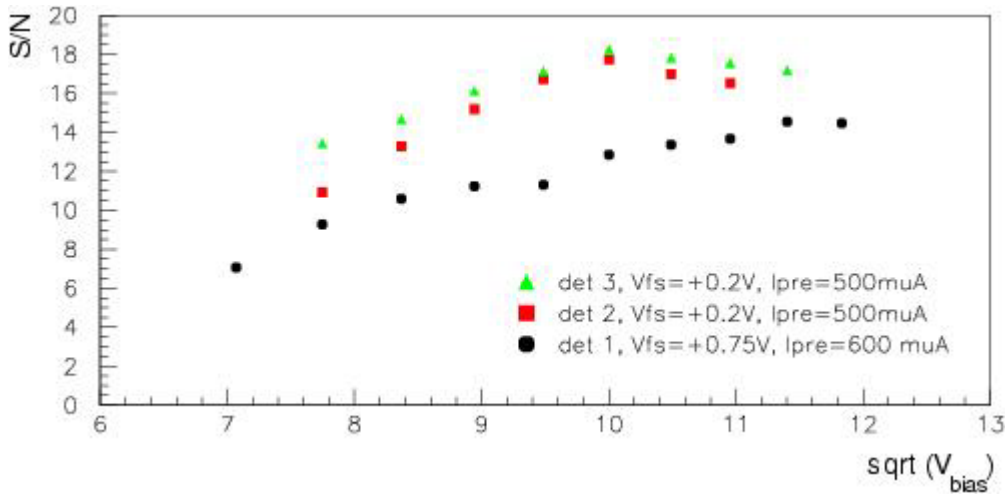




The LHCb Inner Tracker - lab measurements

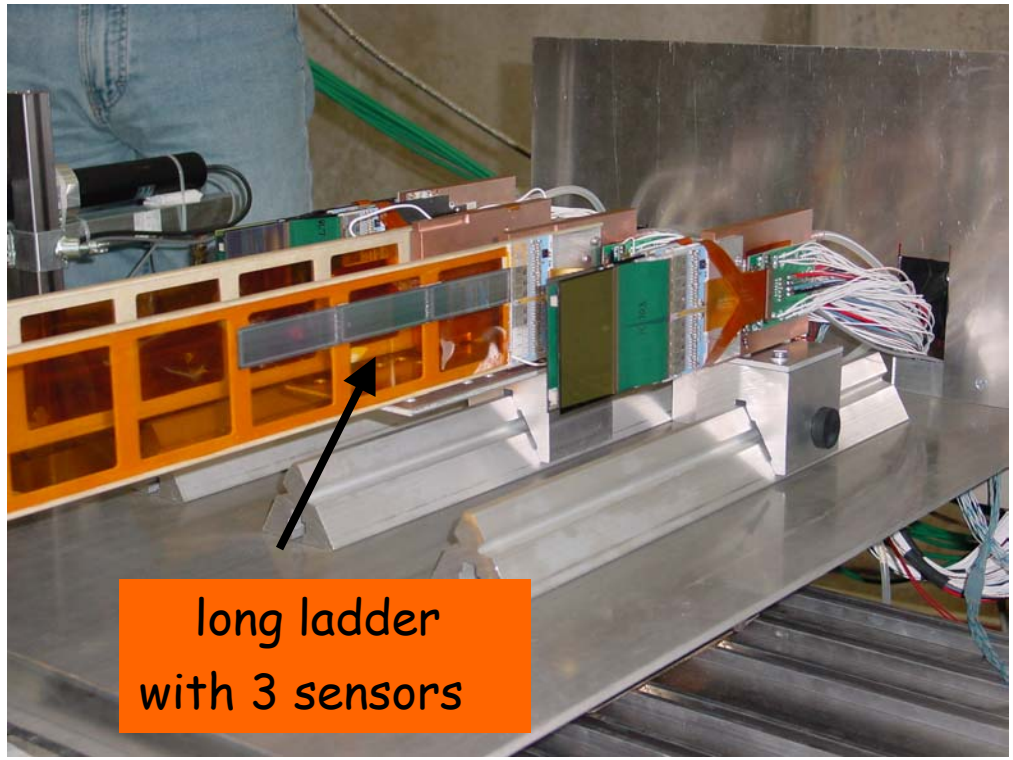
- laser (1068nm) and β-source measurements on test ladders
- pulse height measurement indicates charge loss in between strips
  - detectors were operated slightly above nominal depletion voltage
  - larger overbias not possible due to junction breakdown
- source measurements with different shaping times:
  - long shaping: S/N reaches plateau
  - short shaping: S/N still rises towards higher bias voltages
- improved charge collection by overdepleting detectors





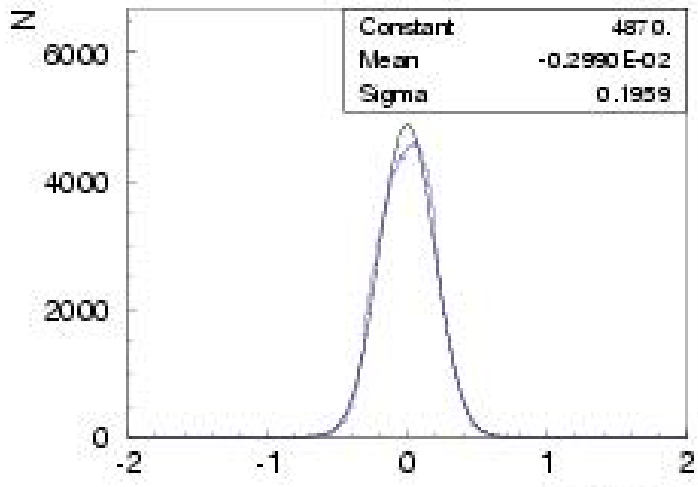
The LHCb Inner Tracker – test beam measurements

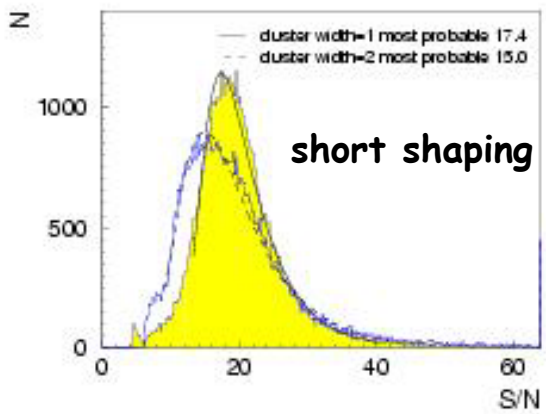
- Test beam in May 2001 at CERN T7 test beam facility with 9 GeV π
- use complete readout system of HERA-B (Helix chip, DAQ …)
- beam telescope for tracking
- two ladders under study
  - short (6.6 cm) and long ladder (19.8 cm)
- study resolution and efficiencies

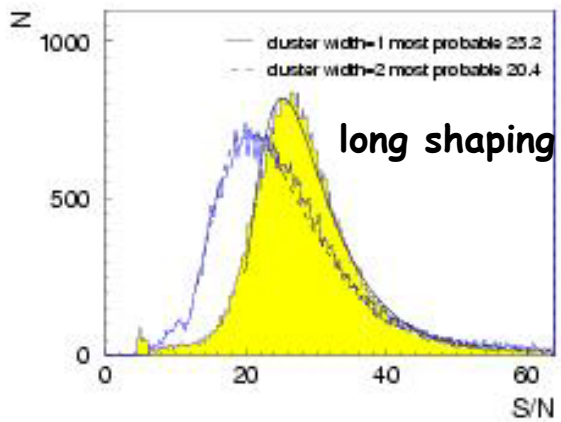


The LHCb Inner Tracker – test beam results for short ladder

- achieved resolution based on track residuals for the 240 μm pitch ladders ~50 μm (would expect 70μm for a pure binary R/O)
- S/N different for clusters having only one single strip and two strips
- indicates charge loss in between strips



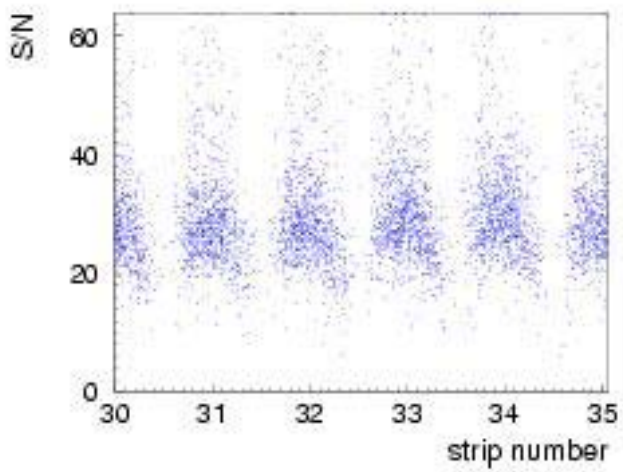




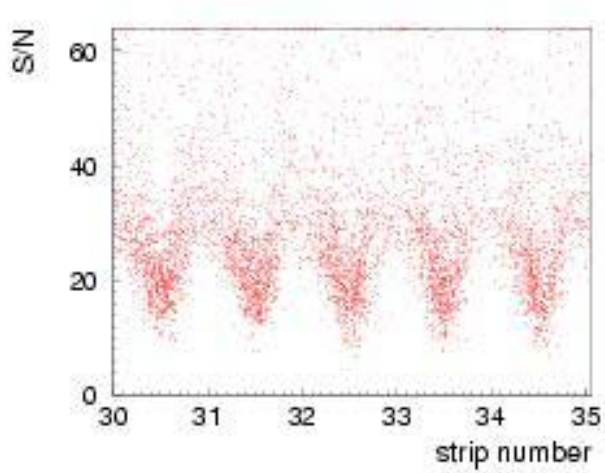
The LHCb Inner Tracker – test beam results for short ladder

- S/N ratio versus track impact position (from beam telescope) for
  - one strip cluster
  - two strip cluster
- one strip cluster populate center of strips
- two strip cluster mainly in between strips have lower S/N => lower efficiency

one strip clusters



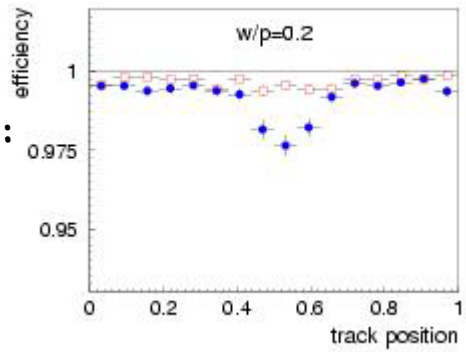
two strip clusters



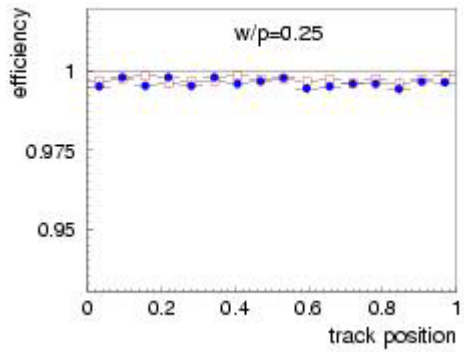
The LHCb Inner Tracker – test beam results for short/long ladder

- hit efficiency versus track position for increasing w/p for short (top row) and long (bottom row) ladders
- two shaping times: blue points for short, red points for long shaping time
- efficiency in between strips increases towards higher w/p

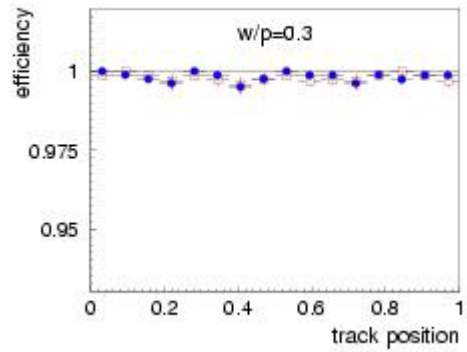
Short ladder:



w/p=0.2

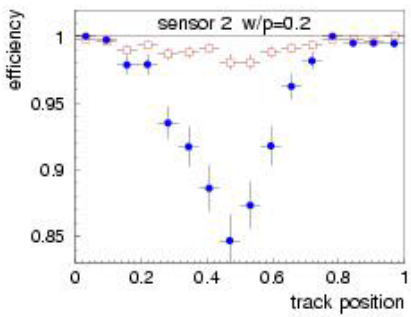


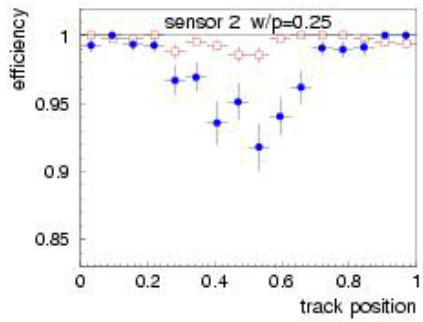
w/p=0.25

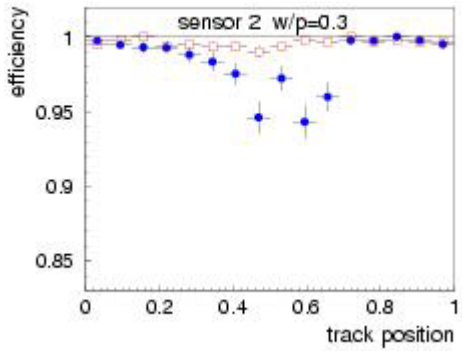


w/p=0.3

Long ladder:





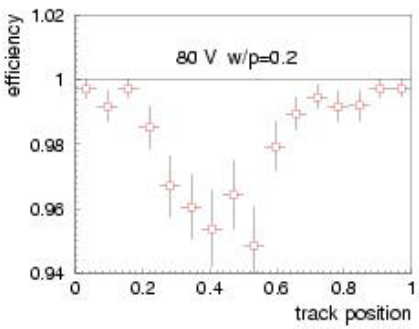


The LHCb Inner Tracker – test beam results for long ladder

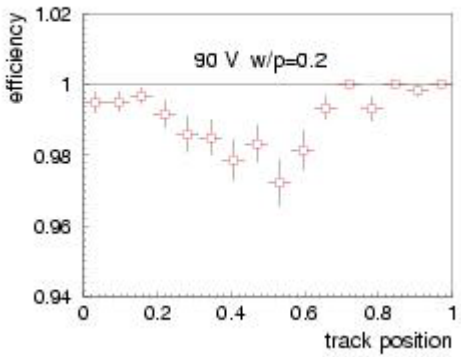
- efficiency loss in between strips of long ladder can be diminished by overbiasing detector
- could not go to much higher bias voltage due to junction breakdown of ladders

higher bias voltage

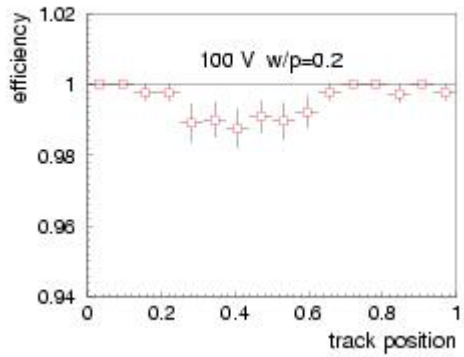
U=80V



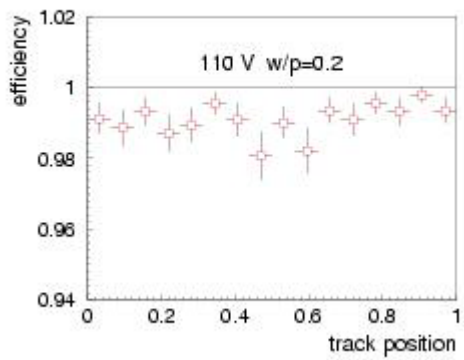
U=90V



U=100V

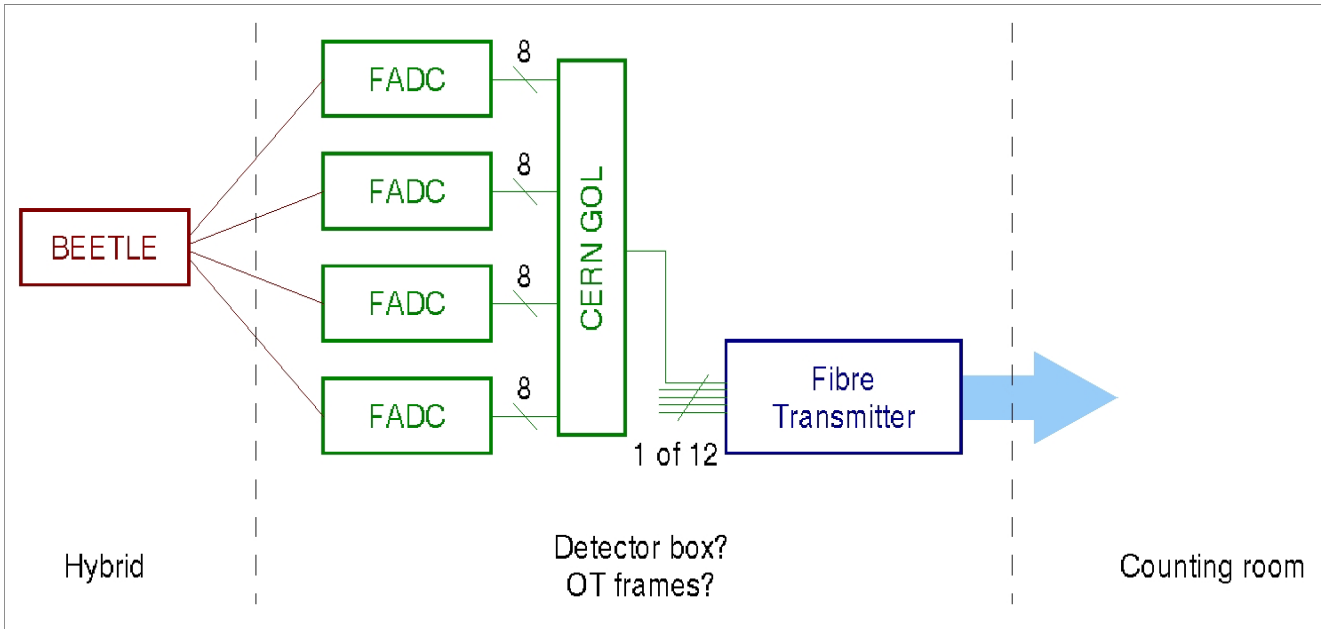


U=110V



The LHCb Inner Tracker – readout electronics

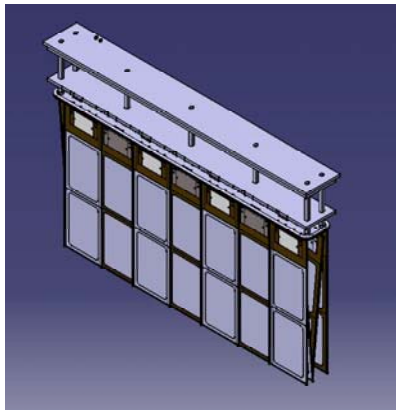
- Beetle readout chip
  - 0,25 μm CMOS, radiation hard, 40MHz clock
  - 128 channel preamplifier device with 160 BC deep pipeline
  - 32x multiplexed analog output for fast readout within 900ns
- 8-bit 40 MSPS FADC
  - two options for FADC under study
- CERN GOL/TTCrx
  - rad. hard serializer 32-bit @ 40MHz to 1.6Gbit/s
  - trigger/clock distribution
- Optical modules
  - 12-channel VCSEL array up to 2.5Gbit/s

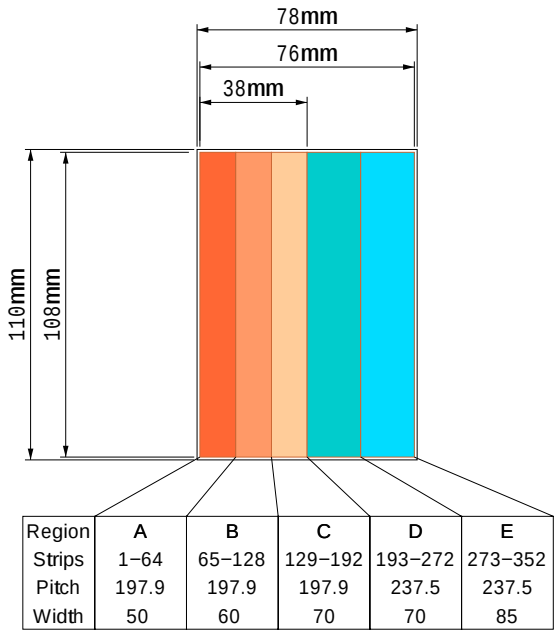


digital optical readout link at 1MHz
Locations of FADC, GOL tbd

The LHCb Inner Tracker – summary

- yet another silicon detector for LHCb having ~14m^2 surface area is being designed
- ladder and station designs are evolving rapidly
- measurements on very first prototype ladders indicate that S/N in between strips is not satisfactory
- improvements of charge collection by overbiasing and higher w/p
- will continue to study effect on a new prototype series with multi-geometry pitches





Region	A	B	C	D	E
Strips	1–64	65–128	129–192	193–272	273–352
Pitch	197.9	197.9	197.9	237.5	237.5
Width	50	60	70	70	85