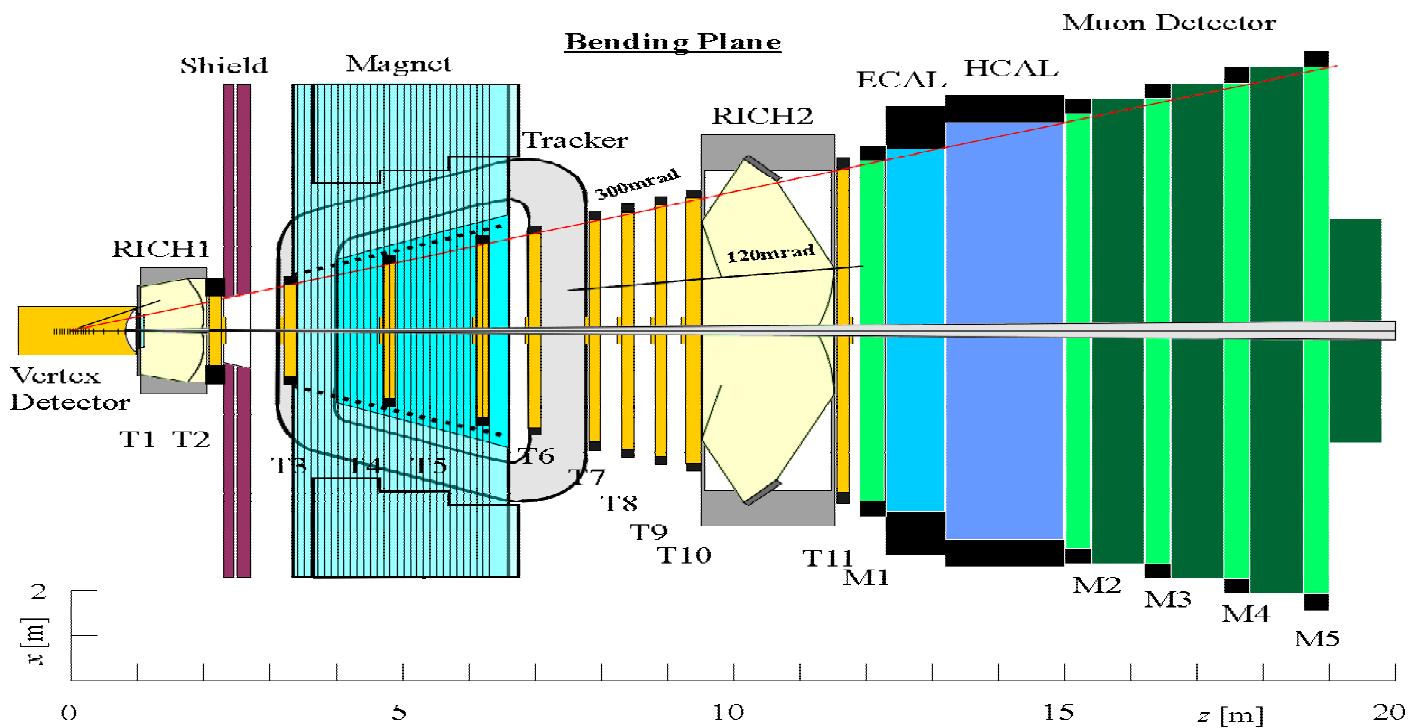


The LHCb Silicon Tracker

10th International Workshop on Vertex Detectors
 VERTEX 2001
 23 – 28 September in Brunnen, Switzerland

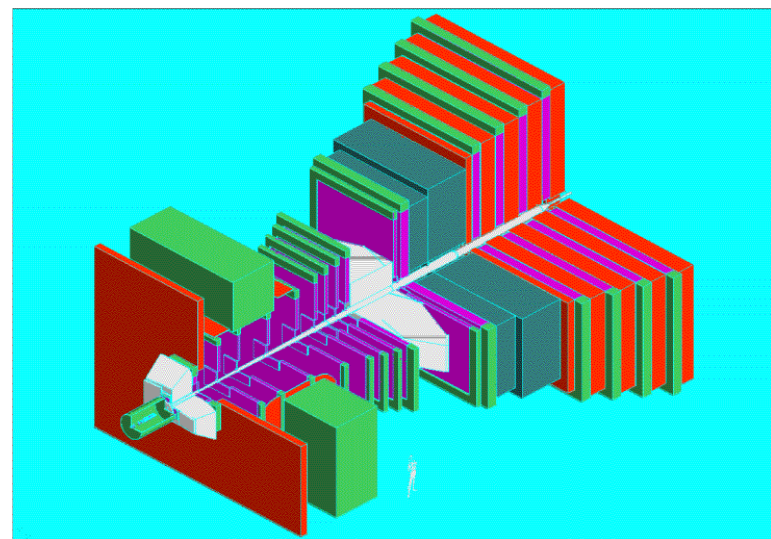
Frank Lehner
 University of Zurich

LHCb Inner Tracker memo 2001-011



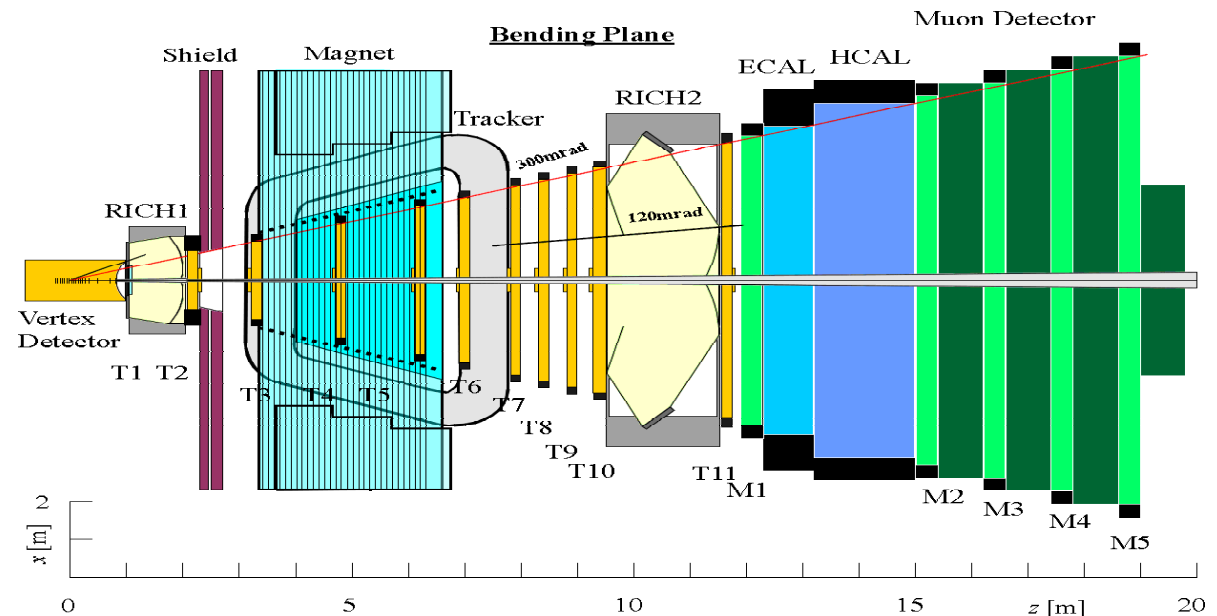
The LHCb experiment

- 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 $\pm 300\text{mrad}$ 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 $\sim 17\text{MeV}$ mass resolution for reconstructed $B \rightarrow \pi\pi$ decays e.g.
 - provide track segments into RICH as input for particle-ID algorithms
 - tracking resolution dominated by multiple scattering \Rightarrow 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

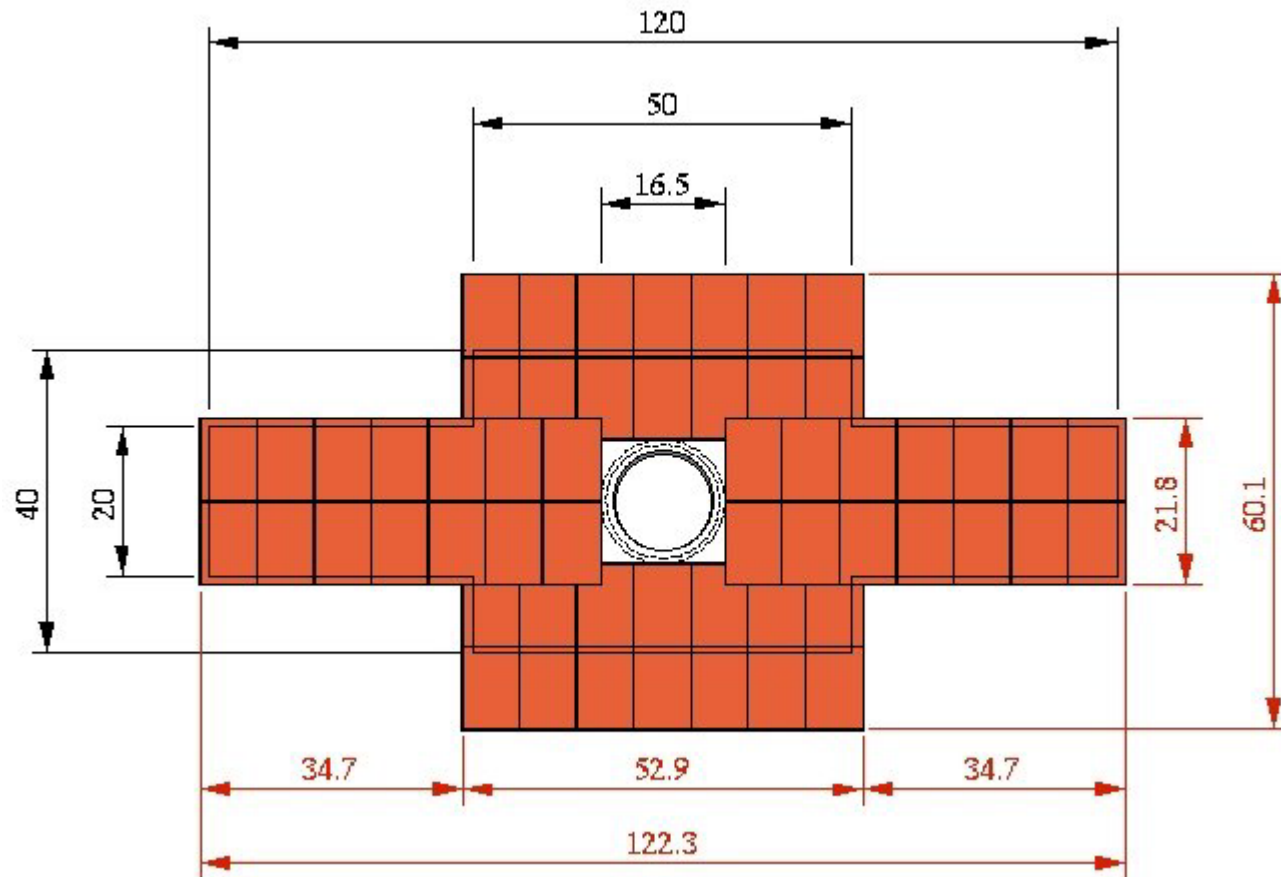


The LHCb Inner Tracker

- detector technology for Inner Tracker driven by
 - sustain high charged particle rate of up to $10^6 \text{cm}^{-2} \text{s}^{-1}$
 - moderate position resolution of $\sim 80 \mu\text{m}$ 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

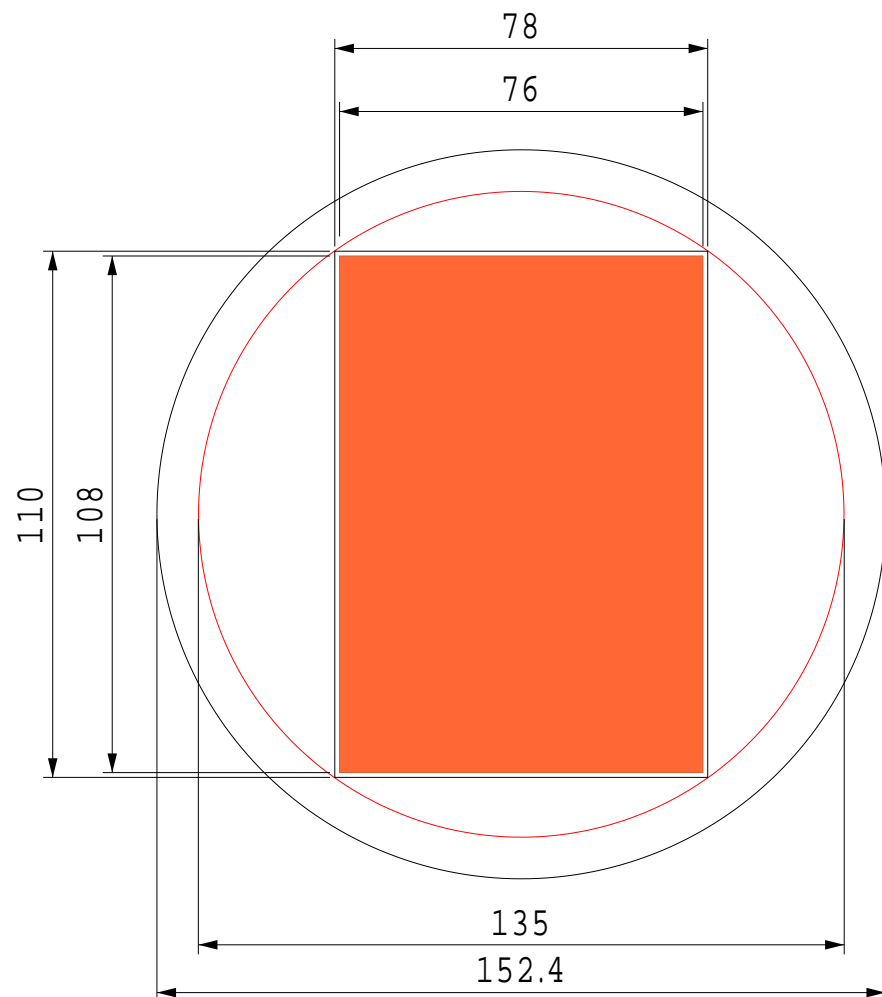
The LHCb Inner Tracker- Station layout

- nine tracking stations along conical beampipe
- four layers each with small angle stereo-view: $0^\circ, \pm 5^\circ, 0^\circ$
- up to 22 cm long silicon ladders
- total silicon area $\sim 14 \text{ m}^2$
- conical beampipe \Rightarrow different layout in each station
- particle fluences higher in equatorial plane (bending plane of magnet)
- accomplished by four independent boxes arranged in cross geometry



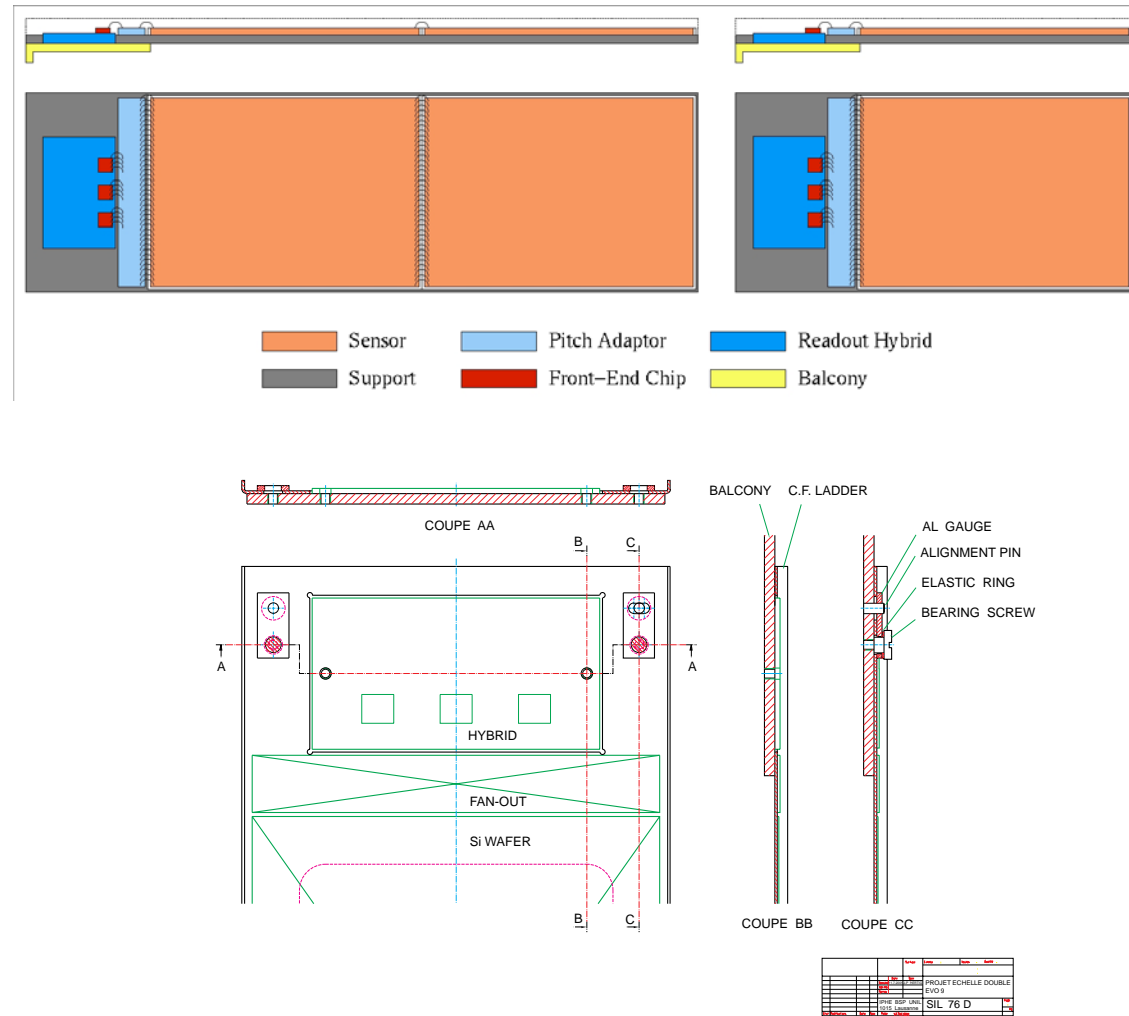
The LHCb Inner Tracker- Sensors

- use single sided p+n silicon sensors will be produced from 6" wafers
- physical length and width: 110 x 78 mm²
- 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 5·10¹³cm⁻²



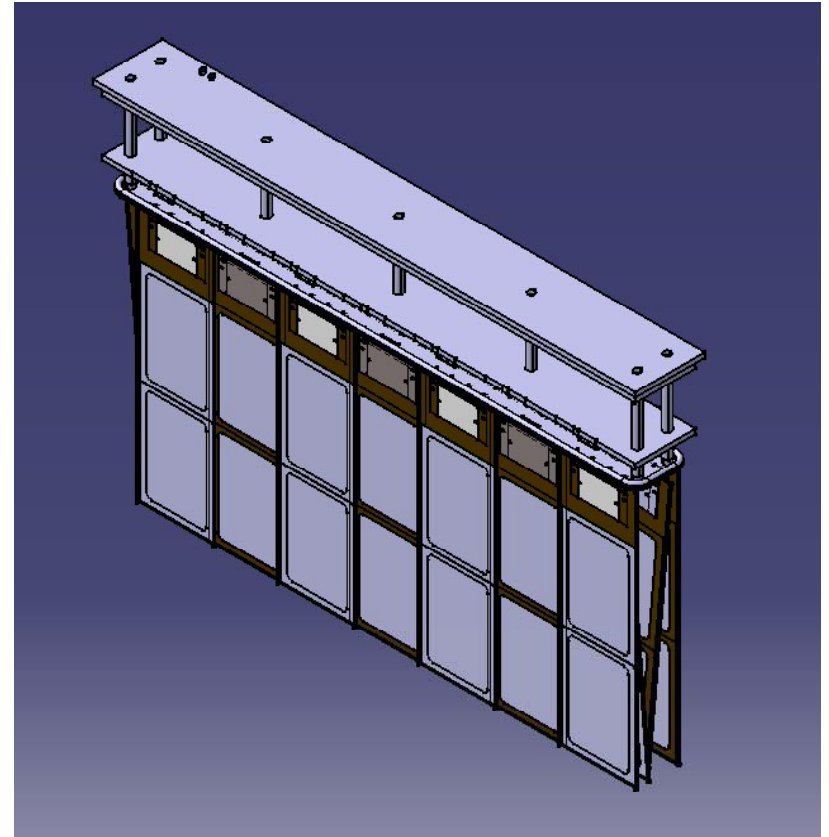
The LHCb Inner Tracker- Ladder design

- 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



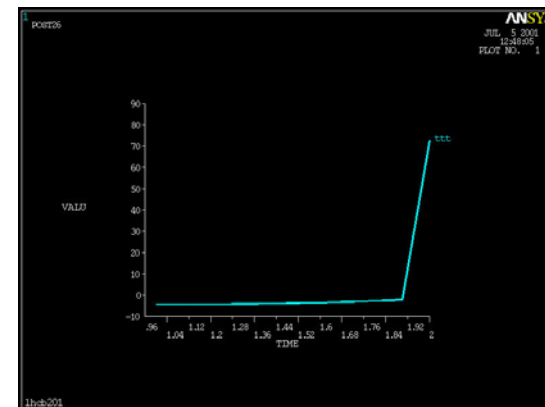
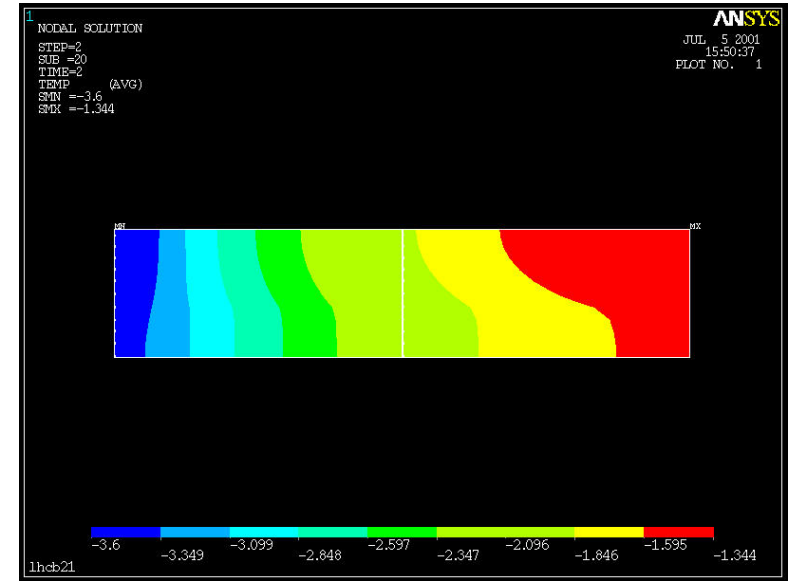
The LHCb Inner Tracker- station/box design

- 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

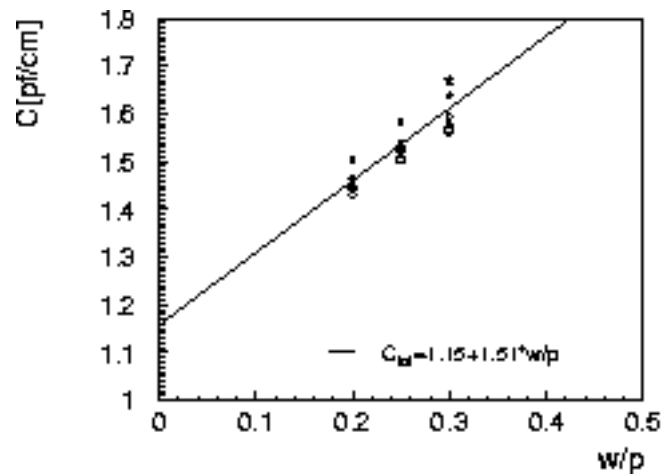
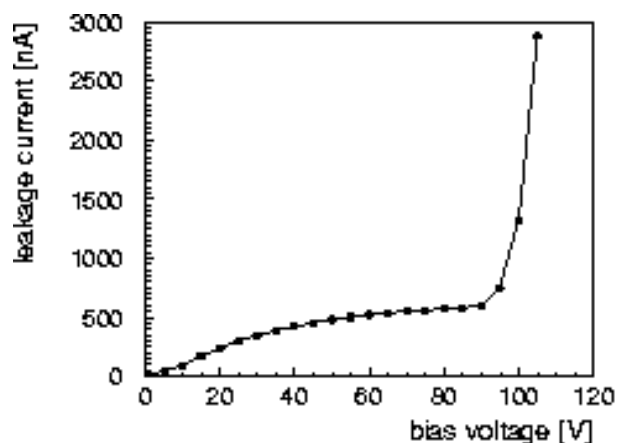
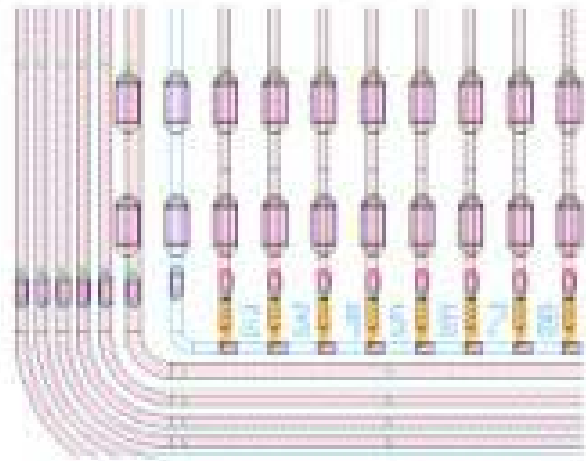
- finite element calculations to optimize thermal performance of ladder
 - include power dissipation by chips and radiation damaged silicon
- silicon can be kept cold over course of 10 years of LHCb running
- however: for too high coolant temperatures risk of thermal runaway present
- minimize risk by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



The LHCb Inner Tracker-first sensor prototypes

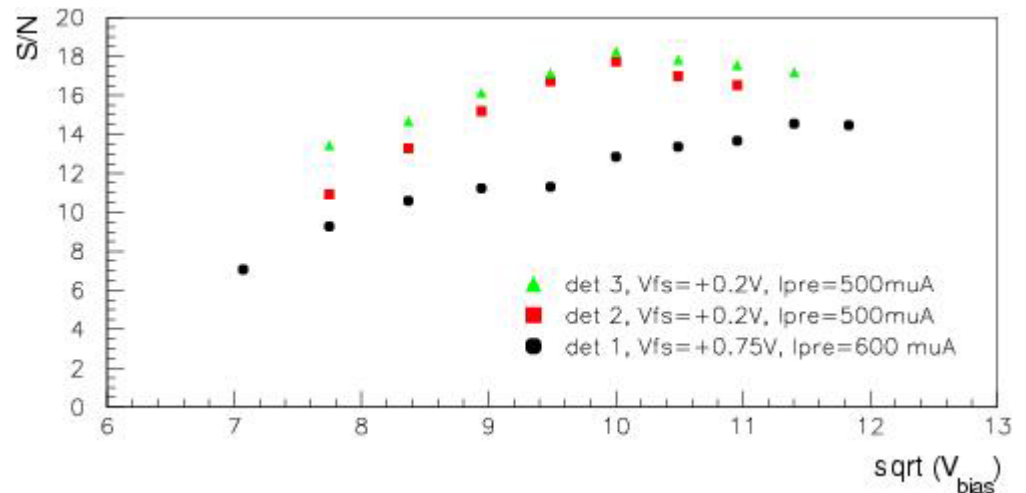
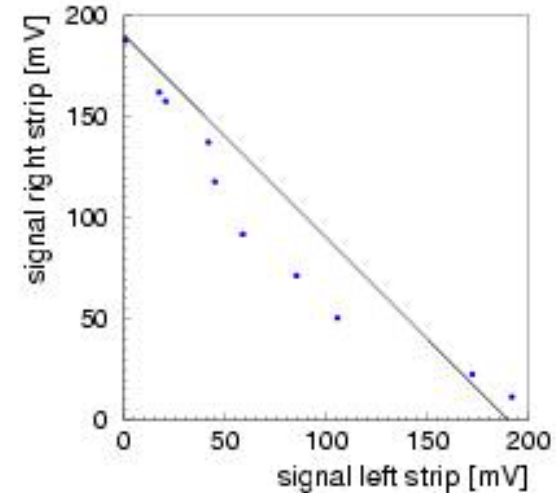
- multi-geometry sensors from SPA Detector in Kiev
 - p+n single sided
 - pitch 240 μ m
 - oxygenated on 4" wafers
 - three different width/pitch ratios
 - ✓ w/p= 0.2, 0.25, 0.3
 - two types of Al metal traces
 - ✓ overhang and underhang
- depletion voltage: 50-70V
- total capacitance: 1.3-1.6pF/cm
-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

**64 strips
66.6 mm long**



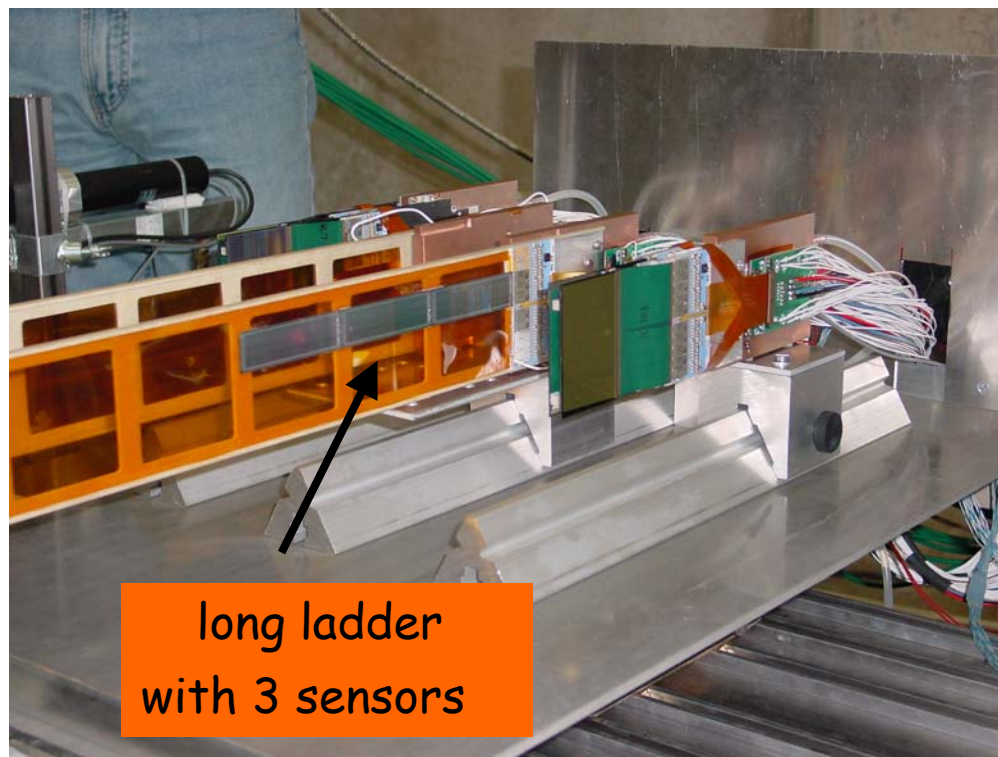
The LHCb Inner Tracker - lab measurements

- 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



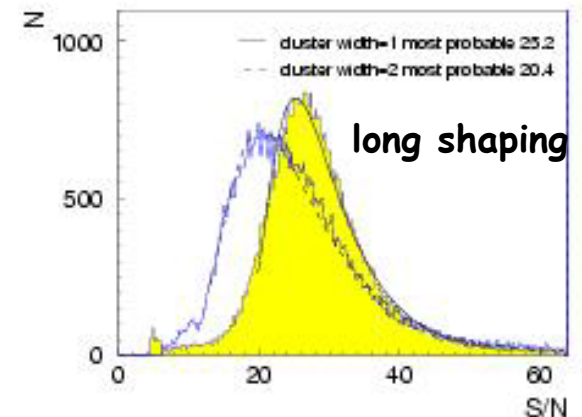
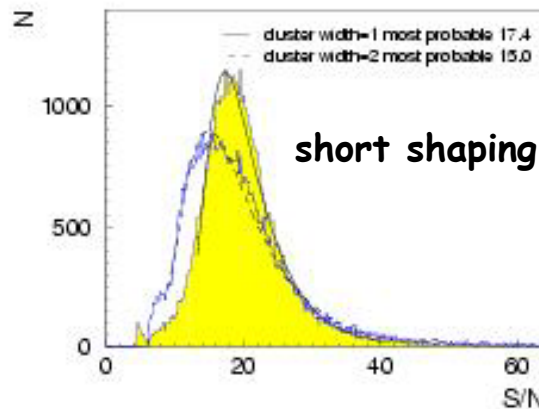
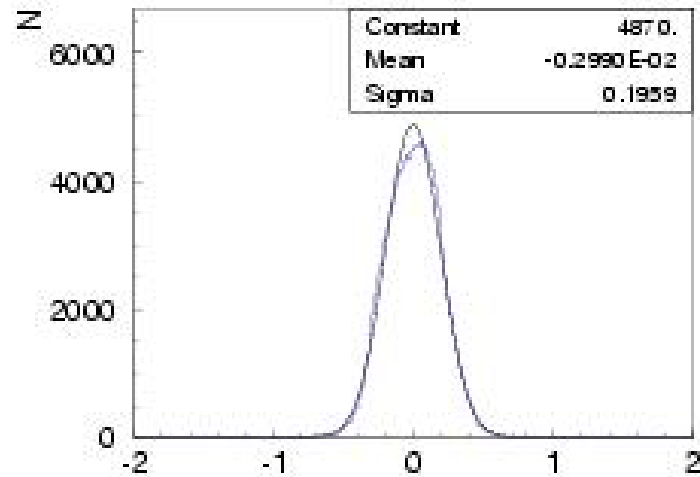
The LHCb Inner Tracker - test beam measurements

- 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

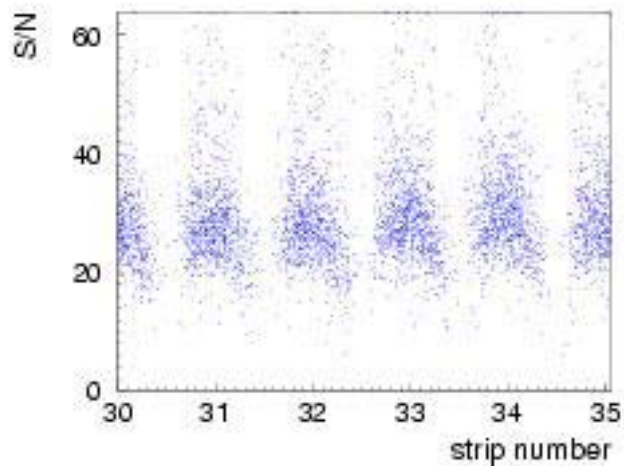
- achieved resolution based on track residuals for the 240 μm pitch ladders $\sim 50 \mu\text{m}$ (would expect 70 μm for a pure binary R/O)
- S/N different for clusters having only one single strip and two strips
- indicates charge loss in between strips



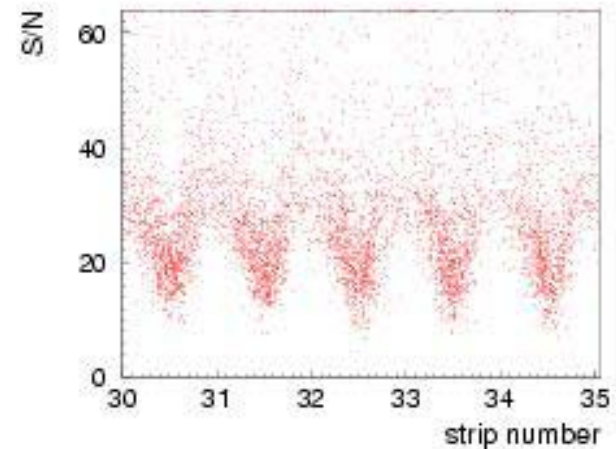
The LHCb Inner Tracker - test beam results for short ladder

- 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



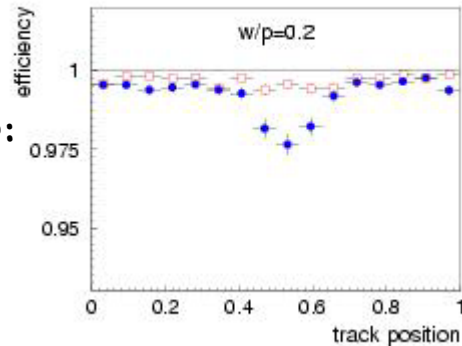
two strip clusters



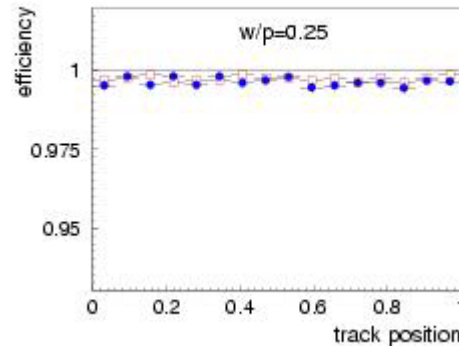
The LHCb Inner Tracker - test beam results for short/long ladder

- 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

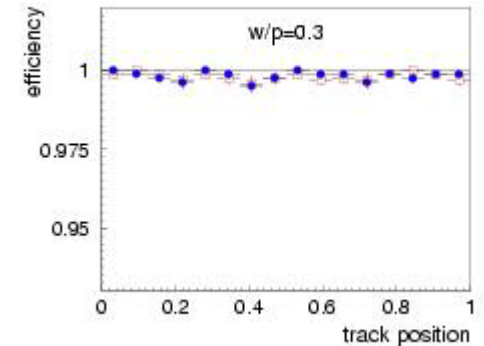
Short ladder:



$w/p=0.2$

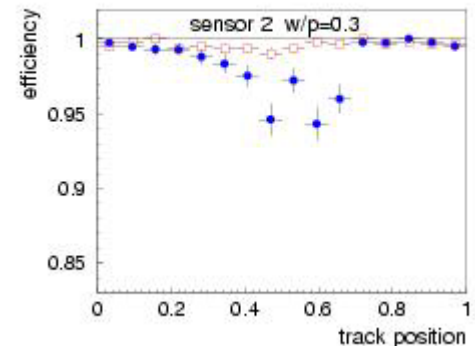
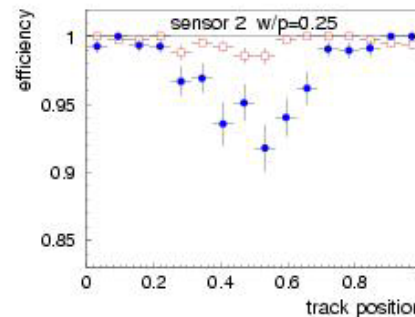
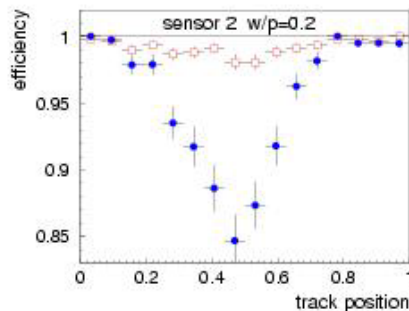


$w/p=0.25$



$w/p=0.3$

Long ladder:



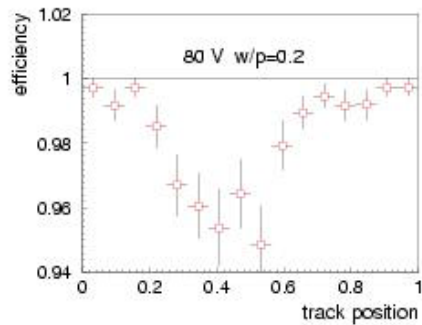
The LHCb Inner Tracker - test beam results for long ladder

- 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

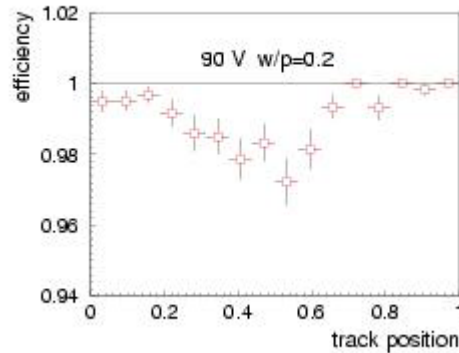
higher bias voltage



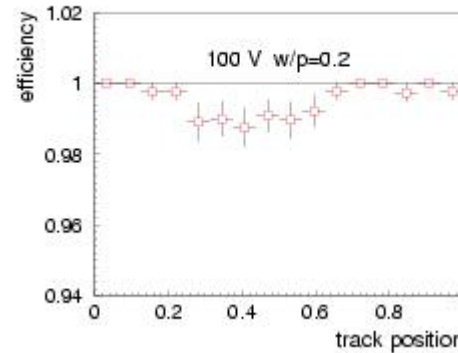
U=80V



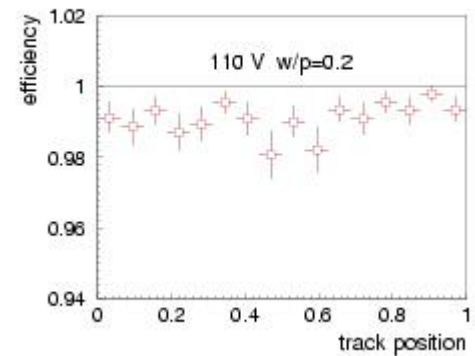
U=90V



U=100V

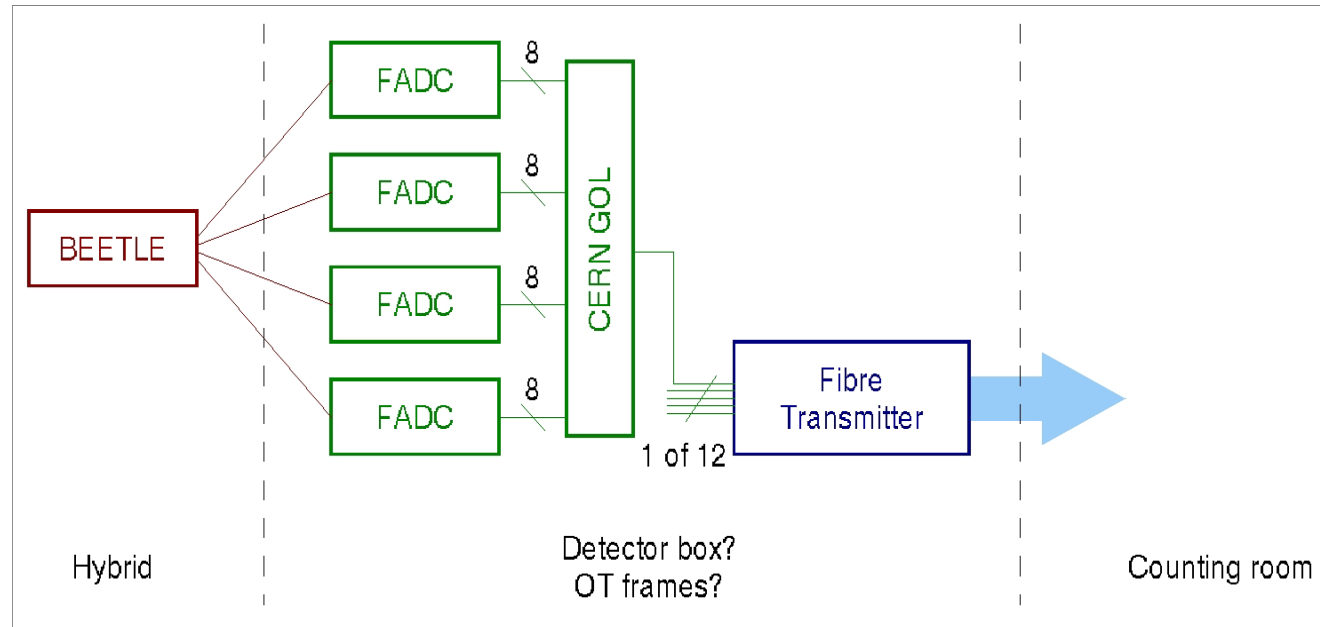


U=110V



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 $\sim 14\text{m}^2$ 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

