The LHCb Silicon Tracker

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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 m²
  - total number of R/O channels: ~300k
The LHCb Silicon Tracker: Requirements

• provide reliable and robust tracking in charged particle environment w/ rates of ~10⁵ 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 (~200 µm) 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 5\(\mu\)m, flat within 50\(\mu\)m
  - thermal conductivity >150 W/mK
  - mechanical stiffness
  - high radiation length

- **first prototypes from Amoco K1100/Mitsubishi K13C2U composites produced**
  - measured \(\lambda\sim 200\) 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 ($X_0 \sim 17\text{cm}$, $\lambda \sim 430 \text{W/mK}$)
  - high density graphitic foams ($X_0$ up to 28 cm, $\lambda$ up to 250 W/mK)
  - Carbon-carbon composites
  - figure of merit: $X_0 \cdot \lambda$

![Graph showing $X_0 \cdot \lambda$ for different materials]
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: $450e + 47e \times C[pF]$ 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
May/June 2002 testbeam at CERN X7
- Hamamatsu multi-geometry sensors
  - Region C: 198\(\mu\)m pitch, \(w/p=0.35\)
  - Regions D & E: 240 \(\mu\)m 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 \(~35\text{ns FWHM}\)
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

Region C of long ladder 200V bias
• 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