

The LHCb Silicon Tracker [★]

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Abstract

Wide pitch silicon micro-strip detectors will be used in both the LHCb Inner Tracker and the Trigger Tracker. In total an area of 12 m² will be covered with silicon using ladders of up to 33 cm in length. The design of both detectors and corresponding test beam results are presented.

1 Introduction

LHCb [1] is a dedicated B physics experiment that will operate at the LHC. It will perform precision measurements of CP violation and rare decays. The detector is a single arm spectrometer (Fig. 1) consisting of a tracking system, vertex detector, RICH detectors, calorimeters and muon system.

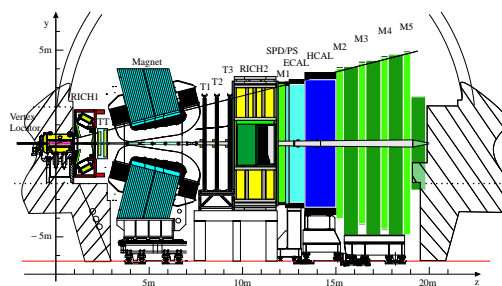


Fig. 1. The LHCb detector.

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¹ <http://lhcb-track.web.cern.ch/lhcb-track/>

2 The Silicon Tracker

The LHCb Silicon Tracker (ST) project consists of two sub-detectors that will be built using silicon micro-strip technology. The first is the inner part of the tracking stations T1-T3. The ‘Inner Tracker’ (IT) will cover a cross-shaped area around the beam-pipe in each of these stations. Despite covering only $\sim 2\%$ of the acceptance 20 % of tracks pass through the Inner Tracker. The second sub-detector is the ‘Trigger Tracker’ (TT). This consists of four layers of silicon located upstream of the magnet. Readout electronics and infrastructure such as High and Low Voltage distribution and cooling will be developed in common for both sub-detectors. In total a surface area of 12 m^2 will be covered with silicon strips resulting in 306,000 readout channels.

The LHC will provide a challenging environment for track reconstruction. On the one hand it is necessary to minimize the material within the detector acceptance in order to reduce multiple scattering and secondary interactions. On the other hand due to the 25 ns bunch crossing rate it is necessary to run with fast shaping (and hence high noise) in order to minimize the number of hits from previous crossings that are seen in a triggered event (‘spillover’). The design of the Silicon Tracker attempts to balance these somewhat contradictory requirements.

3 The Inner Tracker

An Inner Tracker station consists of four independent boxes located around the beam-pipe (Fig 2) . Each box contains four layers of silicon orientated as $0^\circ, 5^\circ, -5^\circ, 0^\circ$. The ladders are mounted on a cooling plate and operated at 5°C to reduce leakage currents. It is intended to use $320 \mu\text{m}$ thick p-on-n silicon strips with a pitch of $200 \mu\text{m}$. Sensors will be cut from 6” wafers and used to produce one (11 cm) and two (22 cm) sensor ladders with 384 strips on each ladder. The front-end chip used by both the IT and TT for readout is

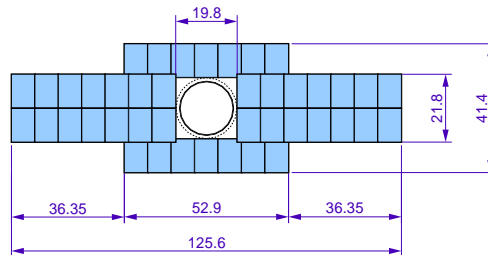


Fig. 2. Layout of an inner tracker station.

the Beetle chip [2]. This is a radiation hard $0.25 \mu\text{m}$ CMOS chip that has been

custom developed for LHCb. The shaping time of the Beetle can be adjusted by programming an internal register, V_{fs} . By increasing the shaping time the noise performance of the chip can be improved albeit at the expense of higher spillover.

Further details on research and development for the IT and the resulting technical design can be found in [3].

4 The Trigger Tracker

The Trigger Tracker is located in the fringe field of the magnet and covers the full detector acceptance. It will consist of four layers of silicon arranged into two half stations separated by 30 cm in z . The splitting of the station allows a rough determination of particle momentum in the Level-1 trigger. The same sensor geometry as in the IT will be used. In the first half station, TTa, as shown in Fig. 3 the sensors are arranged in nine staggered eleven-sensor long ladders to the left and right of the beam-pipe and in five-sensor long ladders above and below the beam-pipe. In TTb ten staggered twelve-sensor long ladders are employed to cover the active area to the left and right of the beam-pipe whilst six-sensor ladders are used above and below the beam-pipe. Electronically, a ladder is split into several readout sectors as indicated by the shading in Fig. 3. In order to minimize the amount of dead material in the acceptance all the front-end hybrids are located at the edge of the detector. Kapton cables ranging in length from 33-55 cm will be used to connect the inner sensors to their corresponding hybrids. Prototypes of such cables are currently being tested in the laboratory. Such cables are expected to have a capacitance of 0.5 pF/cm compared to ~ 1.5 pF/cm for silicon sensors. This leads to a capacitive load of ~ 50 pF for all the readout sectors.

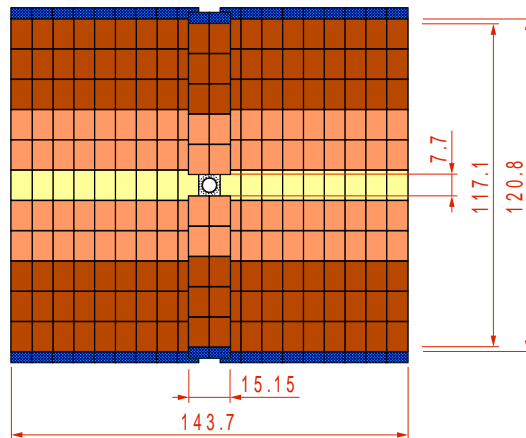


Fig. 3. Layout of TTa.

5 TT prototype ladders

In order to determine the optimal wafer thickness for the TT sensors three prototype ladders have been constructed from the $320\ \mu\text{m}$ -thick multi-geometry prototype sensors developed for the LHCb Inner Tracker, from $410\ \mu\text{m}$ -thick GLAST2000 sensors [5] and from $500\ \mu\text{m}$ -thick CMS-OB2 sensors [6]. Each prototype ladder consisted of three sensors bonded in series. The relevant properties of the ladders are summarized in Table. 1. The performance of the Table 1

Prototype ladder properties.

Ladder	length/cm	thickness/ μm	Pitch/ μm	C_{strip}/pF
LHCb3	32.4	320	198	50.6
GLAST2000	26.3	410	228	41.3
CMS-OB2	28.9	500	183	37.6

ladders has been tested in a $120\ \text{GeV}\ \pi^-$ beam at CERN. Four double-sided silicon detectors provided by the HERA-B vertex detector group [4] served as a beam telescope and allowed the reconstruction of track coordinates with a precision of $\sim 14\ \mu\text{m}$. Each ladder was mounted on rails allowing it to be moved perpendicular to the beam. This allowed measurements to be made for each sensor on a ladder. For tracks that pass close to the centre of a readout strip most-probable signal-to-noise (S/N) ratios of 9.6 for the LHCb3, 15.8 for the GLAST and 21.6 for the CMS are found. These numbers were found to constant over the full length of the ladder. The performance of the ladders is consistent at the level of $\sim 10\%$ with expectations based on the ladder thickness and capacitance given in Table. 1.

As in R+D for the Inner Tracker [3] a significant drop in the S/N ratio is observed in the region between two readout strips for all three ladders. This can be seen for the case of the GLAST ladder in Fig. 4. The relatively low S/N values obtained for the LHCb3 ladder give an average cluster finding

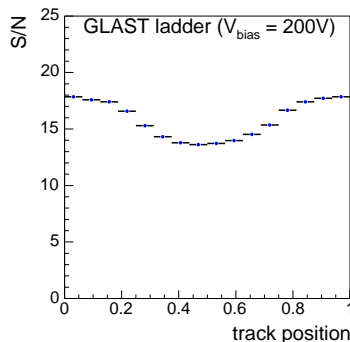


Fig. 4. Signal-to-Noise ratio as a function of the interstrip position for the GLAST ladder.

efficiency of 96.2% . In contrast, efficiencies in excess of 99.8% are observed for both the GLAST and CMS ladders. The efficiency loss between two strips can be reduced by running with slower shaping times as can be seen from Fig. 5. However, such long shaping times lead to an unacceptable level of spillover. It is therefore concluded that for the 33 cm long ladders in the TT station 410 μm thick silicon is required in order to obtain sufficiently good S/N performance with fast shaping.

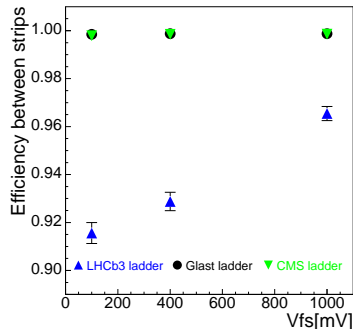


Fig. 5. Cluster finding efficiency in the inter-strip region vs the Beetle parameter, V_{fs} . Large values of V_{fs} correspond to slow shaping.

6 Summary

Both the Inner and Trigger Tracker of the LHCb experiment use silicon micro-strip technology. The research and development phase of both projects is now ending. In the case of TT it has been found that despite the constraints imposed by the challenging environment of the LHC sufficiently high S/N can be obtained for 33 cm long ladders if 410 μm thick silicon is used. Construction of both sub-detectors will commence soon, on track to be ready for data taking at the start of LHC physics operation in 2007.

References

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