LHCb Note 2002-011

The LHCb Silicon Inner Tracker[*]

Frank Lehner

On behalf of the LHCb Inner Tracking Group[1]

Physics Institute, University of Zurich, CH-8057 Zurich

Abstract

The inner part of the LHCb tracking system will be realized in a silicon microstrip technology. The experimental requirements suggest 20 cm long ladders and a readout pitch of around 240 μm. The complete LHCb Inner Tracker system will consist of 9 stations with an overall silicon surface area of approximately 14m^2, depending on the final layout of the tracking system. A report about the current design of the silicon ladders and tracking stations of the Inner Tracker is given. First characterisations of prototype sensors and test beam results of ladders are presented.

Key words: silicon detector, LHCb, tracking detector

---

1 Introduction

LHCb [1] will be a dedicated experiment at the LHC collider, starting its operation in 2006, to investigate CP-violating phenomena in the b-quark sector. The experiment is set up as a single forward spectrometer with a 4 Tm dipole magnet. The detector covers a polar angle of 300 mrad in the magnet bending plane. One of the main challenges of the LHCb detector is a highly selective trigger to collect a large sample of B decays into specific channels. The LHCb tracking system consists presently of 9 planar stations. This number however, is still subject of further optimisation studies in order to further minimise the material without losing the good pattern recognition. The inner part of the tracker system is described in this note. Other components of the LHCb

---

[*] Talk given by Ulrich Straumann at the 10th International Workshop on Vertex Detectors, Vertex 2001 (Brunnen, Switzerland, September 2001).

[1] http://lhcb.web.cern.ch/lhcb-track/html/innertracker

Preprint submitted to Elsevier Preprint *11 March 2002*

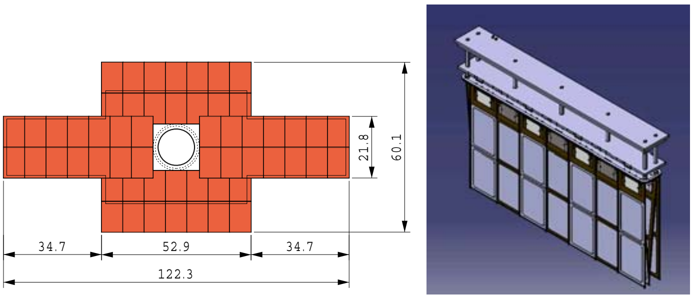

Fig. 1. Left: Cross-shaped layout of a typical Inner Tracker station. Right: Drawing of one box of a station.

detector are the vertex detector system VELO, which is a silicon microstrip based detector, two RICH systems for charged particle identification of pions and kaons in various final states, as well as electromagnetic and hadronic calorimeters and a muon system.

2 The LHCb Inner Tracker design

2.1 Design requirements

The general requirements of the LHCb tracking system are a very robust and reliable track finding in the region between the vertex detector and the calorimeters and a precise measurement of the charged particle momentum as an important ingredient in the mass resolution of the reconstructed B mesons. The design resolution of 80 μm corresponds to a momentum resolution of 0.4%. The momentum resolution of the tracker system will then be dominated by multiple scattering processes for tracks of up to 100 GeV. Therefore, the involved material mass has to be minimised. Moreover, track segments into the two RICH detectors have to be provided in order to serve as an input for the particle identification algorithms.

Since the track density rapidly falls off towards larger distances to the beam axis, the tracking system is split into an inner and outer subsystem with different granularities. Whereas the outer tracker will be realized in a straw-tube drift chamber technology, silicon microstrip detectors will be used for the inner region close to the beampipe. This technology has been chosen due to its reliability in the high particle density environment of the Inner Tracker with charged particle rates of up to 10^6 cm$^{-2}s^{-1}$. The total expected fluence of charged hadron particles in the innermost region leading to radiation damage in silicon material will be approximately $5{\cdot}10^{13}$ cm^{-2} after 10 years of operation.

2.2 The station design

Since the LHCb beampipe which passes through the detector is conical, the layout of each of the 9 stations is slightly different. The inner tracking detector has to cover a larger area due to the increased particle fluxes in the magnet bending plane than in the non-bending plane. The left part of figure 1 shows a typical station layout which is composed of 4 independent quadrants arranged in a cross-shaped way around the beampipe. This layout allows the distance to the beam line for the different stations to be easily adjusted. Each quadrant has four layers of silicon planes with strips oriented in 0°, ±5° and 0° and is enclosed in a light-tight housing made out of a sandwiched foam material in order to provide electrical and thermal insulation to the outside world.

2.3 Silicon sensors and ladder design

The sensitive planes of one quadrant are assembled in a modular fashion. The basic building units are silicon ladders with either a 110 mm (one sensor) or 220 mm (two sensors) long and 78 mm wide active area. The right part of figure 1 shows a drawing of the mounted ladders in a station quadrant. Typically, 7 ladders per plane are arranged such that enough overlap between the ladders for offline alignment purposes is given. The ladders will be produced from 6" single sided p^+n silicon wafers with a thickness of 300 μm. The two-sensor ladders will be assembled by joining two silicon sensors end-to-end together. A front-end hybrid at the end of the ladder carries three readout chips and other electronic components on a Kapton flex circuit. Two options for the silicon strip pitch are discussed: a pitch of either 198 μm or 237.5 μm in order to match the readout granularity of 384 or 320 channels respectively. The silicon sensors will be AC-coupled and biased through polysilicon resistors. About 1500 silicon sensors in total will be necessary to produce the Inner Tracker. The complete ladder is supported by a U-shaped carbon fiber composite which has to provide stiffness and resistance against bending. The carbon fiber composite will be made out of a high thermal conductive fiber material so that the carbon shelf under the silicon can act as a head spreader to give a lower temperature gradient along the silicon sensors.

The carbon fiber support including the silicon sensors is mounted onto a cooling balcony piece using precisely machined holes and guide pins as reference features. These cooling balconies provide a mounting surface for the ladders so that the ladders can be attached to a common cooling plate on top of a station quadrant. The heat generated by the chips is then effectively removed through the hybrids to the balconies and further to the cooling plate. The silicon sensors are in contact with the balcony via the carbon fiber shelf and

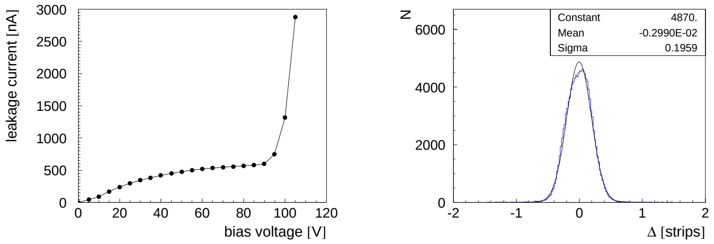

Fig. 2. Left: Leakage current behaviour for a typical example of the prototype sensors. Right: Obtained spatial resolution from test beam measurements on the 240 μm wide pitch ladders. The σ of the fit gaussian distribution is 50 μm.

will be kept cold at temperatures of around 0°C in order to reduce the shot noise of the ladder after irradiation. Several investigations to identify an ideal balcony material are presently underway. A good candidate seems to be a metal matrix composite with unidirectional high thermal conductive fibers infiltrated with magnesium. First engineering prototypes will soon be produced in collaboration with the federal swiss institute EMPA in Thun.

2.4 Thermal studies

A finite element analysis (FEA) has been carried out using the ANSYS program package in order to optimise the ladder design and material choice. The ladder geometry has been realistically modelled and large safety margins for the thermal contact joints and heat dissipation in the chips and the irradiated silicon have been applied. It could be demonstrated in the simulation, that the ladder can be kept cold over the course of 10 operational years of LHCb by cooling from the ladder end. The simulated silicon temperature after 10 years of running remains slightly below 0°C for a coolant temperature of -10°C. However, for higher coolant temperatures, a risk of a thermal runaway due to the increased bulk heat production in the irradiated silicon is present. In order to minimise the runaway risk, a purging of the boxes with cold N_2 gas is foreseen.

2.5 Readout electronics

A new radiation-hard readout chip, the so called Beetle [2] chip fabricated in 0.25 μm CMOS technology, is designed for LHCb purposes and will be attached on the silicon hybrids. The Beetle provides a 128-channel preamplifier and a 168 bunch crossing deep analog pipeline to match the latency of the L0-trigger decision of LHCb. Each Beetle chip will provide 4 analog output ports so that the 32-fold multiplexed signals can be read out and sent to FADCs within 900 ns. The 8-bit digitised information is sent through a 32-bit serializer chip (CERN GOL). The further readout is a 100m long optical link through 12-channel VCSEL arrays to the L1-readout boards in the counting house. The exact location of the FADCs, serializer and VCSEL arrays is not yet defined.

3 First measurement results on sensors and ladders

3.1 The first prototype sensors

In order to study the noise performance and charge collection efficiencies for wide-pitch detectors, multi-geometry sensor prototypes from SPA Detector in Kiev/Ukraine have been ordered. These detectors were manufactured on single sided p^+n 4”-wafers with a constant pitch of 240 μm and a thickness of 300 μm. The sensors were AC-coupled with polysilicon resistor biasing. We have investigated three different ratios of strip width over pitch of w/p= $0.2, 0.25, 0.3$ as well as overhanging and underhanging metal geometry. The electrical properties of the sensors have been measured and are summarised in [3]. The typical depletion voltage of these devices was 50-70 V and the total strip capacitances have been determined to be between 1.3-1.6 pF/cm. The prototype sensors exhibit a rather low junction breakdown of about 100 V only.

3.2 Laser and testbeam measurements

First measurements on test ladders were carried out [4] using an infrared laser system. The silicon detectors were operated slightly above nominal depletion voltage. The pulse height measurements indicated a charge loss in between the strips of 30-40%. A larger biasing of the detectors was not possible due to the early junction breakdown of the sensors.

In testbeam measurements at CERN, a short ladder with 6.66 cm strip length and a long ladder with 20 cm strip length were investigated in order to study the single hit resolution and the charge collection efficiencies. Detailed information about the experimental setup and the analysed results can be found in [5]. The obtained spatial resolution is shown in the right part of figure 2. A gaussian fit to the measured residuals yields a 50 μm resolution, which is much better than the design resolution of 80 μm.

The signal over noise ratio (S/N) for the short ladder is plotted in figure 3

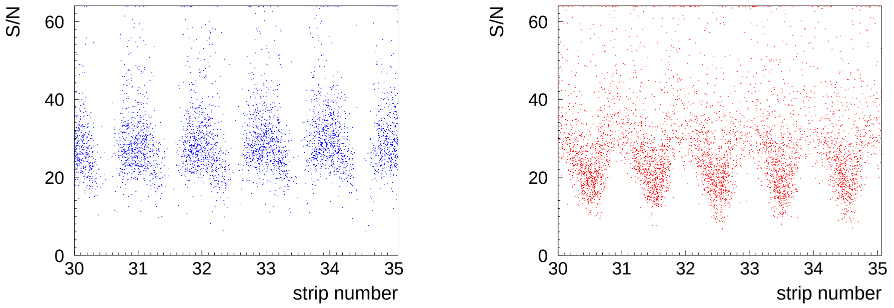

Fig. 3. Distribution of the signal over noise value for one strip cluster (left) and two strip cluster (right) as a function of the track impact position.

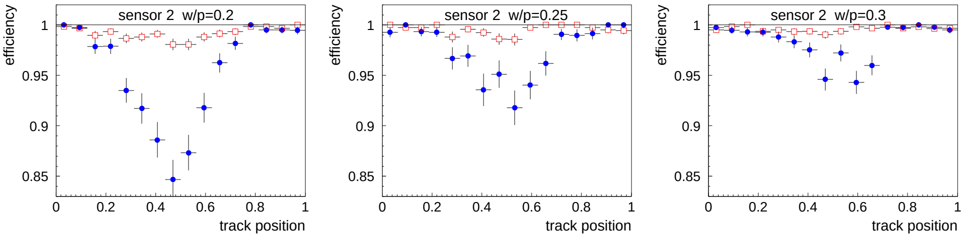

Fig. 4. Hit efficiency as a function of tracking impact for three different width/pitch regions. The applied bias voltage was 90 V.

for reconstructed one-strip clusters (left) and two-strip clusters (right). Both distributions are shown as a function of the track impact obtained from the beam telescope. The events with reconstructed two-strip clusters are populating the region in between the strips and have in average a lower S/N, indicating a ballistic deficit of the charge sharing process. This translates directly into an efficiency loss in between strips as figure 4 indicates. Here, efficiencies are shown for the long ladder with two different shaping times of the preamplifier, again as a function of the impact position of the tracks. The efficiency loss decreases towards higher values of w/p, so that wider strips at constant pitch collect the charge more efficiently. Although longer shaping time would reduce the efficiency loss significantly, a fast shaping of 25 ns is needed for LHCb operation. Hence, the measured charge collection efficiency for the long ladder as it is shown in figure 4 for the fast shaping time is not satisfactory to meet the required tracking performance for an LHCb Inner Tracker. A possible remedy could be an overbiasing of the detectors leading to an increase of the electric fields in between the strips. Such an expected improvement has been indeed measured and is plotted in figure 5 for the long shaping time only. The application of higher bias voltages however, was not possible due to the early junction breakdown of the sensors.

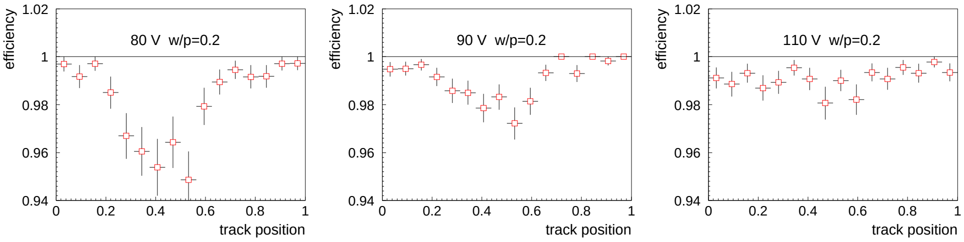

Fig. 5. Hit efficiency as a function of tracking impact for the long ladder and long shaping time for three different bias voltages. The depletion voltage of the sensors was determined by the C-V method to be 50-70 V.

4 Summary

The Inner Tracker of the LHCb experiment is presently being designed in a silicon microstrip technology. It requires a single position resolution of roughly 80 μm, so that relatively wide pitch silicon strip detectors can be used. The ladder and station designs are rapidly evolving and first laboratory measurements on prototype sensors and ladders have been performed. A first testbeam measurement revealed an unacceptable charge collection loss in the region in between the strips for the investigated full-length ladder. The dependence of the charge loss on preamplifier shaping time, w/p ratio of the strips and bias voltage points into the direction of a ballistic charge deficit, meaning that the charge is not collected in time. The charge collection efficiency improves towards higher w/p ratios and with increased overdepletion of the silicon sensors.

References

[1] LHCb technical proposal, CERN/LHCC 98-4.

[2] Niels van Bakel et al., The Beetle reference manual, Version 1, LHCb-2001-46.

[3] F. Lehner et al., Description and Characterisation of Inner Tracker silicon prototype sensors, LHCb-2001-036

[4] C. Bauer et al., Characterisation of Inner Tracker silicon prototype sensors using a 106 Ru-source and a 1083 nm laser system, LHCb-2001-121

[5] C. Bauer et al., Test Beam Results on Inner Tracker silicon prototype sensors, LHCb-2001-135