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Design of the LHCb Silicon Tracker*

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Abstract

The LHCb Silicon Tracker is a large-surface silicon micro-strip detector that will cover an important part of the LHCb tracking system. Its data will be used in the trigger to select high-p_T daughter particles from B-meson decays, and in the offline analysis to reconstruct trajectories of charged particles in the very forward region of the detector. Readout strips of up to 38 cm in length with strip pitches of approximately 200 μm will be employed. For the readout, a custom developed front-end chip and a Gbit digital optical link will be used. The design of detector, silicon sensors and readout link is presented.

1 Introduction

LHCb [2] is a dedicated B-physics experiment that is currently being constructed at the Large Hadron Collider at CERN. Its main goal is to perform precision measurements of CP violation and rare decays. The LHCb detector is designed as a single-arm forward spectrometer and consists of a vertex detector, a tracking system, RICH detectors and calorimeters for particle identification, and a muon system.

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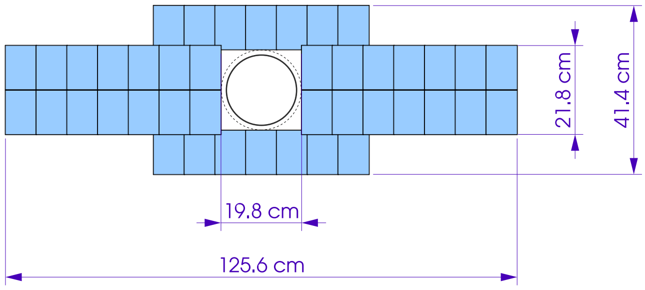

Figure 1: Layout of an IT detection layer.

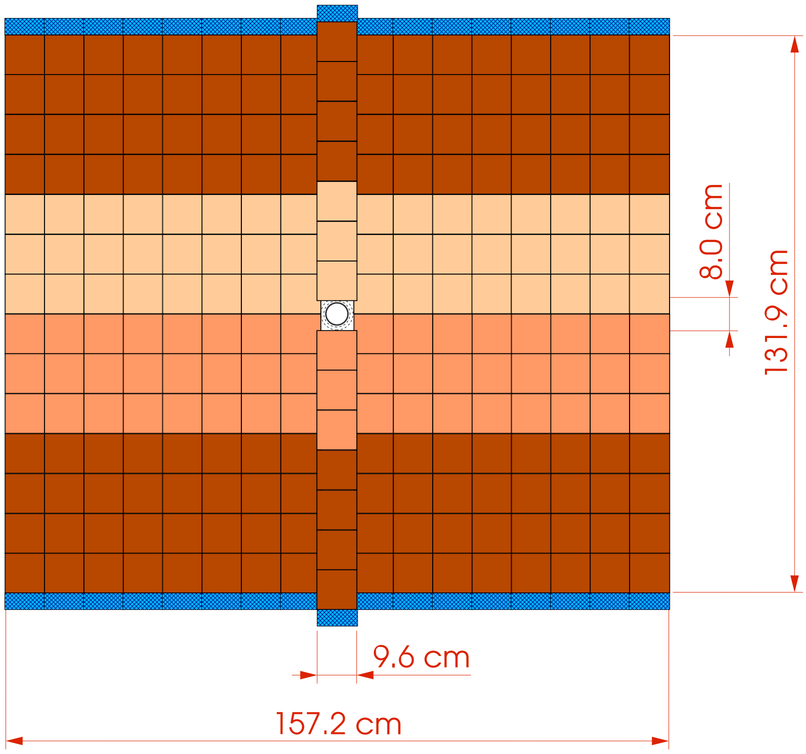

Figure 2: Layout of a TT detection layer. Readout sectors are indicated by different shading.

2 The Silicon Tracker

The LHCb Silicon Tracker (ST) comprises two sub-detector systems, both using silicon microstrip technology: the Inner Tracker (IT) [3] and the Trigger Tracker (TT) [4]. The IT covers a cross-shaped region of approximately 126 cm $\times$ 41 cm around the beam pipe (see Fig. 1) in three tracking stations downstream of the spectrometer magnet. The TT consists of four detection layers (see Fig. 2) that cover the full acceptance of the spectrometer in two stations upstream of the magnet.

In both IT and TT, long readout strips with wide strip pitches will be employed in order to cover the large surface of the detectors and to minimize the number of readout channels. For the IT, silicon ladders with 11 cm and 22 cm long readout strips will be built. They consist of one or two silicon sensors that are connected to their front-end hybrids via a short pitch adaptor. In the case of the TT, 66 cm long ladders each consisting of seven sensors

Table 1: Prototype ladder properties. Each ladder consists of three sensors.

Ladder	Strip length	Sensor thickness	Strip pitch	C_{strip}
IT3	32.4 cm	320 μm	198 μm	50.6 pF
Glast2000	26.3 cm	410 μm	228 μm	41.3 pF
CMS-OB2	28.9 cm	500 μm	183 μm	37.6 pF

will be used. Electronically, each TT ladder is split into a four sensor long outer and a three sensor long inner readout sector. The front-end hybrids for both readout sectors are located at one end of the ladder, outside of the acceptance of the experiment. The sensors of the inner readout sector are connected to their readout chips via 38 cm long Kapton interconnect cables.

Since the momentum resolution in LHCb will be dominated by multiple scattering over a wide momentum range, silicon sensors as thin as possible should be employed in order to minimize the amount of material traversed by the particles. On the other hand, the LHC bunch crossing rate of 40 MHz necessitates fast signal shaping in order to avoid overlapping events from consecutive bunch crossings. This, combined with the large load capacitances caused by long readout strips, leads to a relatively high level of noise. An important goal of the R&D for the Silicon Tracker was to determine the minimum sensor thickness that is required to ensure sufficiently high signal-to-noise ratios for an efficient and robust operation of the detector.

3 Sensor Design

In order to determine the necessary sensor thickness for the TT station, several prototype ladders (see Tab. 1) constructed from 320 μm thick multi-geometry prototype sensors developed for the Inner Tracker [3], from 410 μm thick GLAST2000 sensors [6], and from 500 μm thick CMS-OB2 sensors [7], were tested in a 120 GeV π^- beam at CERN. A beam telescope consisting of four double-sided silicon detectors provided by the HERA-B vertex detector group [8] permitted to reconstruct the impact positions of the π^- tracks with a resolution of approximately 14 μm.

For signal shaping times compatible with LHCb requirements, the test beam measurements gave average most-probable signal-to-noise (S/N) ratios of 8.9 for the IT3, 14.6 for the GLAST2000 and 20.0 for the CMS-OB2 ladders. These values were measured for bias voltages of approximately 130 V above the full depletion voltage of the respective sensors and were found to be independent of the position of the tracks along the readout strips over the full length of the prototype ladders. However, as in earlier measurements [3], a significant drop in the S/N ratio was observed for all prototype ladders in the central region between two readout strips (see Fig. 3).

Resulting particle detection efficiencies as a function of the track impact position are shown in Fig. 4. For the Glast2000 and CMS-OB2 ladders, S/N values are high enough to yield efficiencies above 99.8% even in the central region between two readout strips. For the IT3 module, however, the efficiency decreases to 88% for the region between two strips, which is unacceptable for operation in LHCb.

The observed drop in S/N has been reproduced in a simulation of the charge collection and signal propagation in silicon sensors and readout chip. It is attributed to trapping of charge carriers at the border to the silicon oxide layer in between the readout strips [9].

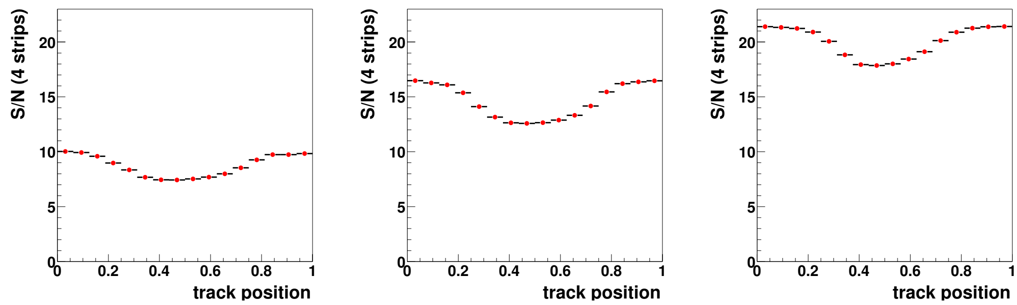

Figure 3: S/N versus track impact position in between readout strips for IT3 (left), Glast2000 (middle) and CMS-OB2 (right). On the abscissa, “0” indicates the center of the left strip and “1” the center of the right strip.

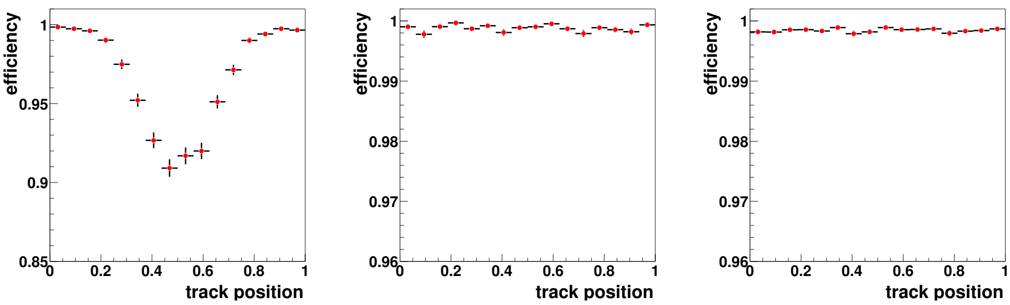

Figure 4: Efficiency versus track impact position for IT3 (left), Glast2000 (middle) and CMS (right).

Details of these measurements, as well as results for IT prototype ladders with 11 cm long and 22 cm long readout strips, are described in [10]. Based on these results, it was decided to employ 500 μm thick sensors for the 38 cm long readout sectors of the TT station. For the 11 cm long and 22 cm long silicon ladders of the IT, 320 μm and 410 μm thick sensors will be used, respectively.

4 The Readout Chain

A dedicated front-end readout chip, the Beetle [5], has been developed for the Silicon Tracker and other LHCb detectors. The chip has been designed in radiation hard 0.25 μm CMOS technology and complies to the requirements of the LHCb trigger and readout scheme. It encorporates 128 readout channels and provides a fast front-end amplifier, followed by an analog pipeline with programmable latency of up to 160 sampling intervals, and differential output amplifiers. Four readout ports permit to read out the multiplexed analog data from all 128 channels within 900 ns, compatible with a maximum trigger rate of 1.1 MHz.

A sketch of the readout chain is shown in Fig. 5. The analog output data of the Beetle are transmitted via approx. 5 m long low-mass copper cables to a service box that is located close to the detector in an area of significantly reduced radiation load. In the service box, the data are digitized using fast 8-bit ADCs operating at 40 MHz. Four ADCs are connected to one GOL chip [11], a radiation-hard gigabit serializer developed at CERN. A laser driver incorporated in the GOL chip is used to control a VCSEL diode and further transmit the digitized and multiplexed data at 1.6 Gbit/s via optical fibres. Commercial 12-fibre optical

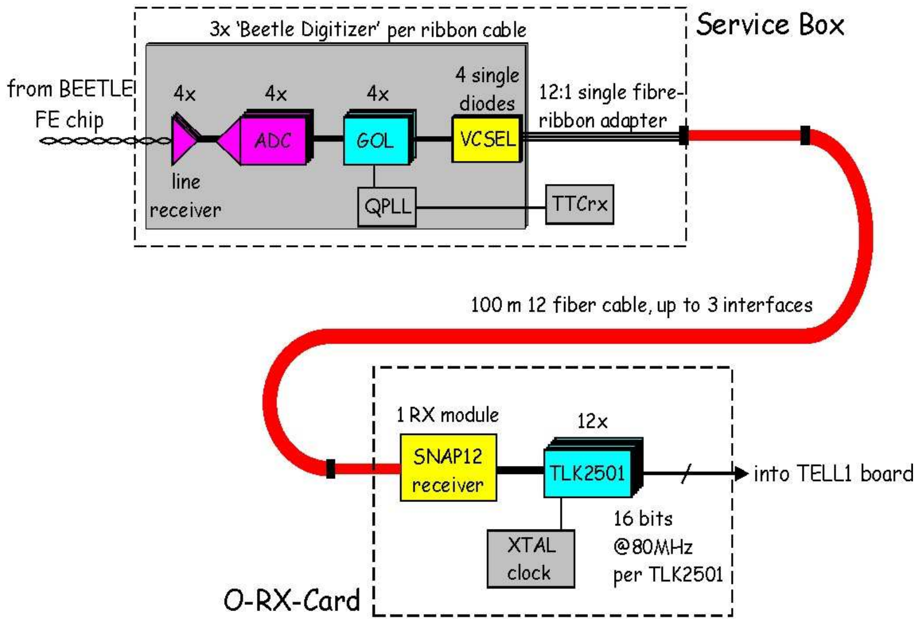

Figure 5: Sketch of the digital optical readout link.

ribbon cables will be employed to bridge the approximately 100 m to the LHCb counting room. Here, an optical receiver card carrying a commercial 12-channel parallel optical receiver and commercial Gbit demultiplexers provides the interface to the TELL1 readout board [12].

A full prototype readout link was assembled and operated successfully in the laboratory. A preliminary analysis gave an estimated bit error rate below 10^{-12}. With the exception of the fast ADC, all components located in the service box have been radiation qualified, both in a neutron irradiation test and in a total ionizing dose irradiation, to at least 50 years of operation at LHCb.

5 Outlook

With the results presented above, the R&D program for the LHCb Silicon Tracker is coming to a successful conclusion. The layout of the detector and the sensor geometry have been chosen after an in-depth measurement program, comprising laboratory test setups and beam tests. The front-end readout chip and the digital optical readout link have been demonstrated to operate to full satisfaction. The ordering of components for the Silicon Tracker has started and construction of the detectors will commence later this year. The detector is on track to being completely commissioned and operational at the startup of LHC.

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