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LHCb Silicon Tracker operations and performance with first data

Matthew Needham[*,†]
École Polytechnique Fédérale de Lausanne
E-mail: Matthew.Needham@cern.ch

The LHCb Silicon Tracker project consists of two sub-detectors the Tracker Turicensis and Inner Tracker that are based upon silicon microstrip technology. In these proceedings first operational experience and studies of detector performance made using data collected during 2010 LHC running are described.

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*Speaker.
†On behalf of the LHCb Silicon Tracker Group. For the full author list see [1].

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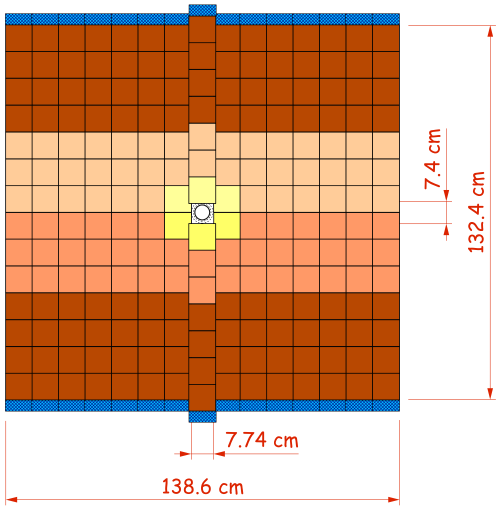

Figure 1: Layout of the x layer in TTa.

1. Introduction

LHCb is a dedicated b physics experiment at the LHC [2]. At the LHC the production of b pairs is peaked in the forward region. Therefore, LHCb is designed as a single arm spectrometer covering the polar angle of 15 - 300 mrad. The Silicon Tracker project consists of two sub-detectors, the Tracker Turicensis and the Inner Tracker, that make use of silicon micro-strip technology.

The Tracker Turicensis (TT) [2] is located in the fringe field of the LHCb dipole magnet and covers the full detector acceptance. It consists of four layers arranged into two half stations separated by 30 cm along the beam axis. The detector is constructed using 500 μm thick p-on-n type sensors of the same design as used in the CMS barrel [3]. The readout pitch is 183 μm. In total there are 143,600 readout channels. The layout of a layer is illustrated in Fig. 1. The areas above and below the beam pipe are each covered by a single seven-sensor long silicon ladder, the areas to the left and to the right of the beam pipe are covered by seven (TTa) or eight (TTb) 14-sensor long ladders. Electronically, each ladder is split into several readout sectors, indicated by the different shadings in the figure. In the innermost part of the detector, where the occupancy is highest, the ladders are split into one, two and four sensor sectors whereas in the outer part three and four sensor sectors are used. The readout hybrids are located at the top and bottom edges of the detector minimizing the amount of dead material in the acceptance. The inner readout sectors are connected to their hybrid via Kapton interconnect cables of length 39 cm and 58 cm. The properties of the TT readout sectors are summarized in Table 1.

The Inner Tracker (IT) covers the region of highest particle density closest to the beam-pipe in the three T stations which are located downstream of the LHCb spectrometer magnet at distance of 7.5 m from the interaction point. Though it covers only 1.5 % of the surface area 20% of the tracks pass through it. An IT station consists of four independent boxes located around the beam-pipe (Fig 2). Each box contains four layers of silicon in the orientation $0^\circ, 5^\circ, -5^\circ, 0^\circ$. For the ladders located left and right of the beam-pipe 22 cm long ladders with a thickness of 410 μm are used [4].

Readout sector	Strip Length /cm	Cable Length/cm	Total Capacitance/ pF
4 sensor	37.8	–	54.9
3 sensor + cable	28.3	39.1	57.3
2 sensor + cable	18.9	39.1	44.1
1 sensor + cable	9.4	58.0	38.4

Table 1: Properties of the TT readout sectors.

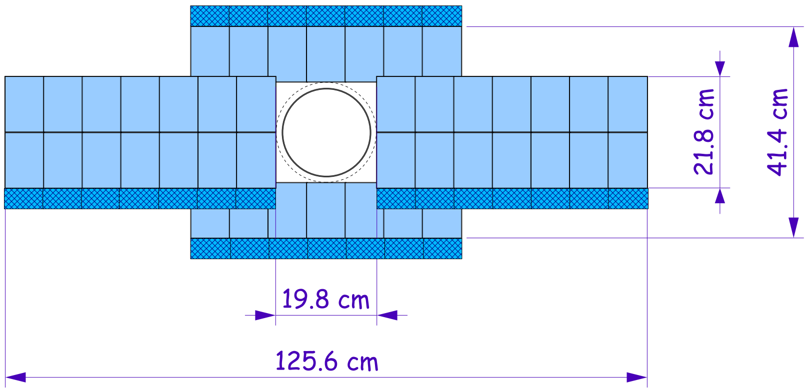

Figure 2: Layout a x layer in IT station 2.

Above and below the beam-pipe ladders of 11 cm in length and 320 μm thickness are used. The readout pitch is 198 μm. In total there are 336 ladders and 129,000 readout channels.

The readout chain is common to both sub-detectors (Fig. 3). On receipt of a trigger request analogue signals from the front-end chip (the Beetle [5]) are transferred via 5 m long copper cables to service boxes located outside the acceptance of the experiment in a low radiation environment. The signals are then digitized and transmitted over a 50 m optical link to the experimental counting house. Here, pedestal subtraction, common mode correction and zero suppression are performed on TELL1 readout boards [6].

During LHC running no access to the detector itself is possible. However, the TT service boxes are located at the side of the detector and access is possible during short machine stops. This has allowed repairs such as replacement of faulty digitizer boards to be performed. For the IT the situation is more difficult. The service boxes are located beneath the IT and the detector has to be opened in order to access them. In this case no repair work is possible outside of long machine shutdowns.

2. Operational Experience

Detector installation was completed by early summer 2008. From then until first LHC collisions at the end of 2009 valuable operational experience was gained in several ways. First, regular standalone tests of the readout chain were performed. Pedestal runs were used to debug the TELL1 zero suppression algorithms and allowed clustering thresholds to be determined. Running at the

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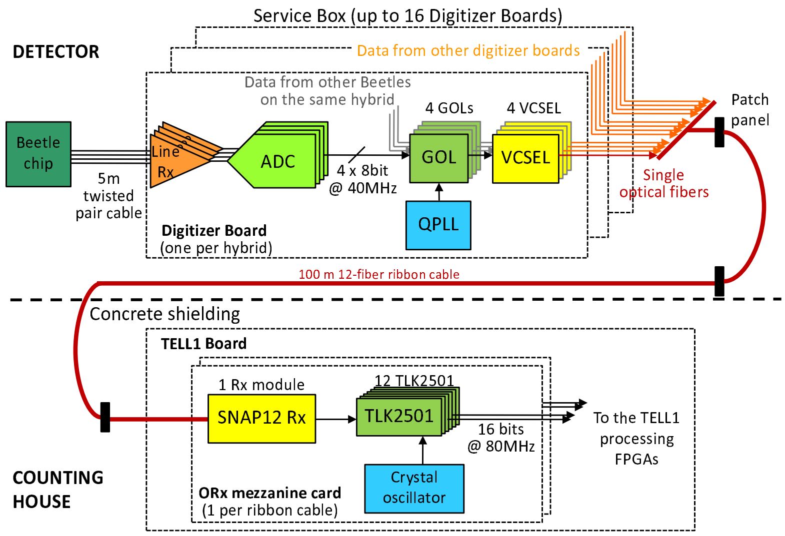

Figure 3: Silicon Tracker Readout chain.

maximum L0 trigger rate of 1 MHz problems in the readout chain were quickly identified. In addition, during summer 2008 LHCb carried out long cosmic runs. The forward geometry of LHCb and the relatively small size of the detector lead to a low rate of reconstructed cosmic tracks. For example in 2.6 million cosmic triggers only three reconstructed tracks traversing all three IT stations were found. However, this running was useful in that it allowed the stability of both sub-detectors to be evaluated over an extended period of time. Finally, during 2008 and 2009 the machine carried out several synchronization tests. Runs were taken where a beam of 450 GeV protons extracted from the SPS was dumped on to a beam stopper (the 'TED') located 350 m downstream of LHCb. Monte Carlo simulation indicate that the majority of the particles produced in the TED which reach the Silicon Tracker are 10 GeV muons. Using this dataset first studies of both IT and TT performance have been made [7]. In these runs the detector occupancies reached up to 8 % creating a challenging environment for track reconstruction. Despite this it was possible to perform a first time and spatial alignment of the detector.

During these tests several faults, mainly related to problems on the service boxes, were identified. Repair work was carried out during the 2008/2009 shutdown. In addition, the TELL1 firmware and offline software was made robust against missing front-end data and bit errors on the optical link. After these changes the whole chain runs stably and reacts properly when new problems develop.

Day-to-day running of the detector is now in the hands of the central LHCb shift crew supported by an on-call expert. To ensure safe and efficient data taking, detailed monitoring of the detector status and detector quality is provided. If problems develop, alarms are generated and appropriate actions automatically taken.

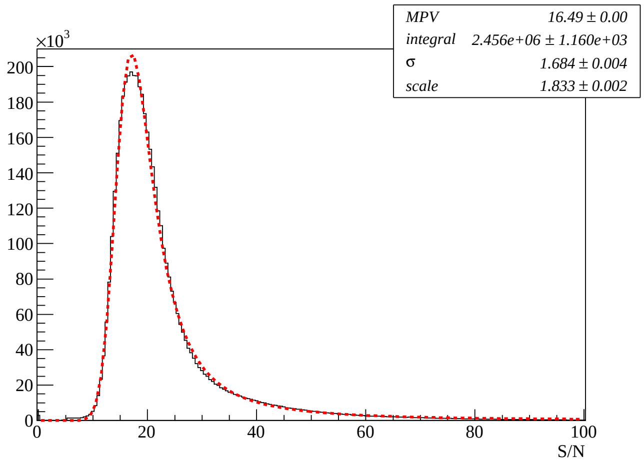

Figure 4: Distribution of S/N for clusters associated to tracks in the Inner Tracker side boxes. A fit to a Landau convolved with a Gaussian is superimposed.

3. Status

At the time of writing [1] 99 % (99.8 %) of the channels in the IT (TT) are functional. Two IT modules that are not functional dominate the inefficiency. One of these has a High Voltage fault whereas the other does not configure. Both faults are located inside the detector box and it is intended they will be fixed during the next long shutdown.

4. Performance

The detector performance has been evaluated using $\sqrt{s} = 7$ TeV collision data collected with a minimum bias trigger. The first step is to perform time and spatial alignment of the detector. The latter is discussed elsewhere in these proceedings [8]. Time alignment was performed as follows. Runs were taken where the delay between the sampling time and the trigger time was varied in 6.5 ns steps around the maximum of the signal, and the Most Probable Value of the signal determined for each set of ladders grouped in one front-end service box. The delay time for the subsequent data taking was the one that maximized the most probable signal amplitude. After this procedure the detector is time aligned with a precision of better than 1 ns.

After time alignment the detector S/N has been evaluated using reconstructed tracks with p > 5 GeV. An example of the S/N example obtained for the ladders in the IT side boxes is shown in Fig. 4. From a fit of a Landau convolved with a Gaussian a Most Probable Value (MPV) of 16.5 is extracted. Figure 5 shows the S/N obtained for the individual IT ladders. For the long (short) ladders a S/N of 16.5 (17.5) is obtained. There is a second peak for the short ladders around S/N ~ 20. These are short ladders for which 410 μm thick sensors rather than 320 μm were used. For the TT ladders the S/N is in the range 13 – 15 depending on the capacitance of the readout sector (Fig. 6). In both cases the measured S/N is within 10 – 20% of that obtained in test-beam [9].

[1] June 2010.

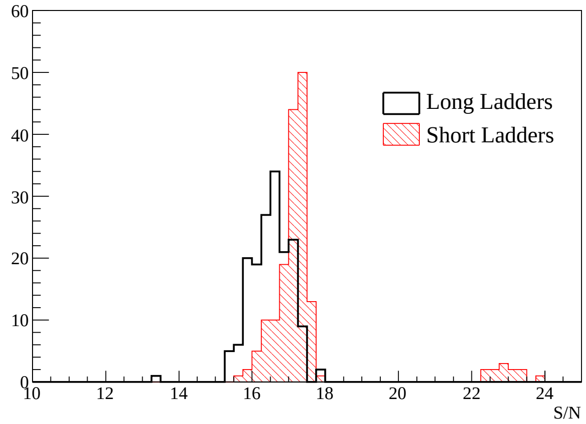

Figure 5: Measured S/N of the Inner Tracker ladders.

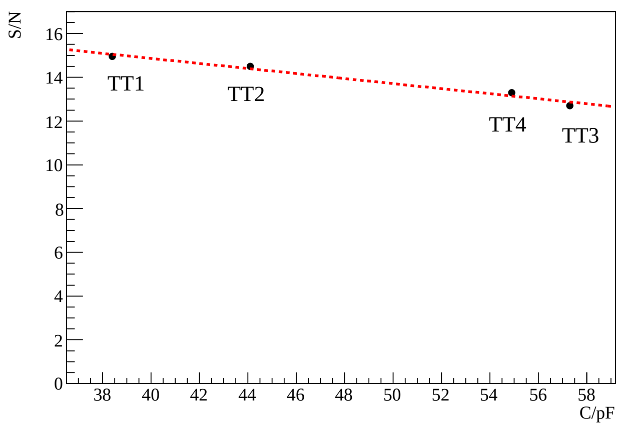

Figure 6: Measured S/N in TT versus readout sector capacitance.

The good S/N of the detector translates into a high cluster finding efficiency. This has been studied using reconstructed tracks. To minimize the effect of ghosts, high momentum isolated tracks are used for these studies. For the TT an efficiency of 99.3% is measured with the default clustering threshold of $S/N > 5$ [2]. In the case of the IT the efficiency is measured to be 99.8%.

Finally, the occupancy observed in the early data has been compared to the expectation from the LHCb Monte Carlo using events with one reconstructed primary vertex. In the TT (IT) 260 (230) clusters per event are observed compared to the Monte Carlo prediction of 200 (160). Though the Monte Carlo underestimates the overall occupancy by 30 – 40%, the shape of the distribution is correctly described. For example Fig. 7 shows the occupancy for the one sensor sectors in the TTaU layer versus the detector channel number. It can be seen that the agreement between data and Monte Carlo is excellent.

[2]With this setting the noise cluster rate is 10^{-5}.

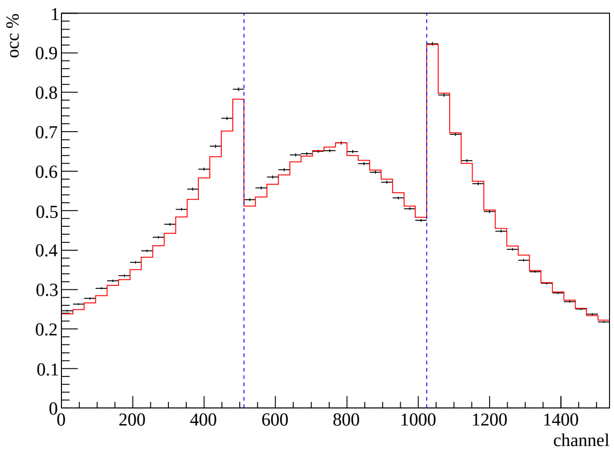

Figure 7: Occupancy in the one-sensor sectors in the TTa stereo layer. The black points are the data, the red line is the Monte Carlo prediction scaled by 30%. Increasing channel number corresponds to increasing x. The dotted lines correspond to module boundaries. The lower occupancy for the central module is due to the fact it is displaced in y compared to the adjacent modules.

5. Summary

Since installation the LHCb Silicon Tracker has run reliably and without major problems. Valuable experience was gained prior to first collisions during both cosmic data taking and the LHC synchronization test. Currently, more than 99 % of the detector channels are functional. First studies with collision data indicate that the detector performance is good and close to the expectations from testbeam.

A few issues remain. Potentially, the most significant of which is that over the last six months seven out of the 2128 optical links in the detector have failed. This has been traced to a sudden degradation in the power of the optical transmitter (VCSEL diode). The cause of these failures is under investigation. In the case of the TT the problematic links are fixed during short machines stops whilst for the IT it is forseen that they will be fixed during the 2009 winter shutdown.

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