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The LHCb Silicon Tracker

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ABSTRACT

The LHCb experiment is designed to perform high-precision measurements of CP violation and search for new physics using the enormous flux of beauty and charm hadrons produced at the LHC. The LHCb detector is a single-arm spectrometer with excellent tracking and particle identification capabilities. The Silicon Tracker is part of the tracking system and measures very precisely the particle trajectories coming from the interaction point in the region of high occupancies around the beam axis. The LHCb Silicon Tracker covers a total sensitive area of about 12 m^2 using silicon micro-strip detectors with long readout strips. It consists of one four-layer tracking station before the LHCb dipole magnet and three stations after. The detector has performed extremely well since the start of the LHC operation despite the fact that the experiment is collecting data at instantaneous luminosities well above the design value. This paper reports on the operation and performance of the Silicon Tracker during the Physics data taking at the LHC during the last two years.

1. Introduction

The LHCb experiment [1,2] is dedicated to the study of heavy flavour physics in proton–proton collisions at the LHC. The primary goal of LHCb is to make indirect searches for new physics in precision measurements of CP violation and rare decays of *b* and *c* hadrons. The detector is a single arm forward spectrometer which covers the pseudorapidity range between 2 and 5 to take advantage of the fact that *b*-pairs are predominantly produced close to the direction of the beam at the LHC.

The LHCb Silicon Tracker (ST) consists of two silicon micro-strip detectors located before and after a 4 Tm dipole magnet. The Tracker Turicensis (TT) is 150 cm wide and 130 cm high and covers the full acceptance upstream of the magnet. The Inner Tracker (IT) is situated in a 120 cm by 40 cm cross-shaped region in the centre of three planar tracking stations downstream of the magnet. The IT covers the region around the beam pipe with the highest density of tracks corresponding to around 1.2% of the total acceptance. The total sensitive area in the TT and IT is 8 m^2 and 4.2 m^2 respectively.

The TT consists of four detection layers with strips oriented at (0°, $+5^\circ$, -5°, 0°) with respect to the vertical axis. The detector uses 500 μm thick p-on-n sensors with a strip pitch of 183 μm. Sensors are bonded together to provide readout sectors with different length strips (up to 37 cm). There are 280 readout sectors and 143 600 readout channels.

Each of the IT stations is constructed from four independent boxes arranged around the beam-pipe. An IT box contains four detection layers with the same orientation as those in the TT. The boxes either side of the beam pipe contain modules with 410 μm thick p-on-n sensors and a strip length of 22 cm. The modules in the boxes above and below the beam pipe are 11 cm long and 320 μm thick. The strip pitch is 198 μm in both cases. There are 336 readout sectors and a total of 129 024 readout channels.

The electronic readout is essentially the same for both detectors. Analogue signals from the silicon strip detectors are amplified by the Beetle front end chip [3] and transmitted via copper cables to service boxes located outside the acceptance. The service boxes contain digitiser boards where the signal is digitised and transmitted via VCSEL diodes to the TELL1 [4] readout board in the counting house. The TELL1 board uses FPGAs to perform pedestal subtraction, common mode noise subtraction and zero suppression of the data.

2. Detector performance

2.1. Time alignment

The data collected during the first proton–proton collisions were used to time align the detector with respect to the LHC collisions. The time alignment procedure ensures that trigger and control signals are synchronised within LHCb and takes into account differences in cable lengths as well as the time of flight for particles passing each station. The optimal delays were determined using a scan over the delay between the sampling

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time of the front-end electronics and the trigger time with respect to the LHC clock. The delays were varied in steps of 6.5 ns and the most probable value (MPV) of the charge distribution was determined for each delay setting from a fit to a Landau convolved with a Gaussian. The peak of the pulse shape as a function of time was found by fitting the expected front-end signal shape to the distribution of the MPV versus the delay. The internal time alignment of the detector is known to be better than 1 ns.

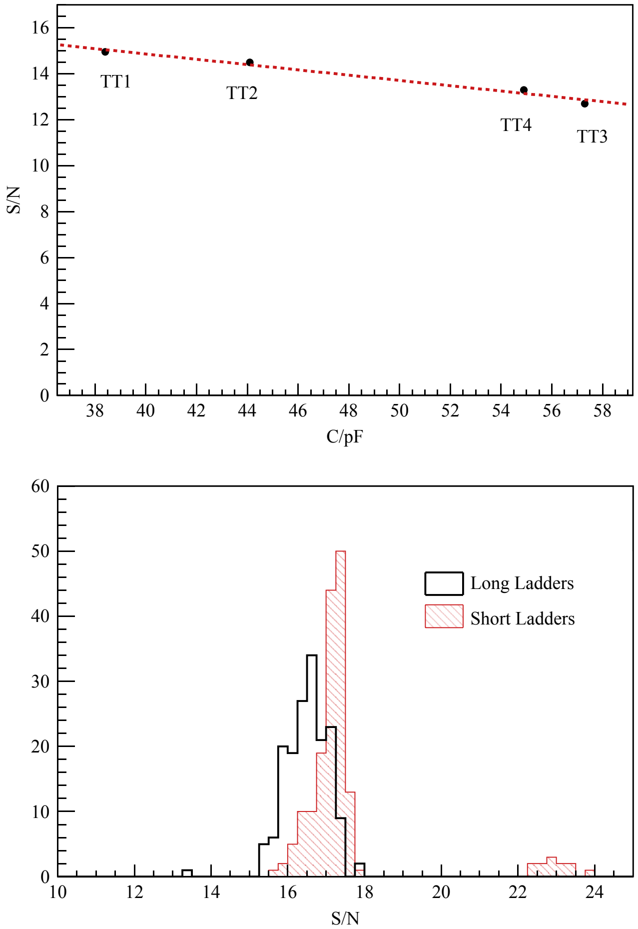

Fig. 1. Measured signal to noise ratio as a function of strip capacitance in TT (top) and for the two different strip lengths in IT (bottom). A second peak around 23 in the distribution of the *S/N* for the short ladders is visible because some 410 μm sensors were used during the module production instead of the 320 μm sensors.

2.2. Signal to noise ratio

The signal to noise ratio (*S/N*) for clusters on tracks reconstructed with a momentum greater than 5 GeV was found to be in the range 12–15 for the TT, and 16.5 and 17.5 for the long and short ladders in the IT respectively. The distribution of the *S/N* measured in the TT is shown in Fig. 1 as a function of the input capacitance of the strip. The MPV determined for each of the sectors in the IT is shown in Fig. 1. The values are in good agreement with those expected from prototype measurements.

2.3. Spatial alignment

A global χ^2 minimisation based on Kalman track residuals [5] was used to perform the spatial alignment of the detectors. The method was extended to include vertex information from $D^0 \rightarrow K^- \pi^+$ decays and applying constraints to their invariant mass [6]. The unbiased residuals, calculated by removing a hit from the track fit and computing the distance between the hit and the extrapolated track position, are shown in Fig. 2 (left) for all IT clusters on tracks. The so-called biased residual, defined as the mean of the unbiased residual distribution for each sector, is also shown in Fig. 2 (right) for all IT sectors. The RMS of the biased residual distribution gives an estimate of the precision of the alignment procedure and was found to be around 14 μm for both TT and IT. The single hit resolution can be extracted by removing the contribution due to the alignment procedure from the unbiased residuals. The hit resolution was measured to be 59 μm and 50 μm for the TT and the IT respectively.

2.4. Hit efficiency

The hit efficiency was measured using isolated tracks with a momentum greater than 10 GeV. The clusters in each sensor were excluded from the track fit in turn and a search was made for clusters in a window around the track. The hit efficiency is defined as the ratio of the number of hits found to the number of hits expected. The efficiency depends on the size of the window used and the maximum efficiency was measured to be 99.3% for IT and 99.7% for TT.

3. Radiation damage

The geometry of the LHCb detector means that the flux of particles across the IT and TT is highly non-uniform. The fluence

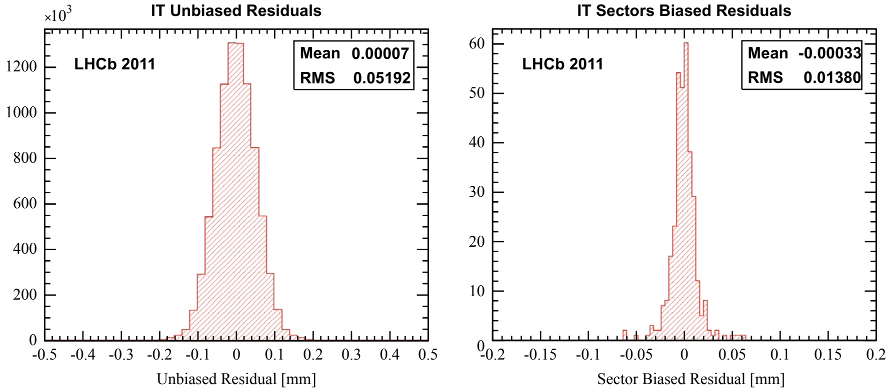

Fig. 2. Distribution of the unbiased (left) and biased (right) residuals in the IT.